The Introduction of the Brown Hare to Britain and Its Bio-Cultural Impact

Zooarchaeological and Morphometric Approaches

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Abstract

The introduction of new fauna is almost without exception not solely about enriching human diet. Instead, non-native fauna can be linked with the arrival new cultural phenomena, especially in the realm of religion. The religious and secular festival of Easter provides a case study with which to explore this phenomenon in the British archaeological and historical record, as its three associated animals - the brown hare, European rabbit, and chicken - are all not native to Britain.

But, the circumstances and timing of the introduction of the brown hare (*Lepus europaeus*) to Britain have never been tackled with the aid of zooarchaeological evidence because zooarchaeologists have lacked the methods necessary to securely separate zooarchaeological brown hare remains from those of Britain's native lagomorph, the Scottish mountain hare (*Lepus timidus*).

This thesis establishes a zooarchaeological baseline for the timing and cultural impact of the brown hare's introduction to Britain. It develops an identification method using traditional, linear morphometrics to separate brown and mountain hares in British populations and applies this to method to archaeological hare remains.

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Glossary and Abbreviations

Terms with Special Uses

Some everyday English terms are given specific meanings in particular contexts in this thesis. More specialised terms from the sciences and statistics could have been employed, but often the natural choices were already used frequently in their technical sense, so it was better to expand the definitions of commonplace words to avoid confusion.

Specimen In a modern zooarchaeological reference collection or natural history collection context (here pertaining to the use of non-archaeological animal bones for as model data sets), a 'specimen' is defined as a single individual animal. In a zooarchaeological context (i.e. uses pertaining to archaeological animal bone), a 'specimen' refers to a single animal bone or bone fragment.

Approach A specific *combination of parameters* that define a method for predictively distinguishing lagomorph bones using a morphometric dataset. For any given skeletal element, the parameters include the combination of measurements (see **Combination**); the morphometric variable (see **Form** (Isometric) **Size** and **Shape**} below); and, in multivariate combinations, the Principal Component used.

Occasionally, and only to avoid immediate repetition, *model* or *models* are used to refer to **Approaches** in a general or collective sense. In all other cases **model(s)** should be read in the normal statistical sense of 'a dataset that can be used for making predictions'.

Combination The combination of metrics used in an **Approach**. These can be uni-

variate (e.g. “Bd”), bivariate (“Bd-Dd”), or trivariate (“Bd-Dd-GL”)

Additionally, see the following definition which applies only within the specific context of **Approaches** as described above:

Morphometric Variable With respect to **Approaches**, this refers to the overarching variables of morphometrics (Form, Size and Shape) and not to the individual metrics that make up a **Combination**.

Morphometrics

Allometric Growth The property of an object that represents scale and shape changing together. A function that scales an object *and* alters its shape is allometric, cf. *Isometric Size*. Form

A variable that contains the total variance of a vector of measurements. Equal to the sum of **size** and **shape**. Isometric Size

The property of an object that represents scale independent of shape. A function that scales an object with no impact on its shape is isometric, cf. **Allometric Growth** Log Scale Index

AKA: “log ratio”. A ratio often used by zooarchaeologists to maximise the utility of morphometric datasets for analysis of size(Meadow 1999). The ratio compares archaeological measurements against a **Log Ratio Standard**, which allows different measurements, incompatible in their raw form, to be compared. Log-shape ratio

A ratio devised by Mosimann (1970) that represents shape, derived from the natural logarithm of a raw linear measurement by subtracting **isometric size** Size

A variable that contains the variance within a vector of measurements that corresponds to the property of an object that scales all of its dimensions equally. Equal to $Form - Shape$. See **Isometric Size**. Shape :The property of an object that is invariant under size, rotation and translation. With respect to linear measurements, equal to $Form - Size$ Traditional Morphometrics

The study of size and shape using linear measurements.

Abbreviations

General

NK Not Known NA

Not Applicable/No Data

Statistics

CV Cross-Validation LDA

Linear Discriminant Function Analysis/Linear Discriminant Function. Also **PLDA** (*Predictive* LDA) LOOCV

Leave-One-Out Cross-Validation PC

Principal Component. PCA

Principal Component Analysis

Zooarchaeological

Specimen/Sample IDs

The following prefixes are used in the text to refer to records in the database produced for this research. Each numerical ID uniquely identifies a specimen within the class denoted by the prefix.

RS A reference specimen from a museum or zooarchaeological reference collection.

One ID per individual animal, e.g. RS100. ZM

A single bone from a reference specimen, e.g ZM100 ZA

A record in the zooarchaeological part of the database. In some cases it uniquely identifies a record but not the bone, usually for skeletal elements or fragments that cannot be measured and so were grouped and given a quantity equal to the number of fragments. In most cases, however, it uniquely identifies a single bone, including all the measured bones. E.g. ZA100 EGG-

A single archaeological bone recorded for this thesis which was also selected for further analysis by the *Easter project*.

Sexing and Ageing

M Male F

Female ZZ

Unsexed F

Fused (Epiphyseal Fusion) FS

Fusing (Epiphyseal Fusion) U

Unfused (Epiphyseal Fusion)

Morphometrics

GMM Geometric Morphometrics LRS

Log-ratio standard LSR

Log-shape ratio LSI

Log-scale index

Chapter 1

Introduction

Following the recent shift towards social research and approaches (overviews in Sykes 2014a; Russell 2011), zooarchaeologists have become increasingly willing to tackle complex human-animal-landscape relationships with archaeological animal bone evidence, moving beyond a sole focus on meat and "secondary product" procurement. One major advancement has been the recognition that the introduction of new fauna by human agency almost always accompanied major cultural change in ancient societies, and the new fauna are frequently associated with religion in those contexts (Lauritsen et al. 2018; Sykes 2012, 2014a).

Religious change in response to new animals makes sense when conceptual geography is considered. Helms (1993) shows that humans map geographical distance onto supernatural distance. The greater the physical distance between the domestic sphere and location of a new object, animal, plant or phenomenon's origin, the more likely the new arrival is to take on supernatural or magical qualities within the culture it has been introduced to. Sykes (2014a) argues that this is particularly relevant to animals: post-processual archaeologists routinely argue that inanimate objects have cultural agency, but animals genuinely have agency, they act back. Consequently, it is not surprising that the arrival of domestic fauna in Britain during the Neolithic coincided with massive cultural change that may have been understood in magical or cosmological terms (Sykes 2014a; Thomas 2004); that horses arriving in the Bronze Age became part of a kingship system that derived its authority from a horse-deity

(Creighton 1995; Sykes 2014a); and that the spread of the European fallow deer (*Dama dama dama* L. 1758) remains around Classical Europe follows that of Artemis/Diana (Sykes 2014a,b). Almost without exception, such introductions are not solely about expanding the meat supply and can be linked with new cultural practices and beliefs (Lauritsen et al. 2018; Sykes 2014a).

This thesis seeks to establish a zooarchaeological baseline for the introduction of the brown hare to Britain (*Lepus europaeus*, Pallas 1778). The brown hare has only recently begun to be popularly recognised as an introduced species, though zooarchaeologists and natural historians have speculated on whether it was an Iron Age or Roman (discussions in Allen 2011; Allen et al. 2011; Sykes 2014a), or perhaps earlier (e.g. Serjeantson 2011: p. 47), introduction for some time. Nevertheless, the timing and circumstances of such an introduction have never been thoroughly investigated with archaeological evidence.

Although conducted and funded as an independent research project (by the Arts and Humanities Research Council Midlands3Cities Doctoral Training Partnership, AHRC-M3C DTP), this thesis was also supported by and conducted in collaboration with the AHRC-funded Exploring the Easter E.g. Project (hereafter "Easter E.g. Project"). The Easter E.g. Project was established to use Easter as a case-study for exploring the bio-cultural effects of anthropic animal migrations. Easter is a major religious and secular festival in modern Britain and therefore intimately connected with British identity through the shared cultural calendar. But neither Easter's Judaeo-Christian religious origins nor its associated fauna - the brown hare , the European rabbit (*Oryctolagus cuniculus*, Linnaeus, 1758), and the chicken (*Gallus gallus*, Linnaeus 1758) - are native to Britain (Lauritsen et al. 2018). Easter's origins and associations with these non-native species are poorly understood, and archaeological evidence has never before been leveraged to tackle this knowledge gap.

This thesis seeks to address these knowledge gaps in relation to the brown hare with (zoo)archaeological evidence, focussing on two core questions:

- When was the brown hare introduced to Britain?
- How did human interactions with the brown hare in Britain develop following the introduction?

The structure of this thesis is as follows:

Following this outline, Chapter 1 concludes with background information on general lagomorph ecology, taxonomy, and morphology. Outlines of the biogeography and ecology of the brown and mountain hare are also given, followed by short sections defining a non-native species, and highlighting naming and abbreviation conventions used in the thesis.

Chapter 2 then introduces in detail the problems this thesis faces with establishing a zooarchaeological baseline for the brown hare, and reviews the existing zooarchaeological evidence for hares in (mainly Southern) England by synthesising established datasets, in which hares are rarely identified to species. This was problematic for this thesis' objectives because there are two species of hare in Britain: the introduced brown hare (*L. europaeus*) and the native mountain hare (*L. timidus*, Linnaeus 1758).

Chapter 3 then engages with the problem of zooarchaeological identification. As no method existed to differentiate between the brown and mountain hare, this was a fundamental barrier to dating the former's arrival in Britain. The chapter therefore presents a morphometric solution to this problem. It describes how a database of linear measurements from modern hare specimens were collated and analysed to create models that can be used to statistically predict the identity of zooarchaeological hare bones, and analyses the results of extensive leave-one-out cross-validation on these models, conducted to determine their effectiveness.

Chapter 4 applies the models created in Chapter 3 to zooarchaeological bones that were sampled from key sites identified in the synthesis from Chapter 2. Having used this metrical method to identify hare bones to species, Chapter 5 returns to traditional zooarchaeological analysis to examine what new information can be added to the knowledge established in Chapter 2 now that analyses of skeletal element representation, butchery, pathology and size change can be applied to hare remains that are identified to species. It also presents the results of radiocarbon dates from key samples.

Chapter 6 then attempts to place the interpretations of this new evidence in a wider cultural context, drawing together evidence from archaeology and other humanities disciplines. Emphasis is placed on using the available evidence to generate hypotheses and suggestions for the direction of future research, some of which will be investigated by the Easter E.g. Project. The chapter examines the merits of the new information generated in the preceding chapters as part of this discussion. Chapter 7 concludes the

thesis with a brief summary of its findings, and makes some comments on the wider implications of this research.

1.1 Background on Lagomorph Taxonomy, Behaviour and Ecology

Hares, along with rabbits, belong to the taxonomic family *Leporidae*, which together with the pikas (*Ochotonidae*) constitute one of the smallest mammalian Orders (*Lagomorpha*) in modern biology. Until the later twentieth century the lagomorphs were one of the least studied faunal groups. Advances have been made since then, but major questions remain unanswered (Chapman et al. 2008).

Lagomorphs were first distinguished from their closest relatives, the rodents, in 1912 by their maxillary incisors - lagomorphs have four, rodents only two (Chapman et al. 1990a, 2008). Like rodents, their teeth grow continuously (Hillson 2005: p. 110-1), but unlike them, lagomorphs have entirely herbivorous diets (Chapman et al. 2008).

All lagomorphs practice coprophagy - they reingest their soft faeces to increase the nitrogen content of their diet (Chapman et al. 2008: p. 5). For this they have historically been included in social rules that prohibit the consumption of meat from animals that "chew the cud" but do not have cloven hooves (Evans et al. 1974: p. 26). Biologically, is an erroneous conflation, however. "Chewing the cud" refers to rumination, the dietary practice of ruminants, in which plant matter is fermented in a specialised stomach - the foregut - and regurgitated for further chewing before reingestion (Akers et al. 2013), an entirely different process to the lagomorphs' coprography.

1.1.1 Predation & Reproductive Behaviour

Adaptations to avoiding predators are a key feature of the lagomorphs (Chapman et al. 2008). The leporids all have large, movable ears for predator detection, and long legs adapted for running at speed. Hares (all belonging to the genus *Lepus*), are bigger than rabbits, have longer ears and are adapted for running at speed across long distances (Angermann et al. 1990; Chapman et al. 1990a; Flux et al. 1990).

This adaptation relates to flight response. Upon detecting a predator, hares typically

remain still under cover until the last possible moment, but then attempt to escape at speed if noticed (Chapman et al. 1990a: p. 5; Flux et al. 1990: p. 62). Some species, especially the brown hare, take a meandering route - by backtracking, circling, or jumping sideways - during such an escape to confuse pursuers (Flux 1981). By contrast, most rabbit species bolt at the first sign of danger, endeavouring to escape to safety underground as soon as possible (Dickenson 2013).

These differences in threat management strategies between hares and rabbits are also related to their reproductive behaviour. Rabbits produce large litters, and their young are born without fur and with their eyes closed (Chapman et al. 1990a: p. 2). As such, rabbits have the ability to burrow and to live in large groups, using their subterranean warrens to protect themselves and their offspring, though most species live above ground most of the time, and only burrow to reproduce (Gibb 1990).

Hares, however, reproduce in smaller numbers, and are more solitary. Their leverets are born fully furred, with their eyes open, and are able to fend for themselves soon after birth (Cowan et al. 1986). Consequently, hares have no need to burrow - instead they avoid predation with their flight response and by being mostly nocturnal. They make nests called 'forms' by digging a shallow, pitched depression, often with the deepest point oriented towards the wind, for shelter (Flux 1981; Pépin et al. 2007). Nevertheless, the mountain hare is one species that has been known to burrow, making short tunnels for protection from weather or predators and to find food, especially in snow (Flux 1981). But, it is claimed they do not burrow in Ireland (Angerbjörn et al. 1995: p. 7).

In addition to these behavioural traits, hare fur changes colour for the winter. Brown hares shift from yellow-brown to grey, whilst mountain hares (depending on sub-species) shift from shades of brown and grey to white (Angerbjörn et al. 1995; Flux et al. 1990).

1.1.2 Taxonomy

The hares are a "notoriously difficult group" taxonomically (Chapman et al. 2008; Suchentrunk et al. 2008), owing to broad phenotypic variation within groups, and overlaps in traditional morphological characteristics (Suchentrunk et al. 2008). Despite progress in recent years, lagomorph specialists have yet to produce a comprehensive

list of hare species, and the definition of a hare species is similarly unresolved (Chapman et al. 2008: p. 7).

1.1.3 Habitat and Ecology

Hares are highly adaptable, but favour open habitats, including tundra, steppes, pastures, tropical savannah, and deserts, and some species (especially the brown hare) have been shown to benefit from landscape clearance for agriculture (Flux et al. 1990).

Different lagomorph species exclude each other from their preferred habitats where they occur in geographic proximity (Flux 1981; Thulin 2003). In Kazakhstan, for example, mountain hare occupies mountain forest, brown hare occupies steppe and agricultural land, and the Cape hare occupies desert (Flux et al. 1990: p. 63).

Thanks to their adaptability, however, a hare species may easily occupy the potential space of its nearest geographical neighbour, but will retreat again to its preferred habitat upon contact with that neighbour (Flux 1981; Thulin 2003). For example, Scottish mountain hares can occupy farmland, and brown hares in Scotland can occupy heather moorland, but only when the other is absent (Flux et al. 1990: p. 62).

Exclusion may therefore be a significant factor in hare ecology and biogeography - both today and historically. Competition with the brown hare has been proposed as an explanation for the distribution of mountain hare across Europe (see below), rather than habitat constraints, for example (Wolfe et al. 1996). Flux (1993) also shows that European rabbits can be more effectively removed from an area through competition with brown hares than by shooting, trapping, predation or myxomatosis.

Despite this tendency towards allopatry (different species occurring in separate areas), sympatry (occurring in the same or overlapping areas) and hybridisation have also been observed. Scottish mountain hares and brown hares appear to be able to feed together without friction where moorland and fields meet (Flux 1981: p. 390) and unidirectional hybridisation between the two species is commonly cited as a factor in the mountain hares' decline (Thulin 2003).

1.1.4 Background on European Hares

Several hare species are native to western Europe, including the brown hare (*L. europaeus*), the mountain hare (*L. timidus*), Corsican hare (*Lepus corsicanus* de Winton 1898), Iberian hare (*Lepus granatensis* Rosenhauer, 1856), and the broom hare (*Lepus castroviejoi* Palcios 1976). Modern Britain has only three lagomorphs - the brown and mountain hare, and Europe's only native rabbit (*Oryctolagus cuniculus*, which is the only species in the *Oryctolagus* genus).

1.1.4.1 The Brown Hare

The brown hare is thought to have originally been restricted to Central Europe, perhaps having evolved in the Middle-Asian steppes (Reid et al. 2007; Thulin 2003: p. 33). Today it is one of the most successful lagomorphs, having expanded to occupy most of Europe and been successfully introduced by humans to Canada, the United States, South America, Australia, and New Zealand (Flux et al. 1990: p. 76). Brown hares find agricultural land particularly favourable, and the spread of agriculture may have helped drive the species' colonisation of Europe (Thulin 2003: p. 33), though modern pesticides and mechanisation have since contributed to their decline (Flux et al. 1990: p. 76-7; Fischer et al. 2012).

Prior to glacial decline in the Pleistocence/Holocene transition the brown hare would have found much of northern Europe inhospitable. Southern Europe may therefore have provided a variety of refugia - possibly isolated from each other - which may account for a number of proposed subspecies (Stamatis et al. 2009: p. 516). Climate change after the Late Glacial Maximum is thought to have facilitated rapid expansion across Europe, and Stamatis et al. (2009: p. 525) found close phylogenetic relationships between brown hare haplotypes occurring in large parts of central, north-western and south-western Europe, which support this hypothesis. They also found that the northern British brown hare population has a haplotype which is otherwise unique to German populations near the Danish border, suggesting that this area may have provided the source population for British brown hares (Stamatis et al. 2009: p. 525).

1.1.4.2 The Mountain Hare

The mountain hare is generally smaller than the brown hare (Angerbjörn et al. 1995), though it varies greatly in size and colour throughout its range, which includes tundra and open forest (Flux et al. 1990: p. 87). It has a circumpolar distribution from Britain to Japan, with populations in Scandinavia, Finland, the Baltic states, Russia, China and Mongolia (more detail in Angerbjörn et al. 1995: p. 3). Populations also exist in the Alps, and islands to which it has been introduced, including the Western Isles (Angerbjörn et al. 1995: p. 3).

Today, two subspecies of mountain hare occupy the British Isles, where they favour heather moors and bogland (Flux et al. 1990: p. 87). The Scottish mountain hare (*L. t. scoticus*) is found only in the Scottish Highlands and places to which it has been introduced, such as the Peak District and South West Scotland (Hewson 1956; Yalden 1984). But, it is plausible that it had a much larger native range in Britain during prehistory (see for example Thulin 2003: p. 30-31; Charles et al. 1994; Hinton 1909; Jacobi et al. 2009).

The Irish Hare (*L. t. hibernicus*) is Ireland's only native lagomorph, and is genetically distinctive compared with both other mountain hare subspecies and hare species overall (Reid 2011). Indeed, recent scholarship has suggested the Irish Hare may yet be reclassified as a separate species (see Reid et al. 2007: p. 129; Reid 2011). Whilst mountain hares traditionally occupy forest, tundra and moorland (Flux et al. 1990), the Irish hare is found across Ireland, on moorland and agricultural land at all altitudes (Angerbjörn et al. 1995). It also consumes a broader range of vegetation compared to other subspecies (Dingerkus et al. 2001; Strevens et al. 2004). This combination of environmental and dietary breadth affords the Irish hare almost complete niche overlap with the brown hare (Reid et al. 2007), which was introduced to Ireland in the nineteenth and twentieth centuries for hunting (Thulin 2003: p. 33). Unlike other mountain hares, most Irish Hares do not have a (fully) white winter coat (Flux et al. 1990: p. 87).

1.1.5 Note on Species Names and Abbreviations

Throughout this thesis, the common names 'brown hare' and 'mountain hare' are used to refer to *Lepus europaeus* and *Lepus timidus*. Most graphs displaying species using

colour represent them with brown and blue, respectively (the latter choice referring an alternate common name for *L. timidus*, "blue hare"). In almost all cases, 'mountain hare' can be understood as a shorthand for "Scottish mountain hare", *L. t. scoticus*. It is never used to refer to the Irish Hare (*L. t. hibernicus*), except when referring to both subspecies collectively.

When the species of a modern specimen is known, or the species of an archaeological specimen has been predicted (Chapters 4), data pertaining to those specimens (Chapters 4 and 5) is shown in graphs and tables with two-letter abbreviations written in capitals: 'BH' and 'MH' for brown and mountain hares respectively, and 'RB' for rabbit. The abbreviation 'IH' also appears in a few contexts for 'Irish Hare'. This is used in contrast with specimens of unknown species, which are always given as 'hare', 'rabbit', or 'lago.' (for 'lagomorph').

1.2 Defining a Non-Native Species

It is worth considering what defines an "introduced" or "non-native" species for Britain, but it is not a simple issue. Whilst there is some consensus that accounting for biological and geographical change over time is important, there is little consensus on the timeline (Crees et al. 2015: p. 144). Environmental change in the Pleistocene-Holocene transition is often considered important, though not always. Some definitions give non-native status to all fauna arriving after the late glacial period (c. 16,000 years BP - Crees et al. 2015: p. 144). In contrast Webb (1985) assigns native status to plants that evolved or arrived in Britain before the Neolithic. This is flawed because it implies that humanity's effects on biogeography were somehow 'natural' before the Neolithic, but 'unnatural' during and afterwards (Willmore 2015: p. 123; Crees et al. 2015: p. 144). This thesis adopts the model in which a non-native British animal is one that arrived after sea-level change (c. 8000-6000 years BP) separated Britain from the European continent (on sea-level change, see Sturt et al. 2013; on non-native species see Sykes 2014a: p.77-8). Such fauna are considered to have required human agency to reach Britain, owing to the need to cross water.

1.2.1 Animal Bones

This thesis makes use of both modern and archaeological animal bone data. To avoid confusion, when referring to modern animals, the term 'specimen' always refers to an individual animal - i.e. a whole or partial skeleton in a zoological or zooarchaeological reference collection. When discussing individual specimens in detail, both this text and the accompanying data reference them with an identifying number, prefixed with the letters 'RS' for 'Reference Specimen' - e.g. 'RS1001'. Individual bones within a Reference Specimen are rarely discussed in any detail in the text, but they can be identified in the accompanying data with an ID number prefixed with the letters 'ZM' which stands for 'Zooarchaeological data (modern)'.

When discussing archaeological bones, 'specimen' is occasionally used as a synonym for 'bone' or 'bone fragment'. This mimics the way that 'specimen' appears in the zooarchaeological quantification method 'Number of Identified Specimens' (NISP). As archaeological bone is fragmentary, the identifier for an archaeological bone (marked in the data with the prefix 'ZA'), uniquely identifies a single *record* in the zooarchaeological database. In other words, an archaeological 'specimen' is not necessarily a whole bone, and multiple records denoting fragments could make up a single bone if it were possible to reassemble them. This thesis also studies Associated Bone Groups (ABGs), where multiple zooarchaeological bones are found in association or articulation, and are considered to represent either a single skeleton or a single cultural 'unit' or event. Archaeological specimens that make up ABGs are united together in the data by a common ABG id, which is indicated by the prefix 'ZABG' - e.g. ZA1001 and ZA1002 are specimens belonging to the ABG 'ZABG001'. The term 'skeletal element' always refers to a specific type of bone in the skeleton; a complete bone belonging to that type; or fragment from a bone of that type.

The term 'sample' is occasionally used as an another synonym for an archaeological 'specimen', but is generally avoided to reduce confusion with the concept of statistical samples or sampling, which would refer to multiple archaeological specimens. Some data tables give an 'EGG ID' (e.g. EGG-0301), which only archaeological specimens that were shared between this project and the Easter E.g. Project have. In this context, individual specimens may be referred to as 'samples' because the Easter Project subsampled from this thesis' larger sample.

1.3 Other Conventions

Other abbreviations were used in the data to reduce data recording time, some of which also appear in figures and data tables present in this text. Details of these can be consulted in the Glossary (above) but I highlight some key cases here:

- Epiphyseal fusion data at the proximal and distal ends of bones are denoted with the field names 'Pf' and 'Df' and use 'F', 'FS' and 'U' to denote the fusion states
- Sex data is abbreviated to 'M', 'F' and 'ZZ' for male, female and unsexed
- Skeletal elements are normally given in tables and graphs as abbreviations in capitals, normally the first three letters of the element's name
  - Four letter abbreviations are used for the calcaneum ('CALC') and mandible ('MAND')
  - Unidentified metapodia are denoted by 'MP', or 'MC' for 'metacarpal', or 'MT' for 'metatarsal'. Specifically identified metapodia are given as one of these abbreviations followed by a number representing their digits (e.g. 'MT2').
- Logical data (True/False or Yes/No) are coded as TRUE or FALSE in this thesis' data files. In tables in the text, TRUE is abbreviated to 'T'; FALSE is normally replaced with '-'

Chapter 2

Current archaeological evidence for hares

Zooarchaeological datasets provide the opportunity to identify the brown hare's introduction to Britain by searching for shifts in the presence of hare remains at archaeological sites through time. Assuming that the mountain hare had a broader distribution in Britain in the Late Glacial Period (Charles et al. 1994; Hinton 1909; Jacobi et al. 2009; Thulin 2003), it is probable that the species' preference for cool climates and tundra or moorland environments (Chapter 1) meant that its retreat, culminating in its present day native range of only the Scottish Highlands, tracked the decline of glacial environments.

Therefore it is reasonable to expect that the presence of mountain hares in England was either low or already non-existent by the Neolithic, and landscape alteration for agriculture beginning in the Neolithic would have promoted habitats more suited to brown hares than mountain hares (Chapter 1). Consequently, major changes in the presence and/or abundance of hare bones in the British zooarchaeological record from the Neolithic onwards would be a dependable indicator of the brown hare's introduction, as these changes would show up clearly against a backdrop of either the mountain hare's absence or a diminished population.

In this chapter, I synthesise a dataset of zooarchaeological hare evidence and conduct

analysis at three scales. The macroscale covers broad changes through time and attempts to identify key areas for further investigation, including regional differences and outlying assemblages. At the mesoscale, I explore smaller portions of time, examining change within the broad periods covered at the macroscale and introducing site types to the analysis as a grouping variable. At the microscale level, I critique the evidence from individual assemblages to identify which early examples of hare remains can be believed and which require further investigation.

2.1 Quantification

Firstly, it is worth considering the type of data to be collected. Zooarchaeological data are normally reported using Number of Identified Specimens (NISP), typically defined as the frequency of specimens identified to skeletal element within a given taxonomic category. Categories can range in exactness from Linnaean class (with or without a size grouping, e.g. medium mammal) to species, though seldom to subspecies. Biases deriving from the depositional processes, burial environment, taxon, and excavation and analysis methods mean that one specimen is not equivalent to another. Differences in NISP between taxa or assemblages should accordingly be expressed as an ordinal scale (x is more/less abundant than y); the magnitude of those differences is generally not analysed (Lyman 2018b). NISP is a standard for reporting zooarchaeological information; it forms the basis of all quantification in this thesis and is the form in which most data synthesised in this chapter were originally reported. It is important to acknowledge, nevertheless, that NISP evolved in response to problems with imprecisely defined quantitative units used earlier in zooarchaeology's history (Lyman 1994). Reports pre-dating the debate about quantification, started in the 1970s, are not always comparable with more recent datasets.

NISP is also biased towards larger taxa; their bones survive burial better, are more easily recovered, and are more likely to produce identifiable pieces upon fragmentation (James 1997; O'Connor 2000: p. 45; Baker et al. 2019). Inevitably therefore, NISP frequencies in hand-collected contexts are inflated for cattle, sheep/goat, pig and larger wild fauna, such as deer, whilst smaller mammals, birds, and fish are underrepresented (Baker et al. 2019: p. 15-18). Additionally, it takes no account of multiple bones potentially coming from a single animal, rather than many.

Minimum Number of Individuals (MNI) is the only alternative method, however, to have remained in widespread use and recognition (Lyman 1994, 2018a,b). The technique derives from NISP the smallest number of individual animals required to produce the observed specimen frequencies for each taxon, by taking account of the portion of the skeletal element represented by each specimen (Baker et al. 2019: p. 45). A mixture of other factors such as side, the number of times the element occurs in the skeleton, size, and age at death are also often included in the calculation (Baker et al. 2019: p. 45; Lyman 2018a).

MNI has historically been used as the main method of reporting animal bone frequencies (e.g. Harcourt 1979), but the numerous ways in which MNI can be calculated mean that it is ineffectual for syntheses comparing different assemblages if NISP data and the MNI calculation method are not presented in the original report (Baker et al. 2019: p. 45). It is seldom the case that protocols are described in the necessary detail (Lyman 2018a). In this thesis, MNI is used (sparingly) in later chapters, but is almost irrelevant in this one, as NISP data for small mammals are seldom reported by skeletal element, so it is impossible to derive hare MNIs from most published and publicly available grey literature datasets.

Presence/absence data are also useful for comparative work with small fauna, as their taphonomic pathways and recovery methods at excavation can render specimen numbers relative to larger taxa unreliable regardless of how those frequencies are presented. It also has the advantage of an unambiguous definition. Moreover, it is easy to derive from other quantitative units or from a report's text in cases where the authors do not assign any numerical quantity to the taxon (as is frequently the case for wild and small species). But, presence/absence forfeits the ability to assess differences between classes in a grouping variable (e.g. site type or time period) if the data are expressed as raw frequencies of assemblages with the taxon present/absent. Instead, they must be expressed as percentages of the total number of assemblages so that sample size can be accounted for.

Finally, is impossible to say whether the NISP of a given taxon in one assemblage is significantly different to that in another if those assemblages have different total NISPs, so it is useful to express NISP for a target taxon as a percentage of some measure of assemblage size. For this, the sum of the NISP for main domesticates - cattle,

sheep/goat, and pig - is a workable choice. It is important to stress here that the concept of the "main domesticates" (MD) is an invention modern scholars project onto the past. It is an etic analytical tool, and so does not account for whether or not any such taxonomic category existed or was considered meaningful in past societies, or whether it would have constituted the same taxa we attribute to it today (see Sykes 2014a: p. 6-8 for discussion of scientific versus cultural taxonomies). "Main domesticates" also reflects zooarchaeologists' preoccupation with economy (meat production and "secondary products"), rather than the vast array of other roles animals can play in human societies (Russell 2011; Sykes 2014a).

Nevertheless, the sum of these three taxa - being present in almost all assemblages from European farming societies - is a more reliable measure of assemblage size and general condition than any alternative, given zooarchaeology's historically low level of standardisation. Grand totals or sub-totals of identified remains, for instance, are inappropriate as different researchers include different taxonomic categories and levels of identification confidence in such aggregate values. The percentage H/MD - Equation (2.1) - is used here to contextualise the quantity of hares present in a given assemblage.

$$H/MD = \frac{NISP_{hare}}{(NISP_{cattle} + NISP_{sheep/goat} + NISP_{pig})} \times 100 \qquad (2.1)$$

It could be argued that the sum of only sheep/goat and pig would be a better choice than MD, as cattle are so much larger than hares that H/MD will always be a highly skewed due to the effect of taxon size on taphonomic pathways. Sheep/goat and pig, though still larger than hares, would be more comparable. Despite this, MD was used because it is a more readily comparable with other studies (for example, the same metric is used by Holmes 2017) and some Neolithic assemblages had no sheep/goat or pig, so would have had to be dropped if cattle had been excluded from the analysis. Furthermore, it was possible to demonstrate that switching to sheep/goat + pig would have had negligible effects on on the distribution of the data (Appendix Fig. A.1).

2.2 Geographical scope

The vast majority of known prehistoric (and therefore most crucial for identifying the brown hare's introduction) hare remains are from Southern England. Data sources used here are thus focused on this region, though some key Iron Age and Roman examples are from Midlands sites. The 'core' study area used (Figure 2.1) comprises Southern England and part of the Midlands, but excludes Wales, Northern England, and Scotland.

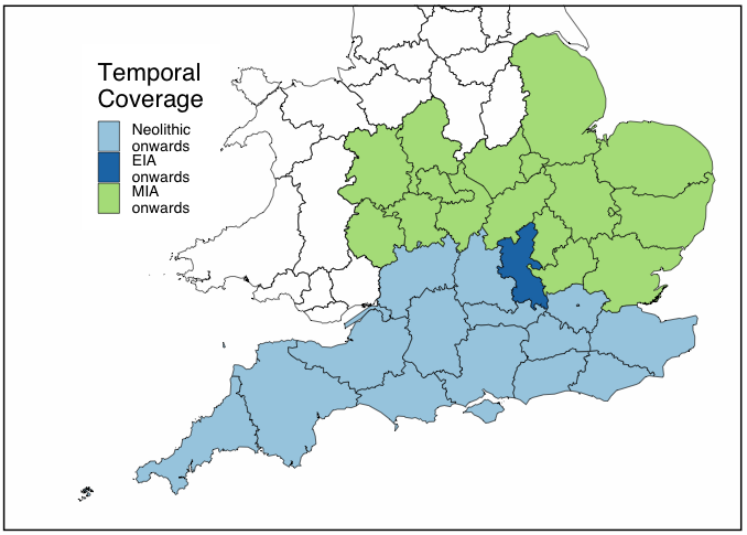

Figure 2.1: Synthesis geographical coverage. Counties are coloured according to the earliest period from which they are represented.

2.3 Data sources

Recent technological developments have precipitated a shift towards digital archiving and Open Data in archaeology (Gaffney et al. 1999; Lake 2012; Morgan et al. 2012). Large syntheses of zooarchaeological assemblages are therefore increasingly common and accessible for further research. The Historic England faunal reviews (Hambleton 2008;

Holmes 2017; Serjeantson 2011) and their accompanying datasets published on the Archaeology Data Service (ADS) are particularly key. Each covers their region and time-periods effectively, but integrating them together into a single deep-time synthesis for hares is problematic. Each has different data aggregation and presentation methods, different approaches to literature review, and different database structures. They are consequently incompatible in their raw form, and time-consuming to rework. Serjeantson and Hambleton lay out their data in similar ways, for example, but for most wild taxa Hambleton only provides presence/absence data rather than NISP. Albarella and Pirnie's (Albarella et al. 2008) exhaustive Midlands dataset, meanwhile, is downloadable as a series of Comma Separated Values (CSV) files extracted from a complex relational database. Though usable in isolation, it is difficult to reconcile with the simpler approach taken by others. Additionally, at the time of writing, the accompanying report was not yet published, so the methodologies and underlying problems with the dataset that require critical attention were knowable only to the authors. Consequently, a compromise approach was used.

For the core periods of interest (Iron Age to Medieval), syntheses that could be reliably integrated on the basis of underlying methodological similarity were selected first (see Figure 2.2 for a temporal outline of all discussed sources). Naomi Sykes' (2007b) Saxon to High Medieval dataset formed the starting point, followed by subsequent syntheses produced by her past students: Allen (2011) for the Middle Iron Age to Late Roman period, Poole (2011) for further detail on the Early to Late Saxon periods, and Bowen (nd) for the Late Medieval. Consequently, Hambleton (2008) was only needed for Late Bronze Age (LBA) and Early Iron Age (EIA) data, due to the overlap with Allen. Serjeantson (2011) was used for the Neolithic to Middle Bronze Age (MBA).

Only the Post-Medieval period remained at that point. Although it was judged important that the period be included, given the lack of attention paid by (zoo)archaeologists to this period until very recently, there was potential for phase aggregation in Holmes' (2017) synthesis to differ from those of Sykes and Bowen where sites overlapped chronologically. As earlier periods were more central to the main research questions of this thesis, they were prioritised for data cleaning and integration (§2.4, below) over the Post-Medieval, from which only a limited subset of assemblages were ultimately included. This subset consists mainly of Post-Medieval assemblages from sites that also have assemblages from earlier periods. This necessarily introduces bias to this portion

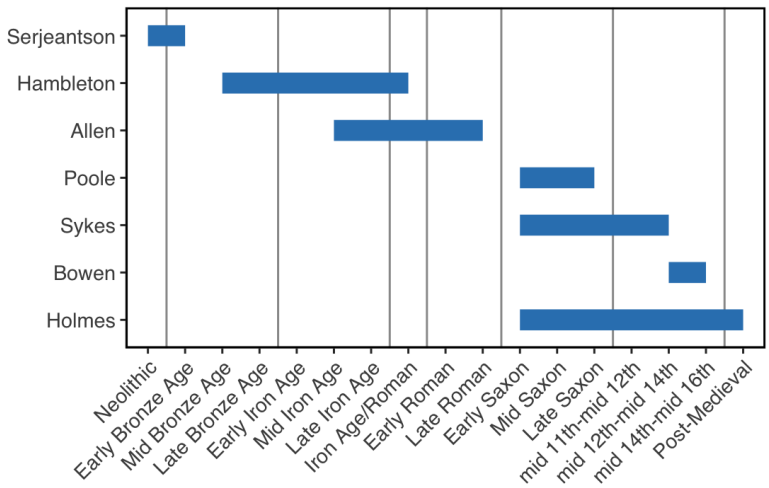

Figure 2.2: Timeline showing data sources discussed in this chapter and their temporal coverage and overlaps.

of the dataset and the analysis and interpretation of it is accordingly moderated. More detailed zooarchaeological research into human-hare-environment interactions in the Post-Medieval period must remain a project for the future, and will benefit from both this thesis and forthcoming landscape studies-driven doctoral research on Late Medieval and Early Modern hare warrens (Kane forthcoming).

2.4 Data binning and cleaning

Deriving this synthesis' dataset from existing syntheses meant that the data were already grouped into chronological bins. But, further consideration was necessary in order to deal with inconsistencies between the source datasets, and modifications to the data were required to deal with chronological overlaps.

This problem was most significant for the Saxon period through to the Late Medieval. Sykes's, Poole's and Bowen's syntheses were all designed to address particular questions within smaller time-frames than the one here. Consequently, fixing overlaps for these syntheses was a priority. Having brought the data together, as many original reports as possible were consulted for verification[1]. Where inconsistencies appeared, they

[1]This is difficult to quantify precisely because modifications to NISP values were made on a taxon-by-taxon basis for every period for every site. Accounting for all time periods (not just the Saxon through to Late Medieval), it is estimated that approximately sixty percent of the assemblages used in the synthesis are supported by reference at least one original report. The remainder relied upon the existing syntheses.

were corrected. Improvements were occasionally made to confusing or ambiguous site names (e.g. Walton, Walton Lodge, Walton Vicarage, and Walton Road in Sykes 2007b). More significant changes to zooarchaeological quantities mainly consisted of ensuring that data for each sites' phases was allocated to only one time bin each - as different syntheses could have aggregated data from multiple phases into a smaller number of bins, but grouped the data differently (as illustrated in Figure 2.3). Using the syntheses without checking for this would have resulted in duplicated counts for bones where phases overlapped.

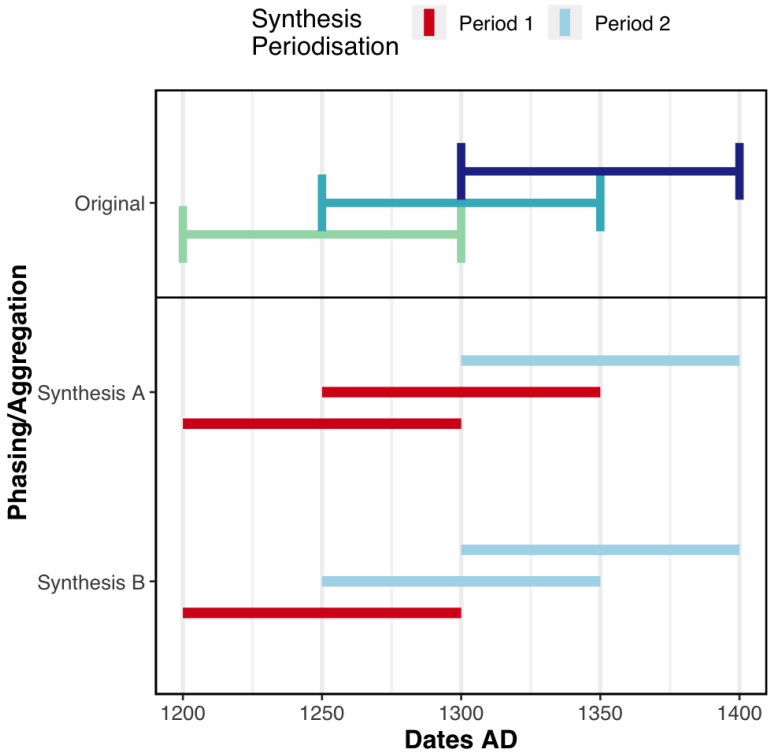

Figure 2.3: Illustration showing how two different syntheses could aggregate three overlapping archaeological phases into two periods by absorbing the intermediate one into the aggregate bin containing the first or last phase. If both syntheses were used as source datasets for a secondary synthesis, this would have the effect of duplicating the data for the intermediate phase.

Whilst binning data can be done systematically - with specific decisions made about

Given the complexity of a new synthesis constructed in this way, the final dataset is shown with citations for either the source synthesis or original reports - with additional comments in the citation where necessary - in an interactive table in an RMarkdown HTML document with a dedicated bibliography, provided in the digital appendices (see Appendix A.5). A simple list of sites arranged by county is given in print in Appendix Table A.2 for convenience.

whether to use mid-points between date ranges; allowing or disallowing overlapping bins; requiring bins to have a maximum duration etc (discussion in Orton et al. 2017) - this synthesis instead prioritised the use of established chronological standards in British archaeology (see FISH 2019: and discussion below in this section and in §2.5). This is because (zoo)archaeology has tended to suffer from poor standardisation, and a synthesis' results are easier to place in the context of other research if scholars maintain a common vocabulary and definitions for key periods in (pre)history.

Furthermore, establishing a more systematic set of bins - especially one based on numeric absolute dates - would have required re-binning the entirety of the dataset. To do so to a high standard would have necessitated comprehensive access to original reports, but this could not be reasonably expected in practice, as a number are either rare and out of print, or unpublished and not readily available in online grey literature repositories. Advanced binning techniques like the aoristic approach used by Orton et al. (2017) would certainly improve the statistical robustness of this chapter's insights, but it was considered beyond the scope of this project for similar reasons concerning access to original data, and also of data quality/resolution. Orton et. al.'s (2017) method works well in their London-based case-study thanks to deep stratigraphy with well-defined dating. In contrast, this project's synthesis works with sites where a phase might be no more precisely defined than the word 'Medieval', for example, so the potential benefits of such an approach are somewhat reduced.

It was more strategic to rely on the periodisaton used by the authors of the source syntheses, as these were either already inline with established standards (see FISH 2019), or easily adjustable to fit them on a case-by-case basis where the aggregation issues described above, or similar ones, were present. Specific examples of the case-by-case changes made are given below, but the overarching approach used was to make changes only where necessary to prevent duplication or other conflicts in the data. The approach also prioritised the periodisation used by Allen (2011), Poole (2011), and Sykes (2007b) as these were the most mutually consistent datasets. Where assemblages present in both Sykes (2007b) and Bowen (nd) conflicted and could not be resolved easily, Holmes (2017) was consulted for additional context.

It was possible in some cases to include site phases that had been excluded originally. For consistency, new phases were only introduced where they could reasonably fit

into the chronological bins used by Sykes, Poole and Bowen. This ensures backwards-compatibility (i.e. the data were not so altered that they could not be interpreted without clear reference to the earlier research). Furthermore, it meant that creating new bins that would inevitably end with very low sample sizes (number of assemblages) could be avoided.

Occasionally, assemblages had to be deleted or redone completely, but these were rare overall. The St Ebbe's (Oxford) assemblages (Wilson 1989; Wilson et al. 1984) were treated as a special case, due to complexity in the original reports. Only a select subset of the data was used, dropping everything from contaminated contexts. The figures differ most markedly from Sykes's version, but match Poole's Saxon data almost exactly. An unaggregated copy of the data used is provided in Appendix Table A.1 for comparison against the original reports and the cited syntheses.

A similar method was taken to integrating Hambleton and Allen, which could be considered in isolation from the post-Roman syntheses. The most important consideration here was Allen's approach to Iron Age and Roman chronology, which is by most systems non-standard. His definitions for the Middle and Late Iron Age slightly differ from more common ones, and he introduces an "Iron Age/Roman transition" (IA/RB) period. This was perfect for the topic of his work but becomes problematic when trying to integrate with the more conventional chronology used by Hambleton. Ultimately, however, it was easier to work with Allen's system than to refit every assemblage into a different one. Maintaining the IA/RB phase was helpful on further reflection, as it could provide the means to detect changing human-hare relationships in a critical period of cultural change.

To fit the two datasets together, Allen's data were adopted in their entirety. Hambleton's EIA data were then added in and all save one of those assemblages' original reports were consulted to replace the presence/absence data with NISPs. Stokeleigh Camp was dropped due to imprecise quantification in the original report; the hares were also suggested to be possible intrusions (Everton 1975). Gussage All Saints (Harcourt 1979) was retained for raw NISP and presence/absence analyses, but was dropped from analyses that express hare NISP relative to the main domesticates, as the latter were reported only as MNI. One of the most important sites in this study is the Iron Age settlement at Winnall Down, Basingstoke (Fasham 1985), where a second settlement

was excavated (Winnall Down II) in 2006 (Davis 2014). The animal bone assemblage from the second settlement was much smaller (n = 143) than that from the first, as well as being heavily fragmented and root-etched (Madgwick 2014). It was not added into this synthesis on the grounds that it is unlikely to be representative of human-animal interactions at the site.

A few of Hambleton's assemblages could not be comfortably divided into MBA, LBA, EIA, MIA or LIA phases, so these were dealt with on a case-by-case basis. Arbitrarily, the ranges including only Bronze Age phases were subsumed into the latest phase covered by their range. So EBA-MBA was grouped with MBA and MBA-LBA with LBA. LBA-EIA phases (n = 5) were dropped, as were broadly dated Bronze - Iron Age assemblages (n = 2). None of these Bronze Age changes affected assemblages with hares. The Iron Age assemblage from Poundbury Camp is only broadly dated as "Iron Age" (Buckland-Wright 1987), so this was kept for macroscale but excluded from mesoscale analyses. The same approach was used for two phases (EIA-MIA and MIA-LIA) from Brighton Hill South (Maltby 1995) and the EIA/MIA assemblage from Suddern Farm (Hamilton 2000a). The Late (B) assemblage (MIA-LIA) from Danebury 1969-78 (Grant 1984) was treated as LIA for mesoscale analyses, but is included as a case study in the microscale discussion.

Allen's data were then verified, though a smaller proportion of the original reports could be consulted. Generally, however, Allen's figures were more consistent with the reports than the post-Roman syntheses had been. In some cases, the published equivalent of a grey literature report used by Allen (or vice versa) was referred to, and a subset of those conflicted with Allen's data for certain taxa/phases (these I have cited as "contra Allen 2011" or similar in the RMarkdown document for the synthesis - see Appendix A.5.

Some of Allen's data for Fishbourne Roman Palace could not be reconstructed from their reports, most likely because Allen aggregates published sources that could be accessed for verification with unpublished sources that could not. It was therefore unclear how NISP figures in each phase had been arrived at, so these assemblages were left unverified and are used exactly as they were found in Allen's thesis. Regardless, Fishbourne is such a unique site given its growing body of evidence for exotic fauna (e.g. Allen et al. 2011; Miller et al. 2016; Best et al. forthcoming) that it is best to

consider it critically as an isolated case study.

Finally, Serjeantson's Neolithic to MBA data were used with negligible modification. That synthesis' chronology is well delineated from Hambleton's and hares are so scarce in this timeframe that each site needed to be considered as a separate case study, so perfect integration by checking original reports was only necessary for the select sites where they were present.

2.5 Dataset overview

The final dataset consisted of 858 assemblages from 519 sites (Table 2.1, Appendix Table A.2), using the chronological bins given in (Table 2.2) to aggregate site phases. For the subsequent macroscale analyses, I use "broad periods" to examine general trends from the Neolithic to the Post-Medieval period (§2.7), whilst shorter time bins ("periods") are used to explore change at a finer resolution, which is particularly relevant for key cultural changes (§2.8). Equally for simplicity and to focus in on Romanisation's impact on human-hare-landscape relationships, Allen's (2011) "Iron Age/Romano-British Transition" bin is used as both a "period" and a "broad period".

All chronological bins (Table 2.2) have been defined either with reference to those used in the corresponding synthesis, or to the standardised chronology advised by the Forum on Information Standards in Heritage (FISH 2019). In many cases the syntheses were already aligned with FISH.

Table 2.1: Number of sites and assemblages per broad period.

Broad Period	Sites	Assemblages
Neolithic	74	90
Bronze Age	29	30
Iron Age	99	124
IA/RB	44	44
Roman	161	224
Saxon	145	172
Medieval	96	157
Post-Med	24	24

Table 2.2: Summary of chronological bins used and their associated dates.

Abbreviation	Broad Period	Period	Centuries	Dates	Source
MESO	Mesolithic	–	–	10,000 BC - 4000 BC	FISH
NEO	Neolithic	–	–	4000 BC - 2200 BC	FISH
ENEO	–	Early Neolithic	–	4000 BC - 3700 BC	Serjeantson 2010
EMNEO	–	Early/Middle Neolithic	–	3800 BC - 3300 BC	Serjeantson 2010
MNEO	–	Middle Neolithic	–	3300 BC - 2900 BC	Serjeantson 2010
LNEO	–	Late Neolithic	–	3000 BC - 2200 BC	Serjeantson 2010
LNEO/EBA	–	Late Neolithic/Early Bronze Age	–	2400 BC - 1800 BC	Serjeantson 2010
BA	Bronze Age	–	–	2600 BC - 700 BC	FISH
EBA	–	Early Bronze Age	–	2000 BC - 1500 BC	Serjeantson 2010
MBA	–	Middle Bronze Age	–	1500 BC - 1200 BC	Hambleton 2008, FISH
LBA	–	Late Bronze Age	–	1200 BC - 700 BC	FISH
IA	Iron Age	–	–	800 BC - AD 43	FISH
EIA	–	Early Iron Age	–	800 BC - 300 BC	FISH
MIA	–	Middle Iron Age	–	c. 400 - 100 BC	Allen 2010
LIA	–	Late Iron Age	–	c. 200 BC - AD 50	Allen 2010

Table 2.2: *(continued)*

Abbreviation	Broad Period	Period	Centuries	Dates	Source
IA/RB	IA/RB	Iron Age/Roman	–	c. 50 BC - AD 100	Allen 2010
RB	Roman	–	–	AD 43 - AD 410	FISH
ER	–	Early Roman	mid 1st - mid 3rd	c. AD 40 - 250	Allen 2010
LR	–	Late Roman	mid 2nd - 5th	c. AD 150 - 400	Allen 2010
SX	Saxon	–	early/mid 5th - mid 11th	AD 410/450 - 1066	FISH
ES	–	Early Saxon	mid 5th - mid 7th	AD 450-650	Poole 2010
MS	–	Mid Saxon	mid 7th - mid 9th	AD 650-850	Poole 2010
LS	–	Late Saxon	mid 9th - mid 11th	AD 850-1066	Poole 2010
MED	Medieval	–	mid 11th - mid 16th	AD 1066 - 1550	This study
NR	–	Norman	mid 11th - mid 12th	AD 1050/66-1150	Sykes 2007
HMED	–	High Medieval	mid 12th - mid 14th	AD 1150-1350	Sykes 2007
LMED	–	Late Medieval	mid 14th - mid 16th	AD 1350-1550	Bowen
PMED	Post-Medieval	Post-Medieval	mid 16th - 19th	AD 1550-c. 1800	This study, cf. FISH

It is helpful to first take an overview of the dataset to reveal potential sources of bias. By percentage of sites, Midlands counties appear underrepresented, but this reflects their coverage only from the Middle Iron Age onwards (Figure 2.4). Oxfordshire and Hampshire clearly produce the most sites, followed by Wiltshire and Dorset. Further evidence for this presents itself by looking at the number of assemblages in each phase by county (Figure 2.5), where patterns follow more widely recognised temporal variance. The South West is famous for its Neolithic and Bronze Age archaeology (Webster 2007), for example, whilst Hampshire and Oxfordshire are well excavated in most periods (Figure 2.5). Hampshire stands out particularly strongly in the Iron Age (partially the influence of the Danebury Environs Programme), whilst Oxfordshire does so in the Medieval period. For the Roman period, Hampshire, Essex, Dorset, and West Sussex have the most coverage. Small numbers of assemblages from almost every county in the study are present for the Saxon period, though Oxfordshire and Norfolk stand out with more.

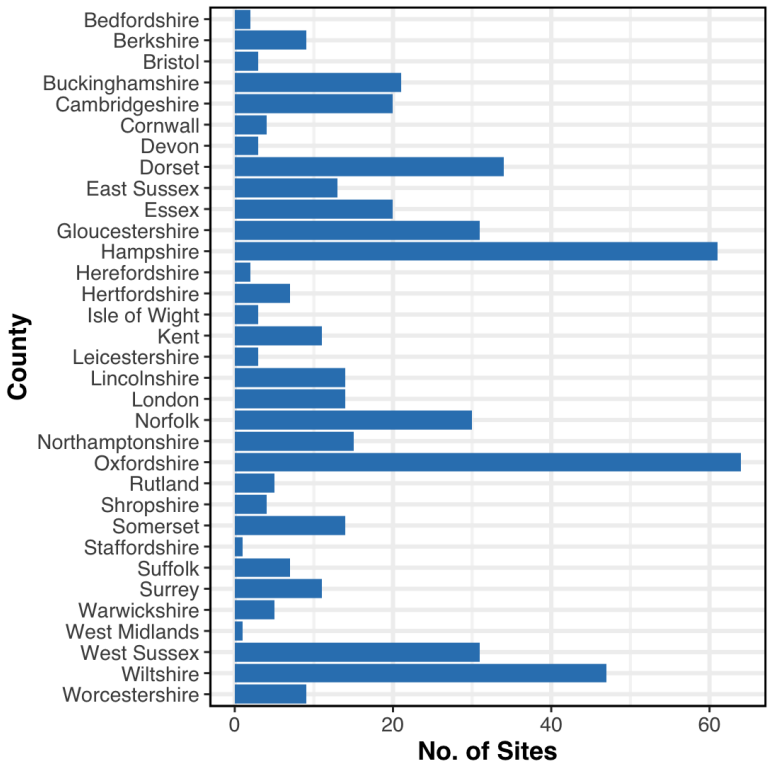

Figure 2.4: Number of sites by county.

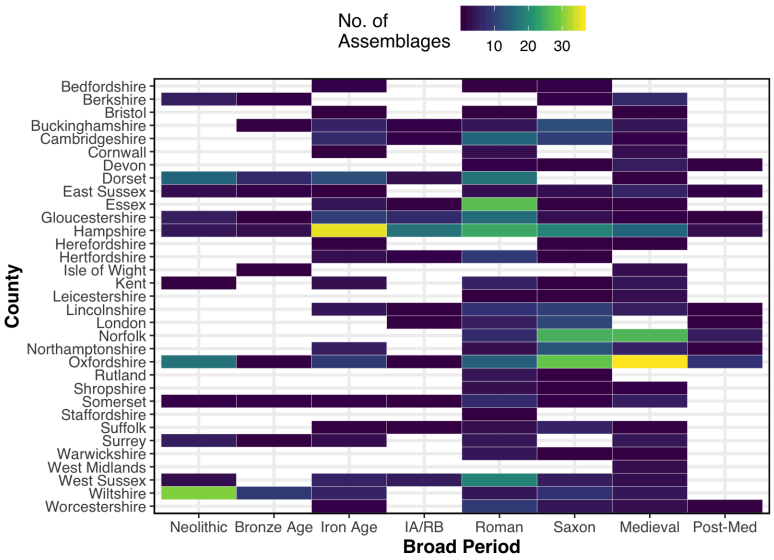

Figure 2.5: Number of assemblages by county and broad period.]{Number of assemblages by county and broad period. Absence of a tile (i.e. white space) indicates no assemblages for that broad period and county.

Spatial distribution of assemblages can be affected by regional variations in burial environment. This is particularly true of Britain, where the geology is varied and complex. Bands of chalky geology exist in the South of England and East Anglia (Figure 2.6, A) and correlate with alkaline soil pH (Figure 2.6, B), which is ideal for bone preservation (Baker et al. 2019: p. 1). Areas with little or no calcium carbonate content, meanwhile, correlate with either slightly acidic or neutral soils in some cases (e.g. Lincolnshire), and in the case of Wales, Devon and Cornwall, strongly acidic soils, which are detrimental to bone preservation. Strongly acidic areas are also found in Sussex and southern Hampshire.

Comparing the distribution of assemblages in the dataset against the calcium carbonate content of British geology clearly shows that animal bone representation traces bands of calcitic geology (Figure 2.7). The vast majority of assemblages are clustered in areas with high calcium carbonate levels, whilst more variable regions have far fewer. Yet, assemblage size (MD) does not appear to be correlated with geology. The same appears to be true of hare representation (Figure 2.8); assemblages with very high numbers of hares seem to be exclusive to chalky areas, but overall hare presence shows no obvious relationship. Assemblages with no hares are common in areas with little or

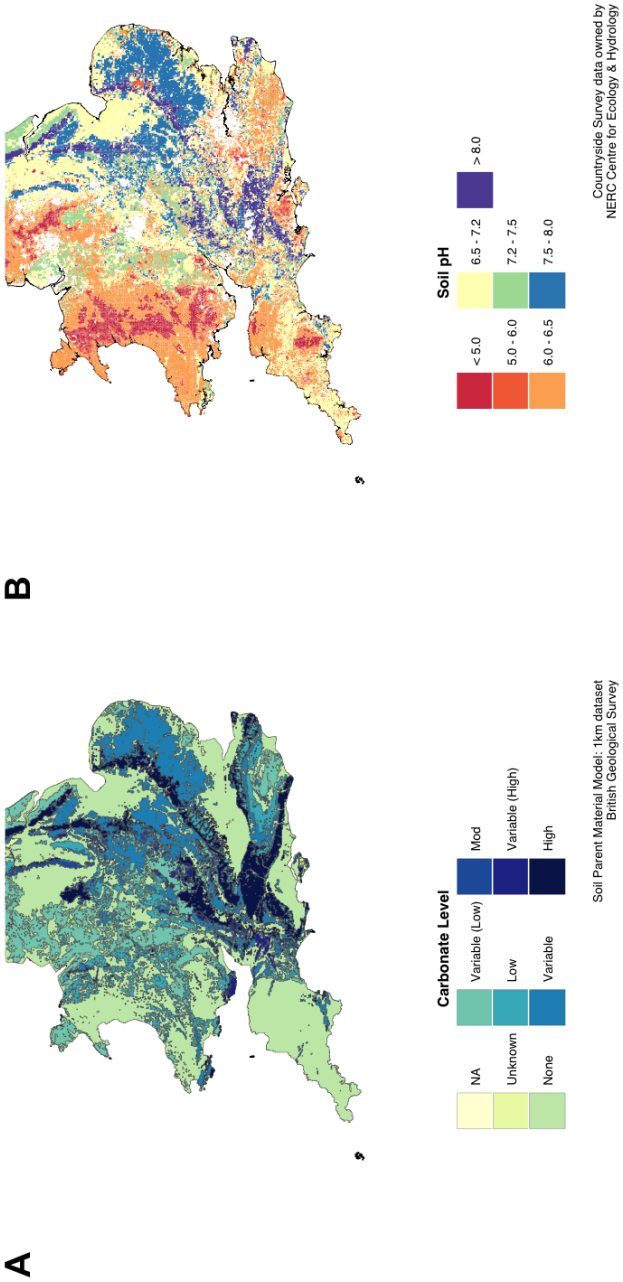

Figure 2.6: UK geology. A) Soil parent calcium carbonate content. B) Soil pH.

no carbonate content, but assemblages with hares are also present in those areas (Figure 2.9). This is encouraging because it means the spatial distribution of hare bones, which are more likely to be underrepresented when deposited in soils with low pH than larger taxa, can now be investigated without having to make any significant adjustment for geological bias, as the data show that the presence/absence of hare remains is not *determined* by geology. Instead, greater focus can be placed on other taphonomic factors, including cultural transforms.

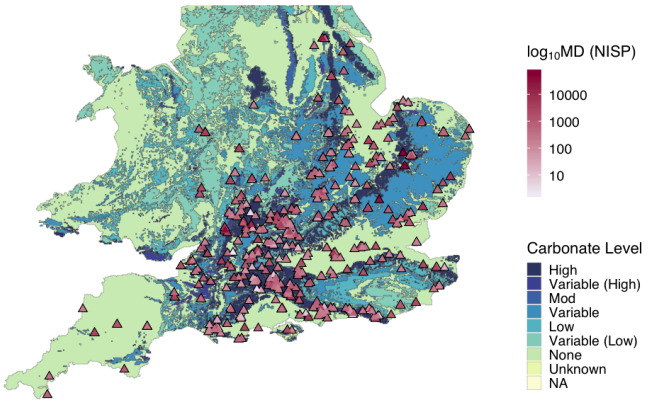

Figure 2.7: Assemblage distribution and log10 size of MD against soil parent calcium carbonate content. Soil parent data from British Geological Survey.

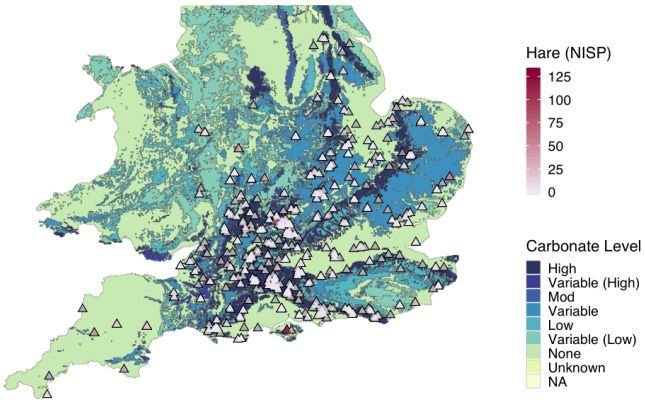

Figure 2.8: Assemblage distribution of hare NISP against soil parent calcium carbonate content. Soil parent data from British Geological Survey.

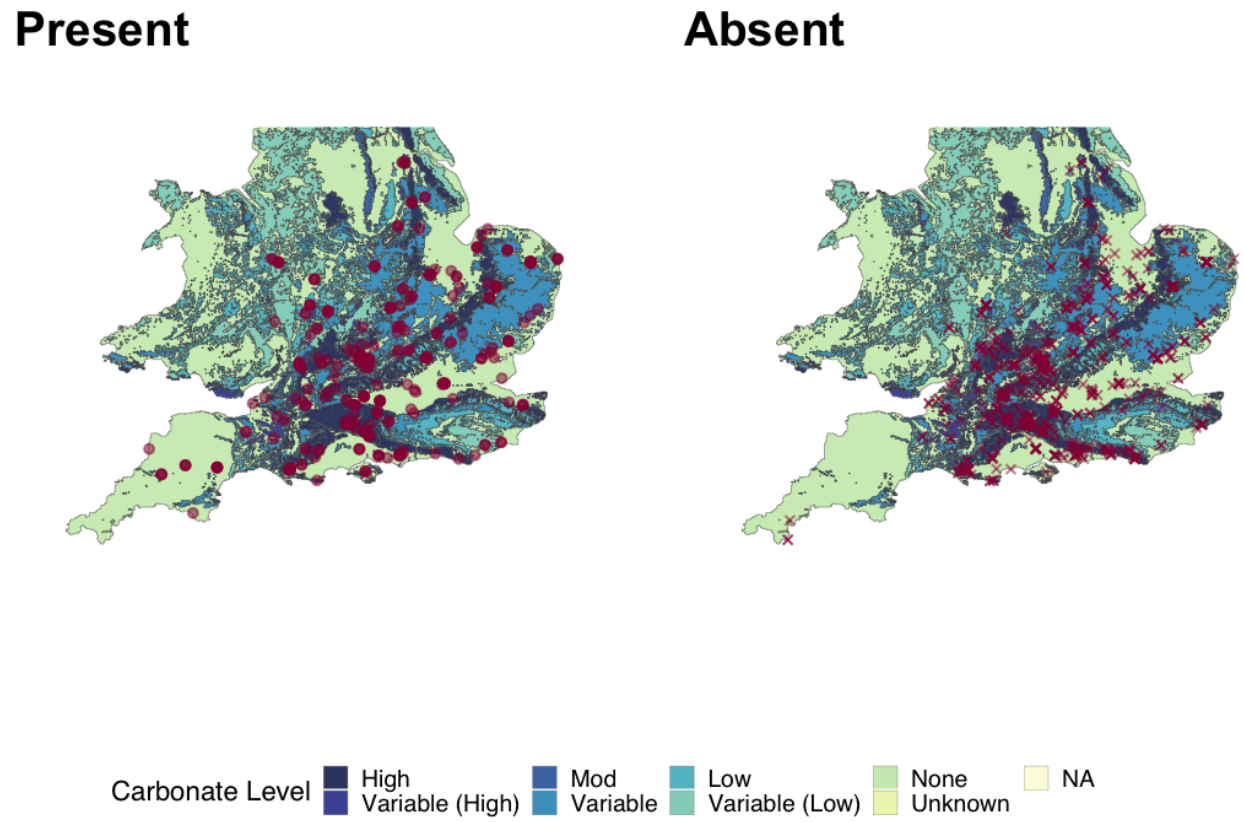

Figure 2.9: Assemblage distribution of hare presence and absence against soil parent calcium carbonate content. Soil parent data from British Geological Survey.

2.6 Analysis approach: statistical description, exploration and inference

Archaeology has a long history of statistical analysis and though the discipline has been divided on their use according to processual/post-processual standpoints (discussion in Orton 1999), it is undeniable that statistics are informative, arguably essential, to any field that deals with samples, uncertain or 'fuzzy' data, and complexity (Thomas 1978). Advances in computational archaeology mean that the literature informed by statistics and data science approaches is growing rapidly as new archaeological applications of these methods are discovered and experimented with (Cobb et al. 2019; Marwick 2017; Richards 1998). This thesis is no exception to that trend, so I use this section to describe some of the methods used, including but not limited to those found in this chapter. All analysis and data visualisation was performed using R (R Core Team 2019), along with several packages from the tidyverse (Wickham 2017).

2.6.1 Descriptive statistics

The most basic level of statistical analysis is description. Descriptive statistics provide crucial information about the distribution of a dataset (VanPool et al. 2011), both aiding interpretation and guiding more advanced analysis. Measures of central tendency - mean, mode and median - describe the *location of the centre* of the distribution (VanPool et al. 2011: p. 45). The mean is used frequently in the calculation of other statistics, and useful in its own right, but it is also highly sensitive to outliers, so some researchers prefer the median for describing heavily skewed datasets (VanPool et al. 2011: p. 47).

Measures of dispersion describe the *shape* of a distribution. Two datasets may have the same mean, for example, but completely different shapes (VanPool et al. 2011: p. 48-9). The two simplest measures are the range (difference between largest and smallest values) and the interquartile range (IQR - the difference between the variants demarcating the lower 25% and upper 25% of the values, known as the 25th and 75th percentiles respectively). Another measure is the Standard Deviation (SD), which refers to the average deviation from the mean, expressing the variation within the data (VanPool et al. 2011: p. 50-3).

As hares normally occur in small numbers, the dataset synthesised here is heavily

right-skewed (Figure 2.10), having many zero values for hare NISP, and many zero or near-zero values for H/MD. Emphasis is accordingly be placed on descriptors that are not so strongly effected by outliers. Yet *detecting* outliers is important, as they represent assemblages of interest, providing key sources of evidence for hares and equally raising questions about *why* they are outliers - i.e. are hares genuinely more abundant in those assemblages than in others, or is further critique of the data and archaeological context required?

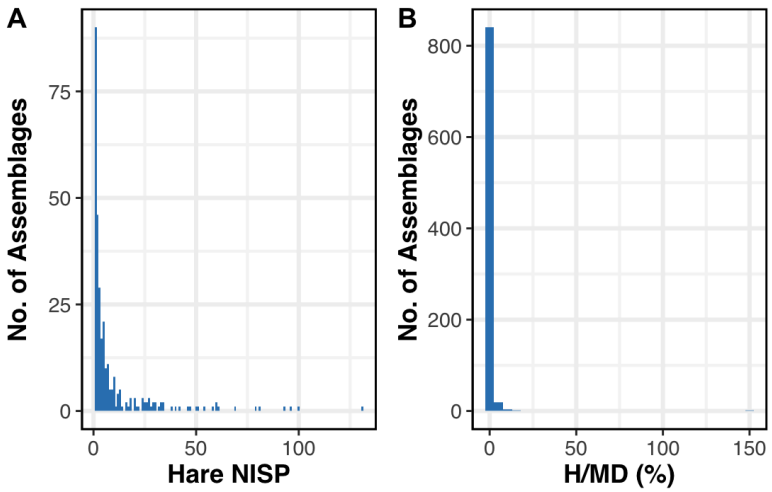

Figure 2.10: Histograms showing right-skew in hare representation. A) Raw hare NISP. B) Hare/MD (%).

Identifying outliers can be done easily with data visualisation. A scatter plot or bar chart often makes outliers clear from their positions relative to the majority of the data. Not all instances are so clear, however, and using only visualisation introduces subjectivity. Conversely, a mathematical method objectively establishes which data points are outliers and which are inliers, and can be consistently repeated across multiple grouping variables and subsets. Several approaches exist but the Tukey method, which is used to create the 'whiskers' in a box plot (Tukey 1977, cited in Hoaglin et al. 1986), is sufficient here.

Tukey's approach works by establishing 'fences' around the first quartile (Q1, the 25th percentile) and the third quartile (Q3, the 75th percentile). The fences are located at 1.5 times the IQR (Hoaglin et al. 1986), subtracted from Q1 and added to Q3 - see Equation (2.2). Values smaller than the lower fence and greater than the upper fence

are considered outliers. For this synthesis, the lower fence is irrelevant as the data are so highly skewed towards zero (and values lower than zero are not possible) but the upper fence allows assemblages that have unusual abundances of hares to be identified objectively and extracted for closer consideration.

$$Q_1 - 1.5 \times (Q_3 - Q_1), Q_3 + 1.5 \times (Q_3 - Q_1) \tag{2.2}$$

2.6.2 Analysing Site Types

Categorisation of archaeological sites according to cultural, social or economic characteristics is an important and pervasive aspect of zooarchaeological research. But it is an etic exercise, and therein lie theoretical and practical problems (see Johnson 2010: p. 83; Allen 2011: p. 42-3). On the theoretical side, it requires a projection of modern categories onto cultures that may never have viewed their cultural environment according to those divisions. Meanwhile, categorical terms vary in application and meaning across spatial and temporal groupings; researchers may interpret the same site differently; and the generation of new knowledge prompts reinterpretation after sites' original publication (discussion in Holmes 2017: p. 10-11; Allen 2011: p. 42-3). Research questions, sample size and other data analysis concerns also influence how archaeological data are grouped using site types (Hambleton 2008: p. 11-12). Finally, zooarchaeological evidence often contributes to a site's characterisation (see, for example, discussion of banjo enclosures in Hambleton 2008: p. 46; Lyminge in Thomas 2013; and Flixborough in Dobney et al. 2007b), so further research using these site type assignments runs the risk of circular reasoning.

Changes in the evidence within a site type can only be made apparent when the same categories are used consistently through time, but not every site type is appropriate to every period and study. This is illustrated by differences between Hambleton's and Allen's datasets. As Allen's data include Roman towns, it is helpful to distinguish these sites from rural settlements, which he divides into 'minor' and 'nucleated' (Allen 2011: p. 42-3) to differentiate small settlements from so-called 'proto-urban' Iron Age sites, such as *oppida* (discussion in Moore 2017; Woolf 1993) and hillforts, and Roman small towns and *vici*. Any finer distinction could have created categories with too small a sample size for useful analysis. Having different research questions, and in the

absence of towns, Hambleton (2008: p. 11) uses finer distinctions: she differentiates, for example, between settlements, enclosed settlements, hillforts, promontory forts, and *oppida*. For this synthesis, Allen's and Hambleton's approaches needed to be integrated not only with each other, but also with those of Poole, Sykes, and Bowen, whose work focuses on periods where sites types can be more regular (post-Roman sites are almost always divided into "urban", "rural", "religious", or "high-status"). Combining all these syntheses necessitates the problematic assumption that terms like "rural" and "urban" meant the same thing to different people in different time periods. Additionally, site types are not necessarily mutually exclusive.

Certain data analysis approaches can remove *some* of the subjectivity of categorisation. The field of exploratory data analysis (EDA) typically uses a combination of data visualisation and descriptive statistics to reveal trends in a dataset. More complex, typically multivariate, techniques also exist and are increasingly popular in archaeology (e.g. Cool et al. 1999; Morris 2008b; Smith 2014). Multivariate EDA methods can allow groups to be identified from the data, rather than imposing pre-determined ones on them. A common approach in archaeobotany, for example, is to use Correspondence Analysis to identify whether pre-determined categories correlate with clusters within the data on the basis of statistical variance. These categories can derive from a variety of variables, such as site or feature type, intra- and inter-site location and stratigraphic factors (examples in Lodwick 2018; Bouchard-Perron et al. 2009; Charles et al. 1997). Alternatively, Cluster Analysis could be employed to focus, more appropriately in this context (the focus being on a single target variable, i.e. the number of hare bones), on grouping sites by their similarity to each other.

Hierarchical Cluster Analysis was attempted for the assemblages in this synthesis, using the NISPs of hares, cattle, sheep/goat and pig, having standardised the values before calculating the distance matrix. But because the presence of hare bones was found to be rare (see results analysis below), the results were only meaningful when sites without hare bones were excluded, at which point the clusters tended to conform to site type trends already established in the literature and observable in these data without the need for a multivariate method. The approach could therefore not contribute any further insight. This was likely because the far greater abundance of the domestic fauna overwhelmed the number of hare bones, or because the approach was underpowered by only utilising four variables (the three main domesticates plus hares). The results

of this analysis are consequently omitted from the text, but dendrograms showing the clustering hierarchies, plus maps showing the spatial distribution of sites grouped by their cluster, can be seen in the digital appendix (Appendix A.5). The discussion of the results instead focusses on the trends observable with simple data visualisation, bearing in mind the theoretical issues with predetermined categories discussed here.

2.6.3 Inferential statistics

Although powerful in their own right, data visualisation, descriptive statistics and exploratory methods do not demonstrate the significance of the patterns they help reveal. Inferential statistics are needed instead. Yet there is a credible argument against the use of inferential testing in archaeology. Wolverton et al. (2016) rightly posit that because cultural (c-) transforms and natural (n-) transforms have non-random effects on samples (see also Orton 1999: p. 31), the underlying requirement that sampling error is randomly generated is not met by archaeological datasets. If error is randomly distributed by a well-designed sampling strategy, larger sample sizes produce less error because more of the population is represented (Orton 1999; Wolverton et al. 2016). Consequently, minor differences and weak relationships become easier to detect as sample size increases (Orton 1999: p. 28; Ellis 2010: p. 32). Statistical significance is consequently tied to the direct random sampling of an extant population, as it represents the idea that a similar result would be achieved if the same population was sampled again using the same random approach and the same number of samples. Archaeologists, unfortunately, cannot ensure sampling error is random as they are seldom able to directly sample a population (Orton 1999; Wolverton et al. 2016). Zooarchaeologists also suffer from the problem that the predominance of fragmentary bone in most assemblages means that observations are not demonstrably independent (Wolverton et al. 2016).

This does not mean that inferential statistics need to be abandoned. Instead, Wolverton et al. (2016) promote effect sizes as measures of whether the sample size is sufficient for identifying statistical significance, and then consider practical or 'real world' significance. Recognition that the primacy of *p*-values in research informed by statistics is flawed (e.g. Halsey et al. 2015) has contributed to an increase in research using effect sizes in psychology and the social sciences in the last twenty years, including the publication of general textbooks on their use, such as Ellis (2010) and Grissom et al.

Table 2.3: Effect size versus statistical significance.

Effect Size	Low Significance (High p)	High Significance (Low p)
Small	Insignificant + Trivial	Significant + Trivial
Large	Insignificant + Important	Significant + Important

(2012).

The use of *p*-values is arguably less important than effect sizes in archaeology because randomly distributed sampling error cannot be assumed (Wolverton et al. 2016). Further, it is common for *p*-values and statistical significance, to be misunderstood as an indicator of the strength of a relationship or the magnitude of a difference, which then leads to an erroneous association with real-world meaning (Ellis 2010: p. 3-4, 32); in archaeology this might be social or economic 'importance'. In fact, statistically significant relationships or differences may be trivial (e.g. when large sample sizes enable a test to identify statistically significant, but weak, relationships), whilst insignificant ones might be important (Table 2.3). By reporting effect size and significance together, researchers are better positioned to interpret the results of their analyses.

Wolverton and colleagues' (2016) argument for using effect sizes in archaeology is equally compelling and relevant to this thesis. It resembles, in regards to data analysis, ideas proposed with respect to theory and interpretation by (Sykes 2014a: p. 9): that in the pursuit of significance through maximising sample size, zooarchaeologists have neglected to consider the grounds on which observed patterns in data are converted into interpretations. Whilst Sykes (2014a) argues that abundance does not demonstrate importance, Wolverton et al. (2016) explain that neither does statistical significance.

Effect sizes provide an informative analytical tool for this thesis, where cases of statistical significance may be few due to small sample sizes and the skewed dataset. The approach taken here then, is to combine the descriptive statistics and exploratory methods described above with inferential statistics and effect size estimates. Nevertheless it is important to stress that effect sizes cannot free archaeologists from the task of interpretation and the theoretical concerns that accompany it; these statistics are still simply numbers that must be placed in appropriate context to reveal their meaning (Ellis 2010: Chapter 2).

2.6.3.1 Selected Tests and Effect Sizes

Appropriate test selection is always critical. Normally distributed datasets are rare in archaeology so parametric statistics are seldom appropriate, for example. This is certainly true here (Figure 2.10), yet non-parametric tests are powerful in these circumstances. The Kruskal-Wallis *H* test (for testing whether groups originate from different distributions) and chi-squared test of independence (Dytham 2011) are used to test for statistical significance in changes in hare bone presence through time and between site types, teamed with their effect size estimates to aid interpretation.

For Kruskal-Wallis, (Wolverton et al. 2016) suggest η^2 but do not mention that it is upwardly biased, especially when sample sizes are small (Grissom et al. 2012: p. 182). ϵ^2 is used here as a more conservative option - see Equation (2.3).

$$\epsilon^2 = \frac{H}{(n^2 - 1)/(n + 1)} \tag{2.3}$$

Meanwhile, ϕ is used for 2×2 chi-squared - Equation (2.4) - and Cramér's V for tables larger than 2×2 - Equation (2.5) (Grissom et al. 2012). Note that the R function for chi-squared, `stats::chisq.test()`, uses Yates' continuity correction by default, but it was disabled for these tests because it is considered an overcorrection and therefore not used for calculating chi-squared when effect sizes are to be applied (Grissom et al. 2012: p. 249).

$$\phi = \frac{\sqrt{\chi^2}}{n} \tag{2.4}$$

$$V = \sqrt{\frac{\chi^2}{n(df_s)}} \tag{2.5}$$

2.6.3.2 Interpreting Effect Sizes

Effect sizes can help identify the most important changes through time, by providing measures that can be compared. All the effect sizes used here belong to the same family as Pearson's correlation coefficient *r*, where -1 is a strong negative relationship, zero an absence of a relationship, and 1 a strong positive one (Ellis 2010: p. 11-12). In most cases, they should have values close to zero, reflecting weak relationships.

Table 2.4: Cohen's benchmarks for effect size estimates for analyses of variance and tests of independence, after Ellis (2010: p. 41). Note that Ellis gives only η^2, shown here, but this thesis uses ϵ^2 which is an equivalent but more conservative statistic.

Type	Estimate	Trivial	Small	Medium	Large
Analysis of variance	η^2	< .01	.01	.06	.14
Tests of independence	ϕ, V	< .10	.10	.30	.50

Interpreting effect sizes is not an arbitrary exercise. Ellis (2010: Chapter 2) stresses that the research context and the potential contribution to knowledge should direct how researchers make inferences from these figures. Effect sizes remain rarely used in archaeology, however, so the Ellis' third recommended approach - Cohen's benchmarks (Table 2.4) - are employed here as an additional guide. Ellis (2010: p. 40-2) urges that these benchmarks should not be used uncritically, however, as context and contribution are more meaningful approaches. Two equal effect sizes might be classed as 'small', for example, but might have very different implications depending on the data being tested and the questions being asked.

2.6.3.3 Pairwise Testing

The majority of applications of the chosen statistical inference tests analysed the relationships between hare bone presence/abundance and pairs of time periods. These pairs were selected in chronological sequence, so that, for example, the Neolithic could be compared with the Bronze Age, the Bronze age with the Iron Age, the Iron Age with the Roman period, and so on. This is because analysing the relationship between presence/abundance and all time periods would inevitably produce a significant result, thanks to a large sample size, whilst revealing nothing about the nature of changes between one period and the next. As the main purpose of this chapter is to determine which periods correspond to important changes in hare bone presence/abundance - which might indicate an introduction - individual changes are far more useful sources of insight than than a statistical understanding of the dataset as a whole.

It is important to acknowledge here that the Kruskal-Wallis *H* test is not normally used for pairwise testing; the Mann-Whitney *U* test (MWU) is a more traditional choice (Dytham 2011: p. 142). This is because MWU is restricted to only two groups (i.e. here, time periods) and is considered to be much more powerful for this purpose (Dytham

2011: p. 142), whilst Kruskal-Wallis is applicable to two or more groups. I am not aware, however, of any reason why pairwise Kruskal-Wallis testing should be prohibited - it is designed for *two or more* groups, not *more than two* (Dytham 2011: p. 142) - and by choosing a weaker test it should be possible to avoid overestimates of the *H* statistic or *p*-value, and thereby avoid statistically significant results that are merely the product of large sample size. Though both tests are non-parametric, the extreme skewness of the data (Figure 2.10), and the non-independence of fragmentary bone (page 65) are good justifications for choosing a more conservative option. It was also strategic to write *R* code for iteratively running chronological sequential Kruskal-Wallis tests, as it provided the opportunity to expand the analysis to tests involving larger numbers of groups if needed, without writing additional code.

2.7 Macroscale

2.7.1 Presence/Absence

Examination of the zooarchaeological data across broad periods is consistent with an introduction of hares occurring in late prehistory. Presence/Absence rises gradually in the Bronze and Iron Ages, followed by a steeper rise in the Roman period (Figure 2.11). A subsequent decline in the Saxon period is consistent with the general absence of wild fauna in Saxon assemblages (Sykes 2010, 2014a: p. 68-70; Poole 2011). The Late Saxon period saw renewed interest in hunting which continued post-Conquest (Sykes 2010, 2014a: p. 70-4, 2007b; Poole 2011) and is reflected in the steep rise in hare presence occurring in the medieval period. A small decline registers in the Post-Medieval period, but the small sample size means it should not be taken at face value.

Chi-squared tests of independence were applied to the presence/absence data in sequential pairs of broad periods to examine individual changes in hare representation from one era to the next. These tests (Table 2.5) show that the transition from the Neolithic to Bronze Age is one of the weakest transitions, excluding the Iron Age to IA/RB, suggesting that the increase in hare presence in the Bronze Age is a relatively trivial change and may be a function of sample size or taphonomic bias.

The transition from the Bronze to Iron Age ($\phi = 0.17$) is much stronger by contrast, though as expected it still constitutes a weak effect according to Cohen's benchmarks

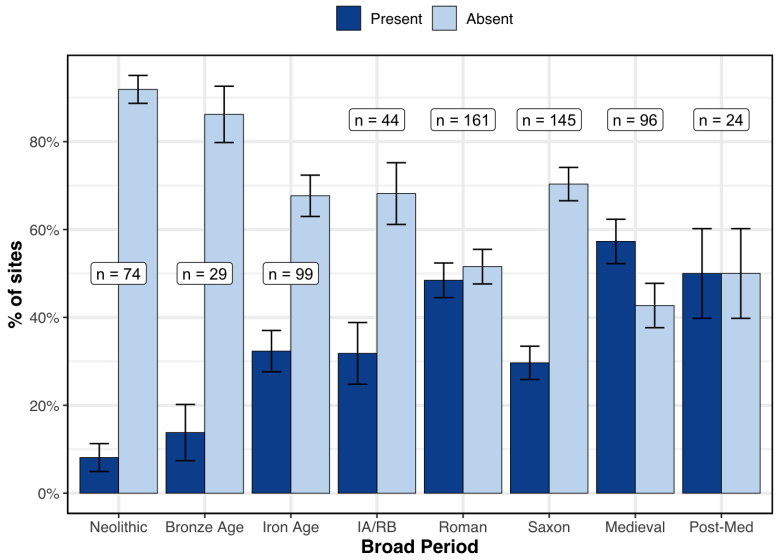

Figure 2.11: Presence/absence of hare remains through time by broad period. n = number of sites. Error bars represent the standard error, calculated with the formula: $s = \sqrt{\frac{p.est \times (1 - p.est)}{n}}$

(Table 2.4). It is consistent with most arguments concerning the timing of the brown hare's arrival (Lauritsen et al. 2018; Sykes 2014a: p. 88-9; Yalden 2010: p. 194-5). Differences between the Iron Age and IA/RB are very slight (Figure 2.11) and the zero ϕ value indicates that there is no practical difference between the two phases. If the other metrics used in this chapter also indicate continuity, it might suggest that cultural changes in the first centuries BC and AD had little impact on the presence of hares in southern Britain, though admittedly not all changes are visible archaeologically.

Significant results were obtained for transitions between the IA/RB and Roman period, between the Roman and Saxon, and the Saxon and Medieval. These corresponded with some of the highest values for ϕ, which indicate stronger correlations. Notably, the decline in hare presence from the Roman to Saxon periods (Figure 2.11) produces a stronger correlation ($\phi = 0.19$) than the rise from the IA/RB to Roman ($\phi = 0.14$). The subsequent rise in the Medieval period is by far the strongest. That these three transitions all produced significant results while none of the others did is likely a demonstration of the effect of sample size on the test's power to detect significant relationships (see page 65).

Table 2.5: Summary of χ^2 analyses on sequential pairs of broad periods for presence/absence representation of hare remains.

TEST	χ^2	DF	ϕ	p-value	Signif.
Neolithic → Bronze Age	0.8	1	0.09	0.381	–
Bronze Age → Iron Age	3.8	1	0.17	0.051	–
Iron Age → IA/RB	0.0	1	0.00	0.952	–
IA/RB → Roman	3.9	1	0.14	0.049	T
Roman → Saxon	11.3	1	0.19	0.001	T
Saxon → Medieval	18.3	1	0.28	< 0.001	T
Medieval → Post-Med	0.4	1	0.06	0.52	–

Mapping presence/absence through time shows some spatial patterning to hare representation. Two approaches were used: one using simple distribution maps, and a second using density estimates. Distribution maps allow individual sites and clusters of sites to be picked out, whilst density emphasises larger clusters and general trends. The density maps were produced using the `geom_density_2d()` group of functions in the ggplot2 package for *R*, which call the `k2de2()` function from the MASS package. This is a two-dimensional kernel density estimation (KDE, see Heumann et al. 2020: Section 2.4 for details) method - 2D methods being essential for spatial data (for "x, y" coordinates) - and is also non-parametric (Long et al. 2019: Section 10.20), which is ideal for the highly skewed dataset dealt with here.

Hares are present mainly in the area around Dorset, Somerset and Gloucestershire in the Neolithic, and this pattern is repeated with one exception in the Bronze Age (Figure 2.12). Absence results show this derives from a westerly bias in Serjeantson's (2011: p. 2-3) dataset, which may reflect preservation biases from calcic geology (Figure 2.6, A) in the west of England (excepting Devon and Cornwall).

Hare bone presence is more common and spatially dispersed in the Iron Age, though it appears that two to three clusters may have existed (Figure 2.12). There is at least one in the Hampshire, Dorset and Sussex area and another in the Cambridgeshire, Suffolk, Northamptonshire area. The West Midlands region and Somerset and Gloucestershire may be a third cluster, or else should be included with the southern one. East Sussex and Kent appear to lack hares, which may reflect local soil acidity (Figure 2.6, B). This trend is continued in the IA/RB, though the smaller sample size means it is less certain.

Figure 2.12: Distribution maps of Neolithic-IA/RB sites showing presence/absence data for hares.

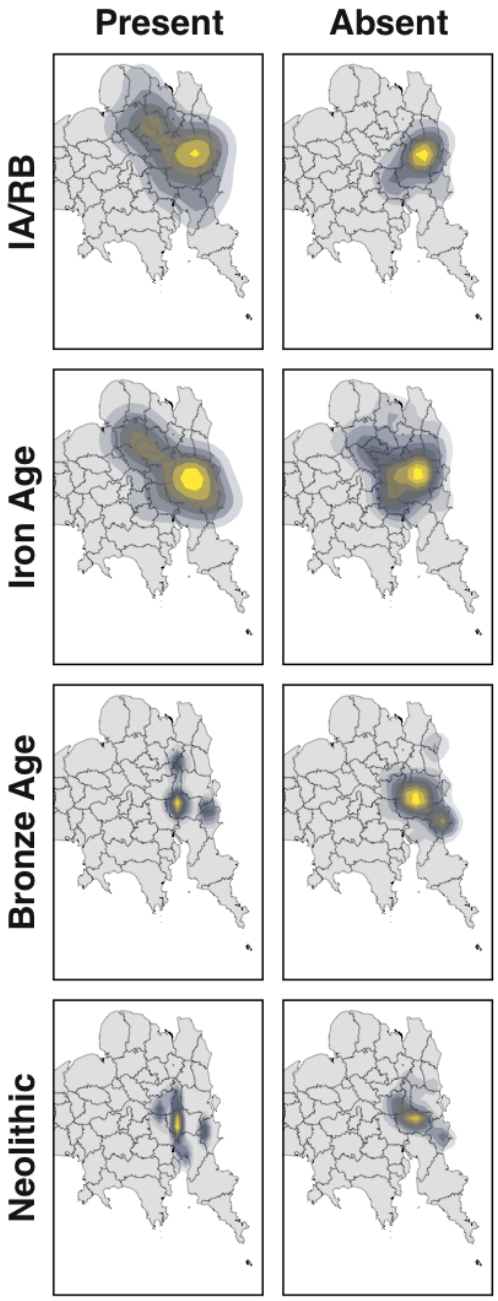

Figure 2.13: Density maps of Neolithic-IA/RB sites showing presence/absence data for hares.

The density maps for the Iron Age and IA/RB (Figure 2.13) emphasise only two clusters of relative high density, though the presence of hares in the West Midlands is subtly indicated. The central southern region is clearly important for having the greatest abundance at a time when brown hares are supposedly a recent introduction, though the east of England should not be discounted. Assemblages without hares are common in central southern England, reflecting the general wealth of Iron Age and Roman archaeology in the region.

Most of southern England and the parts of the Midlands included in this study produce evidence for hares in the Roman period (Figure 2.14). Hares also now appear for the first time in areas where good bone preservation is less probable, such as Cornwall, East Sussex and Kent. Coastal sites would have been instrumental in the spread of hare populations if they were imported from continental Europe (see Sykes 2014a: p. 89), and there is a rise in the number of coastal sites with hares present, compared with the Iron Age and IA/RB. There are no obvious regional variances in the Roman distribution map, though the density map (Figure 2.15) highlights a region spanning from central southern England towards the West Midlands, and a secondary area around London, Essex and Suffolk.

The Saxon period (Figures 2.14 and 2.15) shows a clear decline in the presence of hares in south-west England, though this may be slightly exaggerated by the overall reduction in assemblages from those counties, especially Dorset and Somerset. An easterly trend for hare presence is apparent, though the absence data indicate the same trend so regional variation in hares may again be explained by overall spatiotemporal variance in animal bone assemblages. The clearest area of density is found in Hampshire and counties directly north and north-east of it, such as Greater London and Oxfordshire. The medieval period continues this, though hares are now once again in the south-west of England. Sites in the south-east with hares are also more common. The post-medieval data generally seem to mimic the medieval, when reduced sample size is accounted for.

Comparing all the density maps though time reveals an important trend. Spatial coverage clearly expands over time, but while areas of absence are bigger in the Bronze Age and Neolithic, areas of presence are greater in the Iron Age (Figures 2.13 and 2.15). This is consistent with an introduction. Density in the IA/RB probably reflects

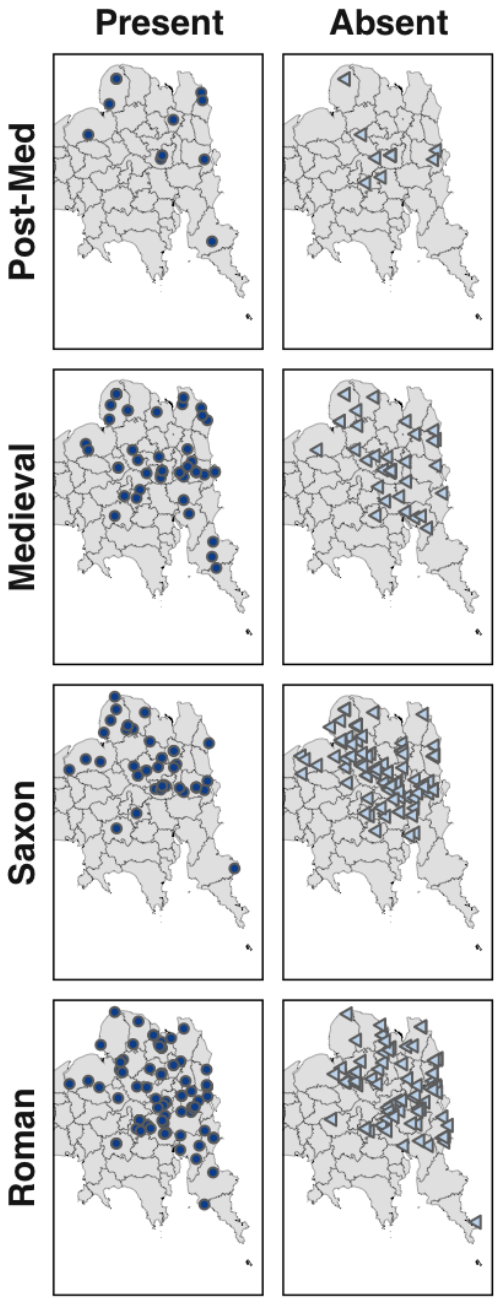

Figure 2.14: Distribution maps of Roman to Post-Medieval sites showing presence/absence data for hares.

Figure 2.15: Density maps of Roman to Post-Medieval sites showing presence/absence data for hares.

more intense excavation in Hampshire, so absence appears to be more dense in this period, but presence is more widespread overall. Coverage and both presence and absence density in the Roman and Saxon periods are about equal, except that absence is slightly more localised. By the medieval period, presence is effectively ubiquitous, whilst absence is the most restricted it has been since the Iron Age.

2.7.2 Raw Number of Identified Specimens (NISP)

Investigating hare presence through raw NISP figures highlights the difficulty of working with heavily skewed data. Figure 2.16 A and B show hare NISP for assemblages by broad period, with assemblages with no hares present included and excluded respectively (Figure 2.16.C shows sample size in terms of sites and assemblages). In both cases the data are skewed towards zero, but the different approaches offer alternative perspectives. Showing all the assemblages (Figure 2.16.A) plays down change and emphasises hares' overall underrepresentation in all periods; the median remains effectively the same and the mean only rises noticeably in the medieval period, where there are the most extreme outliers. Yet it places the rise in hare presence seen in the Iron Age presence/absence data in valuable context. Although presence is rising at this time, hare bones are still so rare that over a third of assemblages with them are outliers.

Visualising only the assemblages with hares present (Figure 2.16.B) allows the genuinely unusual instances to be identified, although it could over-emphasise temporal change. Key outliers in the Iron Age, for example, include Suddern Farm, Sutton Walls, Owslebury, and Winklebury Camp - the last two of which are sites with Associated Bone Groups (ABGs), the significance of which is discussed later in this chapter (§2.9.1, §2.9.3). Two more sites with ABGs - Winnall Down (Maltby 1985) and Blackhorse Road (Legge et al. 1988) - do not appear as outliers because the total NISPs for the ABGs were not given. A full list of outliers from Figure 2.16.B is given in the appendix (Appendix Table A.3).

Key trends are common to both visualisations. Overall, the representation of hare bones is stable at very low numbers until the Roman period, when assemblages with large numbers of hares become less rare for the first time. The subsequent decline in the Saxon period is much less intense for NISP than was the case for presence/absence

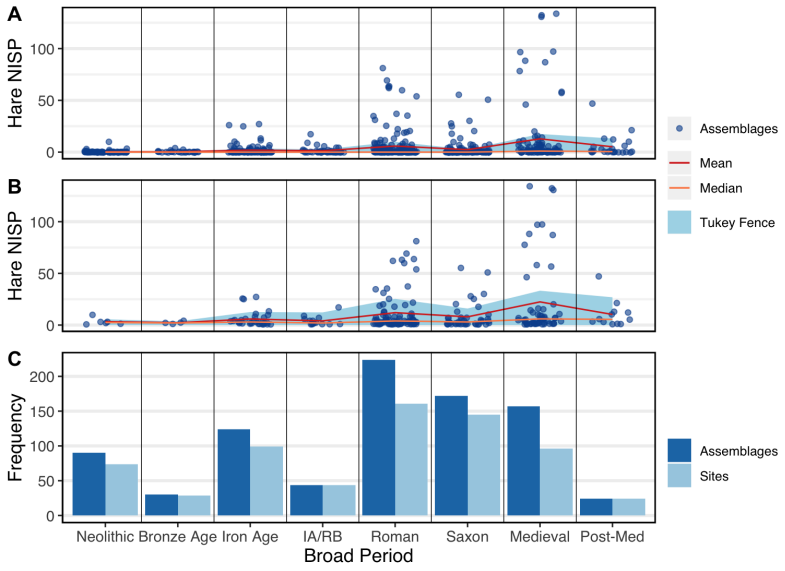

Figure 2.16: Raw NISP values for hares by broad period. A) All assemblages. B) Assemblages with hares present only. C) Sample sizes by broad period, showing count in terms of both assemblages and sites. For A and B, the blue-shaded area represents the space between NISP = 0 and the upper Tukey Fence ($Q_3 + 1.5 * IQR$). Values above this area are therefore outliers, those within it are inliers. There is no lower Tukey Fence shown because no assemblage can have a NISP lower than zero.

Table 2.6: Summary of Kruskal-Wallis *H* tests on sequential pairs of broad periods for raw NISP hare data.

TEST	H	DF	ϵ^2	*p*-value	Signif.
Neolithic → Bronze Age	0.7	1	0.01	0.392	–
Bronze Age → Iron Age	4.2	1	0.03	0.04	T
Iron Age → IA/RB	0.1	1	0.00	0.784	–
IA/RB → Roman	5.2	1	0.03	0.023	T
Roman → Saxon	12.5	1	0.04	< 0.001	T
Saxon → Medieval	21.8	1	0.09	< 0.001	T
Medieval → Post-Med	0.4	1	0.00	0.514	–

(§2.7.1) and though the mean NISP does reduce towards the median value, a small number of outlying assemblages with around fifty hares (Wroxeter and Portchester Castle) keeps the mean close to its value in the Roman period. The first assemblages with more than eighty hares appear in the medieval period, drawing the mean to its highest level. The change in the median (Figure 2.16.B) is subtle, however, emphasising that access to hares was still limited and probably socially restricted (§2.8). The decline in the post-medieval period is sharper than was the case for presence/absence.

Sequential pairs were compared statistically for these data, this time using Kruskal-Wallis tests to determine whether the broad periods in each pair originate from different distributions. The procedure was done twice, one each for Figures 2.16.A and 2.16.B. The whole dataset (Figure 2.16.A and Table 2.6) produced significant results for the Bronze Age to Iron Age pair and for the three pairs running from the IA/RB to the medieval period. This trend matches the results for χ^2 on presence/absence data, with the exception of the Bronze Age to Iron Age pair. Little change is detected from the Iron Age to IA/RB and from the medieval to post-medieval periods, whilst the Saxon to medieval transition stands out as the largest change in hare NISP, and is the only medium-sized effect (Table 2.4).

When assemblages with hares are examined in isolation (Figure 2.16.B and Table 2.7) only the medieval to post-medieval transition produces no change ($\epsilon^2 = 0$), but the other results are more homogenous. Tests on the transitions from Neolithic to Bronze Age and Bronze to Iron Age failed because the number of sites with hares in the two earliest phases are too small for a minimum sample size of five for each group.

Spatial analysis shows a handful of interesting trends. The distribution of assemblages

Table 2.7: Summary of Kruskal-Wallis H tests on sequential pairs of broad periods for raw NISP hare data, subsetted to include only assemblages where hares are present.

TEST	H	DF	ϵ^2	*p*-value	Signif.	NOTE
Neolithic → Bronze Age	–	–	–	–	–	FAIL
Bronze Age → Iron Age	–	–	–	–	–	FAIL
Iron Age → IA/RB	1.0	1	0.02	0.32	–	–
IA/RB → Roman	2.2	1	0.02	0.135	–	–
Roman → Saxon	1.3	1	0.01	0.247	–	–
Saxon → Medieval	3.9	1	0.04	0.049	T	–
Medieval → Post-Med	0.0	1	0.00	0.856	–	–

with hares present (Figure 2.17) is largely without a pattern, but it is clear that in the Iron Age larger numbers of hares are found in the western group identified above (page 71), whilst the eastern group is more homogenous, all returning NISPs between one and five. Density maps for these data include all of the assemblages, but only show that central southern England has the greatest concentration of hares in the Iron Age (Figure 2.18).

In the IA/RB, the assemblages with the largest numbers and the area of greatest density have shifted south-east into West Sussex, where 273 hare bones found at Carne's Seat (Beech 1986), corresponded to at least *thirteen* individuals. It is common for researchers to represent the NISP for a bone group using its MNI (or a similar measure) so that such groups do not bias the given taxon's overall NISP. This is clearly the case for Carne's Seat in Allen's (2011) synthesis. It is unclear, however, whether he deliberately converted this MNI to seventeen (the figure used in this thesis) or simply misread it, although the latter seems likely. Regardless, skepticism is advisable as Beech (1986) suggests that the hares are intrusions. Sykes (2001) later concluded that the majority of these remains were not only intrusive but also misidentified rabbits.

In the Roman period, the sites with large NISPs (51-100) are all close to the south or east coast (Figure 2.17), which lends support to the earlier suggestion that hares were being imported (page 74), though admittedly not every coastal site has similar abundances. The density estimate map for this period supports this trend, though the area bordering Hampshire and West Sussex clearly has the highest concentration (Figure 2.18).

Contrary to the presence/absence data, the Saxon NISPs suggest greater abundance in

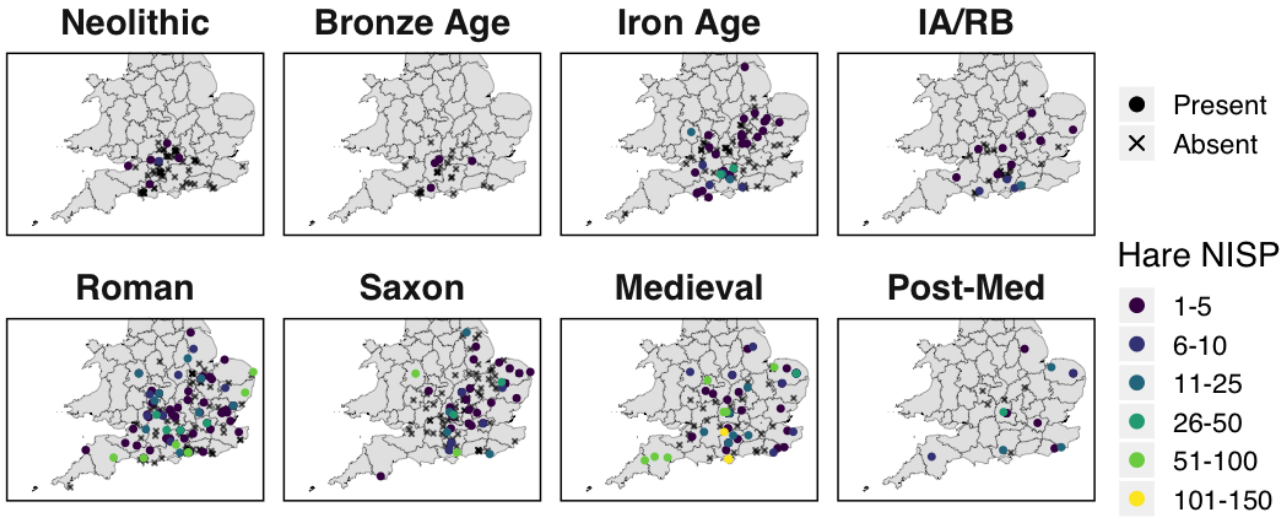

Figure 2.17: Assemblage location maps by broad period showing hare NISP. Includes only sites with hares present.

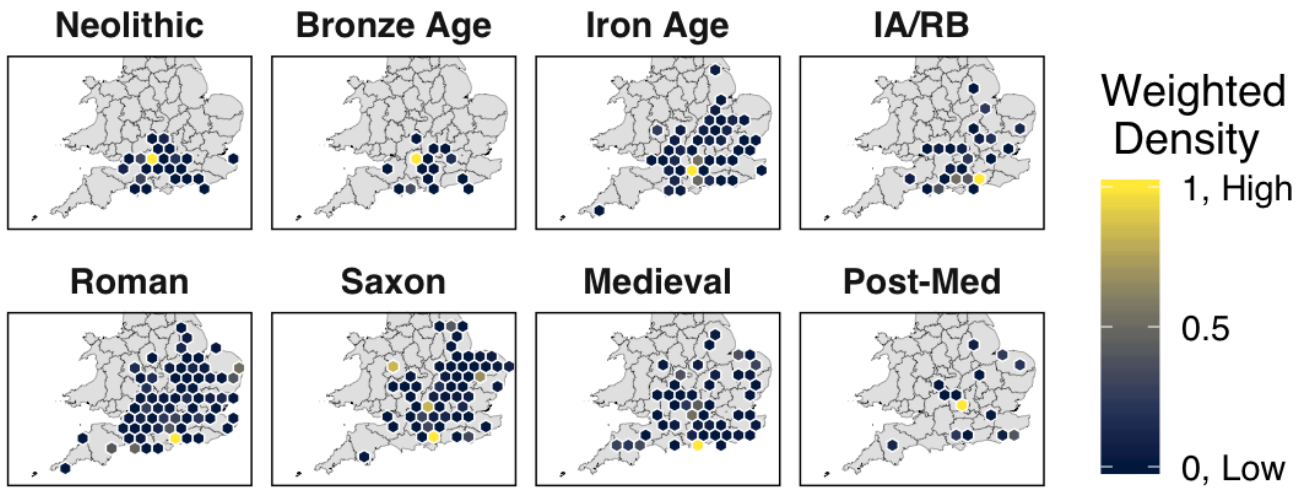

Figure 2.18: Assemblage density by broad period, including all assemblages. Weighted by hare NISP and scaled to maximum density value.

central southern England and the West Midlands (Figures 2.17 - 2.18), mimicking the presence/absence density distribution seen in the Roman period (Figure 2.15). The increased presence of hares in the east of England during the Saxon period meanwhile is represented mainly by assemblages with low numbers of hare bones. The Saxon density map highlights the Southampton area as particularly concentrated. The medieval density map also reflects this, suggesting the intensity of excavation in Southampton (e.g. Garner 1994; Holdsworth et al. 1980; Platt et al. 1975; Walker 1979) biases the distribution. Larger hare assemblages in the east of England also appear at this time, especially in Norfolk. Central England, meanwhile, has the greatest abundance in the post-medieval, reflecting the large animal bone assemblage recovered from Eynsham Abbey (Ayres et al. 2003).

2.7.3 Hare/Main Domesticates

Expressing hare NISP as a percentage of main domesticates offers alternative perspectives on the dataset. Firstly, it highlighted Lanhill Long Barrow, for which the main domesticate data were incompletely quantified, so the total MD value equalled two (for three hares, producing H/MD = 150%). This assemblage therefore skewed all the other results and had to be removed before any meaningful analysis could proceed. The significance of Lanhill is discussed further in the microscale section of this chapter (§2.9).

Next, it is again useful to compare the distribution of assemblages in two forms, once where all data are included, and once where only assemblages with hares are used. The former (Figure 2.19.A) produces patterns very similar to those already seen, except that now the transition from the Bronze to Iron Age represents a subtle decline, whilst the medieval to post-medieval is a rise.

Excluding assemblages without hares (Figure 2.19.B) emphasises differences in the transitions even more. It produces a median sequence that subtly rises in the Iron Age, Roman, and Medieval periods - aligning with expected increases in hare abundance - whereas Figure 2.19.A and the Presence/Absence and raw NISP metrics produced more persistently zero or near-zero medians. A handful of Neolithic and Bronze Age assemblages stand out so much that the Neolithic to Bronze Age transition is a sharp decline in the relative abundance of hares for the first time (Figure 2.19.B). Note that assem-

blages with hares are so rare in the Neolithic that, when all others are excluded, they are all inliers regardless of the proportion of hares to main domesticates. This suggests that not all the Neolithic hares experienced 'normal' taphonomic pathways; further critique of the skeletal element representation, burial environment and depositional circumstances is needed (see §2.9).

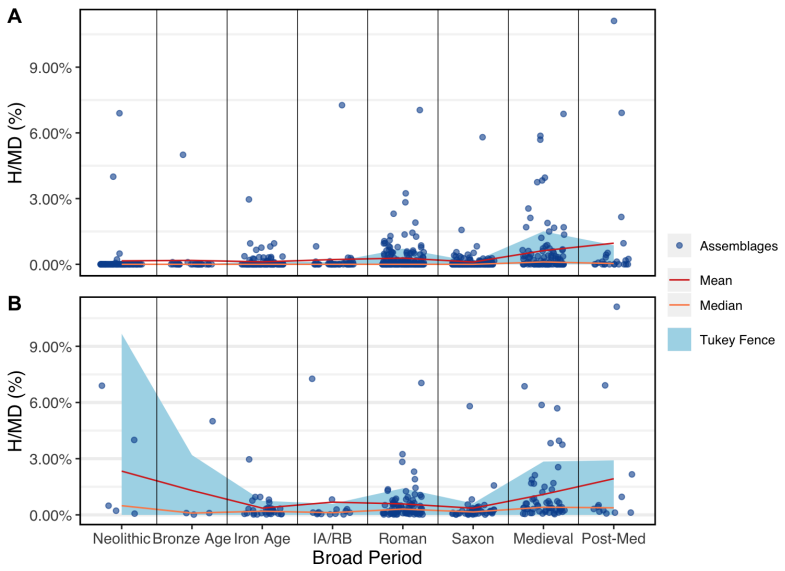

Figure 2.19: H/MD values by broad period. A) All assemblages. B) Assemblages with hares present only. See Figure 2.16.C for sample sizes.

Kruskal-Wallis tests on the H/MD data (Tables 2.8 - 2.9) produced similar patterns to the previous analyses. When examining the entire dataset (Table 2.8, Figure 2.19.A), statistically significant results were again obtained for the three transitions from the IA/RB to the Medieval period. The ϵ^2 figures show there is again no practical difference between the Iron Age and IA/RB and between the medieval and post-medieval periods. The decline from the Neolithic to Bronze age is the weakest change.

Interestingly, the effect size from the Bronze to Iron Age is the same as that of the IA/RB to Roman, possibly suggesting that there was an overall consistent rate of change between the Bronze Age and Roman period. The plateau in the transition from the Iron Age to IA/RB may therefore exist only because of the decision to treat the latter as a broad period. It will be interesting to compare this observation with the mesoscale analysis.

Table 2.8: Summary of Kruskal-Wallis *H* tests on sequential pairs of broad periods for Hare/MD NISP data

TEST	H	DF	ϵ^2	*p*-value	Signif.
Neolithic → Bronze Age	1.1	1	0.01	0.295	–
Bronze Age → Iron Age	3.6	1	0.03	0.057	–
Iron Age → IA/RB	0.0	1	0.00	0.877	–
IA/RB → Roman	5.7	1	0.03	0.017	T
Roman → Saxon	15.2	1	0.05	< 0.001	T
Saxon → Medieval	29.6	1	0.12	< 0.001	T
Medieval → Post-Med	0.4	1	0.00	0.519	–

Table 2.9: Summary of Kruskal-Wallis *H* tests on sequential pairs of broad periods for Hare/MD NISP data, filtered to include only assemblages where hares are present.

TEST	H	DF	ϵ^2	*p*-value	Signif.	NOTE
Neolithic → Bronze Age	–	–	–	–	–	FAIL
Bronze Age → Iron Age	–	–	–	–	–	FAIL
Iron Age → IA/RB	0.7	1	0.01	0.418	–	–
IA/RB → Roman	3.4	1	0.04	0.066	–	–
Roman → Saxon	6.5	1	0.05	0.011	T	–
Saxon → Medieval	21.0	1	0.22	< 0.001	T	–
Medieval → Post-Med	0.0	1	0.00	0.87	–	–

Again the strongest difference is between the Saxon and medieval periods. This is a medium effect size ($\epsilon^2 = 0.12$), though it is worth highlighting that the change from the Roman to Saxon period is just shy of a medium effect size too ($\epsilon^2 = 0.05$, see Table 2.4).

Repeating the same tests on only assemblages where hares are present (Table 2.9, Figure 2.19.B) increases the effect size for some of the transitions, especially the Saxon to medieval, but it has no effect on the Roman to Saxon. Sample size was again too small for the Neolithic/Bronze Age and Bronze Age/Iron Age tests. The IA/RB to Roman transition is no longer a significant change when assemblages with no hares are removed.

Examining spatial distribution with H/MD emphasises the homogeneity of the dataset. It is clear that hares rarely account for more than 2.5% of assemblages where they are present (Figure 2.20), regardless of location. The Saxon period is particularly homogenous. The hare foot ABG from the Late Iron Age ditch at Fishbourne Roman

Palace (Sykes 2005) caused that assemblage to have the largest H/MD percentage, placing the greatest area of density in West Sussex. This is in part exaggerated by a relatively small assemblage, further reduced in size by lower than normal rates of identifiability due to an abundance of burnt material (Sykes 2005: p. 79). Carne's Seat shifts this tendency slightly eastwards in the IA/RB but should be ignored (see page 80).

London produced the assemblage with the highest H/MD value (Figure 2.20) and the greatest area of weighted density (Figure 2.21) in the Roman period. This might be expected to result from deep stratigraphy and intense excavation in central London, but there are in fact only four assemblages and this picture is produced by the thirty-five hares from Winchester Palace (H/MD = 7%). Other key assemblages with H/MD between 1.0% and 3.0% were found in Somerset, Wiltshire, Essex and Norfolk. The greatest areas of density are in the east and central southern areas of England.

The medieval assemblages with the highest H/MD (Figure 2.20) values are Castle Rising, Norfolk (7%) and the 1921-1996 and 2006-9 excavations at Carisbrooke Castle, Isle of Wight (both 6%). Other high-status sites - especially in Hampshire and Oxfordshire, but also Cornwall, Devon and the West Midlands - all had assemblages with H/MD values greater than 1%. Overall there is no clear spatial patterning, though as usual central southern England produces the greatest density of hare remains (Figure 2.21). Sample size is too small for firm conclusions concerning the post-medieval period, though southern Hampshire and Norfolk appear to be areas of greatest abundance.

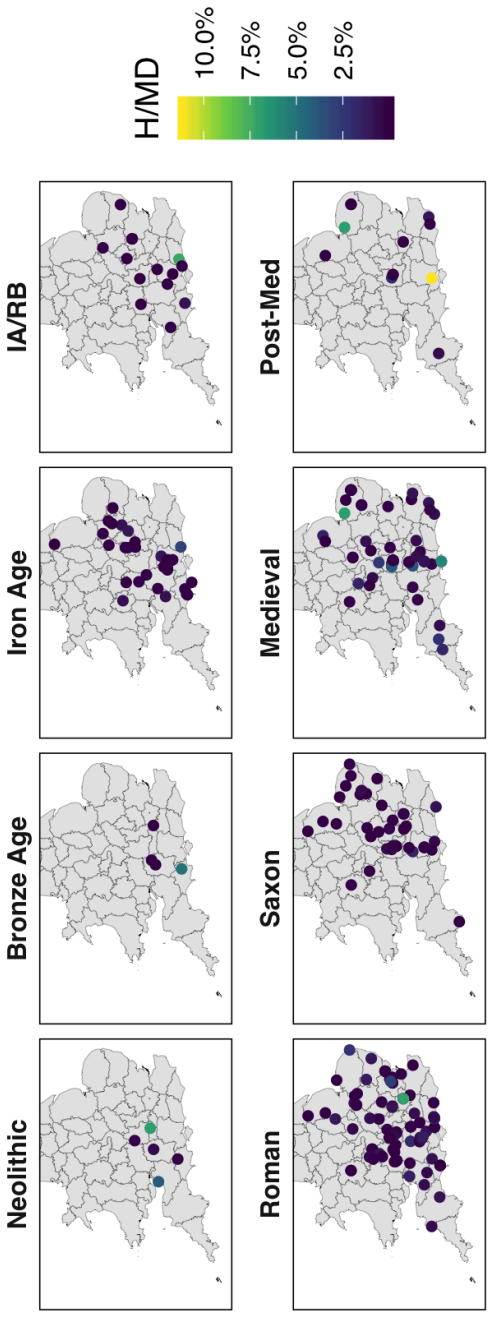

Figure 2.20: Distribution maps by broad period of sites with hares present, showing H/MD percentage.

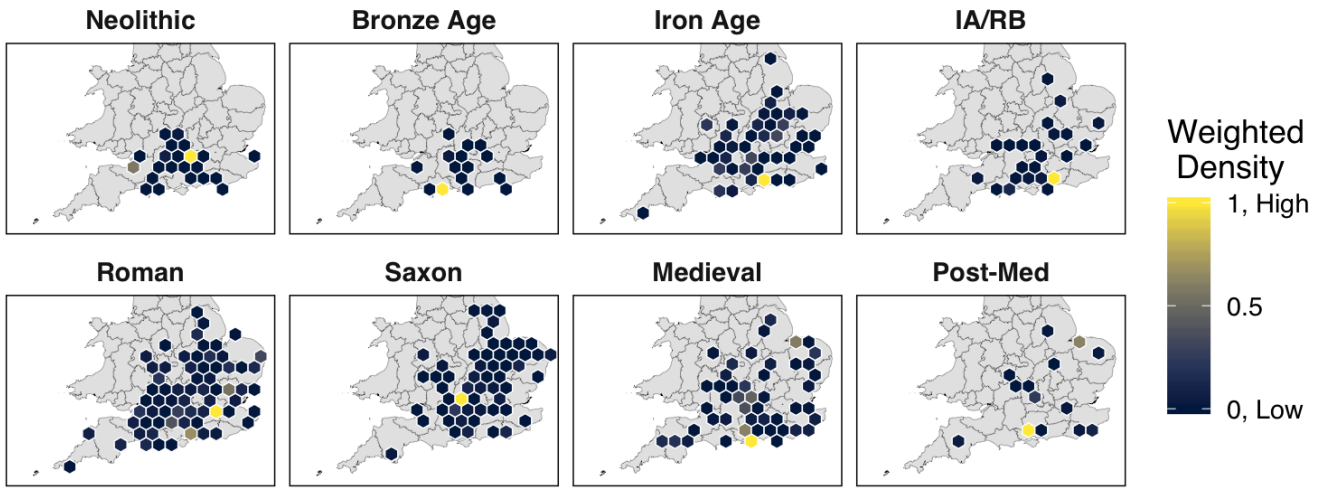

Figure 2.21: Assemblage density by broad period, including all assemblages. Weighted by H/MD and scaled to maximum density value.

2.8 Mesoscale

The mesoscale explores the data at a finer resolution. An overview of the data is presented first, together with tables listing the results of pairwise statistical analyses by period. Then discussion of these results and explorations of site types are presented in five 'slices' of the dataset, designed to pull out key observations concerning major cultural periods and transitions:

- Pre-Iron Age
- Early to Late Iron Age
- Early to Late Saxon
- mid 11th - mid 12th and mid 12th - mid 14th
- mid 14th - mid 16th and Post-Medieval

2.8.1 Mesoscale Overview

The mesoscale dataset consists of 858 assemblages, which was reduced to 854 for H/MD analyses (Table 2.10) as not all hare data could be compared against the MD data (see page 50).

Table 2.10: Sample sizes for mesoscale analysis. Total sample size = 845; 841 for H/MD.

Period	NISP & P/A	H/MD	Difference
Early Neolithic	6	6	–
Early/Middle Neolithic	33	32	1
Middle Neolithic	11	11	–
Late Neolithic	26	26	–
LNEO/EBA	14	14	–
EBA	16	16	–
MBA	4	4	–
LBA	10	10	–
EIA	9	8	1
MIA	40	39	1
LIA	68	67	1

Table 2.10: *(continued)*

Period	NISP & P/A	H/MD	Difference
IA/RB	44	44	–
Early Roman	114	114	–
Late Roman	110	110	–
Early Saxon	37	37	–
Mid Saxon	60	60	–
Late Saxon	75	75	–
mid 11th - mid 12th	47	47	–
mid 12th - mid 14th	64	64	–
mid 14th - mid 16th	46	46	–
Post-Med	24	24	–

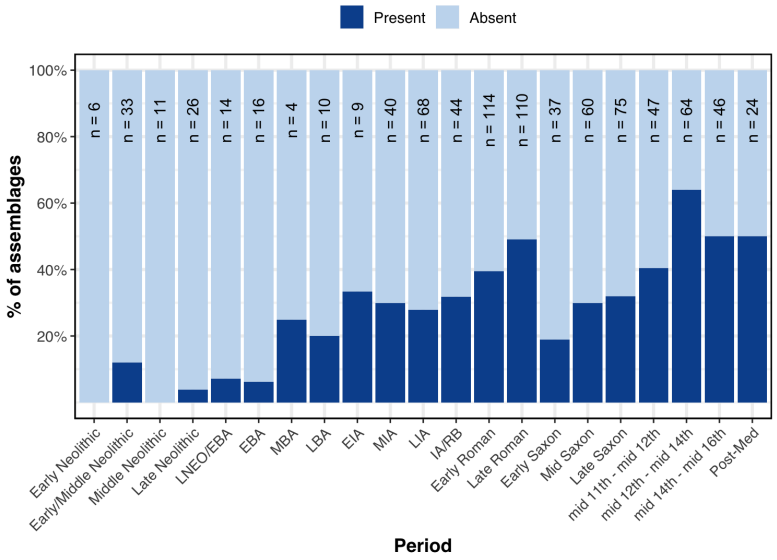

Figure 2.22: Presence/Absence data for hares by period. An alternative visualisation of the data including standard error bars is shown in Figure 2.23

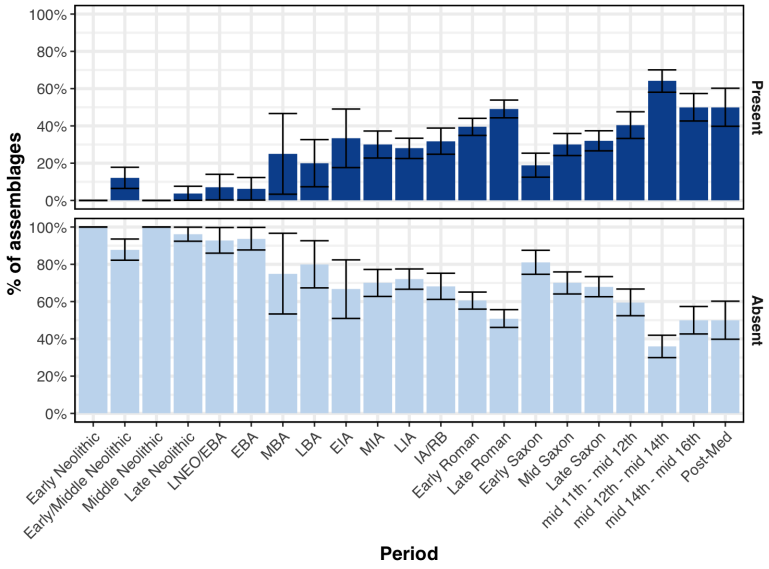

Figure 2.23: Presence/Absence data for hares by period. Error bars represent the standard error, calculated with the formula: $s = \sqrt{\frac{p.est \times (1-p.est)}{n}}$

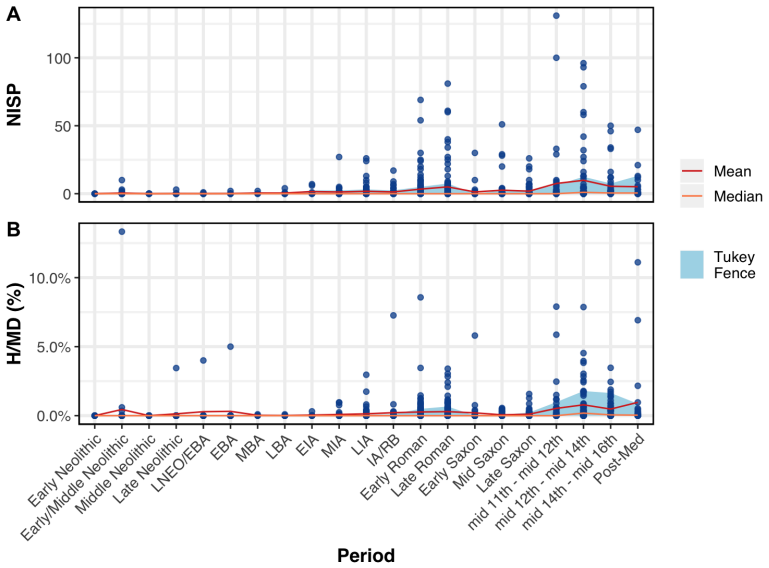

Figure 2.24: Hare NISP by period. A) Raw NISP. B) H/MD (%)

Table 2.11: Summary of χ^2 analyses on sequential pairs of periods for presence/absence representation of hares. Some contingency tables had one observed value equal to zero (indicated).

TEST	χ^2	DF	ϕ	*p*-value	Signif.	NOTE
Early Neolithic → Early/Middle Neolithic	0.8	1	0.14	0.368	–	One value = 0
Early/Middle Neolithic → Middle Neolithic	1.5	1	0.18	0.226	–	One value = 0
Middle Neolithic → Late Neolithic	0.4	1	0.11	0.510	–	One value = 0
Late Neolithic → LNEO/EBA	0.2	1	0.07	0.648	–	–
LNEO/EBA → EBA	0.0	1	0.02	0.922	–	–
EBA → MBA	1.2	1	0.25	0.264	–	–
MBA → LBA	0.0	1	0.06	0.837	–	–
LBA → EIA	0.4	1	0.15	0.510	–	–
EIA → MIA	0.0	1	0.03	0.845	–	–
MIA → LIA	0.1	1	0.02	0.819	–	–
LIA → IA/RB	0.2	1	0.04	0.660	–	–
IA/RB → Early Roman	0.8	1	0.07	0.373	–	–
Early Roman → Late Roman	2.1	1	0.10	0.147	–	–

Table 2.11: *(continued)*

TEST	χ^2	DF	ϕ	p-value	Signif.	NOTE
Late Roman → Early Saxon	10.4	1	0.27	0.001	T	–
Early Saxon → Mid Saxon	1.5	1	0.12	0.226	–	–
Mid Saxon → Late Saxon	0.1	1	0.02	0.803	–	–
Late Saxon → mid 11th - mid 12th	0.9	1	0.09	0.343	–	–
mid 11th - mid 12th → mid 12th - mid 14th	6.1	1	0.23	0.014	T	–
mid 12th - mid 14th → mid 14th - mid 16th	2.2	1	0.14	0.140	–	–
mid 14th - mid 16th → Post-Med	0.0	1	0.00	1.000	–	–

Table 2.12: Summary of Kruskal-Wallis *H*-tests on sequential pairs of periods for raw NISP representation of hares.

TEST	H	DF	ϵ^2	*p*-value	Signif.	NOTE
Early Neolithic → Early/Middle Neolithic	0.8	1	0.02	0.375	–	–
Early/Middle Neolithic → Middle Neolithic	1.4	1	0.03	0.232	–	–
Middle Neolithic → Late Neolithic	0.4	1	0.01	0.515	–	–
Late Neolithic → LNEO/EBA	0.2	1	0.00	0.680	–	–
LNEO/EBA → EBA	0.0	1	0.00	0.962	–	–
EBA → MBA	–	–	–	–	–	FAIL
MBA → LBA	–	–	–	–	–	FAIL
LBA → EIA	0.6	1	0.03	0.429	–	–
EIA → MIA	0.2	1	0.00	0.680	–	–
MIA → LIA	0.0	1	0.00	0.889	–	–
LIA → IA/RB	0.0	1	0.00	0.871	–	–
IA/RB → Early Roman	1.4	1	0.01	0.241	–	–
Early Roman → Late Roman	1.6	1	0.01	0.207	–	–
Late Roman → Early Saxon	10.1	1	0.07	0.001	T	–

Table 2.12: *(continued)*

TEST	H	DF	ϵ^2	*p*-value	Signif.	NOTE
Early Saxon → Mid Saxon	1.5	1	0.02	0.227	–	–
Mid Saxon → Late Saxon	0.1	1	0.00	0.699	–	–
Late Saxon → mid 11th - mid 12th	1.3	1	0.01	0.262	–	–
mid 11th - mid 12th → mid 12th - mid 14th	4.1	1	0.04	0.042	T	–
mid 12th - mid 14th → mid 14th - mid 16th	1.1	1	0.01	0.288	–	–
mid 14th - mid 16th → Post-Med	0.0	1	0.00	0.916	–	–

Table 2.13: Summary of Kruskal-Wallis *H*-tests on sequential pairs of periods for H/MD representation of hares.

TEST	H	DF	ϵ^2	*p*-value	Signif.	NOTE
Early Neolithic → Early/Middle Neolithic	0.6	1	0.02	0.441	–	–
Early/Middle Neolithic → Middle Neolithic	1.1	1	0.03	0.298	–	–
Middle Neolithic → Late Neolithic	0.4	1	0.01	0.515	–	–
Late Neolithic → LNEO/EBA	0.2	1	0.01	0.626	–	–
LNEO/EBA → EBA	0.0	1	0.00	0.962	–	–
EBA → MBA	–	–	–	–	–	FAIL
MBA → LBA	–	–	–	–	–	FAIL
LBA → EIA	0.1	1	0.01	0.714	–	–
EIA → MIA	0.1	1	0.00	0.700	–	–
MIA → LIA	0.0	1	0.00	0.850	–	–
LIA → IA/RB	0.1	1	0.00	0.757	–	–
IA/RB → Early Roman	1.9	1	0.01	0.172	–	–
Early Roman → Late Roman	1.5	1	0.01	0.216	–	–
Late Roman → Early Saxon	9.7	1	0.07	0.002	T	–

Table 2.13: *(continued)*

TEST	H	DF	ϵ^2	*p*-value	Signif.	NOTE
Early Saxon → Mid Saxon	1.0	1	0.01	0.310	–	–
Mid Saxon → Late Saxon	0.3	1	0.00	0.616	–	–
Late Saxon → mid 11th - mid 12th	2.3	1	0.02	0.129	–	–
mid 11th - mid 12th → mid 12th - mid 14th	5.6	1	0.05	0.018	T	–
mid 12th - mid 14th → mid 14th - mid 16th	1.3	1	0.01	0.259	–	–
mid 14th - mid 16th → Post-Med	0.1	1	0.00	0.721	–	–

2.8.2 Pre-Iron Age Evidence

The mesoscale approach to the dataset show that most of the Neolithic hares are dated as either Early/Middle or Late Neolithic, with the former being more abundant by presence/absence (Figure 2.22). But, small sample size for the Early and Neolithic periods mean that this earlier portion of prehistory covered by the dataset is probably not reliable at the mesoscale level.

There is a slight increase in presence to about seven percent of assemblages during the Late Neolithic/EBA, with little subsequent change during the Early Bronze Age. By contrast, the Middle Bronze Age is a major increase to twenty-five percent, but the number of assemblages (n) is only four. The slightly larger sample (n = 10) in the Late Bronze Age produces a percentage presence which is probably closer to the true value. Plotting the data with standard error bars (Figure 2.23) confirms that the MBA has the largest of all the error margins; the true value could conceivably be lower than the estimated percentage for the Early Bronze Age. Chi-squared tests on sequential pairs of periods produced no significant results (Table 2.11), but each transition from the Early until the Late Neolithic does constitute a weak effect size.

Changes from the Late Neolithic until the EBA were trivial, but comparison of the EBA and MBA is the first ϕ value (0.25, Table 2.11) to exceed 0.2, though it is some way off Cohen's benchmark of 0.3 for a medium effect. Despite the comparatively substantial effect, extreme caution is still necessary before suggesting a MBA introduction on this basis; the flaws of a sample size of four cannot be set aside. By contrast, the association between hare presence/absence and the MBA to LBA transition is very weak, and would constitute a trivial effect according to Cohen's benchmarks ($\phi = 0.06$).

That the effect sizes oscillate between trivial and weak correlations over the Neolithic and Bronze Age periods, whilst the data visualisation (Figure 2.22) shows increases, could be suggestive of a long period of attempts to introduce hares to southern England that ultimately failed, or the deliberate importation of select individuals as unique exotica. Such a situation would be equifinal with biases in the data resulting from intrusion, taphonomy and sampling, however, so these observations must remain inconclusive.

Raw NISP and H/MD point overwhelmingly to absence of hares in the Neolithic and

Bronze Age (Figure 2.24). The median values remain consistently at zero, while the mean rises only slightly, despite the presence of significant outliers. The first of these is the Early/Middle Neolithic assemblage from Gatehampton Farm. That the three outliers from the Late Neolithic, Late Neolithic/Early Bronze Age and Early Bronze Age align as an unbroken curve showing a rise in H/MD could be suggestive of a Neolithic/Bronze Age hare introduction, but much more likely just reflects relatively small main domesticate assemblages that produce this curve by chance.

As with the presence/absence data, statistical testing on these periods produced no significant results (Tables 2.12 and 2.13). Weak effects were detected for NISP in transitions between Neolithic periods, but there was effectively no difference between the Late Neolithic and Late Neolithic/EBA period and between the Late Neolithic/EBA and the EBA. Tests on the remaining Bronze Age pairs failed to run due to low sample sizes for at least one of the groups in each test. Results for the H/MD data were virtually identical to the raw NISP tests; the only difference was that the Late Neolithic and Late Neolithic/EBA pair did produce a weak effect of 0.01. Overall, these statistics concur with the data visualisation; very little change occurs in hare bone numbers over this period of prehistory.

That the presence/absence data produce a "doubtful but possible" Bronze Age introduction conclusion, whilst NISP-based metrics are more conclusively on the side of a later arrival of the brown hare, highlights the importance of comparing quantification methods in zooarchaeology. The overall finding of this analysis can only be that these remains require much more detailed critique than is possible at this scale. Consequently, further discussion of this material is deferred to the microscale section (§2.9).

2.8.3 The Iron Age

The Early Iron Age phase has similar problems to the Middle and Late Bronze Age. Though presence/absence data strongly point to a rise in hare presence during this period (Figure 2.22), the sample size of nine is problematic. The period certainly is among the worst three for broad margins of error (Figure 2.23). Yet the error bars do indicate that hare presence was at least around the estimated proportion for the Late Bronze Age (just under twenty percent of assemblages) which can be taken as good

evidence for a genuine rise in the occurrence of hares. This possibility is supported by the chi-squared test comparing the LBA and EIA which produced a ϕ value of 0.15 which, though weak, is the largest effect among all the comparisons made from the Middle Bronze Age until the Late Roman period. Low sample size for the LBA and EIA (n = 10 and 9, respectively), however, suggests there is a high probability that this non-trivial result is a product of chance.

The Middle and Late Iron Age periods constitute a decline in hare presence (Figure 2.22), but the error margins are much smaller (Figure 2.23). Hares were probably present at between twenty and forty percent of assemblages by this time. Overall, data visualisation suggests that across the Iron Age, hare presence was changing. Both the standard error margins and chi-square tests (Table 2.11) suggest, however, that this may be an exaggeration of the data. ϕ values for the transitions between the EIA and MIA and between the MIA and LIA indicate trivial effects, for example, indicating that the presence of hares or their remains at Iron Age sites may have been relatively stable over time, increasing only gradually. If this interpretation is accurate, the large rise in hare presence from the Bronze to Iron Age found in the macroscale analysis (§2.7) reflects the cumulative effect of smaller increases over approximately eight centuries.

This conclusion is given further weight by the raw NISP and H/MD data, which indicate little change in the mean and median values for hare bone abundance, but are accompanied by noticeable increases in the number of outliers (Figure 2.24). The assemblage with the maximum H/MD also moves higher up the scale as the Iron Age progresses. Note also that despite the presence of these outliers, they are neither abundant nor extreme enough to have a major impact on the mean. This supports the hypothesis (see page 84) that these represent the earliest hares to experience 'normal' taphonomic pathways, whilst the Neolithic and Bronze Age examples are considerably more extreme, and therefore can be expected to be intrusive. Further analysis of this evidence in the Microscale section shows that this expectation is supported by the contextual evidence (§2.9).

The suggestion given above that there was little difference between the three periods of the Iron Age is also supported by the raw NISP and H/MD data distributions. Kruskal-Wallis tests (Tables 2.12 and 2.13) on both variables produced ϵ^2 values of zero for each pair, pointing to there being no meaningful difference between them.

Abundances of hares in the Iron Age are so few that site type analyses cannot reveal any particular association. Indeed this conforms to trends identified elsewhere, regardless. Zooarchaeological data generally show no relationships with Iron Age site categories, excepting subtle tendencies for sheep/goat at banjo enclosures and unenclosed settlements and cattle at enclosed settlements (Hambleton 2008).

2.8.4 Hares in Roman Britain

Comparing the transitions from the Late Iron Age to the Late Roman period visually (Figure 2.22) suggests an overall consistent increase in hare presence, perhaps accompanied by a slight uptick in rate of increase in the Early Roman period, and a larger one in the Late Roman. Again, however, sample size effects disguise the complexity in the data. The IA/RB has the smallest sample size of the three, so the standard error (Figure 2.23) shows that at its lowest likely value, presence may be in fact scarcely more than that of the LIA. This is confirmed by the small ϕ value of 0.04 (Table 2.11). Though still classifiable as trivial, it is worth noting that this transition produces a stronger effect than either of the EIA-MIA or MIA-LIA transitions, which could indicate the relative stability of hare presence during the bulk of the Iron Age was shifting by the first centuries BC and AD. But whether this reflects cultural change deriving from pre-conquest contact with the Roman Empire, the conquest itself, or is unrelated to 'Romanization', is unknowable at this stage.

It is surprising to find that the increase in hare presence from the IA/RB to Early Roman period was not enough to produce a small effect size ($\phi = 0.07$, Table 2.11), though it is nevertheless a more substantial increase than was seen between the LIA and IA/RB. It could indicate that even though hares are more prevalent, access to them might have been restricted. If that were true, the small effect ($\phi = 0.1$) marking the transition into the Late Roman period could represent a change in access to hares accompanying changing cultural attitudes to them as populations expanded.

The NISP data support these findings (Figure 2.24). There is very little difference between the distribution of the IA/RB data and the LIA, though it is worth noting that the bulk of the IA/RB assemblages are more tightly compressed than the equivalent LIA ones. The mean in both raw NISP and H/MD only increases in the IA/RB under the influence of Carne's Seat (page 80) and the effect sizes from Kruskal-Wallis tests

indicate there is no meaningful difference between the LIA and IA/RB ($\phi = 0.1$ for both variables).

The Roman period produces interesting patterns in the raw NISP and H/MD data. The Early Roman dataset consists of a tightly compressed number of assemblages with fewer than approximately a dozen hares, some of which are outliers (Figure 2.24.A). As NISP increases up until around twenty-five, however, the assemblages are more dispersed. A notable gap then appears, after which assemblages with between fifty and seventy-five hare bones appear relatively close together. Converting these data to H/MD (Figure 2.24.B) has an interesting impact on the distribution. As normal, the assemblages with the smallest numbers of hares become tightly compressed, but more importantly the gap between the two assemblages with the largest numbers widens significantly. These sites are Fishbourne Roman Palace and Winchester Palace (Figure 2.25). They have unusually large hare assemblages (NISPs: Fishbourne East = 69, Fishbourne Palace = 54, Winchester Palace = 30), but they have different main domesticate assemblages (1995, 3687 and 350, respectively). The gap in H/MD is therefore explained by the much larger relative difference between them in MD than in hares.

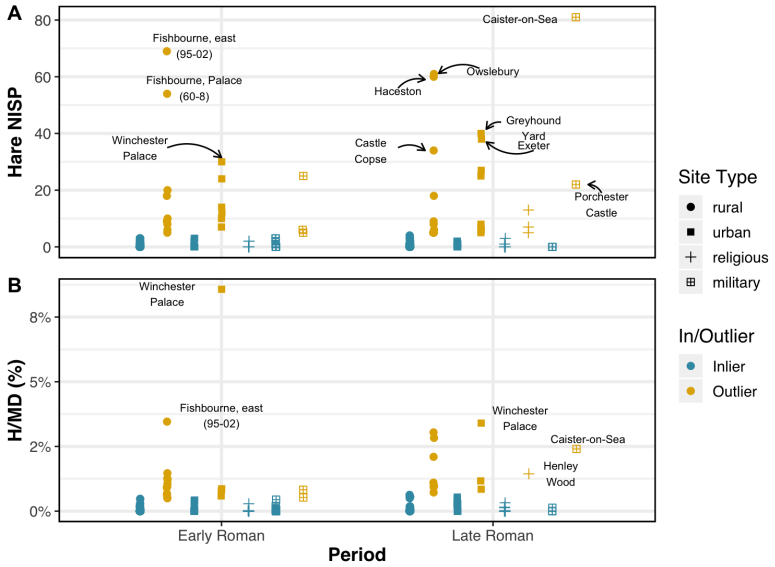

Figure 2.25: Roman assemblages shown by site type and inlier/outlier status on hare NISP and H/MD metrics.

By raw NISP, the Late Roman period has no remarkable difference from the Early

Roman. The largest numbers of hares in the dataset are slightly higher, and overall there appears to be a greater variety of assemblages with above-average numbers of hare bones (Figure 2.24.A). Yet conversion to H/MD (Figure 2.24.B) has a dramatic effect. There are no assemblages in the Late Roman period where hares are more than 3.5% of the assemblage, and even the assemblage with the greatest proportion of hares to MD is lower than the lesser of the two extreme outliers in the Early Roman period. Furthermore, there now appear to be two clusters of assemblages, separated by a small gap. These can be characterised as a group of assemblages with less than 1.7% hares (ninety-six inliers and nine outliers) and another with five outliers consisting of 2.0-3.5% hares. The largest number of hares in this group is eighty-one, from Caister-on-Sea, followed by Castle Copse. Both have reasonably large MD assemblages (3371 and 1621, respectively). The other three in the 2.0-3.5% group are Little Somborne, Winchester Palace and Great Holts Farm. Each has a hare NISP smaller than ten, so only fall into this group because they have small MD values.

Four assemblages in the 0-1.7% group also have unusually large hare assemblages, but do not have bigger H/MD percentages because the overall assemblage sizes are among the largest. These include Owslebury, Hacheston, Exeter and Silchester. Greyhound Yard (Dorchester) and Exeter have very similar hare NISP values (40 and 38, respectively, see Figure 2.25), which is interesting given that they are both local capitals in the south-west of England, but the Greyhound Yard MD value is more than 2.5 times larger than the same for Exeter, so only Exeter is an outlier according to H/MD.

These findings suggest, as hinted to above by the presence/absence data, that access to hares in the Early Roman period was more prevalent than in the Iron Age, but it was also restricted, producing greater numbers of unusual sites with large numbers of hare bones. Meanwhile, in the Late Roman access became more common, producing less diversity. But, Kruskal-Wallis tests on the raw NISP and H/MD data for the Early to Late Roman transition only detected small effect sizes of 0.01, which is no different to the same tests on the IA/RB to Early Roman data. That these distributions do not tally with the impression given by the presence/absence data (where there is a noticeable difference in the transitions between each period) might indicate that hares were becoming more prevalent, but the overall abundance of hare bones and the proportion of assemblages they made up was changing more slowly.

Presence data shows hares to be common at urban and military sites in the Early Roman period, whilst present at only around thirty and twenty-five percent of rural and religious sites, respectively (Figure 2.26). Expected values for some site types were too small for a chi-squared test on the association between presence/absence and all four Early Roman site types separately, but combining the urban and military assemblages and testing against the combined values for rural and religious sites did produce a significant result with a weak effect size ($\chi^2 = 9.51$, $\phi = 0.26$, p-value < 0.01). This at least suggests that hare presence is loosely correlated with centres of strong Roman cultural influence, whether administrative or military. That more rural than religious sites had hares might also be an indicator that hares were socially restricted to high-status villas, such as Fishbourne Roman Palace and Castle Copse, though at this level the site type data are not detailed enough to prove it. It also has to be acknowledged that the religious category has the largest standard error.

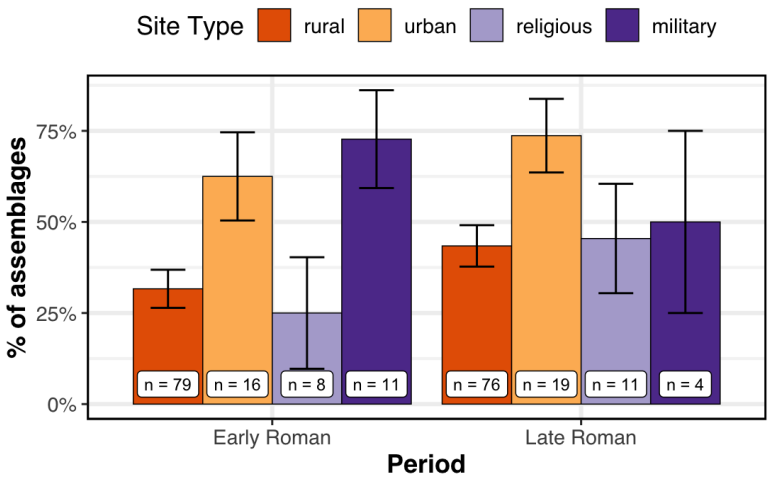

Figure 2.26: Percentages of Roman assemblages with hares present by period and site type. Error bars represent the standard error. *n* equals total sample size (hares present + hares absent).

Hare presence is more uniform in the Late Roman period, and rises for all except the military category (Figure 2.26). This suggests that hares had become more ubiquitous and that humans' relationships with them were changing as a result. We can speculate that, having shifted away from being exotica whose keeping and/or consumption was unique to a limited swathe of society, possibly one that identified in some way as 'Roman', hares were now more widely seen as a food-stuff. That the proportion of

religious sites with hares has increased may indicate that they had retained some of their exotic associations, however, and were being used as offerings or seen as 'sacred meals' (discussions on food and Roman religion in Donahue 2003; Schultz 2016). It is clear, however, that the greatest area of growth is in urban sites. Chi-squared tests for the Late Roman site types against presence/absence were only possible if urban sites were compared against all others as one group; this did produce a significant result ($\chi^2 = 4.43$, $\phi = 0.2$, *p*-value < 0.04), but is of limited interpretive value as it can only confirm a tendency towards presence at urban sites. Presence (but not presence/absence) was also compared for site types against time (Early/Late Roman). Comparing all types produced a weak effect but no significant result ($\chi^2 = 5.89$, $\phi = 0.24$, *p*-value < 0.12).

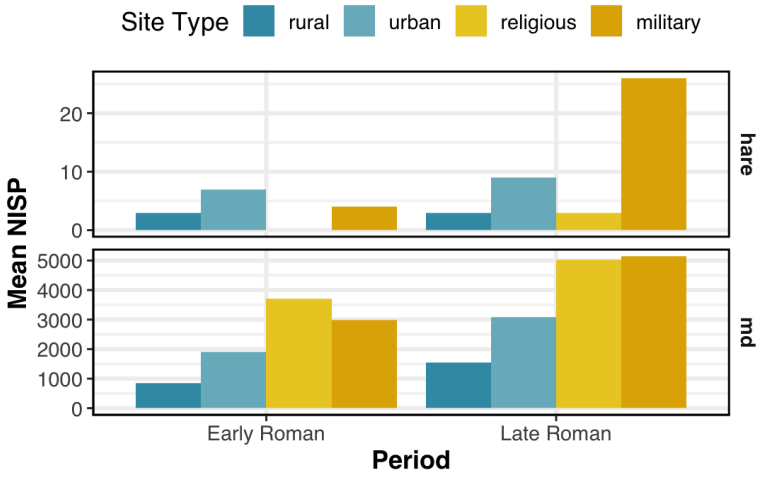

Figure 2.27: Mean Roman NISP values for hare and main domesticates by site type

NISP gives a slightly different impression, but nevertheless supports the idea that hares were becoming more ubiquitous over time. The mean number of hares grows markedly for military sites from the Early to Late Roman period (Figure 2.27), though sample size and the presence of the extreme outlier of Caister-on-Sea has to be taken into account (Figure 2.25). By contrast, increases in urban sites are slight, and the difference in rural sites is negligible (Figures 2.27 and 2.28). Both NISP and H/MD give the impression of reducing variety in hare abundances, with assemblages with small numbers of hare bones becoming more common, even though there is also a slight increase in the number of outliers (Figure 2.28). The change in religious sites also

appears relatively weak in light of the change in military sites, but is perhaps the most important culturally. This is supported by Kruskal-Wallis tests run on the NISP and H/MD data comparing each site type across the two periods (Table 2.14). Sample size for the military category was too low, but all others were run successfully, although none were significant. For both NISP and H/MD the Early to Late Roman transition for religious sites constitutes a medium-sized effect, whilst the rural data produced a small effect, and the urban distributions were effectively the same in both periods.

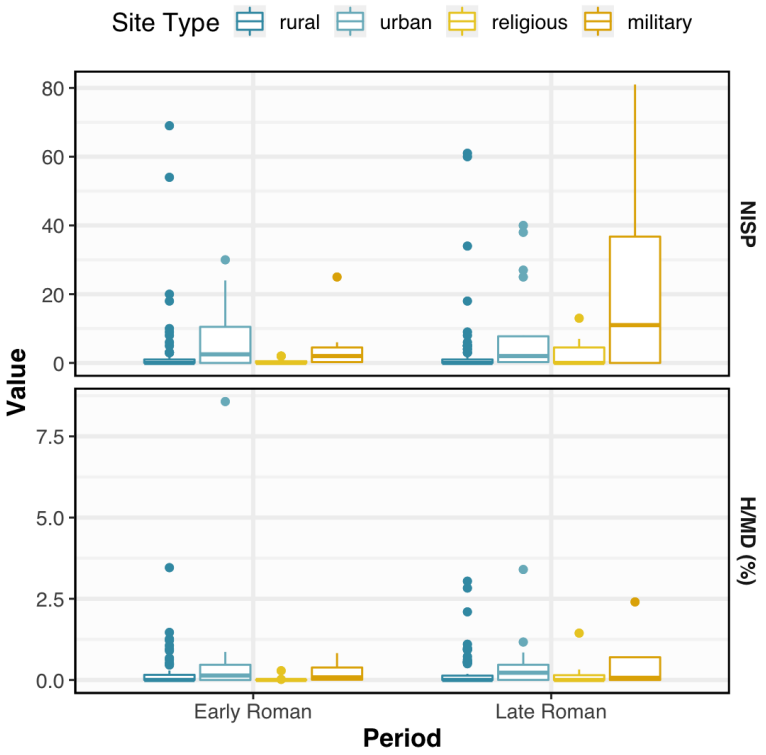

Figure 2.28: Box plots of hare NISP and H/MD in Roman assemblages by site type.

Mapping the Roman assemblages spatially offers some additional insights. In both periods the rural sites are too numerous for any pattern to emerge for Presence/Absence data (Figure 2.29), though it is interesting that in both the Early and Late Roman periods, rural sites are the only assemblages with more than fifty hare bones, and in both periods at least one of those is near the coast (Figure 2.30). A number of urban assemblages in the 11-25 and 26-50 group are also close to coast, though as other sites with smaller numbers also occur in such locations little can be made of this observation.

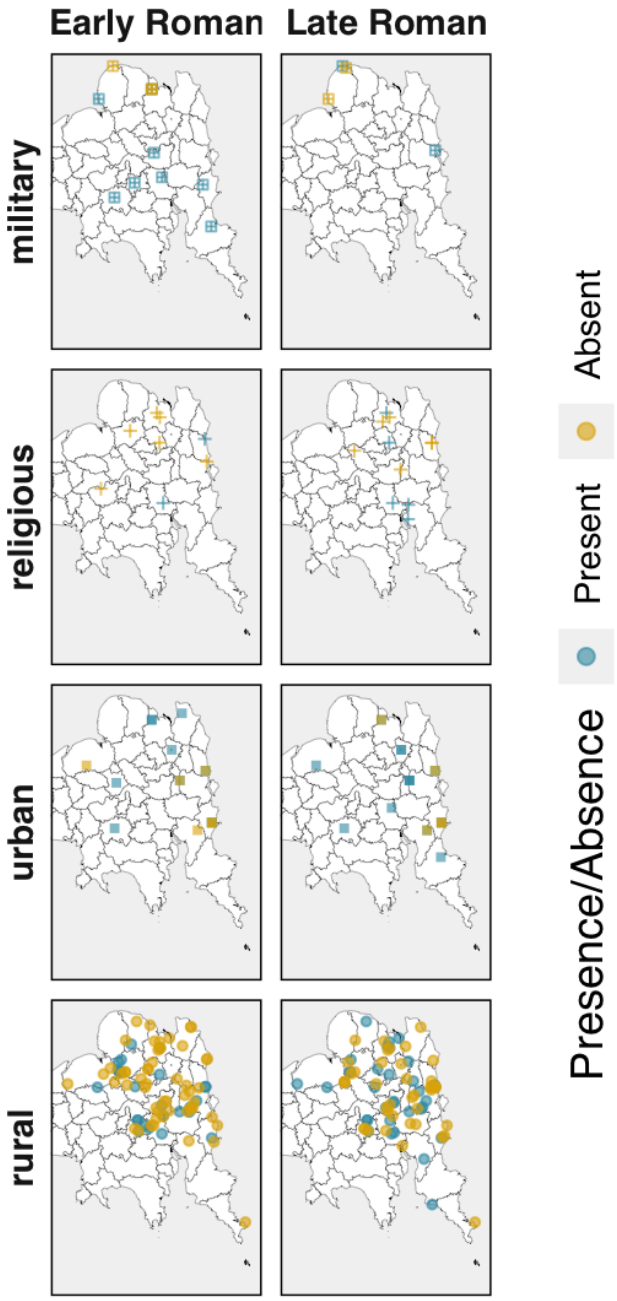

Figure 2.29: Map of Roman assemblages by period and site type for presence/absence data

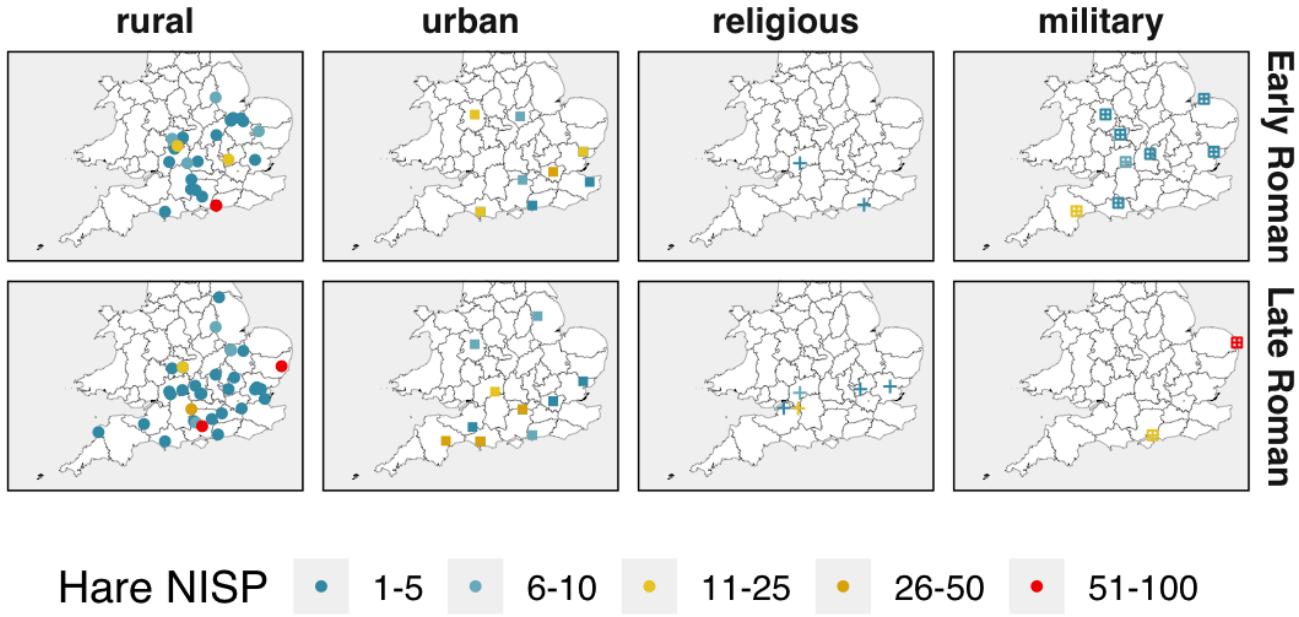

Figure 2.30: Map of Roman assemblages by period and site type for hare NISP data where hares are present

Table 2.14: Kruskal-Wallis test results for NISP and H/MD comparing distributions of Early and Late Roman assemblages for each site type. Tests on military sites could not be run due to low numbers of assemblages in one group or more. No tests were significant.

SITE TYPE	METRIC	H	DF	ϵ^2	*p*-value
religious	NISP	1.3	1	0.07	0.252
religious	H/MD	1.1	1	0.06	0.294
rural	NISP	1.6	1	0.01	0.212
rural	H/MD	1.4	1	0.01	0.241
urban	NISP	0.1	1	0.00	0.775
urban	H/MD	0.1	1	0.00	0.762

2.8.5 Hares in the Saxon Period

The Early Saxon phase presents a marked drop in hare presence, from nearly fifty to less than twenty percent; this occurs despite the much smaller sample size, suggesting a real decline. This is supported by the largest effect size of the chi-squared tests performed on the mesoscale dataset ($\phi = 0.27$, Cohen's benchmarks suggest 0.3 for a medium effect), and one of the two statistically significant results (Table 2.11). Raw NISP records a similarly massive drop, producing the only medium effect size across the entire dataset ($\epsilon^2 = 0.07$), which again was statistically significant (Table 2.12). H/MD gave exactly the same result (Table 2.13).

As the sample size for the Early Saxon period is among the smallest for the post-Roman assemblages, there is a greater margin of error for this period (see Figure 2.23. This raises the issue of whether statistically significant results for the Late Roman to Early Saxon tests occurred only because of the large effect and the large Late Roman sample.

Only two Early Saxon assemblages (Figure 2.31) had ten or more hare bones: West Stow (n = 10) and Oxford Science Park (n = 30). The next highest hare NISP was three (Caister-on-Sea), followed by two from Eynsham Abbey; one bone each was found at Bantham, Barton Court Farm and Pitstone. The only assemblages that were not outliers were those that had no hare bones at all. By H/MD, the picture is almost completely reversed: Oxford Science Park (5.8%) remains the most exceptional outlier, but West Stow is the most marginal of outliers. Its exceptionally large assemblage (Crabtree 1990) produces an MD value of 63,591 so ten hares accounts for less than 0.016% of the main domesticates.

It seems clear that - as with other game species (Sykes 2014a: p. 68-70) - the end of Roman Britain coincided with a substantial decline in hare hunting. Whether the drop in hare presence can be associated with a taboo against the consumption of game - wild fauna feature strongly in funerary practice and art at the time, but not domestic refuse (Sykes 2014a: p. 69-70; Bond 1996) - or simply the absence of a social elite for whom hunting was a marker of cultural identity, is unclear. Sykes' (2010) examination of Early Saxon deer assemblages argues that prior to the seventh century, hunting was seen as a form of economic risk-management. Meanwhile, Saxon custom on game followed the Roman principal of *res nullius* - "property of no one" (Griffin 2007; Sykes 2010). Under these circumstances, it is perhaps unsurprising that hares feature little in the zooarchaeological record.

Hare presence rises again during the Middle Saxon period. The effect size for this increase ($\phi = 0.12$) is not as strong as the decline in the Early Saxon period, but is bigger than any individual increase detected during the Iron Age or Roman period. The LBA to EIA test is the only one discussed so far to have produced a closely comparable result and the Early to Middle Saxon periods have more dependable sample sizes. For NISP, the Middle Saxon is a surprising, albeit minute, peak in the Saxon period, where a handful of extreme outliers raise the mean value (Figure 2.24). A small effect of 0.02 is detected comparing the Early Saxon and Middle Saxon distributions (Table 2.12). For H/MD, the Mid Saxon period is the lowest point of hare abundance in the Saxon era, as the outliers detected by raw NISP are much less extreme when placed in the context of their wider assemblage. An identical effect of 0.02 was detected, suggesting that raw abundance was changing in about the same way as hares' proportional contribution to overall assemblages.

A small number of Mid Saxon assemblages had large quantities of hare by NISP, the largest four being Wroxeter, Portchester Castle, Brandon, and Flixborough with 51, 29, 28 and 20 bones respectively (Figure 2.31). They all have large MD counts, however, so Wroxeter, Portchester and Flixborough are only the sixth, seventh and eighth most extreme outliers according to H/MD, whilst Brandon is an inlier. All of these assemblages are high-status, as were four other outliers according to NISP. Cresswell Field and Pennyland (rural, NISP = 2 each) and North Elmham (religious, NISP = 3) where also classed as outliers, whilst all sites with just one hare bone (n=14) or none (n = 84) were inliers. These results suggest that the association of hare hunting with

Table 2.15: Saxon mean NISP values for hare and MD by period and site type.

Period	Taxon	Rural	Urban	Religious	High Status
Early Saxon	hare	1	–	–	–
Early Saxon	MD	2580	–	–	–
Mid Saxon	hare	0	0	3	13
Mid Saxon	MD	499	7491	7784	11161
Late Saxon	hare	0	1	6	5
Late Saxon	MD	405	1441	1811	3070

elites does begin to apply. Nevertheless, hares bones do not constitute a significantly greater proportion of high-status assemblages than they do at other kinds, though this is in part due to the tendency for high-status sites to have much larger assemblages (Table 2.15).

Examining outliers for H/MD gives a patchwork-like impression of the data by site type. Though five high-status sites are included (the Saxon Palaces, Northamptonshire and Higham Ferrers, in addition to the three mentioned above), they are interspersed with rural sites. Small MD counts account for this mixing.

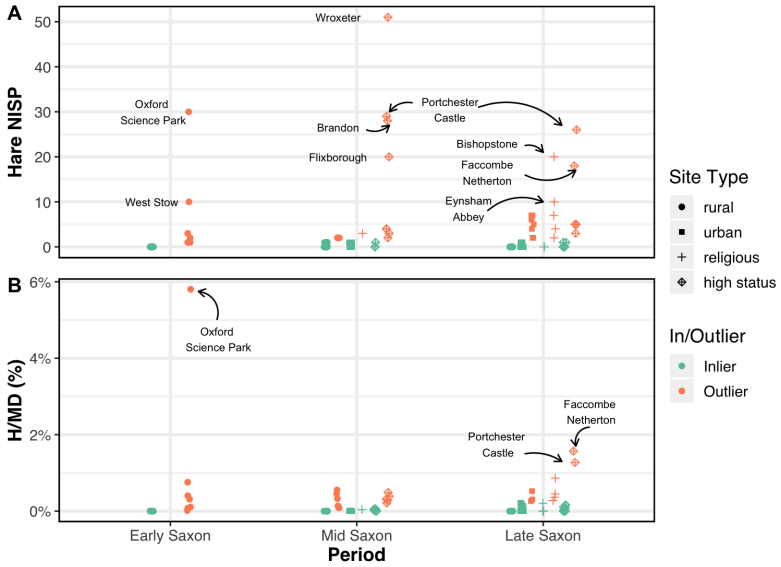

Figure 2.31: Saxon sites shown by site type and inlier/outlier status for Hare NISP (A) and H/MD (B).

The Mid Saxon period saw the re-emergence of hunting as a system of social display,

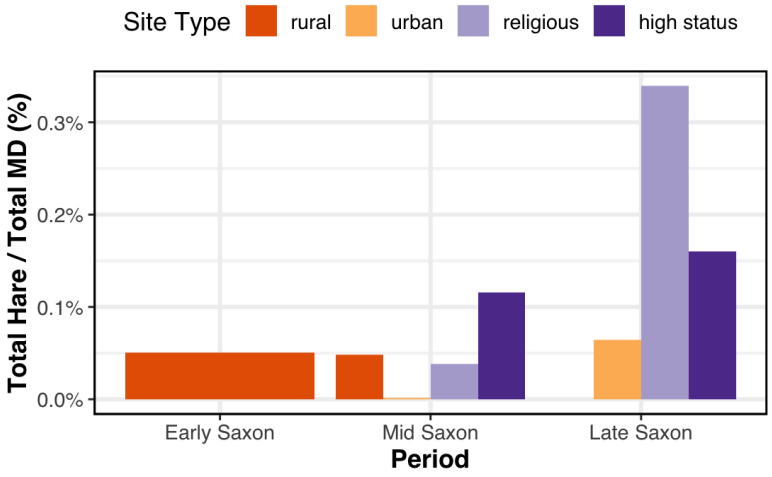

Figure 2.32: Total Hare NISP expressed as a proportion of Total MD NISP (%) for Saxon sites by period and site type

contrasting with the subsistence preoccupations of the fifth to mid -seventh centuries. Although clearly associated with the social elite, wild fauna do appear at other site types. Sykes (2010) argues for a Middle Saxon redistributive system, whereby hunting reinforced social structure and community identities through the redistribution of venison. While the cuts of meat perceived to be of greatest social value would have been retained by elites, lower value cuts would have been given to the peasantry in exchange for their services (Sykes 2010). Meanwhile, food may have been taken as payment in kind by landowners in exchange for the use of their property. Being much smaller than deer, it is highly unlikely that hares would have been divided and shared in the manner of venison. The clear dominance of high-status sites, with small quantities of hares at rural and urban locations needs an alternative explanation. Three equifinal possibilities seem apparent: that hares were hunted or trapped by the peasantry and frequently given as payment in-kind, being more within their means than deer hunting; that hares were hunted by social elites as associations with high-status grew, but subsistence hunting by the peasantry continued under the *res nullius* tradition; or else that hares hunted by elites were eaten at communal feasts hosted at high-status sites (see Sykes 2010: p. 180).

The Late Saxon period constitutes a rise in the proportion of assemblages with hares present, though it is surprisingly small given the known growth in hunting at this

time (Sykes 2010). This is confirmed by a trivial effect of 0.02 detected for ϕ (Table 2.11). But, presence/absence contrasts with a very clear increase in the number of outlier assemblages by NISP and H/MD (Figure 2.24), though it is worth noting that the assemblages are more tightly clustered, suggesting a change in how hares were interacted with, as there are no extreme outliers (compared with the Early Saxon period, for example). If this pattern can be associated with high-status sites (see below), it would fit with the emergence of a Late Saxon elite increasingly engaged with hunting (Sykes 2010). The Kruskal-Wallis tests on NISP and H/MD, detected effect sizes of zero for the transition from the Mid to Late Saxon periods, which is consistent with the picture given by the presence/absence data.

There are only four Late Saxon assemblages with ten or more hare bones. These are Portchester Castle, Bishopstone, Faccombe Netherton and Eynsham Abbey; this means equal numbers of high-status and religious sites. Urban assemblages also account for outliers in this period. Though classed as high-status, Flixborough has only five hares in this period, a substantial decrease of twenty-five percent on the Mid Saxon period (but note the unresolved difficulty in classifying Saxon sites, especially Flixborough, in Blair 2005: p. 204-212; Dobney et al. 2007b; Thomas 2013). No rural sites had hares in the Late Saxon period. Interestingly, the proportion of high-status sites with hares is smaller in the Late Saxon than it was in the Middle Saxon, whilst the number of urban assemblages has increased. The number of religious sites has decreased, but accounting for the sample size of one in the Mid Saxon period suggests that the Late Saxon figure of around seventy percent is a more accurate reflection of the Mid-Late Saxon occurrence of hares at these sites.

Issues around the fluidity of settlement character in the Saxon period (Blair 2005: p. 204-212; Dobney et al. 2007b; Thomas 2013) mean that some skepticism is required of the observation that in the Mid and Late Saxon periods more religious than high-status assemblages have hares. Mean NISP for hares differs between them only by one (Table 2.15) and it is probably safe to suggest that high-status sites tend to benefit from more extensive exploration by archaeologists. Recovery effort is therefore not consistent between site types, so it is worth exercising caution to prevent over-interpretation here.

2.8.6 Hares in Norman and High Medieval Britain

Presence/absence data show an increase in the proportion of assemblages with hares in the period covering the mid 11th to mid 12th centuries (Figures 2.22 and 2.23), consistent with the development of Anglo-Norman hunting culture (Sykes 2007b). The chi-squared test on the association between this period and the Late Saxon produced a ϕ value of 0.09 (Table 2.11), which is trivial according to Cohen's benchmarks but is nevertheless the strongest effect seen since hare presence dropped in the Early Saxon period. This confirms an important change in human interactions with hares at the time.

NISP data support the presence/absence. Mean raw NISP rises to the its highest point so far, although the fact that the median is unchanged does point to the influence of the first assemblages to have more than one hundred hare bones, which are also the most extreme outliers in the dataset (Figure 2.24). H/MD presents a typically moderated view of these data, though it is still the case that the mean value rises to one of its highest points. Both approaches to the NISP data produced weak effects of 0.01 when compared with the Late Saxon period with Kruskal-Wallis tests. That they produce the same result indicates that overall abundance and proportion of assemblages were changing at about the same rate. That these results can be classed as weak whilst presence/absence is more trivial could suggest that hare bone abundances at certain site types were changing more than overall frequency of hares in wider society, which fits with game animals becoming increasingly restricted by forest law under William Rufus and Henry I (Griffin 2007).

This is supported by the presence/absence data shown by site type, where although presence at high-status sites decreases by 2.8% between the two periods, the standard error narrows (Figure 2.33). This indicates that the true value of percentage hare presence in the mid 11th - mid 12th centuries was probably similar to the Late Saxon period. Whilst this apparent lack of change would superficially seem to undermine the assertion that the Norman Conquest created new restrictions on hare hunting, the accompanying decline in the number of hares at religious sites and continued absence of them from rural ones is crucial context. Unfortunately, the decline in religious sites cannot be confirmed with chi-squared as a medium effect size was detected, but the chi-squared value was overestimated due to some of the expected values being

less than five. Changes for urban ($\chi^2 = 0.1$, $\phi = 0.04$, *p*-value = 0.74 and high-status ($\chi^2 = 0$, $\phi = 0.03$, *p*-value = 0.88) sites constituted trivial effects.

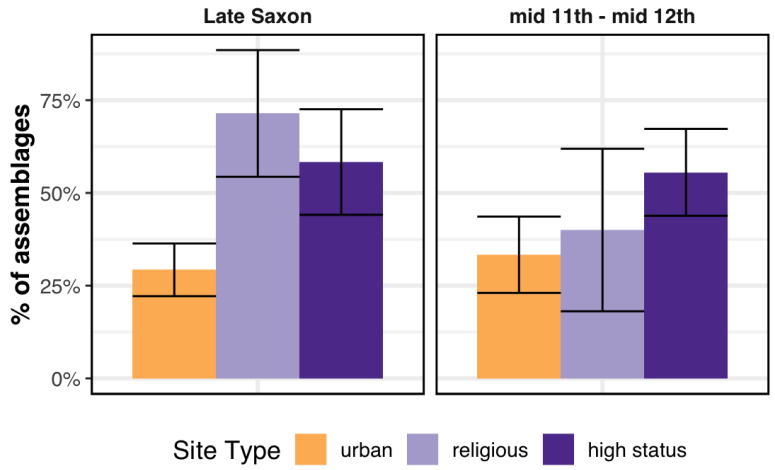

Figure 2.33: Comparison of hare presence by site type for Late Saxon and mid 11th - mid 12th assemblages. Error bars represent the standard error.

For NISP and H/MD, the most notable outliers were those with more than a hundred hare bones: two separate seasons of excavation at Carisbrooke Castle. The sheer quantity of hare bones from these excavations is a near indisputable proxy for a warren associated with the castle. Eynsham Abbey is also prominent according to NISP, but less so when expressed in terms of MD. Faccombe Netherton is the only high-status site other than Carisbrooke to have more than twenty-five hare bones from this period.

Mapping these assemblages highlights geographically widespread absence of hares for all site types except high-status ones (Figure 2.35). Urban sites with hares trace a line from the south-west of England to Norfolk, which suggests that geologically-determined preservation biases may have a greater influence than cultural transforms on which urban sites from this period produced hare bones. By contrast, high-status sites with hares are found across most of the study area. All the high-status sites with no hares are from central southern and south-western England, although this trend is probably exaggerated by the absence of any high-status assemblages in the Essex, Suffolk, and Cambridgeshire area. Spatially, the NISP data are very homogenous (Figure 2.36); the only clear trend is for high-status sites to have the highest numbers of hares, and for the most outlying of those to be positioned in southern England.

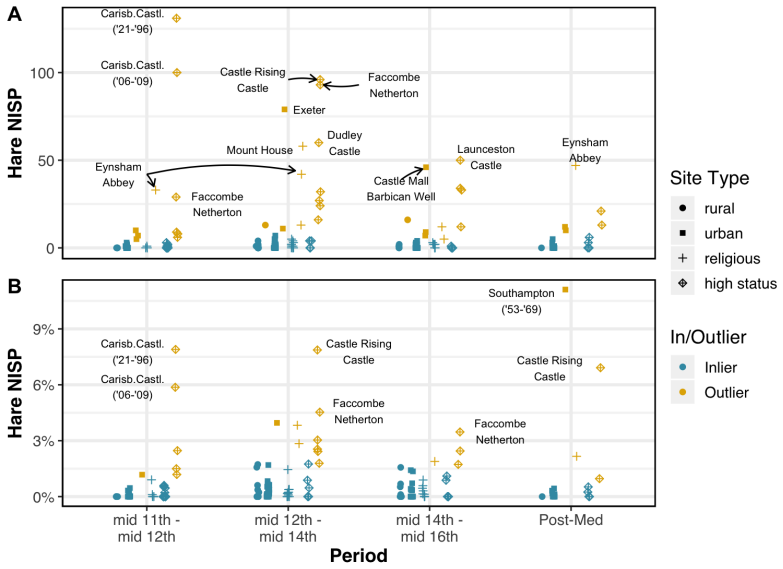

Figure 2.34: Medieval and post-medieval assemblages shown by site type and inlier/outlier status for Hare NISP (A) and H/MD (B).

The transition to the High Medieval period (mid 12th - mid 14th) comes with a dramatic increase in the proportion of assemblages with hares (Figures 2.22, 2.23). The accompanying effect size of 0.23 (Table 2.11) is the third largest for the whole mesoscale analysis, and the largest since hare presence declined in Early Saxon period. It was also statistically significant. This change accounts for the large increase seen for the medieval period at the macroscale level (page 70) and, in contrast to the gradual increase seen over the Roman period, points to a more abrupt rise in hare presence. This fits well with the expansion of hunting culture and the growing numbers of warrens and deer parks at this time, driven by rapid new exchanges of hunting rights between the Crown and nobles following the Forest Charter of AD 1217 and its gradual implementation over the thirteenth century (Cantor 1970; Griffin 2007; Langton 2015).

For raw NISP and H/MD the mid 12th - mid 14th centuries constitute a major change. Mean NISP reaches its highest point in this period, and it is clear from the increased space between the mean and the upper Tukey fence that there is greater dispersal of assemblages towards higher values (Figure 2.24). It is also one of the few periods where the median is visibly higher than zero. Kruskal-Wallis tests comparing this period with the mid 11th - mid 12th centuries produced small effects ($\epsilon^2 = 0.04$, Tables 2.12 and 2.13) and statistically significant results for both approaches to the data.



Figure 2.35: Distribution map of hare presence/absence data by site type for Medieval and Post-Medieval periods.

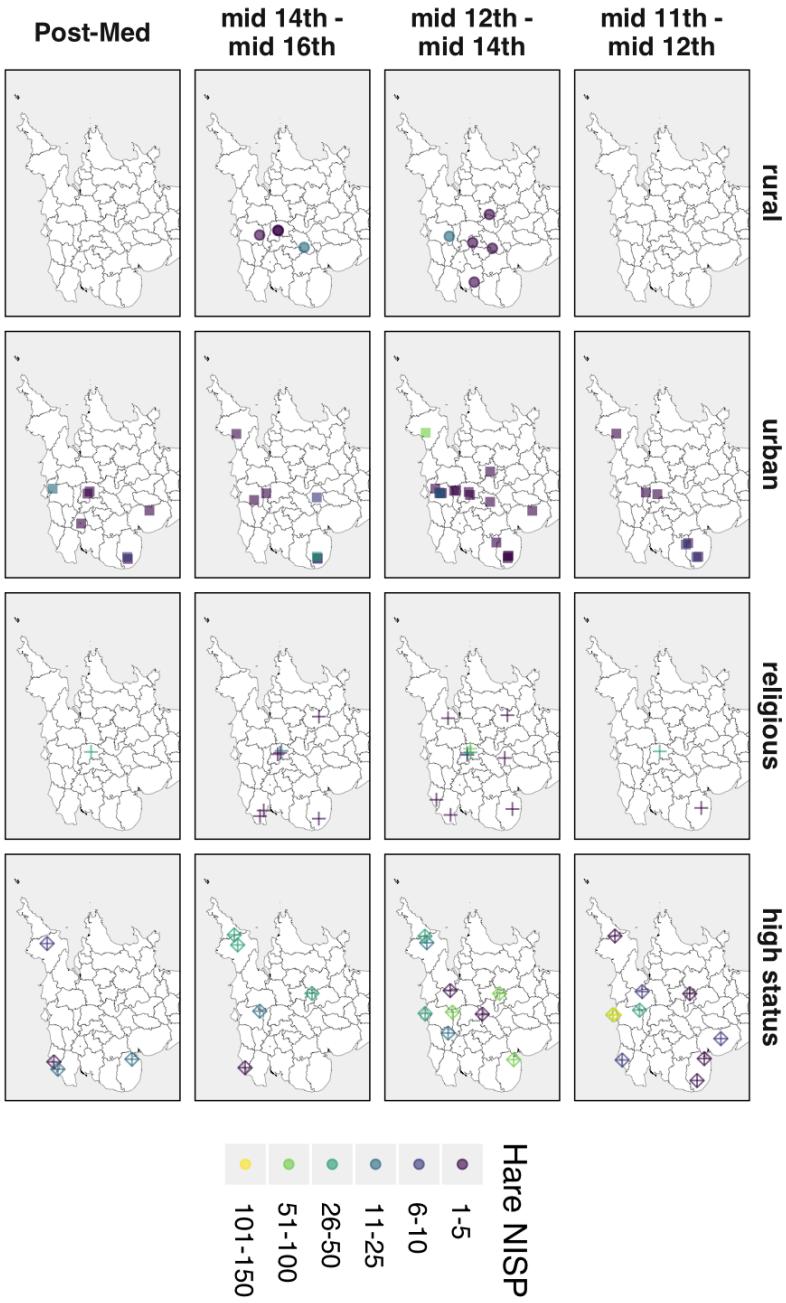

Figure 2.36: Distribution map of Medieval and Post-Medieval assemblages with hares by site type and period for NISP

Hares increase in percentage presence in the High Medieval period for all four site types, including the re-emergence of hares at rural sites (Figure 2.37), which fits with the eventual restoration of hunting rights to groups of lower social status granted by the Forest Charter (Griffin 2007: p. 36-48, 61-2). Standard error bars indicate there could be considerable room for overlap between the site types, though it seems likely that hares were more common at urban than rural sites, as the latter has the largest of the standard errors. High-status assemblages are clearly the most likely to have hares, though as with some earlier periods, there is room for debate regarding the extent to which religious sites mimicked this. Chi-squared tests comparing site types between the mid 11th - mid 12th and mid 12th - mid 14th periods produced a small effect size of 0.25 for urban sites ($\chi^2 = 3.1$, p-value = 0.08); the other types could not be used as expected values were less than five.

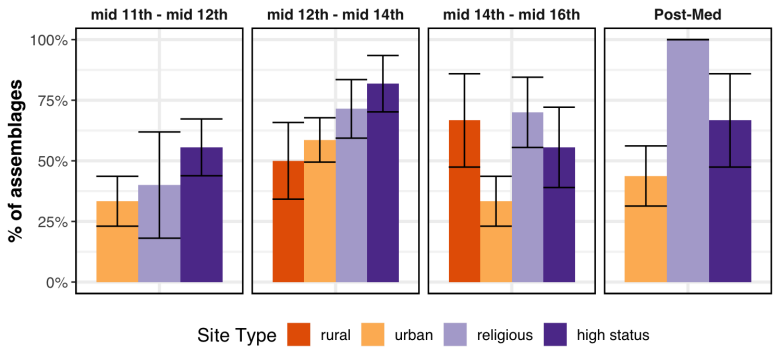

Figure 2.37: Presence of hares by site type for medieval and post-medieval periods. Error bars represent the standard error.

Examining NISP and H/MD by site type reveals similar patterns. The lowest of the outliers for all types is higher than in the Norman period, and the inliers also appear to be more dispersed, especially for H/MD (Figure 2.34). Outliers by NISP at this time include Castle Rising and Faccombe Netherton (Figure 2.34), the latter having increased its quantity of hares to almost one hundred. Exeter is unusual for urban sites at this time with more than seventy-five hares. Eynsham Abbey stands in contrast to Faccombe having only a modest increase in hare NISP. Interestingly, Carisbrooke Castle does not repeat the extreme numbers seen in the Norman period. It is possible that this reflects the supposedly twelfth century arrival of the European rabbit (Sykes et al. 2010). Zooarchaeological evidence for rabbits at Carisbrooke Castle does not appear

until the sixteenth to eighteenth centuries, however (Ayton 2011: p. 29).

Total hare NISP as a proportion of total main domesticates points unambiguously to a dramatic increase in hare numbers at high-status sites, and in fact the proportion at religious sites decreases (Figure 2.38). Spatially, the only rural site that stands out by NISP is in Hampshire (2.36). Urban sites are also very homogenous, with only sites in Devon and Hampshire having notable frequencies. Religious sites with unusual abundances, meanwhile, are in Oxfordshire. High-status sites with large numbers of hares are found across the study area. With Presence/Absence (2.35), spatial patterns in the rural and urban sites seen in NISP are revealed to be trivial; spatial coverage is good for both site types for most regions and assemblages with and without hares are found everywhere.

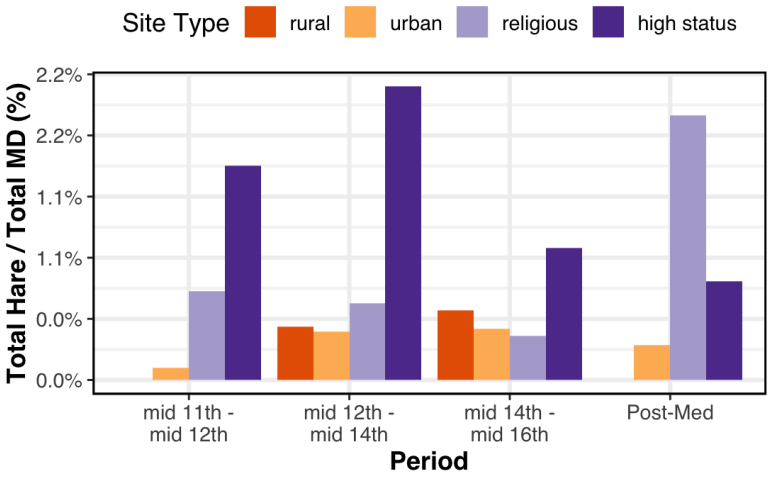

Figure 2.38: Total hare NISP by site type for medieval and post-medieval assemblages, expressed as a proportion of total MD.

2.8.7 Late and Post-Medieval Britain

Hare presence (Figures 2.22 and 2.23) in the Late Medieval period (mid 14th - mid 16th centuries) declines to around half of the assemblages in the dataset, which constitutes a reasonably strong, albeit still small, effect size ($\phi = 0.14$, Table 2.11). Mean NISP and H/MD values also decline (Figure 2.24) with weak effects ($\epsilon^2 = 0.01$, Tables 2.12 and 2.13), though they still remain high in comparison to Pre-Conquest levels. For both approaches to NISP data, extreme outliers are much rarer than they had been in the

Norman and High Medieval periods.

For presence data by site type, the Late Medieval period constitutes a conspicuous change: rural sites are more likely to have hares, whilst urban and high-status sites are less so (Figure 2.37). Religious sites are by comparison relatively unaffected. It has to be considered, however, that due to lower sample sizes, this period has among the largest standard errors so these findings are at best tentative. Only the decline in hares at urban sites can be considered secure. This was confirmed by running chi-squared tests comparing each site type between the High and Late Medieval periods. Expected values less than five were detected for all save the urban sites. A small, but nevertheless surprisingly large, effect of 0.25 ($\chi^2 = 3.1$, *p*-value = 0.08) was found for the urban data. That the effect for urban sites is greater than the overall effect for the transition between the two periods (Table 2.11) suggests human-hare interactions may have changed very differently at different site types, so it is unfortunate this result cannot be compared against the others. There are no apparent spatial trends for these data (Figure 2.35).

For NISP and H/MD, high-status sites still represent the majority of major outliers, though even the most extreme - Launceston Castle - only has fifty hare bones (Figure 2.34). The urban assemblage from the Barbican Well at Castle Mall, Norwich is unusual for urban sites at this time. The assemblage represents a single feature with a specific taphonomic pathway that was extensively excavated and sampled, so it cannot be directly compared to even the wider urban assemblage from Castle Mall, let alone other contemporary urban sites, with the data used here (but see similarities between Castle Mall and the Barbican Well, when more taxa and data types are considered, in Albarella et al. 2009: p. 26-34). Faccombe Netherton is the most extreme outlier for H/MD in this period because of an unusually small MD value.

Despite the declines seen in high-status sites for Presence/Absence and the NISP data, examining total hare NISP as a proportion of total main domesticate NISP reveals that high-status sites still have the most hares in the Late Medieval period (Figure 2.38). A decline of about half, however, still points to a major change in hare hunting.

NISP shows little spatial patterning by site type in the Late Medieval period, though it does seem to be the case that urban and rural sites with larger quantities of hare are more common in the east of England, whilst high-status sites with larger numbers are

found in the west (Figure 2.36). This picture is clearly biased, however, by the dearth of rural sites in the west and of high-status ones in the east, so cannot be taken entirely at face value (see Figure 2.35).

For reasons discussed above (page 46), the Post-Medieval dataset is small and is likely to be biased towards urban and high-status status sites. Analysis at this detailed level therefore needs to be cautious.

Overall hare presence is unchanged from the late to post-medieval (Figures 2.22 and 2.23), and although the margin of error is greater, it is not the largest seen across the entirety of this synthesis. It seems likely that hares would have occurred at around forty percent of sites or more. The lack of change between the two periods is confirmed by chi-squared analysis, which produced an effect size of zero (Table 2.11). For raw NISP, the Post-Medieval period constitutes a small decline in mean hare abundance, indicating fewer extreme outliers and a probable rise in the number of assemblages with small quantities of hares or none. That the upper Tukey fence rises, however, points to a broader distribution of the data. For H/MD the mean rises under the influence of the most extreme outlier seen since the Neolithic, raising the possibility of some unusually small MD values. Kruskal-Wallis tests concur with the chi-squared tests, however; effect sizes of zero point to no change from the Late Medieval period (Tables 2.12 and 2.13).

Eynsham Abbey is the most extreme outlier by NISP in this period, and the only religious site. The remaining outliers are high-status and urban sites: Camber and Castle Rising Castles, and Alms Lane, Norwich. For H/MD, Southampton (1953-69) is an extreme outlier with 11.1% hares. This results from an MD value of 108. Castle Rising is the next outlier with 6.9% hares and an MD value of just 188.

Presence by site type is problematic for this period as there is only one religious site (Eynsham Abbey), so presence equals one hundred percent for this category (Figure 2.37). Furthermore, although high-status sites have second greatest percentage presence in this period, it also has the larger standard error, so the true value may be no different from urban assemblages. No rural sites have hares, but the sample size was only one.

Total hare NISP as a percentage of total MD is similarly biased towards religious sites by Eynsham Abbey (Figure 2.38), which as an overall outlier presents a poor comparison

with the sum of multiple assemblages for the other categories. Otherwise, it seems clear that the association between hares and high-status sites was maintained in the post-medieval period, though it is equally obvious that the High Medieval period is the final peak of hare hunting detectable in this dataset.

Although population decline from the Black Death is regarded as a trigger for the "golden age of hunting" in the mid fourteenth to fifteenth century, concerns about game stocks as the human population recovered in the late fifteenth century prompted new restrictions on hunting (Griffin 2007: p. 61). The Game Laws eroded the rights granted by the Forest Charter, which despite being initially seized upon by barons in the thirteenth century did eventually allow lower social classes to hunt on their own land (Griffin 2007: p. 62). Even though hunting rights had become their own again, elites in the fifteenth century were driven by low rents to seek other ways to profit from their land, so deer populations continued to fall as woodland was sold off for timber (Griffin 2007: p. 73-4). Hunters therefore turned to other game, including hares, which eventually prompted Henry VIII to ban the hunting of hares in the snow in an effort to prevent population decline (Griffin 2007: p. 74). It is not possible to tell whether the drop in hare abundances in this Late Medieval dataset relates to reduced hunting overall as it became increasingly restricted again, or instead to declining hare populations from over-hunting. The primacy of deer in the fourteenth and fifteenth century could also account for it (Sykes 2014a: p. 74). Both the size of this dataset, and wider issues with the recording and dating of post-medieval zooarchaeological assemblages (Holmes 2017: p. 131), mean that it is not possible to detect the historically attested resurgences in hunting after the Civil War, which brought new focus on hare and fox coursing following yet further declines in deer populations (Griffin 2007: p. 110).

Distribution maps of the post-medieval data indicate no spatial relationships for urban sites (Figures 2.35 and 2.36), save that the assemblage with the most hares is Southampton, as previously mentioned. Presence/absence maps show that high-status sites with hares are found in the east and west of England, whilst those in central England have none (Figure 2.35). This could reflect regional patterns of land-use, but more data would be needed to demonstrate it confidently.

2.9 Microscale

Having surveyed the evidence for diachronic changes and trends, we now need to explore key sites in greater detail. In this section, I critique the methods and archaeological context behind the evidence for hares in assemblages dated to periods before, during, and immediately after the supposed Iron Age introduction of the brown hare. The aim of each case study is to understand its biological and cultural significance to the narrative of the brown hare's arrival in Britain, and to determine whether we have enough information to accept the material at face value.

2.9.1 Associated Bone Groups

The study of Associated Bone Groups (ABGs), is essential to this analysis, so it is worth setting out their significance and problems with their study and interpretation first.

Recovery biases coupled with taphonomic effects means that most zooarchaeological evidence is made up of fragmentary bone. When animal remains are in articulation or some other form of 'association', these finds consequently take on a special significance that requires deeper analysis and interpretation than is afforded to the more typical content of a bone assemblage. How this deeper inspection proceeds, however, has changed significantly as research agendas in zooarchaeology have advanced (Morris 2008a).

The earliest ABGs to be discovered were seldom interpreted. The few explanations that were offered were typically functional, such as fall victims or spoiled joints of meat. Morris (2008a) shows, however, that 'ritual' interpretations of ABGs became more common during the 1980s, following new theoretical trends that increased archaeologist's attention on religion and ritual. Annie Grant's (1984: p. 533-43) analysis of the Iron Age deposits from Danebury was particularly seminal in this regard. Articulated animal remains were generally termed 'special deposits' at the time, reflecting the unusual nature of the material, but also carrying problematic cultural meaning (Morris 2012; Wilson 1992). Such a dialogue naturally leads further into even more loaded language and interpretation, such as 'sacrificial offering', 'feasting waste', or 'animal burial'.

Early criteria for identifying special deposits focussed on the absence of evidence for

'normal' exploitation; the lack of correlation between a species' quantitative representation in normal contexts and that in special ones; consistency in body part or species selection; and evidence for deliberate or careful placement (Grant 1984: p. 542; Wait 1985: p. 151). Wait (1985: p. 151) also emphasised that special deposits only occurred in pits, never ditches. Wilson (1992), however, raised concerns about equifinality - ordinary carcass processing and/or butchery could produce similar deposits of part skeletons and articulated limbs to ritual activities.

Hill's (1995: p. 16) groundbreaking work provided the more neutral term now used to discuss these deposits (Associated Bone Group). Moreover, it showed that the structured deposition of material (zoo)archaeologists typically characterise as 'waste', could itself be socially meaningful. Seemingly mundane collections of bone and artefacts are not necessarily any less culturally significant as potential makers for 'ritual' activity than a skeleton or articulated limb. Conversely, Hill (1995: Chapter 10) also showed that almost all Iron Age deposits are in some way structured; this does not mean, though, that every deposit is the product of a ritual practice or set of beliefs. Dividing cultural phenomena arbitrarily into 'ritual' and 'mundane' or 'sacred' and 'profane', is thus showed to be flawed way of thinking that scholars project onto the past (Brück 1999; Hill 1995). Instead it is more helpful to think of activities existing on a scale of ritualisation (Brück 1999). Creating a perfect definition for an ABG is therefore effectively impossible. Archaeologists can only pick apart the motives and behaviours behind this aspect of the zooarchaeological record by evaluating each individual deposit on its own terms, and by placing it within its wider cultural context (Morris 2008a: p. 12).

Contemporary animal introductions is just one example of such a context, and the reason for ABGs' importance in this study. As understanding of anthropogenic animal migrations has grown, it has become apparent that recently arrived species are most prevalent as ABGs in the periods during or immediately after their arrival. Domestic fauna arriving in the Neolithic dominate both ABG and non-ABG contexts in the Neolithic and Bronze Age: Cattle in the Neolithic and sheep/goat in the Bronze Age (Sykes 2014a: p. 80-81, Fig. 4.2 on page 81 for sheep/goat).

Meanwhile, the reintroduction of the horse in the Bronze Age coincides with a tradition of horse burials that lasted well into the Iron Age. Though the number of ABGs rises over this period, horses remain comparatively rare in other contexts, suggesting a

species singled out for special treatment in death (Sykes 2014a: p. 81-2). Together with horse iconography, this has been interpreted as evidence for a new culture of chieftainship or kingship, with horses or a possible Celtic horse-deity acting as a supra-natural mechanism for power legitimisation (Creighton 1995; Sykes 2014a: p. 81-4). Similarly, the earliest domestic fowl in Britain were recovered as skeletons in Iron Age pits (Hamilton 2000b,c) but are otherwise scarce in the contemporary archaeological record (Sykes 2012, 2014a: p. 84). This was followed by Late Iron Age and Roman traditions which involved whole or partial chicken skeletons, or articulated limbs, being deposited in human graves (Sykes 2012: p, 164; Best et al. forthcoming)

Deliberate deposition of animal remains may therefore be a behavioural marker for perceptions and attitudes common to recently introduced species. It fits well with our understanding of human relationships with exotica (Helms 1993), as well as Caesar's (n.d.) claim that chickens and hares were not eaten, but were 'kept' by Iron Age Britons. If these exotic animals were kept and treasured in life for their exotic character, it reasonably follows that they would receive 'special' treatment in death.

The presence of ABGs is therefore useful, on cultural grounds, for detecting the brown hare's arrival. Furthermore, hares have small bones so the potential for the earliest, and consequently crucial, evidence to be intrusive is very high when it comes from isolated bones or bone fragments. An ABG, meanwhile, is far more likely to be securely stratified, as the chances of a group of bones moving through a deposit whilst remaining in association are extremely small, except where the an ABG is in fact not anthropogenic and instead represents the remains of a burrowing animal. Hares, however, typically do not burrow - the mountain hare is an exception, but observations that it tends to burrow into snow for food or for shelter (Chapter 1) suggest that disturbance of archaeological deposits is probably uncommon compared to other burrowing animals, such as rabbits or badgers.

2.9.2 The Pre-Iron Age Evidence

This chapter has already shown that the evidence for hares prior to the Iron Age is scant (see also Table 2.16, below). The earliest convincing archaeological hare remains are purportedly Neolithic in date, coming from the causewayed enclosure, Windmill Hill. Ten bones were recovered in excavations from 1925–1939 (Jope 1965), but were reported

as missing by Grigson (1999: p. 235) in her review of that assemblage published as part of the faunal report for the 1988 excavations. There also appears to be some confusion of the nature of the material - Grigson refers to "ten metapodia", but Jope's report itemises two metacarpals, six metatarsals and two right tibiae.

Considering first Grigson's account, ten metapodia is suggestive of what might recognised today as an Associated Bone Group, which makes arguments against the Neolithic date - on the grounds of potential intrusion - more difficult to justify. Jope's original identification of two tibiae of the same side is possibly less indicative of a genuine ABG; instead the most significant implication is the presence of two individuals. Nevertheless, the general absence of other Neolithic hares is cause for some scepticism. Regardless of dating issues, it is also important to consider identification.

Table 2.16: Neolithic and Bronze Age Assemblages with Hares.

Site	County	Period	Site Type	Hare	MD	H/MD (%)
Ascott-under-Wychwood	Oxon.	E/M Neo.	barrow	1	290	0.34
Lanhill	Wilts.	E/M Neo.	barrow	3	2	150.00
Gatehampton Farm	Oxon.	E/M Neo.	enclosure	2	15	13.33
Windmill Hill	Wilts.	E/M Neo.	enclosure	10	1664	0.60
Hambledon Hill	Dorset	Late Neo.	shafts	3	87	3.45
Brean Down	Somerset	LNEO/EBA	occupation layer	1	25	4.00
Crab Farm Shapwick	Dorset	EBA	barrow	2	40	5.00
Bishops Cannings Down	Wilts.	MBA	rural	2	2069	0.10
Burderop Down	Wilts.	LBA	rural	4	4167	0.10
Runnymede	Surrey	LBA	rural	1	6361	0.02

The original project (Jope 1965) was completed nearly a decade before zooarchaeology's core methods, manuals, and standards were published (e.g. Schmid 1972), so the identification may not be accurate. Certainly the chance that that the bones are mountain hare and not brown hare also cannot be ruled out, as the former's natural range could have been much larger in the Neolithic than it is now (Charles et al. 1994; Hinton 1909; Jacobi et al. 2009). Indeed, the absence of hares in Neolithic assemblages does not disprove this possibility, as wild fauna may have been considered "special" or their consumption taboo (Sykes 2014a: p. 60-4). Absence of evidence in the archaeological record does not prove an animal's absence in the landscape.

Conversely, if the bones are considered to be brown hares, the possibility of multiple phases of brown hare introduction is raised. One Neolithic individual (or two) does not prove the presence of a Neolithic population, or that such a population was the same as that from later periods. Conceivably, this one individual could represent an early population that went extinct before it could become established.

The skeletal element representation poses another interpretation. That the evidence consists of eight small bones, possibly with two tibiae, raises the question of why larger - and therefore more easily recoverable - elements have not also been found. Preservation is one explanation - the metapodia are relatively dense, containing little cancellous bone, so they can be expected to survive well, despite their size. Alternatively, it could be that the bones do not represent a living hare. The exchange of body-parts of exotic fauna prior to the arrival of a living animal has been raised in relation to fallow deer (Miller et al. 2016); a similar scenario could apply here. The temptation to interpret these remains as an early example of a "lucky hare's foot" (Boyle 1973; Ellis 2002) should be resisted, but personal adornment, for any number of purposes, is a possibility. Alternatively, they could be indicative of an imported pelt brought in with the feet attached - similar reasoning has been used as an explanation for the presence of bear claws in Saxon cremations (Bond 1996: p. 85).

Turning to other Neolithic sites, the evidence becomes less convincing, and intrusion the most likely explanation for the remains. Two metatarsals, and the proximal end of an ulna from a juvenile, were found at Lanhill Long Barrow (discussed above, page 83). The barrow was disturbed many times before it was eventually excavated in 1963 (Grant King 1966), so stratigraphic integrity is highly unlikely. As with Windmill Hill,

the remains were analysed prior to zooarchaeology's inception, so the identification may also be doubtful.

Meanwhile, small numbers of hare bones were found at Ascott-under-Wychwood, Gatehampton Farm, and Hambledon Hill (Table 2.16). The single unfused calcaneum from Ascott-under-Wychwood is not discussed in any detail, but is worth highlighting that Mulville and Grigson (2007: p. 238) dismissed fox remains from the barrow as intrusive, along with associated bones of sheep, mole and frog, arguing that these bones represents the use of the barrow as a den. Furthermore, a second "hare" bone is identified but caveated as "hare/rabbit". These finds do not prove that the hare calcaneum is intrusive, but at least points to potential for disruption of the archaeological strata. The same argument is proposed by Legge (2008) for the three hare bones from Hambledon Hill. Some other Neolithic sites not in this dataset (because they were not in Serjeantson 2011) also have hare remains, but again intrusions from burrowing animals render the evidence suspect at best (e.g. Silbury Hill in Worley 2011).

Similar arguments can be made for Bronze Age sites. The entire Brean Down assemblage is caveated with potential intrusions given the site's evidence for burrows - mostly from rabbits but also possibly badgers (Levitan 1990). A vertebra and metapodia fragment from Crab Farm were not dismissed as intrusive, though rabbit bones were also found (Locker 1992). Just as with Ascott-under-Wychwood and Hambledon Hill, badger remains, coupled with prey animals likely to be intrusive - rabbits and mole (Maltby 1992: p. MF2-A7) - suggests that the hare bones from the barrow at Bishops Cannings Down are also intrusions. Meanwhile, intrusive rabbits were abundant at Burderop Down (Maltby 1992: p. MF2-B7). Finally, at Runnymede, a single tibia fragment was identified, but tentatively (Done 1980: p. 74). In each of these cases, it is worth stressing that the presence of burrowing animals does not prove the hares are intrusive, ultimately only direct dating can test this. Nevertheless, the paucity of hare remains in the Neolithic and Bronze Age demonstrated above (§2.7, §2.8) coupled with consistent cause for scepticism on taphonomic grounds explained in this section, convincingly suggests that hares were absent from human spaces (whether domestic, ritual or mortuary) from southern England at this time.

2.9.3 Iron Age and Roman Period

2.9.3.1 Early and Middle Iron Age

The Early (EIA) and Middle (MIA) Iron Age provide the earliest evidence for possible brown hares that are securely stratified. At Winklebury Camp, near Basingstoke, a partial hare skeleton was found in pit 3852 (context 3755). This context is the sealing layer at the top of the pit (Figure 2.39), which also contained a deer skeleton, almost at the very bottom (Jones 1977: p. 64). The site is broadly dated as Early to Middle Iron Age. The zooarchaeological assemblage is rich in ABGs of both wild and domestic animals; found predominantly in pits. Predating Grant's (1984) work on special deposits from Danebury, their significance is not expanded on in any detail, and in his interpretation Jones leans towards accidental deaths caused by the pits acting as traps. Domestic fowl ABGs found at the site were among the earliest examples of chickens in Britain, but radiocarbon dating has shown them to be post-medieval/modern insertions (Best et al. forthcoming). This raises the possibility that other ABGs at the site, including the hare, are also not Iron Age and shows that direct dating is the only way to be sure of the age of this hare skeleton.

Nearby, at Winnall Down, Winchester, a Middle Iron Age hare skeleton was recovered from pit 10161 (Figure 2.40). Like Winklebury, the hare was deposited in the topmost layer (context 10262). Maltby (1985: p. 103) reports that the skeleton is almost complete; the skull was present but smashed, so it was not possible to identify the species using osteological criteria on the maxillary incisor and zygoma (for discussion of these criteria, see Chapter 3).

Finally, at Blackhorse Road, Letchworth, four separate instances of Middle Iron Age hare remains were found. Individual bones (a left distal humerus and a left tibia) were found in a pit in Area XIII. Legge et. al. (1988: p. 94) report that there was no evidence for butchery or burning but that the "position in the pit" implies these bones represent food waste - they do not elaborate on why they reached this conclusion. Two partial hare skeletons, meanwhile, were found in the ditch fill of the second MIA enclosure (Figure 2.41). This is the only known example of a MIA site with a hare ABG outside of Hampshire. All of the hare remains are reported as brown hare, but no mention is made of identification methods. The ABGs' recovery from ditches rather than pits is worth noting, both because it differs from Winnall Down and Winklebury Camp, and

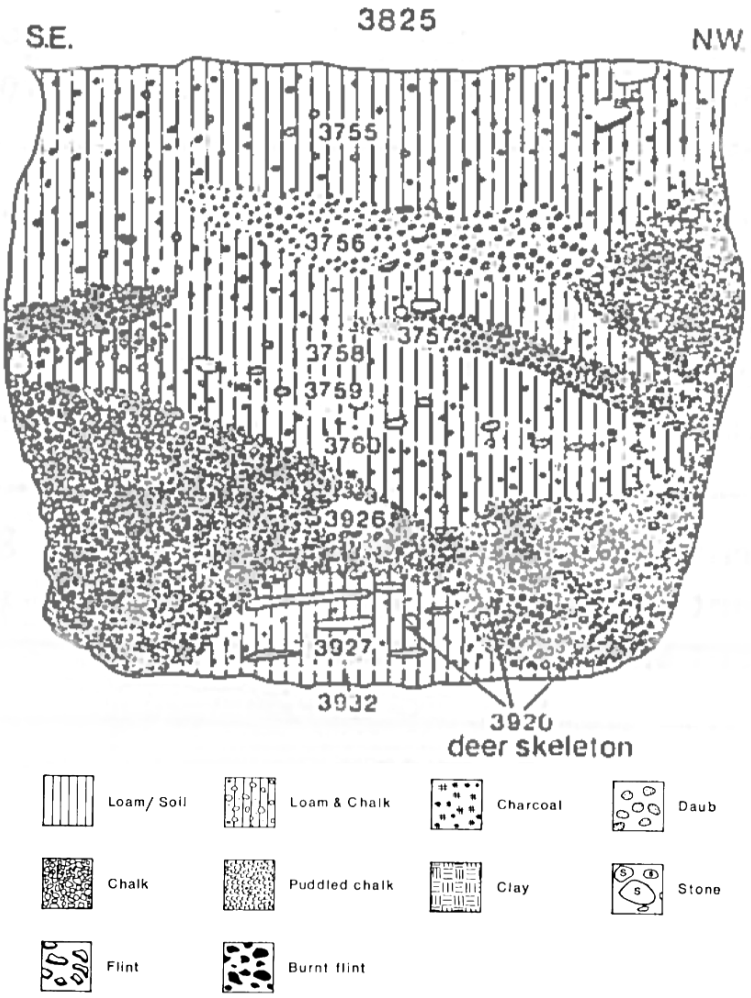

Figure 2.39: Winklebury Camp Pit 3582 section drawing, context 3755 containing hare ABG uppermost. From Smith (1977: Figures 12a and 19)

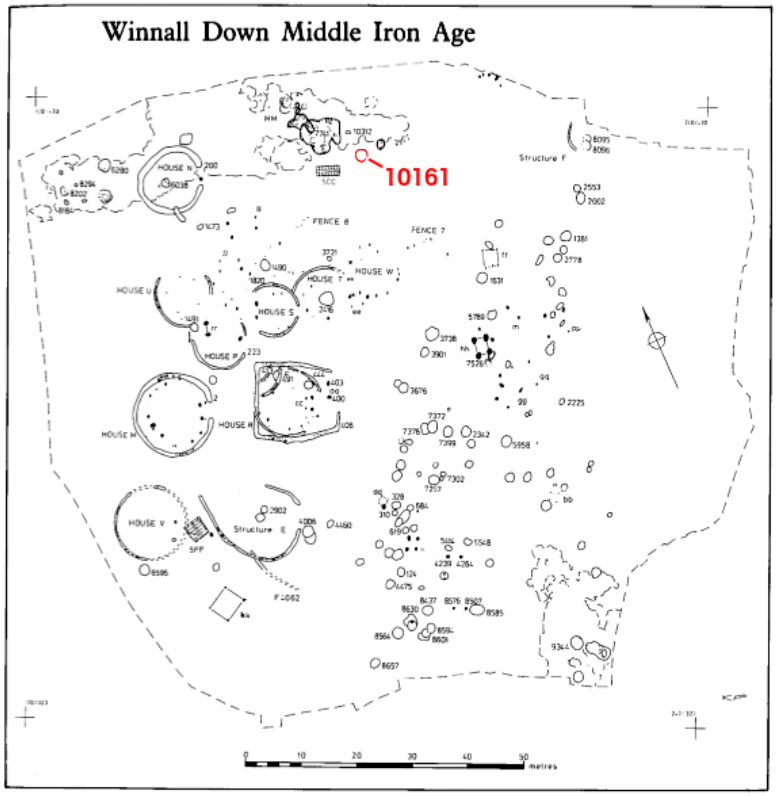

Figure 2.40: Plan of Winnall Down during the Middle Iron Age, from Fasham (1985: p. 19). Pit 10161 re-labelled and highlighted in red for emphasis.

because it contradicts early criteria for identifying special deposits (see page 124).

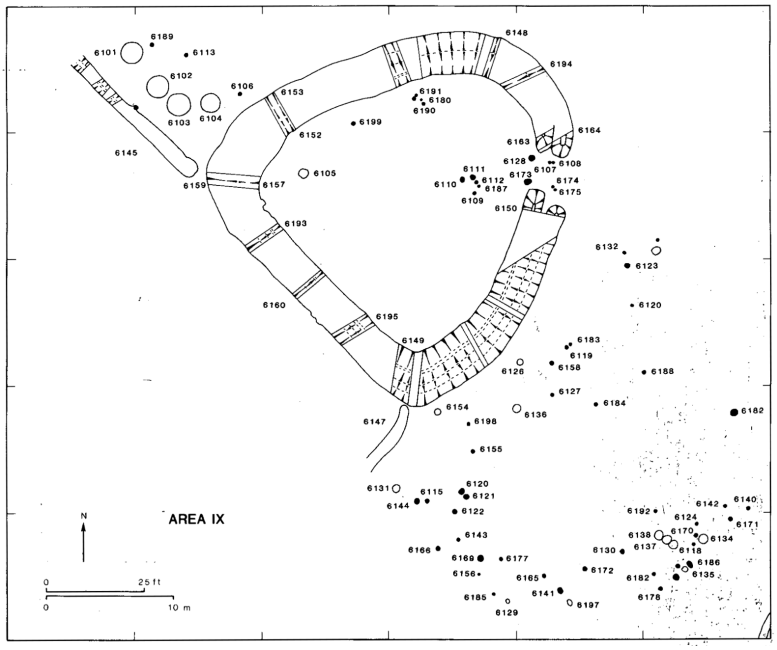

Figure 2.41: Plan of Blackhorse Road, area IX, enclosure 2. From Moss-Eccardt (1988: p. 69).

It is interesting that Blackhorse Road has evidence for both hare ABGs and two individual bones, the latter being a more common trait of hare remains from Late Iron Age sites (see below). Of course, as with the Bronze Age and Neolithic finds of stray bones, they may be intrusive.

2.9.3.2 Late Iron Age

During the Late Iron Age, finds of hare bones become more common. Clear Associated Bone Groups, however, do not become any more prevalent. Instead, isolated bones are found at increasing numbers of sites and more ambiguous ABGs appear.

Hamilton (2000a) reports the skull and larger post-cranial elements of a hare at Suddern Farm, found in a pit (P104/9), possibly representing what was originally a complete skeleton. Butchery marks were found on the pelvis, near the acetabulum - one of the earliest cases of hare butchery. It could suggest that hares were now beginning to be eaten and though the bones are described as a skeleton, it does not seem to be implied that they constitute *articulated* remains. Nevertheless Hamilton later remarks that fox,

Table 2.17: Hare remains from Sutton Walls. After Kenyon (1953: p. 82). All came from Area I, Rampart Cut A, Rampart B. Total NISP = 13, MNI = 2.

Element	NISP
Skull	1
Pelvis	2
Vertebra	2
Sacrum	1
Tibia	3
Ulna	1
Humerus	2
Metatarsal	1

deer and hare "all appeared in contexts suggestive of special deposits". A humerus and a mandible were also found in a LIA/first century settlement ditch.

Nine bones from a "very young" hare were recovered from pit F139-2 at Owslebury and seven more from a slightly older individual from F384-2 (Maltby 1987). This mimics a trends for articulated leverets in the Roman period at Owslebury (see below). Thirteen hare bones were recovered at Sutton Walls, the data for which are reproduced in Table 2.17. No discussion of the remains is included in Kenyon's (1953) report but it is possible to infer from the skeletal element representation that at least two individuals were present, at least one of which might have been a partial articulated skeleton.

Ten hare bones are reported in the data tables for Nettlebank Copse, although Hamilton appears to contradict this in her discussion, referring to "eight of the nine hare bones found" (compare Table 5.8 on pg. 102 with pg. 114 in Hamilton 2000b). These eight came from the banjo enclosure ditch and notably consist of at least six independent finds. This implies that none of the bones can be classed as an ABG; none of them are reported as being in association. One immature ulna came from the external ditch (F158).

The Late Iron Age ditch at Fishbourne Roman Palace has already been mentioned several times in this synthesis. This assemblage consisted of relatively few main domesticate remains in comparison to other sites (see Sykes 2005), so it proved to be an outlier in the quantitative analyses here thanks to the hare ABG, which consisted of seven bones of the hind foot. These were the calcaneum, astragalus and the metatarsals. A fragment of the tibia was also found. It is common butchery practice for the hind

feet to be separated from the limbs by chopping through the distal tibia, rather than by attempting to disarticulate the tibia from the ankle bones. This could suggest that the foot represents butchery waste, but that does not preclude the possibility of religious or symbolic behaviour.

The 1969-78 excavations at Danebury produced four hare bones from its Late (A) phase and five from its Late (B) phase, though only the latter appeared in the data used for this synthesis. Coy (1984: p. 526) lists these remains as *Lepus sp.* but then identifies them in her discussion as "definite identifications" of brown hare. None of these remains are mentioned as being articulated, so it can be assumed they represent disparate bones and could be comparable to food-waste.

Edix Hill produced a NISP of five for hares, which is attributed - along with the single fox bone - to hunting (Davis 1995). One of the bones was a distal femur, but the rest were four different mandibular teeth ($P_3,\ M_1,\ M_2,\ and\ M_3$). This implies the presence of at least one mandible that has not survived deposition; even if these teeth came from different sides, the MNI for the site would still equal only one. Gussage-All-Saints also produced five bones, identified as brown hare. Harcourt (1979: p. 154) notes that the six hares identified from the whole site (the sixth being from the EIA phase) came from six features, implying six different depositional acts and possibly six individuals.

Of the remaining LIA sites to produce hare remains, none had more than three. They include the only religious site for the period, the temple-mausoleum at Bancroft and a variety of settlements in western and eastern England. The majority in fact correspond to the eastern group identified in the macro- and mesoscale levels of this analysis.

2.9.3.3 Iron Age/Roman Transition and Roman Period

Of the IA/RB remains Carne's Seat produced the most hares, but this evidence has already been discounted (page 80). Nine bones were found at Owslebury. These included single fragments recovered from pits (NISP = 1, F266), gullies (NISP = 5, F136) and one from a quarry.

Hayling Island is perhaps the most significant find of this period, consisting of seven bones from a Romano-British temple. Hayling Island, which King (2005: p. 337-41) describes as a "possible 'sacred' island", might have been associated with the Regni, whose capital was at nearby Chichester, close to Fishbourne Roman Palace. It has

also been suggested that the temple was dedicated to a Mars-like god. The wider bone assemblage consisted mainly of sheep and pig and few cattle, which King (2005: p. 337-41) associates with the Gallic character of the temple's architecture.

Six bones were recovered from Tolpuddle Ball in Dorset and four each from Orton Longueville and the forum basilica at Silchester. Crummy (2013: p. 116) emphasises that the number of chicken bones at Silchester rises significantly at the time of the Roman conquest, when hare and goose appear for the first time. This occurs despite evidence for contact with continental Europe in preceding periods.

Key sites in the Early Roman period identified thus far included Winchester Palace, Exeter and Greyhound Yard. These have unusually large numbers of hare bones for the period, and Winchester Palace, Southwark, stood out particularly when placed in the context of low main domesticate numbers. Little comment on was made on the Southwark remains (Rielly 2005) so it is not possible here to make any further inferences on their significance. For Exeter, Maltby (1979: p. 61) notes that of the sixty-eight bones recovered over the Early and Late Roman phases, a minimum of eighteen individuals was identified and fifteen of the fragments came from a third century skeleton. Similarly for Greyhound Yard he notes that fifteen bones came from two bone groups of immature hares from two separate late fourth century cess-pits (Maltby 1993a: p.330). Skeletal element patterns favoured the hind limbs, but Maltby attributes this to recovery biases.

Detailed discussion of the hare remains from Fishbourne Roman Palace is provided by Allen (2011), which provides taphonomic insight rarely afforded to small wild fauna in zooarchaeological reports. Allen detected spatial variance in quantities of hare bones, coupled with associated skeletal element patterning. The Northern Pits and Gully area of the site produced more fractured long bone fragments. These were interpreted as butchery waste given that carcass processing on small animals is likely to fracture bone more often than it is to leave detectable cut or chop marks (Allen 2011: p. 215). The high frequency of hares at Fishbourne overall is suggested to be a proxy for a *leporarium* - an enclosure in which the Romans are known to have kept wild animals, especially hares (Allen et al. 2011; Lauritsen et al. 2018; Sykes 2014a).

The large number of Late Roman hares from Caister-on-Sea are given little direct comment by Harman (1993), although she does reference them in regards to the

variety of sizes of dogs observed in the assemblages: some groups may have been used for hunting. Iconographic evidence points to the Romans keeping different varieties of dog for different roles, as well as direct evidence for hare coursing (Toynbee 2013: p. 102-24), which is also supported by written accounts (see Chapter 6). Owslebury is notable for a number of fourth century AD juvenile ABGs recovered from cess-pits (Maltby 1987). No zooarchaeological report yet exists, so it does not appear in this synthesis, but the third-fourth century bath house from the villa at Whitehall Farm produced large quantities of hare bones, and may be another site where a *leporarium* can be inferred from the zooarchaeological evidence (Lauritsen et al. 2018; Sykes 2014a).

2.10 Conclusion

Analysis of zooarchaeological hare data in England through time has revealed important evidence for ancient human-hare interactions. Rises in the abundance of hare remains in late prehistory and the Roman period are consistent with the introduction of a new species, although there is compelling evidence that the earliest of these are in fact intrusions.

Early and Middle Iron Age Associated Bone Groups simultaneously represent the earliest stratigraphically secure biological evidence for probable brown hares and fit with common cultural behaviours associated with exotic fauna. Although some findings from NISP and presence/absence data suggest a Bronze Age introduction is possible, integrating issues concerning sample size and intrusion with these data leads to the likely conclusion that the brown hare was an Iron Age arrival.

Subsequent changes in hare abundances revealed interesting patterns. Some conform to known cultural trends: Roman attitudes to hunting and landscape coupled with culinary trends correlate well with rises in hare abundances in the first to early fifth centuries AD, followed by a very sharp decline in the Early Saxon period also seen in the record for other wild fauna. Re-establishment of hunting culture later in the Saxon period also fits with subsequent rises, as does the creation of new game laws and forests in the Norman period. In contrast to the gradual increase seen over the Early and Late Roman periods, the High Medieval period produces the strongest increase in hare abundances across the whole dataset, fitting well with the renegotiation of game

laws in the thirteenth century.

The data have also shown exciting possibilities for further enquiry. Associations between hares and religious sites emerging in the Late Roman period suggest there is genuine potential in the zooarchaeological record to detect short-term changes in human-hare relationships as well as long-term ones. Similarly, spatial patterning in the Iron Age and Saxon era might point to multiple centres of hare introduction in the former case, and regional variances in hare populations or hunting in the latter.

The primary concern of this thesis is detecting the introduction of the brown hare in order to trace its bio-cultural impact. Some of the latter goal has already been achieved for hares generally, and this synthesis has shown that simple zooarchaeological bone frequencies are consistent with a late prehistoric introduction. There is no way to directly attribute these observations to the brown hare, however.

In the absence of robust identification methods applicable to most of the major skeletal elements, zooarchaeologists seldom identify hare bones to species. Nevertheless, it is often assumed that hare bones found in England are of brown hare (Crummy 2013; Lauritsen et al. 2018; Sykes 2014a) and not of Britain's native mountain hare (*Lepus timidus*, Linnaeus 1758).

The mountain hare is today considered native only to the Scottish Highlands and is found elsewhere only in places to which it has been recently introduced, such as south-east Scotland and the Peak District (Hewson 1956; Yalden 1984). Archaeological hares found in England are assumed to be brown hares on this basis, but this contentiously projects modern ecological circumstances onto the past. Palaeontological evidence has shown that the mountain hare's ancient distribution was much greater than it is today (Charles et al. 1994; Hinton 1909; Jacobi et al. 2009), and although evidence for them in England declines after the Last Glacial Maximum, there is little proof that they did not survive into late prehistory. Indeed, competition with the brown hare might have been the cause for the mountain hare's eventual retreat to Scotland, if it were present when the brown hare arrived (discussions of lagomorph competition in Flux 1981; Flux et al. 1990; Thulin 2003). For this reason, new identification methodologies are required before the natural and cultural history of the brown hare in Britain can be truly dated and characterised.

Chapter 3

Developing a morphometric method for hare identification

Accurate identification of zooarchaeological hare bones is essential to understanding the chronology , cultural circumstances, and impacts of the brown hare's introduction. In this chapter, I outline the techniques that underpin the process of identifying archaeological bone. I focus on the contribution of linear bone measurements (osteometrics) and how the statistical study of size and shape (morphometrics) can be used to maximise these data's utility. I review how systematists and zooarchaeologists have identified lagomorph bones in past research and the extent to which these methods can be applied to this thesis' questions. I explain the reasons for taking a linear morphometric approach to answering those problems. The final sections of this chapter cover the methodology applied to collecting and cross-validating data from modern hare specimens, which is applied to archaeological specimens in the next chapter (Chapter 4).

3.1 Identification methods in zooarchaeology

The development and re-evaluation of animal bone identification methods is a fundamental requirement of zooarchaeology. Established manuals (e.g. Schmid 1972; Pales et al. 1971, 1981; Hillson 2005, 1992; Cohen et al. 1996) are seldom overturned, but meth-

ods can be critiqued and improved by new technological and biological discoveries, and new research questions can demand new methods. Revisiting old identifications can also overturn established interpretations of archaeological sites (e.g. Allen 2009).

Identification methodologies require, at least initially, the use of criteria relating to morphological characteristics (e.g. Schmid 1972; Pales et al. 1971, 1981; Hillson 2005, 1992; Cohen et al. 1996), which should be used with reference to specimens of known species - ideally from a range of sources and consisting of both males and females of different ages (Baker et al. 2019: p. 43-4). Some approaches (e.g. Tomek et al. 2009, 2002; Bocheński et al. 2009) also employ linear - also called 'traditional' - morphometric data, obtained by measuring linear distances between defined anchor points on a bone.

Some approaches are exclusively morphometric. Metrics are well-established for differentiating sheep and goat (Mallet et al. 2019; Salvagno et al. 2017), domestic pig and wild boar (Albarella et al. 2006; Reed 1961), and contribute to the wider body of literature employing osteological approaches to the same problems (e.g. for sheep/goat Prummel et al. 1986; Payne 1985). Recently, the geometric morphometrics 'revolution' has accelerated the generation of literature on the differentiation of species and populations in the archaeological record (e.g. Evin et al. 2013; Hanot et al. 2017; Ameen et al. 2017), and the technique has effectively replaced traditional linear measurements within the morphometrics discipline (see histories of morphometrics in Rohlf et al. 1993; Adams et al. 2004; Claude 2008: p. 1-2, 69, 133).

The lagomorphs have been understudied by archaeologists, so methods that are applicable to archaeological material for differentiating species and populations are only now beginning to receive wider attention. Osteological criteria and morphometric methods for separating brown and mountain hares were developed in the late nineteenth and early twentieth century, primarily for paleontological material and systematics research (e.g. Hinton 1909; Sanford 1870), but they predate modern reference collections, computational statistics and morphometric theory. They have also remained relatively obscure, so zooarchaeologists have afforded little attention to the methods used in these publications, though their findings and arguments are still occasionally cited (e.g. Turk 1964; Charles et al. 1994).

Hinton (1909) appears to be the most important source for hares in Britain, but his approaches are problematic in the light of more recent research, and cannot be practi-

cally applied here regardless. Though he was not regarded by his contemporaries as a taxonomic "splitter", he regularly assigned trinomials to his identifications (Savage R. J. G. 1963: p. 160-61). He identified Late Pleistocene hares from Ightham Cave as *Lepus timidus anglicus*, separating them from both the extant mountain hare subspecies in Britain, *Lepus timidus scoticus* (Hilzheimer 1906), and the Irish Hare (*Lepus timidus hibernicus* Bell 1837). That zooarchaeologists seldom identify any animal bone to subspecies and that hares have since proven difficult to classify (Chapman et al. 2008: p. 2; Suchentrunk et al. 2008), with major changes having occurred since Hinton was writing, is cause for a cautious reading of Hinton's conclusions for hares' separability.

But Hinton does provide a benchmark for the scale of variance among a variety of hare taxa, although ultimately his sample is too small to demonstrate clear morphometric distinction between mountain and brown hares. Indeed, it demonstrates overlap between them, but the sample is too small to provide insight to the overlap's extent. Consequently, Hinton provides an indicator that brown and mountain hares *might* be discriminated with linear metrics, but his data cannot be used to answer this thesis' questions. Similarly, Hauser's (1921) metrical approach cannot be employed as it relies mainly on lengths (which are rarely available archaeologically, due to fragmentation) and on ratios between measurements on different skeletal elements, which could only be applied to ABGs - where it is safe to assume different bones come from the same individual.

Regarding morphological characteristics, Hinton and his contemporaries (e.g. Hilzheimer 1908) placed the greatest attention on the skull and mandible, which are rarely preserved intact archaeologically. Although criteria based on the maxillary incisor and the comparison of the width and height of the zygoma have become part of the zooarchaeological toolkit (most cite Lawrence et al. (1973) p. 189-92, but they are traceable at least as far back as Hilzheimer (1908), see Figure 3.1), they can rarely be employed in practice in an archaeological context (e.g. Maltby 1985: p. 103). Furthermore, a pilot review of these two criteria I conducted with Fay Worley using modern specimens in the Historic England Zooarchaeology Reference Collection[1],

[1]We examined hare skulls of both species in the HE reference collection. I recorded a separate identification of each skull for both criteria and compared the results with each specimen's known species. Though admittedly the maxillary incisor criterion would have been easier to use with better backlighting or even x-ray, the presence of some contradictory (between the two criteria) or inconclusive (could not determine species from a criterion) results indicated there may be problems with using these osteological traits as diagnostic features. Fay was able to confirm using the specimen prep notes (including pre-skinning

found that they may not be as accurate as has been assumed, though that result could arise from hybridisation between the brown and mountain hare (Thulin 2003). Hilzheimer (1908: p. 406-7) also found problems with separating hares based on the zygomatic arch, but Hinton (1909: p. 227) disputed this, arguing that Hilzheimer's observation stemmed from having confused skulls of brown and mountain hare.

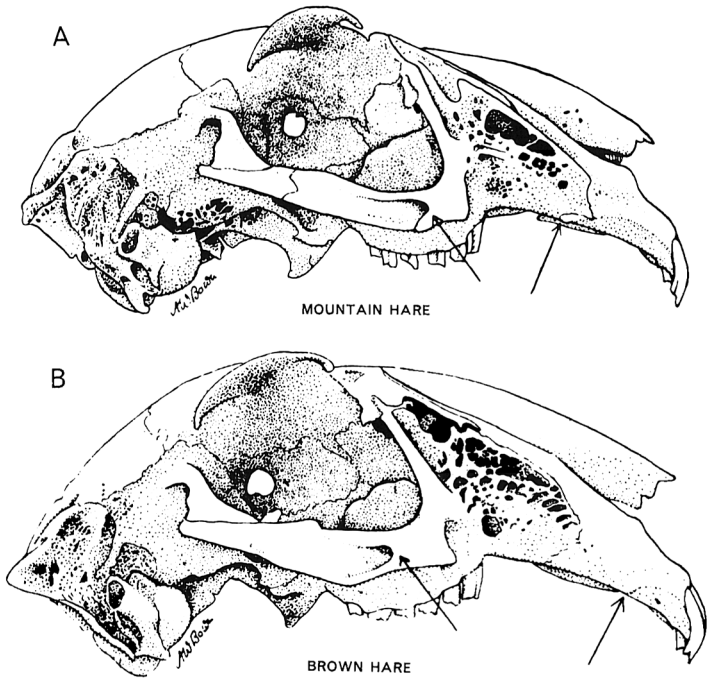

Figure 3.1: Diagnostic criteria for hare skulls. In mountain hares, the root of the maxillary incisor extends past the suture between the premaxilla and the maxilla and the anterior-posterior distance from the end of the groove in the zygoma to its anterior border is shorter than the zygoma's height between these points. In brown hares, the incisor root does not meet the suture and the anterior-posterior distance is longer than the zygoma's height. After Lawrence et al. (1973).

In the later twentieth century, Callou (1997) made the most significant contribution to lagomorph identification in archaeology. Her osteological criteria for separating hares from rabbits were also expanded to separate brown hares from Iberian hares (*Lepus granatensis*, Rosenhauer 1856) by Llorente Rodríguez (2010) using a combination of osteological criteria and traditional morphometrics. Additionally, metric approaches are now being applied to the identification of domestication in rabbits (Watson 2019a,b; Watson et al. 2019a,b) and geometric morphometric approaches to the evolutionary

descriptions) that the hares had not been misidentified or mislabelled.

and biogeographical history of European and Japanese leporids (Pelletier et al. 2015; Sawaura et al. 2018). Whilst some zooarchaeologists separate brown and mountain hare on the basis of size (e.g. Maltby 1993a: p. 330; Bourdillon 2009: p. 79), no study comparing the discriminatory power of different measurements and skeletal elements has yet been published.

It was decided for this study that the most efficient and objectively verifiable approach for creating a new methodology was to focus on morphometrics. Working with metrical data makes it easy to take repeats and test the results statistically in the first instance, and for future researchers to revisit the research in the second - as long as the data and skeletal material used remain accessible. Osteological criteria, meanwhile, can be more subjective and require intimate knowledge of musculoskeletal biology and locomotion to develop and critique.

Having selected morphometrics, a choice between traditional and geometric morphometric data had to be made. Geometric morphometrics is more powerful, and perhaps therefore more likely to produce a clear discrimination between the two species. Data collection, however, is time consuming and analysis is computationally intensive, though efforts have been made recently to speed up photogrammetry for 3D approaches using automation (Evin et al. 2016). Geometric morphometrics (GMM) is also not as easily transferable between researchers as linear measurements are. It requires specialist training to collect and analyse the data, which would render the models effectively useless to anyone working on strictly time-limited projects or with small budgets - for instance, in the public or commercial sector. It was felt important that any new method should be of use to the wider zooarchaeological community, not just academic researchers. Having considered all these issues, linear metrics were selected. The next section will describe how they were used.

3.2 Methodology

To create a method for separating brown and mountain hares using osteometrics some fundamentals needed to be established before data collection could begin. Firstly, a recording protocol, then data sources to target, infrastructure for storing and accessing the data, and finally an analysis design.

3.2.1 Osteometrics Recording Protocol

To ensure the usability of the gathered data for future researchers, the measurement standards established by von den Driesch (1976) were used as an initial baseline. Though Watson (2019a: p. 13) criticise these standards for consequent stagnation of new developments in traditional metrics through too great a focus on orientation, the benefit of a common vocabulary across the discipline for describing osteological measurements is uncontroversial. These standards are among the very few that are nearly universal in zooarchaeology (Orton 2014). Moreover, the practice of extending von den Driesch (1976: hereafter abbreviated to *vdD*) to suit new research questions whilst maintaining her vocabulary for describing and assigning coded abbreviations to measurements is well-established (e.g. Davis 1996; Popkin et al. 2012; Cantryll-Stewart 2018; Salvagno et al. 2017). By following this tradition, this thesis maximises the accessibility of its methods.

Having selected the basic suite of metrics, the protocol was narrowed down to elements likely to be recovered in archaeological contexts. Though nineteen measurements are available in *vdD* for the skull, for example, it cannot be expected to survive due to its fragility, and was discounted. The same decision was made for vertebrae, as these are difficult elements to identify, even to family or genus. The smallest carpal and tarsal bones were also ignored, on the grounds that their small size precludes recovery in hand-recovered contexts.

Other bones needed to be critically assessed in a similar manner, but it was more strategic to identify individual measurements that could be dropped on the grounds of poor intra- or inter-observer error, rather than dismissing entire elements. The mandible, scapula, humerus, radius, ulna, metacarpals, pelvis, femur, tibia, calcaneum, astragalus, and the metapodia (Figure 3.2) were consequently selected for further consideration. A measurement error study was selected as an ideal way to determine whether any of these could or should be dropped in favour of investing more time on the remaining elements/metrics.

Most inter-observer error studies in zooarchaeological osteometrics have shown error rates to fall within acceptable bounds (e.g. Popkin et al. 2012), though admittedly few are ever published in detail (Breslawski et al. 2015; Lyman et al. 2009). Lagomorphs are much smaller than the animals given most attention in zooarchaeology, however,

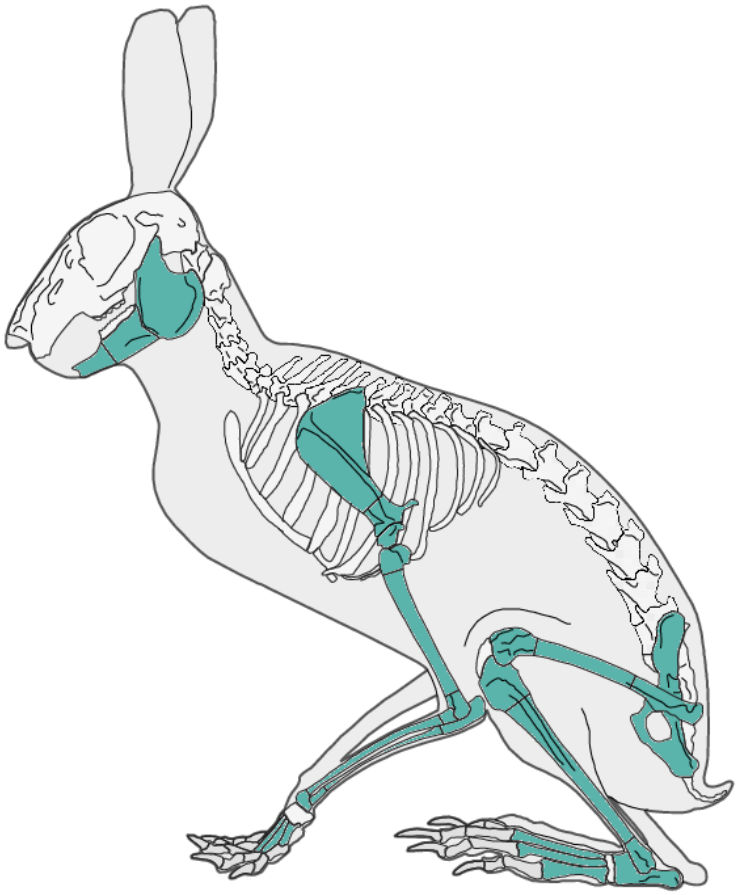

Figure 3.2: Hare skeleton, elements studied for morphometric speciation shown in green. Base image adapted from https://www.archeozoo.org/archeozootheque/picture/2900-lepus_sp/category/149-lagomorphes_langen_lagomorphs_lang_langes_lagomorfos_lang_ by Michel Coutureau.

so the effect of size on error posed an important question: do lagomorphs show high rates of error because their size means that a small difference between observers is proportionally a larger error than would the case for larger taxa? For instance, if error is calculated following Equation (3.1), where for each metric every observation is compared against a standard control value (in lieu of the unknowable true value), percentage error is much larger for measurements that are inherently small - such as breadth and depths, compared to lengths. The mock data in Figure 3.3 show how for a measurement with a control value of 4.5mm, a raw measurement difference of 0.2mm is an error of less than five percent, but 0.9mm equals approximately twenty percent. By contrast, a control measurement of 70mm produces negligible difference in percentage error for values from 0.1mm to 1.0mm away from the control. The data also show that percentage error approximately halves as the control measurement doubles.

$$\% \, Error = \frac{(Observed - Control)}{Control} \times 100 \tag{3.1}$$

Larger measurements are, however, more variable - the larger the mean the greater the variance (VanPool et al. 2011: p. 54-5; Sokal et al. 2012: p. 426-8). Therefore, a second hypothesis might be that, regardless of percentage error, innately small measurements (breadths and depths) are less likely to produce large differences between observers (for example, > 0.3mm might be less likely). Large measurements (lengths) might differ from these by deviating from the control value more often, or by deviating from it by a greater extent (e.g. > 0.5mm).

Modern specimens of hares and domestic rabbits from the University of Nottingham School of Life Sciences were borrowed for the experiment, in which volunteer undergraduate Advantage Award students from the same school measured *vdD* metrics from a selection of the chosen elements. Not being trained zooarchaeologists, the students could not be expected to produce accurate data. Lack of experience, however, meant that where the students did produce results within tolerable levels for inter-observer error, the measurement could be included in the protocol with confidence in its reproducibility, as it can be expected that experienced professionals would produce much less inter-observer variance than untrained students. The students' data can be read as a 'worst case scenario' for inter-observer error. Their data were compared

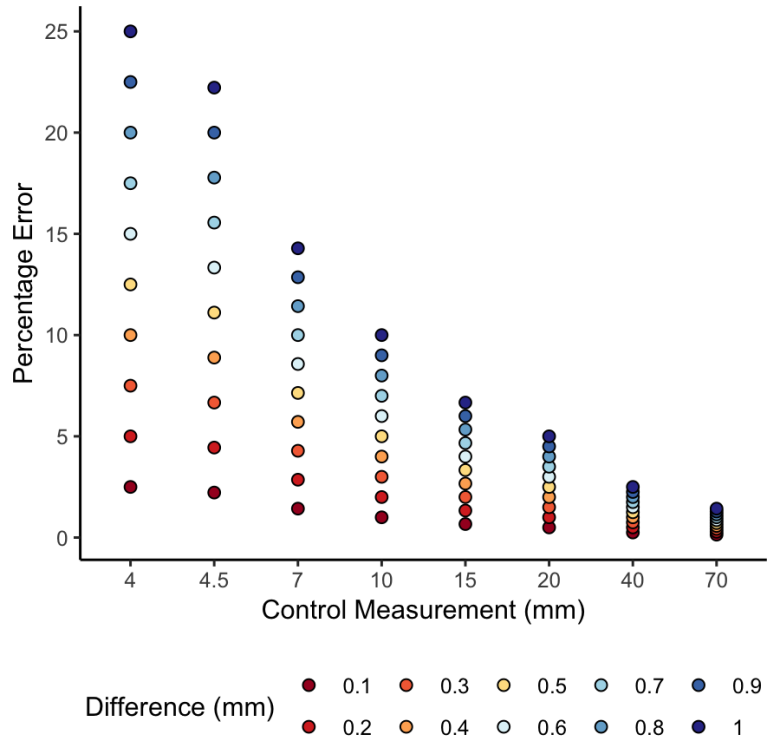

Figure 3.3: Mock percentage errors for eight control values, using observation values ranging from +0.1mm to +1.0mm in difference from the control.

with a standard "control" value for each metric taken on each specimen; these were averages of three repeats taken by the author. An intra-observer dataset, based on twenty repeats per metric taken by the author, was also generated.

Very few measurements were shown to be unreliable and most were adopted for the protocol (a more detailed analysis of these results is included as a RMarkdown document in the digital appendices - see Appendix A.5.1). Nevertheless, the length of the acetabulum (LAR) on the pelvis was rejected, as was the length of the glenoid (LG) on the scapula. A well-preserved distal scapula could typically provide two to three measurements (BG, GLP, SLC); most would provide at least one. The acetabulum, meanwhile, though often the most commonly recovered part of the pelvis in most taxa, is of limited use if other measurable parts are not also found. The ilium shaft, by comparison, provides two measurements alone (SB, SH). No part of the pelvis was expected to be recovered in great numbers archaeologically, given the element's overall fragility in lagomorphs.

With the measurements protocol established, initial data collection commenced. Archaeological sampling (Chapter 4) was conducted in parallel, however, and it became clear that the planned protocol would not produce sufficient sample sizes in the archaeological material. For some elements, such as the tibia, certain epiphyseal ends only have one metric defined in von den Driesch (1976), but it was these portions which were being found in greatest abundance in some assemblages. New measurements were needed in order to ensure at least bivariate, if not multivariate, analyses could be run on as many archaeological samples as possible.

3.2.1.1 Defining new measurements

Creating new metrical standards is not a straightforward task. There can be a temptation to simply add measurements by arbitrarily drawing lines between different portions of a bone. Instead, metrics should be tied to the skeletal and muscular anatomy of the animal under study, and thereby to their locomotion. Even simply using metrics *vdD* defines for the same skeletal element in other species, though a compellingly simple strategy, would therefore be inadvisable without at least consulting anatomical studies or exploring other options first.

Candidates for new metrics were identified by reviewing anatomical and biological

studies that used traditional morphometrics. The volume of literature on lagomorph morphometrics was initially encouraging, but in practice few indices used in these disciplines can be applied here, once fragmentation in archaeological material is considered. It raises the complication, discussed by Richard Meadow in his forward to von den Driesch (1976: p. vii), that identification often requires different measurements to those of studying population change through time. Measurements used by archaeologists for the latter, however, are perhaps more likely to occur archaeologically than measurements used by systematists to distinguish between taxa. Lagomorphs have been the subject of numerous biometrical studies outside of zooarchaeology, but only a handful are based on the skeletal system and fewer still deal with post-cranial bones (Carrier 1983; Reese et al. 2013). Abundant craniometric studies, though shown to be effective for species, sex, age and population discrimination (e.g. Gürbüz et al. 2015; Kraatz et al. 2015; Pintur et al. 2014), are of little use due to the fragility of the cranium.

For the post-cranial skeleton, a handful of measurements were found in the literature. Carrier (1983) defines twenty "lengths" - some of which also appear in Young et al. (2014) - and four diameters. The diameters can be immediately be discarded in favour of von den Driesch's (1976) *shortest breadth of the diaphysis* (SD), the shortest value being much easier to identify than the true middle point of the shaft. Of Carrier's lengths, three are calculated from the others, three are for vertebrae, one is for the pisiform and another for the cranium - all of these can therefore be ignored. Of the remaining measurements, most were analogous to von den Driesch's *Greatest Length*, or else are defined using measurement points that were impractical for archaeological studies using callipers. Measurement 18, for instance runs from the proximal epiphysis of the ulna to the "centre of the trochlear notch". The precise meaning of this is unclear, but the accompanying diagram seems to imply using negative space as an anchor point, which would invite analytical error.

Carrier (1983) does provide two measurements for the proximal femur that could be used, but were not necessary given the three that already exist in von den Driesch (1976). One of Carrier's measurements for the calcaneum was adopted, however, and is defined in Table 3.1. The addition of a new measurement for the calcaneum was important because it is a dense skeletal element, and is normally preserved intact (Pelletier 2018: p. 38). As an ankle bone, it is also fundamental to locomotion (see Curran 2012; Pelletier 2018: p. 38-9), so population differences (including species) are likely to be expressed in

its size and shape. Additionally, von den Driesch (1976) defines only two metrics for this element - GB and GL. The GL is straightforward, but the GB (*Greatest Breadth*) is difficult to measure with standard callipers due to the calcaneum's short length relative to that of the callipers' jaws, making it difficult to hold without rotating it whilst measuring. Additional measurements would greatly enhance this bone's usefulness, and having adopted Carrier's measurement (GLT), four more were devised. The greatest breadth (GBT) and depth (GDT) of the tuberosity (measured on the edge of the epiphysis), were inspired by approximately equivalent measurements defined for white-tailed deer by Cantryll-Stewart (2018). The distal calcaneus is the attachment point for the Achilles tendon and thus is intimately connected to locomotion. The epiphysis is not always preserved archaeologically, however, so two further measurements - the shortest breadth (SBT) and depth (SDT) of the shaft between the epiphysis and the articulation with the astragalus - were also added as experimental approximations of the measurements on the epiphysis.

Several measurements for the scapula are defined by Seckel et al. (2008). Most, however, either have direct parallels in *vdD* or concern parts of this particularly fragile skeletal element that would not be recovered in sufficient numbers archaeologically to be worth including. A similar situation is true for Reese et al. (2013) in their study of pikas; additionally, all the metrics here were lengths, whereas breadths and depths are more useful for fragmented bone.

Where there were still bone portions with few or only one metric available, breadth or depth measurements were added (Bp, Dp, Bd, Dd) following the principles established by von den Driesch (1976). For the humerus, the HTC defined by Davis (1996) was also trialled. It should be stressed that this measurement was originally defined for artiodactyls so it is included here to test whether it might be applicable to lagomorphs, though it has already been used for hare versus rabbit distinctions (Davis et al. 2008).

On the proximal tibia, having observed it to be common in two large Roman hare assemblages (Whitehall Farm and Fishbourne Roman Palace), three variations of depth measurement (Figure 3.9) were created to control for the fragility of this bone portion's cortical surface. The Dp is a simple depth measurement, analogous to similar measurements on other bones, taken from the caudal extremity to the cranial extremity of the proximal end. The DPL is similar, but is taken from the lip on the cranial part of

the epiphysis - this was defined to prevent ambiguity about where the Dp should be measured from, and to provide a measurement in situations where part of the anterior crest is missing - which was observed to be common in specimens where the epiphysis has only recently fused to the plate. The LDp is the depth of the lateral condyle, defined to provide a measurement when only part of the proximal end is preserved.

Only the distal femur remained problematic, having only the Bd (distal breadth) defined by *vdD*. A simple distal depth was not possible, as the curvature of the caudal faces of the condyles and the patellar area in distal and anterior view prevents an accurate measurement from being taken. A length from the most distal part of the condyles to their most proximal point was trialled, but it quickly became clear that the curved shape remained a problem, as repeated measurements were too inconsistent. Protocol development ended at this point, as most elements had sufficient metrics defined; additional developments for the astragalus and metapodia were unnecessary as these small elements were considered both unlikely to be recovered in great numbers and to show marked variances. A summary of all the new metrics is given in Table 3.1.

Table 3.1: Supplementary metrics. References marked * indicate the metric used is a modified version of that in the given source, or one adapted from similar measurements.

Element	Metric	Definition	Source
Humerus	Bp	Greatest proximal breadth. Fig. 3.5	*vdD**
Humerus	Dd	Greatest distal depth. Fig. 3.5	*vdD**
Humerus	HTC	Vertical diameter of the trochlea at its central constriction. Fig. 3.5	Davis (1996)
Radius	Dp	Greatest proximal depth. Fig. 3.6	*vdD**
Radius	Dd	Greatest distal depth. Fig. 3.6	*vdD**
Tibia	Dp	Greatest proximal depth. Measured from the caudal side to the most cranial extremity on the front of the crista tibia. Fig. 3.9	This study
Tibia	LDp	Depth of the lateral part of the proximal epiphysis. Fig. 3.9	This study

Table 3.1: *(continued)*

Element	Metric	Definition	Source
Tibia	DPL	Proximal depth measuring from the caudal side to the cranial lip of the proximal epiphysis. Fig. 3.9	This study
Calcaneum	GLT	Greatest length of the tuber. Measured from the anterior notch of the fibular condyle to the distal epiphysis. Fig. 3.10	17, Carrier (1983), Table 1
Calcaneum	SBT	Shortest breadth of the shaft of the tuber. Fig. 3.10	This study
Calcaneum	SDT	Shortest depth of the shaft of the tuber. Fig. 3.10	This study
Calcaneum	GBT	Greatest breadth of the distal epiphysis i.e. the tuberosity. Fig. 3.10	Cantryll-Stewart (2018)
Calcaneum	GDT	Greatest depth of the distal epiphysis i.e. the tuberosity. Fig. 3.10	Cantryll-Stewart (2018)

Table 3.2: Metrics protocol: summary by element.

Element	Metrics Used	Total No. of Metrics	Figure
Mandible	m1, m2, m3, m4, m5, m5a	6	3.4
Scapula	BG, GLP, SLC, HS, DHA	5	3.4
Humerus	Bp, Dp, GL, GLC, SD, Bd, Dd, HTC	8	3.5
Radius	Bp, Dp, SD, GL, Bd, Dd	6	3.6
Ulna	BPC, DPA, SDO, GL	4	3.6
Pelvis	SB, SH, GL, LFo	4	3.7
Femur	Bp, BTr, DC, GL, GLC, SD, Bd	7	3.8
Tibia	Bp, Dp, DPL, LDp, GL, SD, Bd, Dd	8	3.9
Astragalus	GL	1	3.11
Calcaneum	GB, GL, GLT, SBT, SDT, GBT, GDT	7	3.10
Metapodia	GL, Bd	2	3.11

3.2.1.2 Protocol Summary

The final osteometric protocol consisted of a total of fifty-eight measurements across eleven skeletal elements (counting the metapodia as a single group; MC2-4 and MT2-5 were all measured). A summary of the protocol is shown in Table 3.2, and diagrams for each metric in Figures 3.4 - 3.11. Detailed instructions are included as a manual in the digital appendix (Appendix A.5).

Measurements were recorded with digital callipers. Carbon fibre composite callipers were used, rather than steel. Though they are less hard-wearing, they do not rust and the jaws are less likely to damage fragile bone. Every measurement recorded was the mean of three repeats.

3.2.2 Building the Morphometric Models

The next stage was to build a dataset of measurements taken from modern specimens of known species, ideally with specimen metadata - such as origin, age and sex - also available. It was important to balance obtaining a large sample of hares from British populations with capturing some of the broader variation in brown and mountain hares globally, but especially in Europe. This meant visiting zooarchaeological reference collections and natural history collections both in the UK and abroad. Data for European rabbits (*Oryctolagus cuniculus*, Linnaeus 1758) were also collected so that the models produced could also be used to confirm that archaeological specimens were

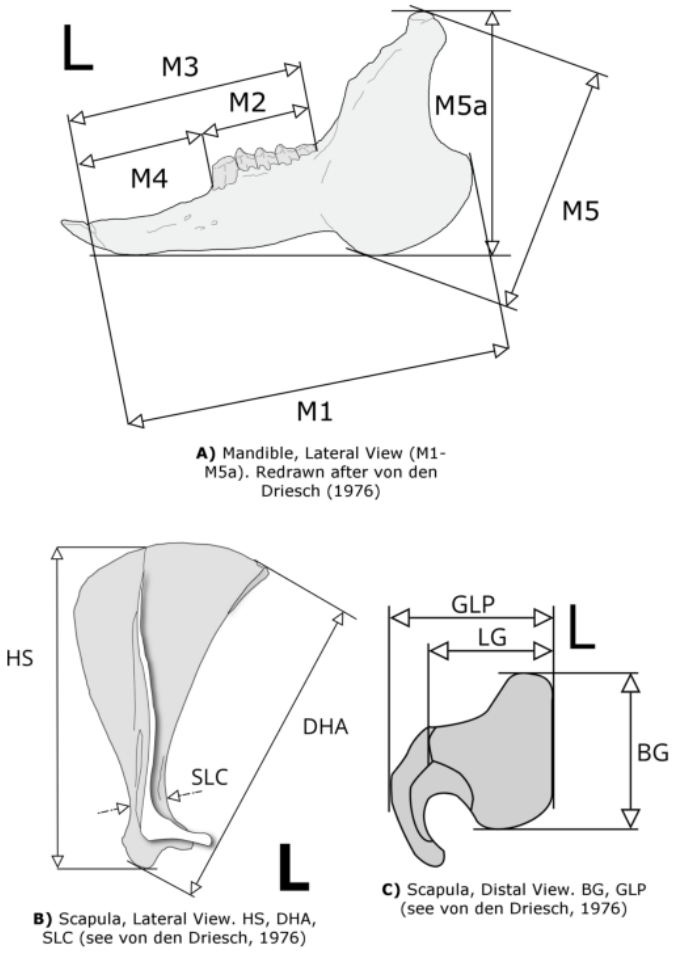

Figure 3.4: Mandible and scapula metrics. 'L' and 'R' indicate the side of the skeleton the element depicted is from.

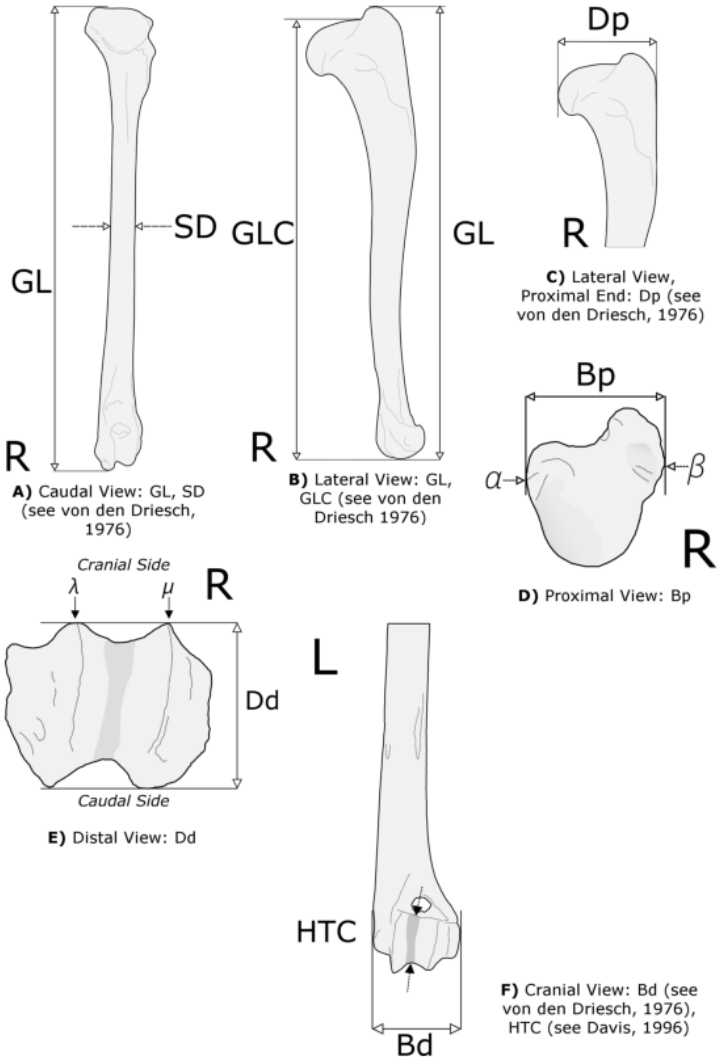

Figure 3.5: Humerus metrics. 'L' and 'R' indicate the side of the skeleton the element depicted is from.

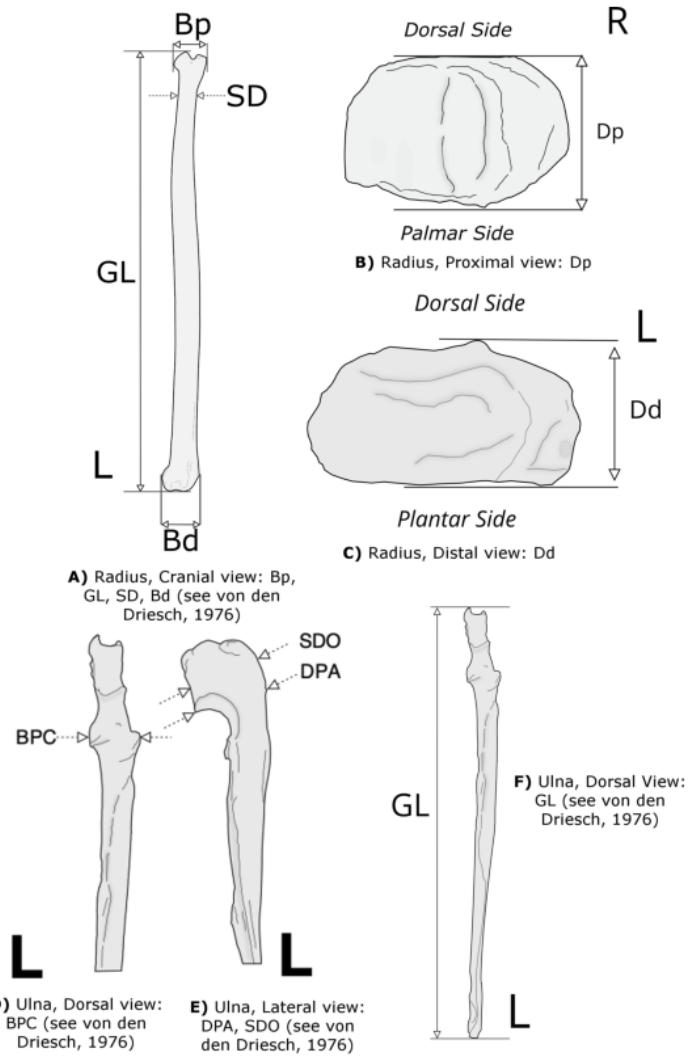

Figure 3.6: Radius and ulna metrics. 'L' and 'R' indicate the side of the skeleton the element depicted is from.

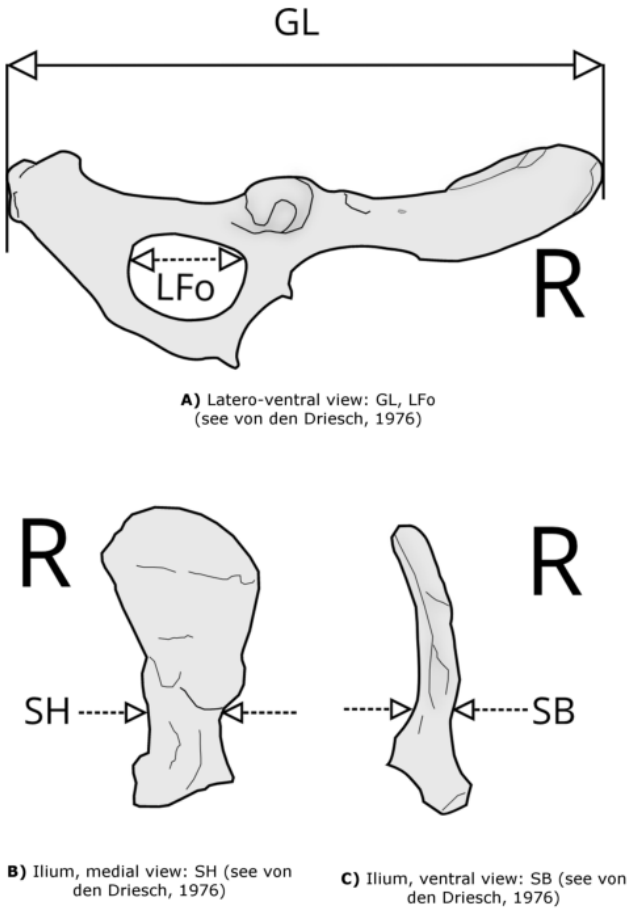

Figure 3.7: Pelvis metrics. 'L' and 'R' indicate the side of the skeleton the element depicted is from.

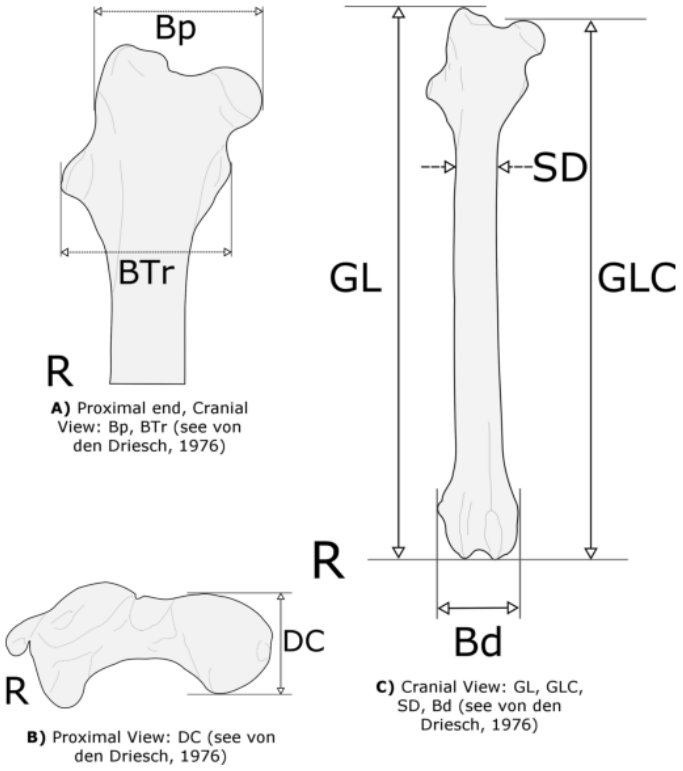

Figure 3.8: Femur metrics. 'L' and 'R' indicate the side of the skeleton the element depicted is from.

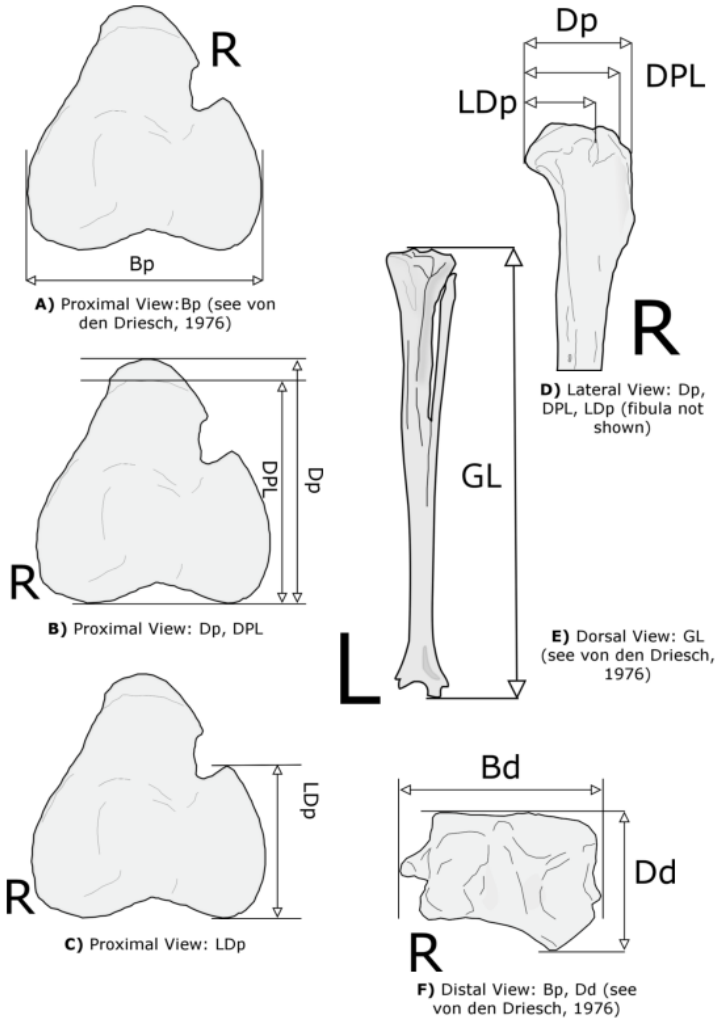

Figure 3.9: Tibia metrics. 'L' and 'R' indicate the side of the skeleton the element depicted is from.

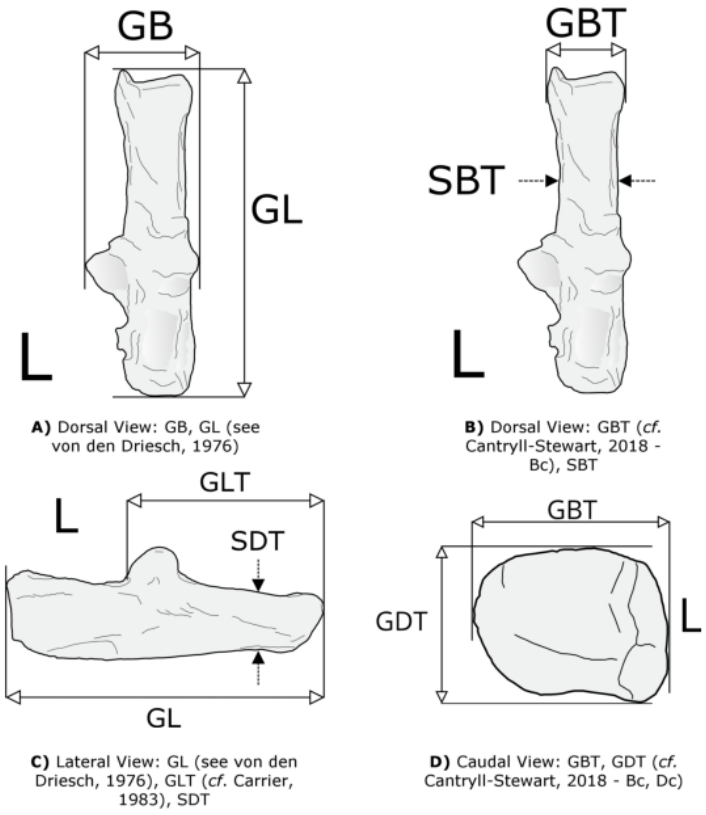

Figure 3.10: Calcaneum metrics. 'L' and 'R' indicate the side of the skeleton the element depicted is from.

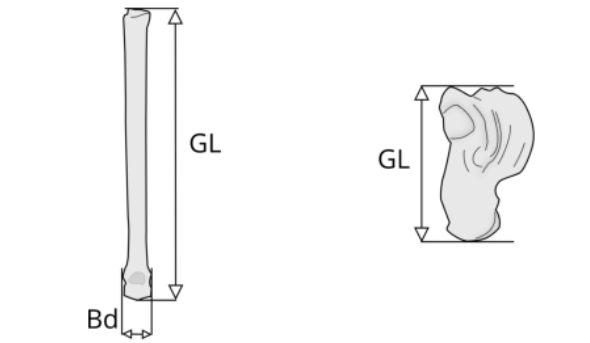

Figure 3.11: Metapodia and astragalus metrics. 'L' and 'R' indicate the side of the skeleton the element depicted is from.

not misidentified rabbits. Irish Hares were recorded where they were available and time permitted. This was to provide context for potential morphometric overlaps within the British hares, as Irish Hares are often considered to have more robust bones than Scottish mountain hares (Hinton 1909: p. 252, 255), which makes them similar to brown hares and fits with their overall size, ecological and behavioural similarity with them (Angerbjörn et al. 1995; Reid 2011). Sample size for Irish Hares was ultimately too small to include in the analyses in this thesis but they provided useful context for reviewing data collection as it proceeded, and may prompt future research.

3.2.2.1 Collections

The National Zooarchaeological Reference Resource (Fairnell et al. 2017) was a valuable tool for identifying UK collections with large numbers of lagomorphs, the most critical of which was Historic England's, at Fort Cumberland, Portsmouth. Over several research trips, this collection provided the vast majority of the brown hare specimens in the dataset, and almost all of the Scottish mountain hares. Other collections identified through the NZRR were the University of Leicester and the private collection owned by Sheila Hamilton-Dyer. For each specimen, all relevant metadata were recorded - sex, age, origin etc - and where both sides (left and right) of each element were present, both were recorded and are averaged in the analyses.

Table 3.3: Collection metadata and number of specimens recorded in total by collection.

Code	Name	Total Specimens Recorded	Country	Acknowledgements
HE	Historic England Zooarchaeology Collection	55	UK	Fay Worley; Polydora Baker
NHM	Natural History Museum, London	30	UK	Roberto Portela Miguez
UoNLS	University of Nottingham Life Sciences Collection	21	UK	Tom Hartman
SHD	SHD-ARCHZOO Reference Collection	20	UK	Sheila Hamilton-Dyer
MNHN	Muséum national d'histoire naturelle: Mammifères (ZM)	16	France	Cécile Callou
SHEUC	University of Sheffield Animal Bone Reference Collection	13	UK	Jess Harrison
LBL	University of Leicester Bone Laboratory	8	UK	Richard Thomas
UoNZRC	University of Nottingham Zooarchaeological Reference Collection	3	UK	–
NJS	Naomi Sykes	1	UK	Naomi Sykes

Natural history collections at the London Natural History Museum (NHM) and the Muséum national d'Histoire naturelle, Paris (MNHN) were also used. The NHM collection is primarily made up of specimens collected in the late nineteenth to mid twentieth century, and reflects scholarship agendas of the time, and of systematics rather than archaeology. Consequently, many of the specimens were still held in articulation by residual soft tissue, and could not be measured. This research trip happened intensively over a period of four days late in the data collection phase, so a more selective approach to recording was adopted for this collection than for others. Fully disarticulated skeletons were prioritised over partially disarticulated ones, and both sides for each element were only recorded for specimens with good metadata or taxa that were represented in lower numbers in the dataset at the time. The primary objective here was to record as many different individuals as possible in a short period of time, in order to ensure the dataset captured a good sample of the diversity available in real-world populations.

The lagomorph collection at the MNHN also strongly reflects its research history. It is dominated by rabbits from Cécile Callou's research (Callou 1997, 2003) and by semi-articulated hares and rabbits from earlier natural history scholarship. As a natural history collection, rather than a zooarchaeological resource, many of the specimens available were represented by the skull only. But, this collection was valuable for its specimens from more diverse origins, providing small numbers from New Zealand, Switzerland and Argentina, as well as a larger sample from France. The New Zealand and Argentinian specimens are from introduced populations so are not good parallels for ancient British hares, but having small numbers of individuals from a diverse geographic area beyond the UK provides some indication of total population diversity and plasticity (i.e. adaptation to new environments).

Further data from both brown and mountain hares were provided from the University of Sheffield zooarchaeological reference collection by Jessica Harrison, to whom I provided an early copy of my dataset whilst data collection was still in progress, to support her MSc thesis on a specimen from a Neolithic assemblage (Harisson 2017).

Table 3.4: Number of modern reference specimens and associated number of bones used in morphometric models.

Species	Specimens (n)	Bones Measured (n)
Brown Hare	61	1250
Mountain Hare	39	1012
Rabbit	23	215

Table 3.5: Specimens used in morphometric models by country of origin

Country	Brown Hare	Mountain Hare	Rabbit
United Kingdom	42	31	14
France	6	2	–
New Zealand	2	–	–
Argentina	1	–	–
Sweden	–	1	–
United States	1	–	–
Unknown	9	5	9

3.2.2.2 Specimens Summary

One hundred and sixty-seven lagomorph specimens (i.e. individual animals) were recorded in total, of which one hundred and twenty-three were used to build morphometric models (Table 3.4). The majority of these were derived from British populations (Table 3.5, Figure 3.12), with some mountain hares from Alpine regions of France - Haute-Alpes and Alpes-de-Haute-Provence - and brown hares from the north and north-east, and Occitanie in the south-west (Figure 3.13).

Of the British specimens, mountain hares were primarily from the area around Galashiels, along with some from the Peak District and Orkney (Figure 3.12); the species is introduced to these areas (Hewson 1956). Some brown hares were also from the Scottish Borders region. As both hare species from the area are present in the dataset, any specimens from the Historic England collection that could have been misidentified were checked against their preparation notes by Dr Fay Worley to ensure that the identification criteria used had been recorded. In each case, the notes confirmed that a sound identification had been made before skeletonization. This does not rule out, however, the possibility of hybrids (Thulin 2003).

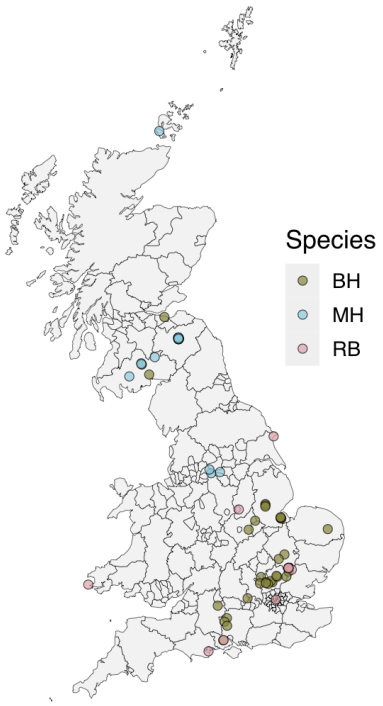

Figure 3.12: Sources for British hares and rabbits with location metadata below county-level. Note the abbreviated species labels described in Chapter 1 (page 37) are used here and in all following figures and table.

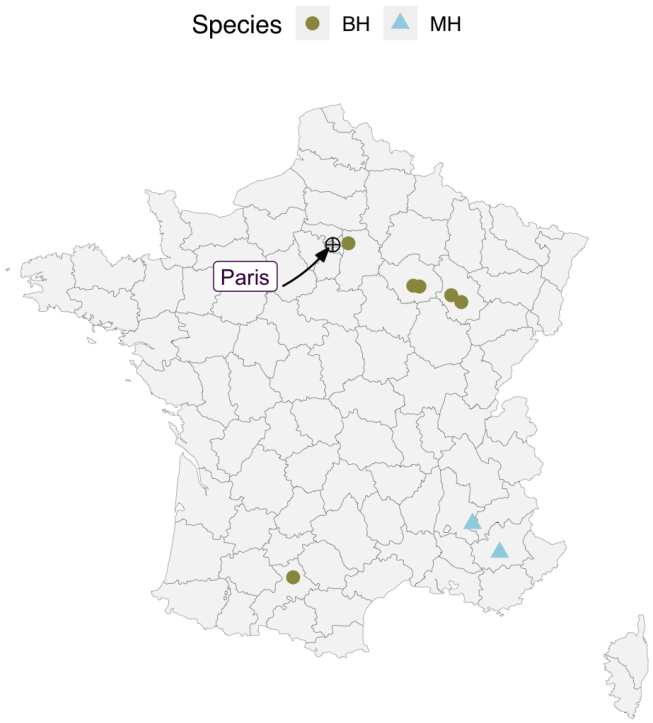

Figure 3.13: Source locations for French hares recorded from the MNHN collection

Table 3.6: Number of modern reference bones used in morphometric models by skeletal element.

Element	Brown Hare	Mountain Hare	Rabbit
MAND	94	60	19
SCAP	108	70	18
HUM	108	70	17
RAD	76	66	17
ULN	98	64	17
MC2	44	44	4
MC3	44	46	4
MC4	46	42	4
PEL	76	70	15
FEM	114	74	16
TIB	114	72	15
CALC	78	68	14
AST	60	66	15
MT2	48	50	10
MT3	46	50	10
MT4	48	50	10
MT5	48	50	10
Total	**1250**	**1012**	**215**

The majority of brown hare specimens came from Lincolnshire and Hertfordshire (Figure 3.14), though other counties in the East Midlands and south of England are also represented. Among the rabbits, several regional populations may be present, with small numbers each from the West Country, London, and the Midlands. Slightly larger groups come from Essex, Cambridge, and South Yorkshire. The only Welsh specimen in the dataset was a rabbit from the island of Skomer (Figure 3.12).

Brown hares dominate the dataset (Table 3.4), however, sample sizes are almost balanced for approximately half the skeletal elements in hares (see page 178, below, for

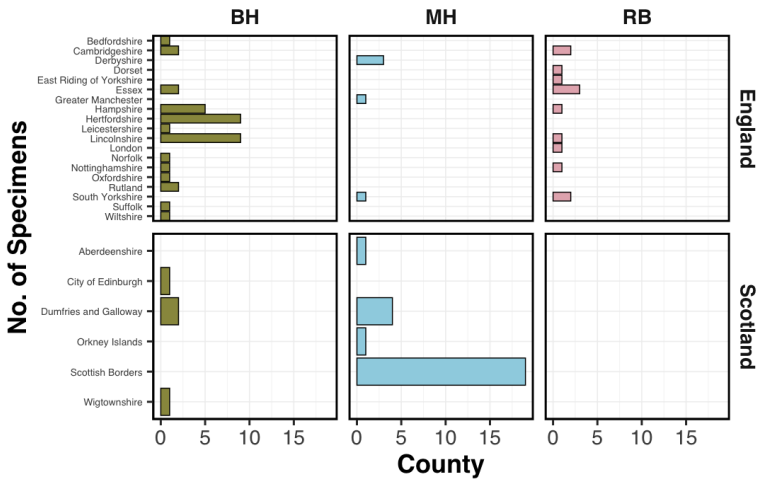

Figure 3.14: Sources for British hares and rabbits with county-level location metadata.

the importance of balancing).

3.2.2.3 Data Storage

All osteometric data were stored in a purpose-built relational database, which also holds the metrics and wider animal bone and context/site information for the archaeological component of this study. The database was built in PostgreSQL for a localhost server on my own computer, but it was later converted to MySQL by Richard Allen (PalaeoBARN, University of Oxford) so that it could be held on an online server for *Exploring the Easter E.g.* project colleagues to access and record data using the same methods that had already been established for this thesis.

3.2.3 Analysis Approach

3.2.3.1 Metrics Combinations

The first consideration for an analysis design was how the data would be used to construct an identification methodology and its associated models. Having collected multiple metrics for each skeletal element, getting the best possible discrimination between species had to be balanced with maintaining relevance to archaeological material. Univariate analysis (assessing one metric at a time) would make the most use of archaeological assemblages, but was unlikely to provide enough discriminatory power.

Conversely, multivariate analysis of a combination of three or more measurements could be much more powerful, but archaeological hare bones are seldom complete enough to provide that many measurements.

A tripartite approach was chosen in which univariate, bivariate, and trivariate analyses would be independently tested and then compared to determine which models worked best. Univariate tests might distinguish between species, and could be extremely valuable in fragmented assemblages and commercial zooarchaeology contexts, but more importantly the univariate results would provide helpful context for multivariate tests, which are more likely to produce accurate models. Bivariate analyses (combinations of two variables) would be more useful for identification, and fit well with the aim of making an identification method accessible to zooarchaeologists without specialised morphometrics or statistics training. They could simply apply their own samples to a scatter plot to compare them against the model data, and use results from this thesis to infer the appropriate level of confidence in their identification. Trivariate analyses (three variables) would require more computational effort, but may be powerful where bivariates fail or produce uncertain separation between species.

Combinations of metrics to test - bivariate and trivariate - were created for each skeletal element. A choice had to be made between selecting only the combinations likely to occur in archaeological settings, or working out all possible combinations (here used in the technical sense, which is distinct from 'permutations', which allow for different orders - i.e. "Bp, BTr, DC" could not be used if "Bp, DC, BTr" was already in the list because they are different permutations of the same combination). The latter approach was chosen on the grounds that in some rare cases - such as ABGs - unlikely combinations are possible and could add value. For instance, in a broken femur with no midsection preserved, but both epiphyses intact, it is still possible to combine the distal breadth with the proximal breath, as long as one can be confident that the fragments are from the same bone. In most cases this is impossible, but ABGs from sealed contexts would be a situation in which this assumption can be made safely. The final list of combinations came to a total of 411 (summarised in Table 3.7, and itemised in Appendix Table A.4).

Table 3.7: Summary of combinations by element for univariate, bivariate and trivariate analyses. The metapodia have been counted as a single element, 'MP'.

Element	Uni	Bi	Tri	Total
MAND	6	15	20	41
SCAP	5	10	10	25
HUM	8	28	21	57
RAD	6	18	16	40
ULN	4	6	4	14
PEL	4	6	4	14
FEM	7	21	33	61
TIB	8	28	56	92
MP	2	1	–	3
CALC	7	21	35	63
AST	1	–	–	1
Total	**58**	**154**	**199**	**411**

3.2.3.2 Data Cleaning and Subsetting

Having collected the modern data, it needed to be cleaned and subsetted into useful groups for analysis. Species names, for example, were originally recorded exactly as they were found in the collections - including old scientific names in some cases - and needed to be standardised. The two-letter codes established above (page 37) were used for each species: "BH" (brown hare), "MH" (mountain hare), and "RB" (European rabbit).

Next, the metrics needed to be scrubbed of outliers as several of the statistical tests and exploratory tools required can be sensitive to extreme values. Scatter plots of bivariate combinations of metrics were used to identity probable recording errors and remove those values from consideration. Other outliers were identified and removed using Tukey's method (page 62).

The values of each metric from the left and right side of the skeleton were then averaged,

where both were recorded, in order to avoid over-representing a single individual and to mitigate the effects of potential asymmetric recording errors (see Table 3.8 for a list of the total number of measurements per element by species after cleaning and averaging for side). The datasets for each element were then filtered into subsets for testing.

Table 3.8: Total number of measurements per element by species after cleaning and averaging for side.

Element	BH	MH	RB
MAND	241	159	92
SCAP	235	155	75
HUM	312	240	91
RAD	157	177	75
ULN	159	117	61
MC2	44	44	8
MC3	44	46	8
MC4	46	42	8
PEL	130	125	52
FEM	350	225	96
TIB	308	235	80
CALC	155	197	60
MT2	48	50	20
MT3	46	50	20
MT4	48	50	20
MT5	48	50	20
AST	30	33	15

Two subsets were created to address different problems. *Subset A* concerns only the separation of mountain and brown hares, and therefore only includes specimens from those species. *Subset B* replicates Subset A but additionally contains European rabbits. *Subset B* is not intended to provide a model for separating hares from rabbits. That

question is well-covered by previous research (Callou 1997; Davis et al. 2008), and would require recoding BH and MH as a single 'hare' group. Instead, this thesis is concerned with the identification of hares, so the BH and MH groups are maintained and the addition of the RB data is to provide a check on archaeological identifications made by Subset A. Any specimens identified as BH or MH with Subset A that become 'rabbit' with Subset B are discounted. Should any archaeological specimens switch between BH and MH when considered with Subset B, they are flagged as potentially erroneous identifications. But, the original identifications were not overturned when this occurred because Subset A is better suited for separating between the hares, as it contains only those two species.

3.2.3.3 Form, Shape and Size

Variance in raw traditional morphometric variables represents variance in an overarching variable referred to as *form*, defined as the sum of variance derived from size and shape - Equation (3.2). According to the Gould-Mosimann school of morphometrics (discussions in Klingenberg 2016), size and shape can be defined and separated, which allows them to be independently tested. For example, in some taxa only form might be shown to discriminate between groups. In others, it could be only size or only shape (for example Darroch et al. 1985: p. 241).

Shape represents the variance remaining when the effects of location, size, and rotation are removed; or alternatively put, the property of an object that is invariant under location, size and rotation (Claude 2008: p. 1). To derive shape, Equation (3.2) need only be rearranged and a mathematical definition of size provided.

Size variation comes in two forms - isometry and allometry. Isometry refers to a function that scales all the original variables equally; isometric change does not affect the proportions of an object, only its scale. Allometry is the opposite, and refers to size change that also alters the shape. Mosimann (1970) provides a mathematical definition for *isometric* size, namely the mean of all the logarithms of any vector of measurements - see Equation (3.3), see Table 3.9 for an example).

$$Form = Size + Shape \tag{3.2}$$

Table 3.9: Isometric size and log shape ratio examples for two distal tibia specimens, Bd:Dd.

Bd	Dd	logBd	logDd	Size	LSR_{Bd}	LSR_{Dd}
15.3	9.3	2.73	2.23	2.48	0.25	-0.25
15.5	9.9	2.74	2.29	2.52	0.22	-0.22

$$Isometric\ Size = \overline{logX} \tag{3.3}$$

$$LSR = logX_i - Isometric\ Size \tag{3.4}$$

Variables expressing the shape component of each raw measurement can be derived with Mosimann's (1970) log-shape ratio (LSRs). Isometric size is subtracted from the logarithm of the raw value - Equation (3.4), see Table 3.9 for an example. Geometric morphometrics has generally superseded LSRs, but they are still occasionally used in current research (e.g. Mallet et al. 2019; Pöllath et al. 2019). Here, for each combination of metrics, isometric size and LSRs were calculated and used to test size and shape independently, in addition to form. The `lmosi()` function for R, from Michel Baylac's (2011) unpublished *Rmorph* package (Claude 2008: p. 100), was provided by Allowen Evin for this.

3.2.3.4 Multivariate Statistics in Morphometrics

Two of the most useful statistical tools in morphometrics for analysing and separating groups are the multivariate techniques, Principal Component Analysis (PCA), and Linear Discriminant Function Analysis (LDA). Both are used in this study.

3.2.3.4.1 Principal Component Analysis Principal Component Analysis is a multivariate data exploration tool which sequentially identifies axes in multidimensional space that explain the most variance available in a dataset (VanPool et al. 2011: p. 285-304; Dytham 2011: p. 244-250), effectively drawing a regression line and rotating the data around it to create a new axis (VanPool et al. 2011: p. 290-1). Having removed the first axis - "principal component" - it then moves on to find an axis describing the next most variation, orthogonal to the first, and creates a second principal component from

that. It continues to iterate this process until either the program has been instructed to stop finding new components, or until there is no more variation that can be extracted. The principal components can then be analysed in two-, or sometimes three-, dimensional space using scatter plots. The advantage of this approach is that relationships between multiple variables are contained within a smaller number of axes than the original data (dimensionality reduction). For multivariate datasets with large numbers of variables, dimensionality reduction can be very helpful; PCA is therefore frequently used in a morphometrics analysis workflow (Claude 2008: p. 106-11).

For bivariate and trivariate combinations of metrics using the form and shape variables, the data were converted into principal components. As PCA reduces dimensionality, only PC1 should be expected to yield useful information in bivariate combinations, and up to PC1 and PC2 in trivariates. PCA is not necessary for univariate form and for all tests on isometric size as these are datasets with a single metric variable.

In studies of form, the first component (PC1) corresponds to the effect of isometric size (Claude 2008: p. 108-9). This is problematic because this expression of size derives from a strong correlation between PC1 and the largest measurement, which is always the most variable because variance is greater in data with a higher mean (VanPool et al. 2011: p. 54-5; Sokal et al. 2012: p. 426-8; Claude 2008: p. 108). This can be solved by log-scaling the raw metrics, which allows PC1 to collect allometric variation, becoming an allometric growth scale rather than an isometric size scale, and leaving the remaining components to reflect variance excluding growth (Claude 2008: p. 108-9). For all tests performed on form, the raw metrics were scaled to their natural logarithm before running a PCA. LSRs, of course, do not require log-scaling as they are already log-transformed values.

3.2.3.4.2 Linear Discriminant Function Analysis Having applied the transformations, each of form, size and shape can be used in Linear Discriminant Function Analysis (LDA). LDA is a method for predictively assigning specimens of unknown identity to a group using a model dataset of specimens of known identity. It does this by maximising the distance between the means of each group, whilst minimising the group variance around those means (Denis 2016: p. 518). LDA was run for each combination of metrics, testing form, size and shape independently. For form and shape, each principal component that returned a percentage of variance greater than zero

was tested. Every combination of metrics was therefore subject to multiple iterations of LDA.

LDA is sensitive, however, to unbalanced sample sizes within the model. If the reference dataset contained seven brown hares and twenty mountain hares, for example, identifications made using these data might be less reliable than if the dataset contained equal numbers of each group. This problem is a common downfall of studies using LDA, especially in archaeology, where obtaining perfectly balanced sample sizes is seldom possible (Evin et al. 2013).

Evin and colleagues (2013) show that a repeated resampling approach to LDA can mitigate against unbalanced samples, whilst still taking advantage of all of the available data. In their method, all individuals from the group with the smallest sample size are included, whilst an equal number of individuals from other groups are randomly selected. This way, perfectly balanced samples are used in the LDA, maximising the reliability of the results. The process is repeated multiple times so that the entire dataset is represented, and an average result is computed. Evin's R function `pldam()` applies this method for predictive LDA and is used in Chapter 4 to identify archaeological hares. To determine the model's accuracy, the `mevolCVP()` function was used to cross-validate the data.

3.2.3.4.3 Cross-Validation Cross-validation (CV) assesses how well a predictive model works. In the case of the LDA applied in this project, it is necessary to test how often the modern reference data allows LDA to assign archaeological specimens to the correct species. Cross-validation estimates each model's accuracy by using the model to identify specimens of known species (a training dataset).

Most forms of cross-validation have a separate model and training dataset, which requires additional data collection. The alternative approach used here, is leave-one-out cross-validation (LOOCV), where the data within the model itself are used as the training dataset. Each individual is in turn removed from the model and predictively assigned to species using the remaining data (Kovarovic et al. 2011: p. 3009). The prediction is then compared against the known species of that individual. By using a leave-one-out approach, there is no need to collect more data, and circular reasoning biases - that would be introduced by assigning a specimen to species using a dataset

that includes itself - can be avoided (Evin et al. 2013: p. 738; Kovarovic et al. 2011: p. 3009).

In Evin's cross-validation function, `mevolCVP()`, LOOCV for LDA is run once on the full unbalanced dataset, providing the "original" cross-validation percentage (CVP) by tallying the number of correct identifications out of the total number of specimens. It is then re-run on balanced samples for a specified number of repeats (1000 is used here). From the CVP results for these repeats, a mean value is calculated, along with 5% and 95% percentiles. In cases where the samples are strongly unbalanced, the original CVP is likely to be optimistic, whilst the mean balanced CVP is a more rigorous reflection of the model's accuracy.

Additionally, two further tests are run as checks. A random assignment is run for the specified number of repeats. Where the number of groups is equal to two (Subset A - BH and MH), random CVP should not deviate significantly from fifty percent. Where the number of groups is three (Subset B - BH, MH and RB), random assignment should produce a mean CVP of approximately thirty-three percent. Finally, balanced random cross-validation applies random assignment to balanced samples; this is the most conservative approach and so a poorer result in comparison to the random test should occur. Problems in the dataset can be detected where either of these checks produces results differing strongly from their expected values.

Across all the principal components, morphometric variables (form, size, shape), and measurement combinations (univariate, bivariate, trivariate) a total of 3760 different iterations of `mevolCVP()` (1880 each for Subset A and B) were run. For clarity, from here onwards, I use the term "*combination*" to refer to sequences of metrics - such as "Bp, GL, SD" versus "Bd, Dd" - and "*approach*" to refer to the association between combinations and the other parameters that make up an individual test. For example, "Bp, GL, SD - shape - PC1" versus "Bp, GL, SD - shape - PC2" versus "Bp, GL, SD - size" are three different approaches using the same combination of metrics. I occasionally use "model" as an approximate synonym for this definition of "approach" but only to avoid tautology, or confusion with "approach" used in its conventional sense.

3.2.3.4.4 Cross-Validation Assessment To identify which approaches provide the best separation between species, a CVP threshold for the balanced samples results

was needed. Such a threshold would ideally be higher than eighty or ninety percent accuracy, but there was potential for this to be too high an expectation for linear metrics. It would not have been productive to set a high expectation too soon, so focus was placed on the *minimum* requirements for an approach to be considered an acceptable method for separating hares.

Two requirements were set. Firstly, an acceptable approach would have a mean CVP equal to, or higher than, seventy-five percent. This means that, on average, accepted approaches would correctly identify archaeological specimens three quarters of the time or more. Secondly, the lower percentile (5%) had to be equal to or higher than 55% for Subset A and 37% for Subset B. These thresholds were based on the expected result for *random* assignment, proportionally raised by a further ten percent - see Equations (3.5) and (3.6). This was done so that for an approach to be accepted, the majority of the *poorest performing repeats using the balanced method* had to better the expected result for random assignment. The threshold was set proportionally (rather than by addition) to the expected result for random assignment so that the relative distance between the threshold and the expected random assignment value was the same for both subsets. Tests that met these two parameters were classified under "accept", and those that did not under "reject".

$$Lower\ Percentile\ Threshold_A = (0.5 \times 1.10) \times 100 \tag{3.5}$$

$$Lower\ Percentile\ Threshold_B = (0.333 \times 1.10) \times 100 \tag{3.6}$$

The thresholds were secondarily used as a ranking mechanism. The threshold values were subtracted from the results for mean CVP and the lower percentile to create a "score" for both figures, which were then added together. This overall score could then be used to order the approaches from best to worst. The most positive scores would be associated with the best approach for separating species, and the most negative with the worst. The point at which approaches switch from being accepted to being rejected would be at scores close to zero (but not all positive scores equal acceptance). The total score was rounded to the nearest integer, as differences of less than one percent are not particularly meaningful. Each unique score was given a rank, with 1

Table 3.10: First five rows of humerus (Subset A) cross-validation results

Rank	Score	Verdict	Variable	Metrics	PC	5%	Mean	95%
1	66	Prefer	Shape	Dp, GL, Dd	PC1	97.6	98.0	100.0
2	63	Prefer	Shape	Bp, Dp, GLC	PC1	95.2	97.3	97.6
3	62	Prefer	Shape	Bp, Dp, GL	PC1	95.2	96.4	97.6
3	62	Prefer	Size	Bd, Dp	–	95.2	96.6	98.4
4	59	Prefer	Form	Bd, Dp	PC1	93.5	95.6	96.8

representing the best (the approaches with the most positive score). It is therefore possible for multiple approaches to hold the same rank if the difference between their scores is less than one percent. A reference table for each subset of each element was created using this method; as most contain hundreds of rows, they can be found in the appendix (§A.3).

For the most measurable skeletal elements, far more approaches met the thresholds than anticipated. In the subsequent sections, where the results are examined element by element, the first ten *ranks* are extracted as 'preferred' approaches, rather than just 'accepted' ones. This was a useful way of partitioning the accepted results for each element into a group with the very highest scores and another with the remaining ones. Archaeological utility could then be assessed by examining the bone completeness requirements of the combination in each approach. The first five *rows* (not ranks) for the humerus (Subset A) are given here in Table 3.10 as an illustrative example.

Finally, a simple 'veto' mechanism was devised for all the accepted approaches. This was done by comparing the distribution of the balanced CVP results with the unbalanced 'original'. Where the original plotted significantly far outside the range of the 5% to 95% percentiles for balanced results, this was taken as a warning of group sample size effects. A total of ninety-nine approaches were selected for consideration, but none were found to show significant deviation of the original CVP value from the balanced range. All had a difference between the original and the nearest percentile of less than seven percent, which was treated as an acceptable distance. Many approaches considered in this analysis were also ones that were likely to be excluded from real-world archaeological application due to the impact of fragmentation. Consequently, none were vetoed. More detailed discussion of these analyses can be found in the digital appendix (§A.5.1).

3.3 Cross-Validation Results

3.3.1 General Observations

Before conducting element-by-element analysis of the CVP results, it was helpful to examine general trends to confirm that cross-validation accuracy reflects the metrics used in each element and the principal component and morphometric variable tested, rather than other factors, particularly (group) sample size.

Examining CVP against the size of the smallest and largest groups, and also the difference between those values, for each combination showed no clear correlation. Examining Subset A for univariate form, the distribution of mean CVP declines at a smallest group size of around twenty to thirty, but then rises again (Figure 3.15). Similarly, multivariate form declines to less than eighty percent around twenty to twenty-five specimens in the smallest group for PC1. That the curve for isometric size follows a similar trajectory confirms that PC1 for form captures allometric growth. For both form and shape in the multivariate approaches, PC1 tests are mainly distributed above the seventy-five percent mean CVP threshold; for form the curve of the PC2 distribution does not exceed seventy percent, though individual tests do; for shape the curve does not breach sixty percent.

Examining the tests arranged by largest group size produces a very different distribution (Figure 3.16). For form, dips in the curve of mean CVP occur for univariate tests at around thirty to forty samples, with a more pronounced one at about forty-five. PC1, meanwhile reaches its lowest point at thirty-five, but climbs afterwards. PC2 and PC3 follow a similar trend, though the drop is found earlier at less than thirty specimens. In this regard, univariate and multivariate PC1 tests for form clearly mimic isometric size again. PC2 and PC3 meanwhile mimic shape. The pattern for PC2 on form is probably reflected in the distribution of PC1 for shape, where mean CVP is consistently low when the largest group size is high. This is probably influenced by the smaller number of tests with sample sizes greater than forty-five in comparison to those with less than that.

That smallest and largest group sizes produce such different distributions could suggest that the difference between these values influences the CVP result regardless of the balancing procedure applied with `mevolCVP()`. Plotting mean CVP against the

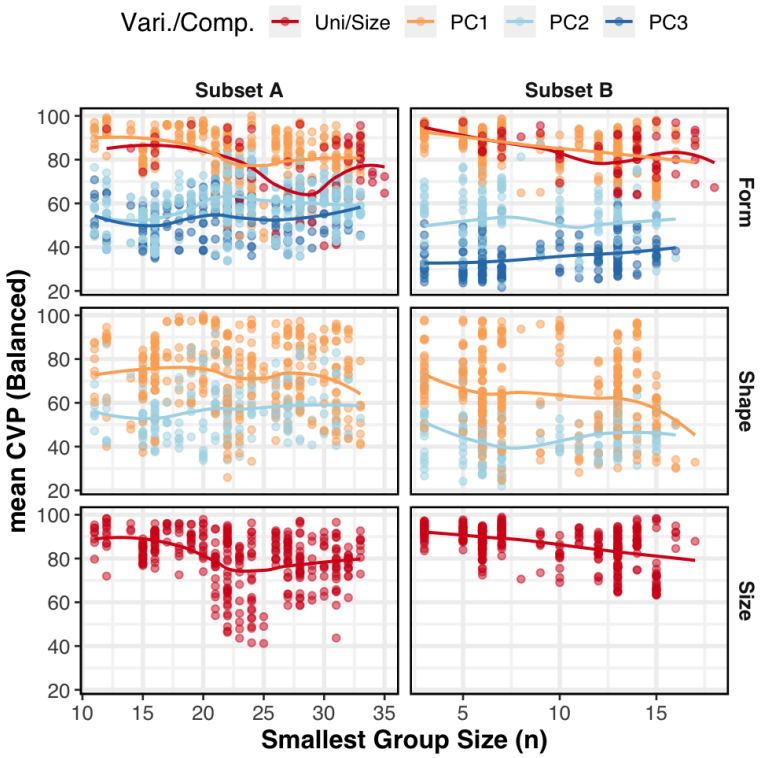

Figure 3.15: Effect of smallest group size on mean (of 1000 repeats) cross-validation percentage (CVP) for balanced linear discriminant function analysis. Each point represents the mean CVP value for one approach (all elements included). Note that univariate form and bi/trivariate size are represented by the same colour (red) because they are applied without principal component analysis, but are in different panels. Lines represent loess regression.

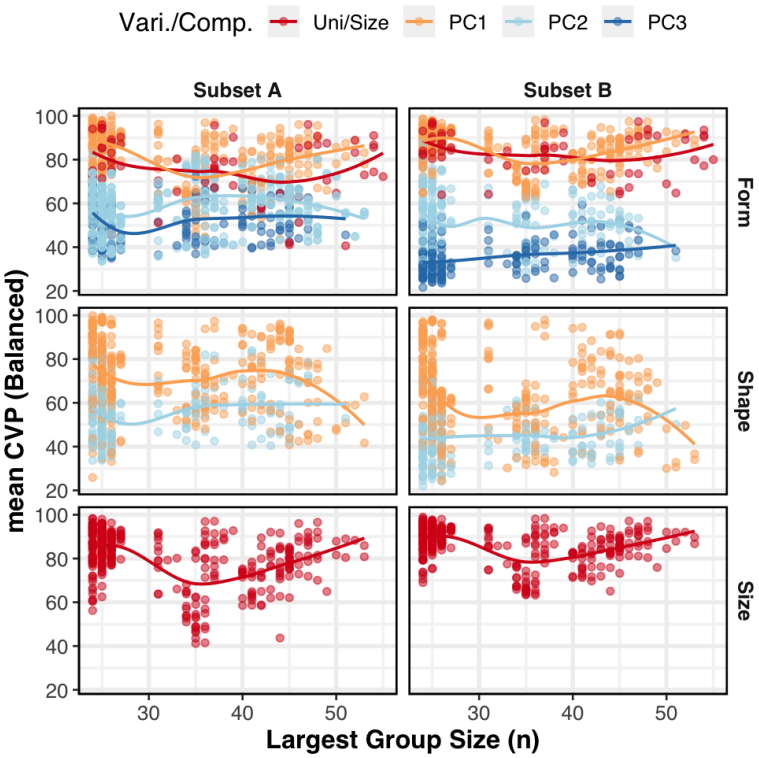

Figure 3.16: Effect of largest group size on mean (of 1000 repeats) cross-validation percentage (CVP) for balanced linear discriminant function analysis. Each point represents the mean CVP value for one approach (all elements included). Note that univariate form and bi/trivariate size are represented by the same colour (red) because they are applied without principal component analysis, but are in different panels. Lines represent loess regression.

difference in smallest and largest group size for each test allays this concern (Figure 3.17). Here it is clearer that CVP oscillates through different sample sizes, and that falls in the CVP distribution at the highest sample sizes are probably associated with smaller numbers of tests. Sample size is probably associated with mean CVP *indirectly*, in that the least measurable elements likely have poorer CVP values and have smaller sample sizes because they are harder to measure. Resampling for balanced sample sizes has likely avoided the biasing effects of unbalanced groups as the relationship between CVP and sample size is non-linear.

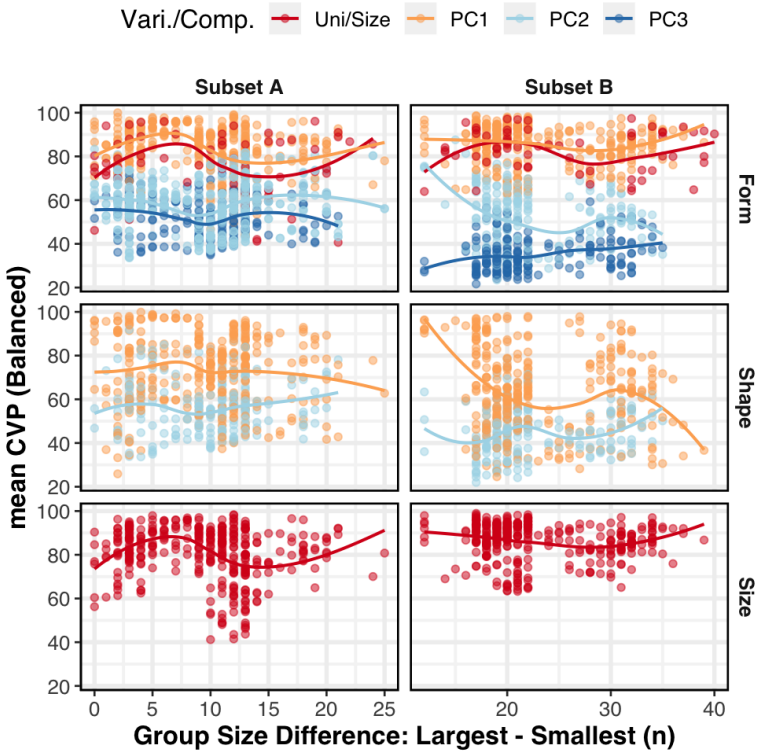

Figure 3.17: Effect of the difference between the size of the smallest and largest groups on mean (of 1000 repeats) cross-validation percentage (CVP) for balanced linear discriminant function analysis. Each point represents the mean CVP value for one approach (all elements included). Note that univariate form and bi/trivariate size are represented by the same colour (red) because they are applied without principal component analysis, but are in different panels. Lines represent loess regression.

Subset B followed very similar patterns, so is not discussed in detail here. One important observation, however, is that distinguishing hares from rabbits is most effective with size and is near impossible with form. Smallest group size also has a near-linear

relationship with CVP for size (Figure 3.15), but it is negative. This suggests that the models may be overly optimistic where the smallest group size is small.

The number of metrics used does not seem to correlate with CVP in all cases (Figure 3.18). Trivariate analyses were consistently better than bivariates for form and shape in PC1, though the margins for this were smaller for form than for shape. In PC2 (form only), bivariates and trivariates performed equally well in Subset A, but bivariates were better by a considerable margin for Subset B. Size produced a similar outcome to PC1 form analyses, with trivariates outperforming bivariates, but only by a narrow margin. The univariate tests (form) performed roughly as well as the PC1 form tests. All these observations are encouraging - they show that even in fragmentary archaeological material, discrimination between hare species is possible as long as one or two measurements can be taken. A third metric may increase confidence in an identification, but is not essential in most cases.

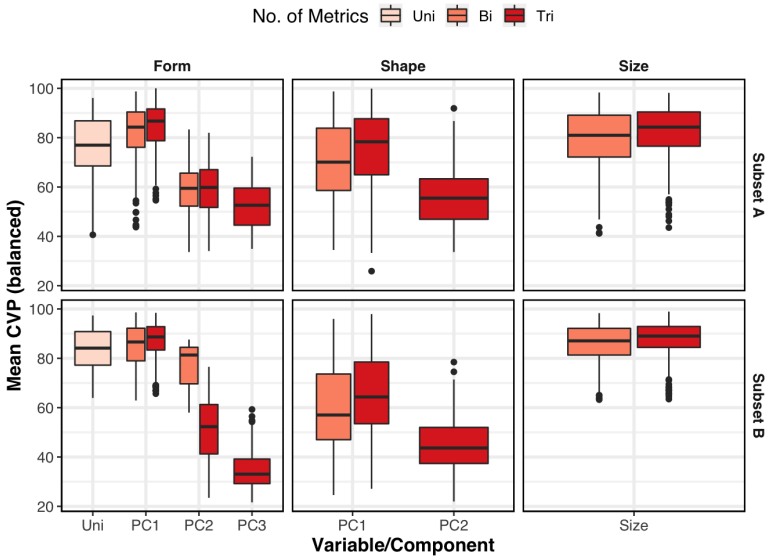

Figure 3.18: Distribution of mean CVP (balanced) for all approaches. Grouped by variable and (for bivariates and trivariates) principal component and the number of metrics in the combination.

3.3.2 Results by element

This section examines CVP results for each element individually. Emphasis is placed on Subset A, as discussed above (page 174). For each element, the overall num-

Table 3.11: Summary of metrics and morphometric variables accepted/rejected through cross-validation for the mandible.

Set	Accept	Reject	Total	Percent Accepted
a	34	152	186	18
b	16	170	186	9

ber of preferred/accepted/reject approaches by subset and morphometric variable (form/size/shape) is considered, along with the distribution of mean balanced CVP within those groups of approaches.

Each discussion pulls out key approaches that either typify the results for the element and subset under discussion, or else are important because they would be useful in archaeological contexts. The majority of these highlighted approaches are illustrated as follows: For bivariates, each figure includes a scatter plot of the log data (form), and box plots giving the distribution of the data tested with `mevolCVP()` (principal components for form and shape, raw values for isometric size). The CVP statistics for each test are shown on the box plots. Where shape is included, the figure also includes a scatter plot of the LSRs. For trivariates, no scatter plots are provided, but box plots of the principal components and isometric size values are still given. These figures are given to illustrate how CVP scores relate to the raw data and their transformations.

3.3.2.1 Mandible

A total of 186 approaches were tested on each subset for the mandible, comprising forty-one unique combinations of metrics. Six were univariate, sixty were bivariate and 120 were trivariate. Ninety-six (including the six univariates) were based on form, fifty-five on shape, and thirty-five on size. A total of thirty-four were accepted (i.e mean CVP was higher than 75%) for Subset A, and sixteen for Subset B (Table 3.11).

The mandible produced some of the lower scoring results of all the elements. For Subset A none of the accepted approaches produced a mean CVP greater than eighty-seven percent; the smallest CVP for the preferred approaches was seventy-eight percent (Figure 3.19). Both form and shape approaches appear in the preferred and other accepted group; all of the size-based approaches were rejected.

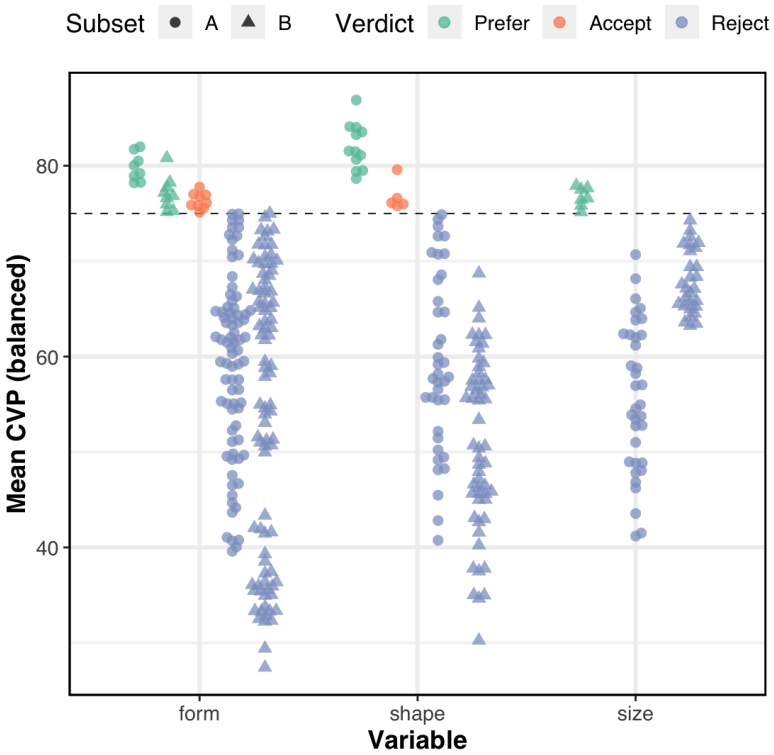

Figure 3.19: Mean CVP (balanced) for mandibles by verdict and morphometric variable for both subsets. Dashed line shows the 75% acceptance threshold.

Table 3.12: First ten ranks of cross-validation results on approaches for separating BH and MH mandibles (Subset A).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	40	Prefer	Shape	m1, m4, m5a	tri	PC1	83.3	86.9	90.5
2	36	Prefer	Shape	m1, m5, m5a	tri	PC1	81.8	84.0	86.4
2	36	Prefer	Shape	m1, m5a	bi	PC1	81.8	84.1	88.6
3	34	Prefer	Shape	m3, m4, m5a	tri	PC1	80.4	83.3	87.0
4	33	Prefer	Shape	m1, m2, m5a	tri	PC1	79.5	83.5	86.4
5	29	Prefer	Form	m1, m2, m5a	tri	PC2	77.3	82.0	86.4
5	29	Prefer	Shape	m1, m3, m5a	tri	PC1	77.3	81.5	86.4
5	29	Prefer	Shape	m2, m3, m5a	tri	PC1	77.1	81.5	87.5
5	29	Prefer	Form	m1, m5a	bi	PC2	77.3	81.7	86.4
6	28	Prefer	Shape	m3, m5a	bi	PC1	77.1	81.1	87.5
7	27	Prefer	Form	m2, m4, m5a	tri	PC2	76.1	80.5	87.0
7	27	Prefer	Shape	m2, m4, m5a	tri	PC1	76.1	80.7	84.8
7	27	Prefer	Shape	m3, m5, m5a	tri	PC1	77.1	79.5	83.3
8	26	Prefer	Form	m2, m5a	bi	PC2	77.1	78.9	81.2
8	26	Prefer	Form	m4, m5a	bi	PC2	76.1	80.0	84.8
9	24	Prefer	Form	m2, m3, m5a	tri	PC2	75.0	79.2	83.3
9	24	Prefer	Shape	m1, m3, m5	tri	PC1	75.0	78.7	84.1
9	24	Prefer	Shape	m1, m5	bi	PC1	75.0	79.4	84.1
10	23	Prefer	Form	m1, m5	bi	PC2	75.0	78.2	84.1
10	23	Prefer	Form	m3, m5a	bi	PC2	75.0	78.2	83.3

A single univariate measurement, *m5a*, met the thresholds for acceptance, though it ranked as joint eighteenth most effective. Notably rank seventeen is the first where approaches started to be rejected, so although m5a passes the established criteria, it should probably not be used for identification. More form than shape approaches were accepted overall and form was more likely to be preferred in bivariate analyses. In trivariate analyses, shape was more likely to be preferred. A total of twenty approaches were preferred (Table 3.12), twelve of which were shape-based. All of the six

measurements available were used in at least one of the preferred measurements. Box plots showing the distribution of PC1 for the top three approaches (ranks 1 and 2) are given in Figures 3.20 and 3.21. The latter also shows the scatter plot of the original log-shape ratios for m1-m5a.

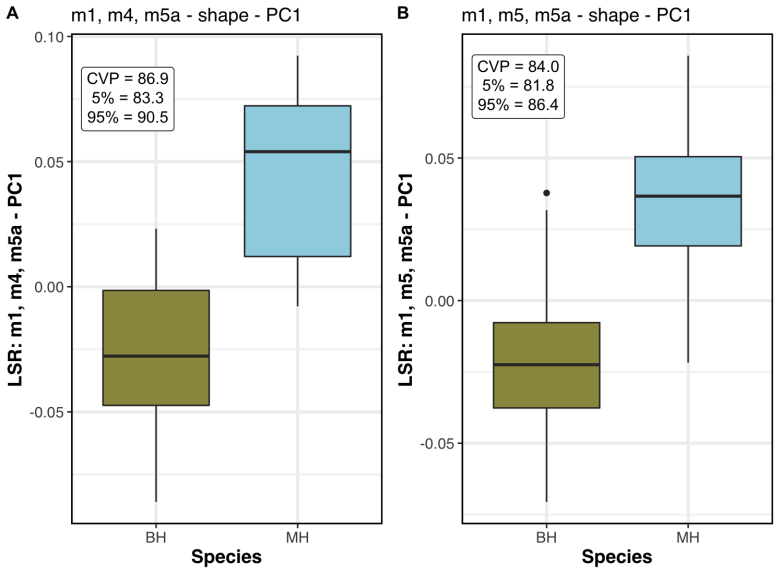

Figure 3.20: Box plots showing distribution of PC1 scores for BH and MH mandibles based on log-shape ratios for A) m1, m4, m5a and B) m1, m5, m5a. Mean cross-validation (balanced) percentages and 5% and 95% intervals indicated. “B" is joint second place with approach shown in Figure 3.21)/

The trend towards trivariate shape analysis being the most effective can be likely explained by the direction of the measurements. Metrics m1, m2, m3 and m4 are all oral-aboral, whilst m5 and m5a are dorsal-basal. That four out of the six are all taken in the same direction and that there are no transverse measurements limits the variation that can be captured by restricting the analysis to two physical dimensions, whereas the other skeletal elements can be examined in up to three. No approaches that excluded m5 and m5a were accepted; all the accepted ones included one or both of them (Figure 3.22). Approaches that included m5a but not m5 were most likely to be preferred. Of the eight preferred approaches which are bivariate, six contained m5a plus one of the oral-aboral measurements; two contained m5. The combination m5-m5a was accepted, but not preferred, for shape and rejected for form and size. This confirms that, with just one exception, combinations need to include measurements in at least two different directions to discriminate between brown and mountain hare

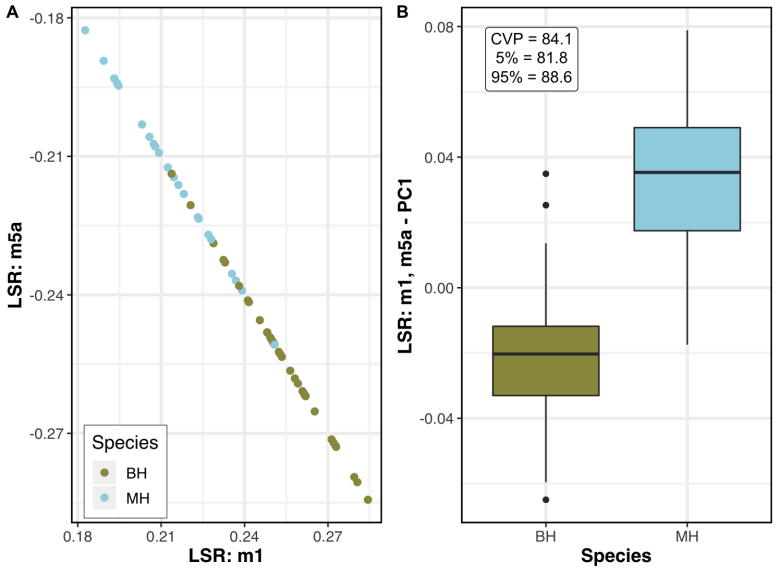

Figure 3.21: Shape analysis of BH and MH mandibles based on log-shape ratios for m1, m5a. A) Scatter plot of the original log-shape ratios. B) Box plot of PC1 scores. Mean cross-validation (balanced) percentages and 5% and 95% intervals indicated.

mandibles.

These results mean that the angle and articulation need to be preserved in order for the mandible to be reliably distinguishable to species. That the third best approach uses the combination m1-m5a, and many of the other approaches also use m1, further emphasises that the mandible needs to be intact for this metrical method to work. This limits the applicability of the method to archaeological samples because the mandible is fragile.

The results for Subset B showed the opposite trend. Shape was ineffective for distinguishing the two hare species plus rabbits; all the accepted approaches were either based on size or form. The accepted approaches (n = 16) only went up to rank eight, so there was no need to distinguish between accepted and preferred ones by selecting the top ten ranks.

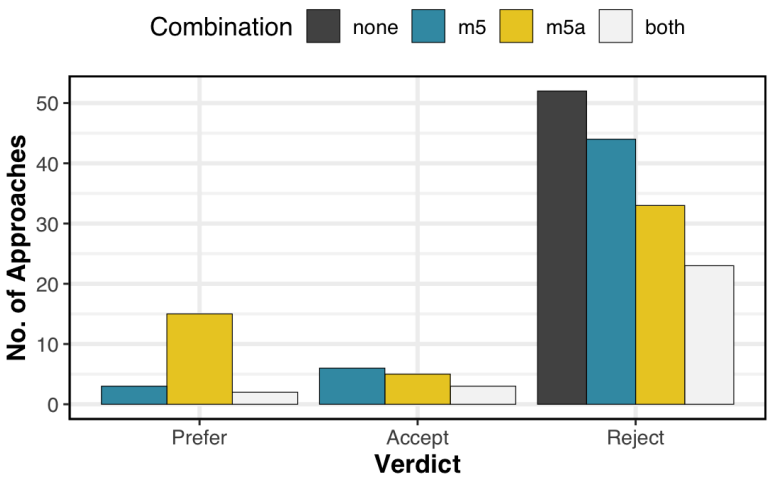

Figure 3.22: Number of Subset A approaches on the mandible according to verdict and whether the combination contains m5, m5a, both, or neither.

Table 3.13: Cross-validation results for all accepted approaches for separating BH, MH and rabbit mandibles (Subset B).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	41	Accept	Form	m5a	uni	–	73.3	80.8	88.9
2	37	Accept	Form	m1, m3	bi	PC1	71.7	77.7	84.6
2	37	Accept	Form	m5, m5a	bi	PC1	71.1	78.2	86.7
3	36	Accept	Size	m5, m5a	bi	–	71.1	77.9	84.4
4	34	Accept	Form	m1, m3, m4	tri	PC1	69.2	77.2	84.6
4	34	Accept	Size	m1, m3	bi	–	69.2	77.7	84.6
4	34	Accept	Size	m1, m3, m4	tri	–	69.2	77.5	84.6
5	33	Accept	Form	m1, m2, m3	tri	PC1	69.2	76.6	84.6
5	33	Accept	Form	m1, m4	bi	PC1	69.2	76.8	84.6
5	33	Accept	Size	m1, m2, m3	tri	–	69.2	76.4	84.6
5	33	Accept	Size	m1, m4	bi	–	69.2	76.6	84.6
6	32	Accept	Form	m1, m2, m4	tri	PC1	69.2	76.0	82.0
6	32	Accept	Size	m1, m2, m4	tri	–	69.2	75.8	84.6
7	31	Accept	Form	m5	uni	–	68.9	75.3	82.2

Table 3.13: *(continued)*

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
8	29	Accept	Form	m3, m4	bi	PC1	66.7	75.2	82.2
8	29	Accept	Size	m3, m4	bi	–	66.7	75.2	82.2

Two univariate approaches were accepted for form (m5 and m5a) but the remaining fourteen were either bivariate or trivariate. In the bivariates, four each were selected for form and size and three each in the trivariates. In both cases, exactly the same combinations were approved for size as for form. The worst performing of the accepted approaches, in joint eighth place, both used the combination m3-m4 (form and size). These were scarcely better than the minimum threshold of seventy-five percent accuracy, having mean CVPs of 75.16% and 75.15% respectively. Again it seems clear that the presence of m5 or m5a makes it more likely for an approach to be successful. Univariate m5a was notably the most successful discriminator (Figure 3.23), but univariate m5 was the third worst of the accepted approaches, with mean CVP of 75.3%.

Visualising the top four approaches (one for first place and three in joint second place) shows that lower CVP scores in Subset B probably derive more from the overlap between brown and mountain hare than from difficulty in separating hares from rabbits. These data clearly separate hares and rabbits in most cases (e.g. Figure 3.24). But, univariate m5 (Figure 3.23) and bivariate m5-m5a show that the smallest of brown hares and the largest of rabbits are metrically similar. Indeed, drawing ellipses around the logged data (Figure 3.25) suggests real-world populations may overlap. Both analysing PC1 of this distribution (thereby converting the data to a growth curve, (Figure 3.25.B) and isolating isometric size (Figure 3.25.C) removes this overlap but the extreme ends of the brown hare and rabbit distributions are still close together.

Overall, the mandible is of mixed effectiveness. For hare discrimination it can be accurate up to eighty-seven percent of the time, but the majority of accepted approaches are between seventy-five to eighty percent accurate. For both subsets, archaeological specimens need to be almost entirely complete for the method to be effective, which will occur rarely. Requiring completeness, however, does mean that when specimens

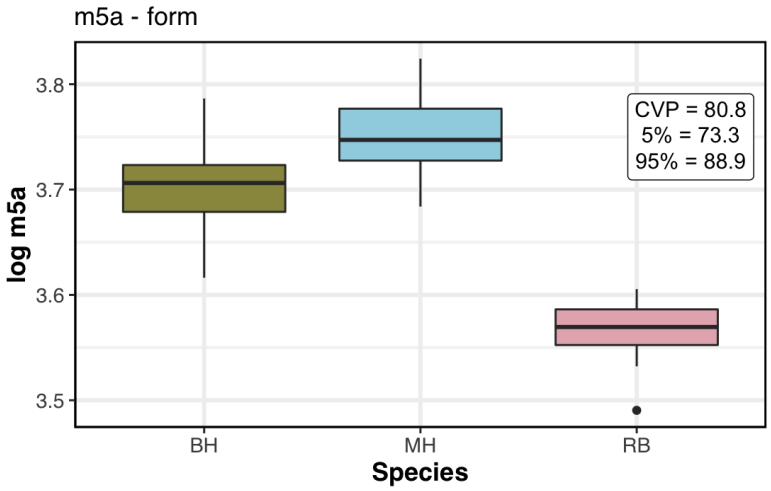

Figure 3.23: Box plot of log m5a values (form) for lagomorph mandibles.

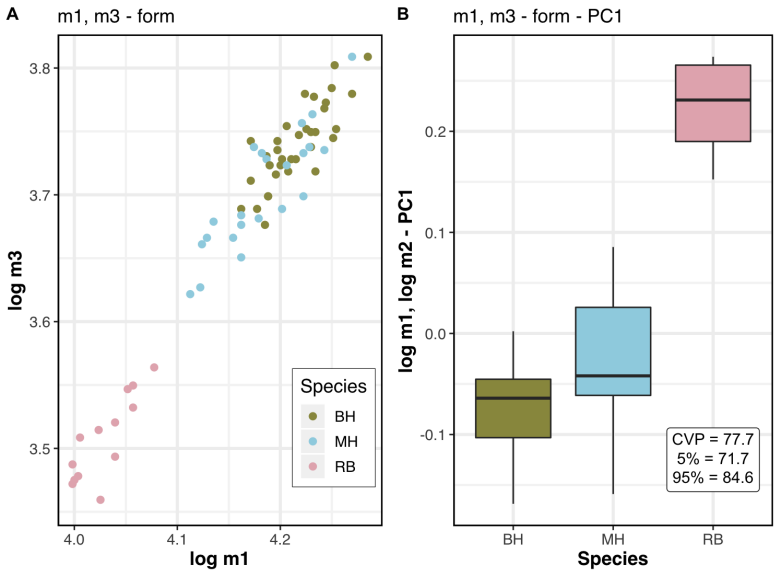

Figure 3.24: Form analysis of lagomorph mandibles using m1 and m3. A) log metrics values B) box plot of PC1 score distribution. CVP results indicated.

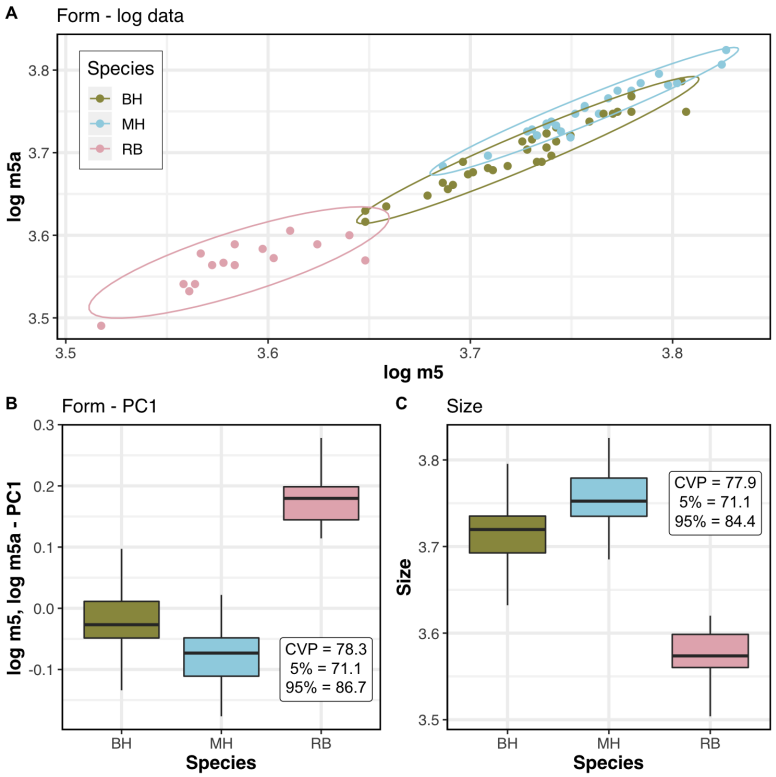

Figure 3.25: Analysis of lagomorph mandibles using m5 and m5a. A) Form: log metrics values B) Form: box plot of PC1 score distribution C) Isometric size. CVP results indicated.

Table 3.14: Summary of metrics and morphometric variables accepted/rejected through cross-validation for the scapula.

Set	Accept	Reject	Total	Percent Accepted
a	44	61	105	42
b	45	60	105	43

are measurable, up to twenty different approaches can be used to distinguish between the hares and up to eighteen to distinguish between the hares and rabbits. The opportunity to use numerous approaches allows the majority verdict of different tests to be taken rather than relying on just one, though greater weight must be lent to the highest scoring approaches.

3.3.2.2 Scapula

The lagomorph scapula is extremely fragile, save at the neck and glenoid. The heights, DHA and HS, are thus highly unlikely to be applicable archaeologically. The distal articulation, however, is dense enough to survive. A total of 105 approaches were applied to each subset, comprising twenty-five unique combinations. Fifty-five approaches were for form, thirty for shape, and twenty for size. Forty-four approaches were accepted in total for Subset A, and forty-five for Subset B (Table 3.14).

Shape was ineffective for the scapula, being rejected for every combination in both subsets; only form and size were accepted. Form initially appears to be more effective, suggesting the distinction between species is in allometric growth (PC1 for form) rather than in isometric size (Figure 3.26). The numbers of preferred and accepted approaches for form are slightly exaggerated by the univariates, however. Once these are accounted for there is little preference toward either form or size.

The distribution of mean CVP was high for the preferred approaches in both subsets, with the majority having CVP values around ninety percent accuracy, and there was little variation between the approaches (Figure 3.27). Other accepted approaches were more variable for Subset A, with mean CVP tending towards eighty to eighty-five percent, but Subset B showed very little variation between accepted approaches. Among the rejected approaches, form for Subset A was skewed towards lower mean CVPs (Figure 3.27), indicating a bimodal distribution of effectiveness (Figure 3.28).

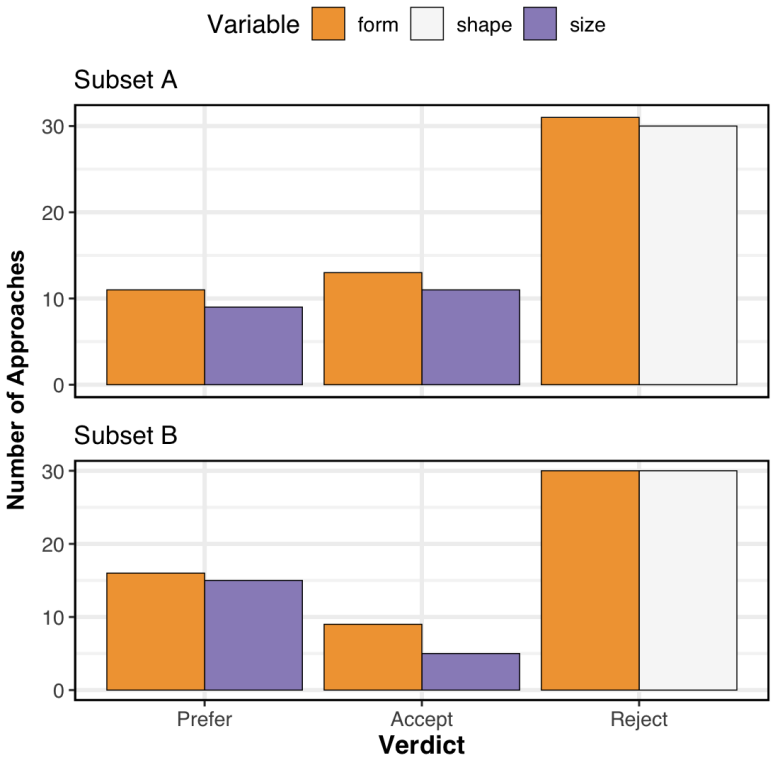

Figure 3.26: Scapula cross-validation verdicts by variable for both subsets.

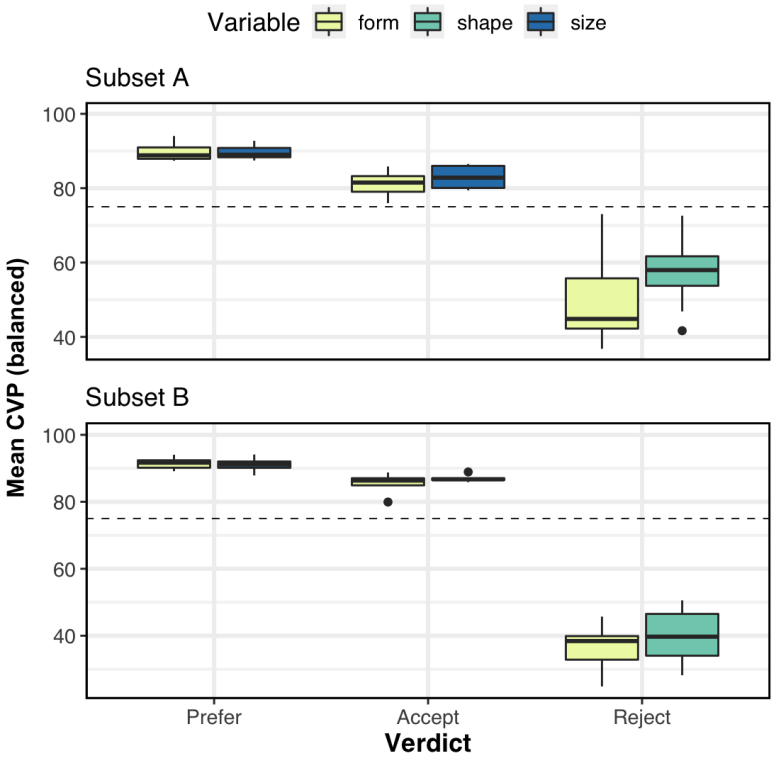

Figure 3.27: Box plots of mean CVP (balanced) for scapulae by verdict and morphometric variable for both subsets. Dashed line shows the 75% acceptance threshold.

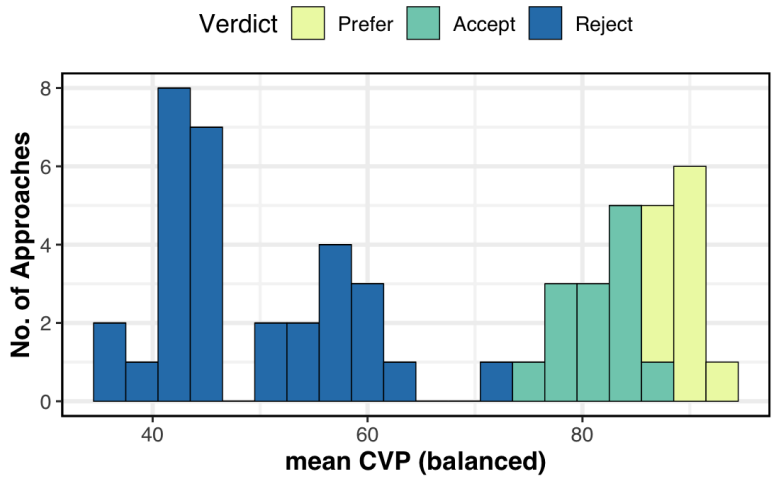

Figure 3.28: Histogram of mean CVP (balanced) for BH vs MH (Subset A) by verdict.

Twenty approaches were preferred for Subset A (Table 3.15), of which five do not require the element to be complete (Table 3.16). A further nine accepted approaches also work with fragmentary specimens. There were eleven unique metrics combinations in the preferred approaches. The most successful ones (tied for first place) were form analysis on the combination GLP-HS (Figure 3.29) and size on BG-GLP-HS (Figure 3.30), which require complete bones. The combination most likely to occur archaeologically is the breadth and length of the glenoid (BG-GLP, Figure 3.31). Form and size analysis on this combination both came in rank seven. Other archaeologically common combinations, BG-SLC and GLP-SLC were also accepted but they rank much lower. Mean CVP for these was still in excess of eighty percent, however (consult Appendix Table A.7 for all results).

Table 3.15: First ten ranks of cross-validation results on approaches for separating BH and MH scapulae (Subset A).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	52	Prefer	Form	GLP, HS	bi	PC1	88.5	94.0	98.1
1	52	Prefer	Size	BG, GLP, HS	tri	–	90.4	91.8	94.2
2	51	Prefer	Size	GLP, HS	bi	–	88.5	92.7	96.2
3	50	Prefer	Form	BG, GLP, HS	tri	PC1	88.5	91.2	94.2
3	50	Prefer	Form	GLP, DHA	bi	PC1	88.9	90.9	92.6
4	49	Prefer	Form	GLP	uni	–	87.9	91.0	93.9
5	48	Prefer	Form	BG, GLP, DHA	tri	PC1	87.0	90.7	94.4
5	48	Prefer	Size	BG, GLP, DHA	tri	–	87.0	90.8	94.4
6	46	Prefer	Size	BG, HS	bi	–	86.5	89.3	92.3
7	45	Prefer	Form	BG, GLP	bi	PC1	86.4	88.6	90.9
7	45	Prefer	Form	GLP, HS, DHA	tri	PC1	86.5	88.8	94.2
7	45	Prefer	Size	BG, GLP	bi	–	86.4	88.3	90.9
7	45	Prefer	Size	BG, GLP, SLC	tri	–	86.4	89.0	90.9
8	43	Prefer	Form	BG, DHA	bi	PC1	85.2	87.5	90.7
8	43	Prefer	Form	BG, HS	bi	PC1	84.6	88.3	92.3
8	43	Prefer	Size	BG, DHA	bi	–	85.2	87.5	90.7
8	43	Prefer	Size	GLP, DHA	bi	–	85.2	87.5	90.7

Table 3.16: Frequency of cross-validation verdicts for BH versus MH (Subset A) scapulae by completeness requirement. "Complete" is defined as "requiring both the proximal and distal epiphyses for the metrics combination to be taken". "Incomplete" means that only one epiphysis is needed.

Verdict	Complete	Incomplete	Percent Complete
Prefer	15	5	75
Accept	15	9	62
Reject	48	13	79

Table 3.15: *(continued)*

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
8	43	Prefer	Size	GLP, SLC, HS	tri	–	84.6	88.5	92.3
9	42	Prefer	Form	BG, GLP, SLC	tri	PC1	84.8	87.4	90.9
10	40	Prefer	Form	GLP, SLC, HS	tri	PC1	82.7	87.4	92.3

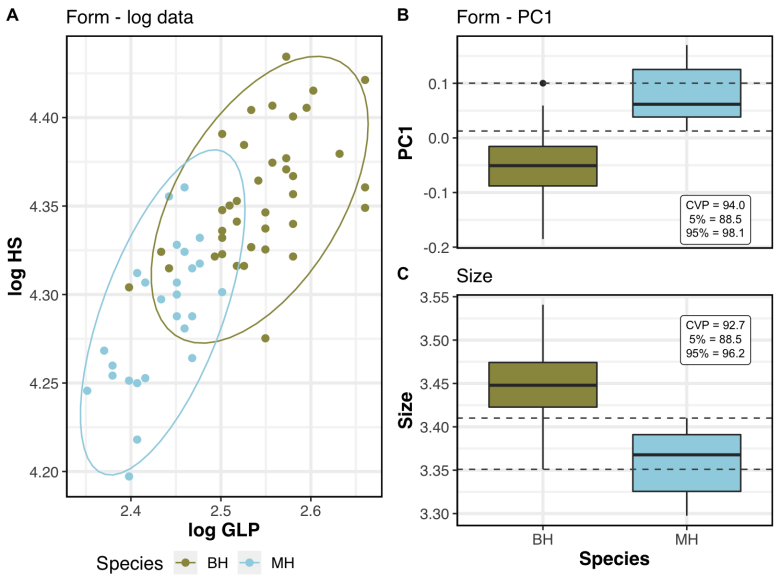

Figure 3.29: Analysis of BH vs MH (Subset A) scapulae using the combination GLP-HS. A) Form - log data B) Form - PC1 scores C) Size. Dotted lines demarcate the area of overlap between the species. Cross-validation results indicated.

Thirty-one approaches were preferred for Subset B (Table 3.17), seven of which were all joint first place, with the 95% confidence interval at 100% accuracy and mean CVP

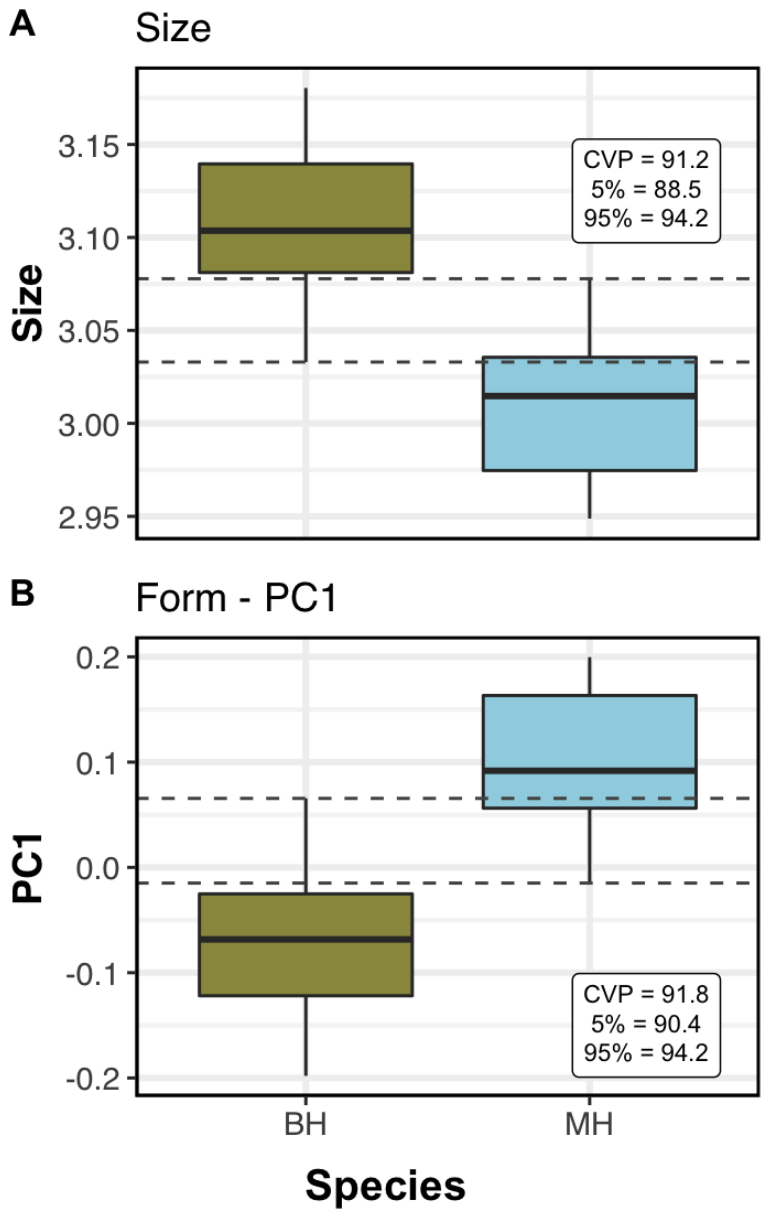

Figure 3.30: Analysis of BH vs MH (Subset A) scapulae using the combination BG-GLP-HS. A) Size B) Form - PC1. Dotted lines demarcate the area of overlap between the species. Cross-validation results indicated.

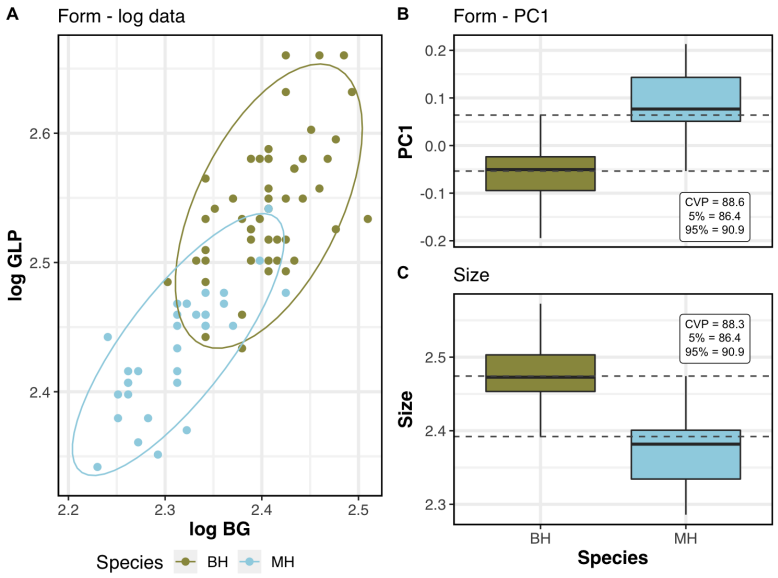

Figure 3.31: Analysis of BH vs MH (Subset A) scapulae using the combination BG-GLP. A) Form - log data B) Form - PC1 C) Size. Dotted lines demarcate the area of overlap between the species. Cross-validation results indicated.

values above 93%. All save one of these (the exception is univariate GLP) requires a mostly complete specimen, as they make use of the height measurements DHA and HS. Nine preferred approaches do not require complete bones, however, as do six other accepted ones (Table 3.18). The most archaeologically relevant combination, BG-GLP is second place for both form and size (Figure 3.32).

Table 3.17: First ten ranks of cross-validation results on approaches for separating BH and MH and rabbit scapulae (Subset B).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	69	Prefer	Form	BG, GLP, DHA	tri	PC1	87.9	93.4	100.0
1	69	Prefer	Form	BG, GLP, HS	tri	PC1	87.9	93.8	100.0
1	69	Prefer	Form	GLP, HS	bi	PC1	87.9	94.0	100.0
1	69	Prefer	Size	BG, GLP, DHA	tri	–	87.9	93.4	100.0
1	69	Prefer	Size	BG, GLP, HS	tri	–	87.9	94.1	100.0
1	69	Prefer	Size	GLP, HS	bi	–	87.9	93.9	100.0
1	69	Prefer	Form	GLP	uni	–	88.2	93.5	98.0

Table 3.17: *(continued)*

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
2	67	Prefer	Form	BG, GLP	bi	PC1	87.5	92.1	95.8
2	67	Prefer	Form	BG, GLP, SLC	tri	PC1	87.4	91.8	97.9
2	67	Prefer	Size	BG, GLP	bi	–	87.5	92.0	95.8
2	67	Prefer	Size	BG, GLP, SLC	tri	–	87.5	92.0	95.8
3	65	Prefer	Form	BG, DHA	bi	PC1	86.1	91.3	97.2
3	65	Prefer	Form	BG, HS	bi	PC1	86.1	91.7	97.2
3	65	Prefer	Size	BG, HS	bi	–	86.1	92.0	97.2
4	64	Prefer	Form	GLP, DHA	bi	PC1	84.8	91.7	97.0
4	64	Prefer	Form	GLP, SLC, HS	tri	PC1	84.8	91.8	97.0
4	64	Prefer	Size	GLP, SLC, HS	tri	–	84.8	91.9	97.0
5	63	Prefer	Size	GLP, DHA	bi	–	84.8	91.2	97.0
6	62	Prefer	Form	GLP, HS, DHA	tri	PC1	83.3	91.3	96.7
6	62	Prefer	Size	BG, DHA	bi	–	83.3	91.1	97.2
7	61	Prefer	Form	BG, SLC, HS	tri	PC1	83.3	90.3	97.2
7	61	Prefer	Size	BG, SLC, HS	tri	–	83.3	90.4	97.2
7	61	Prefer	Size	GLP, HS, DHA	tri	–	83.3	90.6	96.7
8	60	Prefer	Form	GLP, SLC	bi	PC1	83.3	89.1	93.8
8	60	Prefer	Size	GLP, SLC	bi	–	83.3	89.7	95.8
9	59	Prefer	Form	BG, HS, DHA	tri	PC1	81.8	89.4	97.0
9	59	Prefer	Form	GLP, SLC, DHA	tri	PC1	81.8	89.6	97.0
9	59	Prefer	Size	BG, HS, DHA	tri	–	81.8	89.5	97.0
9	59	Prefer	Size	GLP, SLC, DHA	tri	–	81.8	89.9	97.0
9	59	Prefer	Form	BG	uni	–	82.3	89.2	94.1
10	58	Prefer	Size	BG, SLC	bi	–	82.3	87.9	94.1

Overall, the scapula is surprisingly effective for discriminating lagomorph bones. Though still instrumental in locomotion, the scapula is less intimately linked with an animal's interaction with terrain; lower limb and foot bones might therefore be

Table 3.18: Frequency of cross-validation verdicts for BH, MH and rabbit (Subset B) scapulae by completeness requirement. 'Complete' is defined as 'requiring both the proximal and distal epiphyses for the metrics combination to be taken'. 'Incomplete' means that only one epiphysis is needed.

Verdict	Complete	Incomplete	Percent Complete
Prefer	22	9	71
Accept	8	6	57
Reject	48	12	80

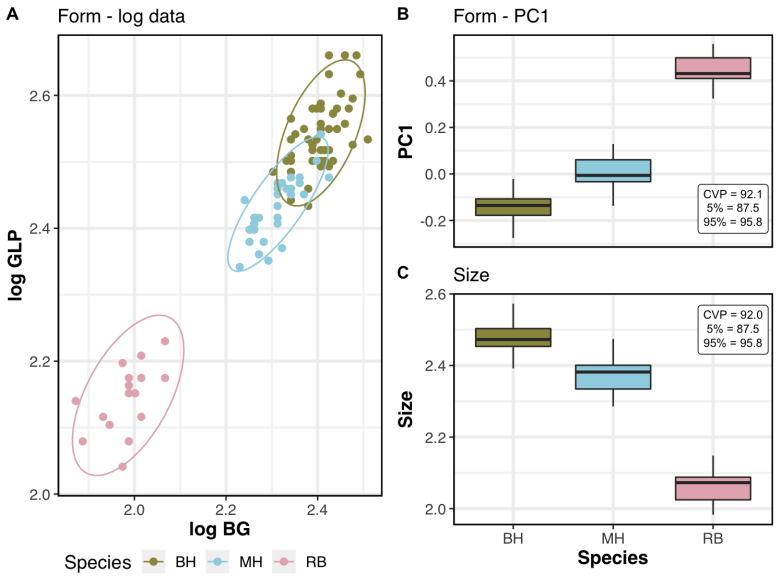

Figure 3.32: Analysis of BH, MH and rabbit (Subset B) scapulae using the combination BG-GLP. A) Form - log data B) Form - PC1 C) Size. Cross-validation results indicated.

Table 3.19: Summary of metrics and morphometric variables accepted/rejected through cross-validation for the humerus.

Set	Accept	Reject	Total	Percent Accepted
a	106	140	246	43
b	113	133	246	46

expected to show better separation between the lagomorphs in this study. This could explain the rejection of all the shape-based approaches, whilst only allometric growth (form PC1) and isometric size were accepted.

3.3.2.3 Humerus

The humerus is one of the more measurable elements, both in terms of the number of anchor points and its potential for preservation archaeologically (being relatively dense, particularly at the distal end). The diaphysis is thin, however, so it is prone to shattering; complete elements should be rare archaeologically. A total of 246 approaches were applied to both subsets, comprising fifty-seven unique combinations. For form, 127 approaches were applied, with seventy for shape and forty-nine for size. Totals of 106 and 113 were accepted for Subsets A and B, respectively (Table 3.19).

For Subset A, forty-three percent of the approaches for the humerus met the threshold for acceptance. Five univariate approaches were accepted on the humerus, but none were among the total of twenty-nine preferred options (Table 3.20). For the bivariates and trivariates, shape-based approaches were most frequently preferred (6 and 8 respectively), but form and size were represented also (Figure 3.33). The two best approaches are visualised in Figures 3.34 and 3.35.

Table 3.20: First ten ranks of cross-validation results on approaches for separating BH and MH humeri (Subset A).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	66	Prefer	Shape	Dp, GL, Dd	tri	PC1	97.6	98.0	100.0
2	63	Prefer	Shape	Bp, Dp, GLC	tri	PC1	95.2	97.3	97.6
3	62	Prefer	Shape	Bp, Dp, GL	tri	PC1	95.2	96.4	97.6
3	62	Prefer	Size	Bd, Dp	bi	–	95.2	96.6	98.4

Table 3.20: *(continued)*

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
4	59	Prefer	Form	Bd, Dp	bi	PC1	93.5	95.6	96.8
5	58	Prefer	Form	Bp, Dp, Bd	tri	PC1	93.2	95.0	95.5
5	58	Prefer	Shape	Bp, GL	bi	PC1	92.9	95.2	97.6
5	58	Prefer	Size	Bp, Dp, Bd	tri	–	93.2	95.1	95.5
5	58	Prefer	Size	Bp, Dp, Dd	tri	–	93.2	94.4	97.7
6	57	Prefer	Form	Bp, Dp, Dd	tri	PC1	93.2	94.3	97.7
6	57	Prefer	Shape	Bp, GLC	bi	PC1	92.9	94.3	97.6
7	56	Prefer	Form	Dp, GL, Bd	tri	PC1	91.7	94.3	96.7
7	56	Prefer	Shape	Dp, GL, GLC	tri	PC1	91.9	94.3	96.8
7	56	Prefer	Shape	Dp, GLC	bi	PC1	91.9	93.9	96.8
8	54	Prefer	Form	Dd, Dp	bi	PC1	90.9	92.9	95.5
8	54	Prefer	Shape	Dp, GL, Bd	tri	PC1	90.0	93.6	96.7
8	54	Prefer	Size	Bp, Dp, HTC	tri	–	90.9	92.6	95.5
8	54	Prefer	Size	Dd, Dp	bi	–	90.9	92.9	95.5
9	53	Prefer	Form	Dp, Bp	bi	PC1	90.9	91.6	93.2
9	53	Prefer	Shape	Dd, GLC	bi	PC1	90.9	91.8	93.2
9	53	Prefer	Shape	Dp, GL	bi	PC1	90.3	93.0	95.2
9	53	Prefer	Size	Dd, Bp	bi	–	90.9	91.6	93.2
10	52	Prefer	Form	Bp, Dp, GL	tri	PC1	90.5	91.2	92.9
10	52	Prefer	Form	Bp, Dp, GLC	tri	PC1	90.5	91.4	92.9
10	52	Prefer	Shape	Dd, GL	bi	PC1	90.9	91.5	93.2
10	52	Prefer	Shape	Dp, GL, HTC	tri	PC1	90.5	91.5	92.9
10	52	Prefer	Shape	GL, GLC, Dd	tri	PC1	90.9	91.5	93.2
10	52	Prefer	Shape	GLC, SD, Dd	tri	PC2	90.5	91.9	92.9
10	52	Prefer	Size	Dp, Bp	bi	–	90.9	91.5	93.2

The combinations used in accepted approaches frequently mixed metrics from the proximal and distal ends, or else required the Greatest Length. Of the preferred

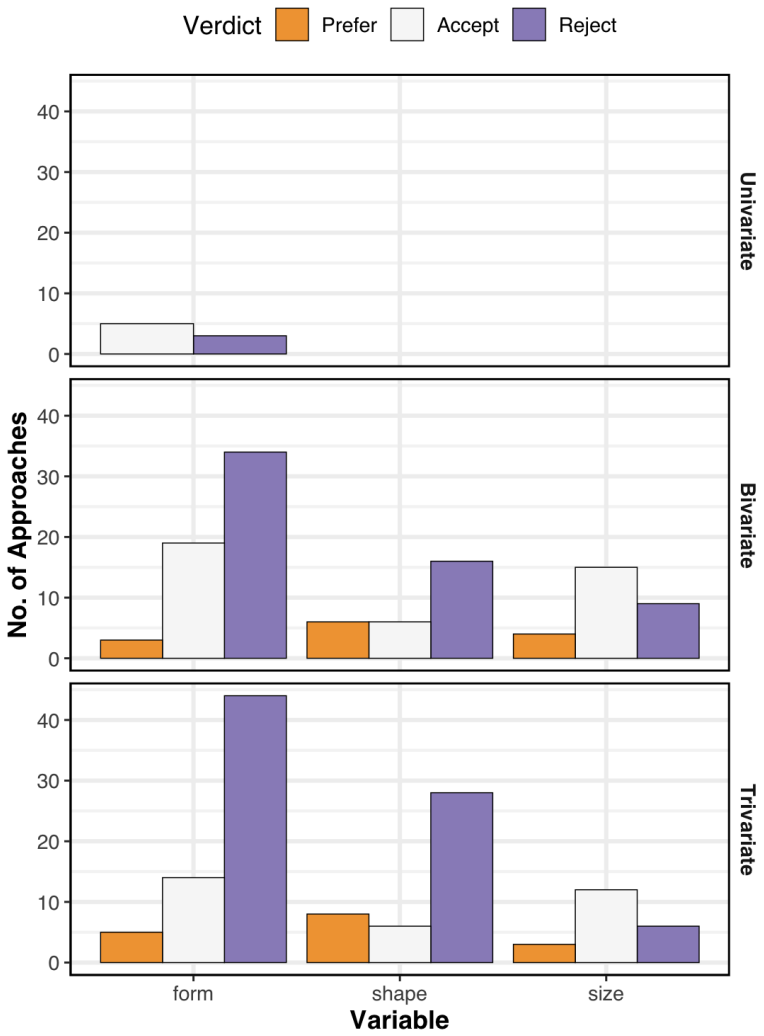

Figure 3.33: Frequency of approaches by cross-validation verdict and number of metrics in the combination for BH vs MH (Subset A) humeri.

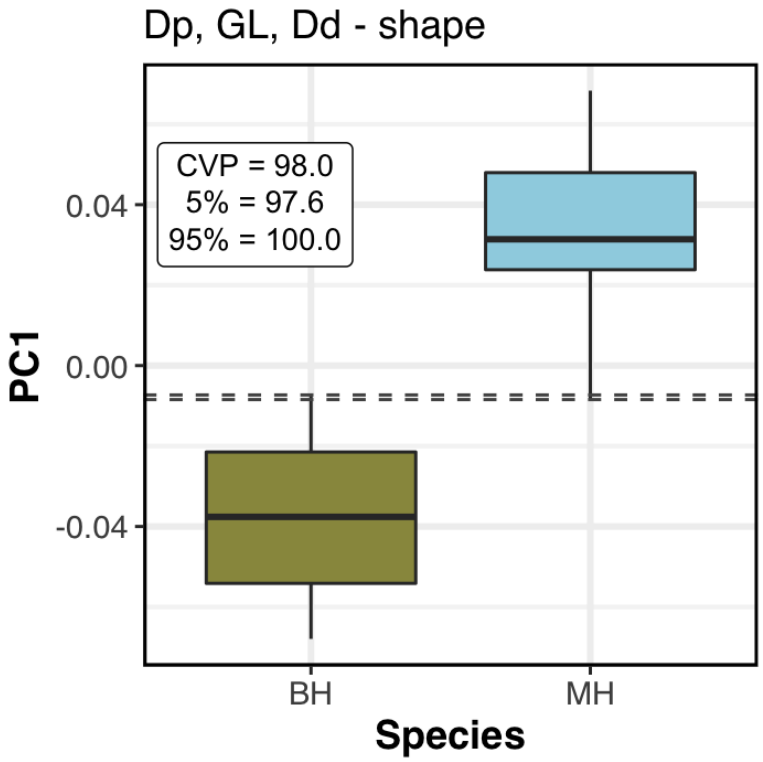

Figure 3.34: Shape analysis on BH vs MH humeri (Subset A) using PC1 on log-shape ratios for the combination Dp, GL, Dd. Dotted lines mark the largest PC1 score for brown hares and the smallest for mountain hares - the space between is the area of overlap. CVP results indicated.

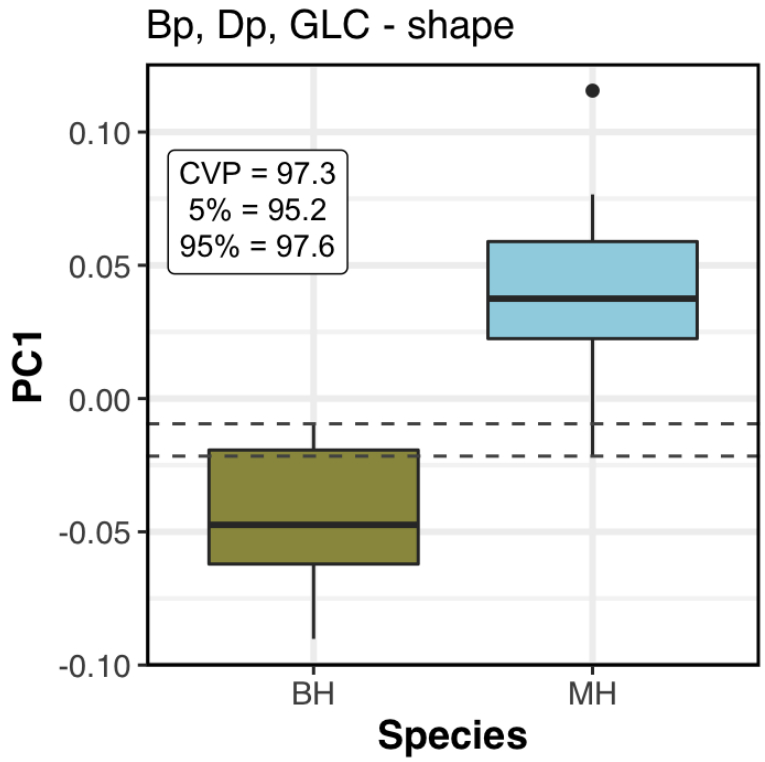

Figure 3.35: Shape analysis on BH vs MH humeri (Subset A) using PC1 on log-shape ratios for the combination Bp, Dp, GLC. Dotted lines mark the largest PC1 score for brown hares and the smallest for mountain hares - the space between is the area of overlap. CVP results indicated.

Table 3.21: CVP results for BH vs MH (Subset A) on the humerus, using form and size on the combination Bd, Dd

Rank	Score	Verdict	Variable	Metrics	5%	Mean	95%
11	50	Accept	Form	Bd, Dd	89.6	90.1	91.7
11	50	Accept	Size	Bd, Dd	89.6	90.0	91.7

approaches, twenty-seven require complete bones. Only two allow for fragmentary specimens, where either only the proximal or distal ends are present. This means that the top twenty-nine models for separating hares have low archaeological utility. The two preferred options that allow fragmentary specimens use the combination Dp-Bp (proximal end - for form and size, with very little difference between them in their CVP scores, Figure 3.36). Form and size approaches on the combination Bd-Dd (distal end, Figure 3.37) came joint eleventh place, so they do not appear in the set of preferred options, but still have excellent CVP scores (results given in Table 3.21).

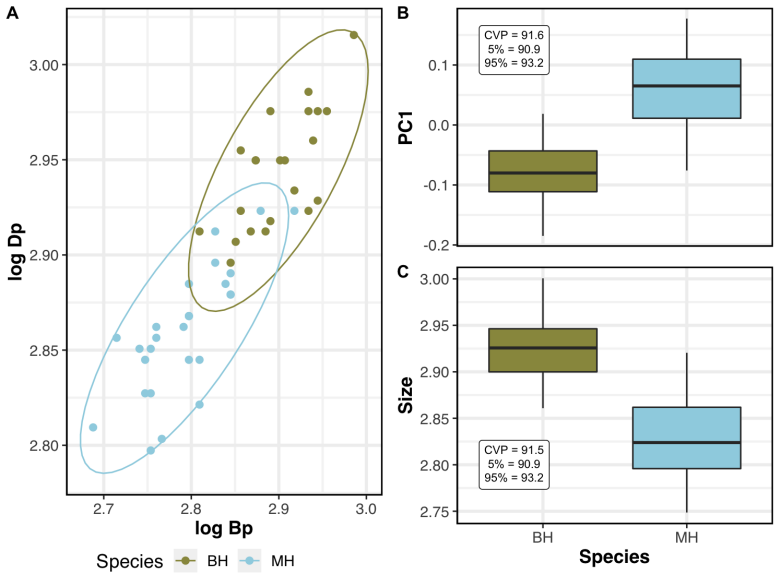

Figure 3.36: Analysis of BH and MH (Subset A) humeri using the combination Dp - Bd. A) Form - log metrics. B) Form - PC1 of the log metrics. C) Size.

Regardless, the CVP results were very good for all of the accepted approaches. Mean CVP was in excess of ninety for the preferred options (Figure 3.38), but the other accepted ones ranged from mean CVPs of seventy-five to ninety-two with the mean and median of these distributions at approximately eighty-three percent. There is

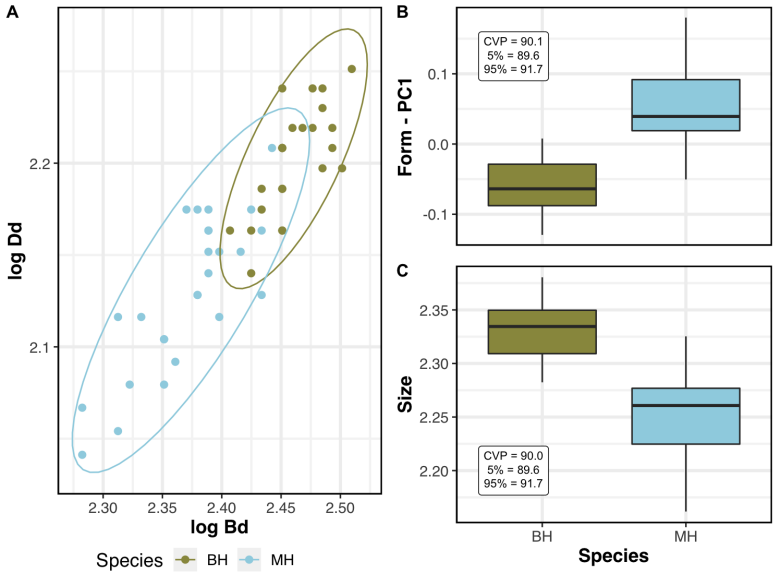

Figure 3.37: Analysis of BH and MH (Subset A) humeri using the combination Bd - Dd. A) Form - log metrics. B) Form - PC1 of the log metrics. C) Size.

no reason to restrict predictive analysis on archaeological material to just the preferred approaches; the user of these models need only decide on a minimum level of confidence. All of the CVP results can be consulted in Appendix Table A.9.

For Subset B, form and size performed better than shape, though all three were present in the preferred approaches (Table 3.22, n = 36). The CVP standard was high, with mean balanced CVP for all the preferred approaches exceeding ninety percent. For twenty-nine of these, the 95% interval reached 100% accuracy. A total of seven preferred approaches can be applied with only one epiphyseal end present, though it was still the case that the majority (81%) require complete specimens. The best performing approaches (joint rank 1) used the combination Bd-Dp (Figure 3.39).

Table 3.22: First ten ranks of cross-validation results on approaches for separating BH and MH and rabbit humeri (Subset B).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	77	Prefer	Form	Bd, Dp	bi	PC1	92.9	97.3	100.0
1	77	Prefer	Size	Bd, Dp	bi	–	92.9	97.0	100.0
2	73	Prefer	Shape	Dp, GL, Dd	tri	PC1	88.9	96.6	100.0

Table 3.22: *(continued)*

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
3	71	Prefer	Form	Bp, Dp, Bd	tri	PC1	88.9	94.8	100.0
3	71	Prefer	Form	Bp, Dp, HTC	tri	PC1	88.9	94.7	100.0
3	71	Prefer	Size	Bp, Dp, Bd	tri	–	88.9	95.0	100.0
3	71	Prefer	Size	Bp, Dp, HTC	tri	–	88.9	94.8	100.0
4	70	Prefer	Form	Dd, Dp	bi	PC1	88.9	94.2	100.0
4	70	Prefer	Size	Bd, Bp	bi	–	88.9	94.2	100.0
5	69	Prefer	Form	Dp	uni	–	88.1	93.7	97.6
6	66	Prefer	Shape	Bd, GLC	bi	PC1	87.2	91.8	97.4
7	65	Prefer	Form	Bd, Bp	bi	PC1	83.3	94.0	100.0
7	65	Prefer	Form	Bp, Dp, Dd	tri	PC1	83.3	94.2	100.0
7	65	Prefer	Size	Bp, Dp, Dd	tri	–	83.3	94.1	100.0
7	65	Prefer	Size	Dd, Dp	bi	–	83.3	94.2	100.0
8	64	Prefer	Form	Dd, Bp	bi	PC1	83.3	93.0	100.0
8	64	Prefer	Shape	Dd, GL	bi	PC1	83.3	93.4	100.0
8	64	Prefer	Form	Bd	uni	–	85.4	91.2	95.8
9	63	Prefer	Form	Bd, Dd	bi	PC1	83.3	92.0	100.0
9	63	Prefer	Form	Dp, Bp	bi	PC1	83.3	92.5	100.0
9	63	Prefer	Form	HTC, Bp	bi	PC1	83.3	92.4	100.0
9	63	Prefer	Shape	Bd, GL	bi	PC1	84.6	90.9	97.4
9	63	Prefer	Shape	Bp, Dp, GL	tri	PC1	83.3	91.9	100.0
9	63	Prefer	Shape	Bp, Dp, GLC	tri	PC1	83.3	92.1	100.0
9	63	Prefer	Shape	Dp, GL, Bd	tri	PC1	84.6	91.2	97.4
9	63	Prefer	Shape	GL, GLC, Bd	tri	PC1	84.6	91.2	97.4
9	63	Prefer	Shape	GL, GLC, Dd	tri	PC1	83.3	92.5	100.0
9	63	Prefer	Size	Bd, Dd	bi	–	83.3	92.5	100.0
9	63	Prefer	Size	Dd, Bp	bi	–	83.3	92.8	100.0
9	63	Prefer	Size	Dp, Bp	bi	–	83.3	92.7	100.0
9	63	Prefer	Size	Dp, GL, Bd	tri	–	84.6	90.7	97.4

Table 3.22: *(continued)*

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
9	63	Prefer	Size	HTC, Bp	bi	–	83.3	92.7	100.0
9	63	Prefer	Size	HTC, Dp	bi	–	83.3	92.2	100.0
10	62	Prefer	Form	HTC, Dp	bi	PC1	83.3	91.7	100.0
10	62	Prefer	Shape	Dd, GLC	bi	PC1	83.3	91.5	100.0
10	62	Prefer	Form	Bp	uni	–	83.3	90.9	100.0

The humerus is clearly a powerful element for separating lagomorph species, overall. Cross-validation percentages for the best approaches have means in excess of ninety percent and the 1000 sampling repeats produce 100% accuracy in a number of cases. Archaeologically, the preferred models cannot be exploited to their full potential as most require complete specimens. Nevertheless, excellent accuracy rates are achievable with the majority of the accepted approaches; a breadth and depth measurement at either the proximal or distal end is sufficient to produce an identification of brown or mountain hare with a high level of confidence.

3.3.2.4 Radius

The radius is a thin skeletal element and is prone to fragmentation. Its articular ends are small and were not expected to have enough variance to discriminate between species. A total of 174 approaches comprising forty unique combinations were applied. Ninety approaches were for form, fifty for shape, and thirty-four for size. Exactly half were accepted for Subset A and ninety-one for Subset B (Table 3.23).

Results for the radius were surprising given the element's small articular ends. Sufficiently diagnostic variance was found in approaches for all three types of morphometric variable. Shape and form were most frequently rejected, but size was more likely to be accepted rather than preferred in distinctions between the hares (Figure 3.40). The inverse is true when rabbits are added, as the hare radius is markedly larger than the rabbit's. Shape was accepted more often than it was preferred in both subsets.

Mean CVP was at a high standard. Preferred approaches all had mean CVP values

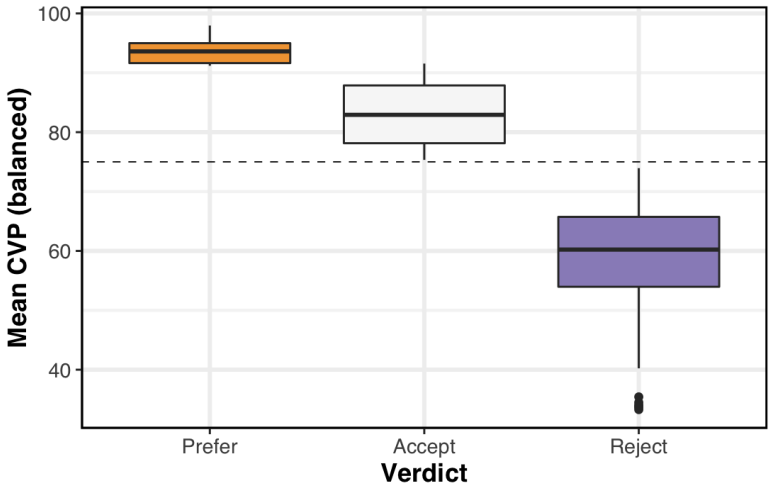

Figure 3.38: Box plot showing distribution of mean CVP (balanced) on approaches for BH vs MH humeri, grouped by verdict. Dashed line shows the 75% acceptance threshold.

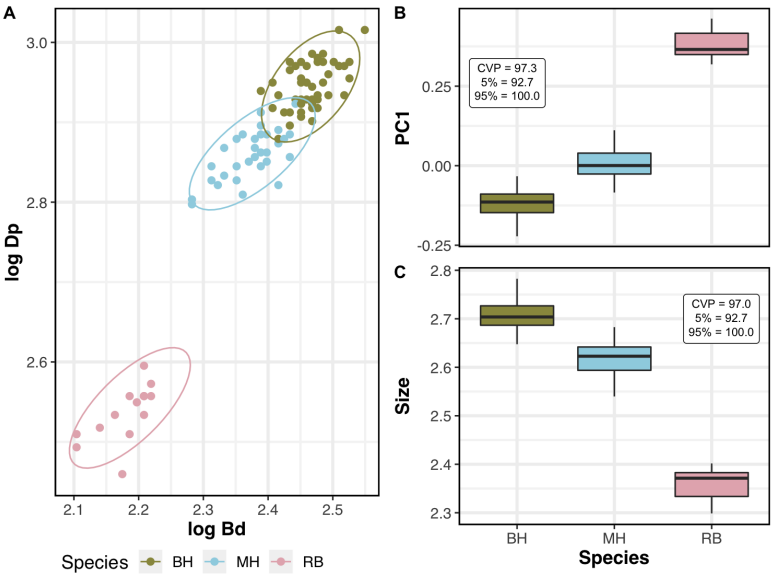

Figure 3.39: Analysis of BH, MH and rabbit (Subset B) humeri using the combination Bd - Dp. A) Form - log metrics. B) Form - PC1 of the log metrics. C) Size.

Table 3.23: Summary of metrics and morphometric variables accepted/rejected through cross-validation for the radius.

Set	Accept	Reject	Total	Percent Accepted
a	87	87	174	50
b	91	83	174	52

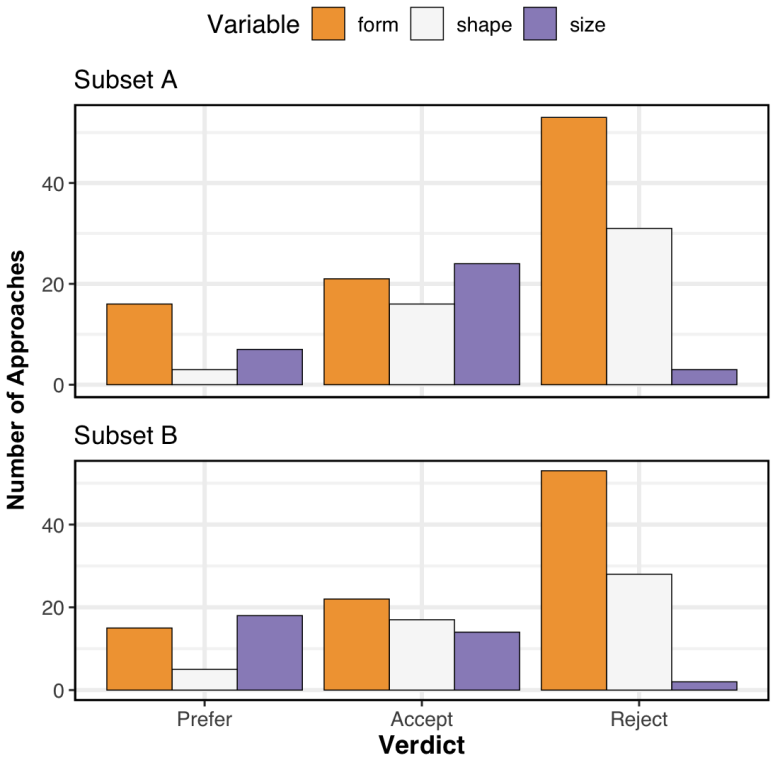

Figure 3.40: Radius cross-validation verdicts by variable for both subsets.

above ninety (Tables 3.24 and 3.28). The distribution of mean CVP among the other accepted approaches seems to be more skewed than has been seen for other elements so far, with greater numbers of approaches with CVP values above ninety (Figure 3.41). The skewness is less pronounced for shape-based approaches, probably because larger numbers of these were rejected than for the other variables. There is very little variance among the size approaches - even the rejected ones have relatively high mean CVP values, in comparison to the wider dispersal of form and shape.

Table 3.24: First ten ranks of cross-validation results on approaches for separating BH and MH radii (Subset A).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	65	Prefer	Form	Bp, SD, Dd	tri	PC1	95.8	99.1	100.0
2	64	Prefer	Form	Bp, Dd	bi	PC1	95.8	97.9	100.0
2	64	Prefer	Size	Bp, Dd	bi	–	95.8	98.3	100.0
2	64	Prefer	Size	Bp, SD, Dd	tri	–	95.8	98.2	100.0
3	63	Prefer	Form	Bp, GL, Dd	tri	PC1	95.8	97.4	100.0
3	63	Prefer	Shape	Bp, GL, Bd	tri	PC1	96.3	96.5	98.2
4	61	Prefer	Form	Bp, GL	bi	PC1	94.6	96.2	98.2
4	61	Prefer	Form	Bp	uni	–	95.5	95.6	97.0
5	60	Prefer	Form	Dd, Bd, SD	tri	PC1	91.7	97.9	100.0
5	60	Prefer	Form	Dd, SD	bi	PC1	91.7	98.7	100.0
6	59	Prefer	Form	Bp, SD, Dp	tri	PC1	92.9	96.1	100.0
6	59	Prefer	Size	Bp, SD, Dp	tri	–	92.9	96.0	100.0
7	58	Prefer	Form	Bp, Dp, Dd	tri	PC1	90.9	97.0	100.0
7	58	Prefer	Size	Dd, Bd, SD	tri	–	91.7	96.2	100.0
7	58	Prefer	Size	Dd, SD	bi	–	91.7	96.7	100.0
8	57	Prefer	Form	Bp, Bd, Dd	tri	PC1	91.7	95.6	100.0
8	57	Prefer	Shape	Bp, GL	bi	PC1	92.9	94.0	98.2
9	56	Prefer	Form	Bp, GL, SD	tri	PC1	92.6	93.4	94.4
9	56	Prefer	Form	Dd, GL	bi	PC1	91.7	94.2	100.0
9	56	Prefer	Form	Dp, Dd	bi	PC1	90.9	94.8	100.0

Table 3.24: *(continued)*

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
9	56	Prefer	Form	GL, Dd	bi	PC1	91.7	94.0	100.0
9	56	Prefer	Shape	Bp, GL, Dp	tri	PC1	91.7	94.5	100.0
9	56	Prefer	Size	Bp, Dp, Dd	tri	–	90.9	95.4	100.0
9	56	Prefer	Form	Dd	uni	–	91.7	94.0	95.8
10	55	Prefer	Form	Dp, GL, Dd	tri	PC1	90.9	94.4	100.0
10	55	Prefer	Size	Dp, Dd	bi	–	90.9	94.0	100.0

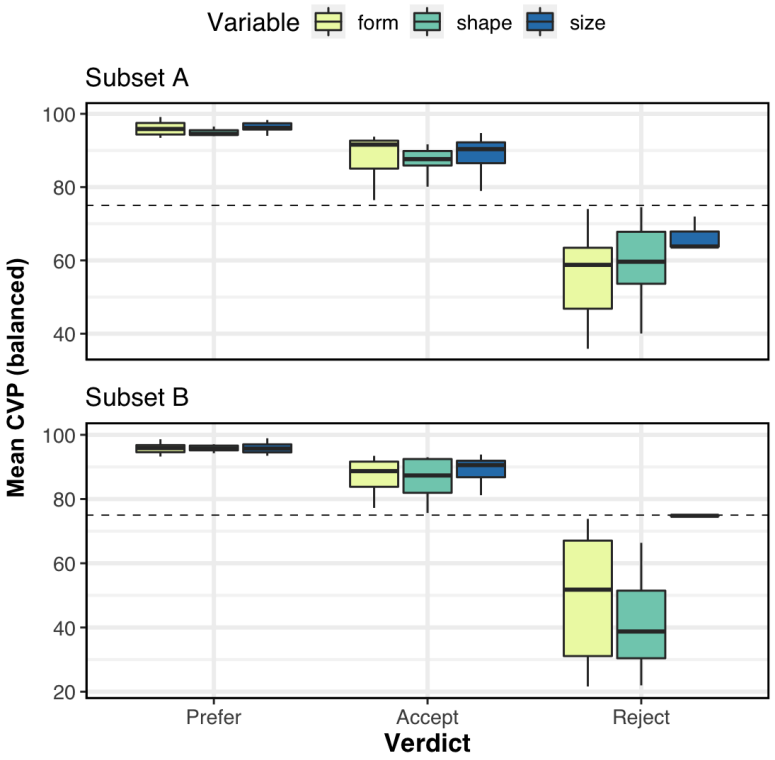

Figure 3.41: Box plots of mean CVP (balanced) for radii by verdict and morphometric variable for both subsets. Dashed line shows the 75% acceptance threshold.

Twenty-six approaches were preferred for brown versus mountain hare distinctions (Subset A), among which there were eighteen unique metrics combinations (Table 3.24). A further sixty one were accepted; overall therefore, exactly half were rejected. The

Table 3.25: Frequency of cross-validation verdicts for BH versus MH (Subset A) radii by completeness requirement. 'Complete' is defined as 'requiring both the proximal and distal epiphyses for the metrics combination to be taken'. 'Incomplete' means that only one epiphysis is needed.

Verdict	Complete	Incomplete	Percent Complete
Prefer	22	4	85
Accept	50	11	82
Reject	75	12	86

Table 3.26: Frequencies of BH vs MH approaches (Subset A) by verdict and number of metrics in the combination.

Verdict	Univariate	Bivariate	Trivariate
Prefer	2	10	14
Accept	2	29	30
Reject	2	33	52

majority of preferred approaches are based on form, though size was most abundant for other accepted approaches. For both preferred and accepted approaches, more used trivariate combinations than bivariate ones, though ten bivariates were still among the preferred options (Table 3.26). None of those can be taken without a complete bone, however (Table 3.25). Of the preferred trivariates, the combination Bp-SD-Dp can be taken with incomplete bones, as long as enough of the diaphysis is present, as the shortest breadth (SD) is always located towards the proximal end (Figure 3.6). Both form and size are preferred for this combination with mean CVPs of ninety-six percent.

Two of the preferred approaches are univariates (Bp and Dd), however, which mitigates issues with archaeological applicability. Furthermore, there are nine accepted bivariate approaches that do not require complete bones (average mean CVP between them is 92.3%, Table 3.27). These use the combinations Bp-SD, Bp-Dp, Dp-SD, and Bd-Dd. The combinations Bp-Dp (Figure 3.42) and Bd-Dd (Figure 3.43) require the least completeness.

Thirty-eight approaches were preferred for Subset B, among which there were twenty-two unique metrics combinations (Table 3.28). These include nine approaches to five combinations of metrics that can be taken without complete bones though they all

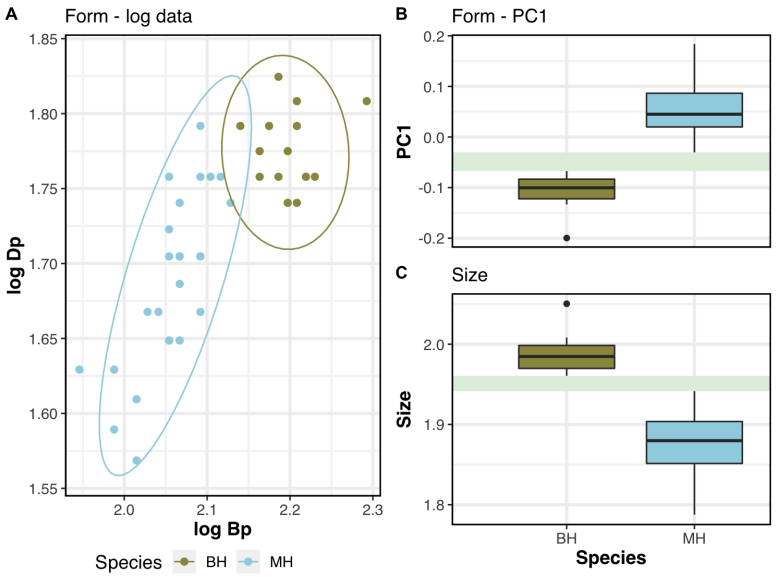

Figure 3.42: Analysis of BH vs MH (Subset A) radii using the combination Bp-Dp. A) Form - log data B) Form - PC1 C) Size. CVP results indicated. Area shaded in green in B and C highlights the lack of an overlap between the species, but note that overlap is detected when ellipses are drawn around the log data in A.

Table 3.27: CVP results for accepted bivariate approaches for BH and MH radii (Subset A) that do not require complete archaeological specimens.

Rank	Score	Variable	Metrics	PC	5%	Mean	95%
11	54	Size	Bp, SD	–	90.9	92.7	93.9
12	53	Form	Bp, Dp	PC1	89.3	93.6	100.0
12	53	Form	Bp, SD	PC1	90.9	92.1	93.9
12	53	Size	Dp, SD	–	89.3	93.3	96.4
13	52	Size	Bp, Dp	–	89.3	92.5	96.4
13	52	Form	Dp, SD	PC1	89.3	92.8	96.4
14	50	Form	Bd, Dd	PC1	87.5	92.7	100.0
14	50	Size	Bd, Dd	–	87.5	92.0	95.8
20	43	Shape	Bd, Dd	PC1	83.3	89.3	95.8

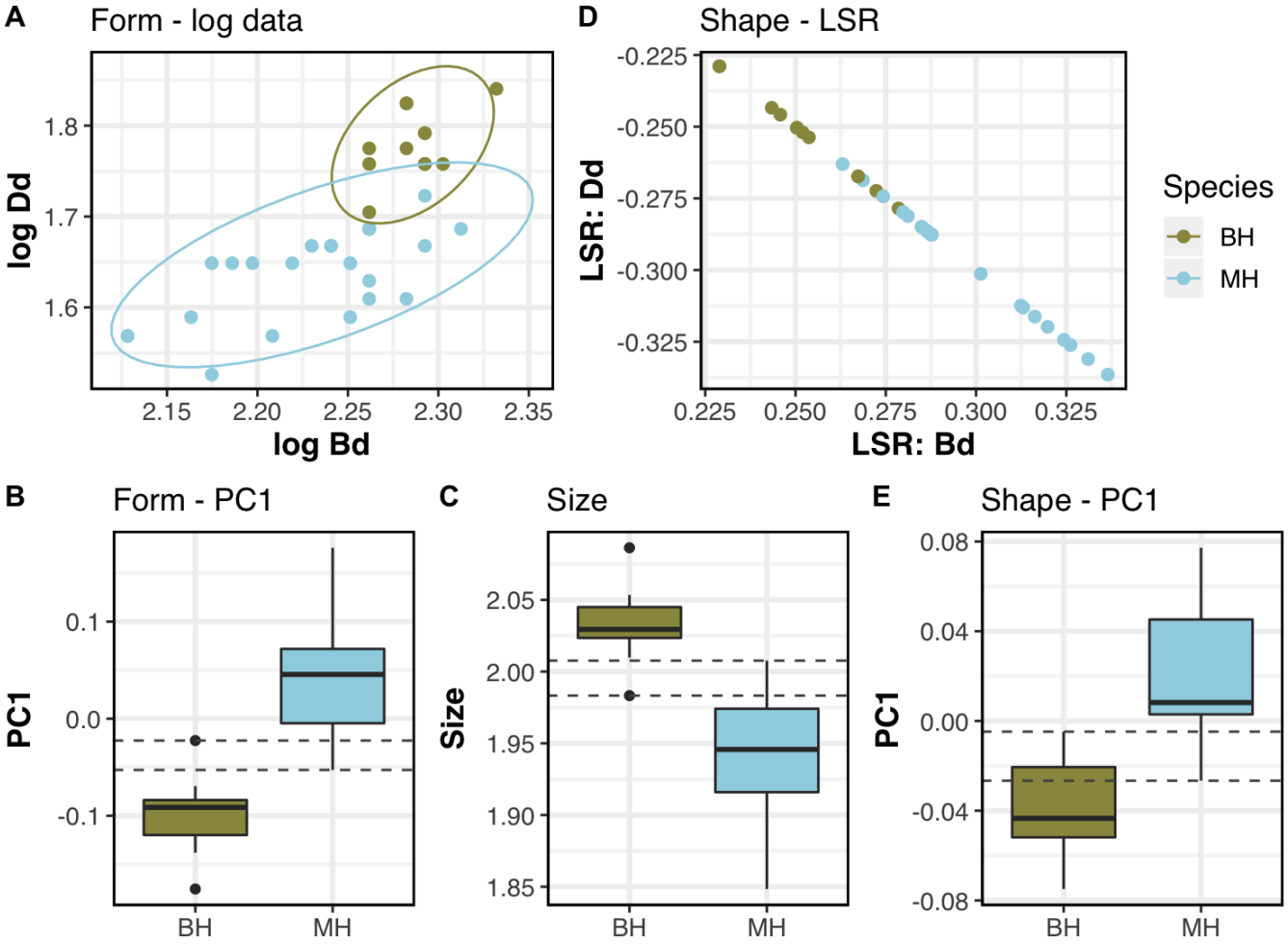

Figure 3.43: Analysis of BH vs MH (Subset A) radii using the combination Bd-Dd. A) Form - log data B) Form - PC1 C) Size D) Log-shape ratios E) Shape - PC1. Refer to Figure 3.43 for CVP results. Dotted lines in B, C and E demarcate the area of overlap between species.

require the proximal end (Table 3.25). Approaches requiring the distal end (Bd-Dd, Bd, and Dd) were all accepted, albeit not preferred) and of them save univariate Bd had mean CVP values above ninety percent.

Table 3.28: First ten ranks of cross-validation results on approaches for separating BH and MH and rabbit radii (Subset B).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	81	Prefer	Form	Bp, Dd	bi	PC1	95.2	98.6	100.0
1	81	Prefer	Form	Bp, SD, Dd	tri	PC1	95.2	98.4	100.0
1	81	Prefer	Size	Bp, Dd	bi	–	95.2	98.3	100.0
1	81	Prefer	Size	Bp, SD, Dd	tri	–	95.2	98.9	100.0
2	78	Prefer	Form	Bp	uni	–	93.8	96.9	100.0
3	77	Prefer	Shape	Bp, GL, Bd	tri	PC1	92.9	96.6	100.0
4	76	Prefer	Size	Dd, SD	bi	–	90.5	97.8	100.0
5	75	Prefer	Form	Bp, SD, Dp	tri	PC1	90.5	97.0	100.0
5	75	Prefer	Form	Dd, SD	bi	PC1	90.5	96.7	100.0
5	75	Prefer	Shape	Bp, GL, Dp	tri	PC1	90.5	97.0	100.0
5	75	Prefer	Size	Bp, Dp, Dd	tri	–	90.5	96.8	100.0
5	75	Prefer	Size	Bp, SD, Dp	tri	–	90.5	97.1	100.0
5	75	Prefer	Size	Dd, Bd, SD	tri	–	90.5	97.1	100.0
6	74	Prefer	Form	Bp, Bd, Dd	tri	PC1	90.5	96.0	100.0
6	74	Prefer	Form	Bp, Dp, Dd	tri	PC1	90.5	95.8	100.0
6	74	Prefer	Form	Dd, Bd, SD	tri	PC1	90.5	95.9	100.0
6	74	Prefer	Shape	Bp, GL	bi	PC1	90.5	95.7	100.0
6	74	Prefer	Size	Bp, Bd, Dd	tri	–	90.5	96.2	100.0
6	74	Prefer	Size	Bp, GL, Dd	tri	–	90.5	95.9	100.0
6	74	Prefer	Size	Bp, SD	bi	–	91.7	94.9	97.9
6	74	Prefer	Size	Dp, Dd	bi	–	90.5	95.8	100.0
7	73	Prefer	Form	Bp, Dp	bi	PC1	90.5	94.9	100.0
7	73	Prefer	Form	Dp, Dd	bi	PC1	90.5	94.8	100.0
7	73	Prefer	Form	Dp, SD	bi	PC1	90.5	94.7	100.0

Table 3.29: Frequency of cross-validation verdicts for BH, MH and rabbit (Subset B) radii by completeness requirement. 'Complete' is defined as 'requiring both the proximal and distal epiphyses for the metrics combination to be taken'. 'Incomplete' means that only one epiphysis is needed

Verdict	Complete	Incomplete	Percent Complete
Prefer	29	9	76
Accept	46	7	87
Reject	72	11	87

Table 3.28: *(continued)*

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
7	73	Prefer	Shape	Bp, GL, SD	tri	PC1	90.5	95.2	100.0
7	73	Prefer	Size	Bp, Dp	bi	–	90.5	95.6	100.0
7	73	Prefer	Size	Dp, Bd, Dd	tri	–	90.5	95.5	100.0
8	72	Prefer	Form	Bp, Dp, Bd	tri	PC1	90.5	93.9	100.0
8	72	Prefer	Form	Dp, Bd, Dd	tri	PC1	90.5	94.4	100.0
8	72	Prefer	Shape	Bp, GL, Dd	tri	PC1	90.5	94.3	100.0
8	72	Prefer	Size	Bp, Dp, Bd	tri	–	90.5	94.6	100.0
8	72	Prefer	Size	Bp, GL	bi	–	90.5	94.1	97.6
8	72	Prefer	Size	Dp, GL, Dd	tri	–	90.5	93.8	100.0
8	72	Prefer	Size	Dp, SD	bi	–	90.5	94.5	100.0
9	71	Prefer	Form	Bp, SD	bi	PC1	89.6	94.1	97.9
10	69	Prefer	Form	Bp, SD, Bd	tri	PC1	88.1	93.2	97.6
10	69	Prefer	Size	Bp, Bd	bi	–	88.1	93.6	97.6
10	69	Prefer	Size	Bp, SD, Bd	tri	–	88.1	93.5	97.6

Overall, the radius is surprisingly effective for separating lagomorph species. As with the humerus, the best approaches do not have much applicability to archaeological material, but there are plenty of other accepted approaches with high cross-validation scores that can be applied.

Table 3.30: Summary of metrics and morphometric variables accepted/rejected through cross-validation for the ulna.

Set	Accept	Reject	Total	Percent Accepted
a	31	21	52	60
b	32	20	52	62

3.3.2.5 Ulna

In hares, the ulna is a significant element because the diaphysis and distal end are so greatly reduced (Figure 3.6) that three of the four available metrics are located on the proximal end. Complete archaeological specimens are rare, if not impossible to find. Consequently, approaches that make use of the Greatest Length, even if diagnostic, need to be discounted.

There are fewer available metrics available than for previous elements; just fifty-two combinations were tested for each subset. Twenty-eight were based on form, fourteen on shape and ten on size. A total of thirty-one were accepted for Subset A and thirty-two for Subset B (Table 3.30). Form-based approaches were most commonly successful for Subset A, followed by size and then shape (Figure 3.44). For Subset B, equal numbers of form and size approaches were preferred, but form outnumbered shape and size for other accepted ones. No size-based approaches were rejected.

All of the preferred approaches had mean CVP values above ninety-percent, of which there were nineteen for Subset A and twenty for Subset B. Form and shape approaches had the highest CVP values for Subset A.

For other accepted approaches, mean CVP was most dispersed for size in Subset A, whilst this was true of form in Subset B. The median of the shape approaches' CVP values was lowest for shape in Subset A, but the distribution was more restricted. Rejected approaches were strongly skewed towards small CVPs for form in Subset B, but skewed towards higher values in Subset A.

Seven approaches requiring only the proximal end were preferred in Subset A (e.g. Figures 3.46, 3.47) and include the only trivariate possible (BPC-DPA-SDO) , a number of bivariates and univariate SDO. All had mean CVP values above ninety-six percent accuracy and occupied ranks four and six. Ranks one to three, five, and seven to

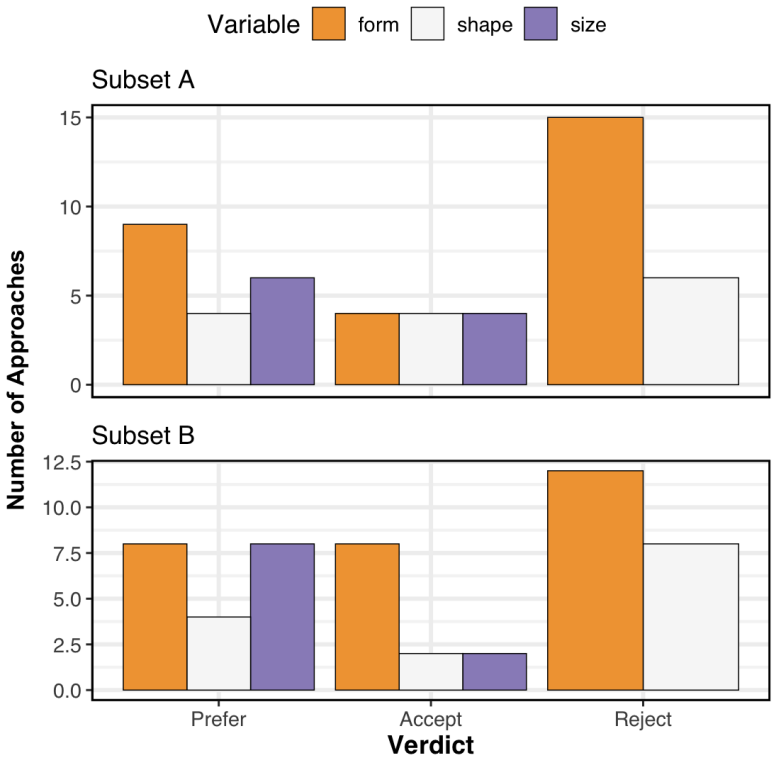

Figure 3.44: Number of approaches on lagomorph ulnae for both subsets by cross-validation verdict and morphometric variable.

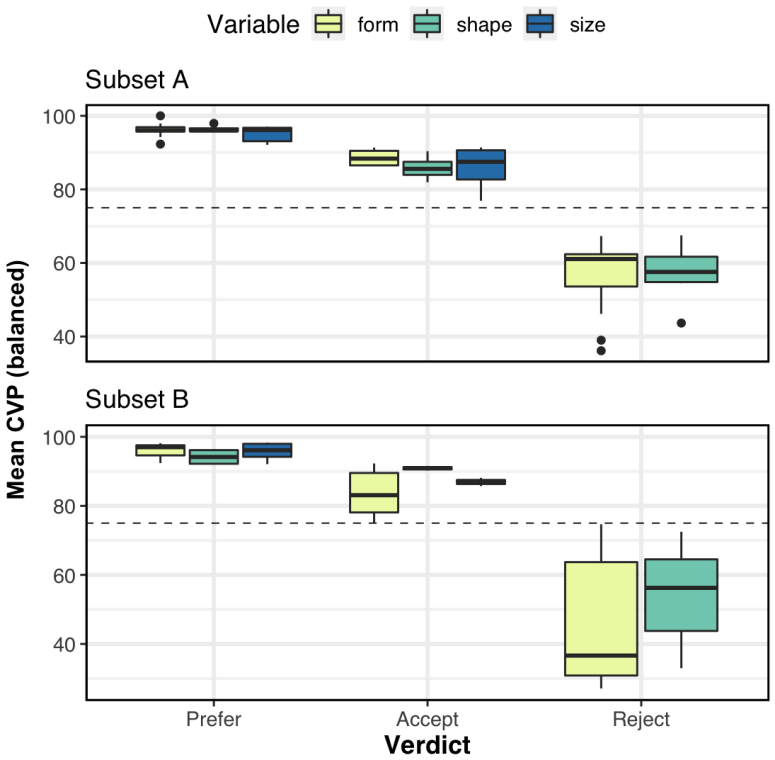

Figure 3.45: Box plots of mean CVP (balanced) for ulnae by verdict and morphometric variable for both subsets. Dashed line shows the 75% acceptance threshold.

ten therefore all require complete bones because they use the Greatest Length. The combination BPC-SDO-GL was found to one hundred percent accurate for form and averaged at 97.9% accurate for shape (Figure 3.48).

A further six approaches not requiring complete bones were accepted, including form and size for BPC-DPA, and univariate BPC and DPA. Univariate DPA, at rank fifteen, is the first approach that does not require complete bones to have a mean CVP value of less than ninety percent. Given that the DPA and SDO are taken close together (Figure 3.6), so they are likely to be recordable together archaeologically, and that both univariate SDO and the combination DPA-SDO appear among the preferred approaches, it is recommended that only approaches with greater than ninety-percent accuracy are used for the ulna. It is unnecessary to use a lower standard in favour of greater archaeological applicability. Despite having relatively few available metrics, the ulna is therefore an excellent skeletal element for separating brown and mountain hares.

Table 3.31: First ten ranks of cross-validation results on approaches for separating BH and MH ulnae (Subset A).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	70	Prefer	Form	BPC, SDO, GL	tri	PC1	100.0	100.0	100.0
2	66	Prefer	Form	SDO, GL	bi	PC1	97.9	97.9	97.9
3	64	Prefer	Shape	BPC, SDO, GL	tri	PC1	95.8	97.9	100.0
4	63	Prefer	Form	BPC, DPA, SDO	tri	PC1	96.4	96.8	98.2
4	63	Prefer	Form	BPC, SDO	bi	PC1	96.4	96.9	98.2
4	63	Prefer	Size	BPC, DPA, SDO	tri	–	96.4	96.9	98.2
4	63	Prefer	Size	BPC, SDO	bi	–	96.4	97.0	100.0
5	62	Prefer	Shape	BPC, DPA, GL	tri	PC1	96.2	96.2	96.2
5	62	Prefer	Shape	DPA, SDO, GL	tri	PC1	95.8	95.8	95.8
5	62	Prefer	Shape	SDO, GL	bi	PC1	95.8	95.8	95.8
5	62	Prefer	Size	BPC, SDO, GL	tri	–	95.8	96.3	100.0
6	61	Prefer	Form	DPA, SDO	bi	PC1	94.6	96.0	98.2
6	61	Prefer	Size	DPA, SDO	bi	–	94.6	96.0	98.2
6	61	Prefer	Form	SDO	uni	–	94.6	96.1	98.2
7	59	Prefer	Form	DPA, SDO, GL	tri	PC1	93.8	95.7	97.9

Table 3.31: *(continued)*

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
8	58	Prefer	Form	BPC, DPA, GL	tri	PC1	94.2	94.2	94.2
9	55	Prefer	Form	BPC, GL	bi	PC1	92.3	92.3	92.3
10	54	Prefer	Size	DPA, SDO, GL	tri	–	91.7	92.1	93.8
10	54	Prefer	Size	SDO, GL	bi	–	91.7	92.1	93.8

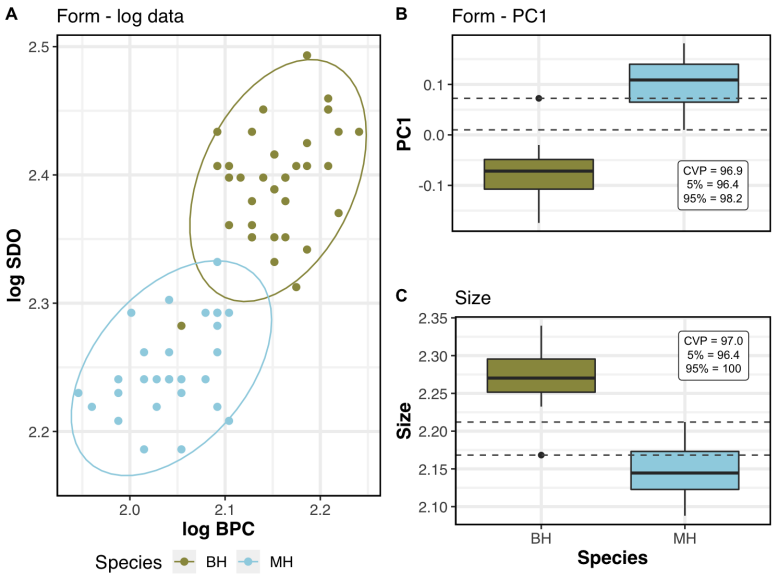

Figure 3.46: Analysis of BH vs MH ulnae using the combination BPC-SDO. A) Form - log data B) Form - PC1 C) Size. CVP results indicated. Dotted lines in B and C indicate area of overlap between species, but note that this overlap only exists because of an outlier. This specimen was from the MNHN collection, originating in the Haute-Marne region of France. It is uncertain whether this result means the specimen should be considered a misidentified mountain hare.

Similar findings were observed for Subset B and are not discussed in detail. Importantly, approaches using BPC-SDO (Figure 3.49) and DPA-BPC are both among the preferred group (Table 3.32).

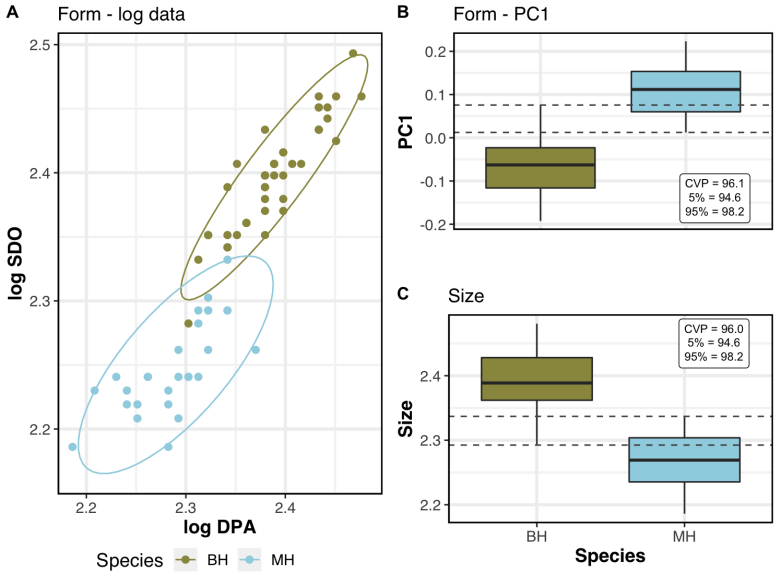

Figure 3.47: Analysis of BH vs MH ulnae using the combination DPA-SDO. A) Form - log data B) Form - PC1 C) Size. CVP results indicated. Dotted lines in B and C indicate area of overlap between species. Note that the outlier identified in Figure 3.46 is identifiable in the mountain hare ellipse in A, but it is not separated from the BH distribution as an outlier in B and C.

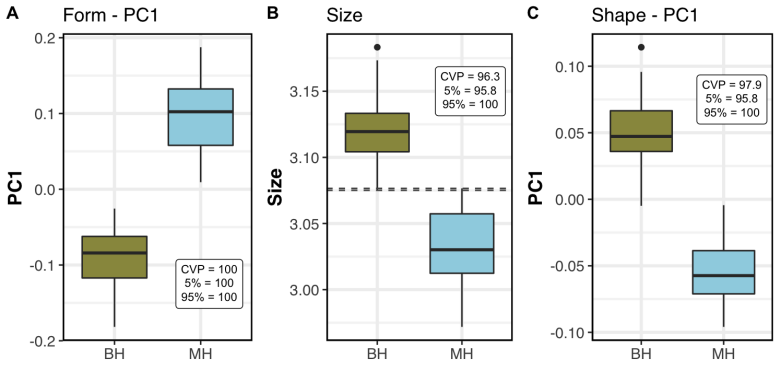

Figure 3.48: Analysis of BH vs MH ulnae using the combination BPC-SDO-GL. A) Form - PC1 B) Size C) Shape - PC1. CVP results indicated. Dotted lines in B indicate area of overlap between species.

Table 3.32: First ten ranks of cross-validation results on approaches for separating BH and MH and rabbit ulnae (Subset B).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	81	Prefer	Form	BPC, DPA, SDO	tri	PC1	95.6	98.0	100.0
1	81	Prefer	Form	BPC, SDO	bi	PC1	95.6	98.2	100.0
1	81	Prefer	Size	BPC, DPA, SDO	tri	–	95.6	98.1	100.0
1	81	Prefer	Size	BPC, SDO	bi	–	95.6	98.3	100.0
2	80	Prefer	Size	BPC, SDO, GL	tri	–	95.2	97.9	100.0
3	78	Prefer	Form	DPA, SDO	bi	PC1	93.3	97.4	100.0
3	78	Prefer	Size	DPA, SDO	bi	–	93.3	97.1	100.0
3	78	Prefer	Form	SDO	uni	–	93.3	97.3	100.0
4	77	Prefer	Form	BPC, SDO, GL	tri	PC1	92.9	96.7	100.0
4	77	Prefer	Shape	BPC, DPA, GL	tri	PC1	92.9	96.4	100.0
5	76	Prefer	Shape	BPC, SDO, GL	tri	PC1	92.9	96.1	100.0
6	73	Prefer	Form	DPA, SDO, GL	tri	PC1	90.5	94.8	97.6
6	73	Prefer	Size	DPA, SDO, GL	tri	–	90.5	95.1	100.0
7	72	Prefer	Size	SDO, GL	bi	–	90.5	94.3	97.6
8	70	Prefer	Form	BPC, DPA	bi	PC1	88.9	94.1	97.8
8	70	Prefer	Size	BPC, DPA	bi	–	88.9	94.1	97.8
9	68	Prefer	Form	SDO, GL	bi	PC1	88.1	92.4	97.6
9	68	Prefer	Shape	SDO, GL	bi	PC1	88.1	92.2	95.2
10	67	Prefer	Shape	BPC, GL	bi	PC1	88.1	92.1	97.6
10	67	Prefer	Size	BPC, DPA, GL	tri	–	88.1	92.1	97.6

In summary, the ulna is limited in archaeological applicability, because the distal end is seldom recoverable. The three metrics on the proximal end, however, are more than sufficient to confidently distinguish between lagomorphs in British populations.

3.3.2.6 Pelvis

The pelvis is another skeletal element where taphonomic processes can greatly impinge on archaeological applicability. Though more robust than the mandible or distal ulna,

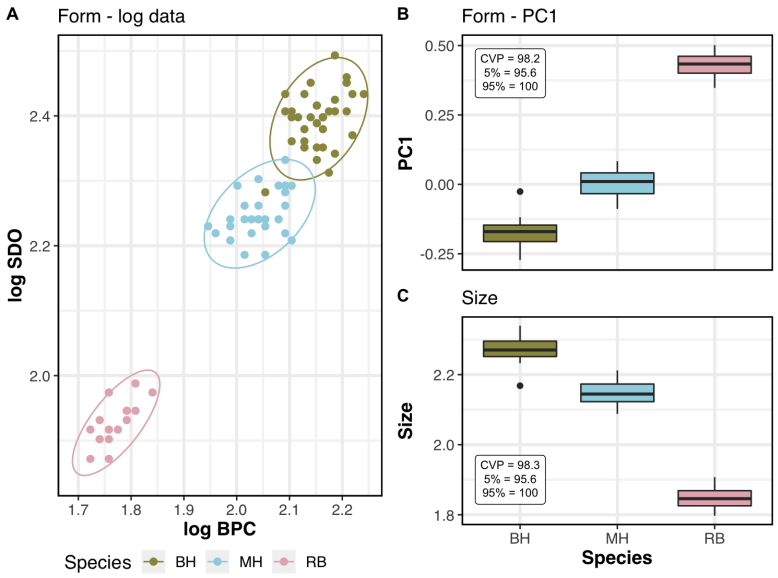

Figure 3.49: Analysis of BH, MH and rabbit ulnae using the combination BPC-SDO. A) Form - log data B) Form - PC1 C) Size.

Table 3.33: Summary of metrics and morphometric variables accepted/rejected through cross-validation for the pelvis.

Set	Accept	Reject	Total	Percent Accepted
a	23	29	52	44
b	24	28	52	46

it is still prone to fragmentation into unmeasurable pieces, and is - even when whole - less measurable than long bones. That it may also vary according to sex (though note that in rabbits Watson et al. (2019a) found variance could not be explained only by age and sex and Pelletier (2019) found negligible evidence for dimorphism across the skeleton) could also complicate the interpretation of the data.

For each subset, fifty-two approaches corresponding to fourteen combinations of metrics (including univariates) were run. Twenty-eight were based on form, fourteen on shape and ten on size (Table 3.33). Twenty-three were accepted for Subset A and twenty-four for Subset B.

For both subsets, all of the shape-based approaches were rejected. Eighteen fell into the top ten (preferred) ranks for Subset A and twenty-one for Subset B (Figure 3.50). That only five and three other approaches were accepted for the subsets, respectively,

suggests a more dichotomous division between the best approaches and the rejected ones than has been seen in other elements, with little middle-ground.

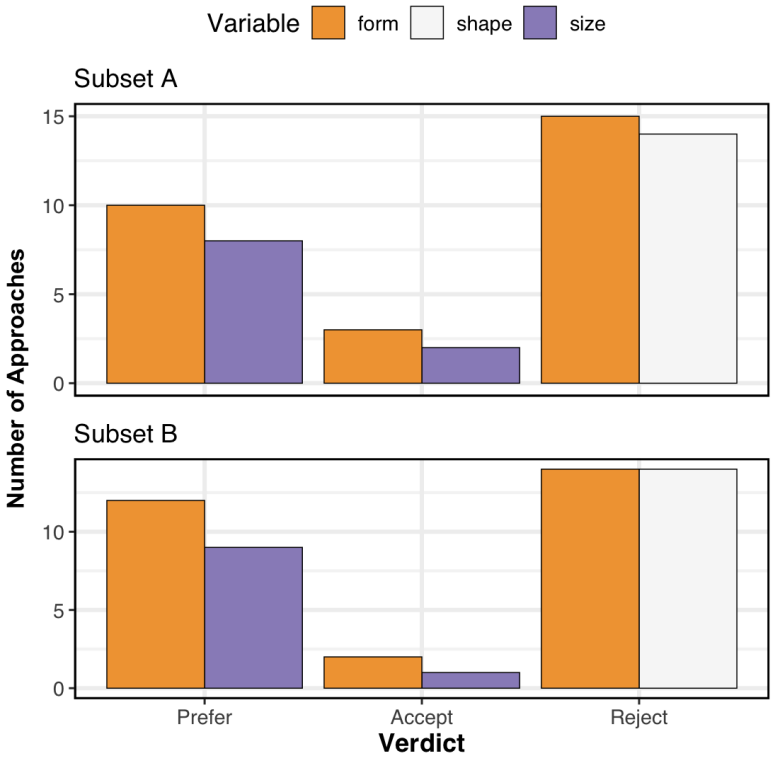

Figure 3.50: Cross-validation verdicts on approaches to lagomorph pelves by morphometric variable for both subsets.

This interpretation is supported by the distribution of mean CVP, especially in Subset B where all the rejected approaches for form had mean CVP values below fifty percent accuracy (Figure 3.51) - well below the seventy-five percent threshold for acceptance. Among the preferred approaches, the pelvis is the worst performing element so far; none in Subset A were more than ninety percent accurate, and only seven in Subset B (Figure 3.52).

The metrics used can be broadly defined as requiring either the portion anterior of the acetabulum (SB, SH), posterior of the acetabulum (LFo), or the whole pelvis (GL). Any combination other than SB-SH or univariate SB, SH and LFo, consequently requires complete bones. For Subset A, only four approaches applicable to fragmented material were accepted, evenly split between "Prefer" (Table 3.34) and "Accept". Importantly, those for preferred approaches are univariate (LFo and SH, Figure 3.53) and the others

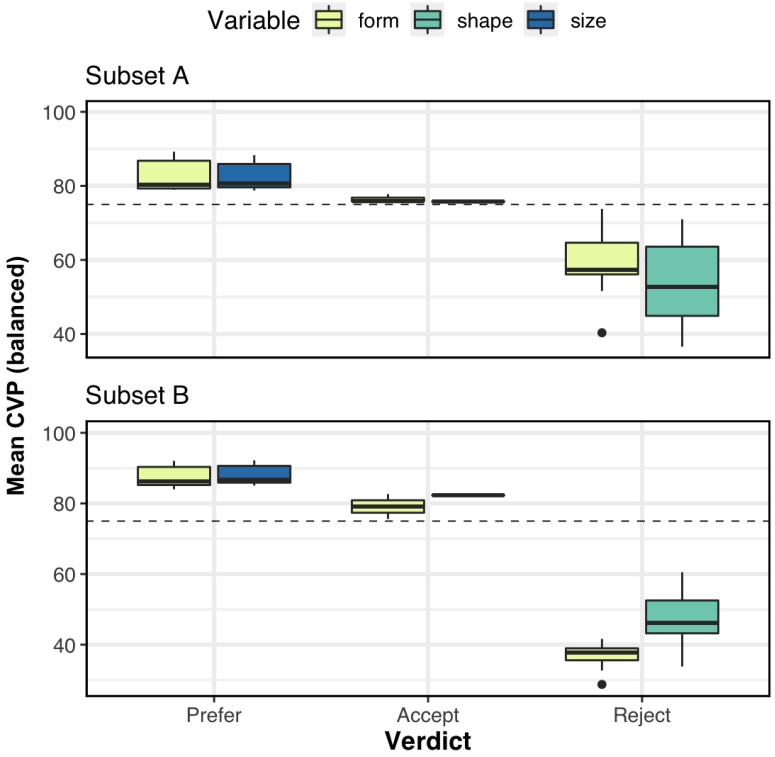

Figure 3.51: Box plots of mean CVP (balanced) for pelves by verdict and morphometric variable for both subsets. Dashed line shows the 75% acceptance threshold.

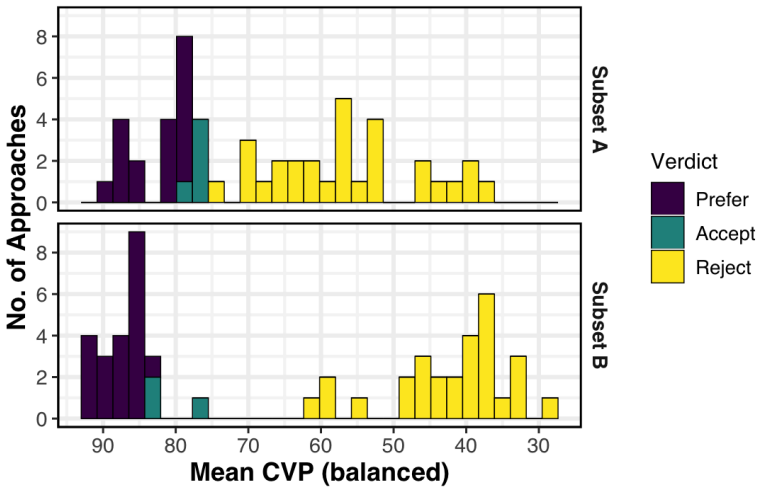

Figure 3.52: Histograms of mean CVP (balanced) for pelves by verdict and subset.

are form and size for SB-SH (Figure 3.54). LFo is unlikely to often be applicable to archaeological material because of the fragility of the pubis and symphysis. SB-SH barely meets the established thresholds with mean CVP equal to 75.9 and 75.7 percent for form and size, respectively.

Table 3.34: First ten ranks of cross-validation results on approaches for separating BH and MH pelves (Subset A).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	48	Prefer	Form	LFo, GL	bi	PC1	88.6	89.2	90.9
2	45	Prefer	Size	LFo, GL	bi	–	86.4	88.3	90.9
2	45	Prefer	Form	GL	uni	–	87.0	88.0	91.3
3	44	Prefer	Form	LFo, SH, GL	tri	PC1	86.4	87.2	88.8
4	43	Prefer	Size	LFo, SH, GL	tri	–	86.4	86.8	88.6
5	40	Prefer	Form	SH, GL	bi	PC1	84.8	85.6	87.0
5	40	Prefer	Size	SH, GL	bi	–	84.8	85.6	87.0
6	31	Prefer	Form	LFo	uni	–	80.3	80.3	80.3
7	29	Prefer	Form	SH, LFo	bi	PC1	79.0	80.3	82.3
7	29	Prefer	Size	SB, SH, GL	tri	–	78.3	81.2	84.8
7	29	Prefer	Size	SH, LFo	bi	–	79.0	80.1	82.3
8	28	Prefer	Form	SB, SH, GL	tri	PC1	78.3	79.7	84.8
8	28	Prefer	Size	SB, LFo	bi	–	79.0	79.3	80.7
9	27	Prefer	Form	SB, LFo	bi	PC1	77.4	79.2	80.7
9	27	Prefer	Form	SH	uni	–	78.1	79.2	81.2
10	26	Prefer	Form	LFo, SB, GL	tri	PC1	77.3	78.9	81.8
10	26	Prefer	Size	LFo, SB, GL	tri	–	77.3	78.8	81.8
10	26	Prefer	Size	SB, GL	bi	–	76.1	79.7	82.6

For Subset B, five approaches applicable to fragmentary bone were accepted, two of which were preferred - again these were the univariate SH and LFo approaches. The three other accepted approaches operable on fragmented material were SB-SH for form and size and univariate SB. SB-SH fared better here, doubtless because it is

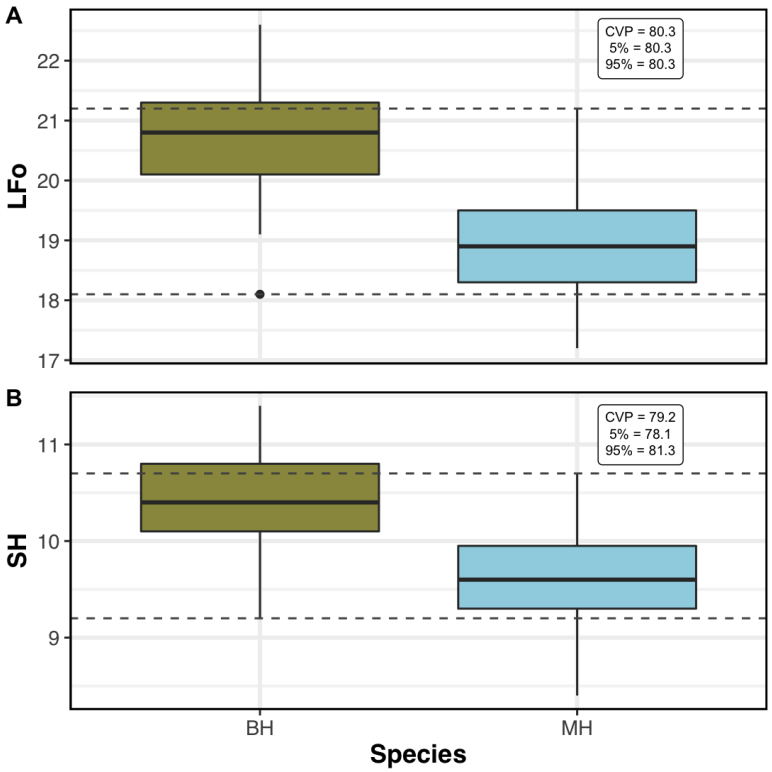

Figure 3.53: Univariate analysis of BH vs MH (Subset A) pelves with A) LFo and B) SH. Dashed lines demarcate area of overlap between species. CVP results indicated.

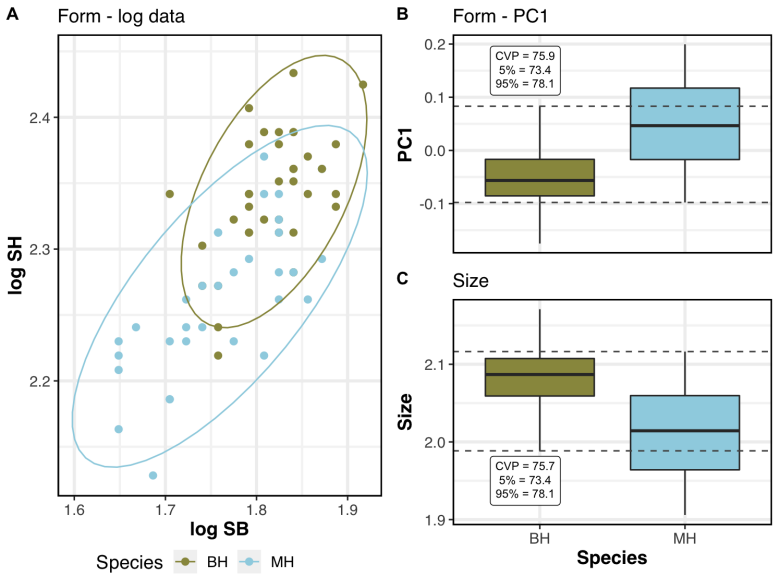

Figure 3.54: Analysis of BH vs MH (Subset A) pelves using the combination SB-SH. A) Form - log data B) Form - PC1 C) Size. CVP results indicated. Dashed lines demarcate area of overlap between species.

easier to separate rabbits from hares generally than it is to separate the three species specifically.

Table 3.35: First ten ranks of cross-validation results on approaches for separating BH and MH and rabbit pelves (Subset B).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	65	Prefer	Size	LFo, GL	bi	–	85.2	92.2	100.0
1	65	Prefer	Form	GL	uni	–	85.2	92.1	100.0
2	64	Prefer	Form	LFo, GL	bi	PC1	85.2	91.9	100.0
2	64	Prefer	Size	LFo, SH, GL	tri	–	85.2	91.0	96.3
3	63	Prefer	Size	SH, GL	bi	–	85.2	90.6	96.3
4	59	Prefer	Form	LFo, SH, GL	tri	PC1	81.5	90.4	96.3
4	59	Prefer	Form	SH, GL	bi	PC1	81.5	90.3	96.3
5	53	Prefer	Form	SH, LFo	bi	PC1	79.5	85.8	92.3
5	53	Prefer	Size	SH, LFo	bi	–	79.5	85.9	92.3
6	52	Prefer	Form	LFo, SB, GL	tri	PC1	77.8	86.8	96.3

Table 3.35: *(continued)*

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
6	52	Prefer	Form	SB, SH, GL	tri	PC1	77.8	86.6	92.8
6	52	Prefer	Size	LFo, SB, GL	tri	–	77.8	86.8	96.3
6	52	Prefer	Size	SB, LFo	bi	–	78.6	85.8	92.9
6	52	Prefer	Size	SB, SH, GL	tri	–	77.8	86.7	92.8
7	51	Prefer	Form	SB, LFo	bi	PC1	78.6	85.5	92.9
7	51	Prefer	Size	SB, GL	bi	–	77.8	85.9	92.6
7	51	Prefer	Form	SH	uni	–	78.6	85.4	92.9
8	50	Prefer	Form	SB, GL	bi	PC1	77.8	84.5	92.6
9	49	Prefer	Form	LFo, SB, SH	tri	PC1	76.9	84.6	92.3
9	49	Prefer	Size	LFo, SB, SH	tri	–	76.9	85.1	92.3
10	47	Prefer	Form	LFo	uni	–	76.2	84.0	90.5

To conclude, the pelvis has proved problematic - following expectations. Nevertheless, several accepted models are applicable to archaeological bones. It must be recognised, however, that using the pelvis requires accepting a lower level of confidence in the models than for other elements, and higher levels of scrutiny and scepticism need to be applied to the identifications made.

3.3.2.7 Femur

The femur is among the more robust long bones in the lagomorph skeleton, and likely to be one of those recovered more often archaeologically. It is also one of the most measurable, having three metrics available for the proximal end, plus one for the distal, two lengths, and the SD (Figure 3.8). Its articular ends do have more cancellous bone than others, however, so measurability may vary considerably with differing taphonomic pathways. The femoral head is the most likely point for disarticulating the hind limb, and so this area may be butchered in archaeological specimens, which could drastically alter measurability. In total, 289 approaches were applied to each subset (Table 3.36). Of the total, 148 were for form, whilst 87 and 54 were based on shape and size respectively.

Table 3.36: Summary of metrics and morphometric variables accepted/rejected through cross-validation for the femur.

Set	Accept	Reject	Total	Percent Accepted
a	126	163	289	44
b	109	180	289	38

For both subsets the majority of approaches were rejected, though there are important disparities between the two (Figure 3.57). More were accepted for Subset A than Subset B (Table 3.36). For Subset A, shape approaches dominated the top ten ranks (preferred) but form and size fared better in the other accepted approaches. By contrast, shape was almost completely rejected for Subset B. That form and size were accepted in near equal amount suggests that size/growth is a much better discriminant between hares and rabbits than shape.

High mean CVP values were rarer in Subset A than B - the most abundant CVP bin is around eighty for A, but more than eighty-five for B (Figure 3.55). Among the preferred approaches, there is similarity in the distribution of mean CVP between the subsets (Figure 3.56). As few approaches for form and size were preferred for Subset A, these have close distributions, but shape is more dispersed. All have values above ninety percent accuracy. Form and size for Subset B are similar, though the centre of the distribution is slightly skewed towards lower values.

Other accepted approaches reveal differences between the subsets (Figure 3.56). For hares (Subset A), the distribution of mean CVP is more widely dispersed, with a skew towards lower values. Subset B, meanwhile is skewed towards higher values; size has an outlying approach with the lowest CVP value among the accepted ones.

For Subset A, seventeen approaches were preferred (Table 3.37) but only two of those are useful for incomplete bones (Bp-BTr-DC and Bp-BTr - both using shape PC1; see Figure 3.58 for the latter). All others required either a length (GL or GLC) or the Bd or SD with one of the measurements on the proximal end. A further 109, however, were accepted, of which twelve work with incomplete bones; nine of the twelve had mean CVP values higher than eighty percent accuracy. These included Bp-DC (Figure 3.59) for form and size, as well as the univariate form approaches for Bp, DC and Bd. This means that even where only one measurement can be taken - at either articular end -

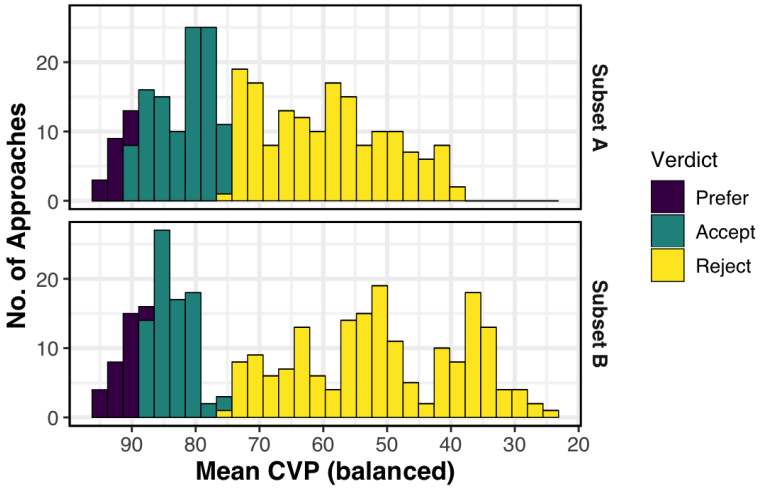

Figure 3.55: Histogram showing frequency of mean CVP values by verdict for both subsets.

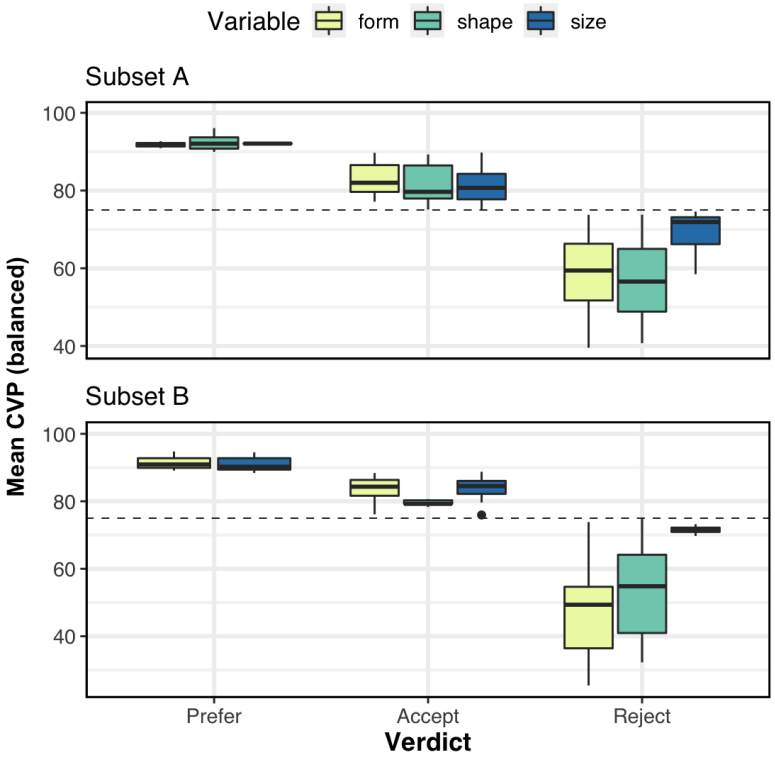

Figure 3.56: Distribution of mean CVP (balanced) by morphometric variable and cross-validation verdict for femora. Both subsets. Dashed line shows the 75% acceptance threshold.

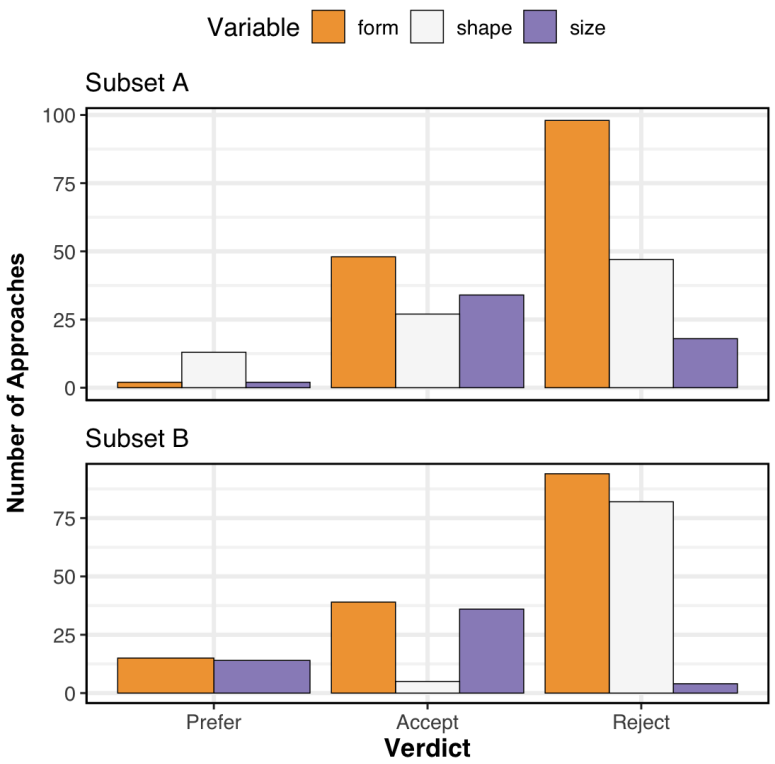

Figure 3.57: Frequency of cross-validation verdicts by morphometric variable for both subsets.

hares can be distinguished with these models and the resulting identification can be expected to be wrong less than fifteen percent of the time. Note that BTr-DC (Figure 3.60) for shape and form scored a mean CVP above eighty, but size scored 76.7% (see Appendix Table A.17 for all the results).

Table 3.37: First ten ranks of cross-validation results on approaches for separating BH and MH femora (Subset A).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	61	Prefer	Shape	Bp, DC, GLC	tri	PC1	95.2	96.1	98.4
2	59	Prefer	Shape	Bp, DC, GL	tri	PC1	93.5	95.1	96.8
3	56	Prefer	Shape	Bp, GL, GLC	tri	PC1	92.2	93.7	95.3
4	55	Prefer	Shape	Bp, BTr, GLC	tri	PC1	91.1	93.9	94.6
5	54	Prefer	Shape	Bp, GLC, Bd	tri	PC1	90.7	92.9	96.3
5	54	Prefer	Shape	Bp, GLC	bi	PC1	90.6	93.1	95.3
6	53	Prefer	Form	Bp, DC, Bd	tri	PC1	90.4	92.7	96.2
6	53	Prefer	Shape	Bp, BTr, GL	tri	PC1	91.1	92.1	94.6
7	51	Prefer	Shape	Bp, GL, Bd	tri	PC1	88.9	92.0	94.4
7	51	Prefer	Shape	Bp, GL	bi	PC1	89.1	91.9	93.8
8	50	Prefer	Shape	DC, GLC, Bd	tri	PC1	88.9	90.8	92.6
9	49	Prefer	Size	Bp, Bd	bi	–	87.0	92.2	96.3
9	49	Prefer	Size	Bp, DC, Bd	tri	–	86.5	92.0	96.2
10	48	Prefer	Form	Bp, Bd	bi	PC1	87.0	90.9	94.4
10	48	Prefer	Shape	Bp, BTr, DC	tri	PC1	87.5	90.5	92.9
10	48	Prefer	Shape	Bp, BTr	bi	PC1	87.5	90.4	92.9
10	48	Prefer	Shape	BTr, DC, SD	tri	PC1	87.9	90.0	93.1

For Subset B, twenty-nine approaches were preferred (Table 3.38), of which nineteen do not require complete archaeological bones. These nineteen were based on eleven unique metrics combinations. These included univariate approaches - Bp, DC and Bd. The smallest mean CVP value among the nineteen was 89.9 percent. A further twenty-one approaches (that work for incomplete bones) were accepted.

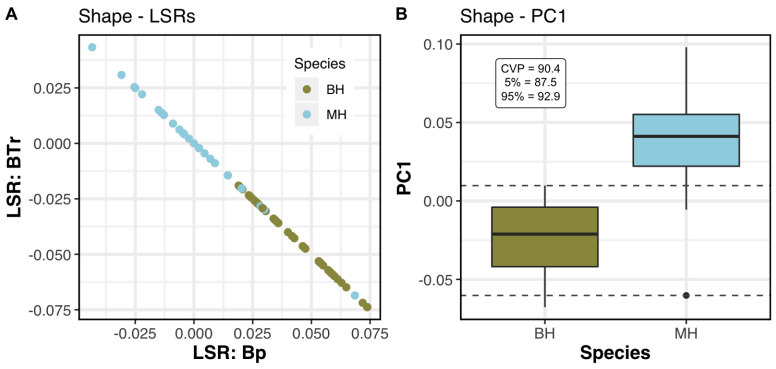

Figure 3.58: Shape analysis of BH vs MH (Subset A) femora using the combination Bp-BTr. A) Scatter plot of log-shape ratios B) PC1. CVP results indicated. Dashed lines demarcate area of overlap between species.

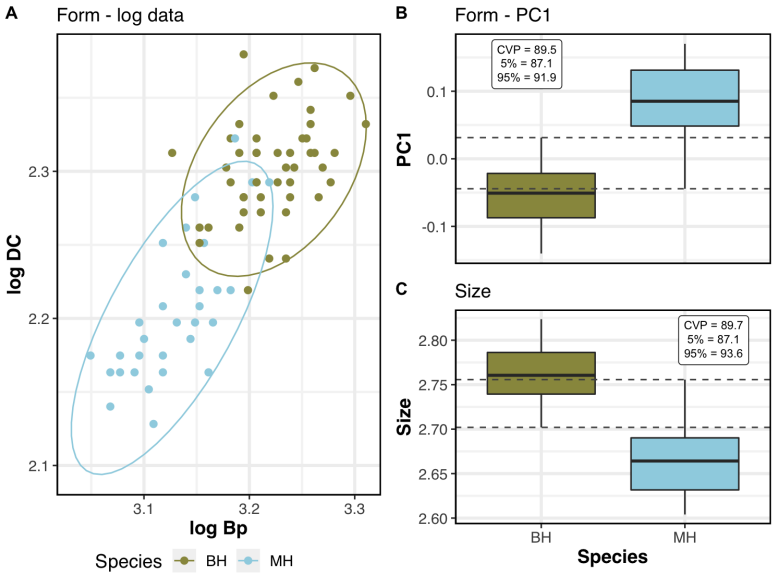

Figure 3.59: Analysis of BH vs MH (Subset A) femora using the combination Bp-DC A) Form - log data B) Form - PC1 C) Size. CVP results indicated. Dashed lines mark area of overlap between species.

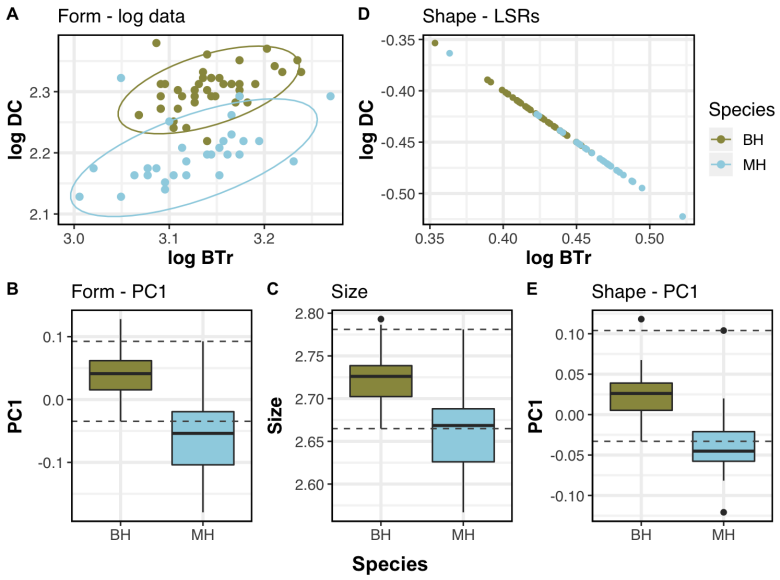

Figure 3.60: Analysis of BH vs MH (Subset A) femora using the combination BTr-DC. A) Form - log data B) Form - PC1 C) Size D) Shape - log-shape ratios E) Shape - PC1. Dashed lines demarcate areas of overlap between species. Refer to Appendix Table A.17 at ranks 22, 27 and 36 for CVP figures.

Table 3.38: First ten ranks of cross-validation results on approaches for separating BH and MH and rabbit femora (Subset B).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	72	Prefer	Form	Bp, DC, Bd	tri	PC1	89.7	94.7	100.0
1	72	Prefer	Size	Bp, DC, Bd	tri	–	89.7	94.5	100.0
2	70	Prefer	Size	Bp, Bd	bi	–	88.1	94.2	100.0
3	69	Prefer	Form	Bp, Bd	bi	PC1	88.1	93.8	97.6
4	68	Prefer	Form	Bp, DC	bi	PC1	87.2	93.4	97.4
4	68	Prefer	Size	Bp, DC	bi	–	87.2	93.4	97.4
5	67	Prefer	Form	Bp, DC, SD	tri	PC1	87.2	93.0	97.4
5	67	Prefer	Form	DC, Bd	bi	PC1	87.2	92.4	97.4
5	67	Prefer	Form	DC, SD, Bd	tri	PC1	87.2	92.6	97.4
5	67	Prefer	Size	Bp, DC, SD	tri	–	87.2	92.8	97.4
5	67	Prefer	Size	DC, Bd	bi	–	87.2	92.8	97.4

Table 3.38: *(continued)*

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
6	64	Prefer	Size	DC, SD, Bd	tri	–	84.6	92.2	97.4
6	64	Prefer	Form	Bp	uni	–	85.7	90.9	97.6
7	63	Prefer	Form	DC, SD	bi	PC1	84.6	90.8	97.4
7	63	Prefer	Size	DC, SD	bi	–	84.6	90.6	97.4
7	63	Prefer	Form	DC	uni	–	84.6	91.2	97.4
8	61	Prefer	Form	Bp, BTr, DC	tri	PC1	83.3	90.4	97.2
8	61	Prefer	Form	Bp, DC, GLC	tri	PC1	84.6	89.3	94.9
8	61	Prefer	Size	Bp, BTr, DC	tri	–	83.3	89.9	97.2
8	61	Prefer	Form	Bd	uni	–	83.3	90.3	95.2
9	59	Prefer	Form	Bp, DC, GL	tri	PC1	82.0	89.5	94.9
9	59	Prefer	Form	Bp, GL, Bd	tri	PC1	82.0	89.5	94.9
9	59	Prefer	Size	Bp, DC, GL	tri	–	82.0	89.4	94.9
9	59	Prefer	Size	Bp, GL, Bd	tri	–	82.0	89.5	94.9
9	59	Prefer	Size	Bp, GLC, Bd	tri	–	82.0	89.4	94.9
10	58	Prefer	Form	Bp, GLC, Bd	tri	PC1	82.0	89.1	94.9
10	58	Prefer	Size	Bp, DC, GLC	tri	–	82.0	88.9	94.9
10	58	Prefer	Size	DC, GL, Bd	tri	–	82.0	88.5	94.9
10	58	Prefer	Size	DC, GLC, Bd	tri	–	82.0	88.4	94.9

In summary, the femur is a highly measurable element with excellent discriminatory power for separating species in British lagomorph populations. Indeed, concerns that no additional metrics could be created for the distal end (page 153), leaving only the Bd, proved unfounded because this measurement was among the preferred approaches for Subset B and for Subset A, though not preferred, still had a high CVP score of 85.6 percent.

3.3.2.8 Tibia

The tibia is a highly measurable skeletal element in lagomorphs. Having a cortical distal end and a moderately cancerous proximal end, it is likely to preserve well in

Table 3.39: Summary of metrics and morphometric variables accepted/rejected through cross-validation for the tibia.

Set	Accept	Reject	Total	Percent Accepted
a	206	250	456	45
b	209	247	456	46

archaeological contexts. The addition of three proximal depth metrics (page 152) ensured measurability in cases where only the proximal end occurred.

In total, 456 approaches were applied to the tibia with 232 based on form, 140 on shape, and 84 on size. A total of 206 were accepted for Subset A and 209 for Subset B (Table 3.39).

All three types of morphometric variable performed well. Form was most frequently preferred in both Subsets and for Subset B most of the size-based approaches passed (Figure 3.61). It is noteworthy that five approaches account for ranks one and two and are all based on shape. The distribution of mean CVP is the most unusual so far for the number of outlier approaches that are detected for Subset A (Figure 3.62). Regardless, the preferred approaches have a high standard of accuracy and the skew towards similarly high values among the other accepted approaches is encouraging. The most common CVP values for Subset A fall in to the second highest bin and are all preferred approaches (Figure 3.63).

For Subset A, sixty-eight approaches were preferred, the largest number of approaches to appear in the top ten ranks so far, and a further 138 were also accepted. As so many approaches were preferred the results are not reproduced here; they can be consulted in Appendix Table A.19. Among the preferred approaches, twelve are usable with incomplete bones. These comprise seven different combinations. There are univariates, Dp and DPL, six bivariate approaches combining either Bp with a proximal depth or two proximal depths (Figures 3.64 and 3.65), plus four trivariates (all proximal end).

That the proximal end fared so well vindicates the decision to define the new three depth measurements, in the absence of good alternatives in the literature. It also bodes well for the archaeological application of these models, as the need for these metrics was identified by observing skeletal element patterns in key archaeological

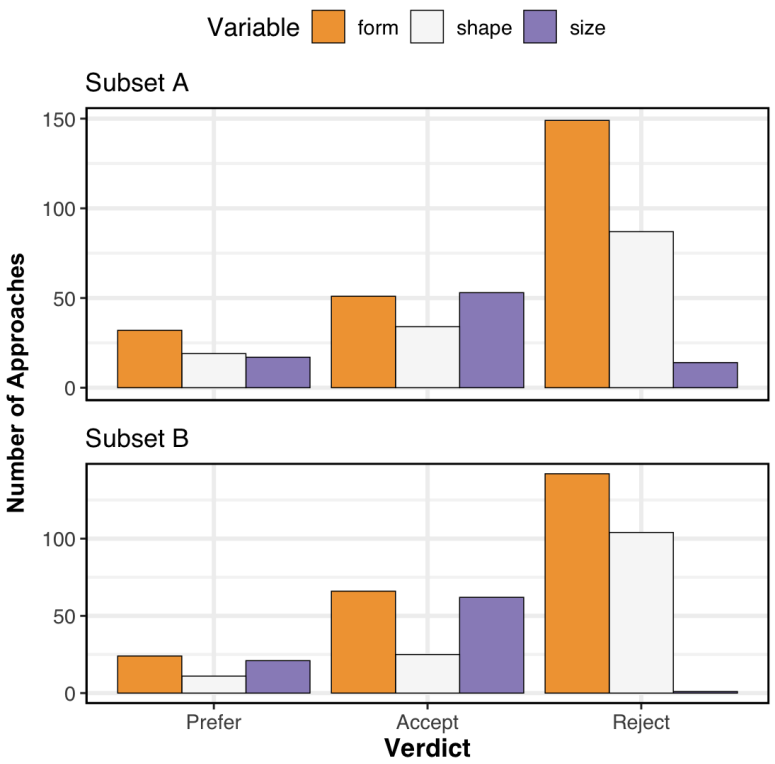

Figure 3.61: Cross-validation verdicts for tibiae by morphometric variable for both subsets.

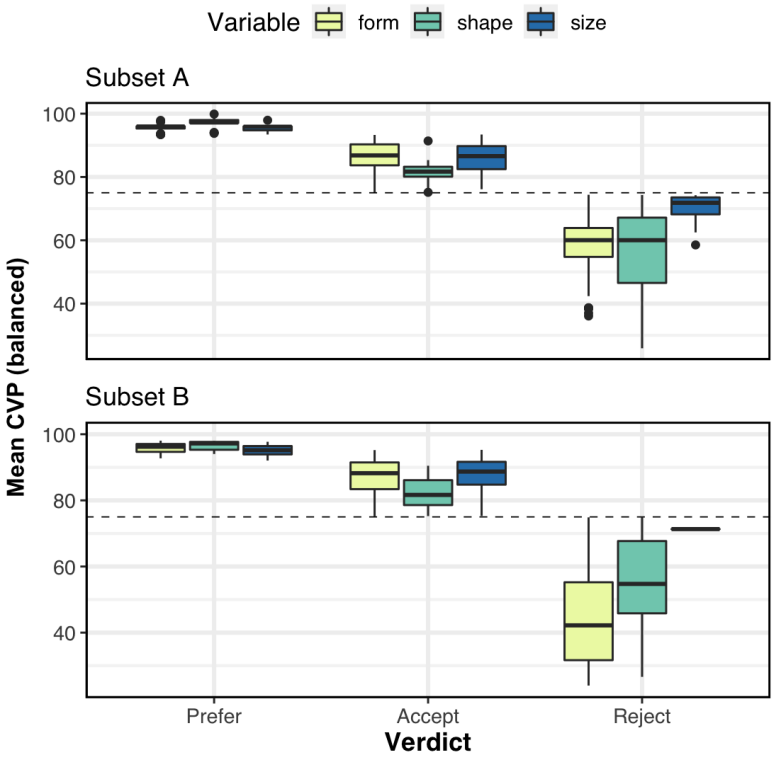

Figure 3.62: Distribution of CVP for approaches on tibiae by morphometric variable and cross-validation verdict. Both subsets shown. Dashed line shows the 75% acceptance threshold.

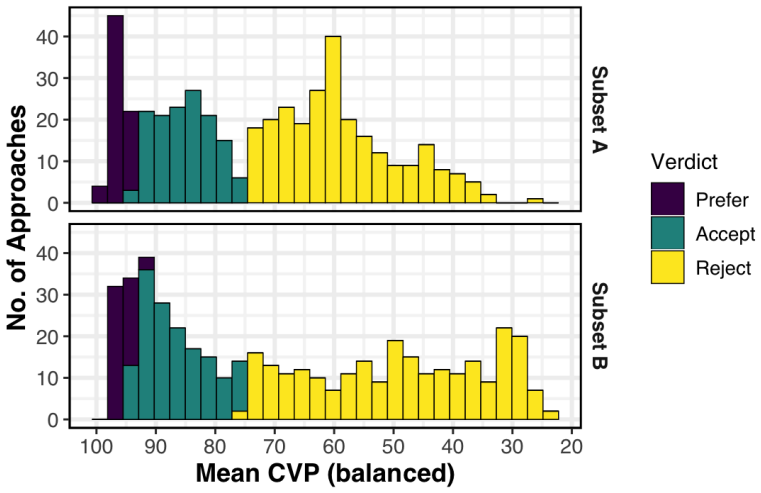

Figure 3.63: Histogram showing mean CVP for approaches on both subsets for the tibia, grouped by verdict.

material (page 152).

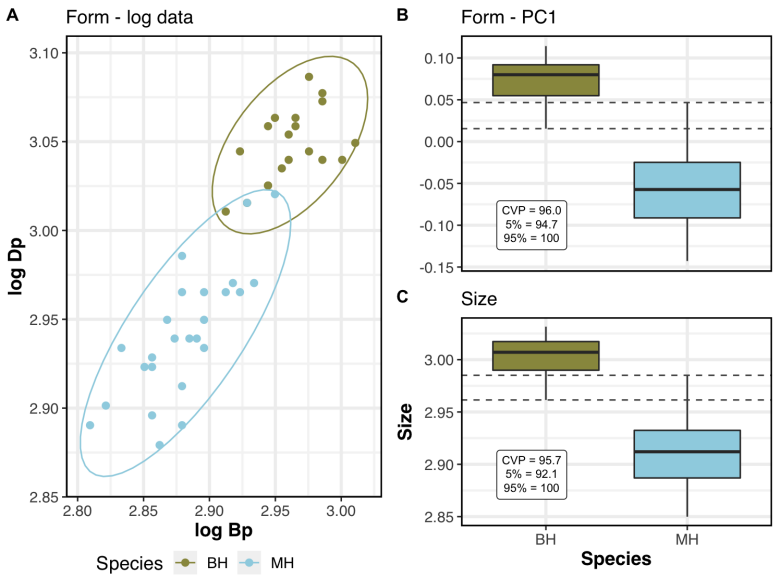

Figure 3.64: Analysis of BH vs MH tibiae using the combination Bp-Dp. A) Form - log data B) Form - PC1 C) Size. CVP results indicated. Dashed lines demarcate areas of overlap between species.

But, the key distal end combination, Bd-Dd, is absent from the preferred approaches. It was accepted for form and size, but is found low in the ranking system. Form (PC1) appears at rank forty and size at forty-two; forty-six was the lowest rank for accepted approaches (Appendix Table A.19). Of the two, form should therefore be preferred, but it must nevertheless be borne in mind that identifications made with the distal end are less effective than those with the proximal.

Fifty-six approaches were preferred for Subset B (all results in Appendix Table A.20), of which eleven work with incomplete bones. The combinations profile of these is similar to Subset A - all involve the proximal end. The combination Bd-Dd ranked higher in this subset, with mean CVP for size (its best performing approach) being 86.4 percent.

In summary, the tibia is a highly measurable element and plenty of archaeologically useful models have been identified. The experimental approach to defining new measurements that fit well with *vdD* was a potential flaw in the methods used here, but instead has been thoroughly justified by cross-validation. There is a disparity between the effectiveness of the proximal and distal end which requires additional consideration, as butchery practices will influence comparability between assemblages.

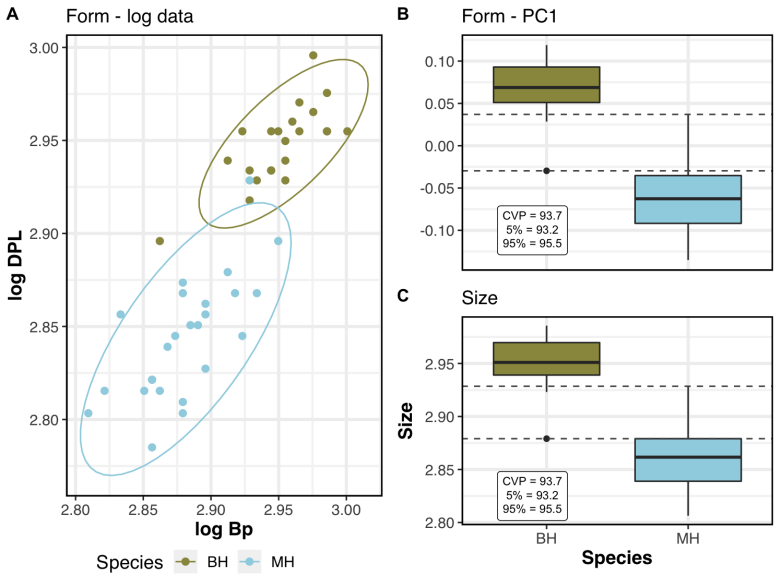

Figure 3.65: Analysis of BH vs MH tibiae using the combination Bp-DPL. A) Form - log data B) Form - PC1 C) Size. CVP results indicated. Dashed lines demarcate areas of overlap between species.

Medieval kitchen assemblages from Woking Palace (Roberts et al. 2017: p. 170) and Little Pickle (Bourdillon 1998: p. 143) have high abundances of distal rabbit tibiae, for example. If similar patterns occur for hares, identifications of bones drawn from kitchens will be more uncertain in comparison to other contexts.

3.3.2.9 Calcaneum

The calcaneum is the most measurable of the foot bones selected for study, though this is only a consequence of extending *vdD*. Being a dense skeletal element, it can be expected to be complete in most archaeological contexts (Pelletier 2018: p. 38), although its size may preclude recovery. The most likely cause of a reduction in measurability would be the distal tuberosity being unfused, which would make the GL, GLT, GBT and GDT unrecordable, leaving the GB, SBT and SDT.

A total of 301 approaches from sixty-three combinations were tested. Form accounted for 154 approaches, shape for 91 and size for 56. For Subset A, a total of 145 were accepted and 119 for Subset B (Table 3.40).

Form and size were the most successful approaches (Figure 3.66). Shape was preferred twice for Subset A and accepted twenty-seven times; sixty-two were rejected. Shape

Table 3.40: Summary of metrics and morphometric variables accepted/rejected through cross-validation for the calcaneum.

Set	Accept	Reject	Total	Percent Accepted
a	145	156	301	48
b	119	182	301	40

was entirely rejected for Subset B, however. In preferred approaches, Subset A is slightly biased towards size over form; the reverse is true for for Subset B. For other accepted approaches, form is more common than size for both subsets, though this reflects form being tested using multiple principal components whereas size is tested as a single raw variable. The highest values of mean CVP for the calcaneum are lower than has been seen for other elements, the highest for Subset A being ninety-three percent accuracy. Mean CVP is more narrowly distributed for Subset B than for A (Figure 3.67), creating a gap between the distribution of preferred/accepted and rejected approaches in B that is not so apparent in A (Figure 3.68). The largest peak in the distribution of Subset B approaches corresponds to the bin for the highest CVP values, pointing to a large number of high-ranking models. That both preferred and accepted models appear in this peak suggests, however, that there are some approaches that scored highly for mean CVP but scored unusually low against the 5% confidence interval. That points to greater variation in cross-validation depending on which specimens are selected by the resampling procedure employed by the `mevolCVP()` function.

For Subset A, forty-seven approaches from twenty-five unique combinations fell into the top ten ranks of preferred models. Importantly, sixteen of those twenty-five were trivariate combinations (e.g. Figure 3.69), eight were bivariate and there was one univariate. This means that the best approaches require highly measurable archaeological specimens. Notably, the top eleven approaches (ranks 1 to 5) all use the SDT. This is intriguing because the SDT and SBT were both created, only with experimentation in mind, to provide approximations of GBT and GDT that might yield a similar result in cases where the latter two could not be taken because the epiphysis was unfused or otherwise missing. Instead, it has been discovered that the SDT is a functional discriminator between hare species in its own right, both as a univariate and when used in combination with measurements that require a complete, fused calcaneum - such as the GBT, GDT, GL and GLT. For example, the combination SDT-GLT (Figure 3.70)

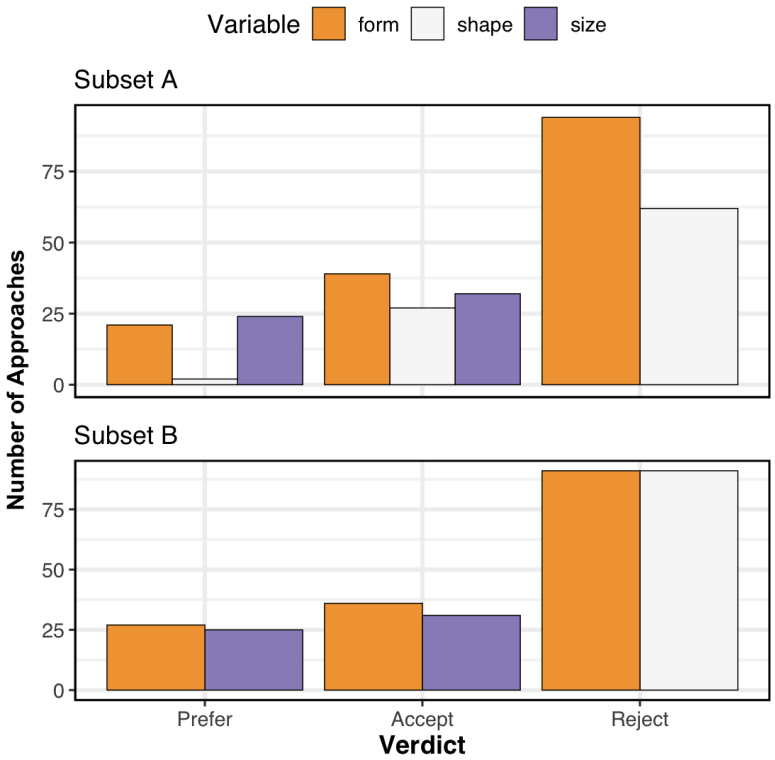

Figure 3.66: Frequency of cross-validation verdicts for both subsets of the calcaneum according to morphometric variable.

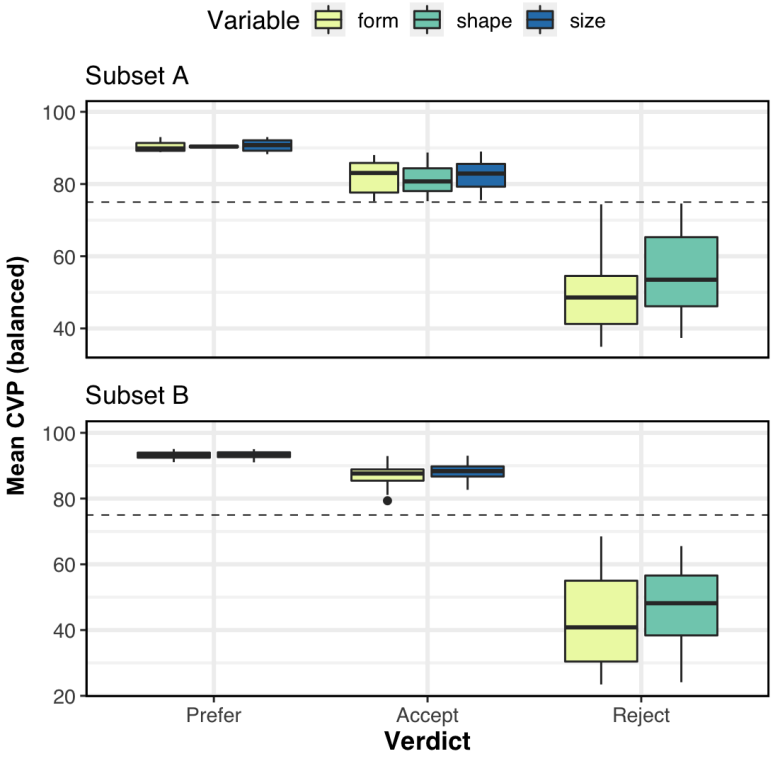

Figure 3.67: Distribution of mean CVP for both subsets of the calcaneum by cross-validation verdict and morphometric variable. Dashed line shows the 75% acceptance threshold.

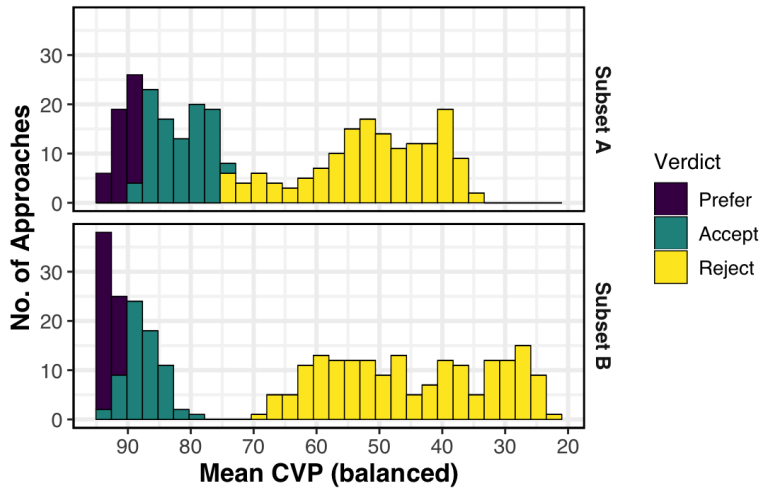

Figure 3.68: Histogram of mean CVP (balanced) for both calcaneum subsets according to cross-validation verdict.

is the best bivariate.

Table 3.41: First ten ranks of cross-validation results on approaches for separating BH and MH calcanea (Subset A).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	54	Prefer	Form	GB, GLT, SDT	tri	PC1	90.6	92.9	96.9
1	54	Prefer	Form	GL, GLT, SDT	tri	PC1	90.6	93.0	96.9
1	54	Prefer	Size	GB, GL, SDT	tri	–	90.6	92.9	96.9
1	54	Prefer	Size	GLT, GDT, SDT	tri	–	90.6	93.0	96.9
2	53	Prefer	Form	SDT, GLT	bi	PC1	90.6	92.5	96.9
2	53	Prefer	Size	GLT, GBT, SDT	tri	–	90.6	92.8	96.9
2	53	Prefer	Size	SDT, GLT	bi	–	90.6	92.6	96.9
3	52	Prefer	Form	GB, GL, SDT	tri	PC1	90.6	91.9	93.8
4	50	Prefer	Size	GB, GBT, SDT	tri	–	87.5	92.5	96.9
4	50	Prefer	Size	GB, GLT, SDT	tri	–	87.5	92.7	96.9
5	49	Prefer	Form	GB, SDT	bi	PC1	87.5	91.1	93.8
5	49	Prefer	Form	GL, GLT, GDT	tri	PC1	87.5	91.7	96.9
5	49	Prefer	Form	SDT, GL	bi	PC1	87.5	91.4	96.9
5	49	Prefer	Size	GB, GDT, SDT	tri	–	87.5	92.0	96.9
5	49	Prefer	Size	GB, SDT	bi	–	87.5	91.5	93.8
5	49	Prefer	Size	GL, GBT, SDT	tri	–	87.5	91.1	93.8
5	49	Prefer	Size	GL, GDT, SDT	tri	–	87.5	91.2	93.8
5	49	Prefer	Size	GLT, GBT, GDT	tri	–	87.5	91.3	93.8
5	49	Prefer	Size	SDT, GL	bi	–	87.5	91.3	93.9
6	48	Prefer	Form	GL, GBT, SDT	tri	PC1	87.5	90.5	93.8
6	48	Prefer	Form	GLT, GBT, SDT	tri	PC1	87.5	90.3	93.8
6	48	Prefer	Size	GL, GLT, SDT	tri	–	87.5	90.3	93.8
6	48	Prefer	Form	SDT	uni	–	87.5	90.3	93.8
7	47	Prefer	Form	GB, GBT, SDT	tri	PC1	87.5	89.5	93.8
7	47	Prefer	Size	GB, GDT	bi	–	87.3	89.8	93.8
7	47	Prefer	Size	GB, GL, GDT	tri	–	87.5	89.7	93.8

Table 3.41: *(continued)*

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
8	45	Prefer	Shape	GB, SDT	bi	PC1	84.4	90.8	96.9
8	45	Prefer	Size	GL, GBT, GDT	tri	–	84.4	90.5	93.8
9	44	Prefer	Form	GBT, GDT, SDT	tri	PC1	84.4	89.3	93.8
9	44	Prefer	Form	GL, GBT, GDT	tri	PC1	84.4	89.3	93.8
9	44	Prefer	Form	GL, GDT, SDT	tri	PC1	84.4	89.9	93.8
9	44	Prefer	Form	GLT, GBT, GDT	tri	PC1	84.4	89.5	93.8
9	44	Prefer	Form	GLT, GDT, SDT	tri	PC1	84.4	89.2	93.8
9	44	Prefer	Form	SDT, GBT	bi	PC1	84.4	89.1	93.8
9	44	Prefer	Shape	GB, GDT, SDT	tri	PC1	84.4	90.0	93.8
9	44	Prefer	Size	GBT, GDT, SDT	tri	–	84.4	89.2	93.8
9	44	Prefer	Size	GDT, GL	bi	–	84.4	89.2	96.9
9	44	Prefer	Size	GDT, GLT	bi	–	84.4	90.1	96.9
10	43	Prefer	Form	GB, GBT, GDT	tri	PC1	84.4	88.8	93.8
10	43	Prefer	Form	GB, GL, GDT	tri	PC1	84.4	88.9	93.8
10	43	Prefer	Form	GB, GLT, GDT	tri	PC1	84.4	89.1	93.8
10	43	Prefer	Form	GBT, GDT	bi	PC1	84.4	89.0	93.8
10	43	Prefer	Size	GB, GBT, GDT	tri	–	84.4	88.7	90.6
10	43	Prefer	Size	GB, GLT, GDT	tri	–	84.4	88.3	93.8
10	43	Prefer	Size	GBT, GDT	bi	–	84.4	89.1	93.8
10	43	Prefer	Size	GL, GLT, GDT	tri	–	84.4	88.7	93.8
10	43	Prefer	Size	SDT, GBT	bi	–	84.4	89.0	93.8

Shape occurs in the list of preferred approaches only twice, whilst there are twenty-one form and twenty-four size approaches. That shape has not performed well almost certainly reflects differences between log-shape ratio and geometric morphometric methods for analysing shape. The calcaneum is a favourable element for archaeological studies, especially using GMM. It survives well, has multiple articular facets that can be targeted, and is intimately connected with locomotion (Pelletier 2018: p. 38-9).

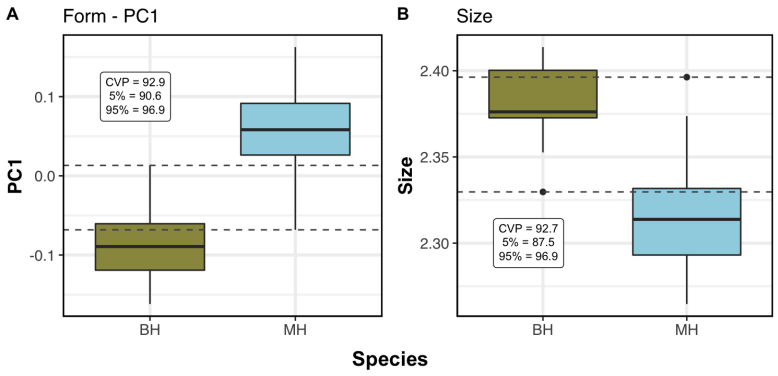

Figure 3.69: Analysis of BH vs MH (Subset A) calcanea using the combination GB-GLT-SDT A) Form - PC1 B) Size. CVP results indicated. Dashed lines demarcate area of overlap between species.

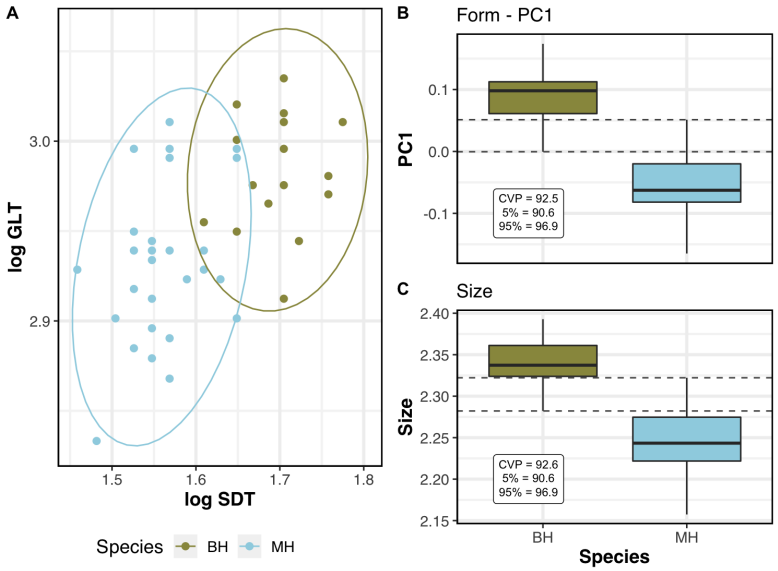

Figure 3.70: Analysis of BH vs MH (Subset A) calcanea using the combination SDT and GLT. A) Form - log data B) Form - PC1 C) Size. CVP results indicated. Dashed lines demarcate area of overlap between species.

But in GMM, landmarks can be placed to target individual facets, condyles and muscle attachments. Linear metrics can only cover overall shape. Secondly, GMM datasets have high dimensionality, and PCA reduces it to tens of dimensions to avoid over-fitting (Kovarovic et al. 2011; Evin et al. 2013; Owen et al. 2014: p. 161). The approach here instead uses only up to three dimensions and employs PCA to convert the data into useable morphometric variables, with the effect of also reducing dimensionality to one dimension per test. Considering these factors, it is perhaps not surprising that a small (therefore having less variance in its measurements, see VanPool et al. 2011: p. 54-5; Sokal et al. 2012: p. 426-8) but morphologically complex element would discriminate between species best when dimensionality was initially higher (three metrics rather than two) and when the majority constituent of the variance (isometric size) has not been removed.

Fifty-two approaches were preferred for Subset B, the combinations included in which are identical to Subset A (Table 3.42). The SDT is still an important metric and the majority of combinations are trivariate. Shape was entirely rejected, but form and size had a high standard of accuracy, with the median of the mean CVP distribution across all the preferred approaches being over ninety-three percent for both variables.

Table 3.42: First ten ranks of cross-validation results on approaches for separating BH and MH and rabbit calcanea (Subset B).

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
1	73	Prefer	Form	GB, GL, SDT	tri	PC1	90.5	95.1	100
1	73	Prefer	Size	GB, GL, SDT	tri	–	90.5	95.0	100
2	71	Prefer	Form	GB, GLT, SDT	tri	PC1	88.9	94.4	100
2	71	Prefer	Size	GLT, GDT, SDT	tri	–	88.9	94.6	100
3	70	Prefer	Form	GL, GBT, SDT	tri	PC1	88.9	94.0	100
3	70	Prefer	Size	GL, GBT, SDT	tri	–	88.9	94.1	100
3	70	Prefer	Size	SDT, GLT	bi	–	88.9	94.2	100
4	68	Prefer	Form	GLT, GBT, SDT	tri	PC1	86.7	94.0	100
4	68	Prefer	Size	GLT, GBT, SDT	tri	–	86.7	94.1	100
5	67	Prefer	Form	GB, SDT	bi	PC1	85.7	93.9	100
5	67	Prefer	Form	GDT, GL	bi	PC1	85.7	93.6	100

Table 3.42: *(continued)*

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
5	67	Prefer	Form	GL, GDT, SDT	tri	PC1	85.7	94.3	100
5	67	Prefer	Form	SDT, GL	bi	PC1	85.7	94.4	100
5	67	Prefer	Size	GB, SDT	bi	–	85.7	93.8	100
5	67	Prefer	Size	GDT, GL	bi	–	85.7	93.6	100
5	67	Prefer	Size	GL, GDT, SDT	tri	–	85.7	94.2	100
5	67	Prefer	Size	SDT, GL	bi	–	85.7	94.4	100
6	66	Prefer	Form	GB, GDT, SDT	tri	PC1	85.7	93.2	100
6	66	Prefer	Form	GB, GL, GDT	tri	PC1	85.7	93.1	100
6	66	Prefer	Form	GL, SBT, SDT	tri	PC1	85.7	92.5	100
6	66	Prefer	Size	GB, GDT, SDT	tri	–	85.7	93.4	100
6	66	Prefer	Size	GB, GL, GDT	tri	–	85.7	93.2	100
7	65	Prefer	Form	GB, GBT, SDT	tri	PC1	83.3	93.9	100
7	65	Prefer	Form	GB, GDT	bi	PC1	85.7	92.0	100
7	65	Prefer	Form	GLT, GDT, SDT	tri	PC1	83.3	94.4	100
7	65	Prefer	Size	GB, GLT, SDT	tri	–	83.3	94.1	100
7	65	Prefer	Size	GL, SBT, SDT	tri	–	85.7	92.4	100
7	65	Prefer	Form	SDT	uni	–	85.7	92.1	100
8	64	Prefer	Form	GDT, GLT	bi	PC1	83.3	93.1	100
8	64	Prefer	Form	SDT, GBT	bi	PC1	83.3	92.9	100
8	64	Prefer	Form	SDT, GLT	bi	PC1	83.3	93.7	100
8	64	Prefer	Size	GB, GBT, SDT	tri	–	83.3	93.5	100
8	64	Prefer	Size	GDT, GLT	bi	–	83.3	93.2	100
8	64	Prefer	Size	GL, GBT, GDT	tri	–	83.3	93.2	100
9	63	Prefer	Form	GB, GBT, GDT	tri	PC1	83.3	92.2	100
9	63	Prefer	Form	GB, GLT, GDT	tri	PC1	83.3	92.4	100
9	63	Prefer	Form	GBT, GDT	bi	PC1	83.3	92.2	100
9	63	Prefer	Form	GBT, GDT, SDT	tri	PC1	83.3	92.8	100
9	63	Prefer	Form	GL, GBT, GDT	tri	PC1	83.3	92.7	100

Table 3.42: *(continued)*

Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
9	63	Prefer	Form	GL, GLT, GDT	tri	PC1	83.3	92.7	100
9	63	Prefer	Form	GL, GLT, SDT	tri	PC1	83.3	92.6	100
9	63	Prefer	Form	GLT, SBT, SDT	tri	PC1	83.3	91.9	100
9	63	Prefer	Size	GB, GLT, GDT	tri	–	83.3	92.4	100
9	63	Prefer	Size	GBT, GDT, SDT	tri	–	83.3	92.7	100
9	63	Prefer	Size	GL, GLT, GDT	tri	–	83.3	92.8	100
9	63	Prefer	Size	GL, GLT, SDT	tri	–	83.3	92.8	100
9	63	Prefer	Size	SDT, GBT	bi	–	83.3	92.6	100
10	62	Prefer	Form	GBT, SBT, SDT	tri	PC1	83.3	91.1	100
10	62	Prefer	Size	GB, GBT, GDT	tri	–	83.3	91.8	100
10	62	Prefer	Size	GBT, GDT	bi	–	83.3	91.6	100
10	62	Prefer	Size	GBT, SBT, SDT	tri	–	83.3	91.0	100
10	62	Prefer	Size	GLT, SBT, SDT	tri	–	83.3	91.8	100

In summary, the calcaneum has proved to be a complex element. Although most elements have performed best with trivariate combinations of metrics, the calcaneum is significant for nearly seventy percent of its preferred approaches being trivariate (both subsets). Consequently, it requires high levels of measurability, but the element's density will fortunately limit fragmentation in most archaeological contexts. The most likely limit on the applicability of these models is the fusion state of the epiphysis.

3.3.2.10 Metapodia

The major foot bones, the metapodia, can be relatively large in hares - especially the metatarsals, and should consequently be recovered in smaller numbers than the major limb bones, but more often than the carpals and tarsals. They are relatively dense, so should be resistant to weathering, but are small enough to break easily and so could fragment upon excavation, if not upon or since deposition. When fragmented, recovery is less likely and identifiability may be reduced as the articulation at the proximal end is essential to distinguish between the digits. Like the astragalus, additional metrics

Table 3.43: Summary of metrics and morphometric variables accepted/rejected through cross-validation for the 2nd metatarsal.

Set	Accept	Reject	Total	Percent Accepted
a	3	3	6	50
b	4	2	6	67

were not created to supplement *vdD*'s Bd and GL as the likelihood of being able to apply them to archaeological material is low for these reasons.

Furthermore, not all of the metapodia were tested, as it was predicted that they would have little discriminatory power. Preliminary data visualisation (Figure 3.71) was used to determine which digits of the fore- and hindlimb should be tested with `mevolCVP()`. The third, fourth and fifth metatarsals produced the clearest distinctions between the species, so these were selected for cross-validation.

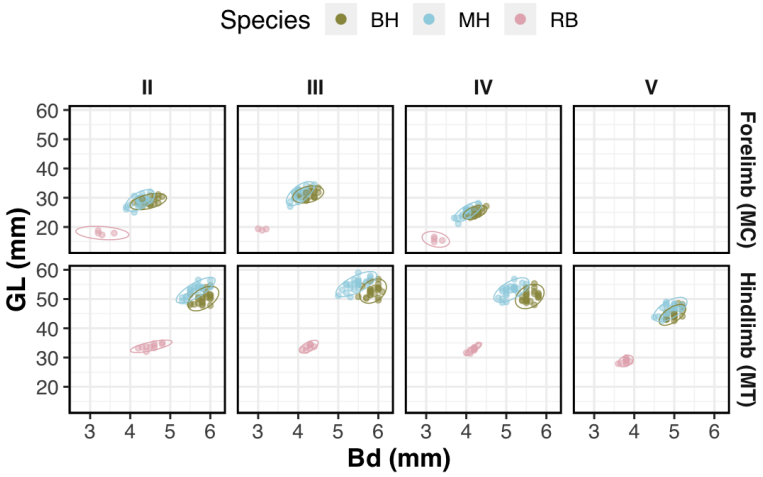

Figure 3.71: Greatest distal breadth (Bd) vs Greatest Length (GL) for lagomorph metapodia. Grouped by element according to digit (II-V) and limb (i.e. metacarpals vs metatarsals).

Six approaches were tested on each element. These constitute the univariate form tests for Bd and GL, and on the Bd-GL combination: form (PC1 and PC2), shape (PC1), and size. For Subset A, the approaches were accepted and rejected in equal numbers for all three elements (Tables 3.43, 3.44 and 3.45). For Subset B, four approaches were accepted and two rejected in all three digits.

Table 3.44: Summary of metrics and morphometric variables accepted/rejected through cross-validation for the 3rd metatarsal.

Set	Accept	Reject	Total	Percent Accepted
a	3	3	6	50
b	4	2	6	67

Table 3.45: Summary of metrics and morphometric variables accepted/rejected through cross-validation for the 4th metatarsal.

Set	Accept	Reject	Total	Percent Accepted
a	3	3	6	50
b	4	2	6	67

Equal numbers of form approaches were accepted and rejected in all three digits for Subset A (n = 2 each, Figure 3.72). For Subset B three form approaches were accepted for each digit and one was rejected. In both subsets, shape was accepted and size rejected in equal numbers across the three digits (n = 1 each).

For MT2 and MT3 it was the case that shape for Bd-GL significantly outperformed form. In MT3 for Subset A shape exceeds ninety-five percent accuracy (Figure 3.73). Likewise, MT4 has the same result, except that form also performs equally well. The differences between the digits is noteworthy, though there is little information within the data that can explain it. A plausible rationalisation, however, is that the central digits, which bear a greater proportion of the animal's weight than the peripheral ones, are subtly more intimately connected with the animal's locomotion. This could explain why the MT3 (Figure 3.75) and MT4 (Figure 3.76) perform better than MT2 (Figure 3.74). Additionally, Curran (2012) explains that cervids place their terminal phalanges on the ground in response to terrain firmness, with effects on bone morphology. Similar effects could apply to brown and mountain hares according to the terrain of their respective habitats, and could extend to the metatarsals as lagomorphs have digitigrade locomotion, but are plantigrade in the hindfoot when stationary (Bensley 1918; Carrano 1997: p. 80). Related factors influencing the effectiveness of univariate approaches might also be connected. Whilst the GL was the only accepted univariate for the MT2, it was the Bd for the MT3 and MT4.

For MT2 in Subset A, the accepted approaches were, in descending order of preference,

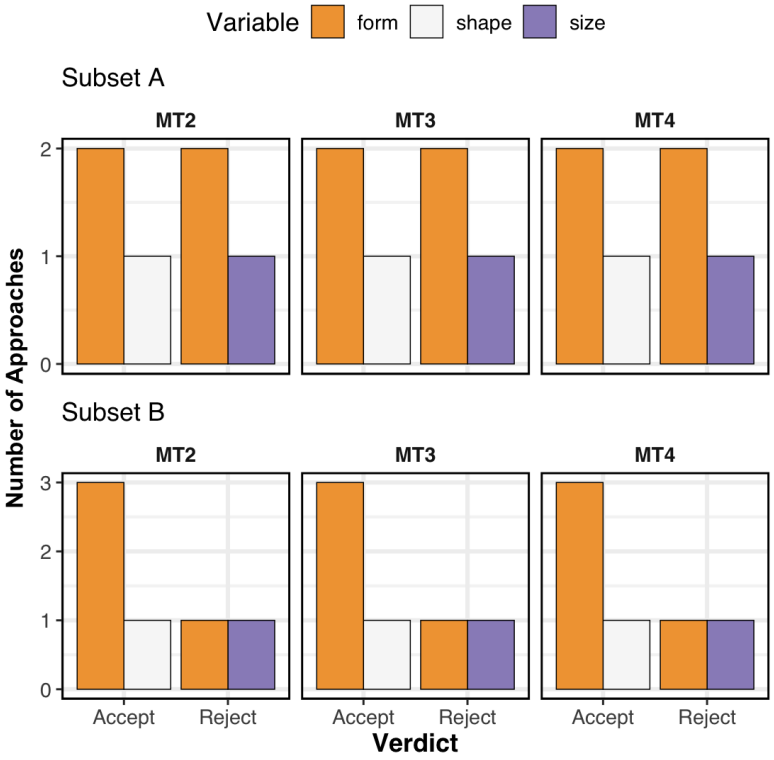

Figure 3.72: Analysis of lagomorph metapodia. Number of approaches by cross-validation verdict, morphometric variable, and element for both subsets.

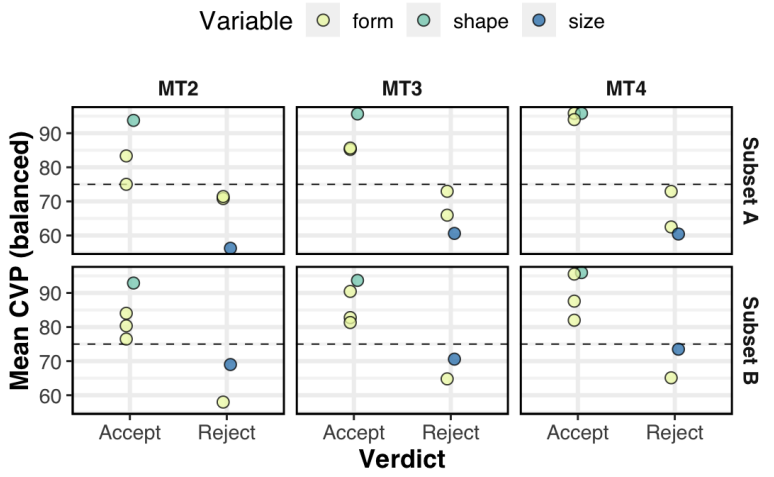

Figure 3.73: Mean CVP for approaches on the metatarsals for both subsets according to verdict and morphometric variable (each point represents and approach). Dashed line shows the 75% acceptance threshold.

shape Bd-GL (PC1), form Bd-GL (PC2), and univariate GL (Table 3.46). Note that the accepted form approach was PC2 and not PC1, the former being analogous to shape anyway. By contrast, MT3 and MT4 require shape PC1 and form PC1 (Table 3.46). Differences between species in MT2 are most pronounced for shape, whilst in MT3 and MT4 it is found in shape and allometric growth (the variance of shape and size together). Note, however, the substantial difference both in the CVP results and the visual overlap of the data between form PC2 and shape PC1 for MT2 (Figure 3.74). Shape's stronger performance here shows that although converting log metrics to principal components turns PC1 from a size axis to a growth axis, leaving other components to capture shape (Claude 2008: p. 108-9), Mosimann's (1970) log-shape ratios are a more effective method for capturing shape variance that distinguishes between species.

Table 3.46: Accepted cross-validation results on approaches for separating BH and MH metatarsals (Subset A).

Digit	Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
MT2	1	58	Accept	Shape	Bd, GL	bi	PC1	93.8	93.8	93.8
MT2	2	37	Accept	Form	Bd, GL	bi	PC2	83.3	83.3	83.3
MT2	3	20	Accept	Form	GL	uni	–	75.0	75.0	75.0
MT3	1	61	Accept	Shape	Bd, GL	bi	PC1	95.7	95.7	95.7
MT3	2	40	Accept	Form	Bd, GL	bi	PC1	84.8	85.2	87.0
MT3	2	40	Accept	Form	Bd	uni	–	84.8	85.6	87.0
MT4	1	62	Accept	Form	Bd, GL	bi	PC1	95.8	95.8	95.8
MT4	1	62	Accept	Shape	Bd, GL	bi	PC1	95.8	95.8	95.8
MT4	2	58	Accept	Form	Bd	uni	–	93.8	94.0	95.8

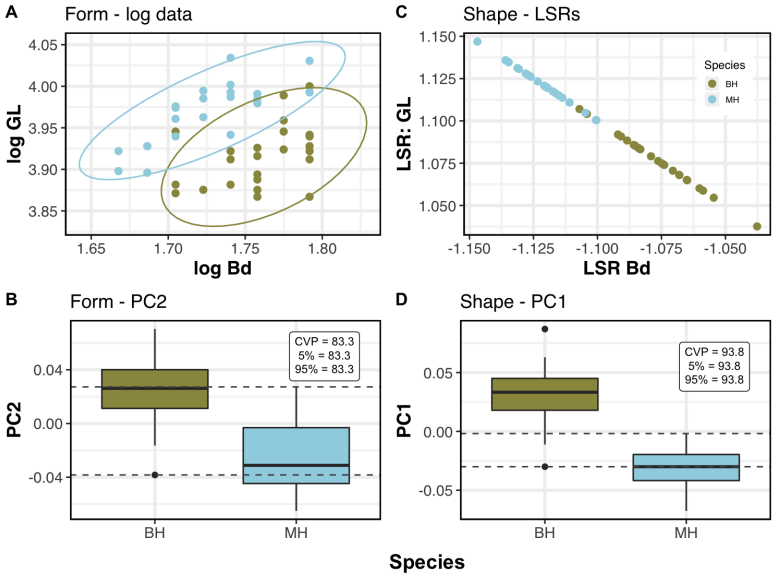

Figure 3.74: Analysis of MT2 for BH vs MH (Subset A) using the combination Bd-GL A) Form - log data B) Form - PC2 C) Shape - LRSs D) Shape - PC1.

Approaches for Subset B followed a similar pattern (Table 3.47), the major difference being that both univariates, Bd and GL, were accepted whereas only one each per digit was accepted in Subset A. This should reflect only the size difference between hares and rabbits.

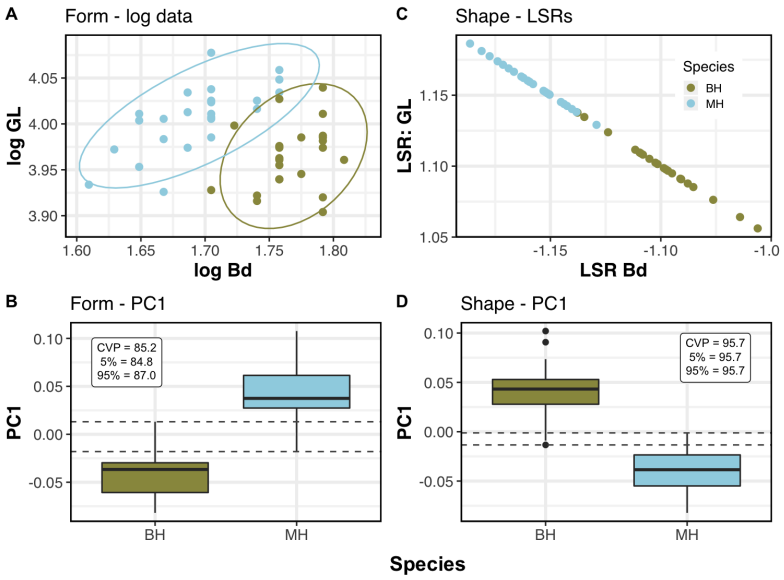

Figure 3.75: Analysis of MT3 for BH vs MH (Subset A) using the combination Bd-GL A) Form - log data B) Form - PC1 C) Shape - LRSs D) Shape - PC1.

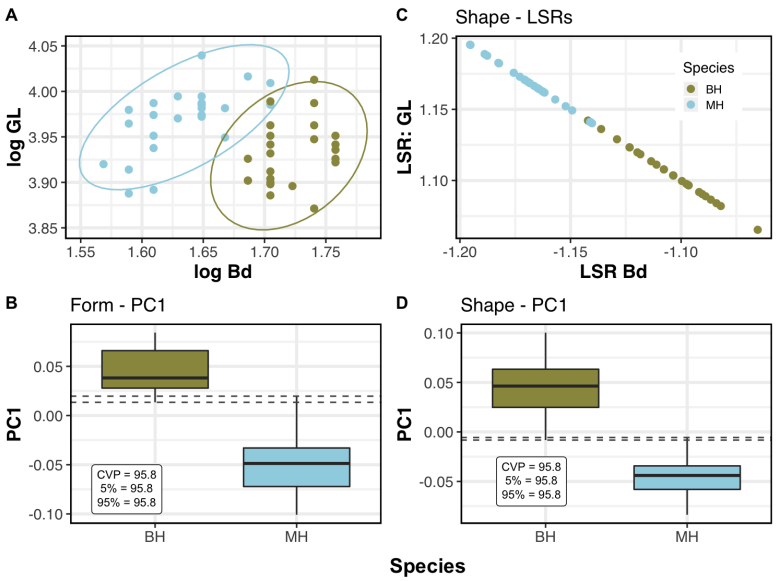

Figure 3.76: Analysis of MT4 for BH vs MH (Subset A) using the combination Bd-GL A) Form - log data B) Form - PC1 C) Shape - LRSs D) Shape - PC1.

Table 3.47: Accepted cross-validation results on approaches for separating BH, MH and rabbit metatarsals (Subset B).

Digit	Rank	Score	Verdict	Vari.	Comb.	NVars	PC	5%	Mean	95%
MT2	1	67	Accept	Shape	Bd, GL	bi	PC1	86.7	92.9	100.0
MT2	2	48	Accept	Form	GL	uni	–	76.7	84.0	93.3
MT2	3	38	Accept	Form	Bd	uni	–	70.0	80.4	90.0
MT2	4	30	Accept	Form	Bd, GL	bi	PC1	66.7	76.5	86.7
MT3	1	68	Accept	Shape	Bd, GL	bi	PC1	87.5	93.7	100.0
MT3	2	61	Accept	Form	Bd	uni	–	83.3	90.5	95.8
MT3	3	43	Accept	Form	GL	uni	–	73.3	82.8	90.0
MT3	4	39	Accept	Form	Bd, GL	bi	PC2	70.8	81.3	91.7
MT4	1	76	Accept	Shape	Bd, GL	bi	PC1	92.6	96.0	100.0
MT4	2	72	Accept	Form	Bd	uni	–	88.9	95.5	100.0
MT4	3	56	Accept	Form	Bd, GL	bi	PC2	81.5	87.6	92.6
MT4	4	43	Accept	Form	GL	uni	–	73.3	82.0	90.0

Table 3.48: Summary of metrics and morphometric variables accepted/rejected through cross-validation for the astragalus.

Set	Accept	Reject
a	–	1
b	1	–

In summary, the metapodia have been one of the most surprising discoveries of this chapter. They were not expected to yield productive models for discriminating hares, but instead have proved to be among the most effective elements. Differences between the digits have also raised some interesting questions and hypotheses for morphometrics.

A legitimate criticism of the analysis here is that it does not cover digit identification as well as species, and it is worth addressing. Whilst potentially informative, it lies beyond the scope this thesis. Furthermore these results show that identification to species works better with the bivariates than the univariates, which necessitates measuring the Greatest Length. That requires archaeological specimens to be complete, so zooarchaeologists will be able to identify the digit from the morphology of the proximal articulation in the overwhelming majority of cases. Morphometrics are therefore unnecessary for identifying the digit.

3.3.2.11 Astragalus

The astragalus is a small element unlikely to be found in most archaeological situations, except in ABGs. For this reason, no further metrics were added to *vdD*'s Greatest Length to increase measurability. Cross-validation found that the GL is ineffective for separating brown and mountain hares, being rejected (Figure 3.77, Table 3.48). For separating the hare species from rabbits, a mean CVP of 77.4 was generated (Figure 3.77, Table 3.49). The result is likely lowered by the model's ineffectiveness for separating hares, but given the visually noticeable size difference between the hare and rabbit astragalus it is possible to recommend that metrics are not strictly necessary for this element.

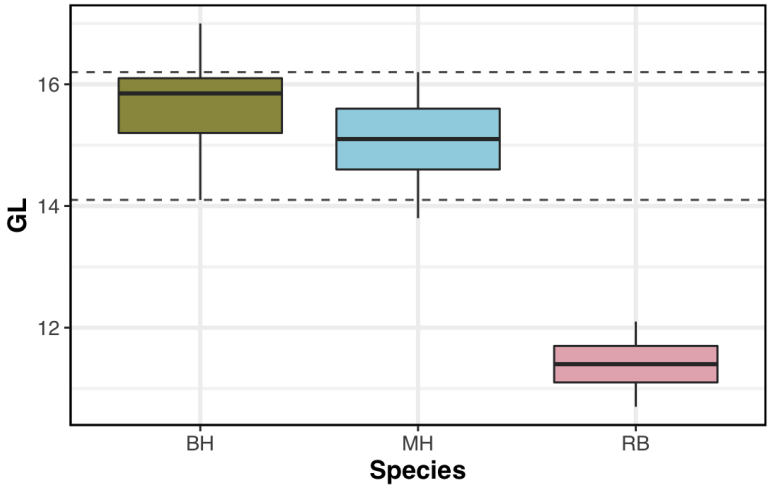

Figure 3.77: Distribution of GL for lagomorph astragali. Dashed lines highlight area of overlap between hares.

Table 3.49: Astragalus CVP results for Subset B Greatest Length (GL).

Rank	Score	Variable	Metric	5%	Mean	95%
1	36	Form	GL	71.1	77.4	84.4

3.4 Summary

In this chapter, I have set out a methodology for identifying the bones of hares from British archaeological populations using traditional morphometrics. This approach was selected in the interest of inter-analyst compatibility and accessibility of the method to non-academic researchers. By applying the morphometric principles of distinguishing form, size, and shape that underly geometric morphometrics, and by working with uni-, bi- and trivariate combinations of metrics it has been possible to test thousands of models - all aimed at maximising applicability to archaeological material.

A resampling approach to cross-validation by Linear Discriminant Function Analysis was used to balance unbalanced samples within the modern data. Minimum thresholds of seventy-five percent accuracy for mean CVP and ten percent more than the equivalent of random assignment for the 5% percentile (55% for Subset A and 37% for Subset B) were set in the expectation that higher standards may eliminate too many

approaches with good archaeological applicability. This proved to be unfounded, but elements differed in the archaeological relevance of their best approaches. Ranking approaches by scoring them using the difference between their mean CVP and fifth percentile CVP and the respective thresholds for those statistics proved an effective way of filtering the results, as did isolating all the approaches that fell into the top ten ranks.

By comparing the top ten ranks with all the other accepted approaches according to completeness requirements, it has been possible to determine which elements could be used with a much higher threshold than the minimum set here (e.g. ninety percent or higher mean CVP) and which would need a lower standard (e.g. eighty to ninety mean CVP) in order to be applicable. Nevertheless, it is clear that researchers using these data can demand a higher standard than the minimum set in this chapter and still work with archaeological material. Though it would be helpful at this stage to present a list of the best measurements for future researchers to take should they need to prioritise, it was actually found that there was no good way to do this that did not produce a list of all the available metrics. The only recommendation I can make is for researchers to record as many metrics as possible per individual archaeological specimen, though it is reasonable to stop at three if the combination recorded ranks highly in the CVP results and testing multiple combinations is not essential.

It now remains to apply these models to archaeological specimens that can help answer the questions posed in this thesis: when was the brown hare introduced to Britain, and what was its bio-cultural history and impact since? These analyses are presented in Chapter 4.

Chapter 4

Identifying archaeological hares

4.1 Sampling

Archaeological sampling needed to focus on the core periods identified in Chapter 2 - the Iron Age and Roman period - whilst also capturing specimens from later eras to provide evidence for investigating change in human-hare interactions through time. Sampling also needed to be targeted at sites instrumental for establishing chronologies and important transitions in hares' bio-cultural history in Britain. Sites with Associated Bone Groups (ABGs) particularly fit that objective.

Hare remains were sampled from thirty sites across Britain (Table 4.1, Figure 4.1). Some sampling trips and data recording also encompassed rabbits to support *Easter E.g.* project research; metric data from these archaeological samples are used to confirm Subset B's ability to act as a filter for any misidentified samples mistakenly passed to Subset A under the conclusion that they were hares. Published and grey-literature sources were also sought for further data (Davis 1995; Pinter-Bellows 1997). Dale Serjeantson provided data from St Albans's Abbey and Naomi Sykes supplied data from Portchester Castle.

Data for Palaeolithic and Mesolithic hares from across Europe, all likely to be mountain

Table 4.1: Number of archaeological sites with measured bones, by country.

Country	Sites
United Kingdom	30
France	3
Switzerland	7
Italy	1
Russia	2



Figure 4.1: Locations of UK sites with lagomorph remains with metrics.

hare, were made available thanks to Alex Jamieson. These, with the possible exception of the Western Isles hares, are less likely to be reliably identified with the British models created in Chapter 3, but nevertheless provide useful opportunities for testing. Together with the rabbits, they will provide further evidence for or against the efficacy of the method.

Important Iron Age ABG sites that were sampled include Winnall Down (Maltby 1985), Blackhorse Road (Legge et al. 1988), Winklebury Camp (Jones 1977) and Fishbourne Roman Palace (Sykes 2005). Two ABGs were reported for Blackhorse Road (Legge et al. 1988: p. 93), but only one was found in the archive. One of the unassociated bones (Legge et al. 1988: p. 94) was found and sampled, however. Additional Iron Age material was selected from Danebury (Coy 1984), Suddern Farm (Hamilton 2000a) and Nettlebank Copse (Hamilton 2000b).

Large Roman assemblages came from Fishbourne Roman Palace (see Allen 2011) and the villa bath house at Whitehall Farm - both were sampled almost in their entirety. No (zoo)archaeological report yet exists for Whitehall Farm, so it is impossible to be sure that the eighty-three bones retrieved from the archive represents every one in the assemblage, but it is still a large sample. A number of bones from the well at Oakridge II may be one of multiple ABGs (Maltby 1993b: p. 61), but due to the way the assemblage was archived (bones loose in boxes arranged by depth, rather than context) it is impossible to be certain which. Some of the juvenile hare skeletons from Owslebury (Maltby 1987) were also found - again it was impossible to match bones to individual skeletons because they were not archived in separate bags.

Options for sampling Saxon hare bones were few given their paucity in this period (Chapter 2), but it was possible to obtain one well-dated bone from Southampton (West Quay, SOU861). Faccombe Netherton (Sadler 1990) provided a large Saxon and medieval assemblage. Other key medieval assemblages were Woking Palace (Roberts et al. 2017) and Guildford Castle (Sykes et al. 2005) and a tightly dated twelfth-century midden from Lincoln Castle (unpublished). Large numbers of hares from post-1843 deposits in the crypt at St Coleman's Church, Portmahomack (Carver et al. 2016), were also made available. Though not likely to be anthropogenic in origin (Carver et al. 2016: p.330), they provided a large collection of bones to identify with the morphometric models.

Total numbers of measured bones (including data acquired from literature and by pers.

Table 4.2: Number of bones with metrics by taxon and country.

Country	Hare	Rabbit	?Hare	?Rabbit	Lago
United Kingdom	650	115	10	6	6
France	3	–	–	–	–
Switzerland	26	–	–	–	–
Italy	7	–	–	–	–
Russia	2	–	–	–	–

Table 4.3: Number of sampled UK sites with measured bones, by broad period.

Broad Period	Sites
Mesolithic	3
Iron Age	6
IA/RB	2
Roman	9
Saxon	3
Late Saxon/Early Medieval	1
Medieval	11
Medieval/Post Medieval	1
Late/Post Medieval	2
Post Medieval	7
Post Medieval/Modern	1
Modern	3
Unknown	2

comm.) are given by taxon and country in Table 4.2. Numbers of UK sites sampled by broad period are given in Table 4.3. All sites are itemised in Table 4.4, with the number of measurable samples for each given by taxon. The distribution of UK site locations is shown in Figure 4.1 and the sites with measurable hares and their sample sizes are shown in Figure 4.2.

Table 4.4: No. of bones with measurements by taxon per site, grouped by broad period and country.

Country	Broad Period	Site Name	Hare	Rabbit	?Hare	?Rabbit	Lago.
Switzerland	Magdalenian	Abri Buttenloch	2	–	–	–	–
Switzerland	Magdalenian	Schweizersbild	1	–	–	–	–
Switzerland	Magdalenian	ThayngenKesslerloch	8	–	–	–	–
UK	Mesolithic	Pabaigh Mor South	1	–	–	–	–
UK	Mesolithic	Teampuil Bágh	2	–	–	–	–
UK	Mesolithic	Tràigh na Beirigh	1	–	–	–	–
France	Mesolithic	Chenet des Pierres	1	–	–	–	–
Switzerland	Mesolithic	Cotencher	4	–	–	–	–
UK	Iron Age	Blackhorse Rd	24	–	–	–	–
UK	Iron Age	Danebury	2	–	–	–	–
UK	Iron Age	Fishbourne Roman Palace	2	–	–	–	–
UK	Iron Age	Nettlebank Copse	3	–	–	–	–
UK	Iron Age	Winklebury Camp	8	–	–	–	–
UK	Iron Age	Winnall Down	24	–	–	–	–

Table 4.4: *(continued)*

Country	Broad Period	Site Name	Hare	Rabbit	?Hare	?Rabbit	Lago.
UK	IA/RB	Fishbourne Roman Palace	3	–	–	–	–
UK	IA/RB	Suddern Farm	1	–	–	–	–
UK	Roman	Baldock	3	–	–	–	–
UK	Roman	Caistor Roman Town	5	–	–	–	–
UK	Roman	Fishbourne Roman Palace	15	–	–	–	–
UK	Roman	Greyhound Yard	6	–	–	–	–
UK	Roman	Hadspen House	2	–	–	–	–
UK	Roman	Higham Ferrers	3	–	–	–	–
UK	Roman	Oakridge II	7	–	–	–	–
UK	Roman	Portchester Castle	2	–	–	1	–
UK	Roman	Whitehall Farm	69	1	–	–	–
UK	Saxon	Faccombe Netherton	5	–	–	–	–
UK	Saxon	Portchester Castle	1	–	–	–	2
UK	Saxon	SOU1382 French Quarter	2	–	–	–	–
UK	Late Saxon/Early Medieval	Faccombe Netherton	1	–	–	–	–

Table 4.4: *(continued)*

Country	Broad Period	Site Name	Hare	Rabbit	?Hare	?Rabbit	Lago.
UK	Medieval	Bamburgh Castle	1	–	–	1	–
UK	Medieval	Camber Castle	5	–	–	–	–
UK	Medieval	Carisbrooke Castle 2006 and 20089	4	–	–	–	–
UK	Medieval	Faccombe Netherton	55	1	–	–	–
UK	Medieval	Guildford Castle	3	–	–	–	–
UK	Medieval	Lincoln Castle	26	–	–	–	–
UK	Medieval	Portchester Castle	6	–	–	–	–
UK	Medieval	Queen's College, Provost's Garden	–	25	–	–	–
UK	Medieval	SOU1382 French Quarter	1	–	–	–	–
UK	Medieval	St Albans Abbey	7	5	–	–	–
UK	Medieval	Woking Palace	2	–	–	–	–
Russia	Medieval	Ulannurskaya2 2011	1	–	–	–	–
UK	Medieval/Post Medieval	St Albans Abbey	2	6	–	–	–
UK	Late/Post Medieval	SOU29 Maddison Street	1	–	–	–	–
UK	Late/Post Medieval	St Albans Abbey	1	–	–	–	–

Table 4.4: *(continued)*

Country	Broad Period	Site Name	Hare	Rabbit	?Hare	?Rabbit	Lago.
UK	Post Medieval	Bamburgh Castle	–	23	–	–	–
UK	Post Medieval	Camber Castle	3	–	–	–	–
UK	Post Medieval	Carisbrooke Castle 2006 and 20089	1	7	–	3	1
UK	Post Medieval	Guildford Castle	1	1	–	–	–
UK	Post Medieval	Queen's College, Provost's Garden	3	31	–	–	–
UK	Post Medieval	St Albans Abbey	–	1	–	–	–
UK	Post Medieval	Woking Palace	2	–	–	–	–
UK	Post Medieval/Modern	Woking Palace	2	–	–	1	–
UK	Modern	Camber Castle	1	–	–	–	–
UK	Modern	St Albans Abbey	1	2	–	–	–
UK	Modern	Tarbat	328	10	10	–	3
UK	Unknown	Bamburgh Castle	1	2	–	–	–
UK	Unknown	Fishbourne Roman Palace	1	–	–	–	–
France	Unknown	Les Douattes Niv 7	1	–	–	–	–
France	Unknown	Mouthe	1	–	–	–	–

Table 4.4: *(continued)*

Country	Broad Period	Site Name	Hare	Rabbit	?Hare	?Rabbit	Lago.
Switzerland	Unknown	Kaltbrunnental	1	–	–	–	–
Switzerland	Unknown	Kohlerhöhle	6	–	–	–	–
Switzerland	Unknown	Schweizersbild	2	–	–	–	–
Switzerland	Unknown	Station de Veyrier	2	–	–	–	–
Italy	Unknown	OrvietoCavita 254	7	–	–	–	–
Russia	Unknown	Tuyana 2011	1	–	–	–	–

One important exception to the sites included requires acknowledgement. Though not present in the synthesis study area in Chapter 2, Fissure Cave in Hartle Dale, Derbyshire is an important site for hare remains. Here, Turk (1964) identified mountain and brown hares together in a Bronze Age deposit, evidence which is occasionally cited, uncritically, by biologists and natural historians as evidence for the coexistence of brown and mountain hares in late prehistoric England (e.g. Thulin 2003). However, cave taphonomy is complex and in Britain stratigraphic integrity in caves is rare. Dowd (Dowd 2015: p. 57-9) argues that caves should be considered as "receptacles of *ex situ* collections of bones and artefacts". Only direct radiocarbon dating can provide accurate temporal context for such remains. Mountain hares were introduced to the Peak District in the nineteenth century (Hewson 1956) and animal bone assemblages from the other caves in Hartle Dale are regarded as non-anthropogenic - potentially the remains of predation by modern carnivores. Wider evidence for burrowing animals such as rabbits and badgers in the caves is also known (Hamshaw-Thomas 1997). Therefore these remains cannot be considered Bronze Age at face value, and would likely return a modern date if radiocarbon dated. An exhaustive metrical, aDNA and C14 study of Fissure Cave is clearly appropriate, but was beyond the scope of this project.

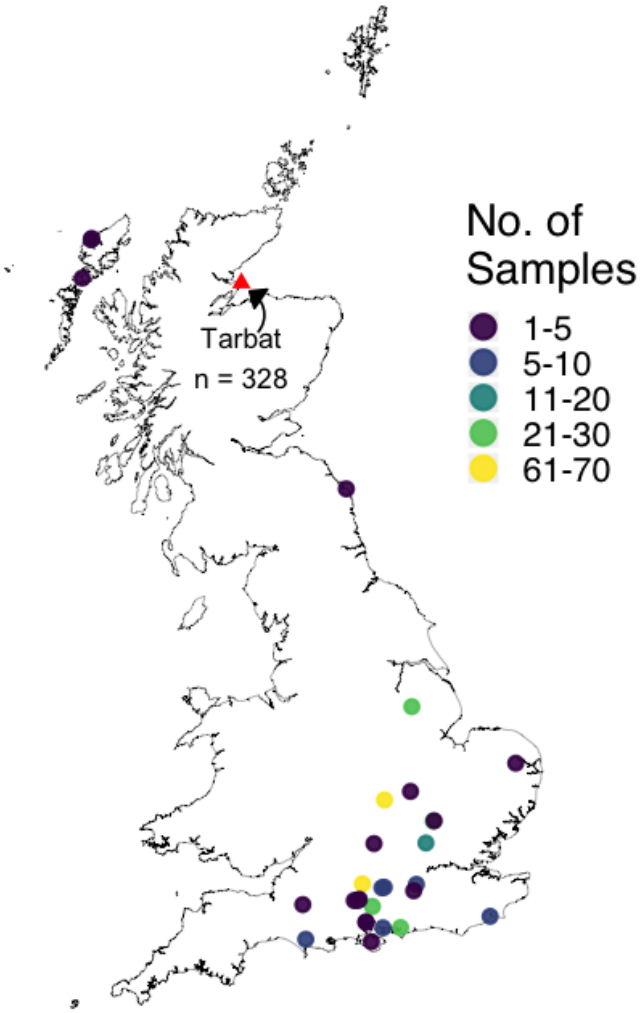

Figure 4.2: Locations of UK sites with measurable hare remains. Hare sample sizes indicated.

4.2 Recording

Sampled bones were identified to genus (hare or rabbit) using reference material at the University of Nottingham and the osteological criteria devised by Callou (1997). Osteometric data were recorded following the protocol set out in Chapter 3. Recorded measurements were the mean of three repeats. Data were entered into the same purpose-built database (§3.2.2.3), using tables dedicated to archaeological data. Wider zooarchaeological information was also recorded following established standards - the methods and the analysis are covered in Chapter 5.

4.3 Identification Protocol

Chapter 3 established the range of cross-validation percentages for 1880 different approaches to hare identification. It showed that the minimum requirement for identification accuracy could be slightly raised without jeopardising the archaeological applicability of these data. It was therefore decided to require mean balanced CVP of 80%. This was a compromise between maintaining the minimum threshold of 75% and raising it to 85%, which excluded too many approaches from some of the less reliable elements (e.g. mandible and pelvis). Lists of the approaches selected for archaeological identification for each subset and element are given in the appendix (Appendix A.4).

R scripts were written to iterate over separate lists of approaches for form, size and shape for each subset. The scripts identified the parameters (morphometric variable - i.e. form/size/shape; metrics combination; and principal component) for each approach; selected the required data; and applied the necessary data transformations described in Chapter 3. They then passed the transformed data to the `pldam()` function by Evin et al. (2013). One thousand re-sampling repeats were performed for each approach (as for `mevolCVP()` in Chapter 3). The `limproba` and `limCVP` arguments of `pldam()` were given the values 55% and 75%, respectively, to ensure that only the *repeats* that met the minimum CVP thresholds established in Chapter 3 were considered when the tests determined the samples' species.

The results were then exported as CSV files for analysis. The primary identifications for each result were grouped by specimen and tallied to provide a total number of identifications to each species. In most cases, specimens were only identified to one

species. In others, whichever verdict was arrived at for the majority of approaches was used as the final designation. For example, a specimen identified as brown hare for three approaches and as mountain hare for four would be classified as mountain hare overall. Where specimens produced a tie between different species, the results for each approach were considered in further detail. To do this, the secondary identifications were examined, taking into account the difference in probability (percentage of LDA repeats) between the primary and secondary identifications, and the CVP results from Chapter 3.

4.4 Results

Of the 817 bones with metrical data, 618 could be identified with the selected approaches. Accounting for all specimens and approaches across both subsets, a total of 16,847 identifications were attempted. Subset A was applied to 460 bones and Subset B to all 618 (including the archaeological rabbits). On average, twenty-seven approaches were applied per bone; dividing this statistic between the subsets arrives at averages of sixteen and fifteen approaches per bone for Subset A and B respectively. The overwhelming majority of bones originally identified as hares (Subset A) were identified as brown hare, with just twenty-one identified as mountain hare, and seven producing a tied result (Table 4.5). Twenty bones thought to be hares were re-identified as rabbits with Subset B (Table 4.6).

Table 4.5: Numbers and percentage of samples identified to each species using Subset A.

Identification	No. of Samples	Percent
BH	432	93.9
MH	21	4.6
Tie	7	1.5

Table 4.6: Samples incorrectly identified as hares osteologically, re-identified as rabbits using Subset B.

ID	Broad Period	Site Name	Element	BH	MH	RB	Verdict
ZA1417	Magdalenian	ThayngenKesslerloch	CALC	1	–	2	RB
ZA1419	Magdalenian	ThayngenKesslerloch	CALC	1	–	2	RB
ZA1390	Saxon	Portchester Castle	FEM	–	–	7	RB
ZA1392	Saxon	Portchester Castle	HUM	1	–	2	RB
ZA1409	Saxon	Portchester Castle	PEL	–	–	1	RB
ZA1403	Medieval	Portchester Castle	PEL	–	–	1	RB
ZA1407	Medieval	Portchester Castle	FEM	–	–	1	RB
ZA1408	Medieval	Portchester Castle	FEM	–	–	3	RB
ZA1044	Modern	Tarbat	MAND	–	–	1	RB
ZA523	Modern	Tarbat	HUM	–	–	28	RB
ZA526	Modern	Tarbat	HUM	–	–	3	RB
ZA767	Modern	Tarbat	MT3	1	1	2	RB
ZA768	Modern	Tarbat	MT3	1	1	2	RB
ZA776	Modern	Tarbat	MT3	1	1	2	RB
ZA777	Modern	Tarbat	MT3	1	1	2	RB
ZA778	Modern	Tarbat	MT3	1	1	2	RB
ZA797	Modern	Tarbat	MT4	1	1	2	RB
ZA809	Modern	Tarbat	MT4	1	1	2	RB
ZA810	Modern	Tarbat	MT4	1	1	2	RB
ZA1416	Unknown	Les Douattes Niv 7	CALC	1	–	2	RB

4.4.1 Brown Hares

Subset A identified 432 samples as brown hare. This is reduced to 423 when the hares re-identified as rabbits with Subset B are excluded. 413 were adequately dated for further analysis below. Of the ten that were undated, eight belonged to the data provided by Alex Jamieson from bones expected to be mountain hare (six from Kohler-höhle and two from Schweizersbild). Though no dating is available they are likely

Table 4.7: Iron Age assemblages by period, showing percentage of specimens by majority identification.

Period	Site	% BH	% MH
Iron Age	Danebury (n = 2)	50	50
EarlyMid Iron Age	Winklebury Camp (n = 8)	100	–
Mid Iron Age	Blackhorse Rd (n = 14)	100	–
Mid Iron Age	Winnall Down (n = 17)	100	–
Late Iron Age	Fishbourne Roman Palace (n = 2)	100	–
Late Iron Age	Nettlebank Copse (n = 3)	100	–

all Palaeolithic/Mesolithic. That these undated specimens have returned a brown hare identification suggests the models used here are not adequate for non-British populations. It is important, however, to recognise the potential effects of age on the identifiability of the bones - none of these eight came with epiphyseal fusion data, so it is not possible to determine whether they were fully or only partially fused. Of the two undated UK samples, one is from Boteler's Castle[1] and therefore probably 12th-13th century AD (Pinter-Bellows 1997); the other is from an assemblage from Higham Ferrers.

Among the Iron Age assemblages, all save one was identified as brown hare (Table 4.7). Eight bones were identified with more than a hundred approaches; the overwhelming majority produced brown hare identifications. These eight all derive from the Iron Age ABGs (Table 4.8).

[1] This site does not appear in Table 4.4 because no precise dating was available for the context.

Table 4.8: Iron Age samples identified with more than 100 approaches, showing number of times in favour of brown and mountain hare and the majority verdict.

Site	Period	Element	ID	BH	MH	Verdict
Winklebury Camp	EarlyMid Iron Age	TIB	ZA306	176	8	BH
Winklebury Camp	EarlyMid Iron Age	CALC	ZA305	106	–	BH
Winklebury Camp	EarlyMid Iron Age	CALC	ZA312	106	–	BH
Blackhorse Rd	Mid Iron Age	CALC	ZA235	97	9	BH
Winnall Down	Mid Iron Age	TIB	ZA320	106	3	BH
Winnall Down	Mid Iron Age	CALC	ZA321	105	1	BH
Winnall Down	Mid Iron Age	CALC	ZA323	106	–	BH
Fishbourne Roman Palace	Late Iron Age	CALC	ZA186	106	–	BH

Table 4.9: Roman assemblages by period, showing percentage of specimens by majority identification.

Broad Period	Site	% BH	% MH
Roman	Baldock (n = 3)	100	–
Roman	Caistor Roman Town (n = 3)	100	–
Roman	Fishbourne Roman Palace (n = 12)	100	–
Roman	Greyhound Yard (n = 1)	100	–
Roman	Hadspen House (n = 1)	100	–
Roman	Higham Ferrers (n = 2)	100	–
Roman	Oakridge II (n = 4)	75	25
Roman	Portchester Castle (n = 2)	100	–
Roman	Whitehall Farm (n = 56)	100	–

For Roman assemblages, only one bone - from the Oakridge II well - was not identified as brown hare (Table 4.9). Significantly, the largest assemblage - Whitehall Farm - produced the largest number of identifiable bones (n = 56) and all of them produced a brown hare result. Only seven bones of Saxon date were identified, though this is just as much an issue of accurate dating evidence as of the Saxon paucity of hares (Table 4.10). Only one hare bone was identified as mountain hare (Portchester Castle), but it is important to recognise that Portchester produced several 'hares' that Subset B re-identified as rabbits.

Thirteen medieval assemblages were sampled, including the Russian site Ulan-Nurskaya which produced a mountain hare identification (Table 4.11). Of the remaining assemblages, only Portchester Castle, Faccombe Netherton and Lincoln Castle produced any mountain hares and the Faccombe and Lincoln samples were the minority of larger sample sizes. The rest identified 100% of samples as brown hare. Three post-medieval assemblages were sampled, producing small numbers of hares (Table 4.12). Camber Castle and Queen's College produced 100% brown hare identifications, whilst Woking Palace was split equally.

Table 4.11: Medieval assemblages by period, showing percentage of specimens by majority identification.

Period	Site	% BH	% MH
Medieval	Bamburgh Castle (n = 1)	100	–

Table 4.11: *(continued)*

Period	Site	% BH	% MH
Medieval	Carisbrooke Castle 2006 and 20089 (n = 2)	100	–
Medieval	Faccombe Netherton (n = 1)	100	–
Medieval	Portchester Castle (n = 3)	–	100
Medieval	Ulannurskaya2 2011 (n = 1)	–	100
mid 11th mid 12th	Faccombe Netherton (n = 11)	100	–
mid 11th mid 12th	SOU1382 French Quarter (n = 1)	100	–
mid 11th mid 12th	St Albans Abbey (n = 4)	100	–
mid 12th mid 14th	Faccombe Netherton (n = 30)	97	3
mid 12th mid 14th	Lincoln Castle (n = 16)	94	6
mid 12th mid 14th	Woking Palace (n = 2)	100	–
mid 14th mid 16th	Camber Castle (n = 2)	100	–
mid 14th mid 16th	Faccombe Netherton (n = 5)	100	–

Table 4.10: Saxon assemblages shown by percentage of specimens by majority identification.

Broad Period	Site	% BH	% MH
Saxon	Faccombe Netherton (n = 4)	100	–
Saxon	Portchester Castle (n = 1)	–	100
Saxon	SOU1382 French Quarter (n = 1)	100	–
Saxon	SOU861 West Quay (n = 1)	100	–

Table 4.12: Post medieval assemblages, showing percentage of specimens by majority identification.

Broad Period	Site	% BH	% MH
Post Medieval	Camber Castle (n = 2)	100	–
Post Medieval	Queen's College, Provost's Garden (n = 3)	100	–
Post Medieval	Woking Palace (n = 2)	50	50

A key finding was that bones from the Iron Age ABGs from Winnall Down, Winklebury Camp, Blackhorse Road and Fishbourne Roman Palace - were all identified as brown hare. Eight ABGs were recorded in total, including the Tarbat ABG which consists of at least eighteen individual hares/leverets. All ABGs produced sufficiently measurable bones to be identifiable with this method, except Baldock and Owslebury because the remains were juvenile. All the ABGs mainly consisted of fragments that were not identifiable with this method, but all of the measurable material that was identified produced a brown hare result, except for a small fraction of the Tarbat bones and one bone from the Roman well at Oakridge II.

4.4.2 Mountain Hares

Twenty-one samples were identified by Subset A as mountain hare. They derive from a mix of skeletal elements (Table 4.13) so there is no pattern that suggests mountain hare identifications derive from elements that had lower cross-validation scores. Four from Portchester Castle and two from Tarbat can be discounted because Subset B identified them as rabbits (Table 4.6). Of the remaining seventeen, five fit with expectations. Between them, they cover the Western Isles, France and Russia and a range of periods. Chenet des Pierres, Pabaigh Mor South and Tràigh na Beirigh are all Mesolithic; Ulan-nurskaya is medieval; clear dating for Mouthe was unavailable but the specimen is

likely to be Palaeolithic or Mesolithic in origin. This suggests that the models could be applicable to non-British populations and studies covering even greater time-depth than the core focus of this thesis.

Table 4.13: Number of bones identified as mountain hare by element and broad period.

Element	Mesolithic	Iron Age	Roman	Saxon	Medieval	Post Medieval	Modern	Unknown
MAND	–	–	–	–	–	–	1	–
SCAP	–	–	–	–	–	–	1	–
HUM	1	–	–	–	1	1	2	1
RAD	1	–	–	–	–	–	–	–
ULN	1	1	–	–	1	–	–	–
PEL	–	–	–	1	1	–	2	–
FEM	–	–	–	–	2	–	–	–
TIB	–	–	1	–	–	–	–	–
MT2	–	–	–	–	1	–	–	–
MT4	–	–	–	–	–	–	–	1

However, nine specimens expected to be mountain hares produced a brown hare identification. Thaygen-Kesserloch, Abri Büttenloch, Kaltbrunnental, in Switzerland (Figure 4.3), produced seven such results, in addition to the undated Kohlerhöhle and Schweizersbild samples mentioned above. Notably the dated specimens were all humeri (Table 4.14). This pattern derives from a sampling decision (no other skeletal elements were sampled from these sites), so inferences regarding the nature of hare populations cannot be made on the basis of these data. Variance in CVP between elements has a bearing on the identifications, however, so element selection is important. Any or all of the humerus' evolutionary history; morphological plasticity in relation to certain terrain types; and trends in inter-observer measurement error, might account for the brown hare results for these particular sites, especially given that the modern, predominantly British sample cannot account for all evolutionary change across Europe since the Palaeolithic and Mesolithic.

Table 4.14: Samples from the Alpine area, plus Ulan-Nurskaya 2. Data show the element; number of times identified as mountain hare, brown hare or failed; the total number of approaches used, and the majority identification.

Broad Period	Site	ID	Element	BH	MH	N/A	Maj. ID	No. Apps.
Magdalenian	Abri Buttenloch	ZA1434	HUM	20	–	1	BH	21
Magdalenian	ThayngenKesslerloch	ZA1425	HUM	2	–	–	BH	2
Magdalenian	ThayngenKesslerloch	ZA1426	HUM	7	–	1	BH	8
Magdalenian	ThayngenKesslerloch	ZA1427	HUM	2	–	–	BH	2
Magdalenian	ThayngenKesslerloch	ZA1428	HUM	2	–	–	BH	2
Magdalenian	ThayngenKesslerloch	ZA1429	HUM	17	3	1	BH	21
Mesolithic	Chenet des Pierres	ZA124	HUM	–	1	–	MH	1
Medieval	Ulannurskaya2 2011	ZA1422	HUM	5	15	1	MH	21
Unknown	Kaltbrunnental	ZA1432	HUM	2	–	–	BH	2
Unknown	Kohlerhöhle	ZA1435	HUM	2	–	–	BH	2
Unknown	Kohlerhöhle	ZA1436	HUM	2	–	–	BH	2
Unknown	Kohlerhöhle	ZA1437	HUM	2	–	–	BH	2

Table 4.14: *(continued)*

Broad Period	Site	ID	Element	BH	MH	N/A	Maj. ID	No. Apps.
Unknown	Kohlerhöhle	ZA1438	HUM	2	–	–	BH	2
Unknown	Kohlerhöhle	ZA1439	HUM	2	–	–	BH	2
Unknown	Kohlerhöhle	ZA1440	HUM	2	–	–	BH	2
Unknown	Mouthe	ZA1424	HUM	2	18	1	MH	21
Unknown	Schweizersbild	ZA1430	HUM	20	–	1	BH	21
Unknown	Schweizersbild	ZA1431	HUM	2	–	–	BH	2
Unknown	Station de Veyrier	ZA1423	HUM	1	1	–	Tie	2

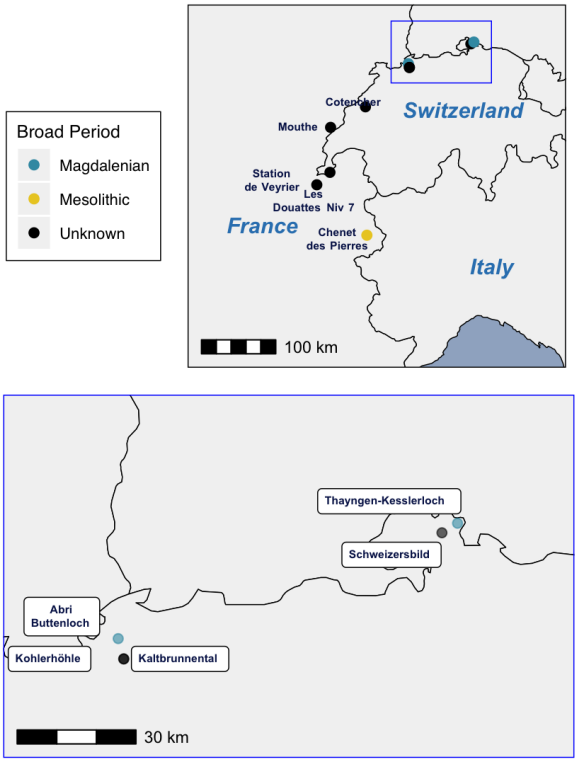

Figure 4.3: Palaeolithic and Mesolithic site locations in the Alpine area. Above: Overview, Below: Sites in the north of Switzerland.

Although such caveats are important, the south-west/north-east discrepancy between the results (Figure 4.4) is undeniable. Samples on the French side of the Alps and at Switzerland's western border with France were identified as either mountain hare or the majority verdict was tied. Samples at Switzerland's northern border with France and Germany were exclusively identified as brown hare. If the identifications are correct, this may reflect the natural geographical range of the two species in the Palaeolithic and Mesolithic. If the identifications are wrong, inaccurate dating or intrusion may account for the results. Modern hare observation data from GBIF (Figure 4.5), though clearly lacking parity in location accuracy and sampling methodology between countries, suggest that mountain hare populations near Switzerland's borders are confined to those with France and Italy, even in the case of the northern border. The area bordering Germany appears to be exclusively populated with brown hares. Climate change means that these distributions can not be uncritically projected onto the periods the archaeological samples purportedly originate from, however, and

that the site locations correspond with the Alps and the Jura Mountains suggests that all these samples should in fact be mountain hares. But, only DNA evidence and radiocarbon dating can resolve the situation fully.

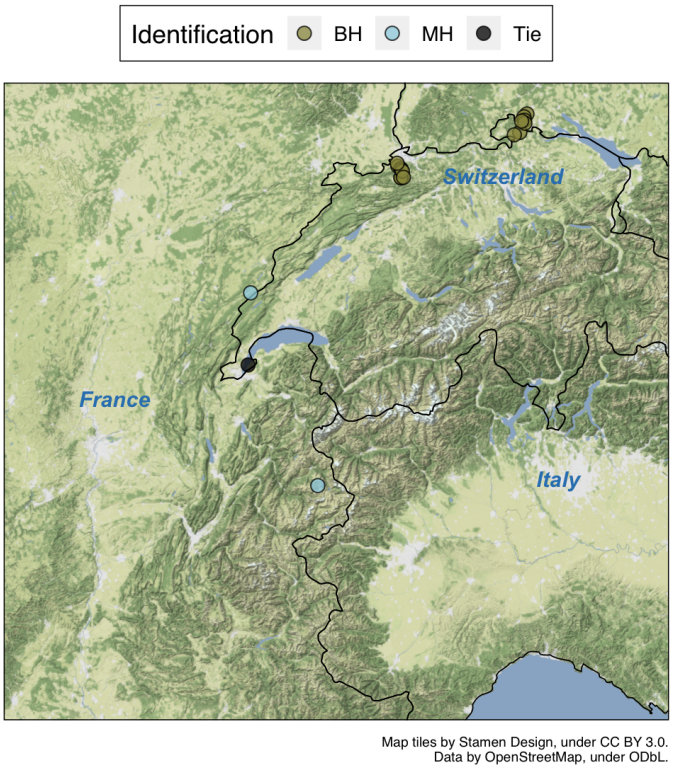

Figure 4.4: Alpine area samples expected to return "mountain hare" identifications shown by site location. Points are jittered around site locality to reveal sample sizes and coloured according to majority identification.

Similar issues relate to the four samples from the Western Isles. The two from Teampuil Bágh, identified as brown hare, contrast with Pabaigh Mor South and Tràigh na Beirigh which were identified as mountain hare (Figure 4.6. Explanations for having arrived at this result are difficult to decide upon. Teampuil Bágh is to the south of the Isle of Harris, whilst the other sites lie further north. But, environmental effects on shape from differences in terrain or size effects from climate (e.g. Bergmann's rule, see Davis 2019), seem unlikely over such a small distance, and would probably be too subtle to detect with linear metrics. Regardless, the sample size here would be too small to support an assertion that climate explains the difference between identifications at Teampuil Bágh and the other sites. However, the fragmentary nature of the samples is

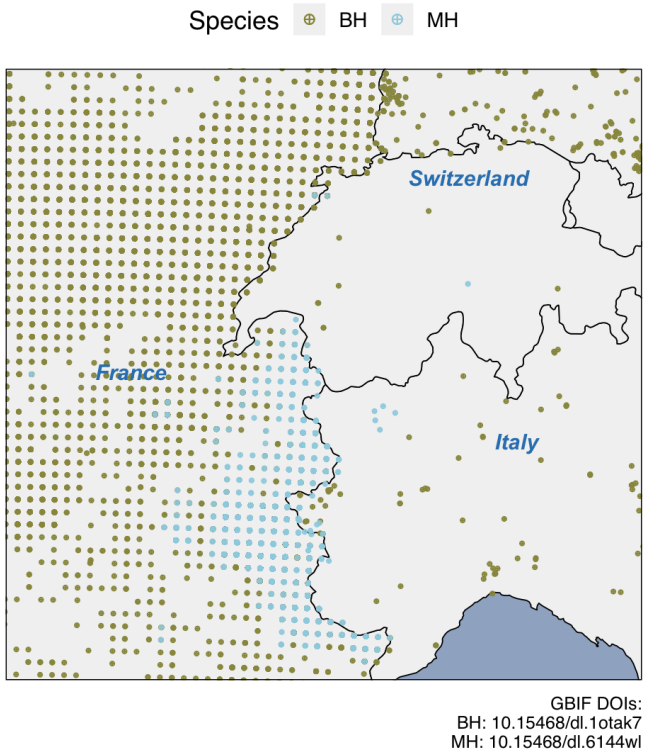

Figure 4.5: Modern hare observation data for the Alpine region from GBIF. Note that the grid-like distribution and geographic coverage of the French data suggest a different approach to sampling and spatial data recording. The distribution shown cannot be taken at face-value and methods are clearly not comparable across borders.

a potential factor. Whilst the Swiss samples identified as brown hare are supported by having been identified with multiple approaches due to their relative completeness (Table 4.14), the Scottish samples were fragmented, and consequently were tested fewer times (Table 4.15), only one of the four can be described as a "secure" majority conclusion. It is perhaps also relevant that the Teampuil Bágh samples comprise a radius and an ulna, so there is a possibility they derive from the same individual, in which case the impression given by the brown hare result is inflated.

Table 4.15: Mesolithic samples from the Western Isles. Data show the element; proximal and distal fusion; number of times identified as mountain and brown hare, total number of approaches used, and the majority identification.

ID	Site	Element	Pf	Df	BH	MH	Maj. ID	No. Apps.
ZA130	Pabaigh Mor South	RAD	F	NK	–	1	MH	1
ZA126	Teampuil Bágh	RAD	F	NK	1	–	BH	1
ZA128	Teampuil Bágh	ULN	F	NK	10	3	BH	13
ZA134	Tràigh na Beirigh	ULN	F	NK	–	1	MH	1

An alternative possibility is presented by preliminary DNA results from Alex Jamieson's (pers. comm.) research on samples from these sites, which indicate that mountain hares were introduced to the Western Isles from Ireland and not from Scotland. Irish hares are generally larger than Scottish mountain hares, and therefore more comparable to brown hares (page 164). If the morphometric range of Irish hares overlaps with small brown hares and large Scottish mountain hares, it would account for the mixed identifications produced here. Robust models for distinguishing between Irish and Scottish mountain hares were beyond the scope of this thesis (page 164). This is an unexpected finding so such models were not included in the project design, but simple plots of the available data do support the hypothesis of an Irish origin for the Western Isles samples (Figures 4.7 and 4.8).

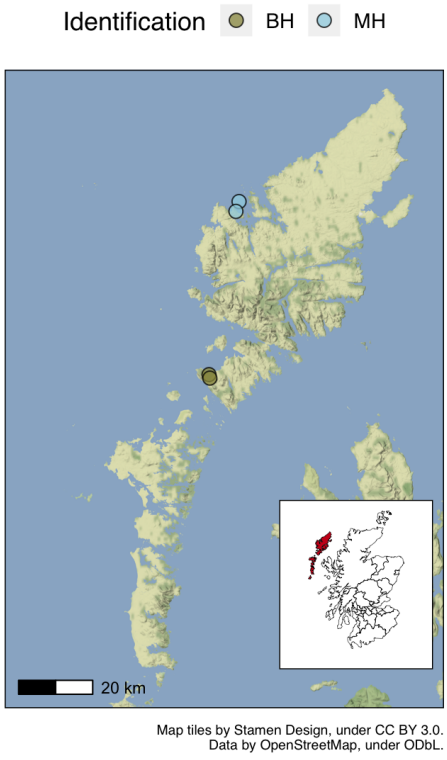

Figure 4.6: Western Isles samples expected to return "mountain hare" identifications shown by site location. Points are jittered around site locality to reveal sample sizes and coloured according to majority identification.

One Iron Age Italian sample, from Orvieto, is probably an incorrect identification. Brown hares are today found in the area but not mountain hares, which are restricted to

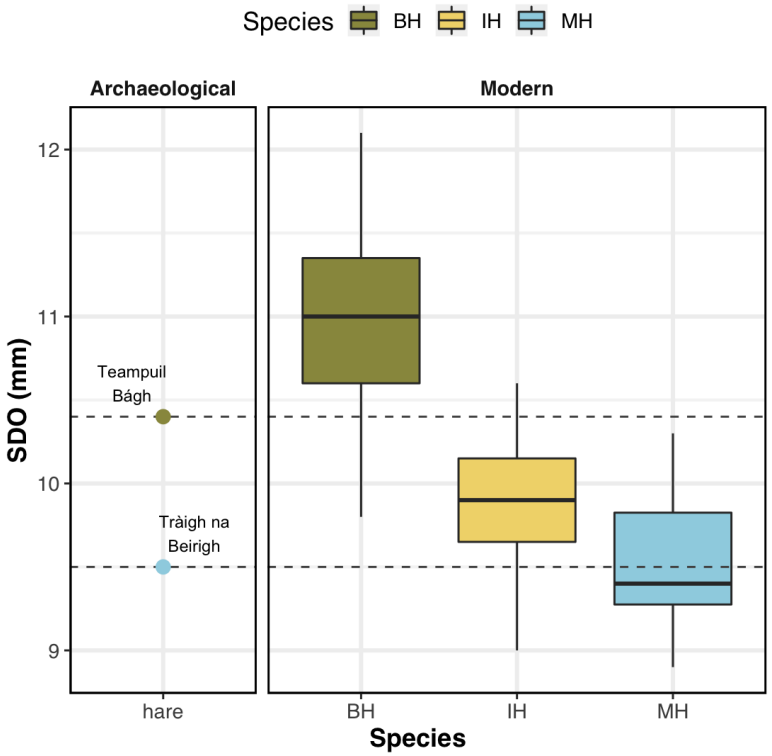

Figure 4.7: Distribution of ulna SDO for brown, Irish and Scottish mountain hares compared to Western Isles archaeological samples.

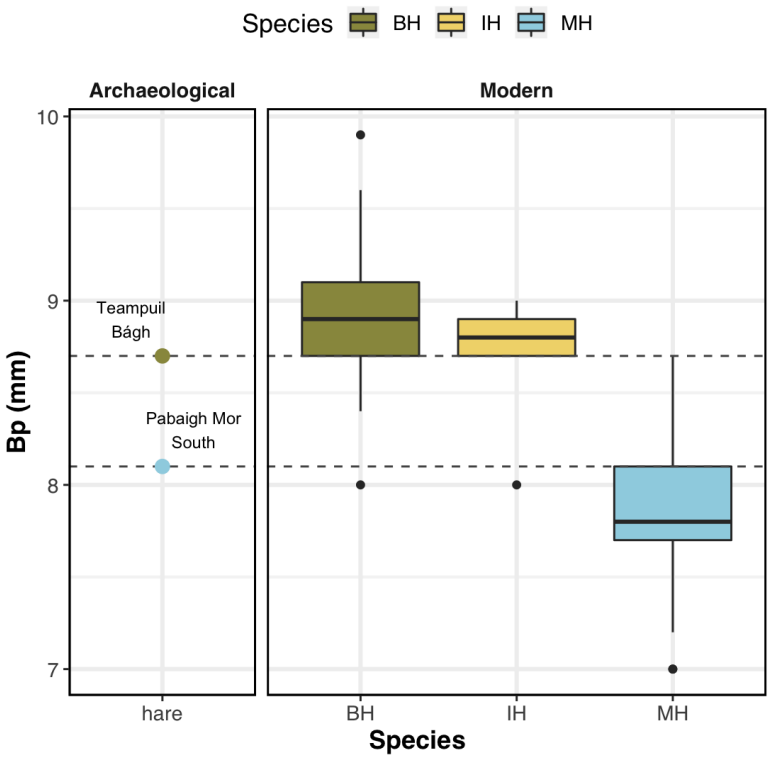

Figure 4.8: Distribution of radius Bp for brown, Irish and Scottish mountain hares compared to Western Isles archaeological samples.

the Alps (Figure 4.9). Although available data on the distribution of Corscian hare (*Lepus corsicanus*) is poor, there is evidence that the species is also present nearby (Figure 4.9), see also Riga et al. (2001)). If *L. timidus* and *L. corsicanus* are morphometrically similar, that might explain the identification arrived at here. Riga et al. (2001) show that *L. europaeus* and *L. corsicanus* are morphometrically distinct on the basis of craniometric data and external body measurements, so it is reasonable to expect that a future morphometric study comparing post-cranial bones of these with *L. timidus* would find they could be distinguished. On the basis of the information available now, however, it seems unlikely that this bone is a genuine mountain hare, though it is important to recognise that, just as in Britain, the distribution of mountain hare in Italy may have been broader in the past than it is now.



Figure 4.9: Orvieto location map with modern human observation of hare species. Observation data from GBIF.

For the Tarbat specimens, the mountain hare verdicts are conceivably accurate, but could also - and perhaps more likely - be a consequence of the assemblage mainly consisting of leverets, or from hybrids. It is noteworthy that the elements were a

Table 4.16: Samples from Tarbat. Data show the element; proximal (Pf) and distal (Df) fusion; number of times identified as brown (BH) or mountain hare (MH); and the total number of approaches.

ID	Site	Element	Pf	Df	BH	MH	No. Apps.
ZA1045	Tarbat	MAND	N/A	N/A	2	11	13
ZA608	Tarbat	SCAP	N/A	F	–	10	10
ZA646	Tarbat	PEL	U	U	–	3	3
ZA648	Tarbat	PEL	U	U	–	3	3

mandible, a scapula and two pelves. These are all elements that tend towards lower mean CVP values and suffer from low measurability. Nevertheless, the mandible and scapula were both identified more than ten times (Table 4.16) and only the mandible produced any brown hare identifications.

Having dealt with the Western Isles and Tarbat samples, the remaining UK bones identified as mountain hare were all expected to be brown hares (Table 4.17). They comprise two ulnae, a tibia, a second metatarsal and a humerus. Only the MT2 and humerus were identified with more than one approach, and only the tibia was complete enough to be identified as fully fused. There is therefore potential for age, like the Tarbat bones, to be a determining factor behind the mountain hare identifications. That the samples are distributed through five periods - one each for Iron Age, Roman and post-medieval; two for the high medieval period - may suggest that these identifications represent errors rather than good evidence for the presence of mountain hares in late prehistoric and historic England. They account for a small proportion of total samples for assemblages in that timeframe and geographic region (Figure 4.10). Nevertheless, it is important to acknowledge that only the forthcoming DNA evidence from the Easter E.g project can verify these identifications, and that the results presented here - especially the mountain hare identified from Danebury - leaves open the possibility that mountain hares were present in Southern England when brown hares were introduced. Nevertheless, the evidence available now suggests that this possibility is unlikely; more samples would probably have been identified as mountain hare if there was any significant population of the species still present in the region.

Table 4.17: UK samples excepting Tarbat and the Western Isles identified as mountain hare, showing number of approaches used (all approaches identified the samples as mountain hare), and epiphyseal fusion states (U = Unfused, F = Fused, NA = Not Applicable, NK = Not Known.

ID	Period	Site	No. Apps.	Element	Pf	Df
ZA1363	Iron Age	Danebury	1	ULN	U	NK
ZA362	Roman	Oakridge II	1	TIB	F	F
ZA1234	mid 12th - mid 14th	Faccombe Netherton	1	ULN	NK	NK
ZA1105	mid 12th - mid 14th	Lincoln Castle	2	MT2	–	F
ZA1064	Post Medieval	Woking Palace	8	HUM	NK	F

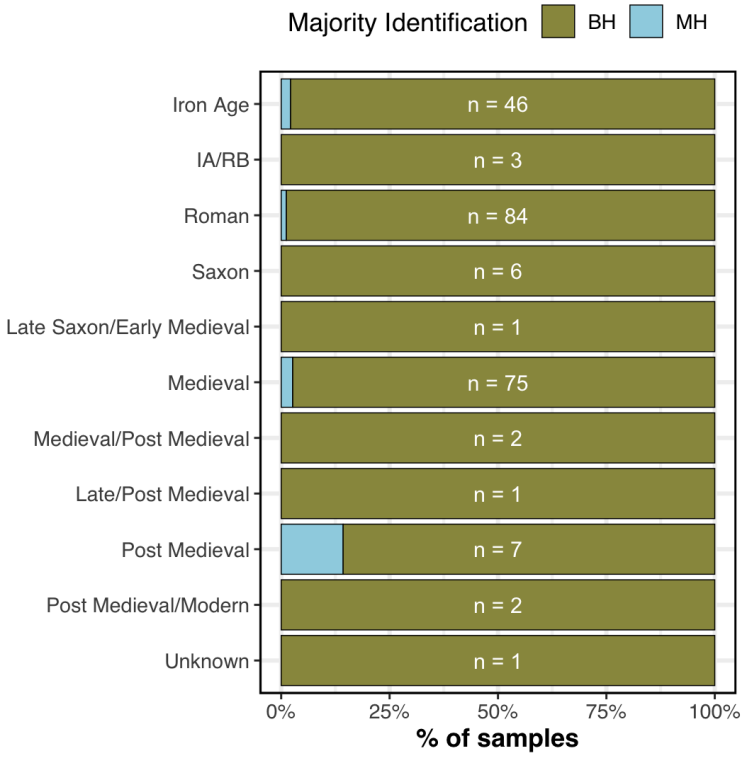

Figure 4.10: UK samples (excluding Tarbat and Western Isles) by majority identification shown as a percentage of total number of identified samples per period.

4.4.3 Rabbits

For Subset B, the proportion of samples identified as brown hare is reduced and the proportion identified as mountain hare increased (Table 4.18). As established in Chapter 3, samples that produced different 'hare' species results with the two subsets were not re-assigned on the basis of Subset B, as the subsets concern fundamentally different questions. The objective here is to verify that samples thought to be hares were not rabbits - this has already been achieved by identifying twenty bones which were in fact rabbits (Table 4.6, above) - and to confirm that accurate identifications of rabbit bones are possible with Subset B.

Comparing taxonomic categories assigned to samples with osteological methods when they were recorded with their metric identifications shows that rabbits can be reliably distinguished using Subset B (Table 4.19). Eighty-four bones initially considered to be rabbits were identified as such with metrics. A single bone (ZA43, an MT3 from

Table 4.18: Numbers and percentage of samples identified to each species using Subset B.

Identification	No. of Samples	Percent
BH	460	74.4
MH	34	5.5
RB	111	18.0
Tie	13	2.1

Table 4.19: Number of samples identified with Subset B by taxon identified at initial recording and majority verdict (BH, MH, RB or Tie).

Taxon	BH	MH	RB	Tie
hare	446	31	18	12
rabbit	–	–	84	1
?hare	3	2	–	–
?rabbit	–	1	1	–
lago	–	–	2	–

Bamburgh Castle) thought to be a rabbit was tied between rabbit and brown hare. This result probably indicates a recording error because a tie between rabbit and mountain hare is more likely given size differences between rabbits and brown hares. No samples thought to be rabbits initially were shown to be hares with metric identification.

Among bones identified as hares tentatively ("?hare"), none were found to be rabbit and Subset B split the identification between brown and mountain hares. Bones tentatively identified as rabbits were split equally by Subset B between mountain hare and rabbit. The two bones identified only to order ("Lagomorph") were found to be rabbits. It is not surprising that among the bones with tentative osteological identifications (Table 4.20, four were in an unfused or fusing state; juvenile bones present complications for both osteological and morphometric identification. Equally unsurprising is the fact that five of these seven bones were from the Tarbat assemblage, which consists of multiple leveret and rabbit skeletons.

Table 4.20: Samples initially identified tentatively to genus or to order. Data show the element; proximal and distal fusion states; number of times identified as brown or mountain hare or rabbit; majority verdict; and the initial taxonomic category assigned during data recording using osteological criteria.

ID	Broad Period	Site	Element	Pf	Df	BH	MH	RB	Majority	Initial Taxon
ZA1366	Post Medieval	Carisbrooke Castle 2006 and 20089	TIB	FS	NK	–	–	14	RB	?rabbit
ZA1069	Post Medieval/Modern	Woking Palace	TIB	F	NK	–	3	–	MH	?rabbit
ZA969	Modern	Tarbat	MAND	–	–	–	1	–	MH	?hare
ZA970	Modern	Tarbat	MAND	–	–	1	–	–	BH	?hare
ZA573	Modern	Tarbat	RAD	U	U	1	–	–	BH	?hare
ZA574	Modern	Tarbat	RAD	U	U	1	–	–	BH	?hare
ZA575	Modern	Tarbat	RAD	U	U	–	1	–	MH	?hare

4.5 Summary

Osteometrics taken from directly sampled hare and rabbit bones, from published and grey literature, and from unpublished datasets (pers. comm.) have shown that the models developed in Chapter 3 can be successfully applied to archaeological lagomorphs. The overwhelming majority of the hare bones sampled derive from UK assemblages from the Iron Age to the Early Modern period and were identified as brown hares. The majority of rabbits were successfully identified as rabbits, which further verifies Subset B's effectiveness as a safety-net for catching samples thought to be hares but which are in fact misidentified rabbits.

A small number of hares were identified as mountain hares. Non-UK Palaeolithic and Mesolithic samples were expected to return this result, though notably not all samples from those assemblages did - some were found to be brown hares. This raises legitimate (and expected) questions, about how effective the models can be for non-British archaeological populations, given that they are dominated by modern British reference specimens. The evolutionary and ecological history of hares between the Last Glacial Maximum and late prehistory also needs to be considered for samples of this age, as size in lagomorphs is known to be sensitive to climate change (Davis et al. 2007: p. 54-9; Davis 2019). An investigation of size change through time may show differences between the non-UK samples to which incorrect metric identifications (if demonstrated by DNA analysis) could be attributable. Similarly, the Iron Age sample from Orvieto identified as a mountain hare can be considered - on the basis of immediately available evidence - an erroneous result, but raises the possibility of further research into the morphometric and archaeological history of hares in Italy.

The Western Isles encountered similar issues, but preliminary DNA results from Alex Jamieson's research suggest that human involvement rather than climate accounts for the results. The potential introduction of *L. timidus* to the Western Isles from Ireland instead of Scotland raises the prospect of future research into the morphometric differences between Irish and Scottish mountain hares and between Irish Hares and UK brown hares. It also indicates that the models, whilst apparently effective for detecting the presence of brown and mountain hares in the British mainland, may struggle elsewhere in the British Isles where complex biogeographical histories exist, like that now emerging for the Western Isles.

Similar considerations apply to Tarbat. On balance, the hare samples should probably be considered brown hares, but the site's location and the assemblage's recent date means hybridisation between brown and Scottish mountain hare cannot be ruled out. The presence of juveniles in the assemblage may also have influenced the results. A study combining a systematic investigation of epiphyseal fusion timing in modern specimens of both hare species with osteometric identification using this thesis' methods could be used to improve the models, and identify an age-threshold below which lagomorph bones could not be considered reliably identifiable with this method. Practical problems with determining the age of wild animals and ethical and environmental regulations on acquiring the carcasses necessary to conduct such a study, may make this impossible, however.

The remaining UK samples identified as mountain hares were few. It is significant that they correlate with issues of epiphyseal fusion *and* elements identified as less reliable (mandible and pelvis), rather than exclusively one or the other. This is reassuring because, taken together with issues discussed above, it demonstrates that although accuracy variance between elements was well-established by Chapter 3, in practice the intersection of multiple complicating factors - age, fragmentation (influencing measurability), element, site location - was more likely to produce unexpected results than any single factor.

This means that hare bones identified as mountain hares from sites in Southern England constitute such a small proportion of the total samples that they can reasonably be dismissed as identification errors. A significant presence of mountain hares in England is unlikely for the period covered by these samples, due to climate change and landscape alteration for agriculture from the Neolithic onwards (Chapter 1). Furthermore, the approaches selected for archaeological identification allow for approximately 20% (having selected a minimum of 80% mean CVP) of identifications to be wrong, though in reality many were even more reliable than that. If there were significant problems with the identification method, some degree of randomness would almost certainly have resulted in more specimens being identified as mountain hares than actually were. It is unlikely that such a strong tendency towards brown hare identifications is a product of chance.

This does not mean, however, that English specimens identified as mountain hares they

can be assumed to be brown hares. Instead they need to be discounted and considered "unidentified", with the caveat that the possibility of a mountain hare presence in England after the Mesolithic cannot be ruled out. The possibility that the introduction of brown hares caused the retreat of mountain hares towards Scotland also remains open.

Nevertheless, this chapter's new evidence establishes a solid basis for the presence of the brown hare from the Iron Age onwards. It is now possible to place these remains back into context to verify the chronology of the brown hare's introduction and determine its cultural circumstances and impact. Radiocarbon dating and typical zooarchaeological analyses - element and butchery patterns, pathology, and size change through time - can now proceed, and form the topic of the next chapter.

Chapter 5

Zooarchaeological Analysis of Hare Remains

Species-level identification of archaeological hare remains means that traditional zooarchaeological analyses can now inform a new narrative of the brown hare's introduction to Britain and its subsequent cultural history. This chapter concerns those analyses and is presented in two parts. The first section describes the types of zooarchaeological data recorded and the methods and standards used. Some of this is devoted to problems that relate specifically to the archaeology of osteological hare remains and this thesis' questions, but which are less commonly discussed in zooarchaeological work. The second section describes and interprets the results of these analyses. Hares have been understudied by archaeologists, and methodological accommodations have been made to solve particular problems associated with them, so the interpretations should be partially read as assessments of future potential for certain data types. The merits of some hypotheses raised by this chapter are expanded upon in Chapter 6, where all of the findings of this thesis are integrated with evidence from other disciplines. Many other questions arising will be answered elsewhere by the *Easter E.g.* team with evidence from genetics, history and linguistics.

5.1 Methodology

Zooarchaeological data were recorded for the samples taken for osteometric identification, entering the data into the purpose-built database. Some analyses in this chapter were applied to only the specimens metrically identified as brown hare, others were applied to both those and unidentified hares, though these are distinguished from identified remains where relevant. None of the data used belong to hares identified as mountain hare or rabbit or producing a tied identification result. The analysis is restricted to the UK sites from the Iron Age onwards, as the other metrically identified samples are from sites that are not strictly relevant to the introduction of the brown hare to Britain, and are too few in number to analyse as in statistically robust groups.

Provision was made in the database for all common types of zooarchaeological information, including markers for taphonomic processes - burning, staining and butchery - as well as pathologies and epiphyseal fusion. To aid quantification and skeletal element representation analysis, specimens were recorded using Serjeantson's (1996) eight-zone system, which divides the major skeletal elements into eight diagnostic zones. A simple presence/absence indicator for each zone allows for bone-portion biases introduced by butchery and fragmentation to be accounted for when quantifying bones, and also analysed for element selection practices.

Regarding cranial elements, Serjeantson extended her system to include mandibles and skulls, but the details of the zones are unpublished, and though the mandible system is relatively well known, it was important that this thesis should provide an accurate record of how it was applied. The lagomorph mandible has a greatly reduced and fragile coronoid process, such that Serjeantson's system - in which the coronoid process and articular condyle are given separate zones because they are clearly separate in artiodactyls and carnivores (Figure 5.1) - makes little sense and could invite confusion. A new system was therefore devised, albeit one that is consistent with the majority of Serjeantson's original (Figure 5.2). Slight adjustments were made to more explicitly define the extent of some zones. The only major change was repurposing of Zone 7 (Z7). It represents the coronoid process in other taxa, but in this system represents the area of the process and the articular condyle. Zone 8 (Z8) was then redefined to encompass the area of the ramus between the angle and the condyle. This is because the process is so fragile that it will almost never be present without the condyle, and

Z7 would almost never be present without Z8.

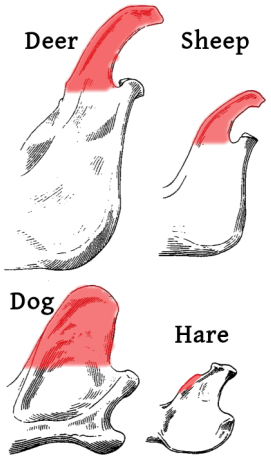

Figure 5.1: Comparison of mandible coronoid processes in deer, sheep, canids and hare. Diagrams after Schmid (1972). Coronoid processes highlighted in red (my addition).

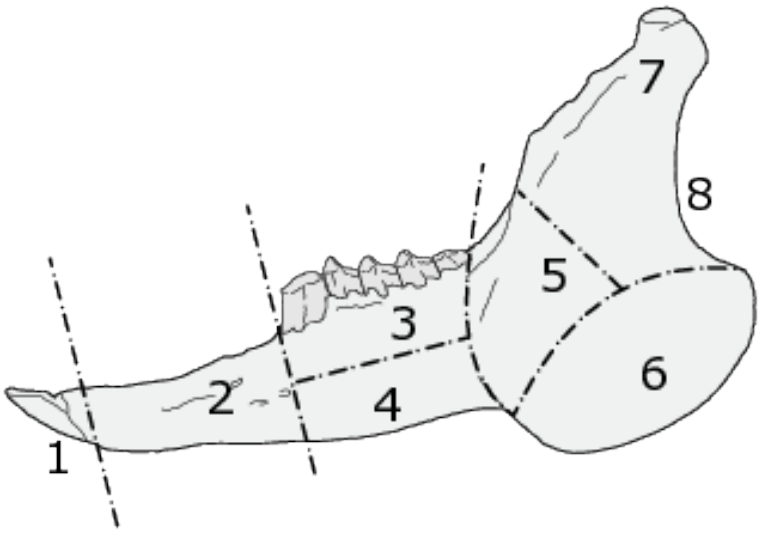

Figure 5.2: Mandible zoning system

5.1.1 Quantification

A general review of quantification in zooarchaeology is given in §2.1. Note that bone/bone fragment counts are represented here as Numbers of Identified Specimens (NISP).

5.1.2 Epiphyseal Fusion

Epiphyseal fusion allows age-at-death to be estimated, and its analysis is often integrated with dental eruption and wear (Baker et al. 2019: p. 46-48; O'Connor 2000: Chapter 8). For a given taxon in an assemblage, comparing the anatomical location and number of fused archaeological epiphyses with the sequence in which the epiphyses fuse as the taxon ages allows age profiles of assemblages to be constructed. Such profiles reflect the proportion of animals in an assemblage that continued living after attaining the age equated with a given stage of osteological development (O'Connor 2000: Chapter 8). Historically, zooarchaeologists have used age profiles to examine economic practices. Age profiles can be used to differentiate between hunting strategies, primary and secondary product economies and for identifying domestication (Baker et al. 2019: p. 46; Symmons 2005). Arguably, however, the majority of attention has been placed on domestic livestock, with particular emphasis on the Neolithic development of dairying and the identification of dairy economies in later periods (e.g. Vigne et al. 2007; Halstead 1998).

Others have argued that this focus reflects the economic focus of zooarchaeology, derived by Western worldviews. Sykes (2014a: p. 11-3) highlights the language of zooarchaeological ageing ("*kill*-off pattern, *mortality* curve and *cull* pattern") - and argues that inverting the implicit theoretical assumption, to focus on life instead of death, would provide entirely different perspectives on human-animal relationships from the same data. Russell (2011: p. 99-100) gives the ethnographic example of the Maasai, who view every slaughter as a sacrifice, and so do not cull young cattle. But, they do eat meat from cattle that die from natural causes. For a culture following a similar regime, a zooarchaeological age profile dominated by young animals would not indicate dairying, but environmental stresses (Russell 2011: p. 99). This demonstrates that ancient human-animal relationships reflected in age profiles need not conform to modern Western assumptions about economy.

Studies of age-profiles in zooarchaeology also have to be treated with a degree of scepticism due to the relative vulnerability to destructive taphonomic processes of a young animal's bones compared to those of an older animals (Halstead 1998; Symmons 2005; Vigne et al. 2007). Symmons (2005) showed, however, that age-mediated taphonomic bias cannot be accounted for by a simple correlation between age and frequencies

in zooarchaeological fusion profiles. Inter-individual variance in bone density (the traditional metric for resilience to taphonomic processes) exists regardless of age, showing that archaeologically invisible factors also influence age-profiles. Additionally, whilst bone density correlates with age, it can be irrespective of the fusion state of the individuals' bones (Symmons 2005).

Research biases introduced when working with small mammals may exacerbate these issues. Small bones are much less likely to be recovered at all and the youngest and the most weathered small mammal bones are more easily damaged during and after excavation. Proportionally less damage is required to render a hare bone unidentifiable in comparison to larger taxa. That most identification manuals for juvenile bones have focussed on domestic ungulates (e.g. Prummel 1987a,b, 1988, 1989) also means that young small fauna may go unidentified in bone assemblages. Therefore, many cases of young hares may have never entered the literature, and so are not accounted for in this thesis.

In the case of (small) wild fauna, other issues also apply. One issue to contend with is the effect of predation. Whilst domestic taxa models are limited by the inability of epiphyseal fusion to inform on age after an animal has reached maturity (Baker et al. 2019) - i.e. once the latest-fusing epiphysis has fused - and equifinality (Halstead 1998: p. 5), the chances of vulnerable prey species like hares and rabbits ever reaching this age point might be reduced by the diversity of potential non-human predators. This includes raptors and small- or medium-sized carnivorous mammals that would not predate on large fauna. Human influences on the landscape and interactions between hares and their predators may, however, control the extent to which such biases manifest in the archaeological record. Assemblages derived from managed populations in Roman *leporaria,* or *enclosed* warrens[1] in later periods, might not have the same profiles as other assemblages. This adds complexity to the task of interpretation, but also raises the possibility of a way to detect hare management.

Even more critical is the difficulty of establishing an epiphyseal fusion scheme against which to compare archaeological epiphyses. Few models for wild taxa exist at all

[1] "enclosed" is important here: the medieval term *warenna*, translated "warren" is a legal term for territory over which a high-status person had hunting rights (right of free warren), not an enclosure (Roberts 1988: p. 83; Cantor 1970) and is therefore distinct from post-medieval hare warrens, which were walled enclosures (Kane forthcoming). Both these terms are distinct from the "rabbit warren", an enclosure for keeping rabbits in a pillow-mound, which medieval sources call a "coneygarth" (Gould 2017).

due to the difficulty of collecting modern wild animals of known age. Deer are an exception thanks to the existence of managed and farmed populations (e.g Carden et al. 2006). Studies on hare ageing appear to be scarce, and none are directly applicable to archaeological material. Eye lens weight and thickness is commonly used to determine age (Bujalska et al. 1965; Kauhala et al. 2001; Tiemeier et al. 1964), and such models could hypothetically be used in a future study as a workaround for the problem of associating epiphyseal fusion with a hare of known age. Admittedly, there may be problems with basing archaeological analysis of epiphyseal fusion on a fusion model that itself is based on a predictive model (the relationship between eye lens metrics and age).

Natural science studies using epiphyseal fusion focus on a narrow suite of epiphyses. Palpation of the distal radius and ulna is regarded as an accurate and efficient method for ageing hares, owing to the gradual thickening followed by shrinkage of this part of the skeleton as the epiphyses fuse (Bujalska et al. 1965; Kauhala et al. 2001). This process (Figure 5.3) is considered to reach completion around one year of age in mountain hares (Kauhala et al. 2001), and the Tarbat assemblage alone is enough confirm that this method could be applied to zooarchaeological material. But, this thesis' zooarchaeological dataset needs coverage of a much greater proportion of the skeleton.

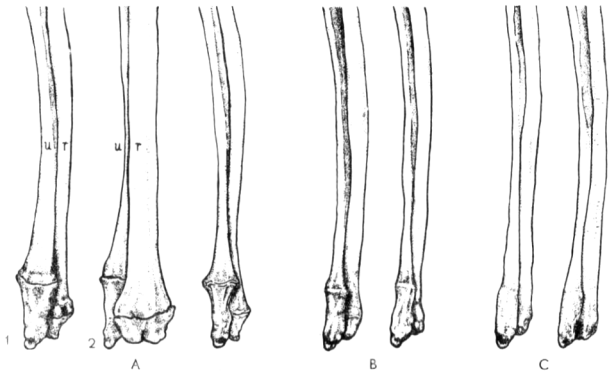

Figure 5.3: Changes in the epiphyseal thickening of the ulna in successive age groups. A, B, C age classes. 1. Viewed from the lateral side. 2 Viewed from the front. u - Ulna, r - Radius. From Bujalska et al. (1965).

Zooarchaeologists often use a simplified schema in which epiphyses are divided into groups, often corresponding to early, mid and late fusing epiphyses (O'Connor 2000;

Price et al. 2016; Sykes et al. 2005). This allows relative profiles to be constructed for each group from percentages of epiphyses in each fusion state (fused, fusing or unfused). As epiphyseal fusion data were recorded for the modern skeletons used to build the morphometric models in Chapter 3, sufficient information is available to build a relative model. This is not a perfect model, but it does provide a way to make use of the archaeological fusion data recorded both to help inform the wider interpretations of this chapter and to evaluate the potential benefit of a future study that could produce a more rigorous model and apply it to a larger archaeological sample.

The modern fusion data are naturally biased towards older individuals because the animals were recorded for metrical data, meaning that the youngest animals in the collections were not always recorded. Nevertheless, it was possible to plot the fusion state of selected epiphyses for brown hares by specimen. By ordering the individual animals by the percentage of fused epiphyses (i.e. *within* individuals) whilst simultaneously ordering the epiphysis types (e.g. distal humerus, distal tibia, proximal femur etc.) by the percentage of them which were fused (i.e. *between* individuals) it is possible to produce a plot in which young individuals cluster to the left of the x-axis and older ones to the right, whilst early-fusing epiphyses plot towards the top of the y-axis and late-fusing ones towards the bottom (Figure 5.4). This provides an approximate sequence which could be used to divide the epiphyses into early, mid and late fusing groups. The only remaining question is where to place the breaks between the groups.

A cluster analysis approach to dividing the epiphyses into groups was tried, but testing the resultant model on archaeological data produced unusually uniform distributions, suggesting that the approach was flawed. Consequently, the analysis was reattempted using the model for jackrabbits created by Dean et al. (2017), which has a sequences approximately equivalent to that shown in Figure 5.4. There are, of course, flaws with applying a model based on New World hares to the brown hare, and also some circularity because Dean and Beaver (2017: p. 165) support their model with comparisons to the brown hare and European rabbit. Nevertheless, the similarity between this model and the sequence in Figure 5.4 is encouraging.

The early, middle and late fusing groups of epiphyses were used to analyse age in hares through time following the percentage-fused method. Only the bones metrically

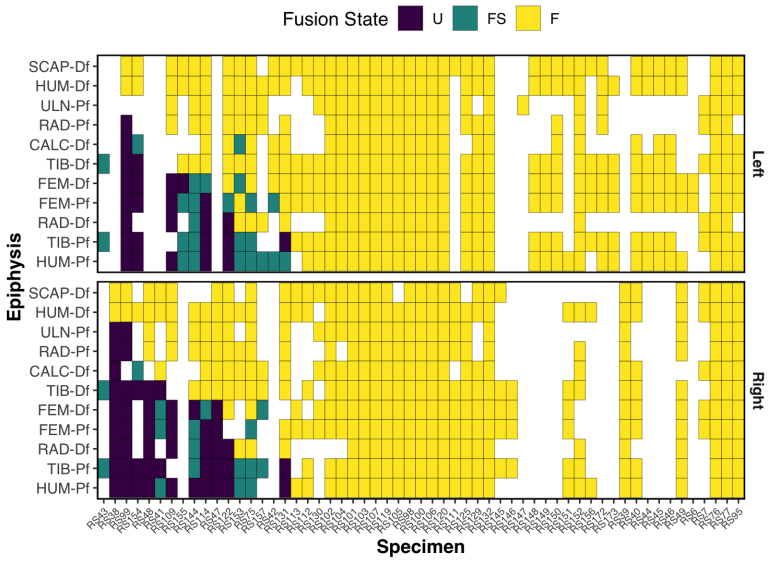

Figure 5.4: Epiphyseal fusion in modern brown hare specimens. Younger individuals plot towards the left of the x-axis and late-fusing epiphyses towards the bottom of the y-axis. Fusion states: F = Fused, FS = Fusing, U = Unfused.

identified as brown hares were analysed. Bones from ABGs were excluded from the fusion profiles; the ABG's ages are discussed separately.

5.1.3 Taphonomy

The study of taphonomy allows archaeologists to understand the natural and cultural processes that determine the creation of the archaeological record (O'Connor 2000). Markers for taphonomic processes in animal bone encompass a variety of data types. For example, staining and root etching provide clues to the nature of the burial environment.

Other taphonomic markers act as proxies for more direct anthropogenic influences on the archaeological record. Some, by extension, are normally interpreted as evidence for meat consumption. Burning is a common example, but it is a complex marker to work with. Zooarchaeologists typically characterise burning using a colour change sequence that correlates with the temperature at which the bone was burnt (Nicholson 1993; Shipman et al. 1984). The temperature achieved by the fire is only one of the influences on colour change, however, so the observed characteristics of burned bone may not reliably reflect the whole reality of the burning process (Nicholson 1993). Nevertheless,

colour is a useful relative marker; as temperature increases, the colour shifts from brown to black to grey to white (Nicholson 1993; Stathopoulou et al. 2019). As it reaches the 'white' stage, cracks may appear as the bone shrinks, and it calcifies, achieving a porcelain-like texture. This structural change combined with colour change is perhaps the most reliable visual indicator of burning, as colour change alone can be confused with the staining effects of minerals in the burial environment (Dupras et al. 2013; Nicholson 1993; Shahack-Gross et al. 1997; Stathopoulou et al. 2019). Dark or brown staining may also result from waterlogged conditions (e.g. Maltby 1993b: p. 49), but this can be distinguished if the staining is patchy or patterned, typically in stripes (Turner et al. 2018).

Burning is normally the product of prolonged exposure to fire, or at high temperatures. Everyday cooking, at temperatures under 200° (Nicholson1993-hg p. 427; Roberts et al. 2002; Koon et al. 2010), is unlikely to be responsible for the majority of archaeological burnt bone (see also Shipman et al. 1984). Consequently, burning should be rare in hares because the temperatures required to cook hare meat do not require the temperatures that would visibly change the colour or structure of their bones. Additionally, significant burning would create structural weakness in already fragile and small bones, so subsequent taphonomic changes during and after burial would likely remove the burning evidence from the archaeological record prior to excavation. Hockett (1991) does note, however, the presence of charring in jackrabbit bones, and burning can protect bones against decay after burial (Baker et al. 2019: p. 1; O'Connor 2000: Chapter 5). Charring and light burning may therefore be expected, but the absence of shrinkage in such cases may make it harder to distinguish burning from mineral staining. Charring and some shrinkage is likely at the extremities of the limbs if it were common to roast hares whole, the feet and distal radius and tibia being the least protected by meat (see Howard 2013; Lloveras et al. 2009; Hockett 1991).

Other cooking methods may be more likely for hares, however. Boiling in particular is under-studied in zooarchaeology, though this in part stems from difficulty identifying evidence for it. Roberts et al. (2002) showed that boiling produces effects similar to those of diagenesis in the burial environment, but extensive periods of boiling time are needed to produce these effects. Severely boiled bone has high porosity, so it is unlikely to survive burial over archaeological timescales (Roberts et al. 2002: p. 492). This thesis used macroscopically observable proxies for boiling, as archaeometric

techniques like that of Roberts et al. (2002) and Koon et al. (2010) were beyond its scope.

Howard (2013) advocates examination for pot-polish to determine whether a bone was boiled. Pot-polish consists of traits resulting from the repeated abrasion of bones as they are stirred within a pot while boiling. Fracture edges are rounded and the cortical surface of the bone is polished, producing a shiny appearance (Howard 2013; White 1992: p. 120-124). Howard (2013: p. 672-683) proposed this interpretation of the hare bones from Whitehall Farm, suggesting that the majority of them derive from a single feasting event, as they come from a single context. From the context's position at the site, this suggests that boiled hare was eaten within the bath house. These bones were re-examined for pot-polish as part of this thesis. Whilst many of the bones do have a shiny appearance, I concluded from this examination that I was not familiar enough with pot-polish to make a confident identification of the phenomenon in other assemblages. Nevertheless, Howard's assessment of the Whitehall Farm bones is compelling, and the possibility that boiling could explain a paucity of burning evidence in other assemblages is taken into account in this chapter's interpretations.

Finally, physical marks and breaks left by human modification of archaeological bone need considering. The analysis of butchery marks - such as chops, cuts, sawing, and shaving - is a standard component of the zooarchaeological toolkit (O'Connor 2000: p. Chapter 5; Baker et al. 2019: p. 53-6). Attempts to standardise butchery recording and data visualisation in zooarchaeology have been made (Orton 2010; Popkin 2005), but none seems to have risen to prominence (Sykes 2014a: p. 15; Baker et al. 2019: p. 53-6). For this thesis, butchery was recorded using the codes for common butchery marks established by Lauwerier (1988) and extended by Sykes (2007b). Marks that did not match these codes were described as free text, but effort was made where possible to standardise the free text to simplify analysis and reduce the need for data cleaning.

Like the other types of zooarchaeological data, the standard interpretive approach to butchery is tailored to much larger fauna than hares. This thesis' butchery data cannot be evaluated in the same way as those of studies on domestic ungulates and large game. Identifiable butchery marks are likely to be rare in hares because small mammals require much less carcass processing, and may have often been cooked relatively whole (Howard 2013; Lloveras et al. 2009). It is likely that skilled butchers

would be capable of skinning and butchering small mammal carcasses without leaving discernible traces (Lloveras et al. 2009: p. 186; Fairnell 2011). Given their size, cooking is likely to be enough for hare meat to be pulled away from bones with minimal force, so defleshing cuts might be rare if it were common to deflesh after cooking, rather than before (Howard 2013; Lloveras et al. 2009). The Whitehall Farm assemblage, potentially representing the use of pots to boil hare meat on the bone (see pot-polish, above), is a good example of this.

Chops and cuts associated with disarticulation might be more common - especially around the proximal femur and acetabulum, at the distal tibia and radius, and around the scapula - as these are typical targets for separating the hindlimbs, feet, and forelimbs, respectively. Experiments on rabbit carcasses by Lloveras et al. (2009) support this. Their experiments also showed that chops and cuts were heavily concentrated on on the mandible, skull, ribs and vertebrae. Together with the pelvis, these constitute body parts that are much less likely to enter the identified portion of lagomorph assemblages. For this reason, butchery was likely to be underrepresented in this thesis' data because the sampling approach was directed by the need for measurable bones and because less diagnostic elements - ribs and vertebrae - are seldom identified to genus or species.

The hare's size might mean that chopping has the effect of shattering bone (Allen et al. 2011: p. 215), rather than leaving recognisable chop marks. This means that the act of chopping could simultaneously remove the evidence for it. However, this raises the possibility that fracturing might act as a proxy for butchery. Hare bones may also have been broken by hand to extract marrow during consumption (Hockett 1991; Howard 2013). Small mammal long bones reduced to bone cylinders by removing their epiphyses are often interpreted as examples of marrow extraction (Hockett 1991; Howard 2013).

Fracturing analysis was therefore used to supplement the butchery data, using Outram's (2002) Fracture Freshness Index (FFI) to systematically record the character of fracture edges in hare bones. FFI is a tool for approximating fracture freshness and is best used with large sample sizes and comparisons between assemblages. It is also normally employed to much larger taxa than hares, whose small bones meant that identifying the key features of helical fractures (which indicate fracturing soon after

death) involved more ambiguity than might have been the case for other taxa. Certain skeletal elements were therefore excluded from the FFI analysis as their overall shape and structure impacts on whether an informative FFI assessment could be made. The pelvis, for instance, is frequently fractured through the ilium and pubis. Here, the thin and compact shape of these areas meant comparison with fracture shapes seen in long bones was too difficult for confident identifications to be made.

5.1.4 Radiocarbon dating

As established in Chapter 2, radiocarbon dating is essential for dating lagomorph bones. The propensity for small bones to move between archaeological strata means that they cannot be assumed to originate from the same period as the other material evidence within the same context. Together with *Easter E.g.* project colleagues, funding for ten radiocarbon dates for lagomorph samples was obtained by application to the NERC Radiocarbon Fund (NRCF). Six of these concerned the earliest hares sampled for this thesis. The samples were submitted to the Oxford Radiocarbon Accelerator Unit for dating and the results are reported in §5.2.8.

5.1.5 Size Change

Having identified archaeological specimens to species with metrics, it was possible to use the same metrical data to investigate diachronic changes in size. One of the most common methods for investigating size-change is the log-size index (LSI, or 'log ratio') approach (Meadow 1999).

Log ratios allow archaeological osteometric datasets to be expanded by combining different measurements (Meadow 1999: Sykes2013-ku), bypassing low sample-size issues caused by fragmentation and recovery biases. Raw metrics are converted to the base 10 logarithm of the ratio between an archaeological metric and a standard value for the same metric - see Equation (5.1). As the standard metrics represent the same individual(s) regardless of element or measurement type, archaeological values from different metrics can be combined, though it is good practice to separate the anatomical planes - length, breadth or depth (Meadow 1999). The distribution of the LSIs can then be used to identify trends in size through time by binning the values and plotting the bins as histograms. A LSI of zero represents an animal equal in size to

the standard, positive values represent larger animals, and negative values represent smaller animals).

$$Log\ Ratio = \log_{10} \frac{Sample}{Standard} \times 10 \tag{5.1}$$

Log ratio standards (LRSs) were created for brown hares by averaging values from modern individuals, a complete male and female, from a single population (Table 5.1, raw data available in the digital appendix - see Appendix A.5, using the same dataset that was collected to build the identification models in Chapter 3. The selected specimens came from Historic England's zooarchaeological reference collection (Table 5.2) and originated from Holbeach, Lincolnshire (Figure 5.5). Values from both specimens were used to create the standard for every metric, except for the astragalus for which only the female specimen was used because no measurement was could be taken from the male.

Table 5.1: Brown hare log ratio standard.

Element	Metric	LRS
MAND	m1	67.7
MAND	m2	18.8
MAND	m3	41.7
MAND	m4	23.0
MAND	m5	41.4
MAND	m5a	40.2
SCAP	BG	10.8
SCAP	DHA	80.2
SCAP	GLP	12.2
SCAP	HS	79.1
SCAP	SLC	6.5
HUM	Bd	11.4
HUM	Bp	17.4
HUM	Dd	8.9
HUM	Dp	18.2

Table 5.1: *(continued)*

Element	Metric	LRS
HUM	GL	98.5
HUM	GLC	96.5
HUM	HTC	5.8
HUM	SD	5.2
RAD	Bd	9.7
RAD	Bp	9.0
RAD	Dd	5.8
RAD	Dp	5.8
RAD	GL	103.3
RAD	SD	4.3
ULN	BPC	8.5
ULN	DPA	10.7
ULN	GL	117.4
ULN	SDO	10.8
PEL	GL	93.6
PEL	LFo	20.8
PEL	SB	6.0
PEL	SH	10.2
FEM	Bd	18.2
FEM	Bp	24.9
FEM	BTr	23.0
FEM	DC	9.8
FEM	GL	120.4
FEM	GLC	115.5
FEM	SD	8.6
TIB	Bd	15.2
TIB	Bp	18.7
TIB	Dd	9.2

Table 5.2: Brown hare specimens used in LRS. Both from Historic England Zooarchaeological Reference Collection and Holbeach, Lincolnshire.

Specimen	HE Accession No.	Sex
RS103	2756	m
RS104	2763	f

Table 5.1: *(continued)*

Element	Metric	LRS
TIB	Dp	20.8
TIB	DPL	19.0
TIB	GL	136.8
TIB	LDp	13.3
TIB	SD	6.2
CALC	GB	11.8
CALC	GBT	7.7
CALC	GDT	6.0
CALC	GL	31.0
CALC	GLT	19.3
CALC	SBT	5.3
CALC	SDT	5.5
AST	GL	16.1
MT2	Bd	5.8
MT2	GL	49.2
MT3	Bd	5.9
MT3	GL	52.3
MT4	Bd	5.7
MT4	GL	50.4

Once all the archaeological metrics were converted to LSIs, it was necessary to choose which measurements to work with. Only one measurement should be used per bone,

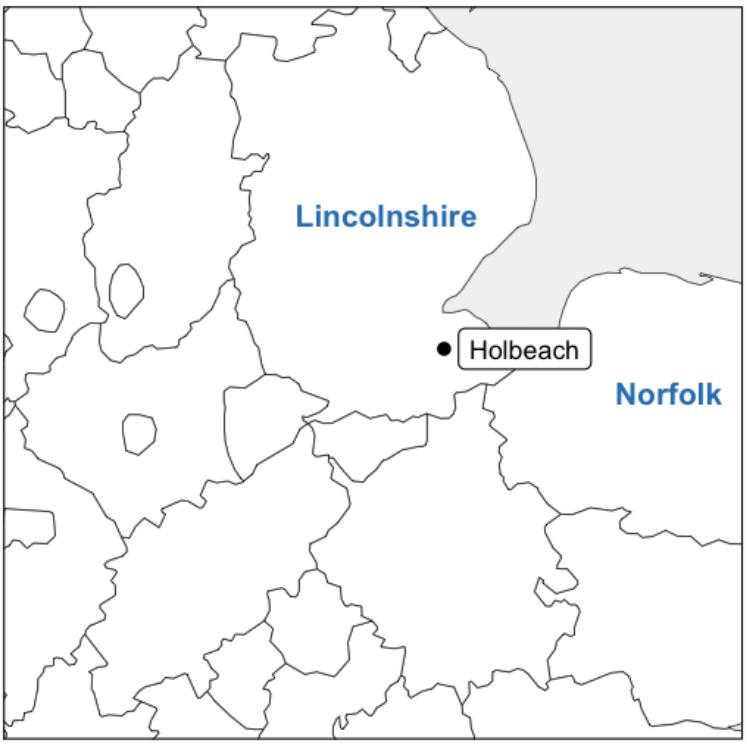

Figure 5.5: Holbeach, Lincolnshire, location map.

so as to not overrepresent individual animals. For bones with only one measurement available, selection is simple, but it becomes difficult for specimens where multiple metrics were recorded.

Zooarchaeologists select metrics for LSI analysis using multiple criteria, but there is no explicitly agreed methodology. Meadow (1999: p.294) raised the solution of averaging LSIs where there is a choice for a single individual, but rejected it on the grounds that an average may not be a good reflection of its source values. Some authors (Davis 1996; Popkin et al. 2012) have recommended ignoring measurements from early-fusing epiphyses to avoid the effects of post-fusion growth. Others have emphasised inter-observer error and therefore prioritised measurements which showed less variance (e.g. Sykes et al. 2013).

It is also common to prioritise measurements by their abundance (Thomas et al. 2013: p. 3310-1; Holmes 2014: p. 78-9). For example, if the proximal breadth (Bp) was the most abundantly recorded metric across all skeletal elements, the Bp from every bone that had that measurement recorded would be the chosen metric. Bones that did not have a Bp could then be represented by the second most abundant metric and so on until every specimen is represented once. This approach enhances comparability between specimens by reducing the number of different measurement types.

Prioritising abundance, however, raises the question of whether differences in LSI distributions observed between different periods or populations are genuinely the product of meaningful change, or researcher-introduced bias. This approach biases the data in favour of particular metric types, even though there is no guarantee that the favoured one is more representative of *size* change than another. LSIs do not account for the evolutionary history of individual skeletal elements and they do not isolate size from shape.

Additionally, this study is the first to collate hare measurements in large quantities, but empirical evidence regarding the relationship between age and morphometric data like that presented for sheep by Popkin et al. (2012) is not available. Informed decisions regarding which measurements to exclude on the basis of post-fusion growth cannot be made from available data. It also cannot be assumed that the age-size-shape dynamics that apply to domestic ungulates also apply to hares.

To resolve this subsampling issue, a computational approach was taken - loosely in-

spired by Evin's `mevolCVP()` and `pldam()` R functions used in previous chapters and Orton's (2017) approach to zooarchaeological meta-analysis.

Two R functions were written to subsample a single metric per specimen. Both were designed to repeat the subsampling for a given number of repeats (1000 were used). After running the functions, the results from both could be binned identically, using a consistent bin-width of 0.2. The frequencies for each bin were then summarised across the 1000 repeats, calculating the mean, standard deviation, and 5%, 25%, 75% and 95% percentiles. It was also possible to calculate the mean LSI for each repeat (mean LSIs are normally shown as arrows on LSI histograms) and examine how the mean shifts depending on metric selection.

The two functions differ in their approach to subsampling. `samp_lsi_random()` selects one LSI per sample at random. This is intended to be the most conservative approach and acts as a control. Differences between bins and grouping variables shown by the percentiles/standard deviation for this approach are likely to be genuine examples of size change or difference. `samp_lsi_abundance()` also selects at random, but is weighted in favour of metrics that are more abundant. For the majority of repeats, the distribution of selected metrics should resemble, though not exactly duplicate, the abundance-favouring approach described above. By comparing trends in LSI distributions between the two methods it should be possible to place interpretations of the data within reasonable degrees of confidence.

To run these functions, the data were grouped by broad period and anatomical plane. Grouping by broad period allows for differences to be observed over time and has no other significance. Grouping by plane, however, necessitates some clarification. Grouping was implemented in the functions to occur *before* subsampling, so the metrics must be sampled for each plane independently of the other planes. The selection of a single metric from a specimen in one plane does not exclude the specimen from selection in another. For example, a femur might have its Bp selected in the breadths group and its DC selected in the depths group. The different planes must therefore be treated as entirely separate analyses. This may differ from some zooarchaeologists' approach.

Experimentation with this repeated subsampling approach showed that the two functions would be effective for exploring the how variance in log ratios changes depending

on which measurements are chosen. As expected, random selection produces marked variation in the number of values selected for each metric type between repeats (Figure 5.6). This means that the random method should produce wide error bars for the LSI histograms.

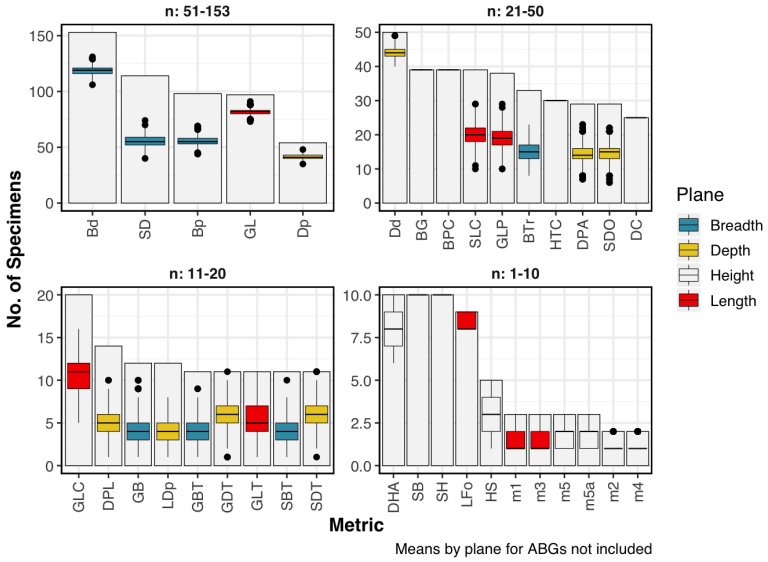

Figure 5.6: Comparison of the total number of available specimens for each metric (grey bars) with the number chosen randomly with `samp_lsi_random()` over 1000 repeats (box plots, filled to indicate the anatomical plane of the metric). The four panels group metrics by the number of available metrics expressed as a range, to allow for readable y-axes. Points indicate outliers.

The weighted selection approach was also found to be effective, but some adjustment was required. Weighting by proportional abundance alone did not produce meaningful differences from random selection, the weighting being insufficient to apply enough preference towards the most abundant metrics. It did not satisfactorily emulate the way zooarchaeologists might apply this preference manually. Experimentation with ways to apply further weight showed that the abundance proportions could be raised to a power, which increases the weighting applied to metrics with higher abundance proportions more than those with lower proportions. Squaring the abundance proportion had little impact, but raising to a power of five (Figure 5.7) shifts the number of specimens chosen for the most abundant metric in each plane (Bd, Dp, HTC and GL) much closer to the maximum available value. Arguments can be made for using an even greater value to raise the proportions, but every increment of one was found to

have less impact than the one before it. Also, the aim here is not to computationally duplicate a manual abundance weighting approach, but to emulate it with the added benefit of producing confidence limits for the interpretations that are drawn from the LSI distributions. A power of five was therefore considered sufficient.

Before proceeding it was possible to check that metrics on the same plane in brown hares do in fact correlate more strongly than metrics on different planes. Pearson's correlation coefficient was applied to pairs of modern brown hare metrics *across* elements. The results were then categorised firstly according to whether the metrics pair derived from metrics on the same plane, and secondly to whether they derived from metrics from the same skeletal element. The results (Figure 5.8) showed that statistically significant results were more likely when the metrics derived from the same plane; tests for matching versus non-matching skeletal elements showed little difference. With this information, an argument could be made for restricting the LSI analysis to just the metrics that appeared in the pairs that produced statistically significant correlation coefficients. This would certainly improve the morphometric robustness of the method, but could markedly undermine the sample size, an important consideration in this analysis, so it was not applied.

Finally, it was necessary to appropriately handle ABGs. It is important that LSI bin frequencies are not biased by multiple bones from the same animal. To account for the diversity of ABGs in the dataset, two approaches were used. For the ABGs from the Iron Age to Roman periods, the mean LSI for each plane was supplied to the subsampling functions. This means that there is no variance between repeats attributable to the ABGs, as only one value per plane per ABG was made available. The relative size of each ABG is also considered independently of the unassociated bones in the ABG case studies section of this chapter (§5.2.9). The Tarbat bones, however were treated as if they were entirely unassociated for three reasons. Firstly they consist of multiple animals, mostly leverets at various stages of epiphyseal fusion, that cannot be separated into distinct individuals. They represent a different class of associated bones to a (semi-)articulated skeleton. Secondly, these bones are the only ones in the 'Modern' broad period of archaeological material. Finally, they are probably non-anthropogenic in origin (Carver et al. 2016: p. 330). For these three reasons it is useful to think of these remains as a representative population for hares in post-1843 Portmahomack. Theoretically, they should produce an approximately symmetrical, possibly log-normal, distribution that

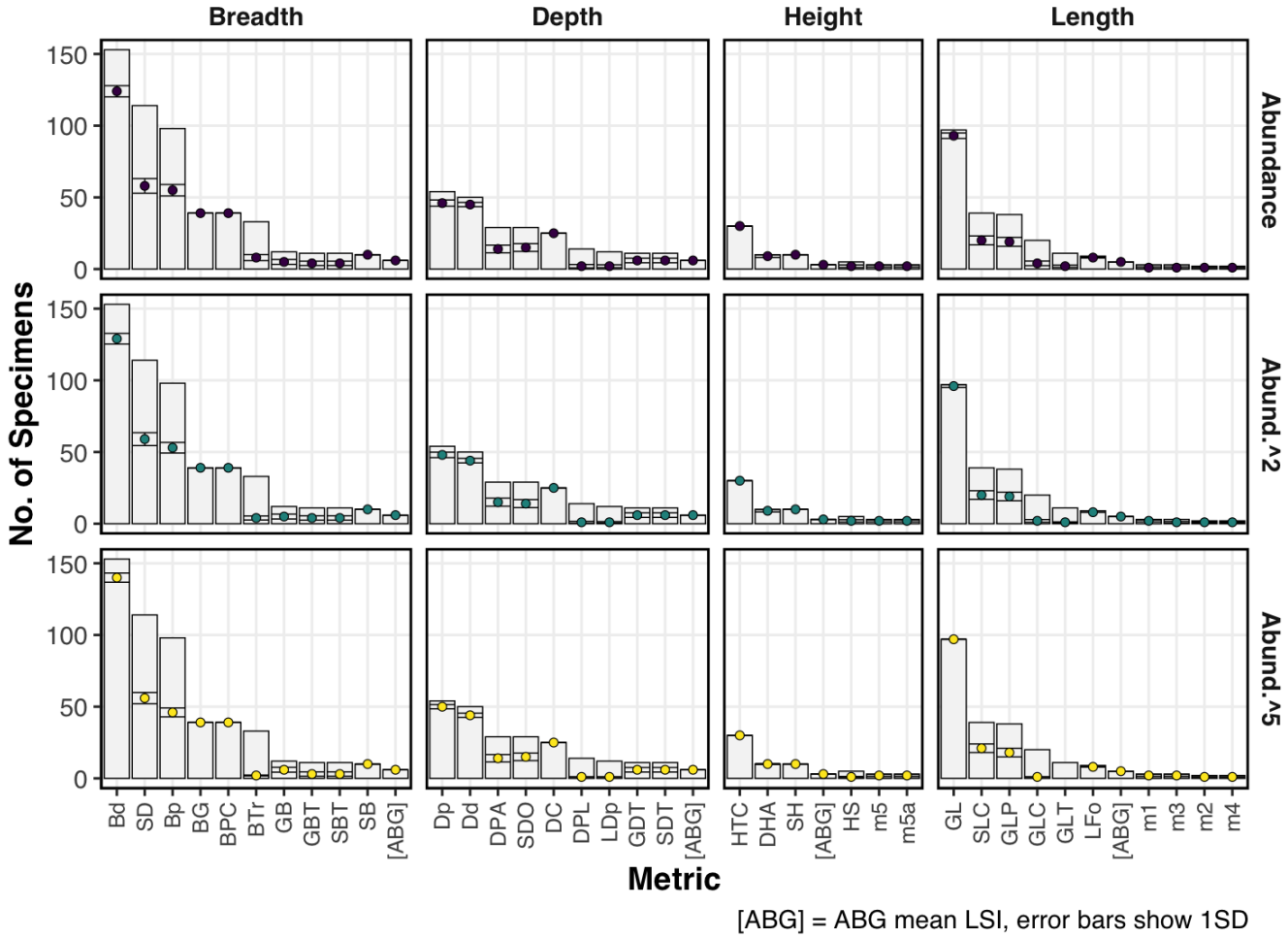

Figure 5.7: Comparison of the total number of available specimens for each metric (grey bars) with the number chosen randomly with abundance weighting with `samp_lsi_abundnace()` over 1000 repeats. Points show the mean frequency and bars show one standard deviation. Facets group the metrics by anatomical plane and the results by the abundance weighting used (plain and raised to a power).

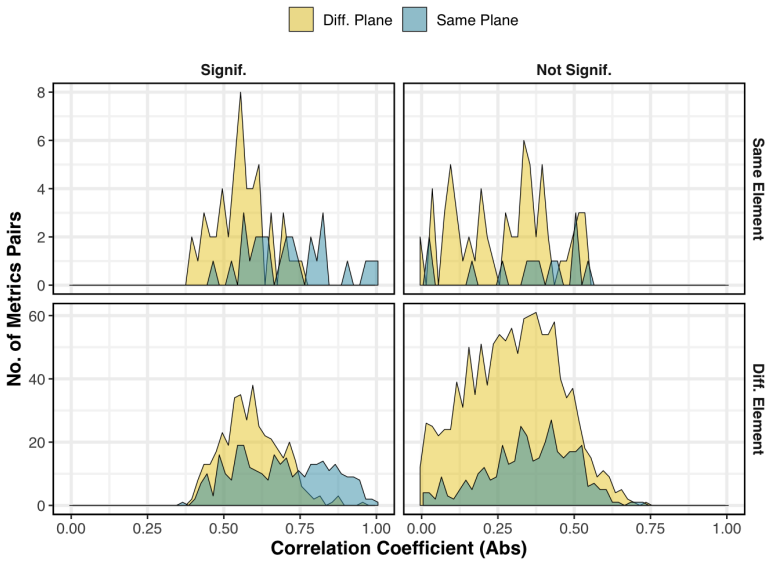

Figure 5.8: Frequency polygons for Pearson's correlation coefficient applied to brown hare metric pairs. Results categorised by whether the pair derived from the same or different element/anatomical plane, and whether the result was statistically significant at $p < 0.01$. Correlation coefficients are presented as absolute values because the direction of the correlation (positive/negative) depends on the order in which the metrics were passed to the statistical test. Note that the panels for 'same' versus 'different' skeletal element have different y-axes because the number of possible combinations between elements is much greater than the number within elements.

may help to contextualise shifts in other periods, particularly in relation to age. For this to happen, these data needed to be left un-averaged.

To account for the fact that the evolutionary histories of each element are not reflected by LSIs, isometric size values were also calculated for each element independently. Chapter 3 showed that the number of potential combinations of metrics to use is high, so this analysis was limited to bivariates. For each element the total number of samples available to each possible metrics combination was calculated and the combinations with the largest sample sizes were selected for analysis. Isometric size was calculated with `lmosi()` and then the data were grouped by broad period.

5.2 Results

5.2.1 Quantification

The relative proportions of unassociated bones (Table 5.3, but see §5.2.9 for ABGs) conforms to the trends in abundance of hare bones in the wider UK archaeological record shown in Chapter 2. Because these bones represent a sampling methodology tailored to metrical identification for the purposes of Chapter 4, NISP values given in Table 5.3 are shown only for information, rather than for archaeological interpretation. Nevertheless these values do provide some interpretive insight. For example, the broad periods with the most bones, Roman and Medieval, have different proportions of bones that turned out to be identifiable. This suggests differences in skeletal element patterning - perhaps relating to butchery practices or waste disposal - have impacted on the relative identifiability of entire hare assemblages or groups of assemblages. These issues are be explored further in this chapter.

5.2.2 Skeletal element representation

Skeletal element patterns in the unassociated remains conform to expectations. The majority of the data derive from the major elements of the hind-feet, the limbs, and the scapula and pelvis (Figure 5.9). Specimens from these elements that were not identified to species make up a greater proportion of their totals in the medieval period than in the Roman. This suggests that either differences in waste disposal or carcass processing and cooking practices between these time periods have impacted

Table 5.3: NISP values for all unassociated hare bones from UK Iron Age to Post-Medieval sites, by broad period and metrically identified species/osteologically identifed taxon.

Broad Period	BH	MH	hare	?hare	Total
Iron Age	5	1	10	1	17
IA/RB	3	–	1	–	4
Roman	77	–	46	–	123
Saxon	6	–	5	–	11
Medieval	73	3	119	2	197
Med/PMed	9	1	6	–	16
Post Medieval/Modern	2	–	2	–	4
Modern	–	–	2	–	2
Unknown	3	–	7	–	10

on the proportion of recovered material that was metrically identifiable. The tendency for lagomorph lower limbs and feet to be recovered in large quantities from deposits associated with preparation waste from medieval kitchens (e.g. for rabbits see Roberts et al. 2017: p. 170; Bourdillon 1998), whilst major limb bones are generally found separately and are interpreted as consumption residue, is certainly a contributing factor.

There is no obvious preference for particular sides of the skeleton (Figure 5.10). There are some clear peaks for certain sides of particular elements (e.g. right posterior limb bones for unidentified medieval hares vs left anterior limb bones for identified medieval brown hares). But, there are no glaring absences in any of the distributions, so there is no reason to believe that the peaks are significant. When examined as proportions, the distributions of left and right bones balance out as approximately equal (Figure 5.11).

Examining the elements covered by Serjeantson's (1996) zone system shows that much of the skeleton is represented uniformly (Figure 5.12). This is consistent with the hypothesis that hares may have been cooked relatively whole, with little or no division of the skeleton between different types of sites or social groups. It also corresponds with the absence of selection for side.

Among the identified brown hares, bias towards particular bone portions is apparent. The distal humerus (Z5-Z8) and proximal radius (Z1-Z4) stand out as particularly common in the Roman and Medieval period. This could result from these portions

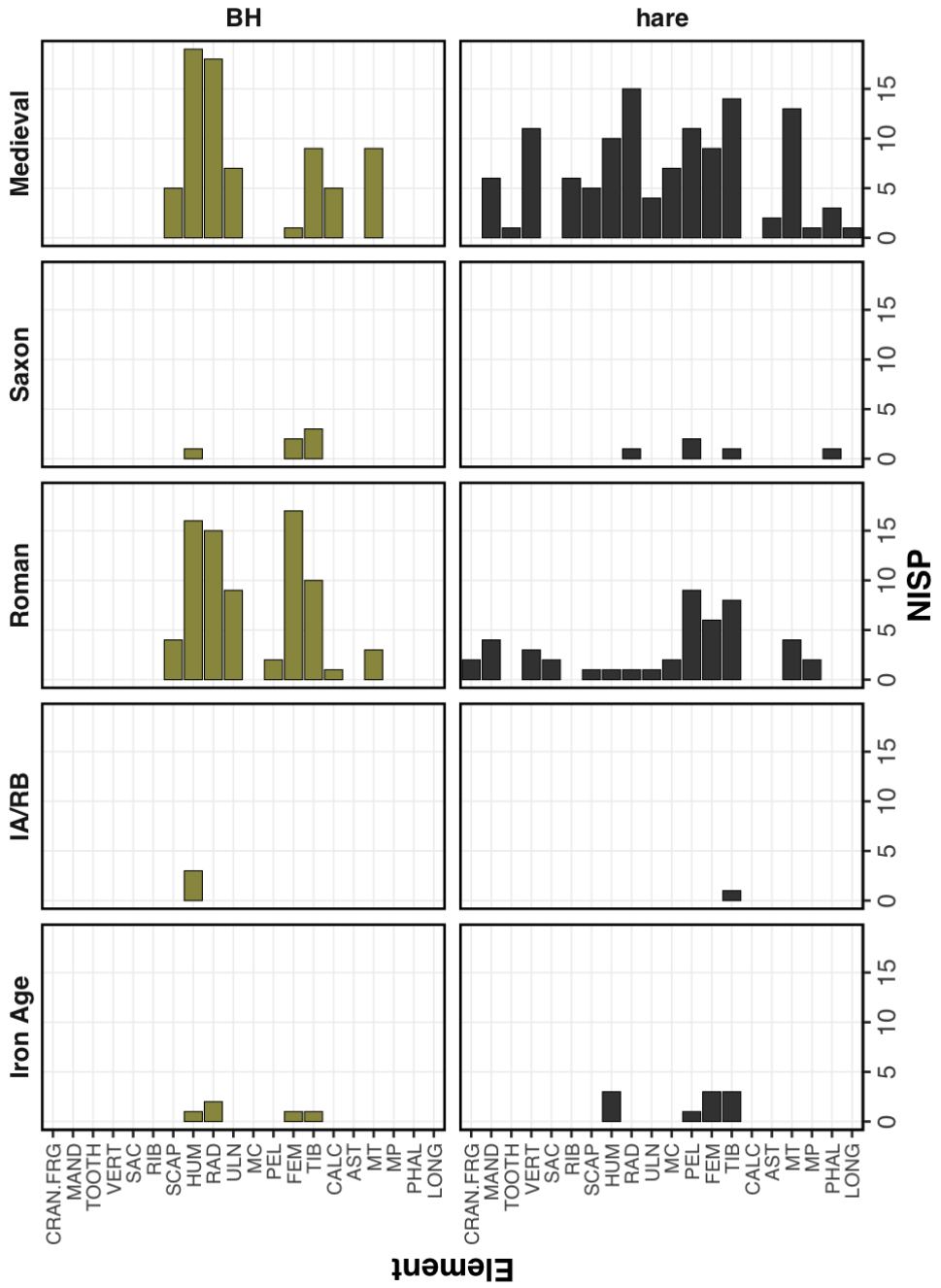

Figure 5.9: Frequencies (Number of Identified Specimens - NISP) of identified brown hares (BH) and unidentified hare bones by skeletal element and broad period.

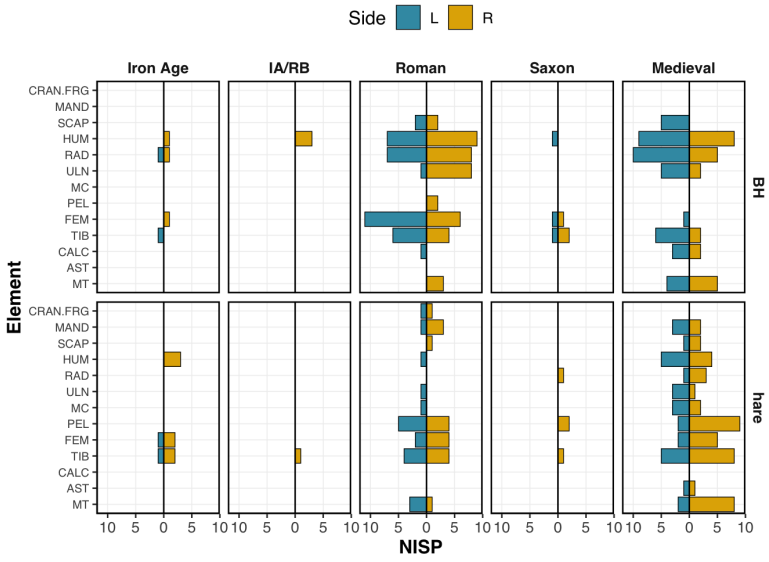

Figure 5.10: Frequency (NISP) of left and right bones by skeletal element and broad period, for identified brown hares and unidentified hares.

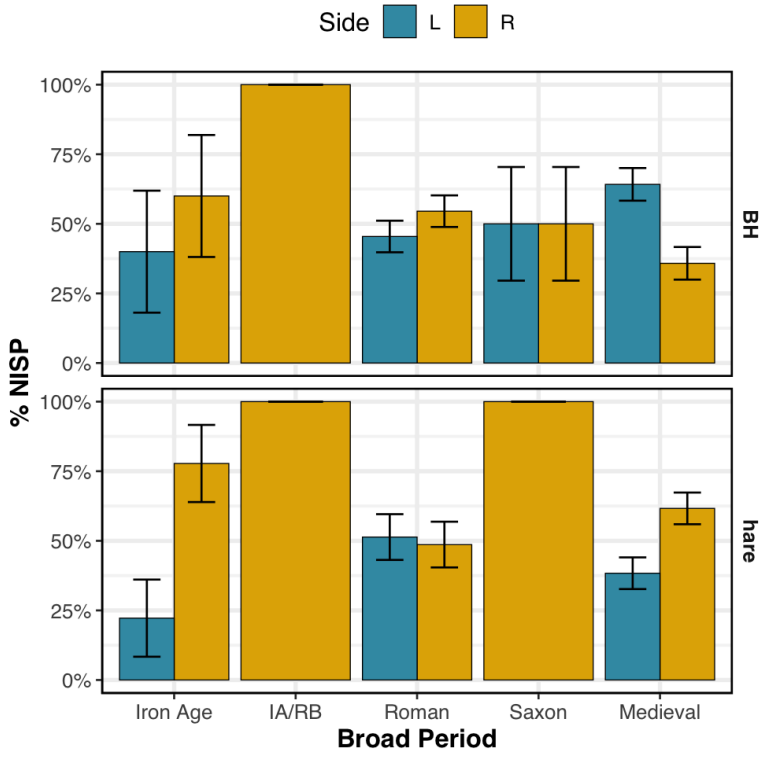

Figure 5.11: Percentage NISP of left and right bones by broad period for identified brown hares and unidentified hares. Error bars show standard error.

being more identifiable, but the homogeneity of each zone's NISP for the same elements among the unidentified remains suggests that the bias is genuine. Such a bias is consistent both with the taphonomic resilience of denser bone portions (especially in the distal humerus), and with the detachment of the forefeet by chopping through the distal radius. The distal radius as the detachment point is supported by slight bias in favour of the distal shaft (Z5-Z6), whilst the distal epiphysis (Z7-Z8) is rarer. But, this last trend may also be a result of the distal epiphysis being less common due to it being a mid-fusing epiphysis.

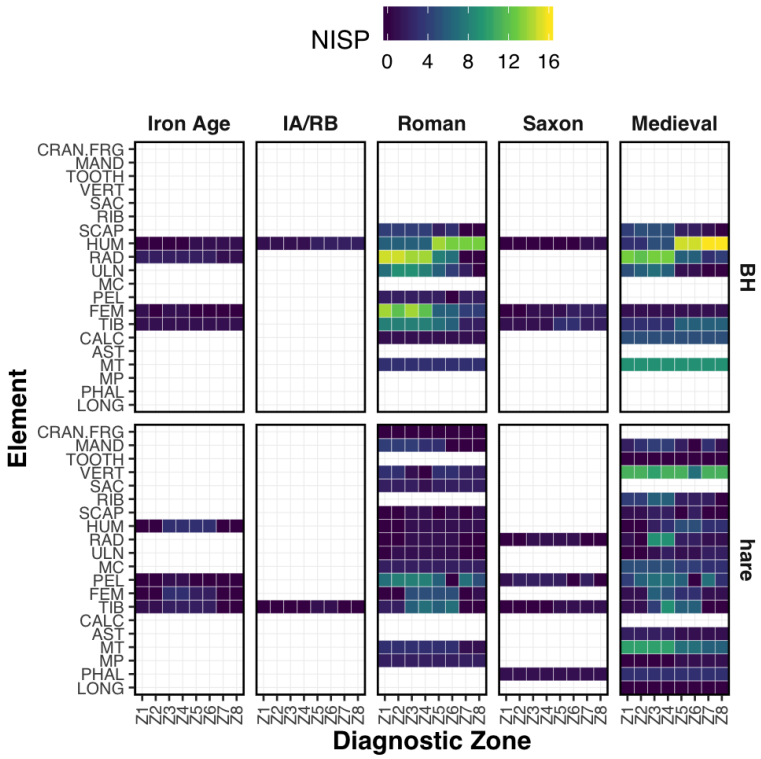

Figure 5.12: Frequency (NISP) of diagnostic zones by skeletal element for all UK sites by broad period. Data split between metrically identified brown hares and unidentified hares. Spaces without tiles (white) indicate absence.

Finally, the Roman period shows a clear bias towards the proximal (Z1-Z4) portion of the femur, whilst femora are more uniformly represented in the medieval period (Figure 5.12). This may support the idea that Roman hares tended to be cooked in a more complete state, or at least with less processing, than medieval hares. It is worth highlighting, however, that the patterns in Roman bone portions are heavily

influenced by Whitehall Farm (Figure 5.13). Much less of the skeleton is present overall at Fishbourne Roman Palace, and is represented uniformly - though admittedly the biases in favour of the proximal femur and radius and distal humerus are still apparent. But, these biases are much more intense at Whitehall Farm. The patterns shown by the zone representation may therefore represent a cultural shift in hare cooking over time, Whitehall Farm being thought to be the later of the two assemblages.

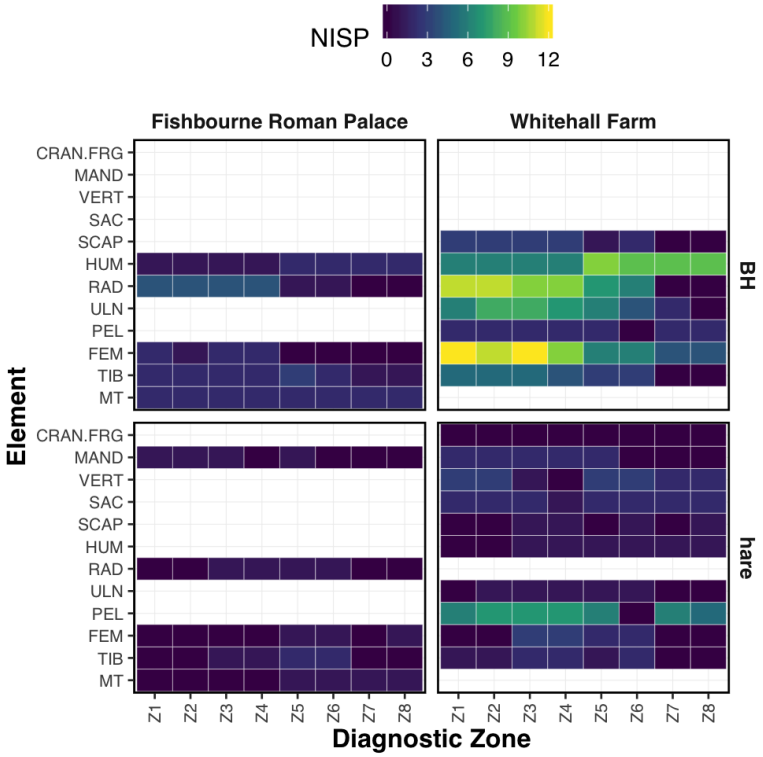

Figure 5.13: Frequency (NISP) of diagnostic zones by skeletal element for Fishbourne Roman Palace and Whitehall Farm. Data split between metrically identified brown hares and unidentified hares. Spaces without tiles (white) indicate absence.

5.2.3 Butchery and Fracturing

As expected, butchery evidence was scant. Multiple types of marks were recorded, but a number of these categories were so scarce that their analysis could not be meaningfully interpreted. Attention was therefore placed solely on straightforward 'chops' and 'cuts'. Chops tended to outnumber cut marks, except in the Iron Age/Roman transition where the combined NISP for these two categories was only equal to three,

so the standard error is wide enough for this difference to be dismissed as unreliable (Figure 5.14). In the Roman and Medieval periods, the total NISP is sufficiently large to be more confident of the tendency towards chop marks, but there is still sufficient overlap between the error bars for there to be no meaningful difference in the overall population. Nevertheless, a tendency towards chopping would make practical sense - fine cuts would be unnecessary to prepare a hare for cooking as they are small enough to cook the meat on the bone. Butchery was absent in the Iron Age hare bones.

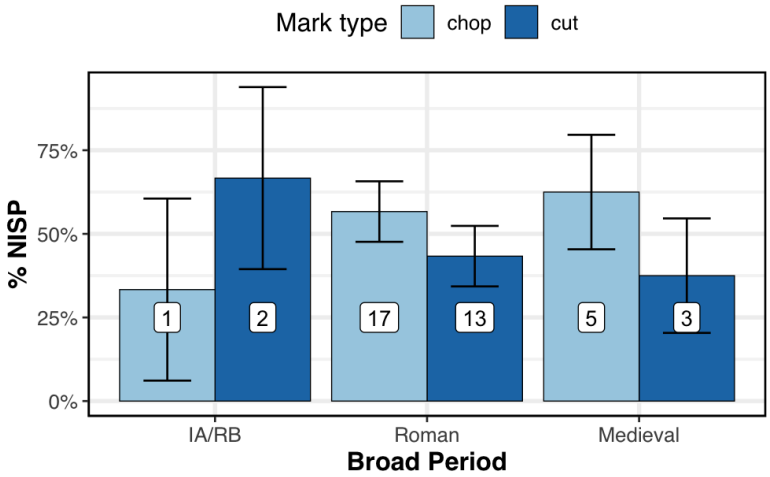

Figure 5.14: Percentage of chop vs cut marks by broad period. Error bars show the standard error. Labels show the raw NISP.

Fracture freshness analysis showed that helical fractures were rare among the selected skeletal elements (Figure 5.15). This suggests that fracturing is no more reliable an indicator of the extent of anthropic modification of hare bones than butchery marks. That most fractures clearly appear in the later stages of the depositional pathway may result from the theoretical tendency of butchery to fracture small bones, which may or may not be immediate. Breaks do not always reflect a single cause, but rather the entire taphonomic pathway. The Fracture Freshness Index may also be unsuitable for bones of this size. The data collection employed here does not account for the creation of jagged-edged fractures by anthropic actions. It is worth acknowledging Howard's (2013) vastly more detailed work on fracturing in lagomorph bones, which takes better account of subtleties in how such bones fracture under different processes than was possible here. A similar approach, aimed at recreating various types of archaeologically observable fracturing patterns for the purpose of creating a reference collection, would

allow this study's data to be improved upon.

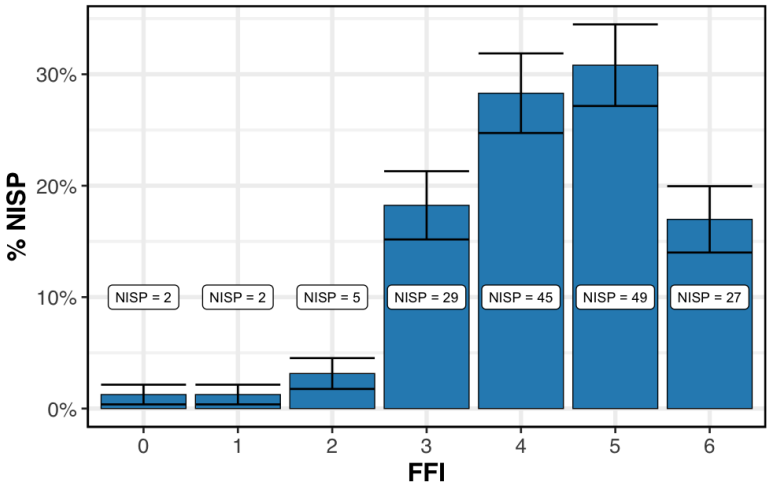

Figure 5.15: Percentage of FFI values across the entire FFI dataset.

In summary, the evidence for anthropic bone modification conforms to expectations. It is extremely scarce, and complicated by some uncertainty about how the size and structure of small mammal bones affects the degree to which the evidence can be recorded and assessed using traditional zooarchaeological methods. The prevailing absence of evidence for butchery in Iron Age hares may be significant as it conforms to patterns observed in other introduced taxa (Sykes 2014a) and suggests that hare consumption might have been prohibited or at least avoided. Human-hare relationships that produced any such prohibition were probably changing by the Late Iron Age, however, as Hamilton (2000a) does report butchery marks from Suddern Farm (§2.9.3.3).

5.2.4 Gnawing

Gnawing was identified on a small handful of bones (Table 5.4). The majority of cases were interpreted as likely being caused by cats; the few that were unspecified probably also fall into that category. Cats typically create puncture marks in the epiphyseal ends of long bones, whereas dogs tend to produce bones with a 'chewed' appearance (Moran et al. 1992; O'Connor 2000). Given this difference in the two main domestic carnivores' behaviour, partly determined by the morphology of their dentition, it makes sense that the evidence for gnawing in hare bones would be produced by cats.

Table 5.4: NISP of gnawed hare bones from UK sites by broad period and site. Values separated according to gnawing interpretation ('cat' or 'unspecified').

Broad Period	Site	Cat	Unspecified
Iron Age	Nettlebank Copse	–	1
Roman	Whitehall Farm	4	–
Saxon	Faccombe Netherton	1	–
Saxon	Portchester Castle	1	–
Medieval	Faccombe Netherton	1	–
Medieval	Lincoln Castle	1	–
Medieval	SOU1382 French Quarter	–	1
Medieval	Woking Palace	1	–

Dog gnawing could be expected to entirely destroy the small and fragile bones of a hare. Conceivably, hares are a more ideal size for cats to handle with their teeth and claws, whereas dogs would probably have been given - or sought out (carnivores do not select bones for gnawing at random, see O'Connor 2000: Chapter 5) - bones from the butchery or consumption waste of much larger fauna.

The gnawing evidence for hares is too sparse to be particularly informative, but it is nevertheless interesting that the assemblage with the most evidence is Whitehall Farm, where three of the four cases derive from the Bath House 1 assemblage. This suggests that cats were not only present on site, but were also present in the bath house when it was host to the event that created the single hare-rich deposit in context 144. The appearance of this evidence in the second/third century AD suggests that hare remains were being treated differently in the mid and later Roman periods to the earlier Roman period.

5.2.5 Burning and Staining

Burning was rarely identified, the most common examples coming from Roman contexts. Burning may, however, have been under-recorded as there was a high incidence of bones with discolouration from the burial environment, which can produce similar appearances. In most cases, brief examination under a stereomicroscope showed that staining - or the adherence of mineral deposits - from iron or manganese oxides were the more likely explanation for most cases of red/red-brown or black discolouration (discussions of staining in O'Connor 2000; Stathopoulou et al. 2019; Dupras et al.

Table 5.5: Number of cases of periosteal new bone identified.

Broad Period	Site	NISP
Roman	Greyhound Yard	4
Roman	Whitehall Farm	3
Medieval	Lincoln Castle	1
Modern	Tarbat	64

2013; Shahack-Gross et al. 1997). Cracking was very rare, supporting the staining interpretation.

The majority of bones from the Whitehall Farm assemblage had a red-brown colour and some had iron oxide deposits on their surface, suggesting the colour of these bones derives from being deposited with or near ferrous metal objects. Other cases of black discolouration not attributable to iron oxides tended to be sufficiently patchy or mottled to be reasonably confident of oxide deposits derived from bacterial, algal or fungal activity (Dupras et al. 2013; Shahack-Gross et al. 1997), rather than burning.

One exception was the Late Iron Age hare ABG from Fishbourne Roman Palace, which was probably lightly charred (§5.2.9.4, below). Its excellent state of preservation, relatively uniform light brown/grey colour, and lack of any cracks from shrinkage, highlights the difficulty of distinguishing between changes caused in the burial environment from burning.

5.2.6 Pathologies

Pathologies were rarely encountered. Periosteal new bone (PNB) was initially recorded wherever it was found, but it occurred in juveniles so regularly, that it was ignored for specimens recorded later. Ultimately, PNB was found only at four sites, most commonly at Tarbat - unsurprising for an assemblage dominated by leverets. It was concluded that only one of the samples with PNB represented pathologies (see below), and the presence of periosteal growth in all others can be attributed to age-related growth.

Traumas were identified in two samples (with thanks to Richard Thomas for interpreting these). One was an unidentified hare metatarsal from Tarbat in good condition (ZA836). The trauma took the form of a fully healed fracture around the middle of the diaphysis. The fracture had healed at a slight angle, with the formation of a small

callus. Periosteal new bone was present.

The second specimen (ZA146, Figure 5.16) was the proximal half of a Roman tibia, metrically identified as brown hare, from the bathhouse at Whitehall Farm. Around the break in the diaphysis, the bone had suffered a compound fracture and was in the process of healing. A periosteal callus was present and an endosteal callus filled the medullary cavity. The callus was woven, indicating that it was active at the time of the animal's death. Thinning of the cortical surface indicated a lack of blood supply. The injury may have contributed to the animal's death as the lack of remodelling on the proximal end indicates that it did not live for more than few weeks after the event.



Figure 5.16: Pathological tibia from Whitehall Farm (ZA146), showing periosteal callus at the middle of the diaphysis.

The pathology is consistent with, though not proof of, a trapping injury. This is exciting evidence because the use of traps and snares is difficult to identify archaeologically. It has been hypothesised that the zooarchaeology of wild fauna is overly male-centric because it is common for men to hunt large game which are abundant archaeologically, whilst anthropological evidence shows that women and children trap archaeologically under-represented (and therefore understudied) small fauna (Sykes 2014a: p. 54). In Fowler (2016) I synthesised zooarchaeological data for small game in Britain and attempted to integrate this evidence with the historical, art historical and modern anthropological context to determine the potential for zooarchaeology to detect women and children's relationships with wild animals. Ultimately, that study was flawed due to the complex taphonomic pathways of small animal bones and the difficulty of establishing a connection between such remains and equally scarce artefactual archaeological evidence for trapping or snaring itself. On its own, this tibia from Whitehall

Farm is insufficient to improve upon that study, but it shows how detailed projects on single species or genera of small game might begin to build up the necessary evidence to answer these bigger-picture questions.

5.2.7 Epiphyseal Fusion

Sample size for epiphyseal fusion was sufficient for analysis in the Iron Age, Roman and Medieval broad periods. Unsurprisingly, each showed that the percentage of fused epiphyses declined from early to middle to late-fusing epiphyses (Figure 5.17). The differences in these profiles between the phases, however, are worth further consideration.

In the Iron Age, there is a greater gap between the proportion of fused early-fusing epiphyses and the proportion of fused mid- and late-fusing ones (Figure 5.17). There is little difference between the mid- and late-fusing Iron Age epiphyses. When standard error for these proportions is taken into account, all three fusion stages overlap. To some degree, this profile must reflect the low sample size for the Iron Age. Whether it can be interpreted as evidence for anthropic bias towards younger individuals in the archaeological record is doubtful, and on the available evidence no firm conclusion can be drawn. However, the possibility of a juvenile bias contrasts with the evidence from the Iron Age ABGs which all represent individuals in an advanced growth stage (§5.2.9).

In the Roman period, all the early fusing epiphyses were fused, and progressively smaller proportions of mid- and late-fusing epiphyses were fused. There is some overlap between the standard errors for mid- and late-fusing epiphyses, but none with with the early fusing. For reasons already outlined, it is impossible to tell whether this profile represents a genuine change from the Iron Age, but it could represent the introduction of Roman hare hunting practices. That all the early-fusing epiphyses were fused suggests that young animals were either avoided or less likely to be captured.

The Roman period contrasts with the Medieval period. Most of the early-fusing epiphyses were fused, and fewer mid-fusing ones were fused. But, an even smaller proportion of late-fusing epiphyses were fused and there is very little overlap between the stages - even when including the broad standard error for the late-fusing epiphyses. The breadth of that error bar reflects the low sample size for those epiphyses, but that small

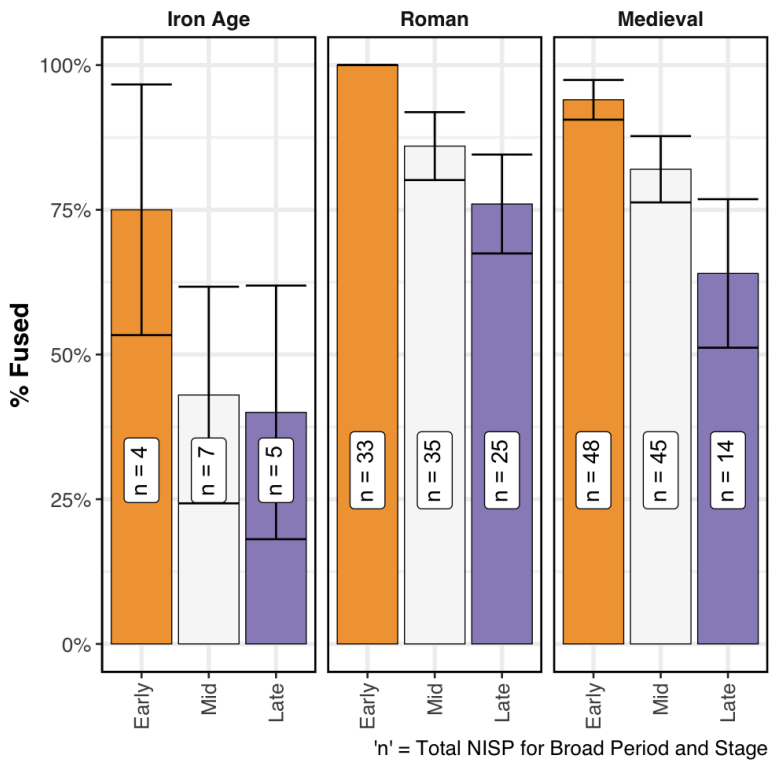

Figure 5.17: Percentage of fused epiphyses in early-, mid-, and late-fusing groups of epiphyses for the Iron Age, Roman, and Medieval Broad Periods.

sample size itself adds an additional layer of information to interpret. If this profile reflects a real tendency to younger individuals, a small sample size for late-fusing epiphyses would be expected because unfused bones are less likely to survive.

The Medieval profile could reflect a shift in hunting practices between the Roman and Medieval period, itself reflecting shifts in how hares and hare hunting were perceived in these periods. It is worth acknowledging that the argument for a shift in hunting practices is currently circular as the interpretation of each of the two profiles as reflecting hunting is somewhat dependent on the other also being interpreted as a hunting profile. Chapter 6 will attempt to address this issue by bringing together independent strands to evidence from archaeological and other sources that will build up a clearer picture of the nature of hare hunting in the Roman and Medieval period, providing better context for the interpretation of these profiles.

In summary, it appears that epiphyseal fusion analysis in hares has potential. On their own, the data gathered here are insufficient to support archaeological interpretation, but integrating these results with other evidence streams will improve upon their contribution in this thesis (Chapter 6). In the future, an expanded dataset coupled with a fusion model specific to brown hares could improve upon these findings.

5.2.8 Radiocarbon dating

Six samples were submitted for radiocarbon dating. Three were derived from the Iron Age ABGs from Blackhorse Road, Winnall Down, and Winklebury Camp. These were submitted to confirm that they represent the earliest hares in (Southern) England. Non-ABG Roman samples from Fishbourne Roman Palace and Whitehall Farm were also submitted to date these key assemblages, as they represent significant stages in the brown hare's bio-cultural history in Britain. The LIA/Roman ABG from the Fishbourne Roman Palace ditch was also submitted, but failed to yield datable material due to charring.

The C14 results (Figure 5.18) are significant for two reasons. Firstly, they confirm the predicted broad dates of each sample. All the successful Iron Age samples were confirmed as Iron Age, and the samples from Fishbourne and Whitehall Farm were confirmed as Roman. The Winklebury Camp ABG's Iron Age date is significant as the bones' excellent condition and the recovery of chicken ABGs from the same site that

proved to be modern (page 131, Best et al., forthcoming) placed an degree of doubt upon it. The Whitehall Farm date is slightly earlier than expected, with the majority of its radiocarbon date range in the second century, rather than the third (Figure 5.18).

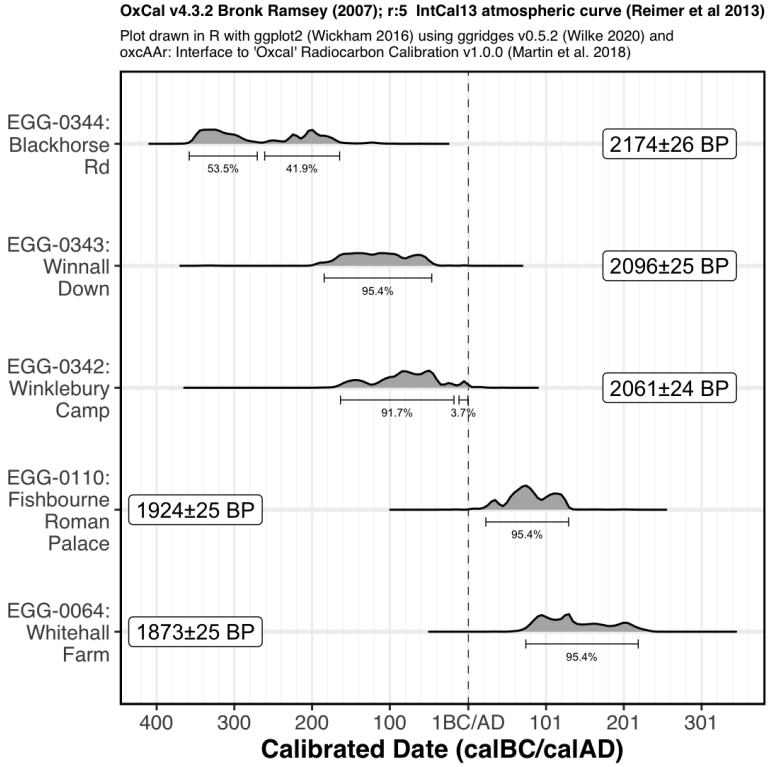

Figure 5.18: Radiocarbon dating results for hare samples. 2 sigma probabilities shown with error bars.

The second point of significance is the chronological order of the Iron Age ABGs. The published data for these sites placed the Winklebury Camp ABG as the earliest, spanning the Early to Middle Iron Age, with Winnall Down and Blackhorse Road as more firmly Middle Iron Age. Radiocarbon dating shows, however, that the Blackhorse Road ABG is the earliest, by a significant margin if the earliest possible date range is true (53.5%), and overlapping only marginally with Winnall Down if the later one is true (41.9%, Figure 5.18). This re-accentuates the hypothesis of two distinct geographical groups of sites with hares proposed in Chapter 2 (§2.7, §2.8) and raises the possibility that they could represent different populations, as there is now evidence that the eastern group predates the other. It is nevertheless extremely tenuous given the limited number of samples. Genetic evidence is required to determine whether the Blackhorse Road and

the Hampshire (Winnall Down and Winklebury Camp) ABGs represent individuals that are sufficiently different to derive from distinguishable populations. Were that shown to be true, the southern population might be descended from the eastern group, or the two could originate from separate introduction events, plausibly from separate areas of continental Europe.

5.2.9 ABG Case Studies

Analysis of the Associated Bone Groups needs to be isolated from the main dataset because the presence of ABGs overwhelms unassociated bone data with information from a finite number of individuals. This is particularly important in this case, where the total NISP for the whole project reaches high numbers only because of ABGs. Furthermore, ABGs are significant in their own right when studying animal introductions (§2.9.1). Consequently, this section replicates some of the analysis already performed for unassociated bones, and attempts to reconstruct partial taphonomic pathways for each ABG. It also briefly inspects the relative size of each animal (Figures 5.21 - 5.23), in preparation for the size change analysis in §5.2.10.

This section arranges the ABGs in approximate chronological order, beginning with the radiocarbon dated Iron Age specimens, followed by the Late Iron Age ditch at Fishbourne Roman Palace, and then by the 3rd/4th century Roman ABGs.

5.2.9.1 Blackhorse Road (360-166 BC)

One of the two Blackhorse Road ABGs was retrieved from the North Hertfordshire Museum archive for this study. The bones suffer from considerable root-etching, which gives the superficial impression of poor preservation in otherwise well-preserved bones.

Among the hare bones there was also an un-erupted human right maxillary second premolar (the P2 - or P4 in zooarchaeological terms), some unidentifiable fragments of larger mammal bone and two - probably intrusive - rodent femora.

The ABG is a nearly complete skeleton (Figure 5.19), consisting of ninety-seven identified specimens. Much of the skull survived in identifiable fragments. Recovery was clearly comprehensive too, as the smallest elements - such as the cuboid, cuneiforms and fabella - are all represented. There appears to be no selection in favour of side and

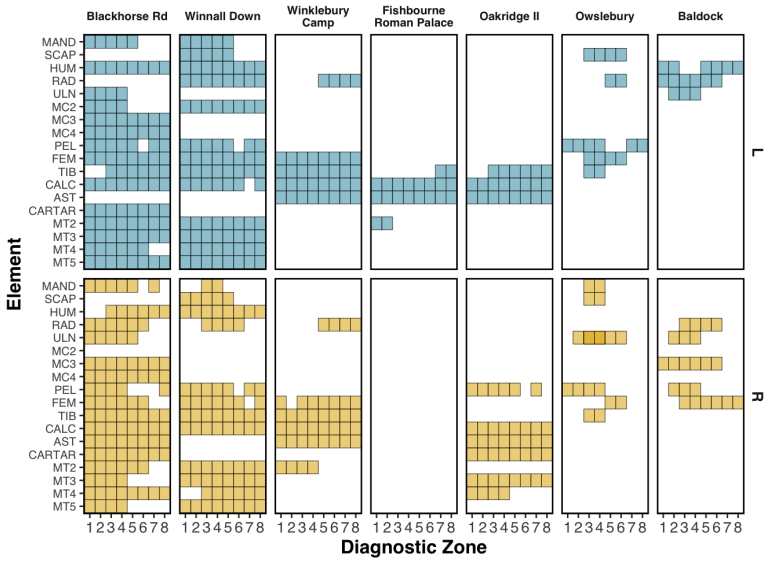

Figure 5.19: Skeletal element representation by element, zone, and side for ABGs. Each tile represents 'present', whitespace represents an absence.

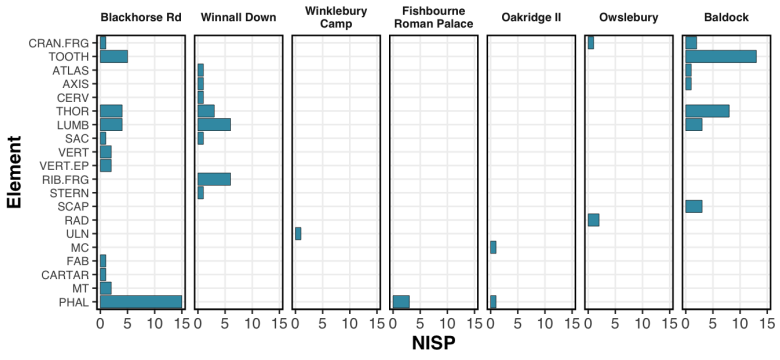

Figure 5.20: Number of Identified Specimens (NISP) for specimens from miscellaneous (especially axial and un-sided) skeletal elements from ABGs. BH = Brown Hare, MH = Mountain Hare.

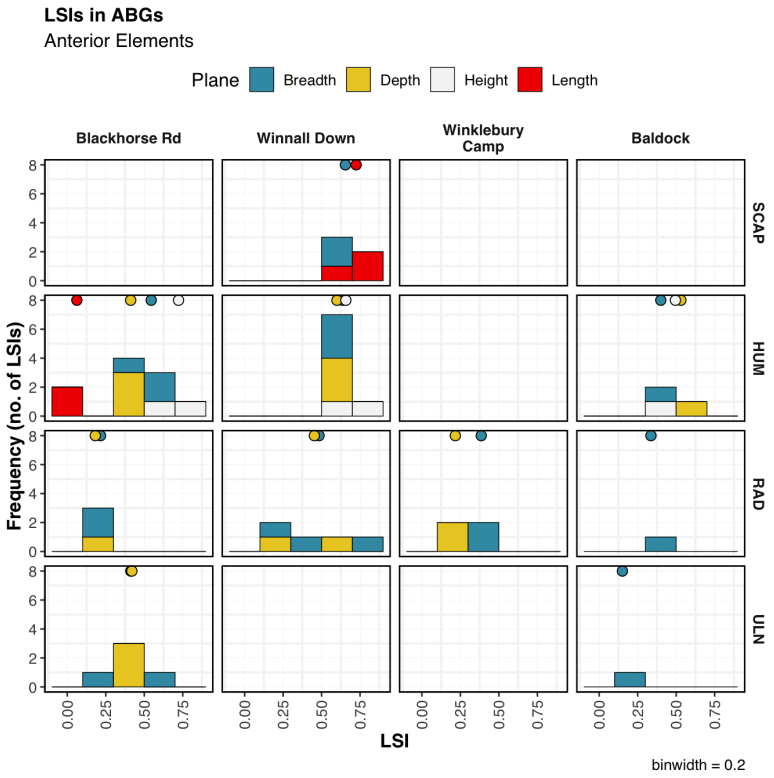

Figure 5.21: LSI histograms for anterior skeletal elements from ABGs, by plane. Points show the location of the mean LSI for each plane on the x-axis.

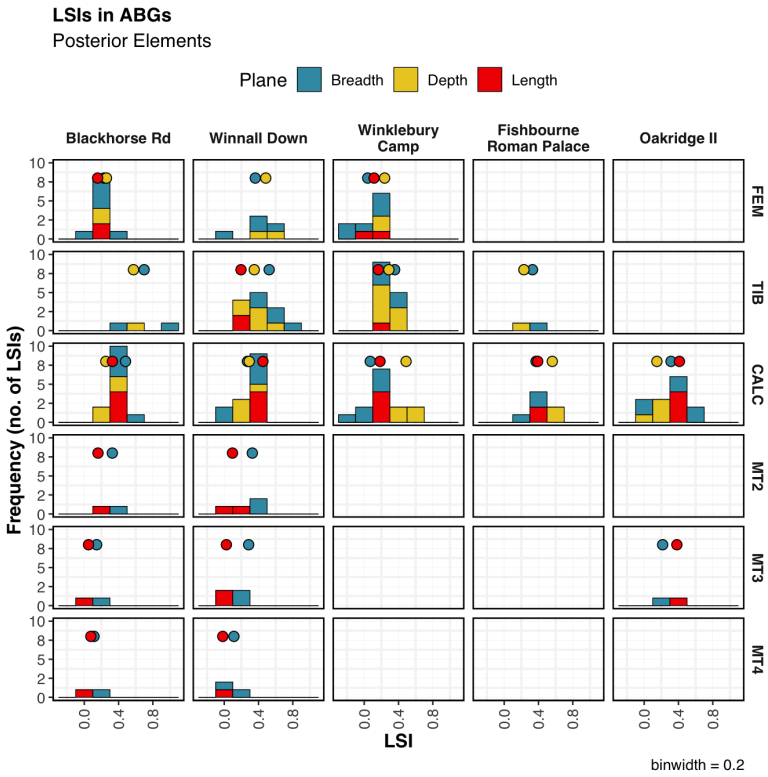

Figure 5.22: LSI histograms for posterior skeletal elements from ABGs, by plane. Points show the location of the mean LSI for each plane on the x-axis.

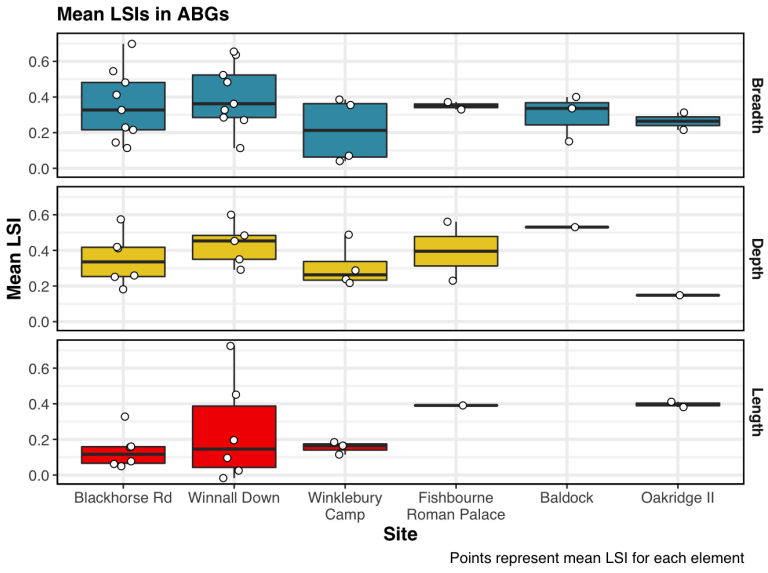

Figure 5.23: Distribution of mean LSIs for each element by ABG and anatomical plane. Points show mean LSI for each skeletal element for each ABG.

absences in skeletal element representation tend to correlate with fragile elements or element portions, such as the distal ulna and radius (Figure 5.19). The representation of vertebrae appears to favour the lower spine.

Aside from the root-etching, few taphonomic markers were observed. A single metapodial had a black stain, which was attributed to mould or oxides. Fractures in broken bones were generally interpreted as modern breaks due to the clean edges with a light colour. One ulna may have been broken in antiquity, but the FFI value of five suggests there is no significance to it. There was no evidence of butchery. The proximal humerus and tibia and distal femur were all fused, showing that the animal was skeletally adult.

Log ratios show that the animal was larger than the modern brown hare standard (Figure 5.23). The most comparable ABG to Blackhorse Road's is Winnall Down's, which is very similar in terms of breadths. In terms of depths and lengths, Winnall Down's ABG may have been a slightly larger animal, but this impression may be a consequence of differences in skeletal element completeness as well as factors that are more directly related to size, such as age, diet and environment.

5.2.9.2 Winnall Down (186-48 BC)

In the Winnall Down ABG, most of the skeleton was present (recorded NISP = 53). Though not as complete as the Blackhorse Road ABG, it is the most comparable to it in terms of skeletal element representation. Most of the major limb bones were identified, though the ulnae and the epiphyseal ends of one radius were absent (Figure 5.19). Other major absences were only among the small, less easily recoverable elements, like the metacarpals, carpals and tarsals, and phalanges.

Like the Blackhorse Road ABG, the lower spine was better represented than the upper, with the sacrum, six lumbar and three thoracic vertebrae present. Unlike Blackhorse Road, the atlas and axis and one other cervical vertebra were found. As originally noted by Maltby (1985), the skull was completely fragmented, but the pieces were overall in good condition: both maxillae and the left frontal and temporal bones could be identified. One each of the maxillary P3, M1 and M2 were also identified. No significant taphonomic modification was present. The humeri, femora and tibiae were all fully fused, showing that the animal was skeletally adult.

LSIs suggest that the Winnall Down ABG is a similar size to the Blackhorse Road hare, probably slightly larger (Figure 5.23). The much broader range of the length LSIs for Winnall Down is probably not significant; instead it results from the presence of the SLC measurement on the scapula, which was not present in the Blackhorse Road data and is consistently larger than the modern standard. Possibly the extreme value for Winnall Down is a recording error, but examining the raw metrics shows that the specimen is consistent with other archaeological hares (Figure 5.24). There is greater diversity in the scapula metrics in later periods, which may indicate that a trend towards large individuals in the Iron Age is a consequence of the demographic profile of the available evidence (age, sex etc) or that a shape change has occurred over time since the Iron Age.

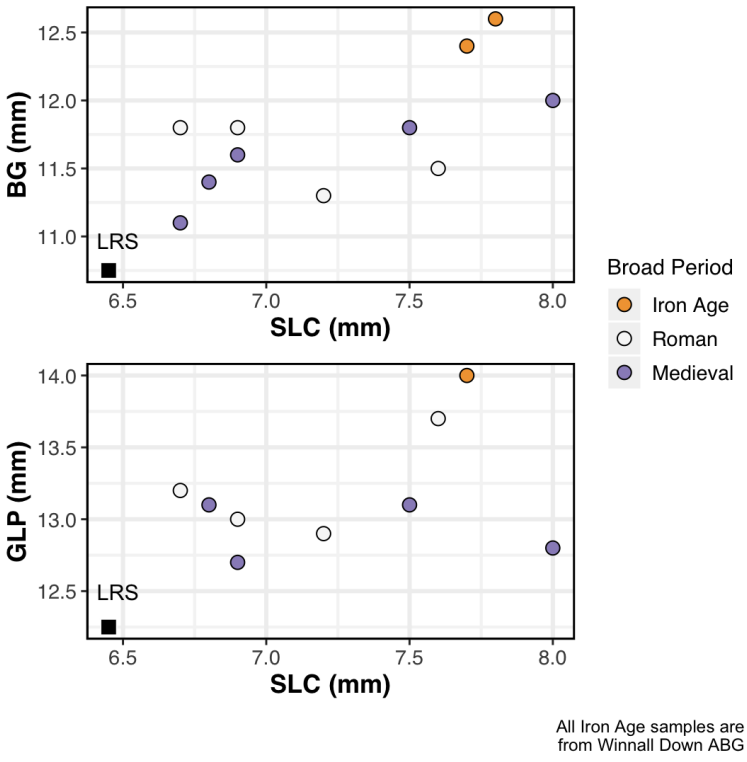

Figure 5.24: Raw measurements of the scapula on the glenoid vs the shortest length of the neck (SLC) in archaeological hares (excluding Tarbat). Values of the LRS shown as a black square.

Despite the influence of the scapula, the median of the average LSIs for each element is almost the same between Blackhorse Road and Winnall Down for lengths, but no-

ticeably higher for breadths and depths at Winnall Down (5.23). This suggests that the Winnall Down hare would have been stockier, but not noticeably taller. A variety of factors could influence this difference - including diet, climate, terrain and genetic differences between populations. The simplest explanation, however, would be natural variance between individuals within a population. This may or may not include age-related growth.

5.2.9.3 Winklebury Camp (165-1 BC)

The Winklebury Camp hare is the least complete of the Iron Age skeletons. Jones (1977: p. 59) reported twenty-seven fragments were recovered, though only fifteen were recorded in this study. This suggests either that the recording method was different or that the ABG was not the only example of hare bones in the total assemblage. Both interpretations are equifinal with the available evidence. Some bones might have been double-counted by Jones (1977) but were single-counted here - the difference may relate to refitting fractured specimens, a practice applied to all the ABGs in this study. But, Jones (1977: p. 64) makes no comment on hares other than to highlight the presence of the ABG, so it is equally plausible that the NISP difference between these data and Jones' relates to other hare bones that are not described in the report.

Winklebury Camp's ABG is represented predominantly by elements from the hind limbs (Figure 5.19). The right patella and second metatarsal and both astragali, calcanea, femora and tibiae were present (and most were complete), though interestingly the pelvis is absent. The anterior skeleton was represented only by the distal parts of both radii and one ulna, and two fragments of the scapula.

The bones were in such excellent condition that the possibility of the ABG not being genuinely Iron Age was seriously considered prior to the radiocarbon results (§5.2.8), especially given the chicken radiocarbon dating evidence from Winklebury Camp (see also Chapter 2, page 131, Best et al. forthcoming). The site lies on chalk-based geology (Figure 5.25) and the pit layer it was deposited in was made up of a mixture of loam and chalk (see §2.9.3.1, esp. Figure 2.39), so alkaline conditions have likely contributed to the bones' excellent preservation. Four of the bones were very lightly stained and there was no evidence for butchery or any indication of significant fracturing.

Overall there is little to be gleaned from the taphonomy of this ABG so it appears to

fall in line with the expected traits of an ABG of a recently introduced animal. There is no evidence that this animal was considered 'food'. It is nevertheless intriguing that few of the skeletal elements are represented, in comparison to the Blackhorse Road and Winnall Down ABGs. The proximal tibiae and distal femora were fused, indicating the animal was skeletally adult.

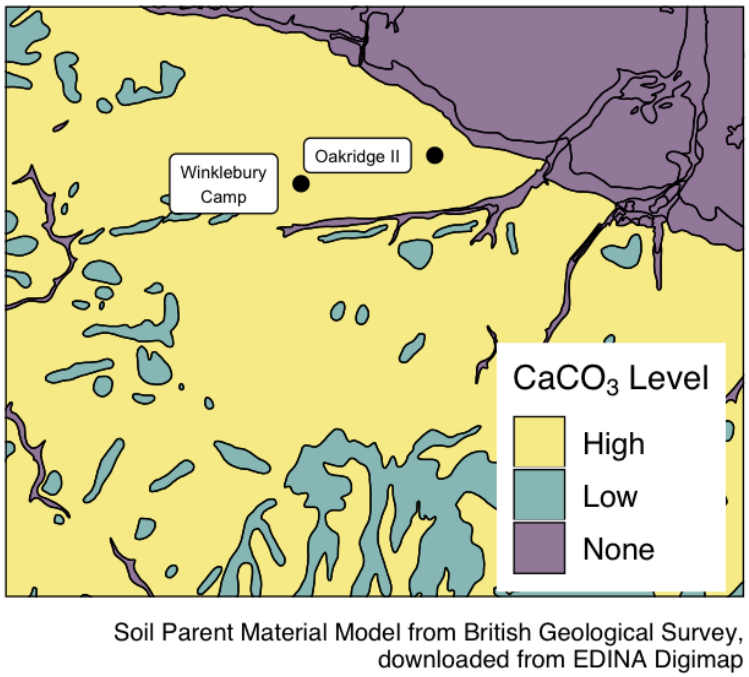

Figure 5.25: Site location of Winklebury Camp and Oakridge II shown with the relative calcium carbonate ($CaCO_3$) content of the local soil parent (downloaded from EDINA Digimap, see also BGS (2011).

Metrically the Winklebury Camp ABG is the smallest of the Iron Age ABGs (Figure 5.23), though this impression might be exacerbated by the Fishbourne Roman Palace ABG's relative incompleteness (see below and Figure 5.19 above), meaning that there are fewer metrics available and therefore less potential for metric diversity relative to Winklebury Camp. Regardless, Winklebury Camp's ABG is clearly the smallest so far, viewed in chronological order from Blackhorse Road.

5.2.9.4 Fishbourne Roman Palace (Late Iron Age)

The ABG from the Late Iron Age ditch at Fishbourne Roman Palace consists of a hare's left hind-foot. The major bones of the ankle - calcaneum, astragalus and the distal epiphysis (fused) of the tibia - are all represented (Figure 5.19). Two proximal phalanges and one intermediate phalanx were present along with the proximal articulation of the second metatarsal. The bones are a uniform grey-brown colour (Figure 5.26) but there was no cracking to indicate shrinkage, so whether or not the bones had been charred along with the rest of the bone assemblage from the ditch (Sykes 2005: p. 79-81) was ambiguous. Similar colours could result from mould activity or oxides in the burial environment. That the sample selected from the ABG for radiocarbon dating failed to yield datable material suggests it was charred, however. The fused distal tibia and calcaneal tuberosity indicate that the animal was at least as old as the age-range of the mid-fusing epiphyses.



Figure 5.26: Hare foot ABG from Fishbourne Roman Palace Late Iron Age Ditch. Source: Author

The Fishbourne ABG is difficult to place in terms of size. A superficial examination of the mean LSI distribution for each element (Figure 5.23) would suggest that it is similar in size to the Winnall Down ABG, which is supposedly the largest of the Iron Age ABGs. But, the Fishbourne ABG is one of the least complete, and its skeletal representation is restricted to one hind-foot. Examining the LSIs for the calcaneum as a histogram, however, shows that it is typical of most hare ABGs (Figure 5.22).

5.2.9.5 Baldock (3rd Century AD)

Stead's excavations at Baldock (Stead et al. 1986) uncovered two third century pits containing hare bones, one of which was the semi-complete skeleton retrieved for this study. The sampled remains came from context A204, but Chaplin & McCormick's (1986: p. 396) comment that "*there were two separate third-century pits (A 204 and A 114) which contained hare bones - in the latter, a semi-complete skeleton*", suggesting either a mislabelling in the archive, or that Chaplin & McCormick confused these contexts in their report. They provide no further information on the hare remains, including whether this skeleton was articulated when recovered, or refitted during analysis. As the Baldock excavations (1968-72) pre-date Annie Grant's (1984) work on bone groups at Danebury, it was not surprising to also find that the bones were not bagged separately from other material from the same context. Nevertheless, it appears likely that these bones represent a single individual, so it was treated as an ABG for the purposes of this study.

The fragmentary and small size of the bones suggest some of the material was sieved, though it is unclear whether or not the larger pieces were hand-collected. In addition to the hare, amphibians and rodents were present in the material extracted from the archive. A juvenile canid skeleton was also present, presumably belonging to a dog. Even though the dog also appears to be a semi-complete skeleton, it was not included in Chaplin & McCormick's (1986: p. 408-9) list of features containing dog skeletons. Possibly this indicates it was not discovered in articulation.

On the left side, the hare is represented exclusively by a partial forelimb. The humerus and the radius were both missing a portion of the proximal shaft, but the unfused proximal epiphysis of the humerus was recovered. The distal humerus was fusing, but not fully fused. As the distal radius and femur, proximal ulnae, and the acetabulum were all unfused this easily establishes the hare as a young individual, but older than the juvenile from the Roman cesspit at Owlsebury (below), which is the most comparable to this ABG.

Both the hare and dog bones bore a white or grey chalky concretion in varying quantities (Figure 5.27), which is probably an indicator of deposition in a cesspit. Zooarchaeologists appear to have left the taphonomy of mammal bone from cesspits understudied, perhaps because bone assemblages are seldom reported at the context-level (Smith

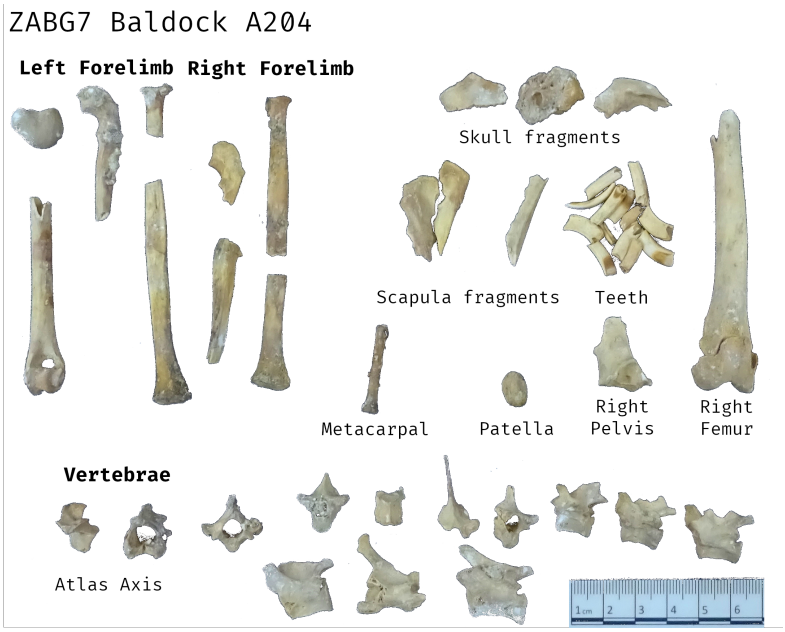

Figure 5.27: Bones and teeth from the Baldock ABG. Source: Author

2013: p. 527, 539). Nevertheless, there appears to be consensus among environmental archaeologists that the burial conditions in cesspits allow for phosphate ions (derived from sewage and food waste) and calcium carbonates (probably from bone) to interact with archaeologically recoverable waste deposited in the pit (Marshall et al. 2008: p. 860; Langgut et al. 2016; Hall et al. 2016). Botanical remains may become mineralised as phosphate and carbonate ions replace their organic content (Langgut et al. 2016; Smith 2013), and it seems likely that such processes explain the mineral deposits adhering to the bones from the Baldock pit. Smith (Smith 2013: p. 539) also suggests that the deposition of ABGs may be a cultural marker of a cesspit.

The Baldock ABG indicates a major shift in the significance of hare ABGs in British archaeological assemblages. Whereas the Iron Age ABGs are probably examples of the deliberate deposition of a socially important animal, the Baldock hare was discarded as waste. It may also be significant that this is the youngest animal from ABGs so far.

As a fragmentary juvenile, the Baldock ABG's relative size cannot be taken at face value, because the sample size is small and age-related allometric change means that the relative proportions of the breadths and depths are likely to reflect the shape of recently fused epiphyses rather than size. It is known, for example, that the distal

radius and ulna thicken and then shrink again during the fusion process (see Figure 5.3 above, and Bujalska et al. 1965). Similar changes elsewhere seem a likely explanation for the median of the LSI distribution being larger than that of Winklebury Camp's ABG (Figure 5.23), despite the Winklebury hare being an older animal.

5.2.9.6 Owslebury (4th Century AD)

A total of twenty-two bones from the Owslebury assemblage were extracted from the Hampshire Archaeological Trust archive. They all appear to represent juveniles in an early developmental stage so none were identified metrically. Seven belonged a very young, possibly neonate, animal from an Iron Age context (F139-2) and probably represent the remains of a skeleton that was deposited in a complete or near-complete state. But, the presence of two right femora in the sampled material indicates that more than one individual was in the bag, so it is effectively impossible to isolate individual animals, even though a total of nine bones were originally identified as single animal (Maltby 1987). They were not treated as an ABG for the purposes of this thesis, therefore, though it is useful to acknowledge their presence here. None of these bones had fused epiphyses and most had new periosteal bone.

Fifteen hare bones from Owslebury that could be confidently treated as an ABG, were recovered from the archive, however. They derive from a fourth century AD context (F646-6) and clearly come from a juvenile. The acetabula were unfused and there were no fused epiphyses. But, this animal was probably in a slightly more advanced growth stage than the Iron Age remains; none of the bones were explicitly recorded as neonate. There was no evidence of butchery and most breaks were identified as modern. As this is such a young individual, no metrics were recorded.

Feature 646 is described as a cesspit with a bone assemblage that is atypical of the site (Maltby 1987). Layer F646-5 included four "substantially complete" cattle skulls and a complete horse skull; sheep/goat bones were mostly found in articulated groups, all but seven of the sixty-six dog bones belonged to the bodies of newborn puppies which "had been dumped in the pit" (Maltby 1987). Two cat skeletons, buzzard and corvid bones and single instances of chicken and thrush were also identified. Sixteen hare fragments, including an ABG, were also found in a separate layer (F646-4) and solitary hare fragments were found in F646-5 and F646-7 (Maltby 1987: Table F646.1).

Although unusual for the whole assemblage, Maltby (1987) describes the dumping of skeletons, skulls and sheep/goat limb extremities in this feature as typical of other cesspits at the site.

5.2.9.7 Oakridge II (4th Century AD)

The Oakridge II Well was represented by 12 bones, including the astragali and calcanea, one of the cuboids, two metatarsals of the right hind-foot, a proximal phalanx and a partial metacarpal (Figures 5.19 and 5.20). Aside from the feet, the tibiae and a right partial pelvis were also present. The skeletal element representation shows remarkable similarities with that of the hare foot from Fishbourne Roman Palace, which may be relevant given the relative geographic closeness of the sites (5.28).

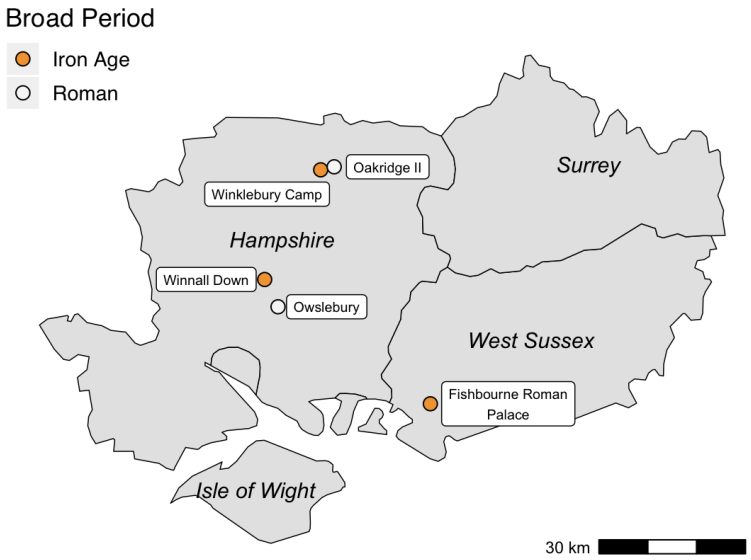

Figure 5.28: Map showing spatial distribution of analysed ABGs from southern England.

The exact identity of these bones is uncertain because the bones were archived loose in a box among other assorted material, but marking on the bones suggests they belong to the adult skeleton (the proximal tibia is fused) found at depths between 67'9" and

69'3" [Maltby1993-eo p. 61]. There is no available evidence that they belong to the leveret found at the same depth or to the adults found at depths greater than 70' listed by Maltby (1993b: p. 61). The depth range of 67'9"-69'3" places the ABG in a period of limited waste accumulation between filling in the late 3rd century/early 4th century and a period of rapid filling in the late fourth century (Oliver 1992: Fig. 7; Maltby 1993b: p. 68). The bones have a dark, red-brown colour, possibly indicating the presence of ferrous metalwork or an iron-rich soil, but this is probably equifinal with deposition in waterlogged conditions. There is no evidence for butchery.

Like the Fishbourne ABG (§5.2.9.4), the Oakridge II skeleton's metrics probably reflect skeletal element representation just as much as size. The LSI distributions are tightly clustered, with the median being most similar to Winklebury Camp for breadths and to Fishbourne for lengths.

5.2.9.8 Discussion

Perhaps the most significant feature of these ABGs is how their skeletal representation, age, size, taphonomy and archaeological context reveals changing human behaviour with respect to hares over time. By placing them in chronological order, starting with Blackhorse Road and ending with the fourth century AD specimens from Owslebury and Oakridge II, a pattern emerges in all of these lines of evidence, which become significant when brought together as a whole.

The Blackhorse Road ABG is an excellently preserved, near-complete adult skeleton, with no butchery marks and found in a ditch. It is also among the largest of the ABG hares. The next Iron Age ABGs - Winnall Down and Winklebury camp, are similarly well-preserved skeletons found in pits, of similar ages and with no butchery. But, they are less complete. The least complete, Winklebury Camp's, is also the first probable decline in size. Next, the Late Iron Age hare foot from the ditch at Fishbourne Roman Palace is the first and only to show any sign of burning. In chronological order, it is also the least complete so far. It lacks cut marks, but the burning and skeletal element representation suggest that the break through the distal tibia results from chopping. This could make Fishbourne the earliest example of credible evidence for hare butchery, and possible cooking. Fishbourne is therefore the first major shift away from the treatment of hare remains seen in the earlier Iron Age ABGs and appears to

be the first step in continuing change during the Roman period.

It is worth highlighting that two major Roman assemblages fall chronologically between the Fishbourne ditch ABG and the first Roman ABG. The earlier is the Roman assemblage from Fishbourne, which at least spans the majority of the first century AD until the first quarter of the second (§5.2.8). It is almost certainly the earliest major assemblage of hare to represent hare consumption, which fits well with the character of Fishbourne as a site known for its exotic fauna (Allen et al. 2011; Best et al. forthcoming; Miller et al. 2016). Chronologically, the next major assemblage is Whitehall Farm's which is even more certainly a 'feasting' assemblage, the majority of which came from a single context in a bathhouse. Radiocarbon dating placed this assemblage in a date range from the third quarter of the first century until the first quarter of the third (§5.2.8). Together, these two assemblages point to a change in human relationships with hares occurring between the LIA ABG from the Fishbourne ditch and the first Roman ABG at Baldock. By the time of the Fishbourne Roman assemblage, hares had probably become food, but there is limited evidence for widespread consumption. By time of Whitehall Farm's bathhouse, hare consumption had clearly spread geographically and may have shifted in terms of cultural significance.

Baldock's ABG represents a further shift. This is the earliest clear juvenile. Though lacking in any unequivocal butchery evidence, the evidence for cess suggests it was deposited as waste. The Roman hare from the cess pit at Owslebury seems to fit into a similar category of depositional practices. The Oakridge II Well hare breaks the trend, being adult, but it was accompanied by other hare remains that were not analysed for this thesis. Wells are also a special case of deposition that are explored in more detail in the next chapter.

Nevertheless, it seems clear that the 3rd/4th century ABGs represent a late-stage in a trajectory of cultural change in how hares and their remains were treated. This trajectory may well have begun in the Late Iron Age, evidenced by the Fishbourne ABG and also the neonate Owslebury group that could not be reliably analysed as an individual skeleton. This shift probably involved a transition away from hares being appropriate for, or perhaps requiring, 'special'/'ritual' deposition (Blackhorse Road, Winnall Down, Winklebury Camp), to being burnt 'ritual' offerings/food (Fishbourne ditch ABG) and meals (Fishbourne assemblage), to more commonly consumed food

(Whitehall Farm). At some point in this sequence, society in Roman Britain would have become culturally at ease with the idea of a hare being treated as 'waste', resulting in the cess pit evidence from Baldock and Owslebury, and probably also the Oakridge II well. These ideas are explored further in Chapter 6.

5.2.10 Size change

A total of 362 specimens were selected for LSI analysis, but that includes having already reduced ABGs down to a mean LSI for each plane. A total of 1060 individual LSI values were therefore available for use, with an average of two to three values per specimen (Table 5.6). This average is higher (3.7) in the Iron Age because of the high proportion of ABGs relative to the total assemblage - each ABG was reduced down to up to four values (one for each plane: breadths, depths, heights, lengths). Because sample size was low for the majority of broad periods, the LSI analysis only included the three major ones - Iron Age, Roman and Medieval - plus the Modern broad period (made up entirely of the Tarbat bones).

Table 5.6: LSI sample size by broad period.

Broad Period	Metrics	Specimens (NISP)	Mean Metrics per Specimen
Iron Age	33	9	3.7
IA/RB	8	3	2.7
Roman	224	79	2.8
Saxon	15	6	2.5
Medieval	206	73	2.8
Med/PMed	18	9	2.0
Post Medieval/linebreak Modern	4	2	2.0
Modern	541	177	3.1
Unknown	11	4	2.8

Isometric size analysis was applied to thirty-two combinations of metrics, distributed between the major skeletal elements at a frequency of three to five combinations per element (Table 5.7, plus one each (Bd-GL) for the four metatarsals (MT2-5). The smallest sample size was twelve, but the average was twenty-five.

Table 5.7: Sample sizes (NISP) for isometric size analysis of selected bivariate combinations of metrics by element. Includes all hares from UK sites dating from the Iron Age onwards.

Element	Combination	NISP
SCAP	BG-SLC	42
SCAP	BG-GLP	40
SCAP	GLP-SLC	40
HUM	Bd-Dd	35
HUM	Dd-HTC	35
HUM	Bd-HTC	34
HUM	Bd-SD	26
HUM	Bd-Dp	16
RAD	Bp-SD	46
RAD	Bp-Dp	23
RAD	Dp-SD	18
RAD	Bd-SD	13
RAD	Bd-Bp	12
ULN	BPC-DPA	31
ULN	BPC-SDO	30
ULN	DPA-SDO	30
FEM	Bp-DC	27
FEM	BTr-SD	26
FEM	BTr-DC	23
FEM	Bp-BTr	21
TIB	Bd-Dd	22
TIB	Dp-DPL	17

Table 5.7: *(continued)*

Element	Combination	NISP
TIB	Bd-SD	15
TIB	DPL-LDp	15
CALC	GB-GL	25
CALC	GBT-GDT	20
CALC	GL-GLT	20
CALC	SBT-SDT	20
MT2	Bd-GL	22
MT3	Bd-GL	22
MT4	Bd-GL	14
MT5	Bd-GL	20

5.2.10.1 Log Scale Indices Results

All four anatomical planes produced distributions with observable patterns (Figures 5.29 and 5.31), though unsurprisingly breadths and depths had a much better sample size for the most important periods (Iron Age to Medieval). Grouping the analysis by plane has probably limited the degree to which the random and weighted selection method differ from each other, and also the size of the error bars for each bin. Nevertheless, this resampling approach is useful because it shows that there are no LSI bins where variance between repeats varies so greatly that the bins overlap significantly (Figures 5.29 and 5.31). Were that the case, it would indicate that entirely different distributions are possible depending on which metrics are chosen.

Almost all the brown hares are larger than the modern standard. The highest peaks in the LSI distributions are normally in the 0.2-0.4 bin, occasionally in 0-0.2 (Figures 5.29 and 5.31). For all planes and periods, the bin one level lower than that denoting equivalence with the standard (-0.2-0) is the smallest bin with any significant height; all the bins lower than it consistently have very few specimens, if any. It is also worth noting that the number of bins below zero is smaller than the number of bins above it, so there is scope for considerable diversity of hare size above the modern

standard. This suggests that hares from modern populations are smaller than ancient ones, perhaps significantly so, and could have implications for the impact of modern anthropic environmental change and other human activity on wildlife.

For breadths, sample size is too small in the Iron Age for any meaningful interpretation in isolation, but it seems to be broadly comparable to the Roman period in terms of the location of its highest peak (Figure 5.29). The largest bin is one level higher in the Iron Age than in the Roman period, adding to the overall impression that Roman hares are marginally skewed towards smaller LSIs than the Iron Age hares, but its difficult to gauge with the histograms alone.

Examining the mean LSIs for breadths in these periods (Figure 5.30) provides a clearer picture. The Iron Age mean is much more variable between repeats, almost certainly due to the variability of the LSI values and lack of any major peaks in frequency. There is a tendency towards values around 0.4. The mean LSI in the Roman period varies little and in the weighted approach was highly concentrated around a single value. Unsurprisingly, random sampling produced a marginally more variable distribution of mean LSIs. It is clear that the Roman hares are most comparable with the smallest of Iron Age hares.

The medieval period is the first period to produce hares large enough to fall into the 1.0-1.2 LSI bin, but it is also the only period with a strong skew to the right, with the majority of specimens having smaller LSIs (Figure 5.29). This is confirmed by the distribution of mean LSIs (Figure 5.30), which show a clear decrease in size from the Roman period. Here, the right-skew is more pronounced in the weighted selection method. The 'Modern' Tarbat specimens show a significant increase in size from the medieval period, though mean LSIs (Figure 5.30) indicate that these hares are not large enough to be comparable with the majority of mean LSIs from the Iron Age.

Depths were less variable than breadths, though this probably reflects the superior abundance of breadths than depths, both in von den Driesch's (1976) standard and the additional metrics created in this thesis (Chapter 3), just as much as it does a genuine lack of variance in archaeological hare populations. This might explain the overall similarity between the Iron Age and Roman depth LSIs when the mean is examined (Figure 5.30).

Even though the depths have a narrower range of LSIs, comparing the Roman and

medieval depths concurs with the findings from the breadths. Both broad periods have their highest peaks in the same bin but the Roman period is left-skewed whilst the medieval is right-skewed (Figure 5.29). The mean LSIs show that, like the breadths, the average medieval hare has an LSI around 0.2, whilst Roman ones are closer to 0.3 (Figure 5.30). The skew difference between weighted and random selection in the medieval mean LSIs is not so pronounced for depths as for breadths, probably a consequence of the smaller degree of choice between metrics.

Again, the 'Modern' Tarbat hares are significantly larger than the medieval ones (Figure 5.30). Unlike the breadths, however, there are no depths that are smaller than the modern standard, which explains why the Tarbat depths are comparable to the Iron Age ones (Figure 5.29), whereas the breadths were less similar between these two periods.

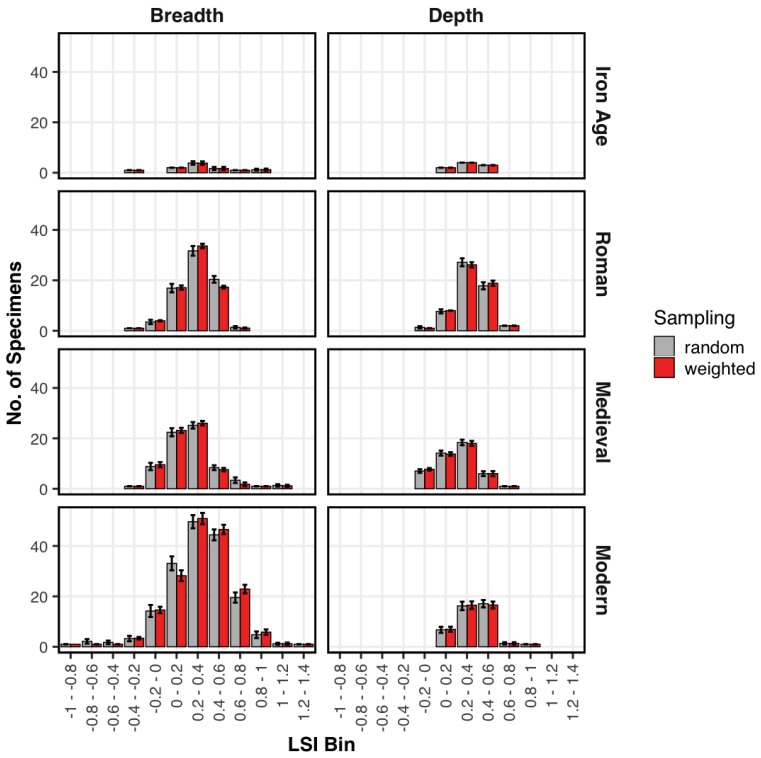

Figure 5.29: LSI distributions by broad period for breadth and depth metrics.

Like depths, heights are restricted by the number of metrics available to record. Consequently there is little or variance between repeats in all periods, and random and

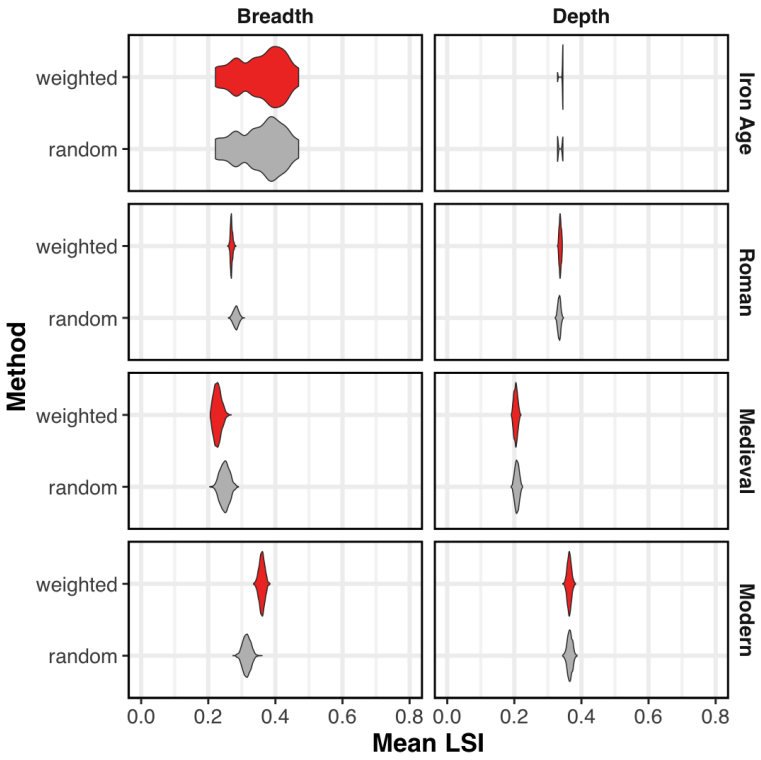

Figure 5.30: Distribution of mean LSI over 1000 repeats for breadth and depth metrics.

weighted selection consistently produced the same result in every period and LSI bin (Figure 5.31). Differences in the representation of identifiable skeletal elements that have a height metric over time also mean that these LSI data have probably not captured an adequate sample of the variance available in Iron Age and Roman hare populations, so it is difficult to assess any trends. Nevertheless, the heights do seem to concur with LSIs from other planes, showing clear decreases in size from the Iron Age to Roman to medieval periods (Figure 5.32). Unusually, the Tarbat hares show a further decrease from the medieval hares, but this could reasonably be attributed to population age-structure. It may be that heights scale more linearly with age than metrics from other planes.

Lengths are more comparable to the breadths and depths, but they have poor sample size in all cases save the Tarbat hares. Like the heights, reduced choice between metrics means there was little or no between repeats until the medieval period when the histograms are examined (Figure 5.31), though the mean LSIs are more variable (Figure 5.32). Change in the lengths over time appears to be more gradual than in the other planes. It appears that lengths increase from the Roman period onwards, though it is not clear to what extent that taphonomic and recovery bias in favour of bones with greater lengths might be influencing this trend.

In summary, the LSIs demonstrate the complexity of relationships between metrics on different anatomical planes, and between size change and the various population dynamics and taphonomic biases that might influence how these changes manifest in zooarchaeological datasets. But, they also make a clear case for decreasing size in brown hares since their introduction, which tallies with the impression given by the analysis of relative size between the Iron Age and Roman ABGs (§5.2.9).

Applying a resampling approach to LSIs has been an effective way to place some measures of confidence around LSI distributions and their interpretation. Separating analyses by plane almost certainly limited the degree of variance possible between repeats, but resampling was still useful for understanding where - and the extent to which - LSI distributions between periods overlapped. This approach may therefore merit further investigation and development; it may be particularly useful for contextualising LSI distributions in studies where low sample size prohibits separating metrics by anatomical plane.

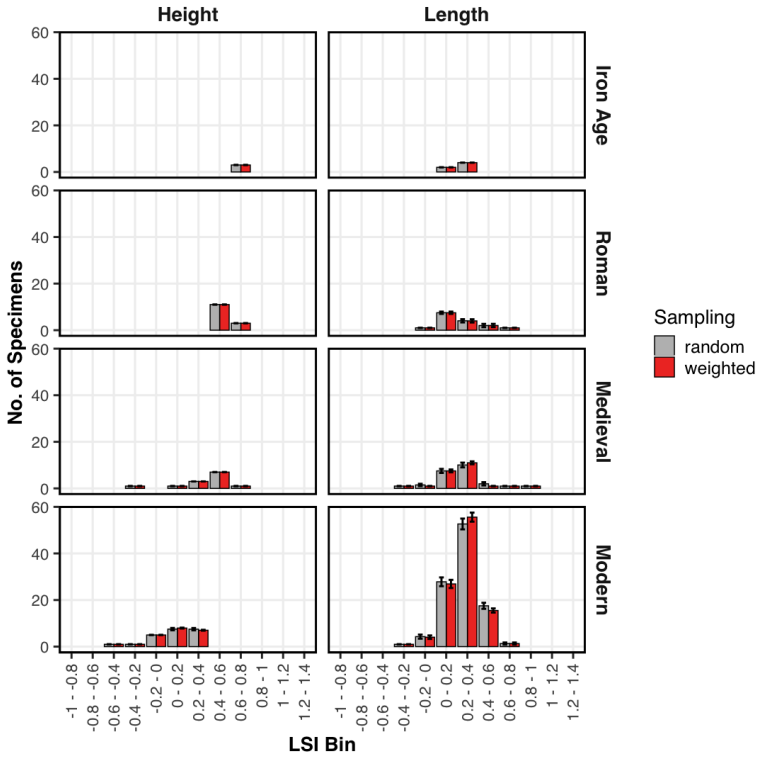

Figure 5.31: LSI distributions by broad period for height and length metrics.

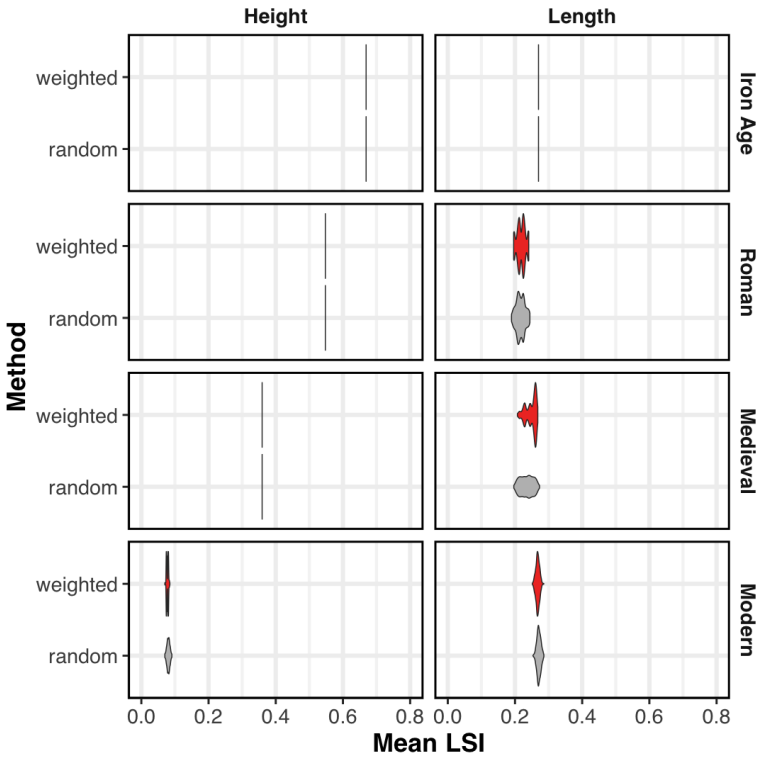

Figure 5.32: Distribution of mean LSI over 1000 repeats for height and length metrics

5.2.10.2 Isometric Size Results

Isometric size generally concurred with the findings of the LSIs, but there is variance between the metrics combinations, highlighting that measures of size do depend on which measurements are used. For the scapula (Figure 5.33), the Iron Age is tightly clustered due to low sample size , but the general trend is for decreasing size over time, except for the GLP-SLC pair which shows an increase in the Medieval period from the Roman. For the humerus, all five combinations show a consistent trend for decreasing size (Figure 5.34). The Bd-Dd is particularly interesting: here the range of sizes IA/RB period, though limited by small sample size, is very similar to the median of the Roman sizes. Possibly this suggests that the decline in hare size began towards the end of the Iron Age, and was not uniquely Roman phenomenon.

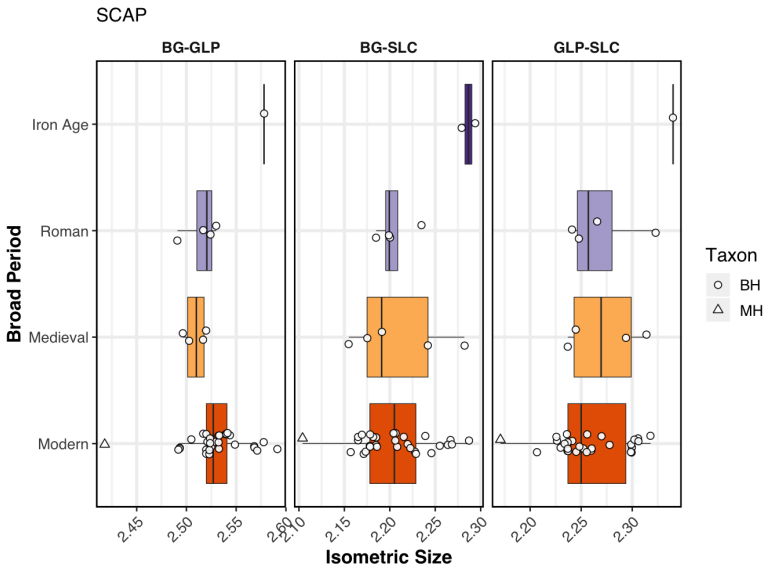

Figure 5.33: Isometric size box plots for metrics pairs from the scapula.

Isometric size for the radius is one of the most consistent with the LSIs (Figure 5.35). All three combinations used show a decline in size from the Iron Age until the Roman period. But, each gives a different impression of the degree of different between sequential periods. For the Bp-Dp, the Iron Age and Roman period are more similar to each other than either are to the Medieval period, which is strongly right-skewed towards small values. But, the Bp-SD shows that the Roman and Medieval period are more similar to each other than either is to the Iron Age. The median sizes for the

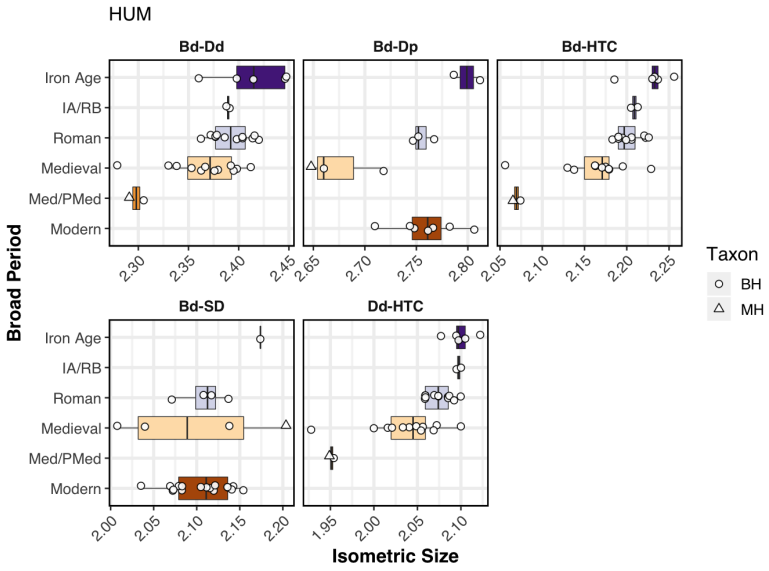

Figure 5.34: Isometric size box plots for metrics pairs from the humerus.

Medieval and Roman periods are effectively identical - the difference between these distributions is their shape. Meanwhile, the Dp-SD shows the three periods to be overlapping but clearly distinct distributions.

For the ulna (Figure 5.36), isometric size is similar to the radius. It consistently shows declines in size over time, though the differences between periods both in terms of median size and the shape of the distributions is less distinct. In contrast, the femur (Figure 5.37) suggests that size increases over time for three out of four of the chosen combinations; the credibility of the decline in the medieval period is undermined by low sample size. The BTr-SD is the combination that disagrees with this trend, concurring with the impression given by other elements. Again, however, low sample size limits the trustworthiness of these distributions.

Four combinations were selected for the tibia, but the Bd-SD is unreliable as its data are limited to only a small selection of the time periods (Figure 5.38). Nevertheless, it seems to concur with the trend shown by the other three combinations, which clearly show declines in isometric size over time. The distal tibia (Bd-Dd) bucks the trend in the medieval period, having a higher median than the Roman period, but the medieval has a much more dispersed distribution and is still skewed towards small values.

The four combinations for the calcaneum are contradictory at best (Figure 5.39). The

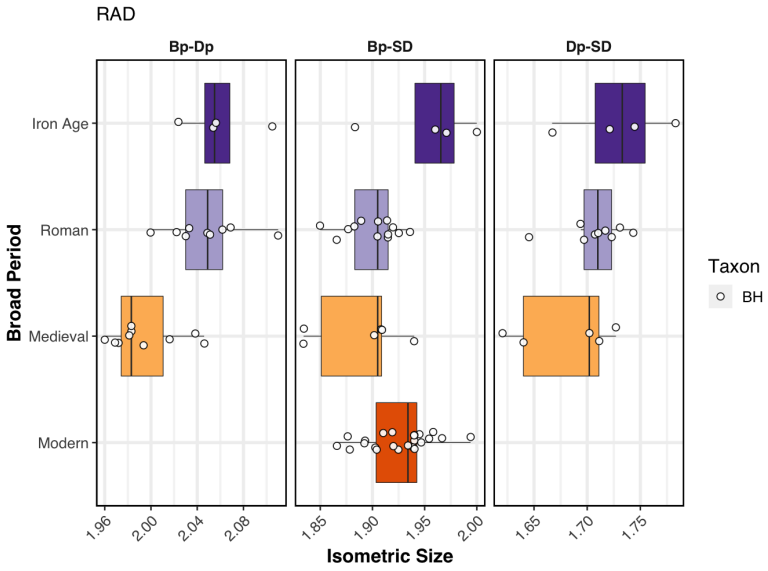

Figure 5.35: Isometric size box plots for metrics pairs from the radius.

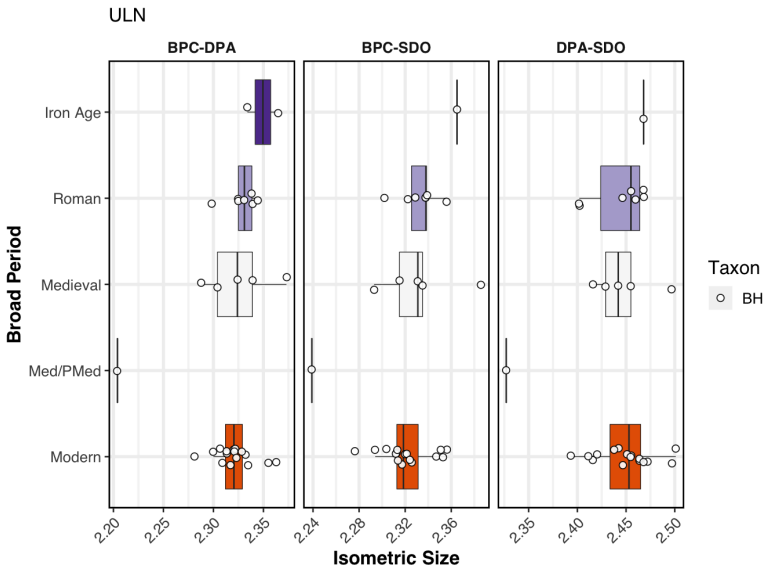

Figure 5.36: Isometric size box plots for metrics pairs from the ulna.

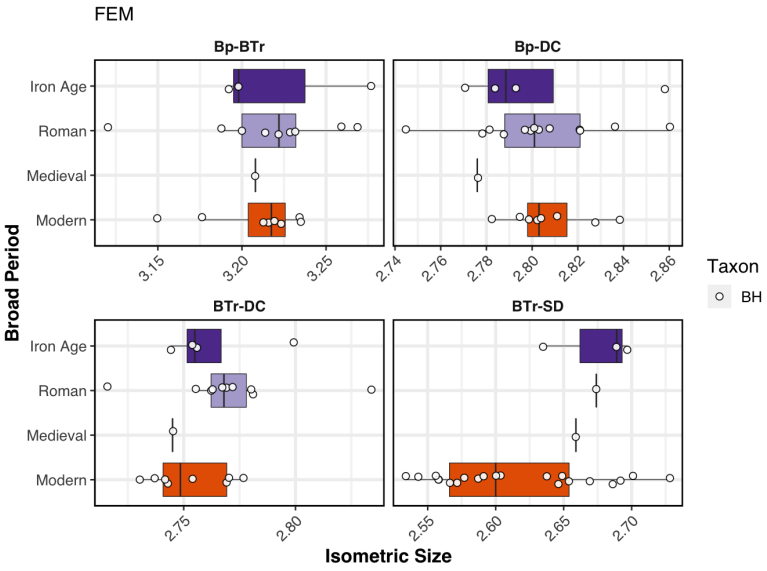

Figure 5.37: Isometric size box plots for metrics pairs from the femur.

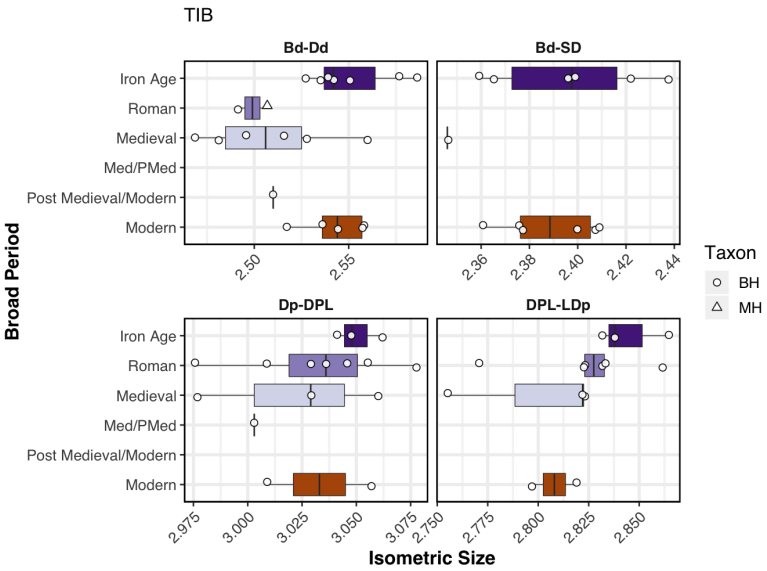

Figure 5.38: Isometric size box plots for metrics pairs from the tibia.

GB-GL suggests declining size over time, but with a significant increase for the Modern specimens, though it should be noted that a considerable number of these were not identified. The GBT-GDT and GL-GLT show fluctuating median size over time but given the different spreads and sample sizes it is questionable whether or not these data support any interpretation of meaningful change. The SBT-SDT is much less ambiguous, but shows increasing size over time. The metatarsals are similarly complex (Figure 5.40), but also suggest increases in size.

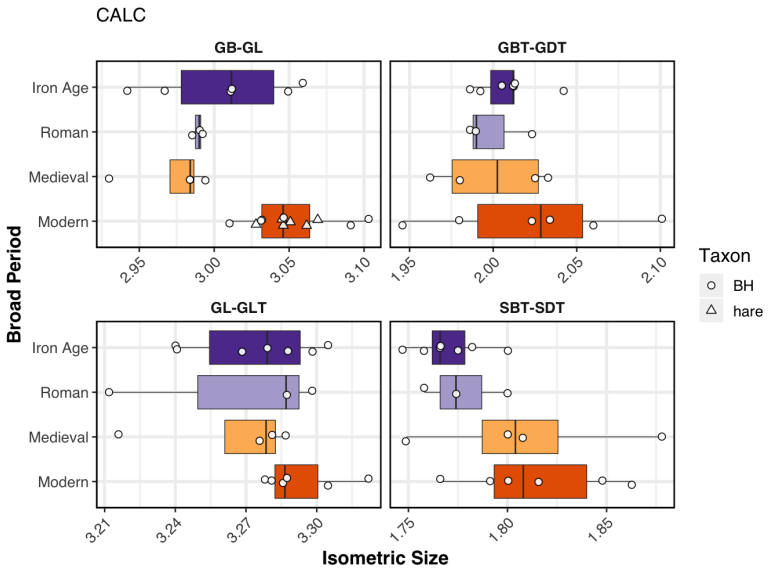

Figure 5.39: Isometric size box plots for metrics pairs from the calcaneum.

5.2.10.3 Size Change Summary

Together, LSIs and isometric size point to - at least - gradually declining size in brown hares from the Iron Age onwards. Isometric size suggests both much sharper decreases and also increases with respect to some combinations of metrics, reflecting the inherent complexity of size change studies. That the Iron Age and Roman ABGs alone (§5.2.9) were enough to reveal the earliest signs of the trend for decreasing hare size, lends further weight to already compelling - albeit complex - trends.

There are numerous plausible explanations for why hares might decline in size in given periods. One persuasive explanation for declines in the medieval period, for example, is that the c. 12th century introduction and c. 13th century population establishment of rabbits in Britain created new competition for the brown hare. Shifts in climate

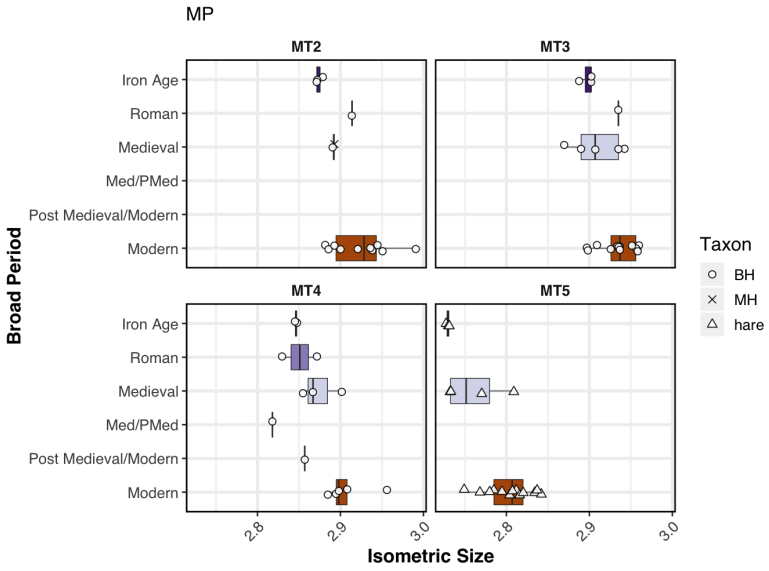

Figure 5.40: Isometric size box plots for Bd-GL from the metatarsals.

might also be involved.

Unfortunately, such interpretations are at best equifinal with various interpretations of the epiphyseal fusion data (§5.2.7). It is clear that young animals make up a greater proportion of the total dataset in the medieval period than in the Roman period. One of the difficulties of working with small mammals is that eliminating bones of young animals could have a significantly detrimental effect on an already limited sample size. It was for this reason, among others, that the additional work required to develop a method for creating measures of confidence for LSIs and combining LSIs with isometric size was considered so important. Together these methods present a convincing trend for declining size, but it is difficult to quantify how much the relative proportion of young animals impacts on a size distribution. Data explaining the relationships between age, epiphyseal fusion, allometric growth and isometric scaling are needed before those questions can be answered.

This means that differences in hunting/trapping practices (including method, location and the time of year) and the potential for overhunting resulting in differing proportions of young animals in different periods are all equifinal with other plausible causes of a size decrease. The merits of some of these interpretations are explored further with other lines of evidence in the next chapter, but the zooarchaeological evidence

on its own must remain inconclusive.

5.3 Conclusion

This chapter is, to my knowledge, the first attempt at a comprehensive study of traditional zooarchaeological data for hares in UK assemblages. It is certainly the first of its scale to work on hare remains identified to species with a reproducible identification method. In many cases, this chapter has exposed areas where the traditional zooarchaeological methods encounter problems when working with fauna smaller than the domestic and wild ungulates and Carnivora most commonly found in zooarchaeological assemblages.

This is particularly the case of taphonomic markers - such as butchery, fracturing and burning - where the standard zooarchaeological toolkits for identifying, recording and interpreting the evidence seem to be ill-equipped for studying bones that do not have the same taphonomic behaviour and pathways as larger fauna. Butchery especially seems to be an area were zooarchaeology requires new debates, methods, and interpretive models, to deal with these fauna.

Nevertheless, this chapter has succeeded in its overall aims - to identify avenues for further enquiry, some of which are explored more in the next chapter. Changes in the skeletal element representation in and burial context of ABGs point to a cultural trajectory in which hares may have gradually shifted in human perception from supernatural in the Iron Age to exotica in the earlier Roman period to a common, albeit probably high-status and still religiously charged, foodstuff in the later Roman era. This is supported by the gnawing evidence from Whitehall Farm, which suggests that by the second/third century AD, hare remains were receiving similar treatment as would be expected for other animals considered to be food. Epiphyseal fusion and size change provide clues to the scale and bio-cultural effects of human interactions with hares, especially through hunting and meat consumption. These areas form the central themes of the next chapter, where the cultural role of the (brown) hare is explored using other lines of evidence: material culture, history, language, and folklore.

Chapter 6

Contributing to a new bio-cultural history of hares in Britain

This thesis has established a zooarchaeological baseline for new narratives of the bio-cultural history of the brown hare in Britain. By bringing these new findings together with wider knowledge from archaeology, (art) history and folklore, this chapter explores the merits of the various hypotheses raised by evidence in the previous chapters. It explores hares through time using a variety of evidence types, both from Britain and elsewhere. It is restricted to a simplified discussion of complex issues from multiple sub-disciplines in archaeology as well as other humanities fields. This chapter should therefore be treated as a speculative assessment of how this thesis' findings may be supported by research from these other fields, and a suggestion for the direction for future research, rather than definitive conclusions.

This chapter focusses primarily on issues most pertinent to the brown hare's earliest history in Britain, namely the (Western) Roman Empire and the pre-Roman Iron Age cultures within that geographical setting. But, it also summarises evidence from Medieval England as the Roman and Medieval periods proved the easiest to contrast in Chapter 5 thanks to better sample size.

It mostly draws on knowledge established in historical and archaeological literature, but also refers to place-name datasets (EPNS 2020; KEPN 2020), and iconographic/zoomorphic artefact data from the Portable Antiquities Scheme (PAS 2020), which were obtained by application for researcher-level access to the PAS. The PAS database was searched using the broadest approach possible, using the keywords 'hare' and 'rabbit' in two separate searches. A broad search is important because records in the PAS are inconsistently entered. Not all zoomorphic finds are given the "zoomorphic" category, for example. Using narrow searches may therefore exclude vast quantities of relevant finds. The results from the two simple searches were downloaded and filtered in R, where it was easier to inspect all the information in order to decide how to exclude irrelevant objects. Non-iconographic finds such as gunshot and net weights, records for which frequently mention rabbits in free-text fields, were easily filtered out. The remaining records were then manually checked by opening the find URL to check for associated images. This enabled further irrelevant objects to be identified and excluded and the remaining ones to be classified according to broad object categories and types of iconographic depictions of hares or rabbits. This chapter only discusses the objects that were unambiguously identified in the PAS item records as depicting hares, or were ambiguously identified and so could be placed in a 'lagomorph' category; explicit 'rabbit' identifications were ignored.

Three themes form the overarching structure of this chapter:

- **Death and Life**: exploring hares in death through the cultural significance of discrete animal bone deposits; considering the lives of hares before burial.
- **Hunting the Hare**: evidence for hare hunting and management in (Pre-)Roman Britain and Gaul, the wider (Western) Roman Empire, and Medieval Britain.
- **Folklore and Religion**: evidence for the hare in folklore, mythology, and religion; the Easter 'Bunny'.

Ancient societies did recognise different types of hares, including the distinctions in seasonal coat-colour between the brown and mountain hare (Pliny 1855: p. VIII 81). Nevertheless, it is reasonable to assume that many beliefs about hares that this chapter discusses apply to multiple hare species. Hares feature prominently and similarly in the folklore, mythology and art of many different cultures (e.g. Evans et al. 1974; Carnell 2010) and Pliny's (- Pliny 1855: p. VIII 81) recognition of the difference between brown

and mountain hares does not mean that they were understood to be different species in a modern biological sense. Linnaean taxonomy mediates between the ancient cultures zooarchaeologists attempt to study and the osteological remains they analyse in order to do so, but it does not reveal how those cultures classified, named, and understood animals with their own systems (Wapnish 1995; Sykes 2014a: p. 6-8). That ancient words for 'hare' also covered rabbits (Sykes et al. 2010: p. 121; Varro nd: p. III 12) shows that past European cultures did not distinguish between the leporids with the clear-cut categories of modern scholarship. This is reassuring because it demonstrates that this chapters' discussions of ancient relationships with and beliefs about hares need not have been constrained to a particular Linnaean binomial. The European and especially British focus of the chapter, combined with the predominance of sites in England among the archaeological evidence this thesis has dealt with, nevertheless means that almost everything the chapter covers would have applied to or influenced ancient human interactions with the brown hare. Furthermore, the evidence presented in Chapter 4, subject to genetic confirmation, showed that mountain hares were probably not present in (Southern) England during the time period this thesis covers. It is safe to say that most of what this chapter covers applies to brown hares in England specifically, as well as hares in Britain generally.

6.1 Death and Life

This thesis has placed major importance on Associated Bone Groups, due to their links with the arrival of new fauna (§2.9.1, §5.2.9). It has also shown that over the most critical time periods within this thesis - the Iron Age and Roman periods - there are differences in the physical and cultural contexts in which brown hare remains are found (§5.2.9.8). To understand these changes, it is necessary to understand the meaning of animal bone deposition in ancient cultures.

The first issue to grapple with is that the deposition/gradual accumulation of waste deposits is not culturally meaningless or neutral. Hill's (1995) recognition that Iron Age pit deposits reflected structured modes of deposition, not just the disposal of waste material, demonstrated that both rubbish and the act of its disposal can have cultural significance. The dichotomy between 'ritual' and 'everyday' is a modern preoccupation, not an ancient one (Brück 1999; Hill 1995). Similarly, what typically

constitutes waste and what does not in the archaeological record is often determined by interpretation according to assumptions based on modern worldviews, rather than those of the cultures being studied (Groot 2009; Hill 1995).

To understand the Iron Age and Roman hare ABGs, three broad - but overlapping - forms of depositional practice need to be considered. Firstly, pit/ditch burials perhaps deriving from animals kept as exotica or 'pets', or from sacrifice (all Iron Age ABGs); secondly, 'waste' disposal in (cess)pits (Baldock and Roman Owslebury); and finally, deposition in wells (Oakridge II).

The most widely known work on the social interpretation of pits in Iron Age British contexts concerns the structured deposition of 'waste' in storage pits, often cut into chalk. These features are thought to have been used for storing grain as their primary function but over time - perhaps a 'lifecycle' - came to be repurposed. Cunliffe (1992) has argued that the Iron Age pit deposits could represent offerings to chthonic deities in the Iron Age Underworld - the pits were used to place material objects and food into the deities' subterranean domain. This may have been to thank the gods for protecting grain during these pits' use for storage (Cunliffe 1992). The Winnall Down and Winklebury Camp ABGs are clear examples of this practice. It is an interesting comparison, however, that the earlier Iron Age ABG - Blackhorse Road - was found in an enclosure ditch and not a pit. Nevertheless, both types fit to some degree with practices that might be associated with the recent introduction of the brown hare. Whilst pits may represent the domain of chthonic deities, enclosure ditches are physical representations of conceptual boundaries (discussion in Rees 2008) between the domestic sphere and its surrounding wilderness - the domain of wild animals and the supernatural. Whether or not these animals were 'sacrificed' is undeterminable - none have butchery marks. But, simply killing an animal would not necessarily leave any signs in archaeological remains.

Wells, particularly in the Roman era, are frequently a repository for significant quantities of archaeological material. Bone, pottery, and metalwork are commonly found in well deposits, and to some extent they may have been seen as convenient places to dump waste (Groot 2009: p. 59; Roskams et al. 2013), though some finds may represent accidental losses (van Haasteren et al. 2013). But faunal remains in wells are normally thought to represent the accumulation of material towards the end of or after its main

period of use as a water source, because such refuse would contaminate the water (Cool et al. 2013; Groot 2009). This raises questions about what might trigger the end of such use and whether animal remains might have particular significance at that point in time. Dogs, for example, appear to be particularly common in wells which suggests that there may be religious implications for the end of a well's lifecycle (Cool et al. 2013; Roskams et al. 2013).

Haasteren and Groot (2013: p. 39-40) argue that deposits found in a well's construction pit (a wide pit dug to a level below the water table before placing the lining, if constructing a lined well) are plausible cases of ritual activity marking the construction - the beginning of the well's life. These may be analogous to foundation deposits (see Woodward et al. 2004). Haasteren and Groot (2013: p. 40), however, compare them to Cunliffe's (1992) interpretation of storage pit offerings, suggesting that well construction offerings were made to appease or thank the gods. By contrast, animal remains are almost always associated with the end of a well's use, so the focus here is on a completely different type of activity to a foundation deposit or storage pit offering. Haasteren and Groot (2013) emphasise that this phase in a well's lifecycle coalesces "functional" and "ritual" behaviours - specially deposited objects and waste could be an offering, but waste (particularly animal remains) would also practically *cause* the end the well's functional use (due to contamination) and so may have been used to mark a culturally determined termination (van Haasteren et al. 2013: p. 41).

The Oakridge II well hare ABGs, including the one analysed in this thesis (§5.2.9.7) fit the profile of deposition relating to the end of a well's use. Whether or not they represent "offerings" is less clear. But, the presence of other wild fauna in the well, especially birds, may indicate that it is such a case (Maltby 1993b; Roskams et al. 2013; Serjeantson et al. 2011).

Given that the hares from the Oakridge II well date from the fourth century, the third and fourth century cesspits at Baldock and Owslebury may fit into a conceptually similar category. Like wells, cesspits are waterlogged environments and the associations between water and ritual deposition in the British Iron Age and Roman period are well-studied (discussions in Roskams et al. 2013; Joy 2011; Hingley 2006; Madgwick 2008: p. 109; Sykes 2014a: p. 65). The idea that watery environments were sacred can be explained with Cunliffe's (1992) idea that Iron Age cultures made offerings to the

Underworld through deposition in subterranean environments, or Madgwick's (2008) view that water was the dominant Iron Age burial medium. If wells can be interpreted as a development of Iron Age deposition in water, the common presence of complete or near-complete animal skeletons in cesspits (Smith 2013: p. 539) might be tenuously interpreted as developments of other depositional practices associated with pits and watery environments. This is not to argue that every animal skeleton in a cesspit represents a 'ritual' - cesspits serve an indisputable practical purpose. Instead it is to suggest that cesspits may have had social 'lifecycles' within which particular types of waste disposal may have had social or other symbolic meaning - perhaps associated with protection or cleanliness. It is important to recognise that features recognisable as a "pit" in a general sense - whether a cesspit, storage pit or well-shaft - can change function over time (Fulford 2001: p. 214); archaeologists can only see an incomplete picture of a feature's use and social significance. Additionally, with regards to the ritual deposition of waste or waste-like material, the location could have been less important than how the action was performed, or what was deposited.

That the Baldock ABG (§5.2.9) is seemingly a co-deposition of a juvenile hare and dog supports this argument. Though difficult to prove with the limited available contextual evidence, it is likely these two animals were deposited in quick succession, if not together, and their similar states of epiphyseal fusion are also suggestive. Dogs are well-documented to have had major religious significance in Roman culture, through associations with protection, healing and hunting (Diana) and carrying chthonic connotations (Cerberus, three-headed guardian of the Underworld - see Woodward et al. 2004: p. 78; Toynbee 2013). Given this evidence, plus the prevalence of the "hare and hound" motif in Roman/Romano-British material culture (§6.2.1, below; and Crummy 2013: p. 123), it is likely that the Baldock ABGs carried more significance than just the mundane disposal of two carcasses. But, this does not contradict the notion that a significant shift in perceptions of hares had happened between the Iron Age ABGs and the Baldock and Owslebury cases. Whatever the religious connotations the animals may have had in life and during the process of their burial, the context (waste) and form of these burials (juvenile, less complete) is very different to the ones from Blackhorse Rd, Winnall Down, and Winklebury Camp.

Before closing this section it is important to acknowledge that - partially through zooarchaeological necessity - it has so far focussed entirely on the moments following

these hares' deaths. But, zooarchaeologists can gain completely different insights when the theoretical focus is shifted to life (Sykes 2014a: passim, but esp. 12-13). It is worth considering how the hares featured in the ABGs could have been treated before they died/were killed and were buried, and thereby contemplate how these and similar animals may have lived.

The increase in hare abundance in zooarchaeological assemblages by the late Roman period makes it is almost certain that the Owslebury, Baldock and Oakridge hares were hunted or trapped in the wider landscape, or similarly recovered from game enclosures (§6.2.1). The earlier ABG hares are more debatable. With the possible exception of the Fishbourne ditch ABG, the exclusive use of adult hares for the Iron Age deposits suggests several possibilities: that hares were normally hunted/trapped outside the springtime breeding season; that adults were specifically targeted; or that juveniles were treated differently and so have not entered the excavated archaeological record in great quantities, exacerbated by taphonomic biases in favour of skeletally adult remains. It is also plausible that the Iron Age ABGs were hares kept in some form of captivity, perhaps analogous to an exotic "pet", though there is very little evidence for it in this period.

The likelihood of any of these explanations would depend on when the brown hare became an established species in the landscape beyond the domestic setting, and on the worldviews and beliefs of the people involved. The very first brown hares to arrive in Britain would almost certainly have done so in cages. Under such a scenario they may have been kept as exotica for a time (and later escaped or been released). But, given that Iron Age societies seem to have revered both the hare (Caesar n.d.: p. V.12) and wild fauna generally (Green 1992; Sykes 2014a: p. 64-5; Serjeantson et al. 2011), it is equally plausible that they were brought with the intent of releasing them soon, if not immediately, after arrival. Indeed it is reasonable to speculate that it could have been considered inappropriate to keep such an animal confined. Although hares can be tamed if captured whilst young (Evans et al. 1974: p. 27), there seems to be some consensus that hares - especially leverets - survive poorly in captivity, or at least that modern attempts to translocate hares are more likely to succeed with captured wild hares than with captive-bred hares (e.g. Angelici et al. 2000; Fischer et al. 2012). They are not social animals, which probably explains both this and the lack of any known domesticated hares (Evans et al. 1974: p. 27-8). It is credible that people in antiquity

would have observed similar trends in captive hares' survivability and behaviours, and therefore preferred to release them either into the wider landscape or into game enclosures as the Romans did (see below).

However, there is Roman artwork that shows hares that are purportedly 'pets' (Toynbee 2013: p. 201-2), but this terminology is problematic because scholars cannot fully dissociate the concept of a 'pet' from the modern and Western-centric relationships - which are often exploitative and carry ecological consequences outside the pet-owner relationship - that the term implies (Sykes2014-la p. 139-40; Sykes et al. 2020). It is difficult to define the term in a way that is universally applicable to modern societies and ancient ones (for problems with definition see Russell 2011: p. 259-263; for projection of modern pet-keeping on to the past see Ritvo 1987). A degree of tameness, but not necessarily domestication, seems to be the minimum requirement for an animal to be a pet. Wild animals can be pets, but they need to have adjusted to human environments to the extent that they do not see humans as predators (Russell 2011: p. 260-1). But this does not mean that all tame animals are automatically pets. Pets are integrated into a family or other societal group to the extent that they may come close to being perceived as a social equal by the humans in that group, though they are ultimately not fully autonomous, and humans retain dominance over them (Russell 2011: p. 261-2).

There is good evidence for animals in ancient societies that meet this minimal definition of a pet as a tame animal considered to be a quasi-human "family member". Small dogs appear to have been kept as companions by the Romans (summary in Sykes 2014a: p. 143-4) and dog burials suggest that at least some were treated as family (Sykes et al. 2020). Something at least analogous to modern pet-keeping did exist in Roman thought.

It would, however, be problematic to use this dog evidence to support the idea that 'pet hares' existed in the Roman world. Hares still regard humans as predators and may have been in some distress if kept in a manner analogous to a modern, hutched pet rabbit (Evans et al. 1974: p. 27-8). Though this does not preclude that ancient societies tried to do so, it does limit the likelihood that they succeed in extensively taming hares and keeping them both confined and healthy for any length of time. Pliny (1855: p. VIII 82) supports this idea with his statement that hares are rarely tamed,

but could not properly be called wild animals. On this basis it can be inferred with some confidence the Romans used hutches primarily, if not exclusively, for fattening hares before consumption, which is known to have occurred thanks to Varro's (nd: p. III 12) statement that "it has recently become the practice to cram hares…they are taken out of the warren and shut up in small hutches where they are fattened".

Depictions that Toynbee (2013: p. 202) interprets as evidence for 'pet' hares (e.g. Figures 6.1 and 6.2), should therefore be interpreted more loosely. They may, for example, represent an *idealised version* of the relationships between some humans and hares in their possession in contexts such as *leporaria*/*vivaria*, especially hares kept for display rather than for hunting and meat. Though pet-keeping is frequently associated with social elites and economic prosperity before the modern era in Europe (Ritvo 1987; Serpell 1987; Sykes et al. 2020), a hare kept primarily as a display of access to exotica need neither be tamed nor considered a social equal. Some evidence suggested to indicate pet hares, such as the Lincoln tombstone (Figure 6.2), may alternatively be symbolic for afterlife fertility (Toynbee 2013: p. 202; Crummy 2013: p. 122). Mounting evidence for widespread human-rabbit interactions in the Roman world, including some claims of evidence of Roman rabbit domestication (e.g. Watson et al. 2019b), suggests that at least some of these depictions may not be hares at all.

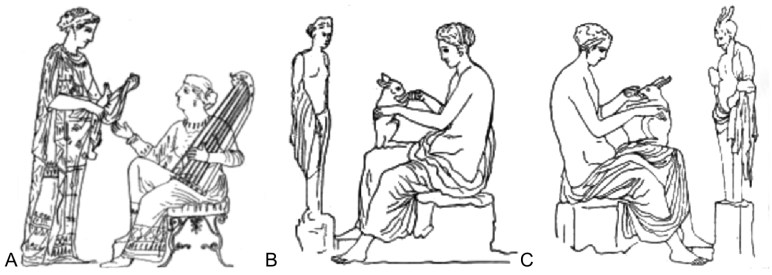

Figure 6.1: A) Villa in Trastevere, Rome: painting of a musician receiving a hare. B and C) Possible divination scenes involving hares (Reinach 1922: p. 325), interpreted as "pet"-keeping evidence by (Toynbee 2013: p. 202). Images from Reinach (1922: p. 263, 325)



Figure 6.2: Roman tombstone showing a boy holding a hare. Found in Lincoln. From https://en.wikipedia.org/wiki/File:Lindum_Colonia.JPG, License: CC BY-SA 4.0.

6.2 Hunting the Hare

Having considered the lives and deaths of hares in antiquity, it is now possible to consider the intervening stage - hare hunting/trapping - in more detail. This section explores such practices from the Iron Age to the medieval period. The first part covers evidence from c. 800 BC to the early fifth century AD in Britain and Gaul, as well as textual evidence from contemporary authors from further afield in the Graeco-Roman world. Due to the geographically and temporally dispersed nature of the data, this part is ordered more thematically than chronologically, though the latter is also attempted where possible. A timeline of the evidence is provided in Figure 6.3. The second part of this section is shorter and tightly constrained to hare hunting in medieval Britain, focussing on the period from the mid eleventh century to mid sixteenth century AD, and is intended to be a brief overview.

Note that this section (mostly) neglects to include evidence from Belgium, the Netherlands, and Germany. This is in part due to a need to place limitations on scope, but also because the French evidence is easy to integrate with the testimony from Roman-era writers, and large proportions of French scholarship are openly accessible online. The Iron Age zooarchaeological record for Belgium is also very poor (Dobney et al. 2007a; Ervynck 1994). For reasons that will become apparent in the religion section (§6.3) these omissions are a flaw, but it must fall to future research to broaden this thesis' findings.

Before starting these discussions it is important to distinguish between hunting and trapping because their differences are culturally meaningful. Hunting is seldom conducted solely for economic purposes: obtaining meat, fur and other animal products. Indeed it is often unsuited for economic efficiency, and is instead a symbolic behaviour, central to which is *direct violence* towards unrestrained wild animals (Cartmill 1993: p. 29-30; Sykes 2014a: p. 52). It must also be deliberate and *premeditated*. Setting traps, laying down poison, self-defence and pest control all *do not* qualify as hunting (Cartmill 1993: p. 29-30; Sykes 2014a: p. 52). Hunting is a symbolic confrontation between "humanness and wildness" and has been cross-culturally regarded as training for war (Cartmill 1993: p. 30; Gray 1985: p. 158; Sykes 2014a: p. 52).

6.2.1 Hare Hunting c. 800 BC - c. 450 AD

The earliest known hunting treatise (Carnell 2010: p. 7) is a Greek text: Xenophon's *Cynegeticus* - "On Hunting" or "Hunting with Dogs" (Vol. 6 in Xenophon 1925) - in which he likens hunters to warriors, establishes hunting as divine knowledge, and provides a manual on hunting hares on foot with the aid of dogs and nets (Cartmill 1993; Gray 1985: p. 158). Xenophon (1925: p. Hunt. 5.28 and 6, especially 6.5-6.28) provides extensive detail on hare hunting including the types of dogs used; how to raise and train them; and how to place and use nets. It seems clear that hare hunting was predominantly a drive-based form of hunting, chasing hares across the landscape.

Xenophon (1925: p. Hunt. 5.14) briefly mentions that "sportsmen…leave the very young ones to the goddess", in which the goddess is certainly Artemis. If this custom was carried over to later Roman hunting tradition and the Artemis/Diana cult (for discussion of Artemis/Diana's general translocation, and evidence in Britain, see Murphy et al. forthcoming; Sykes 2014b), this may explain the increasing presence of juveniles in the British hare ABGs over time (§5.2.9) and the relative lack of young juveniles in disarticulated remains from Roman assemblages (§5.2.7). This hypothesis is supported by Arrian's repetition of this in his version of *Cynegeticus*. It is worth acknowledging here that Xenophon and Arrian were both Greek, the latter strongly identifying with his Greek heritage (Stadter 1967: p. 160). Moreover, Arrian's *Cynegeticus* was specifically intended to update Xenophon's with techniques from "Celtic" Europe that had not been known to the Greeks at the time (Arrian 1841: p. I-II; Stadter 1967, 1976). Consequently, it cannot be guaranteed that the custom of "leaving" leverets for Artemis/Diana was so widely practiced that it ever reached Roman Britain, as the textual evidence is so focussed on the Aegean. Nevertheless, later Iron Age Europe was increasingly well-connected (Cunliffe 1994; Sykes 2014a: Chapter 4, esp. 77-8, 98); "Celtic" hunting appears to have been religiously charged (Green 1992); Artemis/Diana was worshiped in Roman Britain (see, for example Murphy et al. forthcoming); and there is a significant period of time between Xenophon and Arrian (Figure 6.3) within which this custom could have spread further afield.

Alternatively, the relative paucity of juveniles in the Roman data may reflect seasonality in hunting. Arrian (1841: p. XIV) recommends coursing in spring or autumn more than summer because the dogs find the sun too hot. Given that brown hares mate

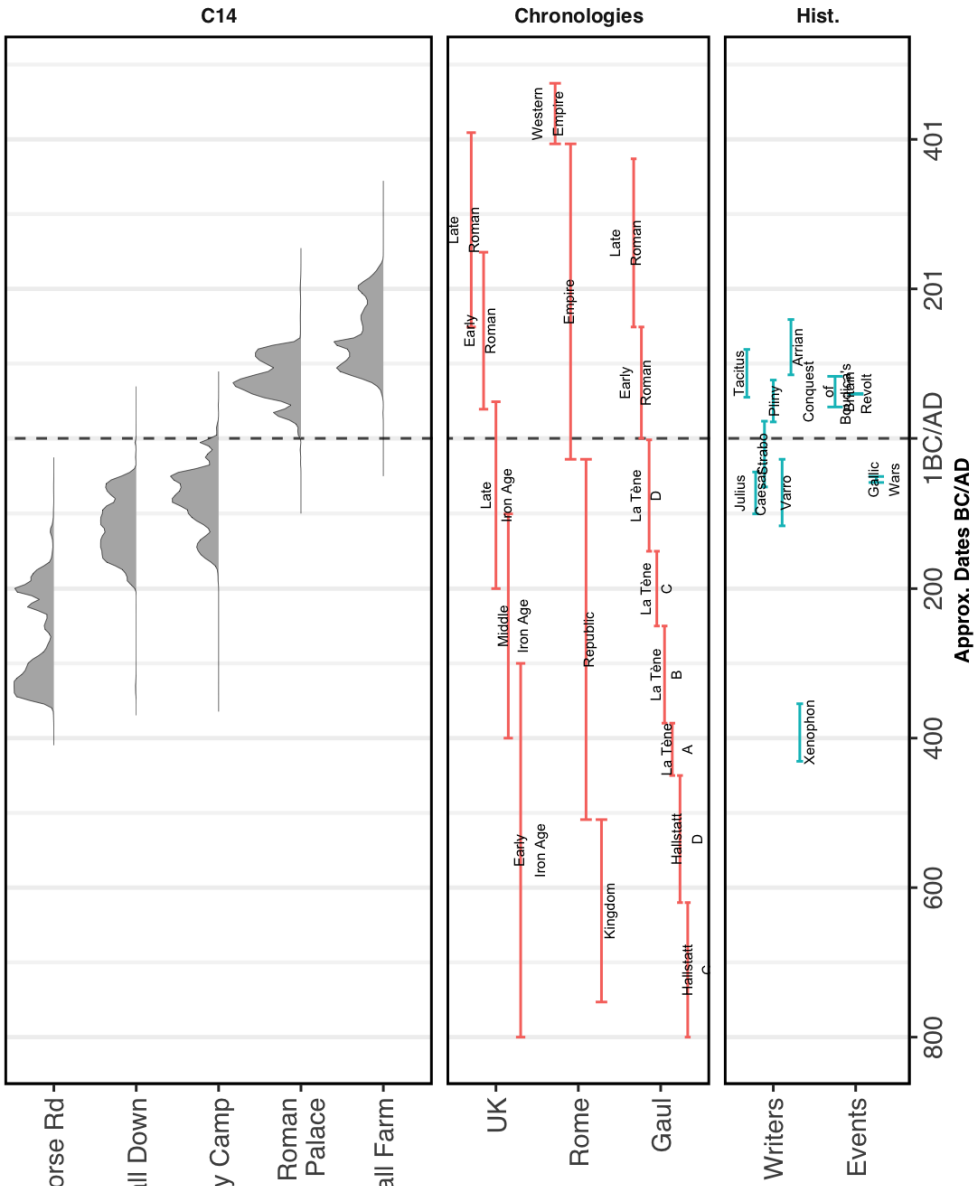

Figure 6.3: Timeline of approximate dates BC/AD for key historical events and classical authors' lifetimes, compared with standard archaeological chronologies for the British and Gaulish Iron Age; historical chronology of phases in Roman history; and the radiocarbon dates for British hares presented in the previous chapter.

in spring, this could suggest that the British zooarchaeological evidence reflects a prevalence of coursing conducted in autumn. Although the justification for avoiding hunting in summer would not strictly apply to Britain due to the cool climate relative to Greece, the practice could still have been observed for cultural reasons. Oppian's (1928: p. I. 133) *Cynegetica* also references this. The increase in abundance of juveniles over time could also be explained more simply by a growing hare population - a growing population is by definition juvenile-rich - resulting in greater chance that they would be hunted and included in archaeological deposits. Nevertheless, it is important not to dismiss the possibility that there may be cultural reasons behind their relative abundance in particular contexts and time periods.

Some sources have argued that the mythic and ceremonial importance of hunting in Greek culture was not shared by the Romans, whose major writers disapproved of it, or at least regarded it as a chore for slaves (Cartmill 1993: p. 42-4). Green (1996) argues against this interpretation, attributing it to modern scholars' cultural biases and some particular misreadings of Roman texts. Nevertheless, there appears to be consensus that the most visible evidence for Roman hunting is high-status in nature during the period of the Roman Empire. It is likely that hunting was more a marker of elite identity rather than religious experience (Sykes 2014a: p. 66; Cartmill 1993: p. 42-4). This is reflected in the British zooarchaeological record, where only elite sites - such as Fishbourne Roman Palace - show significant quantities of bones of wild mammals, birds and fish (Allen et al. 2011; Sykes 2014a: p. 66-8; Allen 2011). But, this does not mean that Roman interactions with wilderness were not sacred - religion and elite identity are not mutually exclusive. Sykes (2014a: p. 68) argues that whilst Iron Age Britons avoided or prohibited consumption of animals from the wilderness, Romans saw it as a "spiritual duty" to bring this space and its fauna to order.

Discussing Silvia's deer in Vergil's Aeneid, Starr (1992) explores Roman concepts of ownership and possession of animals: whilst domestic fauna were governed by ownership, wild fauna were *res nullius* - the property of no one. They became property when someone takes physical possession of them, but reverted to *res nullius* if they escaped. Game enclosures therefore represent a mechanism for claiming ownership of the landscape and its wilderness on a more permanent basis (see also Allen 2015). Game parks and gardens thereby communicated Roman elite power to the British population, and the right to order the natural world (Sykes et al. 2006; Sykes 2009:

p. 31; Allen et al. 2011)

Physical evidence for such parks in Britain is lacking, and rare elsewhere (Davis et al. 2009; Gardeisen et al. 2010), so their presence must be extrapolated from proxies in the (zoo)archaeological record and Roman historical accounts (Sykes 2009). Sykes has argued for the presence of *vivaria* using the evidence for introduced fallow deer (Sykes 2009; Sykes et al. 2006), and both she (Allen et al. 2011; Sykes 2009, 2014a) and this thesis take the view that large quantities of hare bones from Fishbourne Roman Palace and Whitehall Farm are convincing proxies for *leporaria*. The translocation of fauna around the Roman Empire, both for display in parks and for blood sport, communicated Roman status and control of the natural world (discussions in Hughes 2003; Lindstrøm 2010; Allen et al. 2011). It is therefore plausible that multiple phases of brown hare introductions occurred. Whilst this thesis' evidence has shown that at least some individuals arrived centuries before Roman rule was established, new populations may also have been created as a consequence of Roman elites' desires to communicate their power by populating their game enclosures.

Game enclosures are thought to have been common in the Roman world from the late Republic onwards (Sykes et al. 2006; Toynbee 2013: p. 16). Varro (nd: p. III 12) states that keeping animals in enclosures is a practice conducted at villas, and explains that they are still known as *leporaria* but are no longer of an acre or two in size, but sometimes vast forests containing roe and red deer. He also wrote that *leporaria* were so named because the Romans' "distant ancestors" only kept hares in them. It is plausible then that *leporaria* were established in Britain but never exclusively contained hares, as their function had already evolved to include other animals. The abundance of exotic fauna at Fishbourne supports this idea (Allen et al. 2011; Best et al. forthcoming; Miller et al. 2016).

Varro (nd: p. III 12) described *leporaria* as spaces enclosed with walls that are smooth and high to prevent carnivores from entering. Inside, there are coverts for hares to hide in during the day under bushes and grass, and trees with spreading branches to ward off attacks from eagles. He also states that the Romans fattened hares by taking them out of the "warrens" and into hutches.

These accounts give some insight to Roman game parks' social history, construction, and management, yet the method used to retrieve game from them is less clear. The

pathological specimen from Whitehall Farm is suggestive of trapping (§5.2.6), which is otherwise extremely difficult to detect archaeologically (Fowler 2016). Trapping is also much less likely to have been received as a display of elite identity as it involves *indirect* violence (see Cartmill 1993). But, the nature of the assemblage - mainly a single deposit of hare bones from a bath house - suggests that a significant quantity of hares were captured within a short time. Trapping may have been considered a more efficient method than hunting to acquire such a quantity. Alternatively, the Whitehall Farm hares could have been captured using the method described by Xenophon - using dogs to drive hares into nets. Within the context of a walled enclosure, multiple hares could probably be easily captured at speed with this or similar methods.

Arrian, however, is thought to have disapproved of hunting with nets and traps, disagreeing strongly with Xenophon (Stadter 1976). Instead, he advocates coursing on horseback with dogs, the Greeks having adopted "Celtic" techniques and hounds (*vertragi*) in the time since Xenophon wrote his Cynegeticus (Stadter 1976). Arrian (1841: p. XVI) is markedly invested in coursing as a sport in comparison to Xenophon. He was content for a hare to escape after capture, and often deliberately set captured hares free (Arrian 1841: p. XVI), whilst Xenophon emphasised the pleasure of seeing a hare successfully caught. Arrian may also have found coursing a hare in order to capture it for meat to be crude (Stadter 1976: p. 164-5), but this should probably not be taken as an indicator that he did not eat hare meat at all, rather it is a reflection of cultural differences between bloodsport in Xenophon's time and Arrian's. Hare meat was considered a first-class delicacy (Toynbee 2013: p. 201), and Appicus provides recipes for hare (Crummy 2013: p. 113).

The hare bone assemblages from Whitehall Farm and Fishbourne Roman Palace seem to indicate that multiple forms of hare hunting existed in Roman Britain. Both are high-status sites, which the evidence from Arrian would suggest is indicative that hunting that was not strongly focussed on meat procurement, but rather on sport as an expression of identity and skill. But, the quantities from the Whitehall Farm bath house - which can be taken as a single feasting event - suggest the opposite. They could have been mass-captured specifically for meat, so it is debatable whether or not this specific example would have been the result of a coursing spectacle.

That Arrian regarded coursing on horseback both as a superior form of hunting and as

"Celtic" in origin (Arrian 1841: p. XIX-XX) is vital to understanding the bio-cultural history of hares in late prehistoric and Roman Europe, because it potentially means that the development of hare hunting/coursing is intimately connected with Iron Age cultures north of the Alps, one or more of which were presumably involved in the introduction of the brown hare to Britain. Hunting and its social and religious connotations was therefore a likely motivator for the introduction. Consequently, the introduction was almost certainly a cultural and probably *multi*-faunal exchange between Britain and the continent.

Strabo, for example, states that the Britons bred and exported small and fast hunting dogs; later authors describe British dogs as particularly fast and strong (Green 1992: p. 56-7). As the earliest hare ABG predates significant Roman presence in Britain, and those from Winnall Down and Winklebury Camp, only marginally overlap with Caesar and Strabo, this raises the question of whether British hunting dogs - perhaps called Agassaeans/Agassians - were bred in *response* to the introduction of the brown hare, or whether such dogs pre-dated it. There is certainly sufficient time between the Blackhorse Road ABG and Caesar and Strabo for British attitudes to hares to evolve, and both are plausible scenarios.

The possibility that Agassaeans emerged around the late second or first century BC could be read as consistent with the earliest appearance of small numbers of unassociated hare bones in LIA assemblages like Danebury, Suddern Farm and Nettlebank Copse (Chapter 2). Perhaps hares were becoming more acceptable to hunt and their ritual uses changing (see discussion in Folklore and Religion section below, and also Murphy et al. forthcoming), with human interactions with coursing dogs and horses evolving in tandem.

But, the prior absence of the brown hare need not preclude the desire to breed, own, and use hunting dogs, so the hunting dogs mentioned by Strabo could also predate the brown hare's arrival. That hunting in "Celtic" societies appears to have been rare, ritualised, and probably religious (Green 1992: p. 60-62; Arrian 1841: p. XXXIII), would fit well with the existence of specially bred - and therefore socially/ritually meaningful - types of dogs (dogs and horses together seem to have held relatively high social importance to Iron Age societies, see Green 1992: p. 57; Creighton 1995; Sykes 2014a: p. 81-4, 141-3; for abundance of horses and dogs in ABGs see Morris 2008a:

p. 85-6)

Even more interesting is the *vertragus*. Arrian is the main textual source for these greyhound-like dogs, but there is also good artefactual evidence for dogs with such an appearance (e.g. Bennett et al. 2016: Fig. 13; discussion in Toynbee 2013: p. 104-5). "Hare and hound" folding knives (Figure 6.6) are extremely common in British contexts (Figure 6.7), which tend to depict long and slender dogs with long ears, chasing similarly stylised hares. It may be that these depictions represent *vertragi*, which are thought to be Gaulish in origin. That Arrian was writing about the use of *vertragi* for a Greek audience testifies to the great geographical scale at which *vertragi* were traded around the Roman Empire, so the likelihood that they did not reach Britain is small.

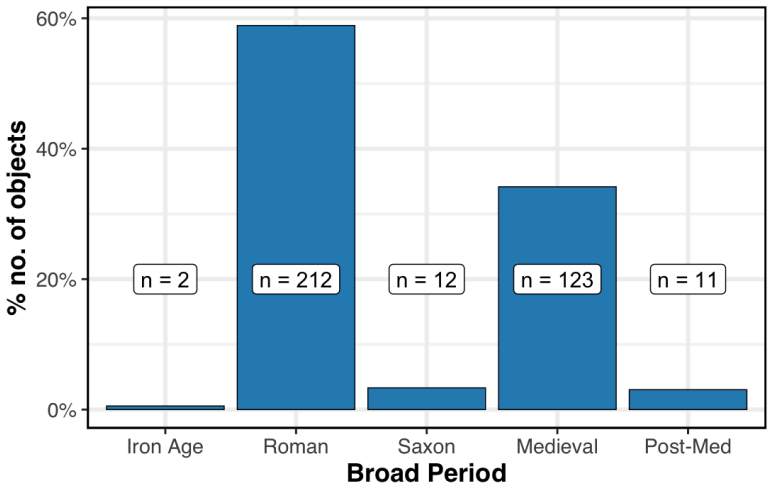

Figure 6.4: Percentage frequency of PAS artefacts depicting (or possibly depicting) hares by broad period.

The Agassaean's bio-cultural history and how they relate to *vertragi* may never be discovered, as textual evidence for both breeds is limited, though there is certainly scope for an integrated (zoo)archaeological, geometric morphometric, and genetic study to attempt to identify them in the archaeological record (Green 1992: p. 57 lists some plausible examples). Some hypotheses about their cultural history present themselves, however. One possibility is that Agassaeans dogs and *vertragi* were essentially the same, or very closely related, though this would contradict the interpretation that Aggassaeans were terrier-like (Figure 6.8), whilst *vertragi* were greyhounds. It would imply that Arrian and Strabo's accounts are an (entirely reasonable) incomplete

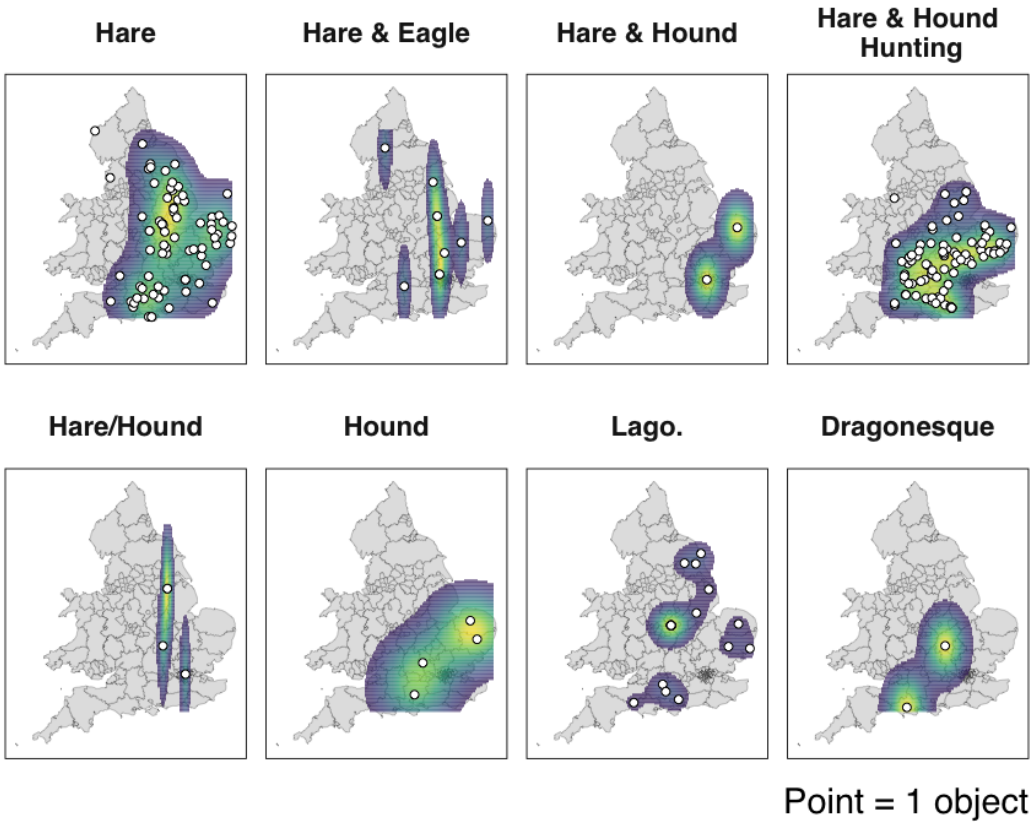

Figure 6.5: Spatial distribution of Roman iconographic finds associated with hares in the PAS database. Finds grouped by the animal/scene depicted. Finds depicting a "hare and hound" *hunting* scene - normally a coursing scene on a knife - are distinguished from other finds depicting both animals. Points show individual finds, heat-map tiles represent density (shown relatively so density is comparable between panels). Note that the identification of dragonesque brooches with hares is not conclusive; there is debate about whether these forms are stylised horses or hares (discussion in https://finds.org.uk/database/artefacts/record/id/578636).



Figure 6.6: Roman folding knife showing a hound chasing a hare (Portable Antiquities Scheme NMS-8E9E57). Rights: Norfolk County Council. License: CC BY-NC-SA.

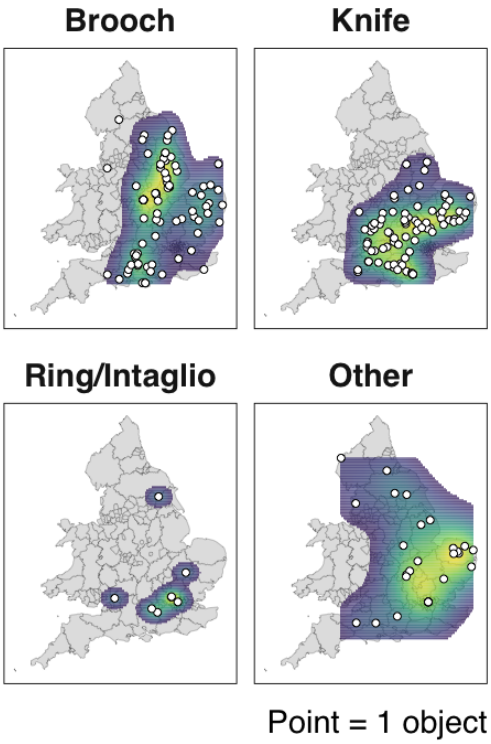

Figure 6.7: Spatial distribution of Roman iconographic finds depicting hares, grouped by object type. Points show individual finds, heat-map tiles represent density (shown relatively so density is comparable between panels).

representation of the complexity of ancient dog breeds. As MacKinnon (2010: p. 291) argues, it is important to recognise that the Roman concept of a "breed" cannot have matched the term's modern, genetic definition; contemporary accounts of Roman dog breeds tend to refer to geographic location or origin, which may be "known, mythical or assumed". Another option is that Agassaeans were bred by Iron Age Britons for another type of hunting, prior to the introduction of the brown hare that were superseded in Britain by *vertragi* as continental forms of hunting became more common. Yet another possibility is that one of these breeds is a descendant of the other, which would indicate complex cross-cultural relationships between Iron Age Britain and the continent, perhaps specifically Gaul, surrounding hunting, hares, and hunting dogs. For now, all of this is mere speculation, but this evidence shows that hunting dogs could be a powerful proxy for hare biogeography, as dogs are better represented in the archaeological record. A future multidisciplinary study would do well to tie the histories of these two fauna together.

6.2.2 Hare Hunting in England c. 1066-1550 AD

Following the Roman period, Britain entered a five hundred year-long era in which wild animals are conspicuous in the archaeological record by their absence. Save for ritual uses and Late Saxon high-status sites, wild fauna do not feature in Saxon zooarchaeological assemblages in any great quantity (Chapter 2, also (Sykes 2014a: p. 68-70; Poole 2011). As Chapter 2 demonstrated, archaeological hare bones conform to this trend, and the rarity of Saxon iconographic finds depicting hares in the PAS data seems to support it (Figure 6.4). It is not until after the Norman Conquest that any significant evidence for hare hunting re-emerges.

Norman rule in England is well-recognised for its effects on interactions with wild fauna (Almond 2011; Sykes 2007b), but most academic attention on the matter has been placed on deer. Archaeological and historical evidence is routinely integrated to explore the nature of human-deer-landscape relationships (e.g. papers in Baker et al. 2015; Sykes 2007a, 2010). Medieval hunting treatises such as the Art of Venery (*Le Art de Venerie* by William Twiti), Book of Hunting (*Livre de chasse* by Gaston Phoebus), Master of the Game (Edward, Duke of York) and the *Boke of St Albans* (late 15th century), provide vital detail on the nature of medieval hunting practices; but, it is important to recognise that they post-date Anglo-Norman hunting culture, so zooarchaeological



Figure 6.8: Bronze figurine depicting a terrier-like dog from either Coventina's Well, Carrawburgh or Chesters (Durham 2012). According to Toynbee (2013: p. 104), it may represent a British dog breed known as Agassaeans. Image taken from Durham (2012), original copyright English Heritage.

evidence has been essential to establishing the impact of the Norman Conquest and Forest Law on English hunting customs (Sykes 2007b). This has been successfully done for deer thanks to the good evidence for pre-Norman roe and red deer hunting, followed by Anglo-Norman shifts in hunting both those species and the reintroduced fallow deer (Sykes 2007b, 2010).

But for hares, there is very little Saxon evidence to compare with the post-Norman evidence (Chapter 2). The post-Conquest data collected in this thesis (Chapter 5) also needed to be considered in an aggregated form in order to have a (statistically) meaningful dataset to work with; they could not be separated into Norman, High Medieval and Late Medieval periods and still maintain adequate sample size. The evidence required to detect change as Sykes (2007b) did for deer is simply not available. But, it is still possible to draw on medieval sources and integrate them with the available zooarchaeological evidence to understand the nature of medieval human-hare interactions overall. Drawing on established trends and narratives in deer hunting will also help - the two did not exist in cultural vacuums, but developed together.

Medieval hunting overwhelmingly took the form of the *chasse par force*, a ritualised hunt in which game would be chased to exhaustion by hounds, hunt servants and mounted aristocrats (Cummins 1988; Sykes 2007b: p. 71). Red deer were the target of these hunts, as they favour open spaces in which hounds and horsemen could easily give chase (Sykes 2007b), and the high esteem in which hunters held hares (Cummins 1988) might be associated with the ability to chase hares over wide open landscapes in a similar fashion. Sykes (2007b) established that rather than being explicitly responsible for introducing *par force* hunting as a practice, the Normans instead ritualised its performance, particularly by introducing the 'unmaking' of the deer, which is best described by the *Boke of St Albans*. By adding new cultural practices, Gallicised jargon and legal restrictions to pre-existing English hunting, the Norman elite expressed their socially superior identity and established control over the English wilderness and its fauna (Sykes 2007b: p. 75). It seems clear that similar *par force* hunts also took place for hares, including a ritual comparable to the unmaking, sometimes called the 'hallow', though the practice seems to have changed over time or varied between France and England (Cummins 1988: p. 115). From the *Master of the Game*, Cummins (1988: p. 115) reports this:

> the hunter who was nearest took the dead hare from the…hounds, held it aloft, and blew the death, '*that men may gader thider*'. The hare was stripped (i.e. its skin was removed, except from the head), the gall bladder and paunch thrown away, and the body was '*choppid also smale as it myghte be so that it hange togedire*'. It was then held high, the master of the hounds blew the death again, and all the hunter hallooed, with the hounds baying around the hare, which the berner '*shuld…pulle as hye as he may every pece from other and cast to every hound his reward*'

Whereas, Phoebus' *Livre de chasse* recommended the following (again, quoted from Cummins 1988: p. 115-6):

> he recommends that the dead hare be placed on the ground, and the hounds encouraged to bark at it, kept back some distance by the huntsmen's staffs. He rewarded his hounds by soaking bread in the hare's blood and spreading it on a bed of straw, sometimes adding fragments of cooked meat and cheese, still keeping the hounds back until the order to them to fall on it. The hare's flesh, he says, is disagreeable to hounds and makes them vomit, and therefore reduces their willingness to hunt the hare. He does, however, allow the kidneys, heart and tongue to be included in the reward.

Hare coursing seems to have been a separate practice, though the focus on deer hunting *par force* - both in contemporary sources and modern scholarship - leaves the distinction somewhat vague. At a minimum, there seems to be consensus that *par force* hunting employed *scent*-hounds, whilst coursing used them predominantly to raise the hare, with *sight*-hounds (aka "gazehounds", greyhounds) used for the chase (Cummins 1988: p. 115). Cummins (1988: p. 115) also alludes to a form of *par force* hare hunting described in the *Master of the Game* which also used greyhounds, suggesting that it is comparable to bow and stable forms of deer-hunting, in which deer were chased into nets or towards waiting archers (Sykes 2007b: p. 74).

Medieval sources also suggest that hare hunting was highly regarded, the hare being described as the 'king of all venery' (Cummins 1988: p. 111). Hare hunts were cheap and could be organised quickly, and so were fitting for everyday sport among the Medieval elite (Almond 2011: p. 67; Cummins 1988). Coursing may have been seen

as an even less physically demanding activity (Cummins 1988: p. 111). This focus on sport echoes Arrian's sentiments (see above) centuries earlier, but the idea of hare hunting as a more 'leisurely' form of aristocratic bloodsport is perhaps newer.

Le livre de Roy Modus suggests that the best time to hunt the hare is in March and April (Cummins 1988: p. 112), the mating season. According to both Phoebus and Twiti hare hunting had no closed season, and so could have occurred throughout the year (Cummins 1988: p. 112). The *Boke of St Albans* suggests that the season began at Michaelmas and lasted until mid summer (Cummins 1988: p. 112). Knowledge that led to Arrian's advice not to hunt in summer (see above) possibly influenced this. Along similar lines, Phoebus recommends to begin hunting hares in the morning during summer, then resting until nones, before recommencing until night (Cummins 1988: p. 112). Together with the evidence from Arrian, these sources suggest that the interpretations of the epiphyseal fusion profiles discussed in the previous chapter have merit. Written sources from both Roman (see above) and Medieval contexts suggest hunting was limited in summer to avoid overheating, but only the medieval sources explicitly recommend hare hunting in spring. This evidence fits with the higher proportions of unfused early- and mid-fusing epiphyses in the Medieval assemblages than the Roman ones.

There is some speculation that the establishment of the British rabbit population around the thirteenth century may have had consequences for the brown hare (e.g. Matheson 1941: p. 380-1). Whether this is a genuine ecological impact or an issue of evidence biases associated with shifts in hunting practices; relative popularity of different game; the changing value of meat and fur etc. is unclear. Nevertheless, whilst issues of sample size prevented robust analysis of the medieval data in smaller time-units in Chapter 5 of this thesis, it is plausible that patterns in the zooarchaeology - such as the size decrease in the Medieval period - reflect some form of competition with the rabbit, and could be explored further with future datasets.

6.3 Folklore and Religion

As solitary and nocturnal fauna, with some species that change their coat-colour seasonally, it is perhaps no surprise that hares have featured extensively in folklore, mythology and religion. The record for human attitudes to hares in these and related

fields is surprisingly rich (see Evans et al. 1974) for an animal that is otherwise poorly understood in modern scholarship, so this section only highlights a few key features that are most relevant to this thesis.

Beginning with Classical Greek and Roman culture, there are numerous examples of folk beliefs about hares, many of which survived well into the medieval and early modern periods of western Europe. Pliny thought that the (mountain) hare turns white from eating snow (Evans et al. 1974: p. 34). Classical authors also report the belief that hares could change sex or were hermaphroditic; they have also been ridiculed for commenting that hares were capable of superfoetation (the ability to conceive during pregnancy), but have subsequently been proven to be correct (Evans et al. 1974: p. 24). Hares were also thought to sleep with their eyes open (Evans et al. 1974: p. 207; Carnell 2010: p. 33-4) and are widely associated with fecundity, even though they are much less productive than rabbits or rodents (Carnell 2010; Evans et al. 1974).

The brown hare's mating process earned the hare a reputation for madness, reflected in the idiom, 'mad as a March hare' (Evans et al. 1974: p. 53-4; Holley et al. 1984). Cummins (1988: p. 116) reports that his grandmother encouraged him to say 'Hares, hares, hares!' when going to bed on the last night of a month to avoid bad luck, a tradition probably tied into the many associations between hares and the moon (Evans et al. 1974). Moonlight was thought to have caused madness if one were touched by it; Cummins (1988: p. 116) appears to be uncertain whether he was appealing for the hare's protection in this regard, or warding off its influence.

The 'hound and hare' motif of Roman hunting knives appears to have resurfaced in Medieval iconography, but large proportions are *monde reversé* depictions, such as hares riding hounds as if hunting on horseback, or wielding bows or clubs against their usual foes, hounds and humans (Figure 6.9). In the PAS dataset, hares are overwhelmingly found on seal matrices (e.g. Figure 6.10) and they are widely dispersed geographically (Figure 6.11), suggesting that the various areas of high density of the different depictions of hares on these artefacts may reflect biases in metal detecting and reporting to the PAS (for discussion of these biases see Robbins 2013), though a more detailed analysis than is possible here could reveal other trends. The use of hares in the *monde reversé* trope was probably widely shared and not strongly associated with particular people or region, aside from the associations with education or high-status implied

by the possession and use of matrices for sealing documents. Nevertheless it seems that plainer depictions of hares or other lagomorphs are more common in central and southern England, whilst *monde renversé* depictions in which a hare is riding a hound is an eastern England tradition (Figure 6.12).



Figure 6.9: Manuscript marginalia depicting hares/rabbits in monde renversé hunting scenes. All from Royal MS 10 E IV (British Library). A) f.60r, B) f. 61r, C)f.61v, D) f.62r.

As with all ancient European art depicting leporids, there is considerable doubt as to whether these are representations of rabbits or hares; often they are assumed to be the former. But, exaggerated ears are often taken by art historians as an indicator of an image depicting a hare rather than a rabbit, and this can realistically be argued for those shown here (Figure 6.9). Also, the violent and martial imagery could have been more closely associated with hares, given the martial nature of the *chasse par force* compared to the gentler activity of collecting rabbits from a pillow-mound, which is associated with women in the Queen Mary Psalter (Figure 6.13). Medieval illuminators' motives are often thought to have been satire and absurdity, and the hare is often thought to be timid or cowardly. The terms "cowardly one" and "faint-heart" are among the seventy-seven names in the medieval English poem 'The Names of the Hare' (Cummins 1988: p. 118). This could make it likely that hares are the intended subjects of these illustrations (Jones 1989: p. 203). Though similar arguments could be posed in favour of interpreting them as rabbits, the motif of lagomorphs taking violent



Figure 6.10: Seal matrix showing a monde renversé depiction of a hare riding a hound and blowing a horn. Image from PAS, IHS-EEC376 (I. Szymanski, CC BY-SA).

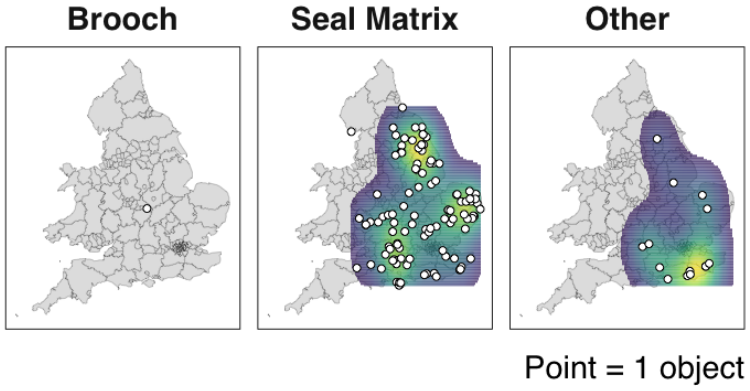

Figure 6.11: Spatial distribution of medieval finds depicting hares or depictions associated with hares or lagomorphs in the PAS database, grouped by object type. Points show individual finds, heat-map tiles represent density (shown relatively so density is comparable between panels).

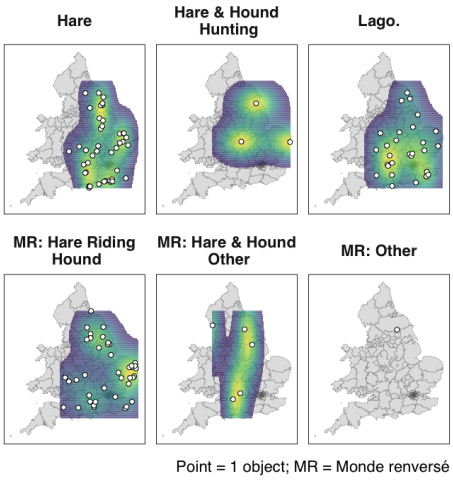

Figure 6.12: Spatial distribution of medieval finds depicting hares or depictions associated with hares or lagomorphs in the PAS database, grouped by type of depiction. Points show individual finds, heat-map tiles represent density (shown relatively so density is comparable between panels).

'revenge' on humans and dogs is common enough to assume this was a significant influence on or consequence of medieval European society's perception of hares, at least among literate people.

The idea that the hare was dangerous also seems to be common. Its "ability to appear out of nowhere" (Cummins 1988: p. 116), along with its supposed hermaphroditic nature may have influenced the association of the hare with witchcraft (more discussion in Evans et al. 1974: Chapter 13; Ellis 2002; Nildin-Wall et al. 1993; and also see in Irish tradition, probably referring to the Irish hare, Ross 1994; Dhuibhne 1993). Among other associations between hares and bad luck (more in Billson 1892; Evans et al. 1974), seeing a hare was regarded as an omen by Scottish fishermen, who avoided saying its name (Evans et al. 1974: p. 214). This may be linked to cross-culturally observed taboos against naming the hare directly, with many Indo-European languages having adopted euphemisms, often referring to its shape, appearance or behaviour. Boyle (1973: p. 322) suggests that some words for "hare" may originally have been euphemisms that became the 'ordinary' word and then were substituted with new ones. The Irish word *girrfhaidh*, a compound of 'short' and 'deer', may have been substituted by *míol maighe* ('plain beast') and *míol buidhe* ('tawny beast' - see Evans et al. 1974: p. 200-212). The medieval English 'Names of the Hare' poem includes 'the beast that



Figure 6.13: Manuscript illustrations depicting women hunting rabbits (A, f. 156r) and collecting rabbits from a pillow-mound with nets and a ferret(B, f. 155v.). From Queen Mary Psalter, MS Royal 2B VII, British Library.

no one dare name' (Cummins 1988: p. 118). Modern dialectal English words for 'hare' take the form of pet names also used for cats (Boyle 1973: p. 322; Evans et al. 1974: p. 34), a number of which are women's personal names (Figure 6.14, see also Gibson 2007).



Figure 6.14: Spatial distribution of modern English dialectal terms for hare. Source: Richard Jones.

Contradicting its ominous associations, the hare is also seen as a protective force. Ellis (2002) notes a 1584 AD account of carrying a hare or rabbit's foot for warding off cramp or arthritis, before going on to discuss the associations between the 'lucky rabbit's foot'

phenomenon and social tensions in the early twentieth century, in which possession of a lucky foot protected against a "dangerous Other- whether trickster, badman, or witch". Other parts of the hare have also used for medicine and protection. Medicinal uses include Classical era accounts of eye-salves; cures for "emotional trembles…and teething-pain in children"; aids for epileptic fits, menstruation and diarrhoea; and cures for poison (Rathbone 1982). Following humoral principles (discussion in Jones et al. 2016) hare meat was considered healthy for people with a cold constitution, in winter, and in cold climates (Cummins 1988: p. 119). By the same principles, however, it could cause sleeplessness and melancholy (Carnell 2010; Cummins 1988).

The theme of protection continues in religious contexts. Murphy et al. (forthcoming) trace associations between hares and British deities through time, beginning with Iron Age Andraste and ending with Easter as a "Internet Meme Goddess" for the Information Age. Andraste is thought to be the goddess thanked by Boudicca having used a hare for pre-battle divination, according to Cassius Dio (Crummy 2013; Lauritsen et al. 2018; Murphy et al. forthcoming). If Dio can be regarded as reliable, Andraste may therefore have been a protective tutelary deity based in warfare (Murphy et al. forthcoming). Note, however, that Crummy (Crummy 2013: p. 119) argues that the hare cannot have been sacred to Andraste, on the basis that Dio intended Boudicca's hare to be representative of the Romans, whilst her speech likens the Britons to powerful dogs and wolves.

Plate-brooches (thought to represent specific deities, Crummy 2013, 2007) in the form of hares (Figure 6.15) become common in the Romano-British period. They have been suggested to represent Venus and Andraste, though Murphy et al. (forthcoming) reject this in favour of a Romano-British reflex of Artemis-Diana. Strong associations between deer and pre-Roman deities (Cernunnos, Callirius) may have prompted alternatives to deer in iconography for Artemis-Diana, perhaps helped by her conflation with Andraste (Murphy et al. forthcoming). Both these deities are linked with violence (war for Andraste, hunting for Artemis-Diana) but most hare-form brooches depict cowering hares, which leads Murphy et al. (forthcoming) to suggest that this Andraste/Diana reflex was associated with "protection from violence and the granting of sanctuary". This interpretation certainly fits with this thesis' suggestion that a paucity of young hares in Romano-British assemblages derives from leverets being the property or under the protection of Artemis/Diana (§6.2.1).



Figure 6.15: Roman brooches in the PAS. A) Hare-form plate-brooch, HAMP-2CB955. B) Plate-brooch, SWYOR-6A1586; there is some debate about whether these forms depict hounds or hares C) Dragonesque brooch, GLO-50D0EA. All have been included in the data presented in this section. Images after PAS, see https://finds.org.uk/database/artefacts/record/id/256655 (Winchester Museum Service, CC BY-SA), https://finds.org.uk/database/artefacts/record/id/929826 (West Yorkshire Archaeological Advisory Services, CC BY), https://finds.org.uk/database/artefacts/record/id/956423 (Bristol City Council, CC BY).

Paradoxically, Eostre - the goddess most closely associated with hares and rabbits in modern popular thought, having given her name to the modern Easter celebration (Lauritsen et al. 2018; Shaw 2011) - is the only one that Murphy et al. (forthcoming) cannot link with the hare. Eostre has a history of controversy among philologists and historians of religion. The only direct evidence for her comes from the Venerable Bede, who has often been accused of inventing her in order to explain the origin of the Old English month name corresponding to April, *Eosturmonath* (Sermon 2008; Shaw 2011). Links between her and the Christian Easter celebration were rationalised by nineteenth century philologists: Jacob Grimm claimed that she can be viewed as a dawn goddess (Shaw 2011: p. 51-2), while Holtzmann (1874: p. 141) speculated that the hare was Ostara's symbolic animal (**Ostara* being Grimm's extrapolation of a German cognate for Eostre). No contemporary written sources or archaeological evidence has ever been found to support Grimm and Holtzmann's suppositions, but they have been continually repeated to such an extent that the belief that Christians 'stole' an originally 'pagan' springtime festival of the dawn goddess Ostara involving hares and symbolic eggs is deeply embedded in modern Easter culture (Lauritsen et al. 2018; Murphy et al. forthcoming).

Drawing together English place-name evidence and inscription evidence for the cult of the *Matronae Austriahenae* from Morken-Harff, in Northern Germany (Figure 6.16),

Shaw (2011: esp. 63-64, 67) proposed the alternative interpretation that Eostre was a local goddess worshipped by people who considered themselves to be 'the eastern people'. Though the cult of Eostre in England and the Matronae Austriahenae in the Rhineland share common etymological origins, this does not mean that Eostre was a pan-Germanic goddess or that there was necessarily any particular cultural connection between the two religious traditions. Rather, the available evidence allows only for the interpretation that shared Germanic naming customs resulted in similar names for the tutelary goddess(es) of disparate groups of self-identifying 'Eastern people' (Shaw 2011: p. esp. 62-4). As such, Eostre had no specific role (such as warfare, sanctuary etc), her focus was her congregation: "a *local* goddess for *local* people" (Murphy et al. forthcoming).

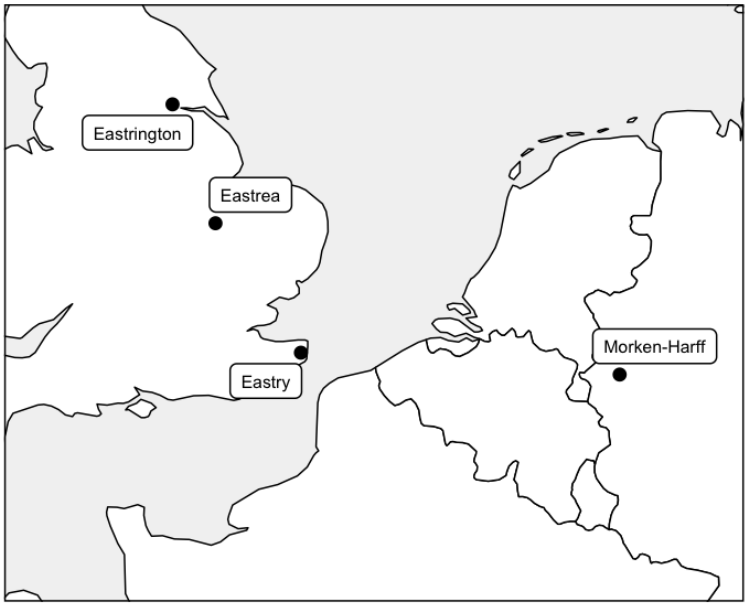

Figure 6.16: Location map of English place-names cognate with Eostre and of Morken-Harff, Germany.

Unfortunately, there is no archaeological, iconographic or place-name evidence to associate Eostre/Ostara with hares at all. English 'hare' place-names almost always have multiple possible etymologies, *hara* (Old English 'hare') being just one and often

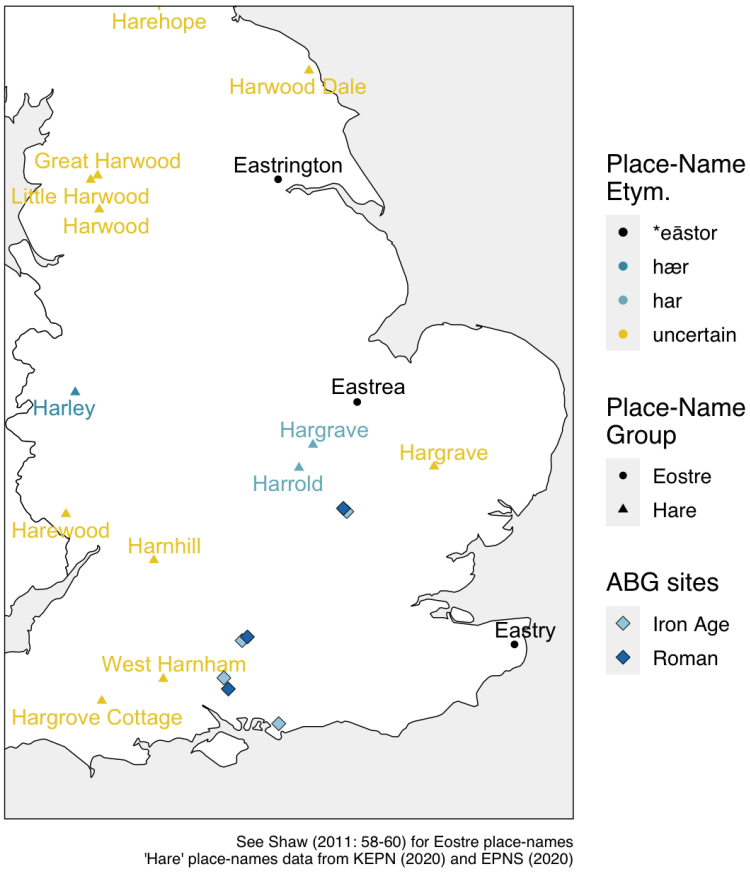

Figure 6.17: Spatial distribution of English place-names associated with Eostre (Shaw 2011) shown with modern 'hare' place-names and the location of Iron Age and Roman ABG sites. 'Hare' place-names may be derived from various Old English words including *hara* (hare), *hær* (rock, tumulus), or *hār* (grey). A few entries in the KEPN (2020) and EPNS (2020) suggest that *hara* it no longer accepted for some names but others are still uncertain (indicated, see legend).

not the favoured interpretation (EPNS 2020; KEPN 2020). Regardless, only a few of the modern English place-names that might derive from *hara* are geographically close (and only at a very broad scale) to Eostre place-names (Figure 6.17). There is a cluster of 'hare'-names and ABG sites in the region of Bedfordshire/Herefordshire, near the Cambridgeshire town of Eastrea, which would be highly suggestive if Hargrave and Harrold had not already been disregarded as possible *hara*-derived names in EPNS (2020). Similarly, there is no iconography from Morken-Harff that associates hares with the Matronae Austriahenae (Lauritsen et al. 2018: p. 291). Additionally, Shaw (2011: p. 64-7) identifies Kent as a key region in which Eostre may have been worshipped, but Kent has very little zooarchaeological evidence for hares, likely a result of acidic geology (Chapter 2).

It is important, however, not to totally discount the possibility of continuity in cultural associations between hares and deities through time. Murphy et al. (forthcoming) show that, with the exception of Eostre, four British hare 'goddesses' from the Iron Age to the present can be associated with hares, likely because these deities represent their society's concerns about violence. As vulnerable prey animals, hares were apt targets on which to project these anxieties (Murphy et al. forthcoming). It is therefore plausible that regional variation in Iron Age relationships with hares not only existed, but persisted during the Roman period, perhaps as a consequence of the social importance of regional/local deities. This is supported, for example, by the common characterisation of Boudicca's tribe, the Iceni, as being more culturally conservative, or resistant to Roman culture, than their neighbours. Harlow (2018: p. 16) rejects the Othering of the Iceni found in earlier research in this regard, but she preserves the idea that material culture trends reflect the "persistence of local burial customs, or the strength of earlier cosmologies and religious preoccupations". It is perhaps also relevant here that Norfolk has almost exclusively *female* deities (Harlow 2018: p. 13).

Additionally, regional variance in the distribution of hare-hound hunting knives compared with that of hare-form brooches is very subtle (Figure 6.7), and may just reflect spatial biases in the PAS, but the religious associations of the brooches (Crummy 2007, 2013) compared with the high-status identity and sporting connotations of the knives, mean it is just enough to support the idea that relationships with hares were not geographically homogenous in the Romano-British period. It is within the bounds of credibility that regional variance in human-hare relationships survived - though

not unchanged - until the end of the Roman period, and influenced how they evolved further under new influences from Germanic-speaking cultures from the fifth century onwards. Specific deities and forms of symbolism certainly changed, but the significance of the hare as cultural metaphor for vulnerability and supranatural wilderness could easily have been sustained and repurposed for new deities and traditions. Though it is necessary to resist specific interpretations or hypotheses here, both for concision and to avoid projecting evidence onto contexts with which it may be incompatible, it is worth noting that these ideas are compatible with current theories of the creation of early "English" identities and societies from both Romano-British and Germanic sources (overview in Loveluck et al. 2011).

That Stamatis et al. (2009) showed with modern DNA that the brown hare may have been introduced to Britain from a population associated with the area of Northern Germany led us (Lauritsen et al. 2018) to suggest that integrated (zoo)archaeological, aDNA and iconographic investigations into the bio-cultural history of the brown hare in Britain, compared with similar data from the wider European context, could reveal evidence for a hare-deity that could support a connection with Eostre. This thesis has made some progress towards that objective from the British archaeological perspective, but the forthcoming aDNA evidence and future zooarchaeological and cultural studies centred on Germanic-speaking Europe will be essential to determining whether this hypothesis has any merit.

Nevertheless, on the basis of current evidence, a very simple and likely explanation for the association between Easter and the hare can be proposed. Shaw (2011: p. 69) argues that the English Christian Easter celebration acquired its name from the month it was celebrated in (Eosturmonath). Hares could have been associated with Easter and springtime simply because their activities start become more visible at this time of year (relative to winter), sunset falling earlier in the day during winter months (Holley et al. 1984). There is no contemporary Saxon evidence for any such cultural association, however.

But, there is evidence for late medieval hare hunting occurring at Easter. In 1620, Lord Zouch was asked for permission to kill a hare on Good Friday, because huntsmen believed that those without a hare for Easter "must eat a red herring" (Billson 1892). Billson (1892) also reports a tradition in Warwickshire in which a hare was exchanged

for a hundred eggs on Easter Sunday (with thanks to Luke John Murphy and Adrian Bott for highlighting these). The hare thereby 'brings eggs at Easter'. Billson (1892) also traces a tradition from Leicester in which a cat was trailed before a pack of hounds at Easter in a mock hunt, the cat representing a hare, back to 1574, when the tradition seems to have involved a real hare. Given that medieval hunting texts recommend hunting hares in springtime because of the mating season (§6.2.2), it would make sense for Easter to be marked with a hare hunt. Notably, Billson's evidence is earlier than von Frankenau's (1682) assertion that the (German) Easter hare originated from the common occurrence of hares in gardens at springtime, acting as a convenient explanation for the appearance of coloured eggs hidden there for children as part of the Easter festivities. The possibility that this tradition could be traced back to a hare/Eosturmonath association in the Saxon period seems doubtful; more likely it was a post-Norman hunting development.

6.4 Summary

Throughout humanity's interactions with hares then, these animals have been emblematic of ambiguity. Hare meat could at once be healthy and unhealthy for different people; they had medicinal uses; hares could be a trickster or a transformed witch; or they could be protection from witches. They could be bad luck, or protection from bad luck. At different times they may have been under the protection of the supranatural entirely (Iron Age Britain) and at others eagerly hunted by social elites (Roman and Medieval Britain). Even in Roman and Medieval settings, the desire to hunt hares is seemingly in tension with with their mysterious and supernatural qualities. Roman hunters left leverets to Artemis/Diana, who protected them, and in Medieval Wales the hare was emblematic of St. Melangell, her sanctuary, and of refuge and asylum (Murphy et al. forthcoming). Today, the hare is involved in similar tensions, both as the animal of the "Internet Meme Goddess" (Murphy et al. forthcoming) and as a prominent figure in modern perceptions of wilderness and its conservation and biodiversity (e.g. Moss 2018; Harvey 2019).

Those final themes, conservation and biodiversity, are crucial to the study of both lagomorphs and the bio-cultural impacts of anthropic faunal diaspora (e.g. Chapman et al. 1990b; Alves et al. 2008; Reid 2011; Caravaggi et al. 2015). They will direct the

conclusions and recommendations for future work on the brown hare in the next and final chapter of this thesis.

Chapter 7

Conclusion and Future Work

This thesis set out to establish a (zoo)archaeological basis for the brown hare's introduction to Britain. Essential to this objective was the need for accurate zooarchaeological identification of the species in the archaeological record, so that the chronology of its arrival and subsequent bio-cultural impact could be understood. This was also intended to inform the Easter E.g. project's investigations into the bio-cultural history of the Easter tradition, with which the brown hare is intimately connected.

The specific challenges associated with working with a species that has bones small enough to be severely impacted by taphonomic and recovery biasses associated with size, but large enough to still be predominantly reported in hand-collected contexts, have played a significant role throughout this thesis. In such a situation zooarchaeological inferences have to be placed within tight bounds of credibility, so the methods employed in this thesis were tailored to make the best of limited and problematic data. This philosophy was first applied to a synthesis of existing zooarchaeological datasets in Chapter 2, which reviewed both general trends and detailed contextual information. There, it was possible to ascertain that evidence supporting the hypothesis of an Iron Age date for the introduction of the brown hare (Sykes 2014a; Yalden 2010) held up to scrutiny better than contrary evidence suggesting a Bronze Age or Neolithic date. Following chapters therefore devoted the greatest attention to the Iron Age and later evidence. The synthesis also showed trends in the relative abundance of hare remains in the archaeological record, many of which conformed to similar trends in the abun-

dance and cultural context of other wild fauna in the Roman, Saxon and Medieval periods.

Having assessed the existing evidence, it was then possible to turn to the issue of identification in Chapters 3 and 4. By using repeated morphometric identification on a dataset obtained by maximising the measurability of fragmented bone, it has been possible to predictively identify the species of the largest sample of archaeological hare bones brought together from British archaeological assemblages so far. The exhaustive cross-validation analysis in Chapter 3 means that these identifications were made using only the most accurate models, without compromising the sample size to too great an extent, which was important when working with a species that is archaeologically scarce. Zooarchaeologists now have access to a robust method for hare species identification based on their existing skills, which is particularly helpful in the commercial and public sector. Though this thesis used predictive statistical methods to perform its identifications, quick identifications can be made for other hare bones by simply plotting the transformed data - laying data points from archaeological specimens over the modern data from this thesis. Any identification made in this way can also be quoted with the associated cross-validation result.

Almost all UK archaeological samples this thesis handled were identified as brown hare in Chapter 4. From this it was possible to conclude that, subject to confirmation by forthcoming aDNA results, the mountain hare was probably absent or at least retreating from England when the brown hare arrived. Currently, there seems to be no evidence that the brown hare caused this retreat, and earlier environmental change (Yalden 2010: p. 194) seems to be the more likely explanation. Radiocarbon dating has shown the earliest identified brown hares to be Iron Age in date, which concurs with most previous assumed arrival dates for the species' arrival (Sykes 2014a; Yalden 2010). Whilst purportedly earlier examples do exist and also deserve radiocarbon dating (e.g. Turk 1964), the contextual evidence strongly suggests that they are intrusive and so were not included here.

Examining the zooarchaeological and contextual character of the identified remains has revealed interesting insights in to nature of human-hare relationships over time. It seems likely that, similar to the chicken (Best et al. forthcoming; Sykes 2012), hares were not treated in the same manner as native fauna by the Iron Age Britons, and

some of their cultural importance was retained in the Roman period. Despite limited evidence, the existence of at least one deity associated with hares in Romano-British culture seems highly likely, and the religious connotations of the hare probably manifested differently between different regions and social groups. The Roman tradition of keeping wild fauna enclosed in game enclosures probably had a significant impact on the social and biological fabric of the British landscape (Allen et al. 2011), a phenomenon the brown hare certainly played a major role in.

Classical and medieval authors attest to the complexity of the bio-cultural history of the hare both in Britain and elsewhere. Dogs, religion, food and social status are all tied-up in the history of the hare, and this thesis has only managed to scratch the surface of the evidence from continental Europe that will be fundamental to a more comprehensive understanding of these issues. In some aspects, the available zooarchaeological evidence fits with written accounts (e.g. epiphyseal fusion), in others it is too great a stretch to interpret the data in any single way (e.g. log-scale indices).

The inevitable limitations of such biased zooarchaeological data encouraged me to be inventive, employing approaches seldom considered worthwhile in zooarchaeology (e.g. prioritising effect sizes in Chapter 2, resampling LSIs in Chapter 5). In other areas, the available data are simply not enough. To push forward with small mammal studies in zooarchaeology, radical transformation of reporting is required. Currently, the discipline is still limited by the lack of attention given in reports to fauna that are represented in low quantities, and individual bones of such fauna are rarely highlighted with their context numbers, which severely limits researchers' ability to locate them in archives. For that reason, this thesis' osteological evidence was dominated by sites with unusually high quantities of hare bones - these sites are oddities, not the norm. A truly comprehensive study that captured a representative sample of real-world diversity - for example, in hare size-change - would have access to the data from 'normal' zooarchaeological assemblages, which tend to have fewer than ten hare bones (Chapter 2). The recommendations for data sharing in Kansa et al. (2020) would be a momentous aid to researchers endeavouring to improve on this thesis.

Seemingly throughout their social history, hares have been associated with religion, good and bad luck, medicine, and witchcraft and tricksters. Perhaps the most salient aspect of all these traits is the ambiguity presented by an animal portrayed as both

"good" and "bad" and both "dangerous" and a symbol of protection and sanctuary. It is apposite then that hares have been difficult to study in modern biology, and that the perception that brown hares are native to Britain has only recently begun to be debunked in popular media. It is no surprise either that the hare is tied up in Murphy and Ameen's (forthcoming) "Internet Meme Goddess" characterisation of the Information Age's Easter tradition, in which varying beliefs about hares and Eostre circulate online, reflecting our anxieties about misinformation and the origin of cultural traditions.

The cultural ambiguity of hares is equally fitting given the brown hare's cultural standing in modern Britain, which exists in tension with its biological status. As an introduced species, the brown hare falls into a category of animals that are frequently demonised and rejected as "alien" invaders in the scholarship and politics of conservation and biodiversity, whilst native species are held in an elevated status (Crees et al. 2015; Murphy et al. forthcoming; Sykes et al. 2019; Willmore 2015).

The genetic "purity" or "integrity" of a native species is a common justification for the allocation of conservation resources (e.g. Caravaggi et al. 2015: p. 689; Reid et al. 2007: p. 135) and it is hard to ignore similarity between the language of far-right politics and that found in these debates (Sykes et al. 2019; Willmore 2015). Deep-time archaeological evidence is almost never included in these discussions, yet when a deep-time approach is taken far more complex biographies emerge. Species once thought to be native can be shown to be introduced, and vice versa. Complex histories of introductions, extinctions, and reintroductions occurring in different time periods for a variety of species (e.g horses - Sykes 2014a: p. 81; fallow deer - Sykes et al. 2011; Sykes 2014a: p. 96; Valenzuela et al. 2016; rabbit - Sykes et al. 2010), as well as indirect human impacts on biogeography (Crees et al. 2015), show that treating 'native' and 'non-native' as well-defined binary opposites is flawed.

Ancient introductions also drove cultural change. Religious change followed the fallow deer (Sykes 2014b) and chicken (Best et al. forthcoming; Sykes 2012), and probably the brown hare (discussed in Chapters 2, 5 and 6). The brown hare has also enriched British hunting culture and folklore over many centuries (Chapter 6). It is therefore no surprise that the brown hare is treasured as an essential feature of the British bio-cultural landscape, and is the subject of various conservation efforts (e.g. Game

and Wildlife Conservation Trust and Hare Preservation Trust - Sykes et al. 2019). It exemplifies the trend for species that arrived in antiquity to be viewed with nostalgic positivity, whilst more recent introductions are rejected as 'aliens' ("shifting baselines syndrome", see Murphy et al. forthcoming).

The realisation that 'nativeness' - as a biogeographical concept - belies human value systems, whilst - as a notional property of a given species - can be based on received wisdom through the decision to ignore deep-time evidence, undermines the notion that biodiversity and conservation policy is based on 'objective' scientific evidence (Crees et al. 2015; Willmore 2015). I join other researchers such as Sykes et al. (2019) and Crees et al. (2015) in the hope that (zoo)archaeological research, like that presented here, will encourage scholars to question why nativeness is a valued trait, and to engage seriously with its complexity. I believe this thesis has demonstrated that, although difficult, it is possible to study the introduction of small mammals archaeologically to contribute to these debates, and that zooarchaeology can benefit from increasing its attention on taxa which are scarce in the archaeological record. Thanks to the new datasets, interpretations, hypotheses, and methods produced in this thesis, we can justifiably look forward to lagomorphs receiving more of this attention in the near future.

Appendix A

Appendices

A.1 Synthesis

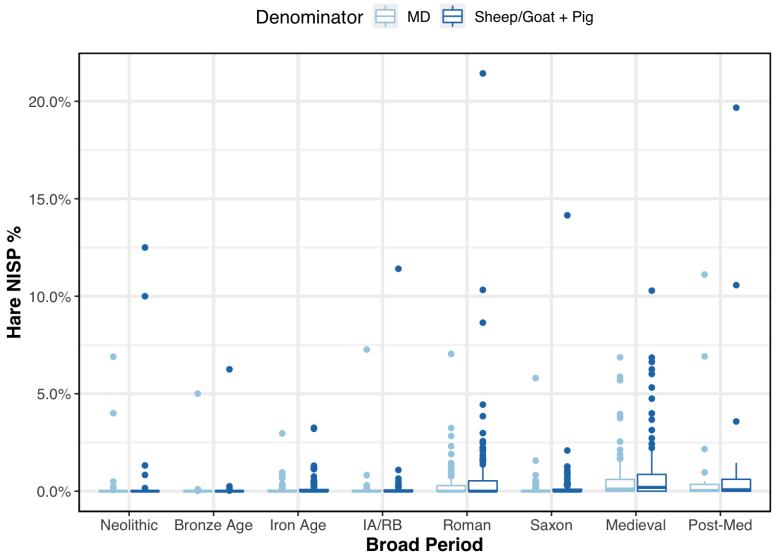

Figure A.1: Comparison of H/MD with H/(Sheep-Goat + Pig) by broad period. Notice that the overall shape of the distributions change little between the denominators, only the position of the outliers.

Table A.1: Unaggregated NISP data from St. Ebbe's sites (Oxford) used in synthesis.

Sitename	Period	Dates	Cattle	SG	Pig	Hare	Rabbit
Church Street, St Ebbe's, Oxford	Late Saxon	11th	410	844	249	2	–
Church Street, St Ebbe's, Oxford	Late Saxon	11th	68	294	84	2	–
Church Street, St Ebbe's, Oxford	mid 12th - mid 14th	12th	608	1673	589	8	–
Church Street, St Ebbe's, Oxford	mid 12th - mid 14th	13th	1203	2512	595	5	1
Church Street, St Ebbe's, Oxford	mid 12th - mid 14th	14th	72	50	42	–	–
Church Street, St Ebbe's, Oxford	mid 14th - mid 16th	15th	31	40	24	1	1
Church Street, St Ebbe's, Oxford	mid 14th - mid 16th	16th	119	178	53	1	18
Church Street, St Ebbe's, Oxford	Post-Med	early 17th	80	118	35	–	1
Church Street, St Ebbe's, Oxford	Post-Med	late 16th	33	75	11	–	5
Church Street, St Ebbe's, Oxford	Post-Med	mid 17th	70	74	19	1	3
Church Street, St Ebbe's, Oxford	Post-Med	mid 18th	93	216	42	–	5
Church Street, St Ebbe's, Oxford	Post-Med	mid-late 17th	104	157	17	4	6
Greyfriars, St Ebbe's, Oxford	Post-Med	17th	109	292	36	1	–
Greyfriars, St Ebbe's, Oxford	Post-Med	18th	137	180	70	–	1

Table A.1: *(continued)*

Sitename	Period	Dates	Cattle	SG	Pig	Hare	Rabbit
Littlegate, St Ebbe's, Oxford	mid 12th - mid 14th	late 12th - early 13th	43	44	9	–	–
Westgate, St Ebbe's, Oxford	mid 11th - mid 12th	11th-12th	25	32	10	–	–
Westgate, St Ebbe's, Oxford	mid 12th - mid 14th	13th	12	19	1	–	–
Westgate, St Ebbe's, Oxford	Post-Med	17th	13	2	–	–	–
Westgate, St Ebbe's, Oxford	Post-Med	18th	43	60	13	–	1

Table A.2: Synthesis site list, arranged by county.

County	Site Name
Bedfordshire	Biddenham Loop
Bedfordshire	Puddlehill, Dunstable
Berkshire	Bartholomew Street, Newbury, Berkshire
Berkshire	Cheap Street, Newbury, Berkshire
Berkshire	Hodcott Down
Berkshire	Kintbury Sewage Works
Berkshire	Lambourn 19
Berkshire	Manor Farm Horton
Berkshire	Reading Business Park
Berkshire	Reading Oracle
Berkshire	Wraysbury
Bristol	Avonmouth
Bristol	Bristol Castle
Bristol	Hallen
Buckinghamshire	Bancroft
Buckinghamshire	Bancroft, temple-mausoleum
Buckinghamshire	Bierton
Buckinghamshire	Burnham Market
Buckinghamshire	Chicheley
Buckinghamshire	George Streeet, Aylesbury, Buckinghamshire
Buckinghamshire	Great Linford
Buckinghamshire	Hartigans, Buckinghamshire
Buckinghamshire	Ivinghoe Beacon
Buckinghamshire	Kingsmead South
Buckinghamshire	Lake End Road, Dorney
Buckinghamshire	Lot's Hole, Dorney
Buckinghamshire	Oxley Park West
Buckinghamshire	Pennyland, Buckinghamshire

Table A.2: *(continued)*

County	Site Name
Buckinghamshire	Pitstone
Buckinghamshire	Walton Lodge
Buckinghamshire	Walton Teachers Centre
Buckinghamshire	Walton Vicarage
Buckinghamshire	Wavendon Gate
Buckinghamshire	Wolverton Mill
Buckinghamshire	Wolverton Turn, Buckinghamshire
Cambridgeshire	Ashwell Site, West Fen Road, Ely
Cambridgeshire	Edix Hill AML 54/95
Cambridgeshire	Eynesbury, Cambridgeshire
Cambridgeshire	Godmanchester
Cambridgeshire	Grandford
Cambridgeshire	Haddenham III, Snow's Farm
Cambridgeshire	Haddenham IV
Cambridgeshire	Haddenham V
Cambridgeshire	Haddenham VI
Cambridgeshire	Haddon
Cambridgeshire	Hillside Meadow, Fordham
Cambridgeshire	Maxey
Cambridgeshire	Orton Hall Farm
Cambridgeshire	Orton Longueville
Cambridgeshire	Parnwell
Cambridgeshire	Station Road, Gamlingay
Cambridgeshire	Stonea Grange
Cambridgeshire	Tort Hill East
Cambridgeshire	Tort Hill West
Cambridgeshire	Wardy Hill
Cornwall	Duckpool

Table A.2: *(continued)*

County	Site Name
Cornwall	Launceston Castle
Cornwall	Newquay, Atlantic Road
Cornwall	Trevelgue
Devon	Bantham
Devon	Exeter
Devon	Okehampton Castle, Devon
Dorset	Conygar Hill
Dorset	Cowleaze pasture
Dorset	Crab Farm Shapwick
Dorset	Dorchester Greyhound Yard
Dorset	Dorchester, County Hall
Dorset	Dorchester, County Hospital
Dorset	Dorchester, South Grove cottage
Dorset	Down Farm Dorset cursus
Dorset	Down Farm Firtree Field
Dorset	Down Farm pond barrow
Dorset	Down Farm Wyke Down henge
Dorset	Eldon's Seat
Dorset	Flagstones
Dorset	Fordington Farm
Dorset	Greyhound Yard
Dorset	Gussage All Saints
Dorset	Hambledon Hill
Dorset	Hengistbury Head
Dorset	Hod Hill
Dorset	Maiden Castle
Dorset	Manor Farm
Dorset	Middle Farm

Table A.2: *(continued)*

County	Site Name
Dorset	Mount Pleasant
Dorset	Pamphill Barford Farm
Dorset	Pamphill Lodge Farm
Dorset	Poundbury
Dorset	Poxwell
Dorset	Quarry Field, Compact Farm
Dorset	Rowden
Dorset	The Foundry, Poole
Dorset	Tolpuddle Ball
Dorset	Whitcombe
East Sussex	Alfriston
East Sussex	Battle Abbey, Sussex
East Sussex	Bishopstone
East Sussex	Black Patch
East Sussex	Camber Castle
East Sussex	Downsview
East Sussex	Lewes Priory, Sussex
East Sussex	Newhaven
East Sussex	North Street, Lewes, Sussex
East Sussex	Offham Hill
East Sussex	Pevensey Castle, Sussex
East Sussex	Ranscombe Hill
Essex	Chelmsford, mansio site AR
Essex	Chelmsford, site AA
Essex	Chelmsford, site S
Essex	Chelmsford, site T
Essex	Chelmsford, temple site
Essex	Chignall

Table A.2: *(continued)*

County	Site Name
Essex	Colchester, Balkerne Heights
Essex	Colchester, Balkerne Lane
Essex	Colchester, Culver Street
Essex	Colchester, Gilberd School
Essex	Colchester, Sheepen
Essex	Elms Farm
Essex	Great Dunmow
Essex	Great Holts Farm
Essex	Kelvedon
Essex	Little Oakley
Essex	North Shoebury
Essex	Rivenhall, Chelmsford, Essex
Essex	Wicken Bonhunt
Essex	Witham
Gloucestershire	1 Westgate Street, Gloucester
Gloucestershire	Abbeymead
Gloucestershire	Barnsley Park
Gloucestershire	Birdlip
Gloucestershire	Charlton Kings
Gloucestershire	Cirencester
Gloucestershire	Claydon Pike, Longdole's Field
Gloucestershire	Claydon Pike, Warrens Field
Gloucestershire	Ditches
Gloucestershire	Frocester
Gloucestershire	Gloucester, Coppice Corner
Gloucestershire	Haymes
Gloucestershire	Hazleton North
Gloucestershire	Kingscote

Table A.2: *(continued)*

County	Site Name
Gloucestershire	Lechlade cursus
Gloucestershire	Middle Duntisbourne
Gloucestershire	Neigh Bridge
Gloucestershire	Norbury Camp
Gloucestershire	North Street, Winchcombe
Gloucestershire	Northwick
Gloucestershire	Nympsfield
Gloucestershire	Portway
Gloucestershire	Roughground Farm
Gloucestershire	Sandy Lane
Gloucestershire	Sherborne House
Gloucestershire	Spratsgate Lane
Gloucestershire	Tewkesbury
Gloucestershire	Uley Bury
Gloucestershire	Uley Shrines
Gloucestershire	Upton, Gloucestershire
Gloucestershire	Whelford Bowmoor
Hampshire	Abbots Worthy
Hampshire	Abbotstone Down
Hampshire	Alma Road, Romsey
Hampshire	Alton
Hampshire	Balksbury Camp, 73/81
Hampshire	Bevis Grange
Hampshire	Bramdean
Hampshire	Brighton Hill South
Hampshire	Buckskin
Hampshire	Bury Hill
Hampshire	Chester Road 53, Eastern Suburbs

Table A.2: *(continued)*

County	Site Name
Hampshire	Chilbolton Down
Hampshire	Cook Street, Southampton (SOU254)
Hampshire	Danebury, 1969-78
Hampshire	Danebury, 1979-88
Hampshire	Easton Lane Interchange
Hampshire	Easton Lane, Winchester
Hampshire	Faccombe Netherton
Hampshire	Fullerton
Hampshire	Grateley South
Hampshire	Hayling Island
Hampshire	Houghton Down
Hampshire	Little Somborne
Hampshire	Lower High Street, Southampton
Hampshire	Martin
Hampshire	Melbourne Street, Southampton
Hampshire	Micheldever Wood
Hampshire	Monk Sherborne
Hampshire	Neatham
Hampshire	Nettlebank Copse
Hampshire	Northbrook, Hampshire
Hampshire	Nutbane
Hampshire	Old Down Farm
Hampshire	Owslebury
Hampshire	Portchester Castle
Hampshire	Quilter's Vault (SOU112)
Hampshire	Riverdene, Basingstoke
Hampshire	Rooksdown
Hampshire	Rucstalls

Table A.2: *(continued)*

County	Site Name
Hampshire	Shavards Farm, Meonstoke
Hampshire	Silchester, defences
Hampshire	Silchester, forum basilica
Hampshire	Silchester, insula IX
Hampshire	Six Dials, Southampton
Hampshire	Southampton
Hampshire	Southampton 1953-1969
Hampshire	St John's Street, Winchester
Hampshire	St Mary's Stadium, Southampton
Hampshire	Suddern Farm
Hampshire	Telecom House, Southampton
Hampshire	Thruxton
Hampshire	Twyford Down
Hampshire	Victoria Road 700, Hampshire
Hampshire	Victoria Road 975, Hampshire
Hampshire	Winchester Northern/Eastern Suburbs
Hampshire	Winchester Staple Gardens
Hampshire	Winchester Western Suburbs
Hampshire	Winklebury Camp
Hampshire	Winnall Down
Hampshire	Woolbury
Herefordshire	Berrington Street, Hereford City
Herefordshire	Sutton Walls
Hertfordshire	Baldock
Hertfordshire	Blackhorse Rd
Hertfordshire	Braughing
Hertfordshire	Chapter House, St Albans Abbey
Hertfordshire	Gorhambury

Table A.2: *(continued)*

County	Site Name
Hertfordshire	Skeleton Green
Hertfordshire	St Albans, Folly Lane
Isle of Wight	Arreton Down
Isle of Wight	Carisbrooke Castle 1921-1996
Isle of Wight	Carisbrooke Castle 2006 and 2008-9
Kent	Canterbury Castle
Kent	Dolland's Moor
Kent	Farningham Hill
Kent	Mount Roman villa
Kent	Peene
Kent	Pepperhill Lane, Kent
Kent	Sandtun
Kent	St Gregory's Priory
Kent	St Mary of Ospringe
Kent	Wainscott
Kent	Wingham
Leicestershire	Austin Friars
Leicestershire	Bonners Lane
Leicestershire	Little Lane, Leicester
Lincolnshire	Belton
Lincolnshire	Billingborough
Lincolnshire	Cowbit
Lincolnshire	Dragonby
Lincolnshire	Flixborough
Lincolnshire	Goltho
Lincolnshire	Lincoln
Lincolnshire	Lincoln City
Lincolnshire	Market Deeping

Table A.2: *(continued)*

County	Site Name
Lincolnshire	Mornington House, Gosberton
Lincolnshire	Nettleton Top, Nettleton
Lincolnshire	Pasture Lodge Farm
Lincolnshire	Quarrington
Lincolnshire	Riby Cross Roads
London	21-22 Maiden Lane, London (West)
London	21-24 Maiden Lane, London (Hamilton-Dyer)
London	28-31 James Street, London
London	Church Court/Hare Court, London
London	Hammersmith
London	Jubilee Hall, London (1985)
London	Keston
London	London, Walbrook Mithraeum
London	Lyceum Theatre, London
London	National Portrait Gallery, London
London	Peabody site, London
London	Shadwell
London	Southwark, Winchester Palace
London	Westminster Abbey, London
Norfolk	Alms Lane, Norwich
Norfolk	Brancaster 1977
Norfolk	Brandon Road 1964-6
Norfolk	Brandon Road 2002
Norfolk	Burgh Castle
Norfolk	Bury Road, Thetford
Norfolk	Caister-on-Sea
Norfolk	Castle Mall
Norfolk	Castle Mall Barbican Well

Table A.2: *(continued)*

County	Site Name
Norfolk	Castle Rising Castle
Norfolk	Coslany Street, Norfolk
Norfolk	Crow Hall Park, Downham Market
Norfolk	Fishergate, Norwich
Norfolk	Greyfriars, Norwich
Norfolk	Hay Green, Terrington St Clement
Norfolk	Heigham Street, Norwich
Norfolk	Kilverstone
Norfolk	King's Lynn, Norfolk
Norfolk	King's Lynn, Norfolk (2003-5)
Norfolk	Mill Lane, Thetford
Norfolk	North Elmham
Norfolk	Norwich Cathedral Refectory
Norfolk	Redcastle Furze, Thetford
Norfolk	Rose Hall Farm, Walpole St Andrew
Norfolk	Sedgeford (CNE07)
Norfolk	Sites 1-5, Knocker's Excavations, Thetford
Norfolk	Spong Hill
Norfolk	St Barnabas's Hospital (Site 1092), Thetford
Norfolk	St Martins-at-Palace Plain, Norfolk
Norfolk	St Nicholas Street, Thetford
Northamptonshire	Black Lion Hill, Northampton
Northamptonshire	Blackthorn
Northamptonshire	Brigstock
Northamptonshire	Burystead
Northamptonshire	Clay Lane
Northamptonshire	Higham Ferrers
Northamptonshire	Kings Meadow Lane, Higham Ferrers

Table A.2: *(continued)*

County	Site Name
Northamptonshire	Lyveden, Northamptonshire
Northamptonshire	Marefair, Northampton
Northamptonshire	Moulton Park
Northamptonshire	Saxon Palaces, Northamptonshire
Northamptonshire	St James' Square, Northampton
Northamptonshire	St Peter's Street, Northampton
Northamptonshire	Weekley
Northamptonshire	West Cotton
Oxfordshire	113-119 High Street, Oxford
Oxfordshire	7-8 Queen Street, Oxford
Oxfordshire	79-80 St Aldates, Oxford
Oxfordshire	Abingdon causewayed enclosure
Oxfordshire	Abingdon oval barrow
Oxfordshire	Alchester
Oxfordshire	All Saints Church, Oxford
Oxfordshire	Appleford
Oxfordshire	Ascott-under-Wychwood
Oxfordshire	Ashville Trading Estate
Oxfordshire	Asthall
Oxfordshire	Audlett Drive, Abingdon
Oxfordshire	Banbury Castle
Oxfordshire	Barton Court Farm
Oxfordshire	Beech House Hotel
Oxfordshire	Bicester Fields Farm
Oxfordshire	Chapel Street, Bicester
Oxfordshire	Church Street, St Ebbe's, Oxford
Oxfordshire	Codrington Library, Oxford
Oxfordshire	Cresswell Field, Yarnton

Table A.2: *(continued)*

County	Site Name
Oxfordshire	Dean Court (A), Oxfordshire
Oxfordshire	Dean Court (B), Oxfordshire
Oxfordshire	Dean Court (C), Oxfordshire
Oxfordshire	Dean Court (D), Oxfordshire
Oxfordshire	Devil's Quoits
Oxfordshire	Dominican Priory, Oxfordshire
Oxfordshire	Dorchester-on-Thames
Oxfordshire	Drayton cursus
Oxfordshire	Eynsham Abbey
Oxfordshire	Farmoor
Oxfordshire	Gatehampton
Oxfordshire	Gatehampton Farm
Oxfordshire	Gravelley Guy
Oxfordshire	Greyfriars, St Ebbe's, Oxford
Oxfordshire	Hamel, Oxford
Oxfordshire	Hinxey Hall, Oxford
Oxfordshire	Jowett Walk, Oxford
Oxfordshire	Lincoln College, Oxford
Oxfordshire	Littlegate, St Ebbe's, Oxford
Oxfordshire	Lowbury Hill
Oxfordshire	Manor Farm, Drayton
Oxfordshire	Middleton Stoney
Oxfordshire	Mill Street, Wantage
Oxfordshire	Mingies Ditch
Oxfordshire	Mount House, Witney
Oxfordshire	New Wintles, Oxfordshire
Oxfordshire	Osney Abbey, Oxfordshire
Oxfordshire	Oxford Castle

Table A.2: *(continued)*

County	Site Name
Oxfordshire	Oxford Science Park
Oxfordshire	Radley Barrow Hills
Oxfordshire	Seacourt
Oxfordshire	Shakenoak
Oxfordshire	Shrivenham Road, Ashbury
Oxfordshire	St Helen's Avenue, Benson
Oxfordshire	Tower Hill Ashbury
Oxfordshire	Trill Mill Stream, Oxford
Oxfordshire	Uffington White Horse
Oxfordshire	Watkins Farm
Oxfordshire	Waylands Smithy
Oxfordshire	Westgate, St Ebbe's, Oxford
Oxfordshire	Wilcote
Oxfordshire	Worton, Yarnton
Oxfordshire	Yarnton
Rutland	Empingham
Rutland	Empingham North
Rutland	Empingham North, Well
Rutland	Empingham West
Rutland	Renner's Park, well
Shropshire	Shrewsbury Abbey
Shropshire	Wroxeter, baths and macellum
Shropshire	Wroxeter, fortress
Shropshire	Wroxeter, Shropshire
Somerset	Bath
Somerset	Benham's Garage
Somerset	Brean Down
Somerset	Cadbury Congresbury

Table A.2: *(continued)*

County	Site Name
Somerset	Cannards Grave
Somerset	Cheddar Palaces
Somerset	Gorsey Bigbury
Somerset	Henley Wood
Somerset	Ilchester
Somerset	Ilchester, Great Yard
Somerset	Shepton Mallet
Somerset	Wells Museum, Somerset
Somerset	Wirral Park, Somerset
Somerset	Yarford
Staffordshire	Rocester
Suffolk	Brandon
Suffolk	Burgh
Suffolk	Hacheston
Suffolk	Ipswich (Crabtree)
Suffolk	Ipswich (Jones & Serjeantson)
Suffolk	Melford Meadows, Brettenham
Suffolk	West Stow
Surrey	Badshot Lea
Surrey	Guildford Castle
Surrey	Hawk's Hill
Surrey	Little Pickle
Surrey	Runfold
Surrey	Runnymede
Surrey	Seven Barrows Gallop
Surrey	Shepperton Staines Rd Farm
Surrey	Staines causewayed enclosure
Surrey	Thorpe Lea

Table A.2: *(continued)*

County	Site Name
Surrey	Worplesdon
Warwickshire	Alcester
Warwickshire	Alcester, AES 76-7
Warwickshire	Alcester, defences
Warwickshire	Boteler's Castle
Warwickshire	Hatton Rock
West Midlands	Dudley Castle
West Sussex	Batten Hanger
West Sussex	Bignor
West Sussex	Botolphs
West Sussex	Bramber Castle, Sussex
West Sussex	Bury Hill
West Sussex	Carne's Seat
West Sussex	Chanctonbury Ring
West Sussex	Chanctonbury Ring, temenos ditch
West Sussex	Chichester, Cattlemarket
West Sussex	Chichester, Lavant Culvert
West Sussex	Chichester, Rowes Garage
West Sussex	Chilgrove 2
West Sussex	Copse Farm
West Sussex	Court Hill Singleton
West Sussex	Elstead
West Sussex	Fishbourne, ditch (1995-2002)
West Sussex	Fishbourne, east (1995-2002)
West Sussex	Fishbourne, Harbour
West Sussex	Fishbourne, Palace (1960-68)
West Sussex	Fishbourne, Westward House
West Sussex	Lavant

Table A.2: *(continued)*

County	Site Name
West Sussex	Marlipins, Sussex
West Sussex	North Bersted
West Sussex	North Marden
West Sussex	Old Erringham, Shoreham
West Sussex	Ounces Barn
West Sussex	Slonk Hill
West Sussex	Steyning Library, Steyning
West Sussex	Tanyard Lane, Steyning
West Sussex	Watergate
West Sussex	Westhampnett
Wiltshire	Amesbury barrow 39
Wiltshire	Amesbury Barrow 42
Wiltshire	Amesbury Barrow 51
Wiltshire	Amesbury chalk plaque pit
Wiltshire	Battlesbury Bowl
Wiltshire	Beckhampton Road
Wiltshire	Bishops Cannings Down
Wiltshire	Boles Barrow
Wiltshire	Budbury
Wiltshire	Burderop Down
Wiltshire	Bury Wood Camp
Wiltshire	Cadley Road, Wiltshire
Wiltshire	Castle Copse
Wiltshire	Chapperton Down
Wiltshire	Cherhill
Wiltshire	Coneybury anomaly
Wiltshire	Coneybury henge
Wiltshire	Crescent Copse Shrewton

Table A.2: *(continued)*

County	Site Name
Wiltshire	Dean Bottom
Wiltshire	Durrington Down Barrow
Wiltshire	Durrington Walls
Wiltshire	Easton Down
Wiltshire	Fussells Lodge
Wiltshire	Groundwell Farm
Wiltshire	Hemp Knoll
Wiltshire	Horslip
Wiltshire	King Barrow Ridge
Wiltshire	Lanhill
Wiltshire	Longstones enclosure
Wiltshire	Malmesbury
Wiltshire	Marden
Wiltshire	Market Lavington
Wiltshire	Millbarrow
Wiltshire	Milton Lilbourne
Wiltshire	Postern Mill Site, Malmesbury
Wiltshire	Ramsbury
Wiltshire	Robin Hood's Ball
Wiltshire	Rockley Down
Wiltshire	Salisbury Beehive
Wiltshire	South Street
Wiltshire	Stonehenge
Wiltshire	Trowbridge
Wiltshire	Wayside Farm
Wiltshire	West Kennet palisade enclosures
Wiltshire	Whitesheet Hill
Wiltshire	Wilsford Shaft

Table A.2: *(continued)*

County	Site Name
Wiltshire	Windmill Hill
Worcestershire	Aston Mill Farm
Worcestershire	Conderton Camp
Worcestershire	Deansway, Worcester
Worcestershire	Droitwich, Bays Meadow
Worcestershire	Droitwich, Dodderhill
Worcestershire	Droitwich, Hanbury Street
Worcestershire	Friar Street, Droitwich
Worcestershire	Upwich, Droitwich
Worcestershire	Worcester, Sidbury

Table A.3: List of assemblages classed as outliers on raw NISP values for hare, arranged by broad period. Calculated using distributions containing only the assemblages where hares were present.

Broad Period	Tukey Fence	Hare NISP	Site
Neolithic	5.6	10	Windmill Hill
Bronze Age	3.6	4	Burderop Down
Iron Age	12.6	25	Owslebury
Iron Age	12.6	26	Suddern Farm
Iron Age	12.6	13	Sutton Walls
Iron Age	12.6	27	Winklebury Camp
IA/RB	12.2	17	Carne's Seat
Roman	25.4	81	Caister-on-Sea
Roman	25.4	35	Castle Copse
Roman	25.4	31	Cirencester
Roman	25.4	63	Exeter
Roman	25.4	69	Fishbourne, east (1995-2002)

Table A.3: *(continued)*

Broad Period	Tukey Fence	Hare NISP	Site
Roman	25.4	54	Fishbourne, Palace (1960-68)
Roman	25.4	64	Greyhound Yard
Roman	25.4	60	Hacheston
Roman	25.4	62	Owslebury
Roman	25.4	37	Silchester, forum basilica
Roman	25.4	35	Southwark, Winchester Palace
Saxon	16.0	20	Bishopstone
Saxon	16.0	28	Brandon
Saxon	16.0	18	Faccombe Netherton
Saxon	16.0	25	Flixborough
Saxon	16.0	30	Oxford Science Park
Saxon	16.0	55	Portchester Castle
Saxon	16.0	51	Wroxeter, Shropshire
Medieval	33.2	131	Carisbrooke Castle 1921-1996
Medieval	33.2	132	Carisbrooke Castle 2006 and 2008-9
Medieval	33.2	46	Castle Mall Barbican Well
Medieval	33.2	97	Castle Rising Castle
Medieval	33.2	97	Dudley Castle
Medieval	33.2	88	Exeter
Medieval	33.2	87	Eynsham Abbey
Medieval	33.2	134	Faccombe Netherton
Medieval	33.2	78	Launceston Castle
Medieval	33.2	58	Mount House, Witney
Medieval	33.2	57	Okehampton Castle, Devon
Post-Med	26.9	47	Eynsham Abbey

A.2 Morphometrics Methods

Table A.4: Itemised list of bivariate and trivariate metrics combinations used.

Element	Number of Variables	Combination
MAND	1	m1
MAND	1	m2
MAND	1	m3
MAND	1	m4
MAND	1	m5
MAND	1	m5a
MAND	2	m1, m2
MAND	2	m1, m3
MAND	2	m1, m4
MAND	2	m1, m5
MAND	2	m1, m5a
MAND	2	m2, m3
MAND	2	m2, m4
MAND	2	m2, m5
MAND	2	m2, m5a
MAND	2	m3, m4
MAND	2	m3, m5
MAND	2	m3, m5a
MAND	2	m4, m5
MAND	2	m4, m5a
MAND	2	m5, m5a
MAND	3	m1, m2, m3
MAND	3	m1, m2, m4
MAND	3	m1, m2, m5
MAND	3	m1, m2, m5a
MAND	3	m1, m3, m4
MAND	3	m1, m3, m5

Table A.4: *(continued)*

Element	Number of Variables	Combination
MAND	3	m1, m3, m5a
MAND	3	m1, m4, m5
MAND	3	m1, m4, m5a
MAND	3	m1, m5, m5a
MAND	3	m2, m3, m4
MAND	3	m2, m3, m5
MAND	3	m2, m3, m5a
MAND	3	m2, m4, m5
MAND	3	m2, m4, m5a
MAND	3	m2, m5, m5a
MAND	3	m3, m4, m5
MAND	3	m3, m4, m5a
MAND	3	m3, m5, m5a
MAND	3	m4, m5, m5a
SCAP	1	BG
SCAP	1	DHA
SCAP	1	GLP
SCAP	1	HS
SCAP	1	SLC
SCAP	2	BG, DHA
SCAP	2	BG, GLP
SCAP	2	BG, HS
SCAP	2	BG, SLC
SCAP	2	GLP, DHA
SCAP	2	GLP, HS
SCAP	2	GLP, SLC
SCAP	2	HS, DHA
SCAP	2	SLC, DHA

Table A.4: *(continued)*

Element	Number of Variables	Combination
SCAP	2	SLC, HS
SCAP	3	BG, GLP, DHA
SCAP	3	BG, GLP, HS
SCAP	3	BG, GLP, SLC
SCAP	3	BG, HS, DHA
SCAP	3	BG, SLC, DHA
SCAP	3	BG, SLC, HS
SCAP	3	GLP, HS, DHA
SCAP	3	GLP, SLC, DHA
SCAP	3	GLP, SLC, HS
SCAP	3	SLC, HS, DHA
HUM	1	Bd
HUM	1	Bp
HUM	1	Dd
HUM	1	Dp
HUM	1	GL
HUM	1	GLC
HUM	1	HTC
HUM	1	SD
HUM	2	Bd, Bp
HUM	2	Bd, Dd
HUM	2	Bd, Dp
HUM	2	Bd, GL
HUM	2	Bd, GLC
HUM	2	Bd, HTC
HUM	2	Bd, SD
HUM	2	Bp, GL
HUM	2	Bp, GLC

Table A.4: *(continued)*

Element	Number of Variables	Combination
HUM	2	Bp, SD
HUM	2	Dd, Bp
HUM	2	Dd, Dp
HUM	2	Dd, GL
HUM	2	Dd, GLC
HUM	2	Dd, HTC
HUM	2	Dd, SD
HUM	2	Dp, Bp
HUM	2	Dp, GL
HUM	2	Dp, GLC
HUM	2	Dp, SD
HUM	2	GL, GLC
HUM	2	HTC, Bp
HUM	2	HTC, Dp
HUM	2	HTC, GL
HUM	2	HTC, GLC
HUM	2	HTC, SD
HUM	2	SD, GL
HUM	2	SD, GLC
HUM	3	Bp, Dp, Bd
HUM	3	Bp, Dp, Dd
HUM	3	Bp, Dp, GL
HUM	3	Bp, Dp, GLC
HUM	3	Bp, Dp, HTC
HUM	3	Bp, Dp, SD
HUM	3	Dp, GL, Bd
HUM	3	Dp, GL, Dd
HUM	3	Dp, GL, GLC

Table A.4: *(continued)*

Element	Number of Variables	Combination
HUM	3	Dp, GL, HTC
HUM	3	Dp, GL, SD
HUM	3	GL, GLC, Bd
HUM	3	GL, GLC, Dd
HUM	3	GL, GLC, HTC
HUM	3	GL, GLC, SD
HUM	3	GLC, SD, Bd
HUM	3	GLC, SD, Dd
HUM	3	GLC, SD, HTC
HUM	3	HTC, Bd, Dd
HUM	3	SD, HTC, Bd
HUM	3	SD, HTC, Dd
RAD	1	Bd
RAD	1	Bp
RAD	1	Dd
RAD	1	Dp
RAD	1	GL
RAD	1	SD
RAD	2	Bd, Dd
RAD	2	Bd, GL
RAD	2	Bd, SD
RAD	2	Bp, Bd
RAD	2	Bp, Dd
RAD	2	Bp, Dp
RAD	2	Bp, GL
RAD	2	Bp, SD
RAD	2	Dd, GL
RAD	2	Dd, SD

Table A.4: *(continued)*

Element	Number of Variables	Combination
RAD	2	Dp, Bd
RAD	2	Dp, Dd
RAD	2	Dp, GL
RAD	2	Dp, SD
RAD	2	GL, Bd
RAD	2	GL, Dd
RAD	2	GL, SD
RAD	2	SD, GL
RAD	3	Bp, Bd, Dd
RAD	3	Bp, Dp, Bd
RAD	3	Bp, Dp, Dd
RAD	3	Bp, GL, Bd
RAD	3	Bp, GL, Dd
RAD	3	Bp, GL, Dp
RAD	3	Bp, GL, SD
RAD	3	Bp, SD, Bd
RAD	3	Bp, SD, Dd
RAD	3	Bp, SD, Dp
RAD	3	Dd, Bd, SD
RAD	3	Dp, Bd, Dd
RAD	3	Dp, Bd, SD
RAD	3	Dp, GL, Bd
RAD	3	Dp, GL, Dd
RAD	3	Dp, GL, SD
ULN	1	BPC
ULN	1	DPA
ULN	1	GL
ULN	1	SDO

Table A.4: *(continued)*

Element	Number of Variables	Combination
ULN	2	BPC, DPA
ULN	2	BPC, GL
ULN	2	BPC, SDO
ULN	2	DPA, GL
ULN	2	DPA, SDO
ULN	2	SDO, GL
ULN	3	BPC, DPA, GL
ULN	3	BPC, DPA, SDO
ULN	3	BPC, SDO, GL
ULN	3	DPA, SDO, GL
PEL	1	GL
PEL	1	LFo
PEL	1	SB
PEL	1	SH
PEL	2	LFo, GL
PEL	2	SB, GL
PEL	2	SB, LFo
PEL	2	SB, SH
PEL	2	SH, GL
PEL	2	SH, LFo
PEL	3	LFo, SB, GL
PEL	3	LFo, SB, SH
PEL	3	LFo, SH, GL
PEL	3	SB, SH, GL
FEM	1	Bd
FEM	1	Bp
FEM	1	BTr
FEM	1	DC

Table A.4: *(continued)*

Element	Number of Variables	Combination
FEM	1	GL
FEM	1	GLC
FEM	1	SD
FEM	2	Bd, GL
FEM	2	Bd, GLC
FEM	2	Bd, SD
FEM	2	Bp, Bd
FEM	2	Bp, BTr
FEM	2	Bp, DC
FEM	2	Bp, GL
FEM	2	Bp, GLC
FEM	2	Bp, SD
FEM	2	BTr, Bd
FEM	2	BTr, DC
FEM	2	BTr, GL
FEM	2	BTr, GLC
FEM	2	BTr, SD
FEM	2	DC, Bd
FEM	2	DC, GL
FEM	2	DC, GLC
FEM	2	DC, SD
FEM	2	GL, GLC
FEM	2	SD, GL
FEM	2	SD, GLC
FEM	3	Bp, BTr, Bd
FEM	3	Bp, BTr, DC
FEM	3	Bp, BTr, GL
FEM	3	Bp, BTr, GLC

Table A.4: *(continued)*

Element	Number of Variables	Combination
FEM	3	Bp, BTr, SD
FEM	3	Bp, DC, Bd
FEM	3	Bp, DC, GL
FEM	3	Bp, DC, GLC
FEM	3	Bp, DC, SD
FEM	3	Bp, GL, Bd
FEM	3	Bp, GL, GLC
FEM	3	Bp, GL, SD
FEM	3	Bp, GLC, Bd
FEM	3	Bp, GLC, SD
FEM	3	BTr, DC, Bd
FEM	3	BTr, DC, GL
FEM	3	BTr, DC, GLC
FEM	3	BTr, DC, SD
FEM	3	BTr, GL, Bd
FEM	3	BTr, GL, GLC
FEM	3	BTr, GL, SD
FEM	3	BTr, GLC, Bd
FEM	3	BTr, GLC, SD
FEM	3	DC, GL, Bd
FEM	3	DC, GL, GLC
FEM	3	DC, GL, SD
FEM	3	DC, GLC, Bd
FEM	3	DC, GLC, SD
FEM	3	DC, SD, Bd
FEM	3	GL, GLC, Bd
FEM	3	GL, GLC, SD
FEM	3	GL, SD, Bd

Table A.4: *(continued)*

Element	Number of Variables	Combination
FEM	3	GLC, SD, Bd
TIB	1	Bd
TIB	1	Bp
TIB	1	Dd
TIB	1	Dp
TIB	1	DPL
TIB	1	GL
TIB	1	LDp
TIB	1	SD
TIB	2	Bd, Dd
TIB	2	Bd, Dp
TIB	2	Bd, GL
TIB	2	Bd, LDp
TIB	2	Bd, SD
TIB	2	Bp, Bd
TIB	2	Bp, Dd
TIB	2	Bp, Dp
TIB	2	Bp, DPL
TIB	2	Bp, GL
TIB	2	Bp, LDp
TIB	2	Bp, SD
TIB	2	Dd, Dp
TIB	2	Dd, GL
TIB	2	Dd, LDp
TIB	2	Dd, SD
TIB	2	Dp, DPL
TIB	2	Dp, GL
TIB	2	Dp, LDp

Table A.4: *(continued)*

Element	Number of Variables	Combination
TIB	2	Dp, SD
TIB	2	DPL, Bd
TIB	2	DPL, Dd
TIB	2	DPL, GL
TIB	2	DPL, LDp
TIB	2	DPL, SD
TIB	2	LDp, GL
TIB	2	LDp, SD
TIB	2	SD, GL
TIB	3	Bp, Bd, Dd
TIB	3	Bp, Dp, Bd
TIB	3	Bp, Dp, Dd
TIB	3	Bp, Dp, DPL
TIB	3	Bp, Dp, GL
TIB	3	Bp, Dp, LDp
TIB	3	Bp, Dp, SD
TIB	3	Bp, DPL, Bd
TIB	3	Bp, DPL, Dd
TIB	3	Bp, DPL, GL
TIB	3	Bp, DPL, LDp
TIB	3	Bp, DPL, SD
TIB	3	Bp, GL, Bd
TIB	3	Bp, GL, Dd
TIB	3	Bp, GL, SD
TIB	3	Bp, LDp, Bd
TIB	3	Bp, LDp, Dd
TIB	3	Bp, LDp, GL
TIB	3	Bp, LDp, SD

Table A.4: *(continued)*

Element	Number of Variables	Combination
TIB	3	Bp, SD, Bd
TIB	3	Bp, SD, Dd
TIB	3	Dp, Bd, Dd
TIB	3	Dp, DPL, Bd
TIB	3	Dp, DPL, Dd
TIB	3	Dp, DPL, GL
TIB	3	Dp, DPL, LDp
TIB	3	Dp, DPL, SD
TIB	3	Dp, GL, Bd
TIB	3	Dp, GL, Dd
TIB	3	Dp, GL, SD
TIB	3	Dp, LDp, Bd
TIB	3	Dp, LDp, Dd
TIB	3	Dp, LDp, GL
TIB	3	Dp, LDp, SD
TIB	3	Dp, SD, Bd
TIB	3	Dp, SD, Dd
TIB	3	DPL, Bd, Dd
TIB	3	DPL, GL, Bd
TIB	3	DPL, GL, Dd
TIB	3	DPL, GL, SD
TIB	3	DPL, LDp, Bd
TIB	3	DPL, LDp, Dd
TIB	3	DPL, LDp, GL
TIB	3	DPL, LDp, SD
TIB	3	DPL, SD, Bd
TIB	3	DPL, SD, Dd
TIB	3	GL, Bd, Dd

Table A.4: *(continued)*

Element	Number of Variables	Combination
TIB	3	GL, SD, Bd
TIB	3	GL, SD, Dd
TIB	3	LDp, Bd, Dd
TIB	3	LDp, GL, Bd
TIB	3	LDp, GL, Dd
TIB	3	LDp, GL, SD
TIB	3	LDp, SD, Bd
TIB	3	LDp, SD, Dd
TIB	3	SD, Bd, Dd
MP	1	Bd
MP	1	GL
MP	2	Bd, GL
CALC	1	GB
CALC	1	GBT
CALC	1	GDT
CALC	1	GL
CALC	1	GLT
CALC	1	SBT
CALC	1	SDT
CALC	2	GB, GBT
CALC	2	GB, GDT
CALC	2	GB, GL
CALC	2	GB, GLT
CALC	2	GB, SBT
CALC	2	GB, SDT
CALC	2	GBT, GDT
CALC	2	GBT, GL
CALC	2	GBT, GLT

Table A.4: *(continued)*

Element	Number of Variables	Combination
CALC	2	GDT, GL
CALC	2	GDT, GLT
CALC	2	GL, GLT
CALC	2	SBT, GBT
CALC	2	SBT, GDT
CALC	2	SBT, GL
CALC	2	SBT, GLT
CALC	2	SBT, SDT
CALC	2	SDT, GBT
CALC	2	SDT, GDT
CALC	2	SDT, GL
CALC	2	SDT, GLT
CALC	3	GB, GBT, GDT
CALC	3	GB, GBT, SBT
CALC	3	GB, GBT, SDT
CALC	3	GB, GDT, SBT
CALC	3	GB, GDT, SDT
CALC	3	GB, GL, GBT
CALC	3	GB, GL, GDT
CALC	3	GB, GL, GLT
CALC	3	GB, GL, SBT
CALC	3	GB, GL, SDT
CALC	3	GB, GLT, GBT
CALC	3	GB, GLT, GDT
CALC	3	GB, GLT, SBT
CALC	3	GB, GLT, SDT
CALC	3	GB, SBT, SDT
CALC	3	GBT, GDT, SBT

Table A.4: *(continued)*

Element	Number of Variables	Combination
CALC	3	GBT, GDT, SDT
CALC	3	GBT, SBT, SDT
CALC	3	GDT, SBT, SDT
CALC	3	GL, GBT, GDT
CALC	3	GL, GBT, SBT
CALC	3	GL, GBT, SDT
CALC	3	GL, GDT, SBT
CALC	3	GL, GDT, SDT
CALC	3	GL, GLT, GBT
CALC	3	GL, GLT, GDT
CALC	3	GL, GLT, SBT
CALC	3	GL, GLT, SDT
CALC	3	GL, SBT, SDT
CALC	3	GLT, GBT, GDT
CALC	3	GLT, GBT, SBT
CALC	3	GLT, GBT, SDT
CALC	3	GLT, GDT, SBT
CALC	3	GLT, GDT, SDT
CALC	3	GLT, SBT, SDT
AST	1	GL

A.3 Cross-Validation Results

A.3.1 Mandible

Table A.5: List of approaches ranked by score for balanced cross-validation results for the mandible (Subset A).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	40	Prefer	Shape	m1, m4, m5a	tri	PC1	83.3	86.9	90.5
2	36	Prefer	Shape	m1, m5, m5a	tri	PC1	81.8	84.0	86.4
2	36	Prefer	Shape	m1, m5a	bi	PC1	81.8	84.1	88.6
3	34	Prefer	Shape	m3, m4, m5a	tri	PC1	80.4	83.3	87.0
4	33	Prefer	Shape	m1, m2, m5a	tri	PC1	79.5	83.5	86.4
5	29	Prefer	Form	m1, m2, m5a	tri	PC2	77.3	82.0	86.4
5	29	Prefer	Shape	m1, m3, m5a	tri	PC1	77.3	81.5	86.4
5	29	Prefer	Shape	m2, m3, m5a	tri	PC1	77.1	81.5	87.5
5	29	Prefer	Form	m1, m5a	bi	PC2	77.3	81.7	86.4
6	28	Prefer	Shape	m3, m5a	bi	PC1	77.1	81.1	87.5
7	27	Prefer	Form	m2, m4, m5a	tri	PC2	76.1	80.5	87.0
7	27	Prefer	Shape	m2, m4, m5a	tri	PC1	76.1	80.7	84.8
7	27	Prefer	Shape	m3, m5, m5a	tri	PC1	77.1	79.5	83.3
8	26	Prefer	Form	m2, m5a	bi	PC2	77.1	78.9	81.2
8	26	Prefer	Form	m4, m5a	bi	PC2	76.1	80.0	84.8
9	24	Prefer	Form	m2, m3, m5a	tri	PC2	75.0	79.2	83.3
9	24	Prefer	Shape	m1, m3, m5	tri	PC1	75.0	78.7	84.1
9	24	Prefer	Shape	m1, m5	bi	PC1	75.0	79.4	84.1
10	23	Prefer	Form	m1, m5	bi	PC2	75.0	78.2	84.1
10	23	Prefer	Form	m3, m5a	bi	PC2	75.0	78.2	83.3
11	22	Accept	Shape	m5, m5a	bi	PC1	72.9	79.6	85.4
12	21	Accept	Shape	m3, m5	bi	PC1	74.0	76.6	80.0
13	20	Accept	Form	m1, m5, m5a	tri	PC2	72.7	76.9	81.8
13	20	Accept	Form	m3, m4, m5	tri	PC2	72.9	76.8	81.2
14	19	Accept	Form	m1, m3, m5a	tri	PC2	72.7	75.9	79.5
14	19	Accept	Form	m1, m4, m5	tri	PC2	71.4	77.8	83.3
14	19	Accept	Form	m3, m5, m5a	tri	PC2	72.9	75.8	81.2

Table A.5: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
14	19	Accept	Shape	m3, m4, m5	tri	PC1	72.9	76.1	79.2
15	18	Accept	Form	m1, m4, m5a	tri	PC2	71.4	77.0	83.3
15	18	Accept	Shape	m4, m5a	bi	PC1	71.7	76.0	80.4
15	18	Accept	Form	m3, m5	bi	PC2	72.0	76.1	80.0
16	17	Accept	Form	m3, m4, m5a	tri	PC2	71.7	75.6	80.4
16	17	Accept	Shape	m1, m4, m5	tri	PC1	71.4	75.8	78.6
17	15	Reject	Form	m4, m5, m5a	tri	PC2	69.6	75.0	80.4
17	15	Reject	Shape	m1, m2, m5	tri	PC1	70.5	74.9	79.5
17	15	Reject	Form	m2, m5	bi	PC2	70.0	74.9	80.0
17	15	Reject	Form	m4, m5	bi	PC2	70.8	74.3	79.2
18	14	Reject	Form	m2, m3, m5	tri	PC2	70.0	73.5	78.0
18	14	Accept	Form	m5a	uni	–	68.8	75.1	83.3
19	13	Reject	Shape	m4, m5, m5a	tri	PC1	69.6	73.7	78.3
20	12	Reject	Form	m1, m2, m5	tri	PC2	68.2	74.3	79.5
20	12	Reject	Form	m1, m3, m5	tri	PC2	68.2	73.5	79.5
20	12	Reject	Shape	m2, m3, m5	tri	PC1	68.0	74.4	78.0
20	12	Reject	Form	m5, m5a	bi	PC2	68.8	72.8	77.1
21	11	Reject	Shape	m2, m5, m5a	tri	PC1	68.8	72.6	77.1
21	11	Reject	Shape	m2, m5a	bi	PC1	68.8	72.6	77.1
22	9	Reject	Form	m2, m5, m5a	tri	PC2	66.7	72.7	77.1
23	7	Reject	Form	m2, m4, m5	tri	PC2	66.7	70.5	72.9
23	7	Reject	Form	m2, m4, m5	tri	PC3	64.6	72.2	77.1
23	7	Reject	Shape	m2, m4, m5	tri	PC1	66.7	70.8	75.0
23	7	Reject	Shape	m2, m5	bi	PC1	66.0	70.7	76.0
24	6	Reject	Form	m5, m5a	bi	PC1	64.6	71.2	79.2
25	5	Reject	Form	m2, m5, m5a	tri	PC3	64.6	70.6	75.0
25	5	Reject	Shape	m2, m5, m5a	tri	PC2	64.6	70.9	77.1
26	3	Reject	Shape	m4, m5	bi	PC1	64.6	68.6	72.9

Table A.5: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
26	3	Reject	Size	m5, m5a	bi	–	62.5	70.7	79.2
27	1	Reject	Shape	m2, m4, m5	tri	PC2	62.5	68.1	72.9
27	1	Reject	Size	m1, m3	bi	–	63.0	68.2	73.9
28	0	Reject	Form	m1, m3, m4	tri	PC1	63.6	66.3	70.5
28	0	Reject	Size	m1, m3, m4	tri	–	63.6	66.1	68.2
29	-1	Reject	Form	m1, m3	bi	PC1	60.9	68.4	73.9
29	-1	Reject	Form	m5	uni	–	62.0	67.3	72.0
30	-3	Reject	Form	m1, m2, m3	tri	PC1	61.4	65.2	70.5
30	-3	Reject	Form	m1, m4	bi	PC1	61.4	65.8	70.6
30	-3	Reject	Shape	m4, m5, m5a	tri	PC2	60.8	65.8	71.7
31	-4	Reject	Size	m1, m2, m3	tri	–	61.4	65.1	68.2
31	-4	Reject	Size	m1, m4	bi	–	61.4	64.7	68.2
32	-5	Reject	Form	m3, m4, m5a	tri	PC1	60.9	64.0	67.4
32	-5	Reject	Form	m3, m4	bi	PC1	60.7	64.6	67.9
32	-5	Reject	Form	m3, m5, m5a	tri	PC1	60.4	64.8	70.8
32	-5	Reject	Form	m3, m5a	bi	PC1	58.3	66.5	70.8
32	-5	Reject	Shape	m3, m5, m5a	tri	PC2	60.4	64.7	68.8
32	-5	Reject	Size	m3, m4	bi	–	60.7	64.0	67.9
33	-6	Reject	Form	m1, m2, m5	tri	PC3	59.1	65.1	70.5
33	-6	Reject	Form	m1, m2, m5a	tri	PC3	59.1	64.8	68.2
33	-6	Reject	Form	m1, m4, m5	tri	PC1	59.5	64.3	69.0
33	-6	Reject	Form	m1, m4, m5a	tri	PC1	59.5	64.7	69.0
33	-6	Reject	Shape	m1, m2, m5	tri	PC2	59.1	64.7	72.7
34	-7	Reject	Form	m4, m5, m5a	tri	PC3	58.7	64.1	69.6
34	-7	Reject	Form	m4	uni	–	58.6	64.4	70.7
35	-8	Reject	Form	m2, m5, m5a	tri	PC1	58.3	63.9	68.8
35	-8	Reject	Form	m3, m5, m5a	tri	PC3	58.3	63.5	68.8
36	-9	Reject	Form	m1, m2	bi	PC1	59.1	61.8	65.9

Table A.5: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
36	-9	Reject	Size	m1, m2	bi	–	59.1	62.4	65.9
36	-9	Reject	Size	m1, m2, m4	tri	–	57.1	63.8	71.4
36	-9	Reject	Form	m1	uni	–	58.7	62.0	65.2
37	-10	Reject	Form	m1, m2, m4	tri	PC1	57.1	63.3	69.0
37	-10	Reject	Size	m2, m3, m4	tri	–	57.4	62.3	66.7
38	-11	Reject	Form	m1, m3, m5a	tri	PC1	56.8	62.5	68.2
38	-11	Reject	Form	m1, m5, m5a	tri	PC1	56.8	61.7	65.9
38	-11	Reject	Form	m2, m3, m4	tri	PC1	57.4	62.0	68.5
38	-11	Reject	Form	m3, m4, m5	tri	PC1	58.3	60.6	64.6
38	-11	Reject	Shape	m3, m4	bi	PC1	57.1	61.8	66.1
39	-12	Reject	Form	m1, m3, m5	tri	PC1	54.5	63.5	70.5
39	-12	Reject	Form	m2, m3, m5a	tri	PC1	56.2	62.1	66.7
39	-12	Reject	Form	m4, m5, m5a	tri	PC1	56.5	61.5	67.4
39	-12	Reject	Form	m1, m2	bi	PC2	56.8	61.5	65.9
40	-13	Reject	Size	m2, m4	bi	–	55.4	62.0	67.9
40	-13	Reject	Size	m2, m5, m5a	tri	–	56.2	61.2	64.6
40	-13	Reject	Form	m2, m3	bi	PC2	57.1	60.3	64.3
41	-14	Reject	Form	m2, m4	bi	PC1	55.4	60.9	66.1
41	-14	Reject	Shape	m1, m2, m5a	tri	PC2	54.5	61.3	68.2
41	-14	Reject	Size	m3, m5, m5a	tri	–	54.2	62.3	70.8
42	-15	Reject	Form	m2, m3, m5	tri	PC1	56.0	59.2	62.0
42	-15	Reject	Shape	m2, m3	bi	PC1	55.4	59.2	62.5
42	-15	Reject	Shape	m2, m4	bi	PC1	55.4	59.4	64.3
42	-15	Reject	Form	m2, m4	bi	PC2	55.4	59.3	64.3
43	-16	Reject	Form	m1, m5a	bi	PC1	54.5	59.5	63.6
43	-16	Reject	Form	m2, m3	bi	PC1	55.4	59.0	62.5
44	-18	Reject	Form	m1, m5, m5a	tri	PC3	52.3	59.5	65.9
44	-18	Reject	Shape	m1, m2, m3	tri	PC2	54.5	57.4	61.4

Table A.5: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
44	-18	Reject	Shape	m1, m2, m4	tri	PC1	54.8	57.7	61.9
44	-18	Reject	Shape	m1, m5, m5a	tri	PC2	52.3	59.9	65.9
44	-18	Reject	Shape	m2, m3, m4	tri	PC1	53.7	57.9	61.1
44	-18	Reject	Size	m2, m3	bi	–	53.6	58.8	62.5
45	-19	Reject	Form	m2, m3, m4	tri	PC2	53.7	57.6	61.1
45	-19	Reject	Shape	m2, m3, m5a	tri	PC2	54.2	57.3	60.4
45	-19	Reject	Size	m1, m5, m5a	tri	–	52.2	59.0	63.6
45	-19	Reject	Form	m3	uni	–	53.5	57.6	62.1
46	-20	Reject	Form	m1, m2, m5	tri	PC1	52.3	57.6	61.4
46	-20	Reject	Shape	m1, m4	bi	PC1	52.3	58.2	63.6
46	-20	Reject	Size	m1, m3, m5	tri	–	52.3	58.2	63.6
47	-21	Reject	Form	m1, m2, m5a	tri	PC1	52.3	56.5	61.4
47	-21	Reject	Shape	m1, m3, m4	tri	PC1	52.3	56.5	61.4
47	-21	Reject	Size	m1, m4, m5	tri	–	52.4	57.0	61.9
47	-21	Reject	Size	m2, m5a	bi	–	52.1	57.0	60.4
48	-22	Reject	Shape	m2, m3, m5	tri	PC2	52.0	55.7	60.0
48	-22	Reject	Shape	m3, m4, m5	tri	PC2	52.1	55.5	60.4
49	-23	Reject	Form	m2, m3, m5a	tri	PC3	52.1	55.1	58.3
50	-25	Reject	Form	m1, m4, m5a	tri	PC3	50.0	55.1	61.9
50	-25	Reject	Form	m2, m4, m5	tri	PC1	50.0	54.6	60.4
50	-25	Reject	Form	m2, m4, m5a	tri	PC1	50.0	55.2	60.9
50	-25	Reject	Shape	m1, m4, m5a	tri	PC2	50.0	55.4	61.9
50	-25	Reject	Size	m1, m2, m5	tri	–	50.0	54.5	59.1
50	-25	Reject	Size	m4, m5, m5a	tri	–	50.0	55.0	58.7
51	-26	Reject	Form	m1, m4, m5	tri	PC3	47.6	56.5	64.3
51	-26	Reject	Size	m1, m4, m5a	tri	–	50.0	53.9	59.5
52	-27	Reject	Shape	m1, m4, m5	tri	PC2	47.6	55.7	61.9
52	-27	Reject	Size	m3, m4, m5	tri	–	50.0	52.7	58.3

Table A.5: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
53	-28	Reject	Form	m2, m3, m5	tri	PC3	50.0	52.3	56.0
54	-29	Reject	Form	m1, m2, m4	tri	PC2	45.2	55.3	61.9
54	-29	Reject	Size	m1, m3, m5a	tri	–	47.7	53.8	59.1
55	-30	Reject	Form	m1, m2, m3	tri	PC2	47.7	52.8	56.8
56	-31	Reject	Form	m3, m4, m5	tri	PC3	47.9	51.1	54.2
57	-33	Reject	Shape	m1, m2, m3	tri	PC1	45.5	51.5	56.8
58	-36	Reject	Size	m3, m4, m5a	tri	–	43.5	51.0	58.7
59	-47	Reject	Shape	m1, m2	bi	PC1	34.1	49.2	56.8
60	-49	Reject	Size	m2, m3, m5	tri	–	27.9	53.4	60.0
61	-50	Reject	Shape	m1, m3	bi	PC1	28.3	52.2	58.7
62	-53	Reject	Form	m1, m5	bi	PC1	27.3	49.8	56.8
62	-53	Reject	Form	m2, m3, m4	tri	PC3	27.8	49.2	55.6
63	-55	Reject	Form	m2, m5a	bi	PC1	25.0	49.7	58.3
64	-56	Reject	Size	m4, m5a	bi	–	26.1	47.8	56.5
65	-57	Reject	Form	m4, m5	bi	PC1	18.8	54.5	64.6
66	-58	Reject	Form	m2	uni	–	20.7	51.3	60.3
67	-59	Reject	Shape	m1, m3, m5a	tri	PC2	20.3	50.2	59.1
67	-59	Reject	Size	m2, m5	bi	–	21.9	49.0	58.0
68	-60	Reject	Form	m1, m2, m3	tri	PC3	20.4	49.5	59.1
68	-60	Reject	Shape	m2, m3, m4	tri	PC2	20.3	49.5	57.4
68	-60	Reject	Shape	m3, m4, m5a	tri	PC2	21.7	48.1	54.4
69	-61	Reject	Size	m3, m5a	bi	–	16.7	52.8	62.5
70	-62	Reject	Form	m1, m3, m5a	tri	PC3	20.4	47.5	56.9
71	-65	Reject	Size	m2, m4, m5	tri	–	16.7	48.1	58.3
72	-66	Reject	Form	m3, m4	bi	PC2	14.3	49.3	60.7
73	-67	Reject	Form	m3, m5	bi	PC1	16.0	46.7	56.0
74	-70	Reject	Size	m1, m2, m5a	tri	–	13.6	46.2	56.8
74	-70	Reject	Size	m1, m5	bi	–	13.5	46.8	56.8

Table A.5: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
75	-71	Reject	Size	m2, m3, m5a	tri	–	10.4	48.9	62.5
76	-72	Reject	Size	m1, m5a	bi	–	9.1	48.8	59.1
77	-73	Reject	Shape	m1, m3, m5	tri	PC2	9.1	48.3	61.4
78	-74	Reject	Form	m1, m3, m5	tri	PC3	9.1	46.5	59.1
79	-76	Reject	Form	m3, m4, m5a	tri	PC3	8.7	45.4	56.5
80	-77	Reject	Form	m1, m2, m4	tri	PC3	9.5	43.7	54.8
81	-78	Reject	Shape	m1, m3, m4	tri	PC2	6.8	45.5	61.4
81	-78	Reject	Size	m2, m4, m5a	tri	–	8.7	43.5	56.5
82	-79	Reject	Form	m4, m5a	bi	PC1	6.5	44.7	58.7
83	-80	Reject	Form	m2, m5	bi	PC1	6.0	44.2	58.0
83	-80	Reject	Shape	m1, m2, m4	tri	PC2	7.1	42.8	57.1
83	-80	Reject	Size	m4, m5	bi	–	8.3	41.5	56.2
84	-81	Reject	Shape	m2, m4, m5a	tri	PC2	8.7	40.8	56.5
84	-81	Reject	Size	m3, m5	bi	–	8.0	41.2	56.0
85	-83	Reject	Form	m2, m4, m5a	tri	PC3	6.4	41.0	58.7
85	-83	Reject	Form	m1, m3	bi	PC2	6.5	40.7	54.4
85	-83	Reject	Form	m1, m4	bi	PC2	6.8	40.1	54.5
86	-85	Reject	Form	m1, m3, m4	tri	PC3	4.5	40.8	59.1
87	-88	Reject	Form	m1, m3, m4	tri	PC2	2.3	39.6	56.8

Table A.6: List of approaches ranked by score for balanced cross-validation results for the mandible (Subset B).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	41	Prefer	Form	m5a	uni	–	73.3	80.8	88.9
2	37	Prefer	Form	m1, m3	bi	PC1	71.7	77.7	84.6
2	37	Prefer	Form	m5, m5a	bi	PC1	71.1	78.2	86.7
3	36	Prefer	Size	m5, m5a	bi	–	71.1	77.9	84.4

Table A.6: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
4	34	Prefer	Form	m1, m3, m4	tri	PC1	69.2	77.2	84.6
4	34	Prefer	Size	m1, m3	bi	–	69.2	77.7	84.6
4	34	Prefer	Size	m1, m3, m4	tri	–	69.2	77.5	84.6
5	33	Prefer	Form	m1, m2, m3	tri	PC1	69.2	76.6	84.6
5	33	Prefer	Form	m1, m4	bi	PC1	69.2	76.8	84.6
5	33	Prefer	Size	m1, m2, m3	tri	–	69.2	76.4	84.6
5	33	Prefer	Size	m1, m4	bi	–	69.2	76.6	84.6
6	32	Prefer	Form	m1, m2, m4	tri	PC1	69.2	76.0	82.0
6	32	Prefer	Size	m1, m2, m4	tri	–	69.2	75.8	84.6
7	31	Prefer	Form	m5	uni	–	68.9	75.3	82.2
8	29	Reject	Form	m1, m2	bi	PC1	66.7	74.6	82.0
8	29	Prefer	Form	m3, m4	bi	PC1	66.7	75.2	82.2
8	29	Prefer	Size	m3, m4	bi	–	66.7	75.2	82.2
8	29	Reject	Form	m1	uni	–	66.7	75.0	82.2
9	28	Reject	Size	m1, m2	bi	–	66.7	74.3	82.0
10	27	Reject	Form	m1, m3, m5	tri	PC1	66.7	73.1	79.5
11	25	Reject	Form	m2, m3, m4	tri	PC1	64.4	73.3	82.2
11	25	Reject	Size	m2, m3, m4	tri	–	64.3	73.2	82.2
11	25	Reject	Form	m4	uni	–	64.5	73.3	81.2
12	24	Reject	Form	m1, m4, m5	tri	PC1	64.1	72.6	82.0
12	24	Reject	Size	m2, m5, m5a	tri	–	64.4	72.5	80.0
13	21	Reject	Form	m3	uni	–	62.2	71.8	80.0
14	20	Reject	Shape	m1, m5a	bi	PC1	64.1	68.7	74.4
14	20	Reject	Size	m1, m3, m5	tri	–	61.5	71.4	79.5
15	17	Reject	Form	m2, m3	bi	PC1	57.8	71.7	80.0
15	17	Reject	Size	m1, m4, m5	tri	–	59.0	71.1	79.5
16	16	Reject	Form	m3, m4, m5a	tri	PC1	57.8	70.5	77.8
16	16	Reject	Form	m1, m5a	bi	PC2	59.0	70.1	79.5

Table A.6: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
17	15	Reject	Size	m2, m3	bi	–	55.6	71.7	80.0
18	14	Reject	Form	m1, m3, m5a	tri	PC1	56.4	69.8	76.9
18	14	Reject	Form	m3, m4, m5	tri	PC1	55.6	70.7	80.0
19	13	Reject	Form	m2, m5, m5a	tri	PC1	55.6	69.7	77.8
19	13	Reject	Size	m2, m4	bi	–	53.3	71.9	82.2
19	13	Reject	Form	m1, m5	bi	PC2	59.0	66.6	71.8
20	12	Reject	Form	m1, m5, m5a	tri	PC2	59.0	65.5	74.4
20	12	Reject	Form	m2, m4	bi	PC1	53.2	71.7	80.0
20	12	Reject	Size	m3, m5, m5a	tri	–	53.3	71.8	82.2
21	11	Reject	Form	m1, m4, m5a	tri	PC1	53.9	70.2	79.5
21	11	Reject	Size	m4, m5, m5a	tri	–	55.6	68.4	77.8
22	10	Reject	Size	m2, m5a	bi	–	53.3	69.4	77.8
23	9	Reject	Shape	m1, m5, m5a	tri	PC1	56.4	65.1	74.4
24	8	Reject	Form	m1, m2, m5	tri	PC1	51.3	69.7	79.5
24	8	Reject	Form	m3, m5, m5a	tri	PC2	57.7	63.2	71.1
25	5	Reject	Form	m2, m3, m5a	tri	PC2	55.6	61.8	68.9
25	5	Reject	Shape	m1, m5	bi	PC1	53.9	64.0	71.8
25	5	Reject	Shape	m2, m4, m5	tri	PC1	55.6	62.2	68.9
25	5	Reject	Shape	m3, m5	bi	PC1	55.6	62.3	68.9
25	5	Reject	Size	m1, m5, m5a	tri	–	48.7	69.4	79.5
25	5	Reject	Form	m3, m5a	bi	PC2	55.6	62.2	68.9
26	3	Reject	Form	m2, m3, m5	tri	PC1	46.7	69.0	80.0
26	3	Reject	Shape	m2, m5	bi	PC1	53.3	62.3	71.1
27	2	Reject	Shape	m1, m2, m5	tri	PC1	53.7	61.4	69.4
27	2	Reject	Shape	m1, m3, m5a	tri	PC2	53.9	60.9	69.2
27	2	Reject	Shape	m2, m3, m5	tri	PC1	53.3	61.5	71.1
27	2	Reject	Size	m1, m2, m5	tri	–	46.1	68.3	76.9
28	1	Reject	Form	m4, m5, m5a	tri	PC1	46.7	66.8	75.6

Table A.6: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
28	1	Reject	Size	m1, m3, m5a	tri	–	46.1	67.1	76.9
28	1	Reject	Form	m2	uni	–	46.3	67.2	77.8
29	0	Reject	Form	m3, m5, m5a	tri	PC1	44.4	68.7	77.8
29	0	Reject	Shape	m2, m3, m5a	tri	PC1	53.3	59.8	66.7
30	-1	Reject	Form	m1, m5, m5a	tri	PC1	43.6	68.5	79.5
30	-1	Reject	Size	m3, m4, m5	tri	–	44.4	67.6	77.8
31	-2	Reject	Form	m1, m2, m5a	tri	PC1	43.6	67.0	76.9
31	-2	Reject	Form	m1, m2, m5a	tri	PC2	48.7	62.2	71.8
31	-2	Reject	Form	m2, m3, m5a	tri	PC1	42.2	68.0	77.8
31	-2	Reject	Shape	m1, m3, m5	tri	PC1	51.3	59.3	69.2
31	-2	Reject	Size	m1, m4, m5a	tri	–	43.5	67.1	76.9
32	-3	Reject	Shape	m1, m3, m5	tri	PC2	51.3	58.9	66.7
32	-3	Reject	Size	m2, m4, m5	tri	–	44.4	65.7	75.6
32	-3	Reject	Form	m3, m5	bi	PC2	51.1	59.0	68.9
33	-4	Reject	Form	m2, m4, m5	tri	PC1	42.2	66.9	77.8
33	-4	Reject	Shape	m2, m4, m5a	tri	PC1	51.1	57.6	66.7
33	-4	Reject	Shape	m2, m5, m5a	tri	PC1	51.1	57.5	64.4
33	-4	Reject	Shape	m3, m5, m5a	tri	PC1	51.1	57.5	64.4
33	-4	Reject	Size	m2, m3, m5	tri	–	42.2	66.7	77.8
33	-4	Reject	Form	m2, m5a	bi	PC2	51.1	57.9	64.4
34	-5	Reject	Form	m2, m4, m5a	tri	PC1	42.2	65.7	75.6
34	-5	Reject	Form	m2, m5, m5a	tri	PC2	48.9	58.8	64.4
34	-5	Reject	Form	m2, m5a	bi	PC1	42.2	65.8	77.8
34	-5	Reject	Form	m3, m5	bi	PC1	42.2	65.1	75.6
34	-5	Reject	Size	m2, m3, m5a	tri	–	42.2	65.2	77.8
34	-5	Reject	Size	m3, m4, m5a	tri	–	42.2	65.8	75.6
35	-6	Reject	Form	m1, m3, m5	tri	PC2	48.7	58.3	66.7
36	-7	Reject	Form	m1, m3, m5a	tri	PC2	46.1	59.5	69.2

Table A.6: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
36	-7	Reject	Form	m3, m4, m5a	tri	PC2	51.1	54.9	60.0
36	-7	Reject	Form	m4, m5	bi	PC1	42.2	63.7	75.6
36	-7	Reject	Shape	m1, m2, m5a	tri	PC1	48.7	57.0	64.1
36	-7	Reject	Shape	m2, m5, m5a	tri	PC2	48.9	56.8	64.4
36	-7	Reject	Shape	m3, m5, m5a	tri	PC2	48.9	56.5	64.4
36	-7	Reject	Size	m2, m5	bi	–	40.0	65.5	75.6
36	-7	Reject	Size	m3, m5a	bi	–	40.0	66.1	80.0
37	-8	Reject	Form	m2, m5	bi	PC1	40.0	64.8	75.6
37	-8	Reject	Shape	m2, m5a	bi	PC1	48.9	55.7	62.2
37	-8	Reject	Shape	m3, m4, m5	tri	PC1	48.9	55.6	62.2
38	-9	Reject	Form	m1, m5	bi	PC1	38.5	65.1	76.9
38	-9	Reject	Size	m1, m5	bi	–	38.5	65.3	76.9
38	-9	Reject	Size	m1, m5a	bi	–	38.5	65.0	76.9
38	-9	Reject	Size	m4, m5	bi	–	40.0	63.2	73.3
38	-9	Reject	Size	m4, m5a	bi	–	40.0	64.1	75.6
39	-10	Reject	Form	m1, m5a	bi	PC1	38.5	63.9	76.9
39	-10	Reject	Form	m4, m5a	bi	PC1	40.0	63.0	73.3
39	-10	Reject	Size	m1, m2, m5a	tri	–	38.5	64.5	76.9
39	-10	Reject	Form	m5, m5a	bi	PC2	48.9	54.0	60.0
40	-11	Reject	Form	m2, m3, m5	tri	PC2	46.7	55.0	64.4
40	-11	Reject	Shape	m1, m2, m3	tri	PC2	46.1	55.5	64.1
40	-11	Reject	Size	m2, m4, m5a	tri	–	37.8	63.5	75.6
40	-11	Reject	Size	m3, m5	bi	–	37.8	63.6	75.6
40	-11	Reject	Form	m2, m5	bi	PC2	46.7	54.6	62.2
41	-12	Reject	Form	m2, m4, m5	tri	PC3	46.7	54.3	62.2
41	-12	Reject	Form	m3, m5a	bi	PC1	37.8	62.9	77.8
42	-13	Reject	Form	m1, m4, m5a	tri	PC2	46.1	53.1	59.0
43	-15	Reject	Shape	m3, m5a	bi	PC1	42.2	55.4	64.4

Table A.6: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
44	-17	Reject	Form	m4, m5a	bi	PC2	44.4	51.6	57.8
45	-18	Reject	Shape	m5, m5a	bi	PC1	44.4	50.4	57.8
46	-19	Reject	Form	m2, m4, m5a	tri	PC2	42.2	51.3	57.8
46	-19	Reject	Form	m3, m4, m5	tri	PC2	42.2	51.2	57.8
46	-19	Reject	Shape	m1, m3	bi	PC1	35.9	58.3	69.2
47	-20	Reject	Form	m4, m5	bi	PC2	42.2	50.7	57.8
48	-21	Reject	Form	m4, m5, m5a	tri	PC2	42.2	50.0	60.0
48	-21	Reject	Shape	m1, m4, m5a	tri	PC1	41.0	50.6	59.0
49	-23	Reject	Shape	m1, m3, m4	tri	PC2	33.3	56.8	66.7
49	-23	Reject	Shape	m1, m3, m5a	tri	PC1	33.3	56.0	71.8
50	-24	Reject	Shape	m1, m2, m5	tri	PC2	38.5	50.7	61.5
51	-26	Reject	Form	m1, m2, m5	tri	PC2	35.9	51.0	61.5
51	-26	Reject	Form	m1, m4, m5	tri	PC2	35.9	50.6	59.0
52	-28	Reject	Shape	m3, m4, m5a	tri	PC1	31.1	53.4	64.4
53	-29	Reject	Shape	m1, m2, m4	tri	PC1	35.9	47.9	59.0
54	-31	Reject	Shape	m2, m4	bi	PC1	35.6	45.7	55.6
55	-32	Reject	Shape	m4, m5a	bi	PC1	31.1	49.4	57.8
56	-33	Reject	Shape	m1, m2	bi	PC1	33.3	46.5	56.4
57	-34	Reject	Shape	m2, m3, m4	tri	PC1	33.3	45.6	55.6
58	-35	Reject	Shape	m3, m4	bi	PC1	31.0	47.1	55.6
59	-36	Reject	Shape	m1, m2, m3	tri	PC1	30.8	45.9	56.4
59	-36	Reject	Shape	m1, m4, m5	tri	PC1	28.2	48.7	61.5
59	-36	Reject	Shape	m4, m5, m5a	tri	PC2	31.1	45.6	53.3
60	-37	Reject	Form	m1, m2, m5	tri	PC3	33.3	41.9	53.9
60	-37	Reject	Form	m2, m4, m5	tri	PC2	33.3	42.0	48.9
60	-37	Reject	Shape	m4, m5, m5a	tri	PC1	26.7	48.8	62.2
60	-37	Reject	Shape	m4, m5	bi	PC1	28.9	46.6	57.8
61	-39	Reject	Shape	m1, m2, m4	tri	PC2	28.2	45.0	53.9

Table A.6: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
61	-39	Reject	Shape	m1, m5, m5a	tri	PC2	30.8	43.0	51.3
62	-40	Reject	Form	m1, m2, m5a	tri	PC3	30.8	41.5	51.3
62	-40	Reject	Form	m4, m5, m5a	tri	PC3	31.1	41.6	48.9
62	-40	Reject	Shape	m2, m4, m5	tri	PC2	31.1	41.6	51.1
62	-40	Reject	Form	m3, m4	bi	PC2	28.9	43.4	51.1
63	-41	Reject	Shape	m1, m2, m5a	tri	PC2	25.6	46.2	56.4
63	-41	Reject	Shape	m3, m4, m5	tri	PC2	26.7	45.0	53.3
64	-43	Reject	Shape	m2, m4, m5a	tri	PC2	26.7	42.7	53.3
65	-44	Reject	Shape	m2, m3, m4	tri	PC2	28.9	40.2	48.9
66	-45	Reject	Shape	m3, m4, m5a	tri	PC2	24.4	43.1	51.1
67	-47	Reject	Form	m2, m5, m5a	tri	PC3	26.7	39.3	48.9
68	-48	Reject	Form	m3, m5, m5a	tri	PC3	26.7	38.5	48.9
69	-51	Reject	Shape	m2, m3, m5a	tri	PC2	24.3	37.8	48.9
70	-52	Reject	Form	m1, m5, m5a	tri	PC3	25.6	35.0	43.6
70	-52	Reject	Shape	m1, m4, m5	tri	PC2	23.1	37.5	51.3
71	-53	Reject	Shape	m2, m3, m5	tri	PC2	22.2	37.8	46.7
71	-53	Reject	Form	m2, m4	bi	PC2	22.2	37.5	48.9
72	-55	Reject	Form	m1, m3, m4	tri	PC2	20.5	37.3	46.1
72	-55	Reject	Shape	m2, m3	bi	PC1	22.2	35.0	44.4
73	-56	Reject	Form	m1, m3, m5a	tri	PC3	20.5	36.4	51.3
73	-56	Reject	Form	m1, m4, m5	tri	PC3	20.5	36.0	48.7
73	-56	Reject	Form	m2, m4, m5a	tri	PC3	20.0	36.4	48.9
74	-57	Reject	Form	m1, m3, m5	tri	PC3	20.5	35.5	51.3
74	-57	Reject	Form	m2, m3, m4	tri	PC2	20.0	35.4	48.9
74	-57	Reject	Form	m2, m3, m4	tri	PC3	20.0	35.9	46.7
74	-57	Reject	Form	m3, m4, m5a	tri	PC3	20.0	36.1	46.7
74	-57	Reject	Shape	m1, m4	bi	PC1	20.5	35.0	43.6
74	-57	Reject	Form	m2, m3	bi	PC2	20.0	35.5	46.7

Table A.6: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
75	-58	Reject	Form	m2, m3, m5a	tri	PC3	20.0	35.0	44.4
75	-58	Reject	Shape	m1, m4, m5a	tri	PC2	20.5	34.6	46.1
76	-60	Reject	Form	m3, m4, m5	tri	PC3	20.0	32.2	44.4
77	-61	Reject	Form	m1, m2	bi	PC2	17.9	33.3	46.1
77	-61	Reject	Form	m1, m3	bi	PC2	17.9	33.3	48.7
77	-61	Reject	Form	m1, m4	bi	PC2	17.9	33.4	46.1
78	-62	Reject	Form	m1, m2, m4	tri	PC2	17.9	32.8	46.1
78	-62	Reject	Form	m1, m3, m4	tri	PC3	17.9	32.3	46.1
78	-62	Reject	Form	m1, m4, m5a	tri	PC3	17.9	32.5	43.6
78	-62	Reject	Form	m2, m3, m5	tri	PC3	17.8	33.4	44.4
79	-64	Reject	Form	m1, m2, m3	tri	PC2	15.4	33.8	46.1
80	-72	Reject	Shape	m1, m3, m4	tri	PC1	10.3	30.2	46.1
81	-73	Reject	Form	m1, m2, m4	tri	PC3	10.3	29.4	43.6
82	-75	Reject	Form	m1, m2, m3	tri	PC3	10.3	27.4	41.0

A.3.2 Scapula

Table A.7: List of approaches ranked by score for balanced cross-validation results for the scapula (Subset A).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	52	Prefer	Form	GLP, HS	bi	PC1	88.5	94.0	98.1
1	52	Prefer	Size	BG, GLP, HS	tri	–	90.4	91.8	94.2
2	51	Prefer	Size	GLP, HS	bi	–	88.5	92.7	96.2
3	50	Prefer	Form	BG, GLP, HS	tri	PC1	88.5	91.2	94.2
3	50	Prefer	Form	GLP, DHA	bi	PC1	88.9	90.9	92.6
4	49	Prefer	Form	GLP	uni	–	87.9	91.0	93.9
5	48	Prefer	Form	BG, GLP, DHA	tri	PC1	87.0	90.7	94.4
5	48	Prefer	Size	BG, GLP, DHA	tri	–	87.0	90.8	94.4

Table A.7: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
6	46	Prefer	Size	BG, HS	bi	–	86.5	89.3	92.3
7	45	Prefer	Form	BG, GLP	bi	PC1	86.4	88.6	90.9
7	45	Prefer	Form	GLP, HS, DHA	tri	PC1	86.5	88.8	94.2
7	45	Prefer	Size	BG, GLP	bi	–	86.4	88.3	90.9
7	45	Prefer	Size	BG, GLP, SLC	tri	–	86.4	89.0	90.9
8	43	Prefer	Form	BG, DHA	bi	PC1	85.2	87.5	90.7
8	43	Prefer	Form	BG, HS	bi	PC1	84.6	88.3	92.3
8	43	Prefer	Size	BG, DHA	bi	–	85.2	87.5	90.7
8	43	Prefer	Size	GLP, DHA	bi	–	85.2	87.5	90.7
8	43	Prefer	Size	GLP, SLC, HS	tri	–	84.6	88.5	92.3
9	42	Prefer	Form	BG, GLP, SLC	tri	PC1	84.8	87.4	90.9
10	40	Prefer	Form	GLP, SLC, HS	tri	PC1	82.7	87.4	92.3
11	39	Accept	Form	BG, SLC, HS	tri	PC1	82.7	85.8	88.5
11	39	Accept	Size	BG, SLC, HS	tri	–	82.7	86.3	90.4
11	39	Accept	Size	GLP, HS, DHA	tri	–	82.7	86.5	92.3
12	38	Accept	Size	GLP, SLC, DHA	tri	–	81.5	86.1	90.7
13	37	Accept	Form	GLP, SLC, DHA	tri	PC1	81.5	85.0	90.7
14	36	Accept	Size	GLP, SLC	bi	–	80.3	85.9	89.4
15	35	Accept	Form	BG, HS, DHA	tri	PC1	80.8	84.5	88.5
16	34	Accept	Size	BG, HS, DHA	tri	–	80.8	83.5	86.5
17	33	Accept	Form	GLP, SLC	bi	PC1	80.3	83.2	87.9
18	32	Accept	Form	BG, SLC, DHA	tri	PC1	79.6	82.8	87.0
18	32	Accept	Size	BG, SLC, DHA	tri	–	79.6	82.8	87.0
18	32	Accept	Form	BG	uni	–	78.8	83.2	87.9
19	30	Accept	Form	BG, SLC	bi	PC1	78.8	81.5	84.8
20	29	Accept	Size	SLC, DHA	bi	–	78.6	80.1	82.1
21	28	Accept	Form	SLC, HS	bi	PC1	76.9	80.6	84.6
21	28	Accept	Size	BG, SLC	bi	–	77.3	80.5	86.4

Table A.7: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
22	27	Accept	Form	SLC, HS, DHA	tri	PC1	76.9	79.6	82.7
22	27	Accept	Size	SLC, HS, DHA	tri	–	76.9	80.1	82.7
23	25	Accept	Size	HS, DHA	bi	–	75.0	79.7	84.6
23	25	Accept	Form	HS	uni	–	75.9	79.0	81.5
24	24	Accept	Form	HS, DHA	bi	PC1	75.0	78.9	82.7
24	24	Accept	Size	SLC, HS	bi	–	75.0	79.4	84.6
25	23	Accept	Form	SLC, DHA	bi	PC1	75.0	77.9	82.1
26	19	Accept	Form	DHA	uni	–	73.2	76.0	80.4
27	12	Reject	Shape	GLP, HS	bi	PC1	69.2	72.6	76.9
27	12	Reject	Form	SLC	uni	–	69.1	73.0	80.9
28	9	Reject	Shape	BG, GLP, HS	tri	PC1	67.3	71.5	75.0
29	4	Reject	Shape	GLP, HS, DHA	tri	PC1	65.4	68.2	71.2
30	3	Reject	Shape	GLP, SLC, HS	tri	PC2	63.5	69.8	76.9
31	-4	Reject	Shape	BG, SLC, HS	tri	PC2	59.6	66.7	75.0
32	-7	Reject	Shape	BG, HS, DHA	tri	PC1	59.6	63.7	67.3
33	-8	Reject	Form	GLP, SLC, DHA	tri	PC2	59.3	62.3	64.8
34	-9	Reject	Shape	BG, HS	bi	PC1	57.7	63.0	69.2
34	-9	Reject	Shape	GLP, DHA	bi	PC1	59.3	61.9	64.8
35	-12	Reject	Shape	BG, GLP, DHA	tri	PC1	57.4	61.0	64.8
36	-14	Reject	Form	GLP, SLC, HS	tri	PC2	55.8	60.7	63.5
36	-14	Reject	Shape	SLC, HS	bi	PC1	55.8	60.4	65.4
37	-15	Reject	Form	BG, SLC, DHA	tri	PC2	55.6	59.3	63.0
37	-15	Reject	Shape	GLP, SLC, DHA	tri	PC2	55.6	59.1	64.8
37	-15	Reject	Form	SLC, DHA	bi	PC2	55.4	60.1	64.3
38	-16	Reject	Shape	BG, DHA	bi	PC1	55.6	58.2	61.1
39	-17	Reject	Shape	BG, SLC, DHA	tri	PC2	55.6	57.9	61.1
40	-18	Reject	Form	BG, SLC, HS	tri	PC2	53.9	57.8	61.5
40	-18	Reject	Shape	BG, GLP, HS	tri	PC2	53.9	58.0	63.5

Table A.7: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
40	-18	Reject	Shape	BG, GLP	bi	PC1	53.0	59.0	63.6
40	-18	Reject	Shape	BG, SLC	bi	PC1	53.0	58.8	63.6
41	-20	Reject	Shape	SLC, DHA	bi	PC1	53.6	56.2	58.9
42	-21	Reject	Shape	BG, HS, DHA	tri	PC2	51.9	56.9	63.5
42	-21	Reject	Form	SLC, HS	bi	PC2	51.9	56.7	61.5
43	-22	Reject	Shape	BG, SLC, HS	tri	PC1	51.9	56.6	59.6
44	-23	Reject	Shape	SLC, HS, DHA	tri	PC1	51.9	55.0	59.6
44	-23	Reject	Form	BG, SLC	bi	PC2	51.5	55.2	60.6
45	-24	Reject	Form	BG, GLP, SLC	tri	PC2	50.0	56.0	62.1
45	-24	Reject	Form	SLC, HS, DHA	tri	PC2	50.0	55.5	61.5
46	-25	Reject	Form	GLP, SLC	bi	PC2	50.0	54.7	59.1
47	-26	Reject	Shape	GLP, HS, DHA	tri	PC2	50.0	54.2	59.6
48	-27	Reject	Shape	GLP, SLC, HS	tri	PC1	48.1	54.8	59.6
49	-28	Reject	Shape	SLC, HS, DHA	tri	PC2	48.1	53.6	61.5
50	-29	Reject	Shape	BG, GLP, SLC	tri	PC2	48.5	53.0	60.6
51	-31	Reject	Shape	HS, DHA	bi	PC1	46.1	53.0	59.6
52	-35	Reject	Shape	BG, GLP, SLC	tri	PC1	43.9	50.9	56.1
52	-35	Reject	Shape	BG, SLC, DHA	tri	PC1	44.4	51.0	57.4
53	-49	Reject	Shape	GLP, SLC, DHA	tri	PC1	33.3	48.1	51.9
54	-54	Reject	Form	GLP, SLC, HS	tri	PC3	24.9	50.6	57.7
55	-56	Reject	Form	BG, HS, DHA	tri	PC2	30.8	43.5	50.0
56	-61	Reject	Form	GLP, HS, DHA	tri	PC2	19.1	49.6	57.7
57	-62	Reject	Form	BG, GLP, SLC	tri	PC3	22.7	45.6	53.0
58	-68	Reject	Shape	BG, GLP, DHA	tri	PC2	14.8	46.9	57.4
59	-71	Reject	Form	BG, HS, DHA	tri	PC3	17.3	42.1	53.9
60	-73	Reject	Form	BG, GLP	bi	PC2	12.1	44.9	54.5
61	-74	Reject	Form	BG, GLP, HS	tri	PC2	11.5	44.8	57.7
62	-79	Reject	Form	BG, GLP, HS	tri	PC3	9.6	41.8	59.6

Table A.7: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
62	-79	Reject	Form	SLC, HS, DHA	tri	PC3	5.8	44.8	65.4
62	-79	Reject	Form	HS, DHA	bi	PC2	7.7	43.7	61.6
63	-80	Reject	Form	BG, SLC, HS	tri	PC3	9.6	40.6	55.8
63	-80	Reject	Form	GLP, HS, DHA	tri	PC3	5.8	43.7	61.5
63	-80	Reject	Form	GLP, DHA	bi	PC2	7.4	42.9	57.4
64	-81	Reject	Form	GLP, SLC, DHA	tri	PC3	5.6	43.3	55.6
64	-81	Reject	Form	BG, HS	bi	PC2	7.7	41.6	59.6
64	-81	Reject	Form	GLP, HS	bi	PC2	7.6	41.0	55.8
65	-82	Reject	Form	BG, GLP, DHA	tri	PC3	5.6	42.3	55.6
66	-84	Reject	Form	BG, GLP, DHA	tri	PC2	7.4	38.5	53.7
66	-84	Reject	Shape	GLP, SLC	bi	PC1	4.5	41.7	56.1
67	-87	Reject	Form	BG, SLC, DHA	tri	PC3	5.6	37.0	57.4
68	-88	Reject	Form	BG, DHA	bi	PC2	5.6	36.8	51.9

Table A.8: List of approaches ranked by score for balanced cross-validation results for the scapula (Subset B).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	69	Prefer	Form	BG, GLP, DHA	tri	PC1	87.9	93.4	100.0
1	69	Prefer	Form	BG, GLP, HS	tri	PC1	87.9	93.8	100.0
1	69	Prefer	Form	GLP, HS	bi	PC1	87.9	94.0	100.0
1	69	Prefer	Size	BG, GLP, DHA	tri	–	87.9	93.4	100.0
1	69	Prefer	Size	BG, GLP, HS	tri	–	87.9	94.1	100.0
1	69	Prefer	Size	GLP, HS	bi	–	87.9	93.9	100.0
1	69	Prefer	Form	GLP	uni	–	88.2	93.5	98.0
2	67	Prefer	Form	BG, GLP	bi	PC1	87.5	92.1	95.8
2	67	Prefer	Form	BG, GLP, SLC	tri	PC1	87.4	91.8	97.9
2	67	Prefer	Size	BG, GLP	bi	–	87.5	92.0	95.8

Table A.8: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
2	67	Prefer	Size	BG, GLP, SLC	tri	–	87.5	92.0	95.8
3	65	Prefer	Form	BG, DHA	bi	PC1	86.1	91.3	97.2
3	65	Prefer	Form	BG, HS	bi	PC1	86.1	91.7	97.2
3	65	Prefer	Size	BG, HS	bi	–	86.1	92.0	97.2
4	64	Prefer	Form	GLP, DHA	bi	PC1	84.8	91.7	97.0
4	64	Prefer	Form	GLP, SLC, HS	tri	PC1	84.8	91.8	97.0
4	64	Prefer	Size	GLP, SLC, HS	tri	–	84.8	91.9	97.0
5	63	Prefer	Size	GLP, DHA	bi	–	84.8	91.2	97.0
6	62	Prefer	Form	GLP, HS, DHA	tri	PC1	83.3	91.3	96.7
6	62	Prefer	Size	BG, DHA	bi	–	83.3	91.1	97.2
7	61	Prefer	Form	BG, SLC, HS	tri	PC1	83.3	90.3	97.2
7	61	Prefer	Size	BG, SLC, HS	tri	–	83.3	90.4	97.2
7	61	Prefer	Size	GLP, HS, DHA	tri	–	83.3	90.6	96.7
8	60	Prefer	Form	GLP, SLC	bi	PC1	83.3	89.1	93.8
8	60	Prefer	Size	GLP, SLC	bi	–	83.3	89.7	95.8
9	59	Prefer	Form	BG, HS, DHA	tri	PC1	81.8	89.4	97.0
9	59	Prefer	Form	GLP, SLC, DHA	tri	PC1	81.8	89.6	97.0
9	59	Prefer	Size	BG, HS, DHA	tri	–	81.8	89.5	97.0
9	59	Prefer	Size	GLP, SLC, DHA	tri	–	81.8	89.9	97.0
9	59	Prefer	Form	BG	uni	–	82.3	89.2	94.1
10	58	Prefer	Size	BG, SLC	bi	–	82.3	87.9	94.1
11	57	Accept	Form	BG, SLC, DHA	tri	PC1	80.6	88.8	97.2
11	57	Accept	Form	BG, SLC	bi	PC1	82.3	87.5	94.1
11	57	Accept	Size	BG, SLC, DHA	tri	–	80.6	88.9	94.6
12	53	Accept	Form	HS, DHA	bi	PC1	78.8	86.5	93.9
12	53	Accept	Form	SLC, HS, DHA	tri	PC1	78.8	87.0	93.9
12	53	Accept	Size	HS, DHA	bi	–	78.8	86.7	93.9
12	53	Accept	Size	SLC, HS, DHA	tri	–	78.8	87.0	93.9

Table A.8: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
13	52	Accept	Size	SLC, HS	bi	–	77.8	86.5	94.4
14	51	Accept	Form	SLC, HS	bi	PC1	77.8	86.3	94.4
14	51	Accept	Size	SLC, DHA	bi	–	77.8	85.9	94.4
14	51	Accept	Form	HS	uni	–	77.8	86.2	94.4
15	50	Accept	Form	SLC, DHA	bi	PC1	77.8	84.8	91.7
15	50	Accept	Form	DHA	uni	–	77.8	84.9	91.7
16	40	Accept	Form	SLC	uni	–	72.5	79.9	86.4
17	-23	Reject	Shape	BG, GLP	bi	PC1	39.6	49.7	58.3
17	-23	Reject	Shape	BG, GLP, SLC	tri	PC2	39.6	50.1	58.3
18	-25	Reject	Shape	BG, DHA	bi	PC1	38.9	48.8	58.3
18	-25	Reject	Shape	BG, SLC, DHA	tri	PC2	38.9	48.8	58.3
19	-29	Reject	Shape	BG, GLP, DHA	tri	PC2	33.3	50.6	63.6
20	-32	Reject	Shape	BG, HS, DHA	tri	PC1	30.3	50.4	60.6
21	-34	Reject	Shape	BG, GLP, HS	tri	PC1	33.3	45.0	51.5
22	-37	Reject	Form	BG, GLP, HS	tri	PC2	30.3	44.9	57.6
22	-37	Reject	Form	GLP, SLC, HS	tri	PC3	30.3	45.7	57.6
22	-37	Reject	Form	GLP, HS	bi	PC2	30.3	45.0	54.7
23	-38	Reject	Shape	BG, HS	bi	PC1	27.8	47.3	63.9
23	-38	Reject	Shape	BG, SLC, HS	tri	PC2	27.8	47.0	61.1
23	-38	Reject	Shape	GLP, HS	bi	PC1	30.3	44.2	51.5
23	-38	Reject	Form	SLC, HS	bi	PC2	33.3	41.7	50.0
24	-41	Reject	Shape	BG, GLP, HS	tri	PC2	27.3	44.8	57.6
25	-42	Reject	Shape	GLP, SLC, HS	tri	PC2	27.3	43.7	57.6
26	-45	Reject	Shape	GLP, HS, DHA	tri	PC2	26.7	41.4	56.7
27	-47	Reject	Form	SLC, DHA	bi	PC2	24.9	40.6	55.6
28	-48	Reject	Form	GLP, HS, DHA	tri	PC2	23.3	41.3	56.7
28	-48	Reject	Form	SLC, HS, DHA	tri	PC3	24.2	40.1	54.5
28	-48	Reject	Shape	HS, DHA	bi	PC1	24.2	40.6	51.7

Table A.8: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
28	-48	Reject	Shape	SLC, HS, DHA	tri	PC2	24.2	40.2	51.5
28	-48	Reject	Form	BG, GLP	bi	PC2	25.0	39.5	47.9
29	-49	Reject	Form	BG, GLP, SLC	tri	PC3	25.0	38.3	47.9
29	-49	Reject	Form	BG, SLC, HS	tri	PC2	25.0	38.8	50.0
29	-49	Reject	Form	BG, SLC	bi	PC2	23.5	39.9	49.0
29	-49	Reject	Form	HS, DHA	bi	PC2	24.2	39.5	51.5
30	-50	Reject	Form	BG, HS, DHA	tri	PC3	24.2	38.5	51.5
30	-50	Reject	Form	GLP, HS, DHA	tri	PC3	23.3	39.9	60.0
30	-50	Reject	Shape	BG, HS, DHA	tri	PC2	24.2	39.0	54.5
30	-50	Reject	Shape	GLP, HS, DHA	tri	PC1	23.3	39.2	50.0
31	-52	Reject	Form	GLP, DHA	bi	PC2	21.2	39.2	51.5
32	-53	Reject	Form	BG, GLP, DHA	tri	PC2	21.2	38.9	51.5
33	-54	Reject	Form	GLP, SLC, HS	tri	PC2	21.2	37.4	48.5
33	-54	Reject	Shape	BG, GLP, DHA	tri	PC1	21.2	37.6	51.5
33	-54	Reject	Shape	SLC, DHA	bi	PC1	22.2	36.3	47.2
34	-55	Reject	Form	GLP, SLC, DHA	tri	PC3	21.2	36.9	51.5
35	-57	Reject	Form	BG, GLP, SLC	tri	PC2	20.8	35.2	43.8
35	-57	Reject	Form	BG, SLC, HS	tri	PC3	22.1	33.2	47.2
35	-57	Reject	Shape	GLP, DHA	bi	PC1	21.2	35.0	45.5
35	-57	Reject	Shape	GLP, SLC, DHA	tri	PC2	18.2	37.9	51.5
36	-58	Reject	Shape	GLP, SLC	bi	PC1	20.8	34.1	41.8
37	-60	Reject	Shape	SLC, HS, DHA	tri	PC1	18.2	34.0	45.5
37	-60	Reject	Shape	SLC, HS	bi	PC1	19.4	33.0	41.7
38	-61	Reject	Form	SLC, HS, DHA	tri	PC2	18.2	33.4	48.5
38	-61	Reject	Shape	GLP, SLC, DHA	tri	PC1	18.2	33.3	45.5
39	-62	Reject	Form	BG, HS	bi	PC2	19.4	31.4	44.4
40	-63	Reject	Form	BG, SLC, DHA	tri	PC2	16.7	33.1	44.4
40	-63	Reject	Shape	BG, GLP, SLC	tri	PC1	18.8	30.6	41.7

Table A.8: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
40	-63	Reject	Form	GLP, SLC	bi	PC2	18.8	31.4	41.7
41	-64	Reject	Shape	BG, SLC, HS	tri	PC1	16.7	32.5	47.2
41	-64	Reject	Shape	BG, SLC	bi	PC1	15.7	32.9	43.1
42	-65	Reject	Form	GLP, SLC, DHA	tri	PC2	15.2	32.8	45.5
43	-67	Reject	Shape	BG, SLC, DHA	tri	PC1	13.9	31.7	44.4
44	-69	Reject	Form	BG, HS, DHA	tri	PC2	15.2	28.7	42.4
44	-69	Reject	Shape	GLP, SLC, HS	tri	PC1	15.2	28.2	39.4
45	-73	Reject	Form	BG, GLP, DHA	tri	PC3	9.1	30.4	48.5
46	-76	Reject	Form	BG, SLC, DHA	tri	PC3	11.1	25.7	41.7
47	-77	Reject	Form	BG, DHA	bi	PC2	11.1	24.9	38.9
48	-78	Reject	Form	BG, GLP, HS	tri	PC3	9.1	25.9	42.4

A.3.3 Humerus

Table A.9: List of approaches ranked by score for balanced cross-validation results for the humerus (Subset A).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	66	Prefer	Shape	Dp, GL, Dd	tri	PC1	97.6	98.0	100.0
2	63	Prefer	Shape	Bp, Dp, GLC	tri	PC1	95.2	97.3	97.6
3	62	Prefer	Shape	Bp, Dp, GL	tri	PC1	95.2	96.4	97.6
3	62	Prefer	Size	Bd, Dp	bi	–	95.2	96.6	98.4
4	59	Prefer	Form	Bd, Dp	bi	PC1	93.5	95.6	96.8
5	58	Prefer	Form	Bp, Dp, Bd	tri	PC1	93.2	95.0	95.5
5	58	Prefer	Shape	Bp, GL	bi	PC1	92.9	95.2	97.6
5	58	Prefer	Size	Bp, Dp, Bd	tri	–	93.2	95.1	95.5
5	58	Prefer	Size	Bp, Dp, Dd	tri	–	93.2	94.4	97.7
6	57	Prefer	Form	Bp, Dp, Dd	tri	PC1	93.2	94.3	97.7
6	57	Prefer	Shape	Bp, GLC	bi	PC1	92.9	94.3	97.6

Table A.9: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
7	56	Prefer	Form	Dp, GL, Bd	tri	PC1	91.7	94.3	96.7
7	56	Prefer	Shape	Dp, GL, GLC	tri	PC1	91.9	94.3	96.8
7	56	Prefer	Shape	Dp, GLC	bi	PC1	91.9	93.9	96.8
8	54	Prefer	Form	Dd, Dp	bi	PC1	90.9	92.9	95.5
8	54	Prefer	Shape	Dp, GL, Bd	tri	PC1	90.0	93.6	96.7
8	54	Prefer	Size	Bp, Dp, HTC	tri	–	90.9	92.6	95.5
8	54	Prefer	Size	Dd, Dp	bi	–	90.9	92.9	95.5
9	53	Prefer	Form	Dp, Bp	bi	PC1	90.9	91.6	93.2
9	53	Prefer	Shape	Dd, GLC	bi	PC1	90.9	91.8	93.2
9	53	Prefer	Shape	Dp, GL	bi	PC1	90.3	93.0	95.2
9	53	Prefer	Size	Dd, Bp	bi	–	90.9	91.6	93.2
10	52	Prefer	Form	Bp, Dp, GL	tri	PC1	90.5	91.2	92.9
10	52	Prefer	Form	Bp, Dp, GLC	tri	PC1	90.5	91.4	92.9
10	52	Prefer	Shape	Dd, GL	bi	PC1	90.9	91.5	93.2
10	52	Prefer	Shape	Dp, GL, HTC	tri	PC1	90.5	91.5	92.9
10	52	Prefer	Shape	GL, GLC, Dd	tri	PC1	90.9	91.5	93.2
10	52	Prefer	Shape	GLC, SD, Dd	tri	PC2	90.5	91.9	92.9
10	52	Prefer	Size	Dp, Bp	bi	–	90.9	91.5	93.2
11	50	Accept	Form	Bd, Dd	bi	PC1	89.6	90.1	91.7
11	50	Accept	Form	Dd, Bp	bi	PC1	88.6	91.5	93.2
11	50	Accept	Size	Bd, Dd	bi	–	89.6	90.0	91.7
11	50	Accept	Form	Dp	uni	–	89.4	90.7	92.4
12	49	Accept	Form	Bd, Bp	bi	PC1	88.6	90.3	93.2
12	49	Accept	Form	Bp, Dp, HTC	tri	PC1	88.6	90.7	93.2
12	49	Accept	Shape	GL, GLC, HTC	tri	PC1	88.6	90.7	93.2
12	49	Accept	Shape	HTC, GL	bi	PC1	88.6	90.7	93.2
12	49	Accept	Shape	HTC, GLC	bi	PC1	88.6	90.5	90.9
12	49	Accept	Size	Bd, Bp	bi	–	88.6	90.3	93.2

Table A.9: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
13	46	Accept	Form	Dp, GL	bi	PC1	87.1	89.1	91.9
13	46	Accept	Shape	Bd, GLC	bi	PC1	86.7	88.9	91.7
13	46	Accept	Size	HTC, Bd, Dd	tri	–	87.5	88.1	89.6
14	45	Accept	Form	HTC, Bd, Dd	tri	PC1	87.5	87.9	89.6
14	45	Accept	Shape	GL, GLC, Bd	tri	PC1	86.7	88.7	91.7
14	45	Accept	Size	HTC, Dp	bi	–	86.4	89.1	90.9
15	44	Accept	Form	Dp, GL, Dd	tri	PC1	85.7	87.9	92.9
15	44	Accept	Form	HTC, Bp	bi	PC1	86.4	87.9	93.2
15	44	Accept	Size	Bp, Dp, SD	tri	–	86.4	87.2	88.6
15	44	Accept	Size	HTC, Bp	bi	–	86.4	88.0	93.2
16	43	Accept	Form	Bp, Dp, SD	tri	PC1	86.4	87.1	88.6
16	43	Accept	Form	Bp	uni	–	84.1	89.1	90.9
17	42	Accept	Form	Bp, GL	bi	PC1	85.7	86.5	88.1
17	42	Accept	Form	Bp, GLC	bi	PC1	85.7	86.6	88.1
17	42	Accept	Size	Bd, HTC	bi	–	85.4	86.2	87.5
18	41	Accept	Form	Bd, HTC	bi	PC1	85.4	85.8	87.5
18	41	Accept	Form	Dp, GLC	bi	PC1	83.9	87.1	90.3
18	41	Accept	Shape	Bd, GL	bi	PC1	83.3	87.9	91.7
19	40	Accept	Form	Bd, GL	bi	PC1	83.3	86.2	90.0
20	39	Accept	Form	Bd, GLC	bi	PC1	83.3	86.0	90.0
20	39	Accept	Size	Dp, GL, Bd	tri	–	83.3	85.5	90.0
21	38	Accept	Form	Bd	uni	–	81.2	86.8	90.6
22	37	Accept	Size	Dd, SD	bi	–	82.6	84.5	87.0
23	36	Accept	Form	Bp, SD	bi	PC1	81.8	84.1	86.4
23	36	Accept	Form	HTC, Dp	bi	PC1	81.8	84.5	88.6
23	36	Accept	Size	Bp, SD	bi	–	81.8	84.5	86.4
24	35	Accept	Form	Dp, GL, HTC	tri	PC1	81.0	83.9	85.7
24	35	Accept	Size	Dp, SD	bi	–	81.8	83.6	86.4

Table A.9: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
25	33	Accept	Form	SD, HTC, Bd	tri	PC1	80.4	82.5	84.8
25	33	Accept	Size	SD, HTC, Bd	tri	–	80.4	82.2	84.8
26	32	Accept	Shape	Dp, GL, SD	tri	PC2	79.0	82.9	87.1
27	30	Accept	Form	GL, GLC, Bd	tri	PC1	78.3	81.2	85.0
27	30	Accept	Form	GL, GLC, Dd	tri	PC2	79.5	80.9	84.1
27	30	Accept	Size	Bd, SD	bi	–	78.1	81.6	84.4
27	30	Accept	Size	Bp, Dp, GL	tri	–	78.6	81.0	83.3
28	29	Accept	Size	Bp, Dp, GLC	tri	–	78.6	80.7	83.3
28	29	Accept	Size	SD, HTC, Dd	tri	–	78.3	80.7	84.8
29	28	Accept	Form	SD, HTC, Dd	tri	PC1	78.3	80.2	82.6
29	28	Accept	Size	Dd, HTC	bi	–	77.1	80.8	85.4
30	27	Accept	Form	Dd, HTC	bi	PC1	77.1	79.8	85.4
30	27	Accept	Form	GLC, SD, Bd	tri	PC1	76.7	79.9	83.3
30	27	Accept	Size	Dp, GL, HTC	tri	–	76.2	80.7	85.7
31	26	Accept	Shape	GLC, SD, Bd	tri	PC2	76.7	79.3	83.3
32	25	Accept	Size	Dp, GL, Dd	tri	–	76.2	79.1	81.0
33	24	Accept	Form	GLC, SD, HTC	tri	PC1	76.2	78.1	81.0
33	24	Accept	Form	Dd	uni	–	75.0	79.0	81.2
34	23	Accept	Form	Dd, GL	bi	PC1	75.0	77.8	79.5
35	22	Accept	Form	Bd, SD	bi	PC1	73.4	78.1	82.8
35	22	Accept	Form	Dd, GLC	bi	PC1	75.0	77.5	79.5
35	22	Accept	Size	Bp, GL	bi	–	73.8	77.9	81.0
35	22	Accept	Size	GLC, SD, Dd	tri	–	73.8	78.3	81.0
36	21	Accept	Form	Dp, GL, GLC	tri	PC2	74.1	77.2	80.7
36	21	Accept	Shape	SD, GLC	bi	PC1	74.2	76.4	79.0
36	21	Accept	Size	Bp, GLC	bi	–	73.8	77.4	81.0
36	21	Accept	Size	Dp, GL, SD	tri	–	74.2	76.5	80.7
36	21	Accept	Size	HTC, SD	bi	–	73.9	77.0	80.4

Table A.9: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
37	20	Accept	Form	HTC, SD	bi	PC1	73.9	76.2	78.3
37	20	Accept	Shape	GLC, SD, HTC	tri	PC1	73.8	76.6	81.0
37	20	Accept	Size	GLC, SD, HTC	tri	–	73.8	76.3	78.6
38	19	Accept	Shape	GL, GLC, SD	tri	PC1	72.6	76.0	79.0
38	19	Accept	Shape	SD, GL	bi	PC1	72.6	76.0	79.0
39	18	Accept	Form	Dp, GL, SD	tri	PC1	72.6	75.6	80.7
39	18	Accept	Form	Dp, SD	bi	PC1	72.7	75.5	78.8
39	18	Accept	Size	Bd, GL	bi	–	71.7	76.4	80.0
40	17	Accept	Form	GLC, SD, Dd	tri	PC1	71.4	75.7	78.6
40	17	Accept	Size	Bd, GLC	bi	–	71.7	75.6	80.0
40	17	Reject	Form	Dd, GL	bi	PC2	72.7	73.8	77.3
40	17	Reject	Form	Dd, GLC	bi	PC2	72.7	73.9	77.3
41	16	Accept	Form	HTC	uni	–	70.8	75.3	79.2
42	15	Reject	Shape	GLC, SD, Bd	tri	PC1	71.7	73.6	76.7
42	15	Reject	Form	Dd, SD	bi	PC2	71.7	73.5	76.1
43	13	Reject	Form	Dd, SD	bi	PC1	69.6	73.0	76.1
43	13	Reject	Form	Dp, GL, Dd	tri	PC2	69.0	73.6	78.6
43	13	Reject	Form	GL, GLC, Dd	tri	PC1	70.5	72.4	75.0
43	13	Reject	Form	GL, GLC, HTC	tri	PC1	70.5	72.8	75.0
43	13	Reject	Form	HTC, GL	bi	PC1	70.5	72.4	75.0
43	13	Reject	Form	HTC, GLC	bi	PC1	70.5	72.3	75.0
44	12	Reject	Size	Dd, GL	bi	–	70.5	72.0	75.0
45	11	Reject	Size	Dp, GL	bi	–	69.3	71.9	74.2
45	11	Reject	Form	Bd, SD	bi	PC2	68.8	72.3	75.0
45	11	Reject	Form	Dp, GL	bi	PC2	69.3	71.9	74.2
45	11	Reject	Form	Dp, GLC	bi	PC2	69.3	72.1	74.2
46	10	Reject	Form	GLC, SD, Bd	tri	PC2	68.3	71.2	73.3
46	10	Reject	Form	GLC, SD, Dd	tri	PC3	69.0	71.4	73.8

Table A.9: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
46	10	Reject	Size	GLC, SD, Bd	tri	–	68.3	71.9	76.7
47	9	Reject	Form	Dp, GL, GLC	tri	PC1	67.7	71.0	74.2
48	8	Reject	Size	Dd, GLC	bi	–	68.2	69.5	72.7
48	8	Reject	Size	Dp, GLC	bi	–	67.7	70.6	75.8
49	7	Reject	Form	Dp, GL, SD	tri	PC3	67.7	69.3	71.0
49	7	Reject	Form	GL, GLC, Bd	tri	PC2	66.7	70.8	75.0
49	7	Reject	Form	GLC, SD, Dd	tri	PC2	66.7	70.4	73.8
49	7	Reject	Shape	Dp, GL, SD	tri	PC1	66.1	70.5	74.2
50	6	Reject	Form	GL, GLC, HTC	tri	PC2	65.9	69.6	72.7
50	6	Reject	Form	GLC, SD, HTC	tri	PC3	66.7	69.0	71.4
51	3	Reject	Size	HTC, GL	bi	–	65.9	66.6	68.2
52	2	Reject	Form	Dp, GL, SD	tri	PC2	64.5	67.2	71.0
53	1	Reject	Form	HTC, GLC	bi	PC2	63.6	67.3	72.7
54	0	Reject	Form	SD, GLC	bi	PC1	62.9	67.0	71.0
54	0	Reject	Form	HTC, GL	bi	PC2	63.6	66.8	70.5
55	-1	Reject	Form	GL, GLC, SD	tri	PC1	62.9	65.7	69.3
55	-1	Reject	Form	SD, GL	bi	PC1	62.9	66.5	71.0
55	-1	Reject	Size	Dp, GL, GLC	tri	–	62.9	65.8	69.3
55	-1	Reject	Size	HTC, GLC	bi	–	63.6	65.7	68.2
55	-1	Reject	Form	Bd, GLC	bi	PC2	61.7	67.0	71.7
56	-2	Reject	Size	SD, GLC	bi	–	62.8	65.0	67.7
57	-3	Reject	Form	SD, HTC, Bd	tri	PC2	63.0	64.1	65.2
57	-3	Reject	Shape	GLC, SD, Dd	tri	PC1	61.9	65.4	69.0
57	-3	Reject	Form	Bd, GL	bi	PC2	61.7	65.3	70.0
58	-4	Reject	Form	Dp, GL, HTC	tri	PC2	61.9	64.6	66.7
58	-4	Reject	Form	Dp, GL, HTC	tri	PC3	61.9	64.0	66.7
58	-4	Reject	Shape	Bp, SD	bi	PC1	61.4	64.8	68.2
58	-4	Reject	Size	SD, GL	bi	–	61.3	64.8	67.7

Table A.9: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
58	-4	Reject	Form	SD	uni	–	61.4	64.7	68.6
58	-4	Reject	Form	Bp, SD	bi	PC2	61.4	64.8	68.2
59	-5	Reject	Size	GL, GLC, HTC	tri	–	61.4	64.0	68.2
60	-6	Reject	Form	Dp, GL, Bd	tri	PC2	60.0	64.3	70.0
60	-6	Reject	Shape	Bd, Dd	bi	PC1	60.4	63.2	64.6
60	-6	Reject	Form	Dp, SD	bi	PC2	60.6	63.6	66.7
61	-7	Reject	Shape	Dp, Bp	bi	PC1	59.1	64.0	68.2
61	-7	Reject	Form	SD, GLC	bi	PC2	59.7	63.0	66.1
62	-8	Reject	Form	Bp, Dp, SD	tri	PC2	59.1	62.6	65.9
62	-8	Reject	Shape	Bp, Dp, SD	tri	PC1	59.1	62.6	65.9
62	-8	Reject	Form	SD, GL	bi	PC2	59.7	62.8	66.1
63	-9	Reject	Form	SD, HTC, Dd	tri	PC2	58.7	61.9	65.2
63	-9	Reject	Shape	Bp, Dp, SD	tri	PC2	59.1	62.2	65.9
63	-9	Reject	Shape	Dd, Bp	bi	PC1	59.1	62.1	63.6
63	-9	Reject	Size	GL, GLC, Bd	tri	–	58.3	62.7	68.3
63	-9	Reject	Form	Bp, GL	bi	PC2	59.5	61.9	64.3
64	-10	Reject	Form	GL, GLC, SD	tri	PC2	58.1	61.9	67.7
64	-10	Reject	Form	GLC, SD, Bd	tri	PC3	58.3	61.7	65.0
64	-10	Reject	Shape	Bp, Dp, HTC	tri	PC2	59.1	61.3	63.8
64	-10	Reject	Size	GL, GLC, Dd	tri	–	59.1	61.3	63.6
65	-11	Reject	Form	Bp, GLC	bi	PC2	57.1	61.8	64.3
66	-12	Reject	Form	SD, HTC, Dd	tri	PC3	56.5	61.8	65.2
66	-12	Reject	Shape	Dd, Dp	bi	PC1	56.8	60.7	63.6
66	-12	Reject	Form	Bd, HTC	bi	PC2	58.3	59.3	62.5
67	-13	Reject	Form	Bp, Dp, GL	tri	PC3	57.1	59.8	66.7
67	-13	Reject	Form	GLC, SD, HTC	tri	PC2	57.1	59.7	61.9
67	-13	Reject	Shape	Bp, Dp, Dd	tri	PC1	56.8	60.3	63.6
67	-13	Reject	Shape	Dp, GL, HTC	tri	PC2	57.1	59.9	64.3

Table A.9: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
67	-13	Reject	Shape	GLC, SD, HTC	tri	PC2	57.1	59.5	64.3
68	-14	Reject	Shape	Bp, Dp, Bd	tri	PC2	56.8	59.4	61.4
68	-14	Reject	Shape	Bp, Dp, GLC	tri	PC2	57.1	59.1	61.9
68	-14	Reject	Shape	Bp, Dp, HTC	tri	PC1	56.8	59.5	63.6
68	-14	Reject	Shape	HTC, Bd, Dd	tri	PC2	56.2	60.2	62.5
68	-14	Reject	Shape	HTC, Bp	bi	PC1	56.8	59.4	63.6
68	-14	Reject	Shape	SD, HTC, Dd	tri	PC2	56.5	59.6	63.0
69	-15	Reject	Form	Bp, Dp, GLC	tri	PC3	54.8	60.3	69.0
69	-15	Reject	Form	SD, HTC, Bd	tri	PC3	56.5	58.3	60.9
69	-15	Reject	Shape	Dd, HTC	bi	PC1	56.2	58.7	62.5
70	-16	Reject	Form	Bp, Dp, GL	tri	PC2	54.8	59.3	64.3
70	-16	Reject	Form	Bp, Dp, GLC	tri	PC2	54.8	59.5	66.7
70	-16	Reject	Shape	Bp, Dp, GL	tri	PC2	54.8	59.5	64.3
70	-16	Reject	Shape	SD, HTC, Bd	tri	PC1	56.5	57.7	60.9
71	-17	Reject	Form	Bp, Dp, SD	tri	PC3	54.5	58.3	61.4
72	-18	Reject	Size	GL, GLC, SD	tri	–	53.2	58.6	64.5
73	-19	Reject	Form	HTC, Bd, Dd	tri	PC2	54.2	56.9	62.5
73	-19	Reject	Form	Dp, Bp	bi	PC2	54.5	56.9	59.1
73	-19	Reject	Form	HTC, SD	bi	PC2	54.4	56.8	58.7
74	-20	Reject	Form	Dp, GL, Dd	tri	PC3	52.4	57.4	59.5
74	-20	Reject	Shape	HTC, SD	bi	PC1	54.4	55.2	56.5
75	-21	Reject	Shape	Dp, GL, Dd	tri	PC2	52.4	56.1	61.9
76	-22	Reject	Form	Bp, Dp, HTC	tri	PC3	52.3	55.3	59.1
76	-22	Reject	Shape	Bd, Bp	bi	PC1	52.3	55.8	61.4
76	-22	Reject	Shape	Bp, Dp, Bd	tri	PC1	52.3	55.7	59.1
77	-23	Reject	Form	Dp, GL, Bd	tri	PC3	51.7	55.2	58.3
77	-23	Reject	Shape	Dp, GL, Bd	tri	PC2	51.7	55.0	58.3
77	-23	Reject	Shape	GL, GLC	bi	PC1	51.6	55.4	59.7

Table A.9: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
78	-24	Reject	Form	Dd, Dp	bi	PC2	52.3	53.7	56.8
79	-26	Reject	Form	GL, GLC, SD	tri	PC3	50.0	54.1	56.5
79	-26	Reject	Form	Dd, HTC	bi	PC2	50.0	54.3	56.2
79	-26	Reject	Form	GL, GLC	bi	PC2	50.0	54.0	58.1
79	-26	Reject	Form	HTC, Dp	bi	PC2	50.0	54.3	59.1
80	-27	Reject	Form	Bp, Dp, Dd	tri	PC3	50.0	53.4	59.1
81	-29	Reject	Shape	GL, GLC, SD	tri	PC2	48.4	52.8	58.1
82	-33	Reject	Shape	SD, HTC, Dd	tri	PC1	43.5	53.8	58.7
83	-40	Reject	Form	GL, GLC, Bd	tri	PC3	41.7	47.8	53.3
83	-40	Reject	Form	Bd, Dd	bi	PC2	43.8	46.4	50.0
84	-41	Reject	Form	HTC, Bd, Dd	tri	PC3	43.6	45.0	47.9
85	-44	Reject	Form	Bd, Dp	bi	PC2	40.3	46.0	53.2
86	-45	Reject	Form	Bp, Dp, HTC	tri	PC2	33.9	51.3	56.8
87	-46	Reject	Form	HTC, Bp	bi	PC2	31.8	51.7	56.9
88	-49	Reject	Shape	Bd, HTC	bi	PC1	33.3	47.6	56.2
89	-54	Reject	Form	GL, GLC, HTC	tri	PC3	31.8	44.1	47.7
90	-56	Reject	Shape	GL, GLC, Bd	tri	PC2	26.7	47.1	55.0
91	-59	Reject	Shape	Bd, Dp	bi	PC1	19.4	51.5	61.3
92	-61	Reject	Shape	GL, GLC, HTC	tri	PC2	25.0	44.3	52.3
93	-66	Reject	Shape	Bd, SD	bi	PC1	15.6	48.3	56.2
94	-75	Reject	Shape	GL, GLC, Dd	tri	PC2	9.1	45.6	61.4
94	-75	Reject	Form	Bd, Bp	bi	PC2	9.1	45.9	56.8
95	-80	Reject	Form	GL, GLC, Dd	tri	PC3	9.0	41.5	61.4
95	-80	Reject	Form	GL, GLC	bi	PC1	6.5	43.7	56.5
95	-80	Reject	Size	GL, GLC	bi	–	6.5	43.7	56.5
96	-81	Reject	Form	Dp, GL, GLC	tri	PC3	6.5	42.1	56.5
96	-81	Reject	Shape	Dd, SD	bi	PC1	6.5	42.2	56.5
97	-82	Reject	Form	Bp, Dp, Bd	tri	PC3	4.5	43.1	61.4

Table A.9: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
97	-82	Reject	Shape	Dp, SD	bi	PC1	7.6	40.8	54.5
97	-82	Reject	Form	GLC	uni	–	6.5	42.0	58.1
98	-84	Reject	Form	GL	uni	–	4.8	41.1	56.5
99	-85	Reject	Form	Bp, Dp, Bd	tri	PC2	4.5	40.2	59.1
99	-85	Reject	Shape	Dp, GL, GLC	tri	PC2	4.8	40.4	56.5
100	-88	Reject	Shape	SD, HTC, Bd	tri	PC2	6.5	35.4	52.2
101	-91	Reject	Form	Bp, Dp, Dd	tri	PC2	4.5	34.0	56.8
102	-92	Reject	Shape	Bp, Dp, Dd	tri	PC2	4.5	33.8	54.5
102	-92	Reject	Form	Dd, Bp	bi	PC2	4.5	33.6	54.5
103	-93	Reject	Shape	HTC, Bd, Dd	tri	PC1	4.2	33.3	54.2
104	-96	Reject	Shape	HTC, Dp	bi	PC1	0.0	34.5	54.5

Table A.10: List of approaches ranked by score for balanced cross-validation results for the humerus (Subset B).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	77	Prefer	Form	Bd, Dp	bi	PC1	92.9	97.3	100.0
1	77	Prefer	Size	Bd, Dp	bi	–	92.9	97.0	100.0
2	73	Prefer	Shape	Dp, GL, Dd	tri	PC1	88.9	96.6	100.0
3	71	Prefer	Form	Bp, Dp, Bd	tri	PC1	88.9	94.8	100.0
3	71	Prefer	Form	Bp, Dp, HTC	tri	PC1	88.9	94.7	100.0
3	71	Prefer	Size	Bp, Dp, Bd	tri	–	88.9	95.0	100.0
3	71	Prefer	Size	Bp, Dp, HTC	tri	–	88.9	94.8	100.0
4	70	Prefer	Form	Dd, Dp	bi	PC1	88.9	94.2	100.0
4	70	Prefer	Size	Bd, Bp	bi	–	88.9	94.2	100.0
5	69	Prefer	Form	Dp	uni	–	88.1	93.7	97.6
6	66	Prefer	Shape	Bd, GLC	bi	PC1	87.2	91.8	97.4
7	65	Prefer	Form	Bd, Bp	bi	PC1	83.3	94.0	100.0

Table A.10: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
7	65	Prefer	Form	Bp, Dp, Dd	tri	PC1	83.3	94.2	100.0
7	65	Prefer	Size	Bp, Dp, Dd	tri	–	83.3	94.1	100.0
7	65	Prefer	Size	Dd, Dp	bi	–	83.3	94.2	100.0
8	64	Prefer	Form	Dd, Bp	bi	PC1	83.3	93.0	100.0
8	64	Prefer	Shape	Dd, GL	bi	PC1	83.3	93.4	100.0
8	64	Prefer	Form	Bd	uni	–	85.4	91.2	95.8
9	63	Prefer	Form	Bd, Dd	bi	PC1	83.3	92.0	100.0
9	63	Prefer	Form	Dp, Bp	bi	PC1	83.3	92.5	100.0
9	63	Prefer	Form	HTC, Bp	bi	PC1	83.3	92.4	100.0
9	63	Prefer	Shape	Bd, GL	bi	PC1	84.6	90.9	97.4
9	63	Prefer	Shape	Bp, Dp, GL	tri	PC1	83.3	91.9	100.0
9	63	Prefer	Shape	Bp, Dp, GLC	tri	PC1	83.3	92.1	100.0
9	63	Prefer	Shape	Dp, GL, Bd	tri	PC1	84.6	91.2	97.4
9	63	Prefer	Shape	GL, GLC, Bd	tri	PC1	84.6	91.2	97.4
9	63	Prefer	Shape	GL, GLC, Dd	tri	PC1	83.3	92.5	100.0
9	63	Prefer	Size	Bd, Dd	bi	–	83.3	92.5	100.0
9	63	Prefer	Size	Dd, Bp	bi	–	83.3	92.8	100.0
9	63	Prefer	Size	Dp, Bp	bi	–	83.3	92.7	100.0
9	63	Prefer	Size	Dp, GL, Bd	tri	–	84.6	90.7	97.4
9	63	Prefer	Size	HTC, Bp	bi	–	83.3	92.7	100.0
9	63	Prefer	Size	HTC, Dp	bi	–	83.3	92.2	100.0
10	62	Prefer	Form	HTC, Dp	bi	PC1	83.3	91.7	100.0
10	62	Prefer	Shape	Dd, GLC	bi	PC1	83.3	91.5	100.0
10	62	Prefer	Form	Bp	uni	–	83.3	90.9	100.0
11	61	Accept	Form	Bp, Dp, SD	tri	PC1	83.3	90.6	100.0
11	61	Accept	Size	Bp, Dp, SD	tri	–	83.1	90.5	100.0
11	61	Accept	Size	HTC, Bd, Dd	tri	–	83.3	90.3	100.0
12	60	Accept	Form	Dp, SD	bi	PC1	83.3	89.5	95.2

Table A.10: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
13	59	Accept	Size	Dp, SD	bi	–	83.3	88.7	95.2
14	58	Accept	Shape	GLC, SD, Bd	tri	PC1	82.0	88.4	94.9
15	57	Accept	Form	Dp, GL, Bd	tri	PC1	82.0	88.0	94.9
16	56	Accept	Shape	Bp, GL	bi	PC1	77.8	90.8	100.0
16	56	Accept	Shape	Bp, GLC	bi	PC1	77.8	90.4	100.0
17	55	Accept	Form	HTC, Bd, Dd	tri	PC1	77.8	89.8	100.0
17	55	Accept	Size	Bd, HTC	bi	–	77.8	89.5	100.0
18	54	Accept	Form	Bd, HTC	bi	PC1	77.8	88.5	100.0
18	54	Accept	Form	Bp, SD	bi	PC1	77.8	88.7	100.0
19	53	Accept	Form	Dd, SD	bi	PC1	77.8	87.6	100.0
19	53	Accept	Size	Bp, Dp, GL	tri	–	77.8	88.2	100.0
19	53	Accept	Size	Bp, Dp, GLC	tri	–	77.8	87.8	100.0
19	53	Accept	Size	Bp, SD	bi	–	77.8	87.7	100.0
19	53	Accept	Size	SD, HTC, Bd	tri	–	77.8	87.8	100.0
19	53	Accept	Size	SD, HTC, Dd	tri	–	77.8	87.5	94.4
20	52	Accept	Form	Bp, Dp, GL	tri	PC1	77.8	87.1	94.4
20	52	Accept	Form	Bp, Dp, GLC	tri	PC1	77.8	86.8	94.4
20	52	Accept	Form	Dd, HTC	bi	PC1	77.8	87.1	100.0
20	52	Accept	Form	SD, HTC, Bd	tri	PC1	77.8	87.3	100.0
20	52	Accept	Size	Dd, HTC	bi	–	77.8	86.8	94.4
20	52	Accept	Size	Dd, SD	bi	–	77.8	87.1	94.4
20	52	Accept	Size	Dp, GL, Dd	tri	–	77.8	86.8	94.4
20	52	Accept	Form	Dd	uni	–	77.8	87.2	100.0
21	49	Accept	Size	Bd, SD	bi	–	77.1	84.6	91.7
21	49	Accept	Size	Dp, GL, SD	tri	–	76.9	84.7	92.3
22	48	Accept	Form	Bd, SD	bi	PC1	77.1	83.6	89.6
22	48	Accept	Form	Dp, GL, SD	tri	PC1	76.9	83.6	89.7
22	48	Accept	Shape	Dp, GL, GLC	tri	PC1	76.9	83.5	89.7

Table A.10: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
22	48	Accept	Shape	Dp, GL	bi	PC1	76.9	83.6	89.7
22	48	Accept	Size	Bd, GL	bi	–	76.9	83.5	89.7
23	46	Accept	Form	SD, HTC, Dd	tri	PC1	72.2	86.7	94.4
23	46	Accept	Size	Dp, GL, HTC	tri	–	72.2	86.6	100.0
24	45	Accept	Form	Dp, GL, Dd	tri	PC1	72.2	85.5	94.4
24	45	Accept	Form	Dp, GL, HTC	tri	PC1	72.2	85.8	94.4
24	45	Accept	Size	Bd, GLC	bi	–	74.4	83.0	89.7
24	45	Accept	Size	GLC, SD, Bd	tri	–	74.4	82.9	92.3
25	44	Accept	Form	HTC, SD	bi	PC1	72.2	84.6	94.4
25	44	Accept	Shape	Dp, GLC	bi	PC1	74.4	82.1	87.2
25	44	Accept	Size	Bp, GL	bi	–	72.2	84.4	94.4
25	44	Accept	Size	Bp, GLC	bi	–	72.2	84.0	94.4
25	44	Accept	Size	Dp, GL	bi	–	74.4	82.2	89.7
26	43	Accept	Size	Dp, GLC	bi	–	74.4	81.3	89.7
26	43	Accept	Size	HTC, SD	bi	–	72.2	83.9	94.4
26	43	Accept	Form	HTC	uni	–	72.2	83.7	94.4
27	42	Accept	Form	GLC, SD, HTC	tri	PC1	72.2	82.0	94.4
27	42	Accept	Size	GLC, SD, HTC	tri	–	72.2	82.7	94.4
28	41	Accept	Size	GLC, SD, Dd	tri	–	72.2	81.9	94.4
29	40	Accept	Form	Dp, GL	bi	PC1	71.8	80.5	89.7
30	39	Accept	Form	Dp, GLC	bi	PC1	71.8	80.2	87.2
30	39	Accept	Form	GLC, SD, Bd	tri	PC1	71.8	80.2	87.2
31	36	Accept	Form	Bp, GL	bi	PC1	66.7	82.4	94.4
31	36	Accept	Form	Bp, GLC	bi	PC1	66.7	81.9	94.4
32	35	Accept	Form	Bd, GL	bi	PC1	69.2	78.3	87.2
32	35	Accept	Shape	Dp, GL, HTC	tri	PC1	66.7	81.0	94.4
33	34	Accept	Form	GLC, SD, Dd	tri	PC1	66.7	80.2	94.4
33	34	Accept	Shape	GLC, SD, Dd	tri	PC1	66.7	79.9	94.4

Table A.10: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
33	34	Accept	Size	Dd, GL	bi	–	66.7	79.8	94.4
34	33	Accept	Form	Bd, GLC	bi	PC1	69.2	76.8	87.2
34	33	Accept	Form	HTC, GL	bi	PC1	66.7	79.1	88.9
34	33	Accept	Shape	GLC, SD, HTC	tri	PC1	66.7	78.7	94.4
34	33	Accept	Shape	SD, GL	bi	PC1	69.2	76.3	84.6
34	33	Accept	Size	Dd, GLC	bi	–	66.7	79.2	88.9
34	33	Accept	Size	HTC, GL	bi	–	66.7	79.5	94.4
34	33	Accept	Size	HTC, GLC	bi	–	66.7	79.4	94.4
34	33	Accept	Size	SD, GL	bi	–	69.2	76.3	84.6
35	30	Accept	Shape	GL, GLC, SD	tri	PC1	66.7	76.0	84.6
35	30	Accept	Shape	SD, GLC	bi	PC1	66.7	75.9	84.6
35	30	Accept	Size	Dp, GL, GLC	tri	–	66.7	76.3	84.6
35	30	Accept	Size	GL, GLC, Bd	tri	–	66.7	75.8	84.6
35	30	Accept	Size	SD, GLC	bi	–	66.7	76.1	84.6
36	28	Reject	Form	SD, GL	bi	PC1	66.7	74.5	82.0
36	28	Reject	Shape	Dp, GL, SD	tri	PC1	66.7	74.4	82.0
37	26	Reject	Form	Dp, GL, GLC	tri	PC1	64.1	74.6	84.6
37	26	Accept	Form	HTC, GLC	bi	PC1	61.1	77.7	88.9
37	26	Reject	Form	SD, GLC	bi	PC1	64.1	74.3	82.0
38	21	Reject	Size	GL, GLC, SD	tri	–	61.5	72.1	82.0
39	20	Accept	Form	Dd, GL	bi	PC1	55.6	77.0	88.9
39	20	Reject	Form	GL, GLC, Bd	tri	PC1	61.5	71.1	79.5
40	19	Accept	Form	Dd, GLC	bi	PC1	55.6	76.2	88.9
40	19	Reject	Form	SD	uni	–	62.8	68.9	76.5
41	18	Reject	Shape	GL, GLC, HTC	tri	PC1	61.1	70.1	83.3
41	18	Reject	Shape	HTC, GLC	bi	PC1	61.1	70.1	77.8
42	13	Reject	Shape	HTC, GL	bi	PC1	55.6	70.0	83.3
43	11	Reject	Form	Dp, GL, GLC	tri	PC2	56.4	67.8	79.5

Table A.10: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
44	8	Reject	Form	Dp, GL	bi	PC2	56.4	63.8	71.8
45	7	Reject	Form	GL, GLC, Bd	tri	PC2	56.4	62.8	69.2
45	7	Reject	Form	GL, GLC, SD	tri	PC1	51.3	68.6	77.0
46	6	Reject	Size	GL, GLC, HTC	tri	–	44.4	73.8	88.9
47	4	Reject	Form	GL, GLC, HTC	tri	PC1	44.4	72.5	88.9
47	4	Reject	Size	GL, GLC, Dd	tri	–	44.4	72.4	88.9
48	2	Reject	Form	Dp, GL, Dd	tri	PC2	44.4	70.0	83.3
48	2	Reject	Form	Bd, GL	bi	PC2	53.7	61.1	69.2
49	0	Reject	Form	Dp, GLC	bi	PC2	51.3	61.9	71.8
50	-1	Reject	Form	Bd, GLC	bi	PC2	51.3	60.7	66.7
51	-2	Reject	Form	Dp, GL, SD	tri	PC3	51.3	59.3	69.2
52	-3	Reject	Form	Dp, GL, Bd	tri	PC2	46.1	63.2	71.8
52	-3	Reject	Form	GL, GLC, Dd	tri	PC2	50.0	59.3	72.2
53	-5	Reject	Form	GL, GLC, Dd	tri	PC1	38.9	69.1	88.9
54	-6	Reject	Shape	Bd, Dp	bi	PC1	40.5	65.8	78.6
55	-7	Reject	Form	GL, GLC, HTC	tri	PC2	44.4	61.4	77.8
55	-7	Reject	Size	GL, GLC	bi	–	41.0	65.1	76.9
56	-9	Reject	Form	Dp, GL, HTC	tri	PC2	38.9	64.7	83.3
56	-9	Reject	Form	GL, GLC	bi	PC1	38.5	65.5	79.5
56	-9	Reject	Shape	Bd, Dd	bi	PC1	38.9	65.1	83.3
56	-9	Reject	Form	GLC	uni	–	38.5	65.6	79.5
57	-10	Reject	Form	GL	uni	–	38.3	64.3	76.9
57	-10	Reject	Form	Dd, GL	bi	PC2	44.4	58.1	72.2
57	-10	Reject	Form	Dd, GLC	bi	PC2	44.4	58.5	72.2
58	-11	Reject	Form	Bp, GLC	bi	PC2	33.3	68.6	83.3
59	-13	Reject	Shape	Bp, Dp, Bd	tri	PC2	38.9	60.3	77.8
59	-13	Reject	Form	Bp, GL	bi	PC2	33.3	66.8	83.3
60	-16	Reject	Shape	Bp, Dp, Bd	tri	PC1	33.3	63.0	83.3

Table A.10: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
61	-18	Reject	Form	Bp, Dp, GLC	tri	PC2	33.3	61.7	83.3
61	-18	Reject	Shape	Bp, Dp, SD	tri	PC2	33.3	61.2	77.8
62	-19	Reject	Form	Bp, Dp, Bd	tri	PC3	38.6	54.8	72.2
62	-19	Reject	Shape	Bd, HTC	bi	PC1	33.3	60.0	77.8
62	-19	Reject	Shape	Dp, Bp	bi	PC1	33.3	60.0	77.8
63	-20	Reject	Form	Bp, Dp, GL	tri	PC2	33.3	59.6	83.3
63	-20	Reject	Shape	HTC, Bd, Dd	tri	PC1	33.3	59.2	77.8
64	-23	Reject	Form	GLC, SD, Bd	tri	PC3	41.0	48.8	56.4
64	-23	Reject	Shape	Bd, Bp	bi	PC1	33.3	56.4	72.2
65	-24	Reject	Shape	SD, HTC, Bd	tri	PC2	33.3	55.4	77.8
65	-24	Reject	Form	Bd, Dd	bi	PC2	33.3	55.5	72.2
65	-24	Reject	Form	HTC, GL	bi	PC2	33.3	55.6	77.8
66	-25	Reject	Form	GLC, SD, Bd	tri	PC2	35.9	52.1	64.1
66	-25	Reject	Shape	HTC, SD	bi	PC1	33.3	54.2	72.2
67	-26	Reject	Form	Bp, Dp, SD	tri	PC3	33.3	53.6	72.2
67	-26	Reject	Shape	Dp, GL, SD	tri	PC2	33.3	53.5	64.1
67	-26	Reject	Shape	Dp, SD	bi	PC1	33.3	53.3	66.7
68	-27	Reject	Shape	GL, GLC	bi	PC1	38.5	46.9	53.9
68	-27	Reject	Form	Bd, Dp	bi	PC2	38.1	48.0	57.1
68	-27	Reject	Form	Dp, Bp	bi	PC2	33.3	52.2	66.7
69	-28	Reject	Form	GLC, SD, Dd	tri	PC3	33.3	51.6	66.7
69	-28	Reject	Shape	Bp, Dp, SD	tri	PC1	33.3	51.3	66.7
70	-30	Reject	Shape	Dp, GL, GLC	tri	PC2	35.9	46.9	56.4
70	-30	Reject	Form	HTC, GLC	bi	PC2	27.8	55.4	72.2
71	-31	Reject	Shape	GL, GLC, Dd	tri	PC2	33.3	48.9	66.7
72	-33	Reject	Shape	Bp, Dp, Dd	tri	PC2	27.8	51.6	72.2
72	-33	Reject	Shape	SD, HTC, Dd	tri	PC2	27.8	51.9	66.7
73	-34	Reject	Shape	Dd, HTC	bi	PC1	27.8	51.3	66.7

Table A.10: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
74	-35	Reject	Form	SD, GLC	bi	PC2	30.6	47.5	59.0
75	-36	Reject	Shape	Dd, Dp	bi	PC1	27.8	49.2	66.7
75	-36	Reject	Shape	Dp, GL, Bd	tri	PC2	28.2	48.5	66.7
76	-37	Reject	Shape	Bp, Dp, HTC	tri	PC1	27.8	48.4	66.7
76	-37	Reject	Shape	HTC, Bp	bi	PC1	27.8	48.1	66.7
76	-37	Reject	Form	SD, GL	bi	PC2	28.2	47.2	59.0
77	-38	Reject	Shape	GL, GLC, HTC	tri	PC2	27.8	47.2	66.7
78	-39	Reject	Form	Dp, GL, SD	tri	PC2	28.2	45.7	56.4
78	-39	Reject	Shape	Bp, SD	bi	PC1	27.8	46.1	61.1
79	-41	Reject	Shape	GL, GLC, Bd	tri	PC2	30.8	41.3	51.3
80	-42	Reject	Form	Bp, Dp, Dd	tri	PC2	27.8	43.3	55.6
80	-42	Reject	Shape	Bp, Dp, Dd	tri	PC1	27.8	43.3	55.6
80	-42	Reject	Form	Dd, Bp	bi	PC2	27.8	42.7	55.6
81	-43	Reject	Shape	SD, HTC, Dd	tri	PC1	22.2	47.0	66.7
82	-44	Reject	Form	Dp, SD	bi	PC2	26.1	42.4	52.4
83	-45	Reject	Form	GL, GLC, SD	tri	PC2	25.6	42.3	53.9
84	-46	Reject	Form	GLC, SD, HTC	tri	PC2	22.2	44.1	66.7
84	-46	Reject	Shape	Dd, SD	bi	PC1	22.2	44.3	61.1
84	-46	Reject	Shape	SD, HTC, Bd	tri	PC1	22.2	44.2	61.1
85	-47	Reject	Shape	GLC, SD, Dd	tri	PC2	22.2	43.5	61.1
86	-48	Reject	Form	GLC, SD, Dd	tri	PC2	22.2	42.0	61.1
86	-48	Reject	Shape	GLC, SD, HTC	tri	PC2	22.2	42.0	61.1
86	-48	Reject	Form	Bd, SD	bi	PC2	25.0	39.6	47.9
87	-49	Reject	Form	HTC, Bd, Dd	tri	PC2	22.2	41.0	61.1
87	-49	Reject	Form	SD, HTC, Bd	tri	PC3	22.2	41.4	55.6
87	-49	Reject	Shape	Dp, GL, Dd	tri	PC2	22.2	41.5	61.1
87	-49	Reject	Shape	GL, GLC, SD	tri	PC2	25.6	38.1	51.3
87	-49	Reject	Form	Dd, SD	bi	PC2	22.2	41.8	61.1

Table A.10: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
88	-50	Reject	Form	Bd, HTC	bi	PC2	22.2	40.2	55.6
89	-51	Reject	Shape	Dd, Bp	bi	PC1	22.2	39.5	55.6
89	-51	Reject	Shape	HTC, Bd, Dd	tri	PC2	22.2	39.6	61.1
90	-53	Reject	Form	GL, GLC, SD	tri	PC3	20.5	39.3	53.9
90	-53	Reject	Shape	GLC, SD, Bd	tri	PC2	23.1	36.2	48.7
91	-55	Reject	Form	GL, GLC	bi	PC2	20.4	37.6	51.3
92	-57	Reject	Shape	Dp, GL, HTC	tri	PC2	16.7	38.9	55.6
93	-58	Reject	Form	Dp, GL, HTC	tri	PC3	16.7	38.1	55.6
93	-58	Reject	Shape	Bp, Dp, HTC	tri	PC2	16.7	37.8	55.6
94	-59	Reject	Form	Bp, Dp, HTC	tri	PC3	16.7	37.4	55.6
94	-59	Reject	Form	GLC, SD, HTC	tri	PC3	16.7	37.4	55.6
95	-60	Reject	Form	Bp, Dp, HTC	tri	PC2	16.7	35.9	55.6
96	-61	Reject	Form	HTC, Bp	bi	PC2	16.7	35.3	55.6
97	-62	Reject	Form	HTC, SD	bi	PC2	16.7	33.6	50.0
98	-63	Reject	Form	Dp, GL, Bd	tri	PC3	15.4	34.0	46.1
99	-64	Reject	Form	Bp, Dp, GLC	tri	PC3	11.1	38.0	61.1
99	-64	Reject	Shape	Bp, Dp, GL	tri	PC2	11.1	37.2	61.1
99	-64	Reject	Shape	Bp, Dp, GLC	tri	PC2	11.1	38.1	61.1
99	-64	Reject	Form	Bp, SD	bi	PC2	11.1	37.4	66.7
100	-65	Reject	Form	Bp, Dp, GL	tri	PC3	11.1	36.6	61.1
101	-66	Reject	Form	SD, HTC, Dd	tri	PC2	16.4	30.6	50.0
102	-68	Reject	Form	HTC, Bd, Dd	tri	PC3	11.1	33.3	55.6
102	-68	Reject	Shape	Bd, SD	bi	PC1	14.6	30.1	41.7
103	-69	Reject	Form	Bp, Dp, Dd	tri	PC3	11.1	32.4	50.0
103	-69	Reject	Form	Bp, Dp, SD	tri	PC2	11.1	32.4	50.3
103	-69	Reject	Form	GL, GLC, Bd	tri	PC3	12.8	30.5	46.1
103	-69	Reject	Form	HTC, Dp	bi	PC2	11.1	32.4	50.0
104	-70	Reject	Form	SD, HTC, Bd	tri	PC2	11.1	31.3	50.0

Table A.10: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
105	-71	Reject	Form	Dp, GL, GLC	tri	PC3	12.8	29.1	43.6
105	-71	Reject	Shape	HTC, Dp	bi	PC1	11.1	30.4	50.0
106	-75	Reject	Form	GL, GLC, Dd	tri	PC3	5.6	32.2	55.6
107	-76	Reject	Form	GL, GLC, HTC	tri	PC3	5.6	30.9	55.6
108	-78	Reject	Form	Bp, Dp, Bd	tri	PC2	5.6	29.1	50.0
109	-80	Reject	Form	Dp, GL, Dd	tri	PC3	5.6	26.9	44.4
110	-82	Reject	Form	Bd, Bp	bi	PC2	5.6	25.5	50.0
111	-83	Reject	Form	SD, HTC, Dd	tri	PC3	5.6	24.6	44.4
111	-83	Reject	Form	Dd, Dp	bi	PC2	5.6	23.8	38.9
112	-84	Reject	Form	Dd, HTC	bi	PC2	5.6	23.0	44.4

A.3.4 Radius

Table A.11: List of approaches ranked by score for balanced cross-validation results for the radius (Subset A).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	65	Prefer	Form	Bp, SD, Dd	tri	PC1	95.8	99.1	100.0
2	64	Prefer	Form	Bp, Dd	bi	PC1	95.8	97.9	100.0
2	64	Prefer	Size	Bp, Dd	bi	–	95.8	98.3	100.0
2	64	Prefer	Size	Bp, SD, Dd	tri	–	95.8	98.2	100.0
3	63	Prefer	Form	Bp, GL, Dd	tri	PC1	95.8	97.4	100.0
3	63	Prefer	Shape	Bp, GL, Bd	tri	PC1	96.3	96.5	98.2
4	61	Prefer	Form	Bp, GL	bi	PC1	94.6	96.2	98.2
4	61	Prefer	Form	Bp	uni	–	95.5	95.6	97.0
5	60	Prefer	Form	Dd, Bd, SD	tri	PC1	91.7	97.9	100.0
5	60	Prefer	Form	Dd, SD	bi	PC1	91.7	98.7	100.0
6	59	Prefer	Form	Bp, SD, Dp	tri	PC1	92.9	96.1	100.0
6	59	Prefer	Size	Bp, SD, Dp	tri	–	92.9	96.0	100.0

Table A.11: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
7	58	Prefer	Form	Bp, Dp, Dd	tri	PC1	90.9	97.0	100.0
7	58	Prefer	Size	Dd, Bd, SD	tri	–	91.7	96.2	100.0
7	58	Prefer	Size	Dd, SD	bi	–	91.7	96.7	100.0
8	57	Prefer	Form	Bp, Bd, Dd	tri	PC1	91.7	95.6	100.0
8	57	Prefer	Shape	Bp, GL	bi	PC1	92.9	94.0	98.2
9	56	Prefer	Form	Bp, GL, SD	tri	PC1	92.6	93.4	94.4
9	56	Prefer	Form	Dd, GL	bi	PC1	91.7	94.2	100.0
9	56	Prefer	Form	Dp, Dd	bi	PC1	90.9	94.8	100.0
9	56	Prefer	Form	GL, Dd	bi	PC1	91.7	94.0	100.0
9	56	Prefer	Shape	Bp, GL, Dp	tri	PC1	91.7	94.5	100.0
9	56	Prefer	Size	Bp, Dp, Dd	tri	–	90.9	95.4	100.0
9	56	Prefer	Form	Dd	uni	–	91.7	94.0	95.8
10	55	Prefer	Form	Dp, GL, Dd	tri	PC1	90.9	94.4	100.0
10	55	Prefer	Size	Dp, Dd	bi	–	90.9	94.0	100.0
11	54	Accept	Form	Bp, Bd	bi	PC1	91.4	92.7	93.1
11	54	Accept	Size	Bp, SD	bi	–	90.9	92.7	93.9
12	53	Accept	Form	Bp, Dp	bi	PC1	89.3	93.6	100.0
12	53	Accept	Form	Bp, SD, Bd	tri	PC1	91.1	91.6	92.9
12	53	Accept	Form	Bp, SD	bi	PC1	90.9	92.1	93.9
12	53	Accept	Shape	Bp, GL, Dd	tri	PC1	91.7	91.7	91.7
12	53	Accept	Size	Bp, GL	bi	–	91.1	91.8	92.9
12	53	Accept	Size	Bp, SD, Bd	tri	–	91.1	91.5	92.9
12	53	Accept	Size	Dp, SD	bi	–	89.3	93.3	96.4
13	52	Accept	Form	Bp, GL, Bd	tri	PC1	88.9	92.9	96.3
13	52	Accept	Form	Dp, SD	bi	PC1	89.3	92.8	96.4
13	52	Accept	Shape	Bp, GL, SD	tri	PC1	90.7	91.0	92.6
13	52	Accept	Size	Bp, Bd, Dd	tri	–	87.5	94.8	100.0
13	52	Accept	Size	Bp, Dp	bi	–	89.3	92.5	96.4

Table A.11: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
13	52	Accept	Size	Bp, GL, Dd	tri	–	87.5	94.0	100.0
14	50	Accept	Form	Bd, Dd	bi	PC1	87.5	92.7	100.0
14	50	Accept	Form	Dp, Bd, Dd	tri	PC1	86.4	93.8	100.0
14	50	Accept	Size	Bd, Dd	bi	–	87.5	92.0	95.8
14	50	Accept	Size	Bp, Bd	bi	–	89.7	90.1	93.1
14	50	Accept	Size	Dp, Bd, Dd	tri	–	86.4	93.9	100.0
15	49	Accept	Form	Bp, Dp, Bd	tri	PC1	86.4	92.5	100.0
15	49	Accept	Form	Bp, GL, Dp	tri	PC1	87.5	91.7	95.8
15	49	Accept	Form	Dp, GL, SD	tri	PC1	87.5	91.6	95.8
16	48	Accept	Size	Bp, Dp, Bd	tri	–	86.4	92.1	95.5
16	48	Accept	Size	Dp, GL, Dd	tri	–	86.4	91.6	95.5
17	47	Accept	Shape	Dd, GL	bi	PC1	87.5	89.8	91.7
17	47	Accept	Shape	GL, Dd	bi	PC1	87.5	89.8	91.7
18	46	Accept	Shape	Dp, GL, SD	tri	PC1	87.5	88.8	91.7
18	46	Accept	Size	Bp, GL, SD	tri	–	87.0	88.5	90.7
19	44	Accept	Shape	Bp, Bd, Dd	tri	PC1	83.3	90.8	95.8
19	44	Accept	Size	Bp, GL, Dp	tri	–	83.3	90.6	95.8
20	43	Accept	Shape	Bd, Dd	bi	PC1	83.3	89.3	95.8
21	42	Accept	Form	Bd, SD	bi	PC1	85.7	86.5	87.5
22	41	Accept	Form	Dp, Bd, SD	tri	PC1	81.8	89.5	95.5
22	41	Accept	Shape	GL, SD	bi	PC1	85.2	85.9	87.0
22	41	Accept	Shape	SD, GL	bi	PC1	85.2	85.9	87.0
22	41	Accept	Size	Dp, Bd, SD	tri	–	81.8	88.9	95.5
23	40	Accept	Shape	Dp, GL, Dd	tri	PC1	81.8	87.7	90.9
24	39	Accept	Form	Dp, Bd	bi	PC1	81.8	87.0	95.5
24	39	Accept	Size	Bp, GL, Bd	tri	–	83.3	85.4	88.9
24	39	Accept	Size	Dp, Bd	bi	–	81.8	87.3	90.9
25	37	Accept	Shape	Bp, Bd	bi	PC1	82.8	83.8	84.5

Table A.11: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
25	37	Accept	Shape	Dp, GL	bi	PC1	79.2	87.6	91.7
26	36	Accept	Shape	Dd, Bd, SD	tri	PC2	79.2	86.7	95.8
26	36	Accept	Size	Dd, GL	bi	–	79.2	87.0	91.7
26	36	Accept	Size	GL, Dd	bi	–	79.2	86.9	95.8
27	35	Accept	Size	Bd, SD	bi	–	82.1	83.3	85.7
27	35	Accept	Size	Dp, GL, SD	tri	–	79.2	85.5	91.7
28	34	Accept	Shape	Dp, GL, Bd	tri	PC1	77.3	87.2	95.5
29	32	Accept	Form	Dp, GL, Bd	tri	PC1	77.3	85.0	90.9
29	32	Accept	Shape	Bp, Dp, Bd	tri	PC1	77.3	84.5	90.9
30	30	Accept	Form	Dp	uni	–	75.0	85.2	92.9
31	26	Accept	Form	GL, SD	bi	PC1	75.9	80.1	83.3
31	26	Accept	Form	SD, GL	bi	PC1	75.9	80.0	83.3
32	25	Accept	Size	GL, SD	bi	–	75.9	79.0	83.3
32	25	Accept	Size	SD, GL	bi	–	75.9	79.0	85.2
32	25	Accept	Form	SD	uni	–	74.2	80.3	81.8
33	23	Accept	Shape	Dp, Bd, Dd	tri	PC1	72.7	80.1	86.4
34	22	Accept	Form	Dp, GL	bi	PC1	70.8	81.6	91.7
34	22	Accept	Size	Dp, GL, Bd	tri	–	72.7	79.7	86.4
35	15	Accept	Form	Dp, GL, Dd	tri	PC2	68.2	76.5	81.8
36	14	Reject	Shape	Bp, SD, Bd	tri	PC1	71.4	72.4	75.0
37	13	Reject	Shape	Bp, Dp, Dd	tri	PC1	68.2	74.5	81.8
38	11	Reject	Shape	Bp, SD, Dp	tri	PC2	67.9	73.2	78.6
38	11	Reject	Shape	Dp, Dd	bi	PC1	68.2	72.6	77.3
39	9	Reject	Form	Bd	uni	–	69.0	70.4	72.4
40	7	Reject	Form	Bp, GL, Dp	tri	PC2	62.5	74.0	83.3
40	7	Reject	Form	Bp, Bd	bi	PC2	67.2	69.6	72.4
41	6	Reject	Shape	Bp, Dp	bi	PC1	64.3	71.3	78.6
41	6	Reject	Shape	Bp, SD, Bd	tri	PC2	66.1	70.0	73.2

Table A.11: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
42	5	Reject	Form	Bp, SD, Bd	tri	PC3	66.1	68.7	71.4
43	4	Reject	Form	Dp, GL, Bd	tri	PC3	63.6	70.8	81.8
43	4	Reject	Size	Dp, GL	bi	–	62.5	72.0	83.3
44	3	Reject	Form	Dp, GL	bi	PC2	62.3	70.4	79.2
45	1	Reject	Shape	Bd, GL	bi	PC1	63.0	67.8	72.2
45	1	Reject	Shape	GL, Bd	bi	PC1	63.0	67.8	72.2
46	0	Reject	Shape	Bd, SD	bi	PC1	64.3	66.0	67.9
47	-1	Reject	Form	Bp, SD	bi	PC2	63.6	65.1	66.7
48	-2	Reject	Shape	Dp, Bd, Dd	tri	PC2	59.1	68.5	77.3
49	-3	Reject	Form	Bd, GL	bi	PC1	62.9	64.3	66.7
49	-3	Reject	Form	GL, Bd	bi	PC1	63.0	64.4	66.7
50	-5	Reject	Size	GL, Bd	bi	–	61.1	63.8	66.7
51	-7	Reject	Form	Bp, GL, Bd	tri	PC2	59.3	63.5	68.5
51	-7	Reject	Size	Bd, GL	bi	–	59.3	63.7	66.7
52	-8	Reject	Form	Bp, Bd, Dd	tri	PC2	54.2	68.2	79.2
53	-9	Reject	Form	Bp, GL, SD	tri	PC2	59.3	62.0	64.8
53	-9	Reject	Form	Bp, GL, SD	tri	PC3	59.3	61.8	64.8
53	-9	Reject	Shape	Bp, SD, Dd	tri	PC1	58.3	62.3	66.7
53	-9	Reject	Form	GL, SD	bi	PC2	59.3	61.9	64.8
53	-9	Reject	Form	SD, GL	bi	PC2	59.3	61.8	64.8
54	-11	Reject	Form	Bp, Dp, Bd	tri	PC3	54.5	64.2	72.7
55	-12	Reject	Form	Bd, GL	bi	PC2	57.4	60.4	63.0
55	-12	Reject	Form	GL, Bd	bi	PC2	57.4	60.3	63.0
56	-13	Reject	Shape	Bp, GL, SD	tri	PC2	57.4	59.6	61.1
57	-14	Reject	Form	Bd, Dd	bi	PC2	54.2	61.7	70.8
57	-14	Reject	Form	Bp, Dp	bi	PC2	53.6	62.9	67.9
58	-15	Reject	Form	Dp, GL, SD	tri	PC3	50.0	64.9	75.0
58	-15	Reject	Shape	Dd, SD	bi	PC1	54.2	60.4	66.7

Table A.11: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
58	-15	Reject	Shape	Dp, Bd, SD	tri	PC1	54.5	60.3	72.7
59	-16	Reject	Shape	Bp, SD	bi	PC1	56.1	58.0	60.6
60	-17	Reject	Form	Bp, SD, Dp	tri	PC3	53.6	59.1	64.3
60	-17	Reject	Shape	Dp, Bd	bi	PC1	50.0	62.7	72.7
60	-17	Reject	Form	Bp, GL	bi	PC2	55.4	57.9	62.5
61	-19	Reject	Shape	Dp, GL, SD	tri	PC2	50.0	61.5	70.8
62	-20	Reject	Form	Dd, Bd, SD	tri	PC3	45.8	64.5	75.0
62	-20	Reject	Form	Dp, GL, SD	tri	PC2	49.8	59.8	66.7
63	-21	Reject	Shape	Bp, Dp, Bd	tri	PC2	50.0	58.7	68.2
64	-22	Reject	Form	Dp, Bd, Dd	tri	PC3	45.5	62.6	77.3
65	-29	Reject	Form	GL	uni	–	50.0	51.1	53.6
66	-34	Reject	Shape	Bp, Dp, Dd	tri	PC2	40.9	55.5	68.2
67	-35	Reject	Shape	Bp, GL, Dd	tri	PC2	37.5	57.5	66.7
68	-38	Reject	Shape	Bp, GL, Bd	tri	PC2	37.0	54.8	59.3
69	-39	Reject	Form	Bp, GL, Dd	tri	PC3	37.5	53.3	62.5
70	-44	Reject	Form	Bp, GL, Dd	tri	PC2	25.0	61.0	70.8
70	-44	Reject	Form	Dp, Bd, Dd	tri	PC2	27.3	58.8	72.7
71	-45	Reject	Form	Dd, GL	bi	PC2	29.2	55.6	66.7
72	-47	Reject	Shape	Dd, Bd, SD	tri	PC1	29.2	53.4	66.7
73	-49	Reject	Form	Bp, Dp, Bd	tri	PC2	22.7	58.5	72.7
73	-49	Reject	Shape	Dp, GL, Dd	tri	PC2	27.3	53.9	68.2
73	-49	Reject	Form	Dp, Dd	bi	PC2	22.7	58.0	72.7
74	-50	Reject	Form	GL, Dd	bi	PC2	24.8	55.6	66.7
75	-54	Reject	Form	Bp, Dp, Dd	tri	PC2	18.2	57.4	72.7
76	-57	Reject	Shape	Dp, GL, Bd	tri	PC2	18.2	54.5	68.2
77	-59	Reject	Shape	Dp, SD	bi	PC1	21.2	50.0	60.7
78	-65	Reject	Form	Bp, Dp, Dd	tri	PC3	13.6	51.7	63.6
79	-66	Reject	Form	Bp, SD, Dp	tri	PC2	10.7	53.6	67.9

Table A.11: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
80	-71	Reject	Form	Dp, Bd, SD	tri	PC2	9.1	50.3	63.6
80	-71	Reject	Form	Dp, GL, Dd	tri	PC3	9.1	49.8	63.9
81	-74	Reject	Shape	Dp, Bd, SD	tri	PC2	9.1	47.2	63.6
82	-75	Reject	Form	Dp, Bd, SD	tri	PC3	9.1	45.6	63.6
83	-76	Reject	Form	Dp, GL, Bd	tri	PC2	9.1	44.9	63.6
84	-77	Reject	Form	Bp, SD, Dd	tri	PC3	8.3	44.3	62.5
85	-79	Reject	Shape	Bp, GL, Dp	tri	PC2	8.3	42.3	58.3
85	-79	Reject	Shape	Bp, SD, Dp	tri	PC1	3.6	47.9	67.9
85	-79	Reject	Form	Dp, Bd	bi	PC2	4.5	46.8	68.2
86	-80	Reject	Form	Bp, Dd	bi	PC2	4.2	45.6	66.7
87	-82	Reject	Form	Bp, SD, Bd	tri	PC2	5.4	43.0	58.9
88	-83	Reject	Form	Bp, GL, Dp	tri	PC3	4.2	42.5	66.7
88	-83	Reject	Shape	Bp, SD, Dd	tri	PC2	4.2	42.9	62.5
89	-84	Reject	Form	Bp, SD, Dd	tri	PC2	4.2	41.6	62.5
89	-84	Reject	Shape	Bp, Bd, Dd	tri	PC2	4.2	41.8	66.7
89	-84	Reject	Form	Dp, SD	bi	PC2	3.6	41.9	60.7
90	-86	Reject	Shape	Bp, Dd	bi	PC1	4.2	40.0	58.3
91	-87	Reject	Form	Bp, Bd, Dd	tri	PC3	4.2	38.9	62.5
91	-87	Reject	Form	Dd, SD	bi	PC2	4.2	39.0	62.5
92	-90	Reject	Form	Bp, GL, Bd	tri	PC3	3.7	36.5	57.4
92	-90	Reject	Form	Dd, Bd, SD	tri	PC2	0.0	39.7	58.3
93	-91	Reject	Form	Bd, SD	bi	PC2	3.6	35.9	48.2

Table A.12: List of approaches ranked by score for balanced cross-validation results for the radius (Subset B).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	81	Prefer	Form	Bp, Dd	bi	PC1	95.2	98.6	100.0

Table A.12: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	81	Prefer	Form	Bp, SD, Dd	tri	PC1	95.2	98.4	100.0
1	81	Prefer	Size	Bp, Dd	bi	–	95.2	98.3	100.0
1	81	Prefer	Size	Bp, SD, Dd	tri	–	95.2	98.9	100.0
2	78	Prefer	Form	Bp	uni	–	93.8	96.9	100.0
3	77	Prefer	Shape	Bp, GL, Bd	tri	PC1	92.9	96.6	100.0
4	76	Prefer	Size	Dd, SD	bi	–	90.5	97.8	100.0
5	75	Prefer	Form	Bp, SD, Dp	tri	PC1	90.5	97.0	100.0
5	75	Prefer	Form	Dd, SD	bi	PC1	90.5	96.7	100.0
5	75	Prefer	Shape	Bp, GL, Dp	tri	PC1	90.5	97.0	100.0
5	75	Prefer	Size	Bp, Dp, Dd	tri	–	90.5	96.8	100.0
5	75	Prefer	Size	Bp, SD, Dp	tri	–	90.5	97.1	100.0
5	75	Prefer	Size	Dd, Bd, SD	tri	–	90.5	97.1	100.0
6	74	Prefer	Form	Bp, Bd, Dd	tri	PC1	90.5	96.0	100.0
6	74	Prefer	Form	Bp, Dp, Dd	tri	PC1	90.5	95.8	100.0
6	74	Prefer	Form	Dd, Bd, SD	tri	PC1	90.5	95.9	100.0
6	74	Prefer	Shape	Bp, GL	bi	PC1	90.5	95.7	100.0
6	74	Prefer	Size	Bp, Bd, Dd	tri	–	90.5	96.2	100.0
6	74	Prefer	Size	Bp, GL, Dd	tri	–	90.5	95.9	100.0
6	74	Prefer	Size	Bp, SD	bi	–	91.7	94.9	97.9
6	74	Prefer	Size	Dp, Dd	bi	–	90.5	95.8	100.0
7	73	Prefer	Form	Bp, Dp	bi	PC1	90.5	94.9	100.0
7	73	Prefer	Form	Dp, Dd	bi	PC1	90.5	94.8	100.0
7	73	Prefer	Form	Dp, SD	bi	PC1	90.5	94.7	100.0
7	73	Prefer	Shape	Bp, GL, SD	tri	PC1	90.5	95.2	100.0
7	73	Prefer	Size	Bp, Dp	bi	–	90.5	95.6	100.0
7	73	Prefer	Size	Dp, Bd, Dd	tri	–	90.5	95.5	100.0
8	72	Prefer	Form	Bp, Dp, Bd	tri	PC1	90.5	93.9	100.0
8	72	Prefer	Form	Dp, Bd, Dd	tri	PC1	90.5	94.4	100.0

Table A.12: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
8	72	Prefer	Shape	Bp, GL, Dd	tri	PC1	90.5	94.3	100.0
8	72	Prefer	Size	Bp, Dp, Bd	tri	–	90.5	94.6	100.0
8	72	Prefer	Size	Bp, GL	bi	–	90.5	94.1	97.6
8	72	Prefer	Size	Dp, GL, Dd	tri	–	90.5	93.8	100.0
8	72	Prefer	Size	Dp, SD	bi	–	90.5	94.5	100.0
9	71	Prefer	Form	Bp, SD	bi	PC1	89.6	94.1	97.9
10	69	Prefer	Form	Bp, SD, Bd	tri	PC1	88.1	93.2	97.6
10	69	Prefer	Size	Bp, Bd	bi	–	88.1	93.6	97.6
10	69	Prefer	Size	Bp, SD, Bd	tri	–	88.1	93.5	97.6
11	68	Accept	Size	Bp, GL, SD	tri	–	88.1	92.2	97.6
12	67	Accept	Form	Bp, Bd	bi	PC1	88.1	92.0	97.6
12	67	Accept	Size	Bd, Dd	bi	–	85.7	93.8	100.0
13	66	Accept	Form	Bd, Dd	bi	PC1	85.7	92.9	100.0
13	66	Accept	Form	Bp, GL, Dd	tri	PC1	85.7	93.5	100.0
13	66	Accept	Form	Dp, Bd, SD	tri	PC1	85.7	92.8	100.0
13	66	Accept	Shape	Bp, Bd, Dd	tri	PC1	85.7	93.0	100.0
13	66	Accept	Shape	Dd, GL	bi	PC1	85.7	92.8	100.0
13	66	Accept	Shape	Dp, GL, Dd	tri	PC1	85.7	92.7	100.0
13	66	Accept	Shape	GL, Dd	bi	PC1	85.7	92.8	100.0
13	66	Accept	Size	Bp, GL, Dp	tri	–	85.7	93.1	100.0
13	66	Accept	Size	Dp, Bd, SD	tri	–	85.7	93.0	100.0
13	66	Accept	Form	Dd	uni	–	85.7	93.1	100.0
14	65	Accept	Form	Bp, GL, Dp	tri	PC1	85.7	91.8	100.0
14	65	Accept	Shape	Bd, Dd	bi	PC1	85.7	92.5	100.0
15	64	Accept	Form	Dp, Bd	bi	PC1	85.7	91.1	95.2
15	64	Accept	Size	Dp, Bd	bi	–	85.7	91.0	95.2
16	63	Accept	Form	Bp, GL, SD	tri	PC1	85.7	89.8	95.2
16	63	Accept	Size	Bp, GL, Bd	tri	–	85.7	89.9	95.2

Table A.12: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
17	61	Accept	Form	Bp, GL	bi	PC1	83.3	90.3	95.2
18	59	Accept	Form	Bd, SD	bi	PC1	83.3	88.4	93.0
18	59	Accept	Shape	Dp, GL, Bd	tri	PC1	81.0	90.4	100.0
18	59	Accept	Size	Bd, SD	bi	–	83.3	88.6	92.9
18	59	Accept	Size	Dd, GL	bi	–	81.0	90.8	100.0
18	59	Accept	Size	Dp, GL, SD	tri	–	81.0	90.4	95.2
18	59	Accept	Size	GL, Dd	bi	–	81.0	90.8	100.0
19	58	Accept	Form	Dp	uni	–	81.0	89.4	95.2
20	57	Accept	Form	Dp, GL, Dd	tri	PC1	81.0	89.0	95.2
20	57	Accept	Form	Dp, GL, SD	tri	PC1	81.0	88.4	95.2
20	57	Accept	Shape	Bp, Dp, Bd	tri	PC1	81.0	88.6	95.2
20	57	Accept	Shape	Dp, Bd, Dd	tri	PC1	81.0	88.6	95.2
21	56	Accept	Shape	Dp, GL, SD	tri	PC1	81.0	87.3	95.2
22	55	Accept	Form	Bp, GL, Bd	tri	PC1	81.0	86.5	92.9
23	52	Accept	Form	SD	uni	–	78.4	86.3	92.2
24	51	Accept	Shape	Dd, Bd, SD	tri	PC1	76.2	87.3	95.2
24	51	Accept	Size	GL, SD	bi	–	78.6	85.6	92.9
24	51	Accept	Size	SD, GL	bi	–	78.6	85.6	92.9
25	50	Accept	Shape	Dp, GL	bi	PC1	76.2	86.8	95.2
25	50	Accept	Size	Dp, GL, Bd	tri	–	76.2	86.2	95.2
26	48	Accept	Form	Dp, GL, Bd	tri	PC1	76.2	84.2	90.5
27	47	Accept	Form	GL, SD	bi	PC1	76.2	83.7	90.5
27	47	Accept	Form	SD, GL	bi	PC1	76.2	83.5	90.5
27	47	Accept	Shape	Bp, Bd	bi	PC1	76.2	83.7	90.5
28	45	Accept	Shape	Bp, SD, Bd	tri	PC1	76.2	81.9	88.1
29	41	Accept	Shape	GL, SD	bi	PC1	73.8	80.3	85.7
29	41	Accept	Shape	SD, GL	bi	PC1	73.8	80.3	85.7
29	41	Accept	Form	Bd	uni	–	73.8	80.0	88.1

Table A.12: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
30	40	Accept	Form	Dd, GL	bi	PC1	71.4	80.9	90.5
30	40	Accept	Size	Dp, GL	bi	–	71.4	81.2	90.5
31	39	Accept	Form	GL, Dd	bi	PC1	71.4	80.4	90.5
32	31	Accept	Form	Dp, GL	bi	PC1	66.7	77.2	90.5
33	30	Accept	Shape	Bp, Dp, Dd	tri	PC1	66.7	76.5	85.7
33	30	Accept	Shape	Dp, Dd	bi	PC1	66.7	75.7	85.7
34	29	Reject	Size	Bd, GL	bi	–	66.7	74.8	83.3
34	29	Reject	Size	GL, Bd	bi	–	66.7	74.8	83.3
35	25	Reject	Form	Bd, GL	bi	PC1	64.3	73.8	83.3
35	25	Reject	Form	GL, Bd	bi	PC1	64.3	73.8	83.3
36	22	Reject	Form	Bp, Bd	bi	PC2	64.3	70.2	76.2
37	21	Reject	Form	Bp, GL, Dd	tri	PC2	61.9	71.8	85.7
38	20	Reject	Form	Bp, GL, Dp	tri	PC2	61.9	71.1	81.0
39	19	Reject	Form	Bp, Bd, Dd	tri	PC2	61.9	69.8	81.0
39	19	Reject	Form	Dd, GL	bi	PC2	61.9	69.6	76.2
39	19	Reject	Form	GL, Dd	bi	PC2	61.9	69.5	76.2
40	18	Reject	Form	Bp, GL	bi	PC2	61.9	68.5	76.2
41	16	Reject	Form	Bp, GL, Bd	tri	PC2	61.9	67.0	73.8
42	14	Reject	Form	Bp, Dp, Bd	tri	PC2	57.1	69.6	81.0
43	13	Reject	Form	Dp, GL, Dd	tri	PC2	57.1	68.2	76.2
43	13	Reject	Shape	Bd, GL	bi	PC1	59.5	66.4	73.8
43	13	Reject	Shape	GL, Bd	bi	PC1	59.5	66.3	73.8
44	12	Reject	Form	Dd, Bd, SD	tri	PC2	57.1	67.8	76.2
44	12	Reject	Form	Dp, Bd, Dd	tri	PC2	57.1	68.0	76.2
45	8	Reject	Form	Bp, GL, SD	tri	PC2	57.1	63.7	71.4
45	8	Reject	Form	Bd, Dd	bi	PC2	57.1	63.6	71.4
46	6	Reject	Shape	Bp, Dp	bi	PC1	52.4	66.0	76.2
47	-1	Reject	Shape	Bp, SD, Dd	tri	PC1	47.6	64.5	81.0

Table A.12: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
48	-6	Reject	Shape	Dd, SD	bi	PC1	42.9	63.6	76.2
49	-7	Reject	Form	Dp, GL, Bd	tri	PC2	47.6	57.8	66.7
50	-10	Reject	Shape	Bp, SD, Dp	tri	PC1	38.1	64.3	76.2
50	-10	Reject	Form	GL	uni	–	38.1	64.2	76.2
51	-17	Reject	Form	Dp, GL	bi	PC2	42.9	52.6	61.9
52	-18	Reject	Form	Dp, GL, SD	tri	PC2	42.9	51.5	61.9
52	-18	Reject	Form	SD, GL	bi	PC2	42.9	51.9	59.5
53	-20	Reject	Form	GL, SD	bi	PC2	40.5	51.8	59.5
54	-21	Reject	Form	Dp, Dd	bi	PC2	38.1	53.2	61.9
55	-22	Reject	Form	Bp, SD, Dd	tri	PC2	33.3	57.3	71.4
55	-22	Reject	Shape	Bp, SD	bi	PC1	39.6	51.1	60.4
56	-23	Reject	Form	Bp, SD, Dp	tri	PC3	33.3	56.4	66.7
57	-24	Reject	Form	Bp, SD, Bd	tri	PC3	40.5	48.0	54.8
58	-25	Reject	Form	Bp, Dp	bi	PC2	33.3	54.5	66.7
58	-25	Reject	Form	Dd, SD	bi	PC2	28.6	59.6	76.2
59	-26	Reject	Shape	Bd, SD	bi	PC1	38.1	48.6	57.1
60	-27	Reject	Shape	Bp, SD, Dp	tri	PC2	38.1	47.3	57.1
61	-28	Reject	Form	Bp, Dp, Dd	tri	PC2	33.3	51.8	61.9
62	-30	Reject	Form	Bp, SD, Bd	tri	PC2	33.3	49.8	61.9
63	-32	Reject	Shape	Bp, Dd	bi	PC1	28.6	52.5	71.4
64	-34	Reject	Form	Bp, SD	bi	PC2	33.3	45.3	52.1
65	-36	Reject	Form	Bp, GL, SD	tri	PC3	33.3	43.1	50.0
66	-38	Reject	Form	Bd, SD	bi	PC2	30.9	43.6	57.1
67	-40	Reject	Form	Bp, Dd	bi	PC2	28.6	44.1	57.1
68	-43	Reject	Form	GL, Bd	bi	PC2	28.6	41.0	52.4
69	-44	Reject	Form	Bd, GL	bi	PC2	28.6	40.6	50.0
70	-49	Reject	Shape	Bp, SD, Bd	tri	PC2	26.2	37.9	47.6
71	-52	Reject	Shape	Bp, GL, Bd	tri	PC2	19.1	41.4	59.5

Table A.12: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
71	-52	Reject	Shape	Dp, Bd	bi	PC1	19.1	41.9	57.1
72	-53	Reject	Shape	Bp, Bd, Dd	tri	PC2	19.1	40.5	57.1
73	-54	Reject	Shape	Dp, Bd, SD	tri	PC1	19.1	39.6	57.1
74	-57	Reject	Shape	Dp, Bd, SD	tri	PC2	19.1	36.8	52.4
75	-58	Reject	Form	Bp, GL, Bd	tri	PC3	16.7	38.4	57.1
76	-60	Reject	Form	Dp, Bd, SD	tri	PC2	14.3	38.9	61.9
76	-60	Reject	Shape	Bp, SD, Dd	tri	PC2	18.8	34.3	52.4
77	-62	Reject	Shape	Bp, GL, SD	tri	PC2	19.1	31.4	42.9
78	-63	Reject	Shape	Dd, Bd, SD	tri	PC2	14.3	35.2	57.1
79	-64	Reject	Shape	Bp, GL, Dd	tri	PC2	14.3	34.3	52.4
80	-69	Reject	Form	Dp, SD	bi	PC2	14.3	29.8	47.6
81	-71	Reject	Form	Dp, Bd	bi	PC2	9.5	32.1	52.4
82	-72	Reject	Form	Bp, SD, Dp	tri	PC2	9.5	30.9	52.4
82	-72	Reject	Form	Dd, Bd, SD	tri	PC3	9.5	31.1	52.4
82	-72	Reject	Shape	Dp, GL, SD	tri	PC2	9.5	30.7	47.6
83	-74	Reject	Form	Bp, SD, Dd	tri	PC3	9.5	29.2	47.6
83	-74	Reject	Form	Dp, GL, Bd	tri	PC3	9.5	29.6	47.6
83	-74	Reject	Shape	Dp, GL, Bd	tri	PC2	9.5	29.6	47.6
83	-74	Reject	Shape	Dp, SD	bi	PC1	9.5	29.6	52.4
84	-75	Reject	Form	Bp, GL, Dd	tri	PC3	9.5	28.6	47.6
85	-76	Reject	Form	Bp, GL, Dp	tri	PC3	9.5	27.1	42.9
85	-76	Reject	Shape	Bp, Dp, Dd	tri	PC2	9.5	27.0	42.9
86	-77	Reject	Form	Bp, Bd, Dd	tri	PC3	4.8	30.5	52.4
86	-77	Reject	Form	Bp, Dp, Bd	tri	PC3	9.5	26.0	42.9
86	-77	Reject	Form	Dp, Bd, SD	tri	PC3	9.5	25.8	42.9
87	-81	Reject	Form	Dp, GL, SD	tri	PC3	4.8	27.4	42.9
87	-81	Reject	Shape	Dp, GL, Dd	tri	PC2	4.8	26.6	47.6
88	-82	Reject	Form	Bp, Dp, Dd	tri	PC3	4.8	26.1	42.9

Table A.12: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
88	-82	Reject	Shape	Dp, Bd, Dd	tri	PC2	4.8	25.9	47.6
89	-83	Reject	Form	Dp, Bd, Dd	tri	PC3	4.8	25.2	47.6
90	-84	Reject	Shape	Bp, Dp, Bd	tri	PC2	4.8	24.4	42.9
91	-86	Reject	Form	Dp, GL, Dd	tri	PC3	4.8	21.6	42.9
91	-86	Reject	Shape	Bp, GL, Dp	tri	PC2	4.8	22.0	38.1

A.3.5 Ulna

Table A.13: List of approaches ranked by score for balanced cross-validation results for the ulna (Subset A).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	70	Prefer	Form	BPC, SDO, GL	tri	PC1	100.0	100.0	100.0
2	66	Prefer	Form	SDO, GL	bi	PC1	97.9	97.9	97.9
3	64	Prefer	Shape	BPC, SDO, GL	tri	PC1	95.8	97.9	100.0
4	63	Prefer	Form	BPC, DPA, SDO	tri	PC1	96.4	96.8	98.2
4	63	Prefer	Form	BPC, SDO	bi	PC1	96.4	96.9	98.2
4	63	Prefer	Size	BPC, DPA, SDO	tri	–	96.4	96.9	98.2
4	63	Prefer	Size	BPC, SDO	bi	–	96.4	97.0	100.0
5	62	Prefer	Shape	BPC, DPA, GL	tri	PC1	96.2	96.2	96.2
5	62	Prefer	Shape	DPA, SDO, GL	tri	PC1	95.8	95.8	95.8
5	62	Prefer	Shape	SDO, GL	bi	PC1	95.8	95.8	95.8
5	62	Prefer	Size	BPC, SDO, GL	tri	–	95.8	96.3	100.0
6	61	Prefer	Form	DPA, SDO	bi	PC1	94.6	96.0	98.2
6	61	Prefer	Size	DPA, SDO	bi	–	94.6	96.0	98.2
6	61	Prefer	Form	SDO	uni	–	94.6	96.1	98.2
7	59	Prefer	Form	DPA, SDO, GL	tri	PC1	93.8	95.7	97.9
8	58	Prefer	Form	BPC, DPA, GL	tri	PC1	94.2	94.2	94.2
9	55	Prefer	Form	BPC, GL	bi	PC1	92.3	92.3	92.3

Table A.13: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
10	54	Prefer	Size	DPA, SDO, GL	tri	–	91.7	92.1	93.8
10	54	Prefer	Size	SDO, GL	bi	–	91.7	92.1	93.8
11	52	Accept	Form	BPC, DPA	bi	PC1	90.3	91.3	93.5
11	52	Accept	Size	BPC, DPA	bi	–	90.3	91.4	93.5
12	51	Accept	Shape	BPC, GL	bi	PC1	90.4	90.4	90.4
12	51	Accept	Size	BPC, DPA, GL	tri	–	90.4	90.4	90.4
13	49	Accept	Form	BPC	uni	–	89.1	90.2	92.2
14	43	Accept	Form	DPA, GL	bi	PC1	86.5	86.5	86.5
14	43	Accept	Shape	DPA, GL	bi	PC1	86.5	86.5	86.5
15	40	Accept	Form	DPA	uni	–	83.9	86.5	88.7
16	39	Accept	Size	BPC, GL	bi	–	84.6	84.6	84.6
17	37	Accept	Shape	DPA, SDO	bi	PC1	82.1	84.6	87.5
18	31	Accept	Shape	BPC, DPA, SDO	tri	PC2	78.6	82.0	85.7
19	24	Accept	Size	DPA, GL	bi	–	76.9	76.9	76.9
20	5	Reject	Form	DPA, GL	bi	PC2	67.3	67.3	67.3
21	2	Reject	Shape	BPC, SDO	bi	PC1	64.3	67.5	71.4
22	1	Reject	Form	BPC, DPA, SDO	tri	PC3	64.3	66.2	69.6
23	-7	Reject	Form	BPC, DPA, GL	tri	PC2	61.5	61.5	61.5
23	-7	Reject	Form	BPC, GL	bi	PC2	61.5	61.5	61.5
23	-7	Reject	Form	SDO, GL	bi	PC2	60.4	62.7	64.6
24	-8	Reject	Form	BPC, SDO, GL	tri	PC2	60.4	62.0	64.6
25	-9	Reject	Shape	BPC, DPA, SDO	tri	PC1	58.9	62.5	67.9
25	-9	Reject	Form	DPA, SDO	bi	PC2	57.1	63.6	69.6
26	-11	Reject	Form	BPC, DPA, GL	tri	PC3	59.6	59.6	59.6
26	-11	Reject	Form	DPA, SDO, GL	tri	PC2	58.3	61.1	64.6
27	-14	Reject	Form	DPA, SDO, GL	tri	PC3	56.2	59.6	62.5
27	-14	Reject	Shape	BPC, DPA	bi	PC1	56.5	59.3	61.3
28	-15	Reject	Form	BPC, DPA	bi	PC2	56.5	58.2	61.3

Table A.13: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
29	-18	Reject	Shape	BPC, DPA, GL	tri	PC2	55.8	55.8	55.8
30	-23	Reject	Shape	DPA, SDO, GL	tri	PC2	52.1	54.5	58.3
31	-38	Reject	Form	GL	uni	–	46.1	46.1	46.1
32	-56	Reject	Form	BPC, SDO	bi	PC2	24.9	49.0	55.4
33	-57	Reject	Shape	BPC, SDO, GL	tri	PC2	29.2	43.7	50.0
34	-86	Reject	Form	BPC, DPA, SDO	tri	PC2	5.4	39.0	55.4
35	-88	Reject	Form	BPC, SDO, GL	tri	PC3	6.2	36.1	58.3

Table A.14: List of approaches ranked by score for balanced cross-validation results for the ulna (Subset B).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	81	Prefer	Form	BPC, DPA, SDO	tri	PC1	95.6	98.0	100.0
1	81	Prefer	Form	BPC, SDO	bi	PC1	95.6	98.2	100.0
1	81	Prefer	Size	BPC, DPA, SDO	tri	–	95.6	98.1	100.0
1	81	Prefer	Size	BPC, SDO	bi	–	95.6	98.3	100.0
2	80	Prefer	Size	BPC, SDO, GL	tri	–	95.2	97.9	100.0
3	78	Prefer	Form	DPA, SDO	bi	PC1	93.3	97.4	100.0
3	78	Prefer	Size	DPA, SDO	bi	–	93.3	97.1	100.0
3	78	Prefer	Form	SDO	uni	–	93.3	97.3	100.0
4	77	Prefer	Form	BPC, SDO, GL	tri	PC1	92.9	96.7	100.0
4	77	Prefer	Shape	BPC, DPA, GL	tri	PC1	92.9	96.4	100.0
5	76	Prefer	Shape	BPC, SDO, GL	tri	PC1	92.9	96.1	100.0
6	73	Prefer	Form	DPA, SDO, GL	tri	PC1	90.5	94.8	97.6
6	73	Prefer	Size	DPA, SDO, GL	tri	–	90.5	95.1	100.0
7	72	Prefer	Size	SDO, GL	bi	–	90.5	94.3	97.6
8	70	Prefer	Form	BPC, DPA	bi	PC1	88.9	94.1	97.8
8	70	Prefer	Size	BPC, DPA	bi	–	88.9	94.1	97.8

Table A.14: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
9	68	Prefer	Form	SDO, GL	bi	PC1	88.1	92.4	97.6
9	68	Prefer	Shape	SDO, GL	bi	PC1	88.1	92.2	95.2
10	67	Prefer	Shape	BPC, GL	bi	PC1	88.1	92.1	97.6
10	67	Prefer	Size	BPC, DPA, GL	tri	–	88.1	92.1	97.6
11	66	Accept	Form	BPC	uni	–	86.3	92.3	96.1
12	65	Accept	Shape	DPA, SDO, GL	tri	PC1	85.7	91.6	97.6
13	63	Accept	Shape	DPA, GL	bi	PC1	85.7	90.2	95.2
14	62	Accept	Form	DPA	uni	–	84.4	90.7	95.6
15	60	Accept	Form	BPC, DPA, GL	tri	PC1	83.3	89.1	95.2
16	59	Accept	Size	BPC, GL	bi	–	83.3	88.1	92.9
17	54	Accept	Size	DPA, GL	bi	–	80.8	85.7	92.9
18	51	Accept	Form	BPC, GL	bi	PC1	78.6	84.7	90.5
19	45	Accept	Form	DPA, GL	bi	PC1	76.2	81.5	88.1
20	40	Accept	Form	SDO, GL	bi	PC2	73.8	79.0	85.7
21	34	Accept	Form	BPC, SDO, GL	tri	PC2	71.4	75.1	81.0
22	32	Accept	Form	BPC, DPA, GL	tri	PC2	69.0	75.5	81.0
23	31	Reject	Form	DPA, SDO, GL	tri	PC2	69.0	74.7	81.0
24	26	Reject	Shape	DPA, SDO	bi	PC1	66.7	72.5	80.0
24	26	Reject	Form	BPC, GL	bi	PC2	66.7	72.0	78.6
25	15	Reject	Shape	BPC, DPA, SDO	tri	PC1	60.0	67.9	75.6
26	8	Reject	Form	DPA, GL	bi	PC2	57.1	63.6	71.4
27	3	Reject	Shape	DPA, SDO, GL	tri	PC2	52.4	63.4	71.4
28	2	Reject	Shape	BPC, SDO	bi	PC1	53.3	61.8	68.9
29	-11	Reject	Form	GL	uni	–	38.1	63.9	73.8
30	-29	Reject	Shape	BPC, DPA, SDO	tri	PC2	37.8	46.3	55.6
30	-29	Reject	Shape	BPC, SDO, GL	tri	PC2	33.3	50.7	59.5
31	-38	Reject	Form	BPC, DPA, SDO	tri	PC3	31.0	43.5	51.1
32	-45	Reject	Form	DPA, SDO	bi	PC2	26.7	41.1	48.9

Table A.14: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
33	-55	Reject	Shape	BPC, DPA, GL	tri	PC2	21.4	36.1	47.6
34	-64	Reject	Shape	BPC, DPA	bi	PC1	15.6	33.0	46.7
35	-65	Reject	Form	BPC, DPA	bi	PC2	15.4	32.2	46.7
36	-66	Reject	Form	DPA, SDO, GL	tri	PC3	14.3	32.0	42.9
37	-68	Reject	Form	BPC, SDO	bi	PC2	13.3	31.4	46.7
38	-70	Reject	Form	BPC, DPA, SDO	tri	PC2	13.3	29.1	42.2
39	-73	Reject	Form	BPC, SDO, GL	tri	PC3	11.9	28.0	42.9
40	-74	Reject	Form	BPC, DPA, GL	tri	PC3	11.9	27.1	38.1

A.3.6 Pelvis

Table A.15: List of approaches ranked by score for balanced cross-validation results for the pelvis (Subset A).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	48	Prefer	Form	LFo, GL	bi	PC1	88.6	89.2	90.9
2	45	Prefer	Size	LFo, GL	bi	–	86.4	88.3	90.9
2	45	Prefer	Form	GL	uni	–	87.0	88.0	91.3
3	44	Prefer	Form	LFo, SH, GL	tri	PC1	86.4	87.2	88.8
4	43	Prefer	Size	LFo, SH, GL	tri	–	86.4	86.8	88.6
5	40	Prefer	Form	SH, GL	bi	PC1	84.8	85.6	87.0
5	40	Prefer	Size	SH, GL	bi	–	84.8	85.6	87.0
6	31	Prefer	Form	LFo	uni	–	80.3	80.3	80.3
7	29	Prefer	Form	SH, LFo	bi	PC1	79.0	80.3	82.3
7	29	Prefer	Size	SB, SH, GL	tri	–	78.3	81.2	84.8
7	29	Prefer	Size	SH, LFo	bi	–	79.0	80.1	82.3
8	28	Prefer	Form	SB, SH, GL	tri	PC1	78.3	79.7	84.8
8	28	Prefer	Size	SB, LFo	bi	–	79.0	79.3	80.7
9	27	Prefer	Form	SB, LFo	bi	PC1	77.4	79.2	80.7

Table A.15: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
9	27	Prefer	Form	SH	uni	–	78.1	79.2	81.2
10	26	Prefer	Form	LFo, SB, GL	tri	PC1	77.3	78.9	81.8
10	26	Prefer	Size	LFo, SB, GL	tri	–	77.3	78.8	81.8
10	26	Prefer	Size	SB, GL	bi	–	76.1	79.7	82.6
11	22	Accept	Form	LFo, SB, SH	tri	PC1	75.8	75.8	75.8
11	22	Accept	Form	SB, GL	bi	PC1	73.9	77.8	80.4
11	22	Accept	Size	LFo, SB, SH	tri	–	75.8	75.8	75.8
12	19	Accept	Form	SB, SH	bi	PC1	73.4	75.9	78.1
12	19	Accept	Size	SB, SH	bi	–	73.4	75.7	78.1
13	13	Reject	Form	SB, GL	bi	PC2	69.6	73.8	78.3
14	11	Reject	Form	SB, SH, GL	tri	PC2	69.6	71.0	76.1
15	9	Reject	Form	SB	uni	–	69.1	69.6	70.6
16	8	Reject	Shape	SB, GL	bi	PC1	67.4	71.0	73.9
17	3	Reject	Shape	SB, SH, GL	tri	PC1	65.2	68.2	71.7
18	-1	Reject	Form	LFo, SB, SH	tri	PC2	64.5	64.5	64.5
18	-1	Reject	Shape	LFo, SB, SH	tri	PC1	64.5	64.5	64.5
19	-2	Reject	Shape	SB, LFo	bi	PC1	62.9	65.0	66.1
19	-2	Reject	Form	SB, LFo	bi	PC2	62.9	64.8	66.1
20	-12	Reject	Shape	LFo, SB, GL	tri	PC1	56.8	60.8	63.6
21	-15	Reject	Form	SB, SH, GL	tri	PC3	54.4	60.2	63.0
21	-15	Reject	Form	SH, GL	bi	PC2	56.5	58.2	60.9
22	-18	Reject	Form	LFo, SB, GL	tri	PC2	54.5	57.3	61.4
22	-18	Reject	Form	LFo, SB, GL	tri	PC3	54.5	57.2	59.1
22	-18	Reject	Shape	SB, SH	bi	PC1	54.7	57.6	59.4
23	-19	Reject	Form	LFo, GL	bi	PC2	54.5	56.7	59.1
23	-19	Reject	Form	SB, SH	bi	PC2	54.7	56.7	59.4
24	-24	Reject	Form	LFo, SH, GL	tri	PC3	50.0	55.5	63.6
25	-27	Reject	Form	LFo, SB, SH	tri	PC3	51.6	51.6	51.6

Table A.15: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
26	-29	Reject	Shape	LFo, SB, GL	tri	PC2	47.7	53.4	56.8
26	-29	Reject	Form	SH, LFo	bi	PC2	48.4	52.2	54.8
27	-30	Reject	Shape	SH, LFo	bi	PC1	48.4	52.0	54.8
28	-36	Reject	Shape	LFo, SB, SH	tri	PC2	46.8	46.8	46.8
29	-67	Reject	Shape	SB, SH, GL	tri	PC2	17.4	45.9	54.4
30	-81	Reject	Shape	SH, GL	bi	PC1	4.3	44.6	56.5
31	-82	Reject	Shape	LFo, SH, GL	tri	PC2	6.8	41.3	52.3
32	-83	Reject	Shape	LFo, SH, GL	tri	PC1	6.8	40.4	54.5
33	-85	Reject	Form	LFo, SH, GL	tri	PC2	4.5	40.3	56.8
34	-89	Reject	Shape	LFo, GL	bi	PC1	4.5	36.5	56.9

Table A.16: List of approaches ranked by score for balanced cross-validation results for the pelvis (Subset B).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	65	Prefer	Size	LFo, GL	bi	–	85.2	92.2	100.0
1	65	Prefer	Form	GL	uni	–	85.2	92.1	100.0
2	64	Prefer	Form	LFo, GL	bi	PC1	85.2	91.9	100.0
2	64	Prefer	Size	LFo, SH, GL	tri	–	85.2	91.0	96.3
3	63	Prefer	Size	SH, GL	bi	–	85.2	90.6	96.3
4	59	Prefer	Form	LFo, SH, GL	tri	PC1	81.5	90.4	96.3
4	59	Prefer	Form	SH, GL	bi	PC1	81.5	90.3	96.3
5	53	Prefer	Form	SH, LFo	bi	PC1	79.5	85.8	92.3
5	53	Prefer	Size	SH, LFo	bi	–	79.5	85.9	92.3
6	52	Prefer	Form	LFo, SB, GL	tri	PC1	77.8	86.8	96.3
6	52	Prefer	Form	SB, SH, GL	tri	PC1	77.8	86.6	92.8
6	52	Prefer	Size	LFo, SB, GL	tri	–	77.8	86.8	96.3
6	52	Prefer	Size	SB, LFo	bi	–	78.6	85.8	92.9

Table A.16: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
6	52	Prefer	Size	SB, SH, GL	tri	–	77.8	86.7	92.8
7	51	Prefer	Form	SB, LFo	bi	PC1	78.6	85.5	92.9
7	51	Prefer	Size	SB, GL	bi	–	77.8	85.9	92.6
7	51	Prefer	Form	SH	uni	–	78.6	85.4	92.9
8	50	Prefer	Form	SB, GL	bi	PC1	77.8	84.5	92.6
9	49	Prefer	Form	LFo, SB, SH	tri	PC1	76.9	84.6	92.3
9	49	Prefer	Size	LFo, SB, SH	tri	–	76.9	85.1	92.3
10	47	Prefer	Form	LFo	uni	–	76.2	84.0	90.5
11	46	Accept	Form	SB, SH	bi	PC1	76.2	82.7	90.5
11	46	Accept	Size	SB, SH	bi	–	76.2	82.3	88.1
12	30	Accept	Form	SB	uni	–	66.7	75.6	82.2
13	-15	Reject	Shape	SH, GL	bi	PC1	37.0	60.5	74.1
14	-16	Reject	Shape	LFo, SH, GL	tri	PC1	37.0	59.3	74.1
15	-20	Reject	Shape	SB, SH, GL	tri	PC2	33.3	59.0	74.1
16	-23	Reject	Shape	SH, LFo	bi	PC1	35.9	54.1	66.7
17	-27	Reject	Shape	SB, SH	bi	PC1	38.1	47.9	57.1
18	-29	Reject	Shape	LFo, SB, SH	tri	PC2	35.9	47.7	59.0
19	-37	Reject	Shape	LFo, SB, SH	tri	PC1	30.8	45.1	53.9
20	-41	Reject	Shape	LFo, SH, GL	tri	PC2	25.9	46.1	59.3
20	-41	Reject	Shape	SB, GL	bi	PC1	25.9	46.2	59.3
20	-41	Reject	Shape	SB, LFo	bi	PC1	28.6	43.2	52.4
21	-44	Reject	Shape	LFo, SB, GL	tri	PC2	25.9	43.2	55.6
22	-45	Reject	Form	SB, GL	bi	PC2	25.9	41.6	52.0
23	-50	Reject	Form	SH, GL	bi	PC2	22.2	40.1	51.9
24	-51	Reject	Form	SB, SH, GL	tri	PC3	22.2	39.1	55.6
24	-51	Reject	Form	SH, LFo	bi	PC2	23.1	38.1	51.3
25	-52	Reject	Form	LFo, SH, GL	tri	PC2	22.2	38.7	51.9
26	-53	Reject	Form	LFo, SB, GL	tri	PC3	18.5	41.4	59.3

Table A.16: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
26	-53	Reject	Shape	LFo, GL	bi	PC1	22.2	37.1	51.9
26	-53	Reject	Form	SB, LFo	bi	PC2	21.4	38.6	50.0
27	-55	Reject	Form	LFo, SB, SH	tri	PC2	20.5	37.4	48.7
28	-57	Reject	Form	SB, SH, GL	tri	PC2	18.5	37.4	51.9
28	-57	Reject	Shape	SB, SH, GL	tri	PC1	18.5	37.1	51.9
29	-58	Reject	Form	LFo, SH, GL	tri	PC3	18.5	36.5	51.9
30	-60	Reject	Shape	LFo, SB, GL	tri	PC1	18.5	33.8	48.1
31	-61	Reject	Form	LFo, GL	bi	PC2	18.5	32.9	44.4
32	-62	Reject	Form	LFo, SB, SH	tri	PC3	17.9	32.7	43.6
33	-63	Reject	Form	LFo, SB, GL	tri	PC2	14.8	35.3	51.9
34	-67	Reject	Form	SB, SH	bi	PC2	16.6	28.7	40.5

A.3.7 Femur

Table A.17: List of approaches ranked by score for balanced cross-validation results for the femur (Subset A).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	61	Prefer	Shape	Bp, DC, GLC	tri	PC1	95.2	96.1	98.4
2	59	Prefer	Shape	Bp, DC, GL	tri	PC1	93.5	95.1	96.8
3	56	Prefer	Shape	Bp, GL, GLC	tri	PC1	92.2	93.7	95.3
4	55	Prefer	Shape	Bp, BTr, GLC	tri	PC1	91.1	93.9	94.6
5	54	Prefer	Shape	Bp, GLC, Bd	tri	PC1	90.7	92.9	96.3
5	54	Prefer	Shape	Bp, GLC	bi	PC1	90.6	93.1	95.3
6	53	Prefer	Form	Bp, DC, Bd	tri	PC1	90.4	92.7	96.2
6	53	Prefer	Shape	Bp, BTr, GL	tri	PC1	91.1	92.1	94.6
7	51	Prefer	Shape	Bp, GL, Bd	tri	PC1	88.9	92.0	94.4
7	51	Prefer	Shape	Bp, GL	bi	PC1	89.1	91.9	93.8
8	50	Prefer	Shape	DC, GLC, Bd	tri	PC1	88.9	90.8	92.6

Table A.17: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
9	49	Prefer	Size	Bp, Bd	bi	–	87.0	92.2	96.3
9	49	Prefer	Size	Bp, DC, Bd	tri	–	86.5	92.0	96.2
10	48	Prefer	Form	Bp, Bd	bi	PC1	87.0	90.9	94.4
10	48	Prefer	Shape	Bp, BTr, DC	tri	PC1	87.5	90.5	92.9
10	48	Prefer	Shape	Bp, BTr	bi	PC1	87.5	90.4	92.9
10	48	Prefer	Shape	BTr, DC, SD	tri	PC1	87.9	90.0	93.1
11	47	Accept	Form	Bp, DC	bi	PC1	87.1	89.5	91.9
11	47	Accept	Form	Bp, DC, SD	tri	PC1	87.1	89.7	91.9
11	47	Accept	Form	DC, Bd	bi	PC1	87.0	89.5	92.6
11	47	Accept	Shape	DC, GLC	bi	PC1	87.5	89.1	90.6
11	47	Accept	Size	Bp, DC	bi	–	87.1	89.7	93.5
11	47	Accept	Size	Bp, DC, SD	tri	–	87.1	89.8	91.9
12	46	Accept	Shape	Bp, BTr, Bd	tri	PC1	87.0	89.3	91.3
12	46	Accept	Size	DC, Bd	bi	–	87.0	89.2	92.6
13	45	Accept	Size	DC, SD	bi	–	86.4	88.3	90.9
14	44	Accept	Form	Bp, BTr, DC	tri	PC1	85.7	88.7	92.9
14	44	Accept	Form	Bp, DC, GL	tri	PC1	85.5	88.1	90.3
14	44	Accept	Form	Bp, GL, Bd	tri	PC1	85.2	88.5	90.7
14	44	Accept	Form	Bp, GLC, Bd	tri	PC1	85.2	88.4	90.7
14	44	Accept	Shape	DC, GL, GLC	tri	PC1	85.5	88.3	90.3
14	44	Accept	Shape	DC, GL	bi	PC1	85.5	88.2	90.3
15	43	Accept	Form	Bp, DC, GLC	tri	PC1	85.5	87.9	90.3
15	43	Accept	Shape	DC, GL, Bd	tri	PC1	84.6	88.6	92.3
16	42	Accept	Form	Bp	uni	–	84.4	87.5	90.6
17	41	Accept	Shape	BTr, DC, Bd	tri	PC1	83.3	87.4	91.7
17	41	Accept	Shape	BTr, DC, GLC	tri	PC1	84.5	86.6	89.7
17	41	Accept	Size	DC, SD, Bd	tri	–	83.3	87.4	92.6
18	40	Accept	Form	BTr, DC, Bd	tri	PC1	83.3	86.8	89.6

Table A.17: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
18	40	Accept	Form	DC, SD, Bd	tri	PC1	83.3	87.0	90.7
18	40	Accept	Shape	Bp, BTr, SD	tri	PC1	83.9	85.9	89.3
18	40	Accept	Shape	BTr, DC, GL	tri	PC1	83.9	86.3	89.3
18	40	Accept	Form	DC	uni	–	83.3	86.8	90.9
19	39	Accept	Form	Bp, GL	bi	PC1	82.8	86.4	89.1
20	38	Accept	Form	Bp, BTr, Bd	tri	PC1	82.6	85.5	89.1
20	38	Accept	Form	Bp, GLC	bi	PC1	82.8	85.6	87.5
20	38	Accept	Form	DC, GLC, Bd	tri	PC1	81.5	86.5	90.7
20	38	Accept	Size	Bp, BTr, DC	tri	–	82.1	85.7	91.1
21	37	Accept	Form	DC, GL, Bd	tri	PC1	80.8	86.4	90.4
21	37	Accept	Form	Bd	uni	–	81.7	85.6	90.0
22	36	Accept	Form	DC, SD	bi	PC1	81.8	83.9	86.4
22	36	Accept	Shape	BTr, DC	bi	PC1	81.0	84.5	87.9
23	35	Accept	Shape	BTr, SD	bi	PC1	80.0	84.8	88.3
23	35	Accept	Size	Bp, DC, GL	tri	–	80.7	84.6	88.7
23	35	Accept	Size	Bp, DC, GLC	tri	–	80.7	84.3	88.7
24	34	Accept	Form	DC, GLC	bi	PC1	81.2	83.0	85.9
24	34	Accept	Size	Bp, GL, Bd	tri	–	79.6	84.6	88.9
24	34	Accept	Size	Bp, GLC, Bd	tri	–	79.6	84.3	87.0
25	32	Accept	Size	DC, GL, Bd	tri	–	78.8	83.0	88.5
26	31	Accept	Form	Bd, GLC	bi	PC1	78.6	82.8	87.5
26	31	Accept	Form	DC, GL	bi	PC1	79.0	82.4	85.5
26	31	Accept	Size	BTr, DC, Bd	tri	–	79.2	82.2	85.4
27	30	Accept	Form	Bd, GL	bi	PC1	77.8	82.1	85.2
27	30	Accept	Form	BTr, DC	bi	PC1	77.6	82.3	86.2
27	30	Accept	Size	Bp, SD	bi	–	78.1	81.5	84.4
27	30	Accept	Size	DC, GLC, Bd	tri	–	77.8	82.2	87.0
28	29	Accept	Form	Bp, GL, SD	tri	PC1	78.1	81.1	84.4

Table A.17: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
28	29	Accept	Form	Bp, GLC, SD	tri	PC1	78.1	80.5	82.8
28	29	Accept	Form	BTr, DC, GLC	tri	PC1	77.6	81.0	84.5
28	29	Accept	Form	BTr, DC, SD	tri	PC1	77.6	81.9	86.2
28	29	Accept	Form	DC, GLC, SD	tri	PC1	78.1	80.5	84.4
28	29	Accept	Shape	BTr, GLC, SD	tri	PC1	77.6	81.0	84.5
28	29	Accept	Size	Bd, GL	bi	–	77.8	81.2	85.2
29	28	Accept	Form	DC, GL, SD	tri	PC1	77.4	80.8	85.5
29	28	Accept	Shape	BTr, GL, SD	tri	PC1	76.8	81.3	85.7
29	28	Accept	Size	Bd, GLC	bi	–	76.8	81.2	85.7
30	27	Accept	Form	Bp, GL, GLC	tri	PC1	76.6	80.0	84.4
30	27	Accept	Form	Bp, SD	bi	PC1	76.6	80.2	84.4
30	27	Accept	Form	BTr, DC, GL	tri	PC1	76.8	80.5	83.9
30	27	Accept	Form	BTr, GL, Bd	tri	PC2	76.1	80.5	84.8
30	27	Accept	Size	Bp, BTr, Bd	tri	–	76.1	80.6	84.8
30	27	Accept	Size	Bp, GL	bi	–	76.6	80.2	84.4
30	27	Accept	Size	Bp, GL, SD	tri	–	76.6	80.2	82.8
30	27	Accept	Size	Bp, GLC, SD	tri	–	76.6	80.2	82.8
30	27	Accept	Form	BTr, Bd	bi	PC2	77.1	80.3	83.3
31	26	Accept	Shape	Bp, GLC, SD	tri	PC1	76.6	79.7	82.8
31	26	Accept	Size	Bd, SD	bi	–	75.0	80.8	83.9
31	26	Accept	Size	Bp, GLC	bi	–	76.6	79.8	82.9
31	26	Accept	Size	BTr, DC, SD	tri	–	75.9	79.9	84.5
31	26	Accept	Form	Bp, BTr	bi	PC2	76.8	79.5	82.1
32	25	Accept	Shape	SD, GLC	bi	PC1	75.8	79.2	81.8
33	24	Accept	Form	Bp, BTr, GL	tri	PC1	75.0	78.6	82.1
33	24	Accept	Form	Bp, BTr, SD	tri	PC1	75.0	78.9	82.1
33	24	Accept	Form	BTr, GLC, Bd	tri	PC2	75.0	78.6	81.3
33	24	Accept	Form	GL, GLC, Bd	tri	PC1	74.1	79.7	85.2

Table A.17: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
33	24	Accept	Shape	GL, GLC, SD	tri	PC1	75.0	78.7	81.2
34	23	Accept	Form	Bp, BTr, GLC	tri	PC1	75.0	78.3	82.1
34	23	Accept	Form	Bp, BTr, GLC	tri	PC2	75.0	78.3	82.1
34	23	Accept	Form	Bp, BTr	bi	PC1	75.0	78.3	82.1
34	23	Accept	Form	DC, GL, GLC	tri	PC1	75.8	77.2	79.0
34	23	Accept	Shape	Bd, GL	bi	PC1	74.1	78.5	85.2
34	23	Accept	Shape	Bp, DC, Bd	tri	PC2	75.0	78.1	80.8
35	22	Accept	Form	Bp, BTr, GL	tri	PC2	75.0	77.1	80.4
35	22	Accept	Shape	BTr, GL, Bd	tri	PC1	73.9	78.3	82.6
35	22	Accept	Shape	GL, GLC, Bd	tri	PC1	74.1	78.2	83.3
36	21	Accept	Form	Bd, SD	bi	PC1	73.2	78.0	82.1
36	21	Accept	Form	GLC, SD, Bd	tri	PC1	73.2	77.8	82.1
36	21	Accept	Shape	BTr, Bd	bi	PC1	72.9	77.8	83.3
36	21	Accept	Size	BTr, DC	bi	–	74.1	76.7	79.3
36	21	Accept	Size	DC, GLC, SD	tri	–	73.4	77.7	81.2
36	21	Accept	Size	GL, SD, Bd	tri	–	72.2	78.6	83.3
37	20	Accept	Form	GL, SD, Bd	tri	PC1	72.2	77.5	81.5
37	20	Accept	Shape	BTr, GLC, Bd	tri	PC1	72.9	76.7	81.2
37	20	Accept	Shape	SD, GL	bi	PC1	73.4	76.9	79.7
37	20	Accept	Size	Bp, BTr, SD	tri	–	73.2	76.6	80.4
37	20	Accept	Size	DC, GL, SD	tri	–	72.6	77.8	80.7
37	20	Accept	Size	GL, GLC, Bd	tri	–	72.2	77.6	83.3
38	19	Accept	Size	Bp, GL, GLC	tri	–	73.4	75.7	79.7
38	19	Accept	Size	GLC, SD, Bd	tri	–	71.4	77.2	83.9
39	18	Accept	Shape	Bd, GLC	bi	PC1	71.4	76.9	83.9
39	18	Accept	Size	DC, GL	bi	–	72.6	75.1	80.7
40	17	Accept	Shape	Bp, GL, SD	tri	PC1	71.9	75.4	78.1
40	17	Accept	Shape	DC, GLC, SD	tri	PC1	71.9	75.1	78.1

Table A.17: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
40	17	Accept	Size	BTr, DC, GL	tri	–	71.4	75.3	78.6
40	17	Accept	Size	DC, GLC	bi	–	71.9	75.3	79.7
41	16	Accept	Shape	DC, Bd	bi	PC1	70.4	75.8	81.5
42	15	Reject	Form	SD, GLC	bi	PC1	71.2	73.4	77.3
42	15	Reject	Size	BTr, DC, GLC	tri	–	70.7	74.6	79.3
43	14	Reject	Form	SD, GL	bi	PC1	70.3	73.8	78.1
43	14	Reject	Size	DC, GL, GLC	tri	–	71.0	73.1	77.4
43	14	Reject	Form	BTr, SD	bi	PC2	70.0	73.6	76.7
44	13	Reject	Shape	Bp, GLC, SD	tri	PC2	70.2	72.5	75.0
44	13	Reject	Shape	DC, GL, SD	tri	PC2	69.3	73.8	77.4
44	13	Reject	Size	Bp, BTr, GL	tri	–	69.6	73.8	76.8
44	13	Reject	Size	Bp, BTr, GLC	tri	–	69.6	73.1	76.8
44	13	Reject	Size	BTr, GL, Bd	tri	–	69.6	73.8	78.3
45	12	Reject	Size	Bp, BTr	bi	–	67.9	74.2	80.4
45	12	Reject	Size	BTr, GLC, Bd	tri	–	68.8	73.1	77.1
46	11	Reject	Form	Bp, BTr, Bd	tri	PC2	67.4	73.6	78.3
46	11	Reject	Shape	DC, GL, SD	tri	PC1	67.7	72.8	77.4
46	11	Reject	Size	SD, GLC	bi	–	68.2	72.9	75.8
46	11	Reject	Form	SD	uni	–	68.6	72.2	75.7
47	9	Reject	Form	BTr, DC, GL	tri	PC2	67.9	71.2	75.0
47	9	Reject	Form	GL, GLC, Bd	tri	PC2	66.7	72.8	77.8
47	9	Reject	Shape	DC, SD, Bd	tri	PC2	66.7	72.5	77.9
47	9	Reject	Size	BTr, GL, SD	tri	–	67.9	71.2	75.0
47	9	Reject	Size	BTr, GLC, SD	tri	–	67.2	71.5	75.9
47	9	Reject	Size	GL, GLC, SD	tri	–	67.2	71.9	75.0
47	9	Reject	Size	SD, GL	bi	–	67.2	71.9	76.6
48	8	Reject	Form	BTr, DC, SD	tri	PC2	67.2	70.7	74.1
48	8	Reject	Form	GL, GLC, SD	tri	PC1	67.2	71.1	75.0

Table A.17: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
48	8	Reject	Shape	Bp, GL, SD	tri	PC2	67.2	70.6	73.4
48	8	Reject	Shape	GL, SD, Bd	tri	PC2	66.7	71.2	75.9
49	7	Reject	Form	BTr, DC, GLC	tri	PC2	65.5	71.0	75.9
49	7	Reject	Form	BTr, GLC, SD	tri	PC1	67.2	69.8	74.1
49	7	Reject	Size	BTr, Bd	bi	–	66.7	70.0	75.0
49	7	Reject	Form	BTr, DC	bi	PC2	67.2	70.1	72.4
50	6	Reject	Form	BTr, GL, SD	tri	PC1	66.1	69.6	76.8
50	6	Reject	Form	DC, GL, GLC	tri	PC2	66.1	70.0	72.6
50	6	Reject	Shape	DC, GLC, SD	tri	PC2	65.6	70.8	76.6
50	6	Reject	Shape	GLC, SD, Bd	tri	PC1	66.1	70.2	75.0
51	5	Reject	Form	Bp, BTr, DC	tri	PC2	66.1	69.1	73.2
51	5	Reject	Form	BTr, GL, Bd	tri	PC1	65.2	70.0	73.9
51	5	Reject	Shape	Bp, Bd	bi	PC1	64.8	70.3	77.8
51	5	Reject	Shape	GLC, SD, Bd	tri	PC2	66.1	69.0	73.2
52	4	Reject	Form	Bp, GL, GLC	tri	PC2	65.6	68.8	73.4
52	4	Reject	Shape	GL, SD, Bd	tri	PC1	64.8	69.1	74.1
53	2	Reject	Form	BTr, DC, Bd	tri	PC2	62.5	69.1	75.0
54	1	Reject	Form	Bp, GLC, Bd	tri	PC2	63.0	67.8	72.2
55	0	Reject	Form	BTr, GLC, Bd	tri	PC1	62.5	67.7	72.9
56	-1	Reject	Form	Bp, BTr, SD	tri	PC2	62.5	66.7	69.6
56	-1	Reject	Form	GLC, SD, Bd	tri	PC3	62.5	66.4	69.6
56	-1	Reject	Shape	BTr, GLC, Bd	tri	PC2	62.4	66.5	70.8
56	-1	Reject	Form	Bd, GLC	bi	PC2	62.5	66.8	69.6
56	-1	Reject	Form	DC, GLC	bi	PC2	62.5	66.4	70.3
57	-2	Reject	Form	Bp, GLC, SD	tri	PC3	62.5	65.3	71.9
57	-2	Reject	Form	BTr, SD	bi	PC1	61.7	66.0	73.3
57	-2	Reject	Form	Bp, GLC	bi	PC2	62.5	65.6	68.8
58	-3	Reject	Form	Bp, GL, SD	tri	PC3	60.9	65.9	70.3

Table A.17: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
58	-3	Reject	Form	BTr, Bd	bi	PC1	60.4	67.0	72.9
58	-3	Reject	Size	BTr, SD	bi	–	61.7	64.9	68.3
58	-3	Reject	Form	DC, GL	bi	PC2	61.3	66.1	69.3
59	-5	Reject	Form	Bp, DC, GL	tri	PC3	59.7	64.9	67.7
59	-5	Reject	Form	BTr, GL, SD	tri	PC2	60.7	64.8	67.9
59	-5	Reject	Form	Bp, GL	bi	PC2	60.9	64.0	68.8
60	-7	Reject	Form	Bp, DC, GLC	tri	PC3	59.7	63.0	66.1
60	-7	Reject	Form	BTr, GLC, SD	tri	PC2	60.3	63.1	67.2
61	-8	Reject	Form	Bp, GL, Bd	tri	PC2	59.3	63.1	66.7
61	-8	Reject	Form	DC, GLC, SD	tri	PC3	57.8	63.9	68.8
61	-8	Reject	Shape	Bd, SD	bi	PC1	58.9	62.8	66.2
61	-8	Reject	Form	GL	uni	–	59.4	62.1	65.6
61	-8	Reject	Form	GLC	uni	–	59.1	63.3	66.7
62	-9	Reject	Form	DC, GL, SD	tri	PC3	58.1	62.6	66.1
62	-9	Reject	Form	GL, GLC	bi	PC1	59.4	62.1	65.6
62	-9	Reject	Size	GL, GLC	bi	–	59.4	62.1	65.6
63	-10	Reject	Form	GL, SD, Bd	tri	PC3	57.4	62.7	68.5
63	-10	Reject	Shape	BTr, GL, Bd	tri	PC2	56.5	63.5	69.6
64	-11	Reject	Size	BTr, GL, GLC	tri	–	57.1	61.8	67.9
64	-11	Reject	Form	Bd, GL	bi	PC2	57.4	62.0	66.7
64	-11	Reject	Form	BTr, GL	bi	PC2	57.1	61.7	66.1
65	-12	Reject	Form	BTr, GL, GLC	tri	PC1	57.1	60.8	64.3
65	-12	Reject	Form	DC, GL, Bd	tri	PC2	55.8	62.2	71.2
65	-12	Reject	Shape	BTr, DC, GLC	tri	PC2	56.9	61.1	65.5
65	-12	Reject	Size	BTr, GLC	bi	–	56.9	61.0	63.8
66	-13	Reject	Form	DC, GLC, Bd	tri	PC2	55.6	61.0	68.5
67	-15	Reject	Form	Bp, BTr, GLC	tri	PC3	55.4	59.4	62.5
67	-15	Reject	Form	BTr, GL, GLC	tri	PC2	55.4	59.5	62.5

Table A.17: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
67	-15	Reject	Shape	Bp, BTr, GLC	tri	PC2	55.4	59.5	64.3
68	-16	Reject	Form	Bp, BTr, DC	tri	PC3	55.4	59.0	62.5
68	-16	Reject	Shape	Bp, DC, GL	tri	PC2	54.8	59.4	66.1
68	-16	Reject	Shape	DC, SD, Bd	tri	PC1	53.7	60.0	66.7
68	-16	Reject	Form	DC, SD	bi	PC2	54.5	59.0	63.6
69	-17	Reject	Form	Bp, BTr, SD	tri	PC3	53.6	59.4	64.3
69	-17	Reject	Shape	Bp, BTr, DC	tri	PC2	53.6	59.1	62.5
69	-17	Reject	Shape	Bp, DC, GLC	tri	PC2	54.8	58.0	62.9
69	-17	Reject	Form	BTr, GLC	bi	PC2	55.2	58.0	62.1
70	-18	Reject	Form	Bp, GL, Bd	tri	PC3	53.7	58.0	63.0
70	-18	Reject	Size	BTr, GL	bi	–	53.6	58.5	62.5
71	-19	Reject	Form	BTr, GL, GLC	tri	PC3	53.6	57.4	60.7
71	-19	Reject	Shape	Bp, BTr, GL	tri	PC2	53.6	57.1	60.7
71	-19	Reject	Shape	Bp, BTr, SD	tri	PC2	53.6	57.8	60.7
71	-19	Reject	Shape	BTr, GL, GLC	tri	PC2	53.6	57.3	60.7
71	-19	Reject	Form	Bp, SD	bi	PC2	53.1	58.3	64.1
72	-20	Reject	Form	Bp, GLC, Bd	tri	PC3	51.9	58.2	63.0
72	-20	Reject	Form	DC, GL, SD	tri	PC2	53.2	56.4	59.7
72	-20	Reject	Form	DC, SD, Bd	tri	PC2	53.7	56.8	61.1
73	-21	Reject	Form	SD, GLC	bi	PC2	53.0	56.1	59.1
74	-22	Reject	Shape	Bp, BTr, Bd	tri	PC2	52.2	56.1	60.9
74	-22	Reject	Shape	BTr, DC, GL	tri	PC2	51.8	56.2	60.7
74	-22	Reject	Shape	BTr, GL	bi	PC1	51.8	56.6	60.7
74	-22	Reject	Form	Bd, SD	bi	PC2	51.8	56.1	60.7
75	-23	Reject	Form	Bp, DC, SD	tri	PC2	51.6	55.1	59.7
75	-23	Reject	Form	BTr, GLC	bi	PC1	51.7	55.3	60.3
75	-23	Reject	Form	DC, GLC, SD	tri	PC2	51.6	55.5	59.4
75	-23	Reject	Form	GL, GLC, SD	tri	PC2	51.6	55.5	59.4

Table A.17: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
75	-23	Reject	Shape	BTr, GL, GLC	tri	PC1	51.8	55.5	58.9
76	-25	Reject	Form	Bp, DC, GL	tri	PC2	50.0	55.2	59.7
76	-25	Reject	Form	GL, SD, Bd	tri	PC2	50.0	54.5	59.3
76	-25	Reject	Shape	BTr, DC, Bd	tri	PC2	50.0	55.2	62.5
77	-26	Reject	Form	Bp, BTr, GL	tri	PC3	50.0	53.8	58.9
77	-26	Reject	Shape	Bp, GL, Bd	tri	PC2	50.0	54.2	61.1
77	-26	Reject	Form	GL, GLC	bi	PC2	50.0	54.5	57.8
78	-28	Reject	Form	BTr, GL	bi	PC1	48.2	53.4	58.9
79	-29	Reject	Shape	GL, GLC	bi	PC1	48.4	52.4	57.8
80	-30	Reject	Form	BTr, DC, GLC	tri	PC3	48.3	51.6	55.2
80	-30	Reject	Form	GLC, SD, Bd	tri	PC2	48.2	51.7	55.4
81	-32	Reject	Form	Bp, GL, SD	tri	PC2	46.9	50.7	54.7
81	-32	Reject	Form	SD, GL	bi	PC2	46.9	51.5	57.8
82	-33	Reject	Form	Bp, DC, GLC	tri	PC2	45.2	51.9	58.1
82	-33	Reject	Form	BTr, DC, GL	tri	PC3	46.4	50.3	53.6
83	-35	Reject	Form	DC, GL, GLC	tri	PC3	45.2	49.6	53.2
83	-35	Reject	Shape	BTr, DC, SD	tri	PC2	43.1	52.2	56.9
84	-36	Reject	Form	GL, GLC, SD	tri	PC3	43.8	50.4	54.7
84	-36	Reject	Shape	DC, GL, GLC	tri	PC2	45.2	48.9	53.2
85	-37	Reject	Form	Bp, GLC, SD	tri	PC2	43.8	48.9	54.7
86	-42	Reject	Shape	BTr, GLC	bi	PC1	36.2	51.6	56.9
87	-52	Reject	Shape	Bp, GLC, Bd	tri	PC2	29.6	48.8	55.6
88	-56	Reject	Form	Bp, DC, Bd	tri	PC3	21.1	52.6	63.5
88	-56	Reject	Form	Bp, GL, GLC	tri	PC3	26.6	47.7	53.1
89	-59	Reject	Form	Bp, BTr, Bd	tri	PC3	17.4	53.5	69.6
89	-59	Reject	Shape	Bp, GL, GLC	tri	PC2	25.0	45.7	51.6
89	-59	Reject	Shape	DC, GLC, Bd	tri	PC2	24.0	47.4	55.6
90	-60	Reject	Form	DC, GL, Bd	tri	PC3	21.1	48.8	57.7

Table A.17: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
90	-60	Reject	Shape	DC, GL, Bd	tri	PC2	21.1	49.0	57.7
91	-62	Reject	Shape	GL, GLC, SD	tri	PC2	23.4	44.4	51.6
92	-64	Reject	Form	BTr, DC, SD	tri	PC3	18.9	47.1	56.9
93	-65	Reject	Form	DC, GLC, Bd	tri	PC3	18.5	46.2	57.4
94	-67	Reject	Shape	Bp, DC, SD	tri	PC2	12.8	50.2	62.9
95	-69	Reject	Form	BTr, GL, SD	tri	PC3	10.7	49.9	58.9
95	-69	Reject	Form	DC, SD, Bd	tri	PC3	13.0	48.2	64.8
96	-70	Reject	Shape	Bp, DC	bi	PC1	14.5	45.3	54.8
96	-70	Reject	Form	DC, Bd	bi	PC2	11.1	49.1	63.0
97	-71	Reject	Form	Bp, DC, Bd	tri	PC2	13.5	45.2	55.8
98	-72	Reject	Form	Bp, Bd	bi	PC2	14.7	43.2	55.6
99	-73	Reject	Form	GL, GLC, Bd	tri	PC3	14.7	42.5	55.6
100	-76	Reject	Form	Bp, DC, SD	tri	PC3	9.7	44.0	59.7
101	-77	Reject	Shape	DC, SD	bi	PC1	7.6	45.8	56.1
101	-77	Reject	Shape	GL, GLC, Bd	tri	PC2	11.1	41.8	53.7
102	-78	Reject	Form	BTr, GL, Bd	tri	PC3	10.9	41.0	54.4
102	-78	Reject	Shape	Bp, DC, SD	tri	PC1	9.6	42.4	54.8
103	-79	Reject	Form	BTr, DC, Bd	tri	PC3	10.4	40.5	60.4
104	-80	Reject	Shape	Bp, DC, Bd	tri	PC1	7.7	42.8	55.8
105	-81	Reject	Shape	BTr, GL, SD	tri	PC2	5.4	43.5	57.1
105	-81	Reject	Form	Bp, DC	bi	PC2	6.5	42.6	56.5
106	-82	Reject	Shape	Bp, SD	bi	PC1	4.7	43.7	56.2
107	-84	Reject	Form	BTr, GLC, Bd	tri	PC3	6.2	40.0	52.1
107	-84	Reject	Shape	BTr, GLC, SD	tri	PC2	5.1	40.7	56.9
107	-84	Reject	Form	BTr	uni	–	5.0	40.6	55.0
108	-85	Reject	Form	BTr, GLC, SD	tri	PC3	5.2	39.5	53.5

Table A.18: List of approaches ranked by score for balanced cross-validation results for the femur (Subset B).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	72	Prefer	Form	Bp, DC, Bd	tri	PC1	89.7	94.7	100.0
1	72	Prefer	Size	Bp, DC, Bd	tri	–	89.7	94.5	100.0
2	70	Prefer	Size	Bp, Bd	bi	–	88.1	94.2	100.0
3	69	Prefer	Form	Bp, Bd	bi	PC1	88.1	93.8	97.6
4	68	Prefer	Form	Bp, DC	bi	PC1	87.2	93.4	97.4
4	68	Prefer	Size	Bp, DC	bi	–	87.2	93.4	97.4
5	67	Prefer	Form	Bp, DC, SD	tri	PC1	87.2	93.0	97.4
5	67	Prefer	Form	DC, Bd	bi	PC1	87.2	92.4	97.4
5	67	Prefer	Form	DC, SD, Bd	tri	PC1	87.2	92.6	97.4
5	67	Prefer	Size	Bp, DC, SD	tri	–	87.2	92.8	97.4
5	67	Prefer	Size	DC, Bd	bi	–	87.2	92.8	97.4
6	64	Prefer	Size	DC, SD, Bd	tri	–	84.6	92.2	97.4
6	64	Prefer	Form	Bp	uni	–	85.7	90.9	97.6
7	63	Prefer	Form	DC, SD	bi	PC1	84.6	90.8	97.4
7	63	Prefer	Size	DC, SD	bi	–	84.6	90.6	97.4
7	63	Prefer	Form	DC	uni	–	84.6	91.2	97.4
8	61	Prefer	Form	Bp, BTr, DC	tri	PC1	83.3	90.4	97.2
8	61	Prefer	Form	Bp, DC, GLC	tri	PC1	84.6	89.3	94.9
8	61	Prefer	Size	Bp, BTr, DC	tri	–	83.3	89.9	97.2
8	61	Prefer	Form	Bd	uni	–	83.3	90.3	95.2
9	59	Prefer	Form	Bp, DC, GL	tri	PC1	82.0	89.5	94.9
9	59	Prefer	Form	Bp, GL, Bd	tri	PC1	82.0	89.5	94.9
9	59	Prefer	Size	Bp, DC, GL	tri	–	82.0	89.4	94.9
9	59	Prefer	Size	Bp, GL, Bd	tri	–	82.0	89.5	94.9
9	59	Prefer	Size	Bp, GLC, Bd	tri	–	82.0	89.4	94.9
10	58	Prefer	Form	Bp, GLC, Bd	tri	PC1	82.0	89.1	94.9
10	58	Prefer	Size	Bp, DC, GLC	tri	–	82.0	88.9	94.9

Table A.18: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
10	58	Prefer	Size	DC, GL, Bd	tri	–	82.0	88.5	94.9
10	58	Prefer	Size	DC, GLC, Bd	tri	–	82.0	88.4	94.9
11	57	Accept	Form	DC, GL, Bd	tri	PC1	82.0	87.9	94.9
11	57	Accept	Form	DC, GLC, Bd	tri	PC1	82.0	87.8	94.9
11	57	Accept	Size	BTr, DC, Bd	tri	–	80.6	88.8	94.4
12	56	Accept	Form	Bp, SD	bi	PC1	81.0	88.1	95.2
12	56	Accept	Form	BTr, DC, Bd	tri	PC1	80.6	88.4	94.4
12	56	Accept	Size	Bp, SD	bi	–	81.0	87.7	95.2
13	54	Accept	Form	Bp, BTr, Bd	tri	PC1	79.5	87.2	92.3
13	54	Accept	Form	Bp, GLC	bi	PC1	79.5	86.9	92.3
13	54	Accept	Size	Bd, GL	bi	–	79.5	87.2	94.9
13	54	Accept	Size	Bd, GLC	bi	–	79.5	87.0	94.9
13	54	Accept	Size	Bp, BTr, Bd	tri	–	79.5	86.8	92.3
14	53	Accept	Form	Bd, GL	bi	PC1	79.5	86.6	94.9
14	53	Accept	Form	Bd, GLC	bi	PC1	79.5	86.2	92.3
14	53	Accept	Form	Bp, GL	bi	PC1	79.5	86.7	94.9
14	53	Accept	Form	Bp, GL, SD	tri	PC1	79.5	86.4	92.3
14	53	Accept	Form	Bp, GLC, SD	tri	PC1	79.5	86.2	92.3
14	53	Accept	Size	Bd, SD	bi	–	78.6	86.7	92.9
14	53	Accept	Size	Bp, GL	bi	–	79.5	86.4	94.9
14	53	Accept	Size	Bp, GL, SD	tri	–	79.5	86.0	92.3
14	53	Accept	Size	Bp, GLC	bi	–	79.5	86.3	92.3
15	52	Accept	Form	Bd, SD	bi	PC1	78.6	86.4	92.9
15	52	Accept	Size	DC, GL, SD	tri	–	79.5	85.7	92.3
16	51	Accept	Form	BTr, DC, SD	tri	PC1	77.8	86.2	94.4
16	51	Accept	Size	BTr, DC, SD	tri	–	77.8	86.2	94.4
17	50	Accept	Form	DC, GL, SD	tri	PC1	76.9	85.4	92.3
17	50	Accept	Size	Bp, GLC, SD	tri	–	76.9	85.5	92.3

Table A.18: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
17	50	Accept	Size	DC, GLC, SD	tri	–	76.9	85.5	92.3
17	50	Accept	Size	GL, SD, Bd	tri	–	76.9	85.6	92.3
18	49	Accept	Form	Bp, BTr, SD	tri	PC1	76.9	84.8	92.3
18	49	Accept	Form	BTr, DC	bi	PC1	77.8	84.3	91.7
18	49	Accept	Form	DC, GL	bi	PC1	76.9	84.6	92.3
18	49	Accept	Form	DC, GLC	bi	PC1	76.9	84.5	92.3
18	49	Accept	Form	DC, GLC, SD	tri	PC1	76.9	85.2	92.3
18	49	Accept	Form	GL, SD, Bd	tri	PC1	76.9	85.0	92.3
18	49	Accept	Size	Bp, BTr, SD	tri	–	76.9	84.4	92.3
18	49	Accept	Size	DC, GL	bi	–	76.9	84.9	92.3
18	49	Accept	Size	DC, GLC	bi	–	76.9	84.8	92.3
18	49	Accept	Size	GL, GLC, Bd	tri	–	76.9	84.6	92.3
18	49	Accept	Size	GLC, SD, Bd	tri	–	76.9	84.7	92.3
19	48	Accept	Form	Bp, GL, GLC	tri	PC1	76.9	83.6	89.7
19	48	Accept	Form	GL, GLC, Bd	tri	PC1	76.9	83.3	92.3
19	48	Accept	Form	GLC, SD, Bd	tri	PC1	76.9	84.2	92.3
19	48	Accept	Size	Bp, GL, GLC	tri	–	76.9	83.6	92.3
20	46	Accept	Size	BTr, DC	bi	–	75.0	84.2	91.7
21	45	Accept	Form	Bp, BTr, GL	tri	PC1	75.0	82.9	91.7
21	45	Accept	Form	Bp, BTr, GLC	tri	PC1	75.0	82.6	88.9
21	45	Accept	Form	Bp, BTr	bi	PC1	74.4	83.0	89.7
21	45	Accept	Form	BTr, DC, GL	tri	PC1	75.0	82.7	91.7
21	45	Accept	Form	BTr, DC, GLC	tri	PC1	75.0	82.7	91.7
21	45	Accept	Size	Bp, BTr, GL	tri	–	75.0	82.3	91.7
21	45	Accept	Size	BTr, DC, GL	tri	–	75.0	82.9	91.7
21	45	Accept	Size	BTr, DC, GLC	tri	–	75.0	82.5	88.9
21	45	Accept	Size	BTr, GLC, Bd	tri	–	75.0	82.3	88.9
22	44	Accept	Form	DC, GL, GLC	tri	PC1	74.4	82.2	89.7

Table A.18: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
22	44	Accept	Size	Bp, BTr	bi	–	74.4	82.6	89.7
22	44	Accept	Size	BTr, GL, Bd	tri	–	75.0	81.9	88.9
22	44	Accept	Size	DC, GL, GLC	tri	–	74.4	82.5	89.7
23	43	Accept	Form	SD, GL	bi	PC1	74.2	81.0	89.7
23	43	Accept	Size	SD, GL	bi	–	74.4	81.1	89.7
24	42	Accept	Size	Bp, BTr, GLC	tri	–	72.2	82.0	88.9
25	40	Accept	Form	BTr, GL, Bd	tri	PC1	72.2	80.3	88.9
25	40	Accept	Form	BTr, GL, SD	tri	PC1	72.2	80.0	88.9
25	40	Accept	Form	BTr, GLC, Bd	tri	PC1	72.2	80.8	88.9
25	40	Accept	Form	GL, GLC, SD	tri	PC1	71.8	80.8	89.7
25	40	Accept	Form	SD, GLC	bi	PC1	71.8	80.9	87.2
25	40	Accept	Shape	GL, GLC, Bd	tri	PC1	71.8	80.7	87.2
25	40	Accept	Size	BTr, GLC, SD	tri	–	72.2	80.1	86.2
25	40	Accept	Size	GL, GLC, SD	tri	–	71.8	80.6	87.2
25	40	Accept	Size	SD, GLC	bi	–	71.8	81.3	89.7
25	40	Accept	Form	SD	uni	–	72.9	80.0	87.5
26	39	Accept	Form	BTr, GLC, SD	tri	PC1	72.2	79.8	86.1
26	39	Accept	Shape	Bd, GL	bi	PC1	71.8	80.3	87.2
26	39	Accept	Size	BTr, Bd	bi	–	71.8	80.4	87.2
26	39	Accept	Size	BTr, GL, SD	tri	–	72.2	79.6	88.9
27	38	Accept	Form	BTr, Bd	bi	PC1	71.8	78.7	87.2
27	38	Accept	Shape	Bd, GLC	bi	PC1	71.8	79.2	87.2
28	36	Accept	Shape	BTr, GL, Bd	tri	PC1	69.4	79.2	88.9
29	35	Accept	Shape	BTr, GLC, Bd	tri	PC1	69.4	78.3	86.1
30	30	Accept	Form	BTr, SD	bi	PC1	66.7	76.1	84.6
30	30	Accept	Size	BTr, SD	bi	–	66.7	75.9	84.6
31	29	Reject	Shape	Bp, BTr, Bd	tri	PC1	66.7	74.8	82.0
32	28	Reject	Shape	Bp, Bd	bi	PC1	66.7	74.0	81.0

Table A.18: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
33	23	Reject	Shape	DC, GL, Bd	tri	PC1	64.1	71.8	79.5
34	21	Reject	Shape	BTr, Bd	bi	PC1	61.5	71.8	79.5
35	20	Reject	Form	GL, GLC	bi	PC1	59.0	73.8	84.6
35	20	Reject	Form	GL	uni	–	59.0	73.5	84.6
36	19	Reject	Shape	Bp, GL, Bd	tri	PC1	59.0	72.7	82.0
36	19	Reject	Shape	Bp, GLC, Bd	tri	PC1	59.0	72.5	82.0
36	19	Reject	Shape	BTr, DC, SD	tri	PC1	61.1	70.5	77.9
37	18	Reject	Shape	Bp, BTr, SD	tri	PC1	61.5	68.8	76.9
37	18	Reject	Shape	Bp, DC, Bd	tri	PC1	61.5	69.6	79.5
37	18	Reject	Shape	BTr, SD	bi	PC1	61.5	69.2	76.9
38	17	Reject	Shape	BTr, GLC, SD	tri	PC1	61.1	68.7	77.8
38	17	Reject	Shape	DC, GLC, Bd	tri	PC1	61.5	68.0	76.9
38	17	Reject	Size	GL, GLC	bi	–	56.3	73.2	82.0
38	17	Reject	Form	GLC	uni	–	56.3	73.7	84.6
39	16	Reject	Shape	Bp, BTr, GLC	tri	PC1	61.1	67.9	75.0
39	16	Reject	Shape	BTr, GL, SD	tri	PC1	61.0	68.2	75.1
40	12	Reject	Form	Bp, BTr, GLC	tri	PC2	58.3	66.2	75.0
41	9	Reject	Shape	DC, GL, GLC	tri	PC1	56.4	65.3	71.8
41	9	Reject	Shape	DC, GL	bi	PC1	56.4	65.2	71.8
41	9	Reject	Shape	DC, GLC	bi	PC1	56.4	65.2	71.8
41	9	Reject	Size	BTr, GL, GLC	tri	–	50.0	71.8	83.3
41	9	Reject	Size	BTr, GLC	bi	–	50.0	71.3	83.3
42	8	Reject	Shape	Bp, DC, GL	tri	PC1	56.4	64.3	71.8
42	8	Reject	Shape	Bp, DC, GLC	tri	PC1	56.4	64.7	71.8
42	8	Reject	Shape	GL, GLC, SD	tri	PC1	56.4	64.0	71.8
42	8	Reject	Shape	SD, GLC	bi	PC1	56.4	64.2	71.8
43	7	Reject	Form	Bp, BTr, GL	tri	PC2	55.6	64.3	72.2
43	7	Reject	Form	BTr, GL, GLC	tri	PC1	47.2	72.2	83.3

Table A.18: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
44	5	Reject	Form	Bp, BTr, Bd	tri	PC2	53.9	63.9	71.8
44	5	Reject	Form	BTr, GLC	bi	PC1	47.2	70.8	80.7
44	5	Reject	Shape	Bp, BTr, GL	tri	PC1	52.8	64.7	72.2
44	5	Reject	Shape	Bp, GLC, SD	tri	PC1	53.9	63.5	74.4
44	5	Reject	Shape	SD, GL	bi	PC1	53.9	63.8	71.8
45	4	Reject	Form	BTr, GL	bi	PC1	47.1	69.9	80.6
45	4	Reject	Shape	Bp, GL, SD	tri	PC1	53.9	62.8	71.8
45	4	Reject	Shape	DC, GL, SD	tri	PC1	53.9	62.7	69.2
45	4	Reject	Shape	DC, GLC, SD	tri	PC1	53.9	62.9	71.8
45	4	Reject	Size	BTr, GL	bi	–	47.2	69.7	80.6
46	3	Reject	Form	BTr, Bd	bi	PC2	51.3	64.3	74.4
47	0	Reject	Form	BTr, GL, Bd	tri	PC2	50.0	63.2	72.2
48	-1	Reject	Shape	GL, SD, Bd	tri	PC1	51.3	60.7	69.2
48	-1	Reject	Shape	GLC, SD, Bd	tri	PC1	51.3	60.7	69.2
48	-1	Reject	Form	Bp, BTr	bi	PC2	51.3	60.1	69.2
49	-4	Reject	Form	BTr, GLC, Bd	tri	PC2	47.2	61.2	72.2
49	-4	Reject	Shape	Bp, DC, GLC	tri	PC2	48.7	59.6	69.2
50	-7	Reject	Shape	GL, SD, Bd	tri	PC2	43.6	62.2	74.4
50	-7	Reject	Form	BTr	uni	–	41.0	64.8	76.9
51	-8	Reject	Shape	Bp, GLC	bi	PC1	48.7	55.7	64.1
52	-9	Reject	Form	Bp, GL, GLC	tri	PC2	46.1	57.3	64.1
53	-10	Reject	Shape	GLC, SD, Bd	tri	PC2	41.0	61.9	71.8
54	-11	Reject	Shape	Bp, BTr, SD	tri	PC2	41.0	60.2	69.4
55	-13	Reject	Form	BTr, DC, GL	tri	PC2	44.4	55.1	63.9
56	-14	Reject	Form	BTr, DC, GLC	tri	PC2	44.4	54.5	63.9
56	-14	Reject	Shape	Bp, BTr, DC	tri	PC2	44.4	54.7	63.9
56	-14	Reject	Shape	Bp, GL, GLC	tri	PC1	46.1	53.0	61.5
57	-15	Reject	Shape	Bp, BTr, DC	tri	PC1	44.4	53.5	61.1

Table A.18: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
57	-15	Reject	Shape	DC, GL, Bd	tri	PC2	41.0	57.1	66.7
58	-16	Reject	Shape	Bp, GL, SD	tri	PC2	41.0	55.4	64.1
58	-16	Reject	Form	SD, GLC	bi	PC2	38.5	57.8	66.7
59	-17	Reject	Form	SD, GL	bi	PC2	38.5	56.8	66.7
60	-18	Reject	Shape	Bp, BTr	bi	PC1	38.5	56.3	66.7
60	-18	Reject	Shape	Bp, DC, GL	tri	PC2	38.5	56.0	66.7
60	-18	Reject	Shape	Bp, GL	bi	PC1	43.6	50.9	59.0
60	-18	Reject	Shape	DC, GLC, Bd	tri	PC2	38.5	55.9	66.7
61	-19	Reject	Form	GL, GLC, Bd	tri	PC2	41.0	52.6	61.5
61	-19	Reject	Form	BTr, SD	bi	PC2	35.8	57.6	71.8
62	-20	Reject	Form	Bp, GLC, Bd	tri	PC2	35.9	56.4	66.7
62	-20	Reject	Form	DC, GLC, SD	tri	PC2	38.5	54.7	64.1
62	-20	Reject	Shape	DC, Bd	bi	PC1	41.0	51.8	61.5
63	-22	Reject	Shape	Bp, GLC, Bd	tri	PC2	35.9	55.2	66.7
63	-22	Reject	Shape	Bp, GLC, SD	tri	PC2	35.9	54.9	64.1
63	-22	Reject	Form	Bp, GLC	bi	PC2	35.9	55.1	66.7
64	-23	Reject	Form	BTr, DC, SD	tri	PC2	33.3	56.4	72.2
64	-23	Reject	Form	DC, GL, GLC	tri	PC2	38.5	51.2	59.0
65	-25	Reject	Form	Bp, BTr, SD	tri	PC2	33.3	54.8	71.8
65	-25	Reject	Form	Bp, GL, SD	tri	PC3	35.9	52.2	61.5
65	-25	Reject	Shape	Bp, BTr, Bd	tri	PC2	33.3	54.4	69.2
65	-25	Reject	Shape	BTr, DC, Bd	tri	PC1	33.3	54.5	66.7
65	-25	Reject	Shape	DC, SD, Bd	tri	PC2	35.9	52.1	61.5
65	-25	Reject	Form	Bd, GL	bi	PC2	35.9	51.9	61.5
65	-25	Reject	Form	Bp, GL	bi	PC2	33.3	54.0	64.1
66	-26	Reject	Form	GL, SD, Bd	tri	PC2	33.3	53.2	64.1
66	-26	Reject	Form	GLC, SD, Bd	tri	PC2	33.3	53.8	64.1
67	-27	Reject	Form	Bp, GLC, SD	tri	PC2	33.3	52.6	64.1

Table A.18: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
67	-27	Reject	Form	Bp, GLC, SD	tri	PC3	33.3	52.5	64.1
67	-27	Reject	Form	DC, GL, SD	tri	PC2	33.3	52.3	61.7
67	-27	Reject	Shape	BTr, DC, GLC	tri	PC1	33.3	52.1	66.7
67	-27	Reject	Form	Bd, SD	bi	PC2	35.7	50.2	59.6
68	-28	Reject	Form	Bp, BTr, DC	tri	PC2	33.3	51.7	61.1
68	-28	Reject	Shape	Bp, GL, Bd	tri	PC2	30.8	53.7	66.7
68	-28	Reject	Shape	Bp, SD	bi	PC1	30.9	53.8	64.3
68	-28	Reject	Form	Bd, GLC	bi	PC2	33.3	51.2	64.1
69	-29	Reject	Form	Bp, DC, GLC	tri	PC2	33.3	50.6	64.1
69	-29	Reject	Form	BTr, DC, Bd	tri	PC2	33.3	50.4	61.1
69	-29	Reject	Form	DC, GL, Bd	tri	PC2	33.3	50.6	64.1
69	-29	Reject	Form	DC, GLC, Bd	tri	PC2	33.3	50.8	64.1
69	-29	Reject	Shape	BTr, DC, GL	tri	PC1	33.3	50.0	66.7
70	-30	Reject	Form	Bp, DC, GL	tri	PC2	33.3	49.4	61.5
70	-30	Reject	Form	Bp, GL, Bd	tri	PC2	30.8	52.2	64.1
70	-30	Reject	Form	Bp, GL, SD	tri	PC2	30.8	51.8	61.5
70	-30	Reject	Shape	BTr, DC, Bd	tri	PC2	33.2	50.0	61.1
70	-30	Reject	Form	BTr, DC	bi	PC2	33.3	49.5	61.1
70	-30	Reject	Form	DC, GL	bi	PC2	33.3	49.2	61.5
70	-30	Reject	Form	DC, GLC	bi	PC2	33.3	49.8	64.1
71	-32	Reject	Form	Bp, SD	bi	PC2	33.3	47.3	57.1
72	-33	Reject	Form	GLC, SD, Bd	tri	PC3	30.8	48.7	61.5
73	-34	Reject	Form	GL, SD, Bd	tri	PC3	30.8	47.7	61.5
73	-34	Reject	Shape	Bp, DC	bi	PC1	30.8	48.0	59.0
73	-34	Reject	Shape	Bp, DC, SD	tri	PC1	30.8	47.6	59.0
73	-34	Reject	Shape	BTr, DC, GLC	tri	PC2	33.3	45.8	58.3
73	-34	Reject	Shape	BTr, DC	bi	PC1	30.6	48.4	61.1
74	-36	Reject	Shape	BTr, DC, GL	tri	PC2	30.6	46.0	55.6

Table A.18: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
75	-37	Reject	Form	BTr, GLC, SD	tri	PC2	27.8	48.1	66.7
75	-37	Reject	Form	GL, GLC, SD	tri	PC2	28.2	47.9	64.1
75	-37	Reject	Shape	Bp, DC, SD	tri	PC2	28.2	47.0	59.0
76	-38	Reject	Form	BTr, GL, SD	tri	PC2	27.6	46.9	66.7
77	-39	Reject	Form	Bp, BTr, SD	tri	PC3	33.3	40.5	48.7
77	-39	Reject	Form	DC, SD, Bd	tri	PC3	30.6	43.3	53.9
78	-42	Reject	Form	DC, SD, Bd	tri	PC2	28.2	42.9	53.9
79	-43	Reject	Shape	DC, GL, SD	tri	PC2	28.2	41.6	53.9
79	-43	Reject	Form	DC, Bd	bi	PC2	28.2	41.2	51.3
80	-44	Reject	Form	BTr, GLC, Bd	tri	PC3	27.8	41.1	50.0
80	-44	Reject	Form	DC, GL, SD	tri	PC3	28.2	40.7	51.3
81	-45	Reject	Shape	DC, GLC, SD	tri	PC2	28.2	39.7	51.3
82	-46	Reject	Form	Bp, DC, GL	tri	PC3	25.6	41.1	51.3
82	-46	Reject	Form	Bp, DC, GLC	tri	PC3	25.6	41.4	51.3
83	-47	Reject	Form	DC, GLC, SD	tri	PC3	25.6	40.0	51.3
83	-47	Reject	Shape	BTr, GL, Bd	tri	PC2	25.0	40.8	50.0
83	-47	Reject	Shape	BTr, GLC, Bd	tri	PC2	25.0	40.3	50.1
84	-48	Reject	Form	Bp, DC, SD	tri	PC2	25.6	39.0	48.7
85	-49	Reject	Shape	Bp, DC, Bd	tri	PC2	23.1	40.6	48.7
85	-49	Reject	Shape	GL, GLC, Bd	tri	PC2	25.6	37.8	48.7
86	-50	Reject	Form	BTr, GL, Bd	tri	PC3	25.0	37.9	47.2
86	-50	Reject	Shape	BTr, GL, GLC	tri	PC1	25.0	37.3	47.2
87	-51	Reject	Form	BTr, DC, GLC	tri	PC3	22.2	39.3	50.0
88	-52	Reject	Form	BTr, DC, GL	tri	PC3	22.2	38.1	50.0
88	-52	Reject	Shape	DC, SD, Bd	tri	PC1	23.1	37.9	51.3
89	-53	Reject	Form	Bp, DC, SD	tri	PC3	23.1	36.8	48.7
89	-53	Reject	Shape	BTr, GL, GLC	tri	PC2	22.2	37.6	52.8
89	-53	Reject	Shape	BTr, GL, SD	tri	PC2	22.2	37.0	47.2

Table A.18: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
89	-53	Reject	Shape	DC, SD	bi	PC1	23.1	37.0	46.1
90	-54	Reject	Form	Bp, DC, Bd	tri	PC2	23.1	36.0	46.1
90	-54	Reject	Shape	BTr, GL	bi	PC1	22.2	36.7	47.2
90	-54	Reject	Shape	BTr, GLC	bi	PC1	22.2	36.9	47.2
90	-54	Reject	Shape	BTr, GLC, SD	tri	PC2	22.2	36.3	47.2
90	-54	Reject	Form	Bp, Bd	bi	PC2	21.4	37.4	50.0
91	-55	Reject	Form	Bp, BTr, GLC	tri	PC3	22.2	36.0	47.2
91	-55	Reject	Form	Bp, DC, Bd	tri	PC3	20.5	37.4	48.7
92	-56	Reject	Form	DC, SD	bi	PC2	20.5	35.7	46.1
93	-57	Reject	Form	DC, GL, Bd	tri	PC3	20.5	35.7	48.7
93	-57	Reject	Shape	Bd, SD	bi	PC1	19.1	36.6	47.6
93	-57	Reject	Shape	DC, GL, GLC	tri	PC2	20.5	35.0	48.7
93	-57	Reject	Shape	GL, GLC	bi	PC1	20.5	35.4	48.7
93	-57	Reject	Shape	GL, GLC, SD	tri	PC2	20.5	35.2	46.1
94	-58	Reject	Form	Bp, DC	bi	PC2	20.5	34.1	43.6
95	-59	Reject	Form	Bp, BTr, GL	tri	PC3	19.4	34.6	47.2
95	-59	Reject	Form	BTr, GLC, SD	tri	PC3	19.4	33.8	47.2
95	-59	Reject	Form	DC, GLC, Bd	tri	PC3	17.9	35.6	48.7
95	-59	Reject	Shape	Bp, BTr, GL	tri	PC2	19.4	34.0	47.2
95	-59	Reject	Shape	Bp, GL, GLC	tri	PC2	20.5	33.5	46.1
96	-60	Reject	Form	BTr, GL, GLC	tri	PC3	16.7	36.3	50.0
96	-60	Reject	Form	BTr, GL, SD	tri	PC3	19.4	33.0	47.2
96	-60	Reject	Shape	Bp, BTr, GLC	tri	PC2	19.4	33.2	44.4
96	-60	Reject	Form	BTr, GL	bi	PC2	19.4	33.4	47.2
96	-60	Reject	Form	BTr, GLC	bi	PC2	19.4	33.2	44.4
96	-60	Reject	Form	GL, GLC	bi	PC2	17.9	34.9	48.7
97	-61	Reject	Shape	BTr, DC, SD	tri	PC2	19.4	32.2	44.4
98	-64	Reject	Form	BTr, GL, GLC	tri	PC2	16.7	32.5	47.2

Table A.18: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
99	-66	Reject	Form	Bp, BTr, DC	tri	PC3	13.9	33.1	47.2
100	-68	Reject	Form	Bp, GL, Bd	tri	PC3	15.4	29.3	43.6
101	-69	Reject	Form	Bp, BTr, Bd	tri	PC3	12.8	30.7	48.7
101	-69	Reject	Form	DC, GL, GLC	tri	PC3	12.8	31.3	46.1
102	-70	Reject	Form	Bp, GL, GLC	tri	PC3	12.8	30.3	46.1
102	-70	Reject	Form	BTr, DC, SD	tri	PC3	13.9	29.3	41.7
102	-70	Reject	Form	GL, GLC, SD	tri	PC3	12.8	29.9	43.6
103	-73	Reject	Form	Bp, GLC, Bd	tri	PC3	12.8	26.7	43.6
104	-76	Reject	Form	GL, GLC, Bd	tri	PC3	10.3	26.7	41.0
105	-79	Reject	Form	BTr, DC, Bd	tri	PC3	8.3	25.4	38.9

A.3.8 Tibia

Table A.19: List of approaches ranked by score for balanced cross-validation results for the tibia (Subset A).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	67	Prefer	Shape	DPL, GL, Dd	tri	PC1	97.5	99.9	100.0
2	66	Prefer	Shape	Bp, Dp, GL	tri	PC1	97.2	99.2	100.0
2	66	Prefer	Shape	Bp, DPL, GL	tri	PC1	97.5	98.0	100.0
2	66	Prefer	Shape	DPL, GL	bi	PC1	97.5	98.7	100.0
2	66	Prefer	Shape	DPL, LDp, GL	tri	PC1	97.5	98.8	100.0
3	65	Prefer	Form	DPL, Bd	bi	PC1	97.5	97.9	100.0
3	65	Prefer	Form	DPL, GL, Bd	tri	PC1	97.4	97.7	100.0
3	65	Prefer	Shape	DPL, GL, Bd	tri	PC1	97.4	97.4	97.4
3	65	Prefer	Shape	DPL, GL, SD	tri	PC1	97.5	98.0	100.0
3	65	Prefer	Shape	LDp, GL, Bd	tri	PC1	97.5	97.4	97.5
3	65	Prefer	Size	DPL, Bd	bi	–	97.5	97.9	100.0
4	64	Prefer	Shape	Bp, GL, Bd	tri	PC1	96.4	97.3	98.2

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
4	64	Prefer	Shape	Dp, DPL, GL	tri	PC1	97.1	97.2	100.0
4	64	Prefer	Shape	Dp, GL, Bd	tri	PC1	97.1	97.1	97.1
4	64	Prefer	Shape	Dp, GL, Dd	tri	PC1	97.2	97.2	97.2
4	64	Prefer	Shape	Dp, GL	bi	PC1	97.2	97.2	97.2
4	64	Prefer	Shape	Dp, LDp, GL	tri	PC1	97.2	97.2	97.2
5	62	Prefer	Form	DPL, GL	bi	PC1	95.0	97.3	100.0
5	62	Prefer	Shape	Bp, LDp, GL	tri	PC1	95.2	96.8	100.0
6	61	Prefer	Form	Bp, Dp	bi	PC1	94.7	96.0	100.0
6	61	Prefer	Form	Bp, DPL, Bd	tri	PC1	95.0	96.0	97.5
6	61	Prefer	Form	Bp, DPL, GL	tri	PC1	95.0	96.0	97.5
6	61	Prefer	Form	DPL, Bd, Dd	tri	PC1	95.0	95.8	97.5
6	61	Prefer	Form	DPL, LDp, SD	tri	PC1	95.0	95.7	97.5
6	61	Prefer	Form	DPL, SD, Bd	tri	PC1	94.7	96.1	97.4
6	61	Prefer	Shape	Dp, GL, SD	tri	PC1	94.4	97.0	97.2
6	61	Prefer	Size	Bp, DPL, Bd	tri	–	95.0	96.0	97.5
6	61	Prefer	Size	DPL, Bd, Dd	tri	–	95.0	95.9	97.5
6	61	Prefer	Form	Dp	uni	–	94.7	96.0	97.4
7	60	Prefer	Form	Bd, Dp	bi	PC1	94.4	96.0	100.0
7	60	Prefer	Form	Bp, Dp, Bd	tri	PC1	94.4	96.0	100.0
7	60	Prefer	Form	Bp, Dp, DPL	tri	PC1	94.1	96.0	100.0
7	60	Prefer	Form	Dp, Bd, Dd	tri	PC1	94.4	95.4	97.2
7	60	Prefer	Form	Dp, DPL, Bd	tri	PC1	93.8	95.9	100.0
7	60	Prefer	Form	Dp, DPL, GL	tri	PC1	94.1	96.0	100.0
7	60	Prefer	Form	Dp, DPL, LDp	tri	PC1	94.1	96.1	100.0
7	60	Prefer	Form	Dp, DPL	bi	PC1	94.1	96.0	100.0
7	60	Prefer	Form	Dp, DPL, SD	tri	PC1	94.1	95.9	100.0
7	60	Prefer	Form	Dp, GL, Bd	tri	PC1	94.1	95.7	100.0
7	60	Prefer	Form	Dp, GL	bi	PC1	94.4	96.0	100.0

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
7	60	Prefer	Form	Dp, SD, Bd	tri	PC1	94.4	95.9	100.0
7	60	Prefer	Size	Bd, Dp	bi	–	94.4	95.9	97.2
7	60	Prefer	Size	Bp, Dp, Bd	tri	–	94.4	96.0	100.0
7	60	Prefer	Size	Bp, Dp, DPL	tri	–	94.1	96.0	100.0
7	60	Prefer	Size	Dp, DPL	bi	–	94.1	96.0	100.0
7	60	Prefer	Size	Dp, DPL, Bd	tri	–	93.8	96.0	100.0
7	60	Prefer	Size	Dp, DPL, SD	tri	–	94.1	95.9	100.0
8	58	Prefer	Form	Bp, DPL, SD	tri	PC1	92.5	95.9	97.5
8	58	Prefer	Size	Bp, Dp	bi	–	92.1	95.7	100.0
8	58	Prefer	Size	DPL, SD, Bd	tri	–	92.1	95.7	97.4
8	58	Prefer	Form	DPL	uni	–	93.2	94.5	97.7
9	57	Prefer	Form	Bp, Dp, GL	tri	PC1	91.7	95.2	100.0
9	57	Prefer	Form	Bp, DPL	bi	PC1	93.2	93.7	95.5
9	57	Prefer	Form	Dp, DPL, Dd	tri	PC1	91.2	95.4	100.0
9	57	Prefer	Shape	Bd, GL	bi	PC1	92.9	94.1	96.4
9	57	Prefer	Shape	Bp, GL, Dd	tri	PC1	92.6	93.9	96.3
9	57	Prefer	Size	Bp, DPL	bi	–	93.2	93.7	95.5
9	57	Prefer	Size	Dp, Bd, Dd	tri	–	91.7	94.9	97.2
10	56	Prefer	Form	Bp, DPL, Dd	tri	PC1	92.9	93.4	95.2
10	56	Prefer	Form	DPL, Dd	bi	PC1	92.9	93.5	95.2
10	56	Prefer	Form	DPL, GL, Dd	tri	PC1	92.5	93.4	95.0
10	56	Prefer	Form	DPL, LDp, Bd	tri	PC1	92.5	93.5	95.0
10	56	Prefer	Form	DPL, SD	bi	PC1	92.5	93.5	95.0
10	56	Prefer	Shape	GL, Bd, Dd	tri	PC1	92.6	93.8	96.3
10	56	Prefer	Size	Bp, DPL, Dd	tri	–	92.9	93.6	95.2
10	56	Prefer	Size	Bp, DPL, SD	tri	–	92.5	93.5	95.0
10	56	Prefer	Size	Dp, DPL, LDp	tri	–	91.2	94.7	97.1
10	56	Prefer	Size	DPL, Dd	bi	–	92.9	93.4	95.2

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
11	55	Accept	Form	Dd, Dp	bi	PC1	92.1	92.7	94.7
11	55	Accept	Size	Dp, SD, Bd	tri	–	91.7	93.4	97.2
12	54	Accept	Size	Dp, DPL, Dd	tri	–	91.2	92.8	97.1
12	54	Accept	Size	Dp, DPL, GL	tri	–	91.2	92.6	94.1
13	53	Accept	Form	DPL, GL, SD	tri	PC1	90.0	93.3	95.0
13	53	Accept	Form	DPL, LDp, Dd	tri	PC1	90.5	92.4	92.9
13	53	Accept	Form	DPL, LDp, GL	tri	PC1	90.0	92.9	95.0
14	52	Accept	Form	Bp, Bd	bi	PC1	90.3	91.7	91.9
14	52	Accept	Size	Bp, SD, Bd	tri	–	90.0	92.0	95.0
14	52	Accept	Size	DPL, LDp, Bd	tri	–	90.0	92.0	95.0
15	51	Accept	Form	Bp, Dp, Dd	tri	PC1	89.5	91.4	94.7
15	51	Accept	Form	Dp, GL, Dd	tri	PC1	88.9	91.7	94.4
15	51	Accept	Form	Dp, LDp, Bd	tri	PC1	88.9	92.0	97.2
15	51	Accept	Shape	Bp, GL	bi	PC1	89.3	91.4	92.9
15	51	Accept	Size	Dp, LDp, Bd	tri	–	88.9	91.8	94.4
16	50	Accept	Form	Bp, Dp, SD	tri	PC1	89.5	90.8	94.7
16	50	Accept	Size	Bp, Bd	bi	–	88.7	91.6	91.9
16	50	Accept	Size	Bp, Dp, Dd	tri	–	89.5	90.6	92.1
16	50	Accept	Size	Bp, Dp, SD	tri	–	89.5	90.8	92.1
16	50	Accept	Size	Dd, Dp	bi	–	89.5	90.9	94.7
17	49	Accept	Form	Bp, Bd, Dd	tri	PC1	88.3	90.2	93.3
17	49	Accept	Form	Bp, SD, Bd	tri	PC1	88.3	90.7	93.3
17	49	Accept	Form	DPL, LDp	bi	PC1	88.6	90.6	93.2
18	48	Accept	Form	Bp, DPL, LDp	tri	PC1	88.6	89.7	93.2
18	48	Accept	Form	Dp, LDp, SD	tri	PC1	86.8	91.0	94.7
18	48	Accept	Form	DPL, SD, Dd	tri	PC1	87.5	90.4	92.5
18	48	Accept	Size	Bp, DPL, LDp	tri	–	88.6	89.8	93.2
18	48	Accept	Size	DPL, GL, Bd	tri	–	86.8	91.5	94.7

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
18	48	Accept	Size	DPL, SD	bi	–	87.5	90.3	92.5
19	47	Accept	Form	Bp, Dp, LDp	tri	PC1	86.8	89.7	94.7
19	47	Accept	Form	Dp, LDp	bi	PC1	86.8	89.8	94.7
20	46	Accept	Form	Bp, GL, Bd	tri	PC1	87.5	88.0	89.3
20	46	Accept	Form	Dp, GL, SD	tri	PC1	86.1	89.8	94.4
20	46	Accept	Form	Dp, SD	bi	PC1	86.8	89.1	94.7
20	46	Accept	Size	Bp, Bd, Dd	tri	–	86.7	89.5	91.7
20	46	Accept	Size	Bp, Dp, LDp	tri	–	86.8	89.3	92.1
21	45	Accept	Size	Dp, LDp, SD	tri	–	86.8	88.4	92.1
21	45	Accept	Size	DPL, LDp, SD	tri	–	85.0	89.9	95.0
22	44	Accept	Form	Bp, LDp, Bd	tri	PC1	86.4	88.0	93.2
22	44	Accept	Form	Bp, SD, Dd	tri	PC1	86.2	88.1	91.4
22	44	Accept	Form	LDp, Bd, Dd	tri	PC1	86.4	87.4	88.6
22	44	Accept	Size	Bp, LDp, Bd	tri	–	86.4	87.8	90.9
22	44	Accept	Size	DPL, LDp	bi	–	86.4	87.8	90.9
22	44	Accept	Size	LDp, Bd, Dd	tri	–	86.4	87.4	88.6
22	44	Accept	Form	Bp	uni	–	85.5	88.9	91.9
23	43	Accept	Size	Dp, GL, Bd	tri	–	85.3	87.5	91.2
23	43	Accept	Size	DPL, LDp, Dd	tri	–	85.7	87.3	90.5
24	42	Accept	Size	Bp, SD, Dd	tri	–	84.5	87.9	91.4
24	42	Accept	Size	Dp, LDp	bi	–	84.2	87.5	92.1
25	41	Accept	Form	Bd, LDp	bi	PC1	84.1	86.6	88.6
25	41	Accept	Form	Dp, LDp, Dd	tri	PC1	84.2	86.8	89.5
25	41	Accept	Form	Dp, LDp, GL	tri	PC1	83.3	87.9	94.4
25	41	Accept	Size	Bd, LDp	bi	–	84.1	86.6	88.6
25	41	Accept	Size	Bp, SD	bi	–	83.3	87.9	93.3
25	41	Accept	Size	Dp, SD	bi	–	84.2	86.7	92.1
25	41	Accept	Size	DPL, SD, Dd	tri	–	85.0	86.0	90.0

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
26	40	Accept	Form	Bp, Dd	bi	PC1	83.3	86.6	90.0
26	40	Accept	Form	Bp, LDp, Dd	tri	PC1	84.8	85.1	87.0
26	40	Accept	Size	Bp, LDp, Dd	tri	–	84.8	85.0	87.0
27	39	Accept	Form	Bp, LDp	bi	PC1	83.3	85.3	85.4
27	39	Accept	Form	Bp, SD	bi	PC1	83.3	85.7	88.3
27	39	Accept	Form	Dp, SD, Dd	tri	PC1	84.2	85.2	89.5
27	39	Accept	Size	Bp, Dd	bi	–	83.3	86.0	88.3
27	39	Accept	Size	Bp, Dp, GL	tri	–	83.3	85.6	88.9
27	39	Accept	Form	Bd	uni	–	83.3	85.4	87.9
28	38	Accept	Size	Bd, SD	bi	–	82.8	85.2	87.6
28	38	Accept	Size	Bp, DPL, GL	tri	–	82.5	85.4	90.0
29	37	Accept	Shape	Bp, Dp, Dd	tri	PC1	81.6	85.1	89.5
29	37	Accept	Shape	Dp, LDp	bi	PC1	81.6	85.3	89.5
30	36	Accept	Form	Bd, GL	bi	PC1	82.1	84.0	87.5
30	36	Accept	Form	Bp, LDp, SD	tri	PC1	81.8	84.3	86.4
30	36	Accept	Shape	Dp, LDp, Bd	tri	PC1	80.6	85.2	88.9
30	36	Accept	Size	Dp, LDp, Dd	tri	–	81.6	84.4	86.8
31	35	Accept	Size	Dp, LDp, GL	tri	–	80.6	84.2	88.9
31	35	Accept	Size	Dp, SD, Dd	tri	–	81.6	83.9	86.8
32	34	Accept	Form	Bp, GL, Dd	tri	PC1	79.6	83.9	87.0
32	34	Accept	Form	Bp, GL	bi	PC1	80.4	83.7	87.5
32	34	Accept	Form	Bp, GL, SD	tri	PC1	80.4	83.7	87.5
32	34	Accept	Form	Bp, LDp, GL	tri	PC1	81.0	83.0	85.8
32	34	Accept	Form	LDp, SD, Bd	tri	PC1	81.0	83.3	85.7
32	34	Accept	Shape	Bp, GL, SD	tri	PC2	80.4	83.9	87.5
32	34	Accept	Shape	Dp, LDp, SD	tri	PC2	79.0	85.0	89.5
32	34	Accept	Shape	DPL, Dd	bi	PC1	81.0	83.4	85.7
32	34	Accept	Shape	DPL, LDp, Dd	tri	PC1	81.0	83.4	85.7

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
32	34	Accept	Shape	LDp, GL	bi	PC1	81.0	83.1	88.1
32	34	Accept	Shape	LDp, GL, SD	tri	PC2	81.0	83.1	88.1
32	34	Accept	Size	Bp, LDp	bi	–	81.2	82.5	85.4
33	33	Accept	Form	Bd, SD	bi	PC1	79.7	83.4	87.5
33	33	Accept	Shape	LDp, GL, Dd	tri	PC1	81.0	82.1	85.7
34	32	Accept	Shape	DPL, Bd, Dd	tri	PC1	80.0	82.2	85.0
34	32	Accept	Size	Bp, LDp, SD	tri	–	79.5	82.3	84.1
34	32	Accept	Size	DPL, GL, Dd	tri	–	80.0	82.0	85.0
34	32	Accept	Size	SD, Bd, Dd	tri	–	79.0	83.3	88.7
35	31	Accept	Form	LDp, GL, Bd	tri	PC1	77.5	83.9	90.0
35	31	Accept	Shape	Bp, DPL, LDp	tri	PC1	79.5	81.1	84.1
35	31	Accept	Shape	Dd, Dp	bi	PC1	79.0	82.0	84.2
35	31	Accept	Shape	Dp, SD, Dd	tri	PC2	79.0	82.5	84.2
35	31	Accept	Shape	DPL, LDp	bi	PC1	79.5	81.1	84.1
35	31	Accept	Size	DPL, GL	bi	–	77.5	83.7	87.5
35	31	Accept	Size	LDp, SD, Bd	tri	–	78.6	82.4	85.7
36	30	Accept	Shape	Bp, Dp, LDp	tri	PC1	76.3	83.3	89.5
36	30	Accept	Shape	Bp, DPL, Dd	tri	PC1	78.6	81.8	85.7
36	30	Accept	Size	Dp, GL	bi	–	77.8	82.5	86.1
37	29	Accept	Form	GL, Bd, Dd	tri	PC1	77.8	81.3	83.3
37	29	Accept	Shape	Dp, LDp, Dd	tri	PC1	79.0	80.2	84.2
38	28	Accept	Form	GL, SD, Bd	tri	PC1	76.8	80.7	85.7
38	28	Accept	Form	SD, Bd, Dd	tri	PC1	75.8	81.8	87.1
38	28	Accept	Shape	Dp, Bd, Dd	tri	PC1	77.8	80.5	86.1
38	28	Accept	Shape	Dp, DPL, Dd	tri	PC1	76.5	81.1	88.2
38	28	Accept	Shape	DPL, LDp, Bd	tri	PC1	77.5	80.3	82.5
38	28	Accept	Shape	DPL, SD, Dd	tri	PC2	77.5	80.1	82.5
38	28	Accept	Size	DPL, LDp, GL	tri	–	77.5	80.9	85.0

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
39	27	Accept	Form	Dd, LDp	bi	PC1	78.3	79.2	82.6
39	27	Accept	Shape	DPL, LDp, SD	tri	PC2	77.5	79.5	82.5
39	27	Accept	Shape	GL, SD, Bd	tri	PC2	75.0	81.5	87.5
39	27	Accept	Size	Dd, LDp	bi	–	78.3	78.7	80.4
39	27	Accept	Size	LDp, GL, Bd	tri	–	77.5	80.0	82.5
39	27	Accept	Size	LDp, SD, Dd	tri	–	77.3	79.5	81.8
40	26	Accept	Form	Bd, Dd	bi	PC1	76.6	79.4	82.8
40	26	Accept	Shape	Bp, DPL	bi	PC1	77.3	78.9	81.8
40	26	Accept	Shape	Dp, DPL, LDp	tri	PC1	73.5	82.9	88.2
40	26	Accept	Shape	LDp, Bd, Dd	tri	PC2	77.3	78.5	81.8
40	26	Accept	Size	Bp, GL, Bd	tri	–	76.8	79.2	82.1
40	26	Accept	Size	Dd, SD	bi	–	75.8	79.8	83.9
40	26	Accept	Size	Dp, GL, Dd	tri	–	75.0	81.0	86.1
41	24	Accept	Shape	Bp, Dp, DPL	tri	PC1	73.5	80.7	85.3
42	23	Accept	Shape	Bp, DPL, Bd	tri	PC2	75.0	78.1	82.5
42	23	Accept	Size	Bd, Dd	bi	–	75.0	78.3	81.2
42	23	Accept	Size	Bp, GL, SD	tri	–	75.0	78.4	82.1
43	22	Accept	Form	LDp, GL, Dd	tri	PC1	73.8	77.7	81.0
43	22	Accept	Form	LDp	uni	–	75.0	76.9	79.2
44	20	Accept	Form	Dd, SD	bi	PC1	72.6	77.8	83.9
44	20	Accept	Size	Bp, LDp, GL	tri	–	73.8	76.1	78.6
45	19	Accept	Shape	Dd, GL	bi	PC1	70.4	78.4	83.3
45	19	Accept	Shape	DPL, SD, Bd	tri	PC1	73.7	75.2	79.0
45	19	Accept	Shape	SD, GL	bi	PC1	72.4	76.7	82.8
46	18	Accept	Form	LDp, SD, Dd	tri	PC1	72.7	75.2	77.3
46	18	Accept	Shape	DPL, SD	bi	PC1	72.5	75.6	77.5
47	17	Reject	Shape	Bp, DPL, SD	tri	PC2	72.5	74.2	77.5
48	16	Reject	Size	Bp, GL	bi	–	71.4	74.2	78.6

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
48	16	Reject	Size	DPL, GL, SD	tri	–	72.5	74.0	77.5
49	15	Reject	Shape	Bp, Dp	bi	PC1	71.0	74.3	76.3
49	15	Reject	Shape	Bp, LDp, Dd	tri	PC2	71.7	73.1	76.1
49	15	Reject	Form	SD	uni	–	70.6	74.4	77.9
50	14	Reject	Shape	Bp, Dp, SD	tri	PC2	71.0	73.4	76.3
50	14	Reject	Size	Bp, GL, Dd	tri	–	70.4	73.6	77.8
50	14	Reject	Size	LDp, SD	bi	–	70.5	73.7	77.3
51	13	Reject	Form	LDp, GL	bi	PC1	69.0	74.3	78.6
51	13	Reject	Shape	Bd, Dd	bi	PC1	70.3	73.0	76.6
51	13	Reject	Shape	SD, Bd, Dd	tri	PC2	69.3	73.2	77.4
52	12	Reject	Size	Bd, GL	bi	–	69.6	72.2	75.0
53	11	Reject	Size	GL, SD, Bd	tri	–	67.9	73.3	76.8
54	10	Reject	Form	Dp, Bd, Dd	tri	PC2	66.7	73.5	80.6
54	10	Reject	Form	GL, SD, Dd	tri	PC1	66.7	73.1	79.6
54	10	Reject	Form	LDp, GL, Bd	tri	PC2	67.5	72.7	77.5
54	10	Reject	Size	GL, Bd, Dd	tri	–	68.5	71.4	74.1
54	10	Reject	Size	GL, SD, Dd	tri	–	68.5	71.5	74.1
55	9	Reject	Form	GL, Bd, Dd	tri	PC2	68.5	70.6	74.1
55	9	Reject	Size	Dp, GL, SD	tri	–	66.7	72.6	80.6
55	9	Reject	Form	Bd, GL	bi	PC2	67.9	71.5	75.0
56	8	Reject	Form	Bp, LDp, GL	tri	PC2	66.7	71.2	76.2
56	8	Reject	Shape	Bp, Dp, Bd	tri	PC2	66.7	71.5	75.0
56	8	Reject	Shape	Dp, DPL, SD	tri	PC1	67.7	69.9	73.5
56	8	Reject	Shape	DPL, SD, Dd	tri	PC1	67.5	70.8	75.0
56	8	Reject	Shape	GL, SD, Dd	tri	PC2	66.7	70.9	77.8
57	7	Reject	Form	Dp, GL, Dd	tri	PC2	66.7	70.0	72.2
57	7	Reject	Shape	Dp, DPL, Bd	tri	PC1	65.6	71.8	78.1
57	7	Reject	Size	LDp, GL, Dd	tri	–	66.7	70.8	76.2

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
57	7	Reject	Form	Dd	uni	–	66.7	70.5	74.2
58	6	Reject	Form	LDp, GL, Dd	tri	PC3	66.7	68.9	71.4
58	6	Reject	Form	SD, GL	bi	PC1	63.8	71.9	77.6
58	6	Reject	Shape	Bp, Bd, Dd	tri	PC1	65.0	71.0	76.7
59	5	Reject	Form	LDp, SD	bi	PC1	65.9	68.6	72.7
59	5	Reject	Shape	DPL, Bd	bi	PC1	65.0	69.9	75.0
59	5	Reject	Shape	DPL, LDp, Dd	tri	PC2	66.7	68.3	71.4
59	5	Reject	Form	Dd, Dp	bi	PC2	65.8	69.7	76.3
60	4	Reject	Form	Bp, GL, Bd	tri	PC2	66.1	68.2	71.4
60	4	Reject	Shape	Bd, Dp	bi	PC1	63.9	70.3	77.8
60	4	Reject	Shape	Bp, SD, Dd	tri	PC2	63.8	69.8	75.9
60	4	Reject	Form	Dd, GL	bi	PC2	64.8	68.7	72.2
60	4	Reject	Form	LDp, GL	bi	PC2	66.7	67.6	69.0
61	3	Reject	Shape	Bd, LDp	bi	PC1	65.9	66.7	68.2
62	2	Reject	Form	Dp, SD, Dd	tri	PC3	63.2	68.9	73.7
62	2	Reject	Form	DPL, SD, Dd	tri	PC3	65.0	67.4	70.0
62	2	Reject	Form	LDp, GL, SD	tri	PC3	64.3	67.3	71.4
62	2	Reject	Shape	GL, SD, Dd	tri	PC1	63.0	68.7	77.8
62	2	Reject	Size	LDp, GL	bi	–	64.3	67.3	69.0
63	1	Reject	Form	GL, SD, Bd	tri	PC3	64.3	66.9	69.6
63	1	Reject	Shape	Bp, Dd	bi	PC1	61.7	69.3	75.0
63	1	Reject	Shape	Bp, DPL, SD	tri	PC1	62.5	68.8	72.5
63	1	Reject	Shape	Bp, GL, SD	tri	PC1	62.5	68.1	75.0
63	1	Reject	Shape	Dp, SD	bi	PC1	63.2	67.5	71.0
63	1	Reject	Shape	GL, SD, Bd	tri	PC1	60.7	69.9	75.0
64	0	Reject	Form	Bp, GL, Dd	tri	PC2	63.0	67.0	70.4
64	0	Reject	Form	DPL, GL, SD	tri	PC2	62.5	67.7	70.0
64	0	Reject	Form	GL, SD, Dd	tri	PC3	63.0	67.0	72.2

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
64	0	Reject	Shape	Bp, LDp, Bd	tri	PC1	63.6	66.7	68.2
64	0	Reject	Shape	Dp, SD, Bd	tri	PC1	63.9	65.8	69.4
64	0	Reject	Shape	LDp, GL, Dd	tri	PC2	64.3	66.2	69.0
64	0	Reject	Shape	LDp, SD, Bd	tri	PC2	64.3	65.7	69.0
64	0	Reject	Form	DPL, Dd	bi	PC2	64.3	66.0	69.0
65	-1	Reject	Form	Bp, DPL, GL	tri	PC2	62.5	66.5	70.0
65	-1	Reject	Form	DPL, LDp, GL	tri	PC2	62.5	67.0	70.0
65	-1	Reject	Form	Bp, GL	bi	PC2	62.5	66.9	71.4
65	-1	Reject	Form	DPL, SD	bi	PC2	62.5	66.7	70.0
66	-2	Reject	Form	Bp, GL, SD	tri	PC3	62.5	65.9	69.6
66	-2	Reject	Form	Dd, GL	bi	PC1	61.0	66.6	70.4
66	-2	Reject	Form	DPL, GL, Dd	tri	PC2	62.5	65.3	67.5
67	-3	Reject	Form	DPL, Bd, Dd	tri	PC2	62.5	64.6	67.5
67	-3	Reject	Shape	Bp, LDp, SD	tri	PC2	61.4	65.4	70.5
67	-3	Reject	Shape	DPL, LDp, SD	tri	PC1	62.5	64.4	67.5
68	-4	Reject	Form	DPL, SD, Dd	tri	PC2	62.5	63.9	67.5
68	-4	Reject	Shape	Bp, DPL, Bd	tri	PC1	60.0	66.1	70.0
69	-5	Reject	Form	Bp, Dp, Dd	tri	PC2	60.5	64.6	68.4
69	-5	Reject	Form	Dp, LDp, GL	tri	PC2	58.3	67.1	80.6
69	-5	Reject	Form	LDp, GL, SD	tri	PC1	61.9	63.4	66.7
69	-5	Reject	Shape	Dp, LDp, Dd	tri	PC2	60.5	64.5	68.4
69	-5	Reject	Shape	Dp, SD, Bd	tri	PC2	58.3	66.9	77.8
70	-6	Reject	Form	Bp, DPL, LDp	tri	PC2	61.4	63.0	65.9
70	-6	Reject	Form	DPL, GL, Bd	tri	PC2	60.5	63.8	68.4
70	-6	Reject	Shape	Bp, LDp	bi	PC1	60.4	63.3	66.7
71	-7	Reject	Form	Bp, DPL, SD	tri	PC2	60.0	63.4	65.0
71	-7	Reject	Form	Bp, LDp, Dd	tri	PC3	60.9	61.9	63.0
71	-7	Reject	Form	DPL, LDp, Dd	tri	PC3	59.5	63.2	66.7

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
71	-7	Reject	Form	SD, Bd, Dd	tri	PC3	59.7	63.5	69.3
71	-7	Reject	Shape	Bp, DPL, Dd	tri	PC2	59.5	63.7	66.7
71	-7	Reject	Size	SD, GL	bi	–	60.3	63.1	67.2
71	-7	Reject	Form	DPL, GL	bi	PC2	60.0	63.3	65.0
72	-8	Reject	Form	Dp, DPL, Dd	tri	PC2	58.8	63.5	67.7
72	-8	Reject	Form	GL, SD, Bd	tri	PC2	58.9	63.1	66.1
72	-8	Reject	Size	LDp, GL, SD	tri	–	59.5	62.5	66.7
72	-8	Reject	Form	Bd, Dd	bi	PC2	59.4	62.6	65.6
72	-8	Reject	Form	Bp, SD	bi	PC2	58.3	63.4	68.3
72	-8	Reject	Form	Dp, SD	bi	PC2	57.9	63.6	68.4
73	-9	Reject	Form	Bp, Dp, GL	tri	PC2	58.3	62.5	72.2
73	-9	Reject	Form	Bp, SD, Dd	tri	PC3	58.6	62.8	69.0
73	-9	Reject	Form	Dp, DPL, Bd	tri	PC3	56.2	64.8	71.9
73	-9	Reject	Shape	Bp, Bd, Dd	tri	PC2	58.3	62.4	66.7
73	-9	Reject	Form	Dp, GL	bi	PC2	58.3	62.3	63.9
73	-9	Reject	Form	DPL, LDp	bi	PC2	59.1	61.9	65.9
74	-10	Reject	Form	Dp, GL, Bd	tri	PC2	55.9	64.5	67.7
74	-10	Reject	Form	Dp, GL, SD	tri	PC2	58.3	61.5	66.7
74	-10	Reject	Form	Dp, LDp, Dd	tri	PC2	57.9	62.6	65.8
74	-10	Reject	Form	DPL, LDp, SD	tri	PC3	57.5	62.6	67.5
74	-10	Reject	Form	SD, GL	bi	PC2	58.6	61.3	63.8
75	-11	Reject	Form	Dp, LDp, Dd	tri	PC3	57.9	60.7	65.8
75	-11	Reject	Form	DPL, SD, Bd	tri	PC2	57.9	61.6	65.8
75	-11	Reject	Form	GL, Bd, Dd	tri	PC3	57.4	61.2	64.8
75	-11	Reject	Shape	Dp, SD, Dd	tri	PC1	57.9	61.4	65.8
75	-11	Reject	Shape	GL, Bd, Dd	tri	PC2	57.4	61.3	64.8
75	-11	Reject	Form	Dp, LDp	bi	PC2	57.9	60.8	63.2
76	-12	Reject	Form	DPL, LDp, SD	tri	PC2	57.5	60.7	65.0

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
76	-12	Reject	Shape	Bp, LDp, Bd	tri	PC2	56.8	60.8	63.6
76	-12	Reject	Shape	Dp, LDp, SD	tri	PC1	57.9	60.0	63.2
76	-12	Reject	Shape	DPL, SD, Bd	tri	PC2	55.3	63.2	68.5
76	-12	Reject	Form	Bp, Dd	bi	PC2	56.7	61.2	65.1
77	-13	Reject	Form	Bp, Bd, Dd	tri	PC2	56.7	60.3	65.0
77	-13	Reject	Form	Bp, DPL, Dd	tri	PC2	57.1	59.8	61.9
77	-13	Reject	Form	DPL, LDp, Dd	tri	PC2	57.1	59.8	61.9
77	-13	Reject	Form	Bp, DPL	bi	PC2	56.8	60.1	63.6
78	-14	Reject	Form	Bp, GL, SD	tri	PC2	55.4	60.5	66.1
78	-14	Reject	Form	Dp, DPL, GL	tri	PC2	55.9	60.3	64.7
78	-14	Reject	Form	Dp, DPL, LDp	tri	PC2	55.7	60.4	64.7
78	-14	Reject	Form	Dp, LDp, Bd	tri	PC2	55.6	60.2	63.9
78	-14	Reject	Form	Dp, LDp, SD	tri	PC3	55.3	60.3	65.8
78	-14	Reject	Form	LDp, SD, Dd	tri	PC2	56.8	59.3	63.6
78	-14	Reject	Shape	Dp, DPL	bi	PC1	55.9	60.3	64.7
78	-14	Reject	Shape	Dp, DPL, SD	tri	PC2	55.9	60.1	64.7
78	-14	Reject	Form	Bd, SD	bi	PC2	56.2	59.9	64.1
79	-15	Reject	Form	Bp, LDp, SD	tri	PC2	54.5	60.0	63.6
79	-15	Reject	Form	Bp, SD, Bd	tri	PC2	55.0	59.8	63.3
79	-15	Reject	Form	DPL, LDp, Bd	tri	PC2	55.0	59.9	67.5
79	-15	Reject	Shape	Bp, Dp, Bd	tri	PC1	55.6	59.8	63.9
79	-15	Reject	Shape	Bp, Dp, SD	tri	PC1	55.3	60.0	65.8
79	-15	Reject	Shape	Bp, LDp, SD	tri	PC1	54.5	60.1	63.6
80	-16	Reject	Form	Bp, LDp, Bd	tri	PC3	54.5	59.0	61.4
80	-16	Reject	Shape	Bp, Dp, Dd	tri	PC2	55.3	59.2	63.2
80	-16	Reject	Shape	Bp, LDp, Dd	tri	PC1	56.5	57.2	58.7
80	-16	Reject	Shape	Dd, SD	bi	PC1	53.2	60.3	67.7
80	-16	Reject	Form	Bp, LDp	bi	PC2	56.2	58.2	58.3

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
81	-17	Reject	Form	Bp, DPL, Bd	tri	PC3	55.0	58.3	65.0
81	-17	Reject	Form	GL	uni	–	55.2	58.0	62.1
82	-18	Reject	Form	Dp, SD, Dd	tri	PC2	55.3	57.0	60.5
82	-18	Reject	Form	LDp, GL, SD	tri	PC2	54.8	56.8	59.5
82	-18	Reject	Form	LDp, SD, Bd	tri	PC2	54.8	57.3	61.9
82	-18	Reject	Form	Dp, DPL	bi	PC2	52.9	59.5	64.7
82	-18	Reject	Form	LDp, SD	bi	PC2	54.5	57.1	59.1
83	-19	Reject	Form	Bp, LDp, SD	tri	PC3	54.5	56.1	61.4
83	-19	Reject	Form	Dp, DPL, SD	tri	PC2	52.9	58.3	61.8
84	-20	Reject	Form	Dp, GL, SD	tri	PC3	50.0	59.5	63.9
84	-20	Reject	Form	Dp, LDp, SD	tri	PC2	52.6	57.4	60.5
84	-20	Reject	Shape	SD, Bd, Dd	tri	PC1	53.2	56.4	61.3
84	-20	Reject	Size	Dd, GL	bi	–	51.9	58.5	64.8
85	-21	Reject	Form	Dp, DPL, SD	tri	PC3	50.0	59.0	64.7
85	-21	Reject	Shape	Bp, Dp, LDp	tri	PC2	52.6	56.0	63.2
85	-21	Reject	Shape	LDp, SD, Bd	tri	PC1	52.4	56.6	59.5
86	-22	Reject	Form	Bp, Dp, SD	tri	PC2	52.6	55.8	60.5
86	-22	Reject	Form	Bp, SD, Dd	tri	PC2	51.7	56.5	60.3
86	-22	Reject	Form	Dp, SD, Bd	tri	PC2	52.8	55.0	58.3
87	-23	Reject	Form	Bp, LDp, Bd	tri	PC2	52.3	54.8	56.8
87	-23	Reject	Form	LDp, Bd, Dd	tri	PC3	52.3	55.1	56.8
87	-23	Reject	Shape	LDp, GL, SD	tri	PC1	52.4	54.8	57.1
88	-24	Reject	Form	Bp, DPL, SD	tri	PC3	50.0	55.7	62.5
89	-25	Reject	Form	Bp, Dp, DPL	tri	PC3	47.1	57.7	67.7
90	-26	Reject	Form	Bp, Dp, LDp	tri	PC2	50.0	54.4	63.2
90	-26	Reject	Form	LDp, SD, Dd	tri	PC3	50.0	53.5	56.8
91	-27	Reject	Form	Bp, DPL, Dd	tri	PC3	47.6	55.9	66.7
91	-27	Reject	Form	SD, Bd, Dd	tri	PC2	48.4	54.4	59.7

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
91	-27	Reject	Shape	Bp, DPL, LDp	tri	PC2	47.7	55.0	61.4
91	-27	Reject	Form	Dd, LDp	bi	PC2	50.0	52.9	54.4
92	-28	Reject	Form	LDp, SD, Bd	tri	PC3	50.0	51.5	54.8
92	-28	Reject	Form	Bd, LDp	bi	PC2	50.0	52.3	54.5
92	-28	Reject	Form	Bp, Dp	bi	PC2	44.6	57.7	68.4
93	-30	Reject	Form	Bp, Dp, SD	tri	PC3	42.1	58.0	63.2
93	-30	Reject	Form	Dp, LDp, Bd	tri	PC3	38.9	60.6	66.7
94	-31	Reject	Form	Bp, LDp, Dd	tri	PC2	47.8	50.8	52.2
94	-31	Reject	Form	Bd, Dp	bi	PC2	38.9	60.3	66.7
95	-32	Reject	Form	DPL, GL, SD	tri	PC3	47.5	50.8	55.0
96	-33	Reject	Form	DPL, Bd	bi	PC2	42.5	54.8	62.5
97	-35	Reject	Form	Dp, SD, Bd	tri	PC3	36.1	59.1	66.7
98	-36	Reject	Shape	Bp, GL, Dd	tri	PC2	42.6	51.1	57.4
99	-38	Reject	Form	Bp, Bd, Dd	tri	PC3	36.6	55.2	61.7
99	-38	Reject	Form	DPL, SD, Bd	tri	PC3	39.5	52.8	60.5
100	-41	Reject	Form	Dp, DPL, Dd	tri	PC3	29.4	59.4	70.6
101	-43	Reject	Form	Bp, Dp, DPL	tri	PC2	29.4	57.8	67.7
102	-44	Reject	Form	LDp, GL, Bd	tri	PC3	35.0	51.1	57.5
103	-45	Reject	Form	Bp, Dp, Dd	tri	PC3	26.3	58.2	68.4
104	-46	Reject	Form	Bp, DPL, LDp	tri	PC3	31.8	52.1	61.4
105	-50	Reject	Form	Bp, Dp, Bd	tri	PC3	27.8	52.1	61.1
106	-52	Reject	Shape	Dp, DPL, Bd	tri	PC2	21.7	56.8	68.8
107	-55	Reject	Form	Dp, DPL, GL	tri	PC3	20.6	54.8	64.7
108	-56	Reject	Form	Bp, Dp, LDp	tri	PC3	18.4	55.6	65.8
109	-59	Reject	Form	Dd, SD	bi	PC2	24.2	46.7	53.2
110	-60	Reject	Shape	Dp, Bd, Dd	tri	PC2	19.4	50.9	61.1
111	-61	Reject	Shape	Bp, LDp, GL	tri	PC2	23.8	44.8	50.0
112	-63	Reject	Form	Dp, DPL, Bd	tri	PC2	15.6	51.2	65.6

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
112	-63	Reject	Shape	Bp, SD	bi	PC1	19.9	47.5	56.7
113	-64	Reject	Shape	DPL, Bd, Dd	tri	PC2	15.0	50.9	65.0
114	-66	Reject	Shape	Bp, SD, Dd	tri	PC1	13.8	50.1	58.6
115	-67	Reject	Shape	Bp, Bd	bi	PC1	16.1	46.9	56.5
115	-67	Reject	Shape	Bp, Dp, GL	tri	PC2	16.7	46.4	61.1
115	-67	Reject	Shape	Bp, SD, Bd	tri	PC1	16.7	46.7	56.7
116	-69	Reject	Form	Bp, SD, Bd	tri	PC3	15.0	46.4	56.7
116	-69	Reject	Form	Dp, GL, Bd	tri	PC3	11.8	49.3	61.8
116	-69	Reject	Shape	Bp, DPL, GL	tri	PC2	12.5	48.0	60.0
117	-70	Reject	Form	Bp, GL, Dd	tri	PC3	11.1	49.3	59.3
117	-70	Reject	Shape	Bp, Dp, DPL	tri	PC2	8.8	50.9	64.7
118	-71	Reject	Shape	LDp, Bd, Dd	tri	PC1	15.9	43.4	54.5
119	-73	Reject	Form	DPL, GL, Bd	tri	PC3	10.5	46.9	60.5
119	-73	Reject	Shape	Bp, SD, Bd	tri	PC2	11.7	45.8	56.7
119	-73	Reject	Shape	Dp, DPL, Dd	tri	PC2	5.9	51.0	70.6
119	-73	Reject	Shape	Dp, DPL, GL	tri	PC2	5.9	51.0	64.7
119	-73	Reject	Shape	Dp, GL, Bd	tri	PC2	11.8	44.8	58.8
119	-73	Reject	Shape	LDp, SD, Dd	tri	PC2	15.9	41.5	50.0
120	-74	Reject	Form	Bp, DPL, GL	tri	PC3	12.5	43.5	57.5
120	-74	Reject	Form	Dp, DPL, LDp	tri	PC3	5.9	50.6	64.7
121	-75	Reject	Form	Bp, Dp, GL	tri	PC3	8.3	46.7	61.1
121	-75	Reject	Shape	Dp, GL, SD	tri	PC2	11.1	43.5	58.3
122	-76	Reject	Form	Bp, DPL, Bd	tri	PC2	10.0	43.7	57.5
123	-77	Reject	Form	Dp, Bd, Dd	tri	PC3	8.3	44.8	58.3
123	-77	Reject	Shape	Bd, SD	bi	PC1	9.4	43.6	57.8
124	-78	Reject	Form	Bp, Dp, Bd	tri	PC2	8.3	43.4	58.3
124	-78	Reject	Form	Bp, GL, Bd	tri	PC3	8.9	43.1	55.4
124	-78	Reject	Form	GL, SD, Dd	tri	PC2	9.3	42.4	57.4

Table A.19: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
125	-79	Reject	Form	DPL, GL, Dd	tri	PC3	7.5	43.2	60.0
125	-79	Reject	Form	LDp, Bd, Dd	tri	PC2	9.1	42.4	52.3
126	-80	Reject	Shape	Bp, GL, Bd	tri	PC2	7.1	42.5	55.4
126	-80	Reject	Shape	Dp, DPL, LDp	tri	PC2	8.8	41.6	52.9
126	-80	Reject	Shape	DPL, GL, Bd	tri	PC2	5.3	44.4	60.5
126	-80	Reject	Shape	LDp, SD	bi	PC1	9.1	40.7	54.5
127	-81	Reject	Form	DPL, LDp, Bd	tri	PC3	10.0	38.7	55.0
127	-81	Reject	Shape	Dp, LDp, Bd	tri	PC2	5.6	43.7	61.1
128	-82	Reject	Form	Bp, Bd	bi	PC2	4.8	43.3	54.8
129	-83	Reject	Form	Dp, GL, Dd	tri	PC3	8.2	38.6	61.1
129	-83	Reject	Form	Dp, LDp, GL	tri	PC3	8.3	38.6	50.0
130	-84	Reject	Form	DPL, Bd, Dd	tri	PC3	7.5	38.4	55.0
130	-84	Reject	Shape	Dd, LDp	bi	PC1	8.7	37.0	47.8
130	-84	Reject	Shape	DPL, LDp, Bd	tri	PC2	7.5	38.4	55.0
131	-85	Reject	Shape	Dp, GL, Dd	tri	PC2	5.6	39.2	55.6
131	-85	Reject	Shape	Dp, LDp, GL	tri	PC2	2.8	41.9	55.6
132	-86	Reject	Form	LDp, GL, Dd	tri	PC2	7.1	37.0	52.4
133	-87	Reject	Form	DPL, LDp, GL	tri	PC3	5.0	38.5	57.5
134	-90	Reject	Shape	DPL, GL, SD	tri	PC2	5.0	34.9	50.0
135	-91	Reject	Shape	DPL, GL, Dd	tri	PC2	5.0	33.7	55.0
136	-92	Reject	Form	Bp, LDp, GL	tri	PC3	2.4	36.1	52.4
137	-93	Reject	Shape	LDp, GL, Bd	tri	PC2	0.0	36.7	62.5
138	-94	Reject	Shape	DPL, LDp, GL	tri	PC2	0.0	35.8	57.5
139	-102	Reject	Shape	LDp, SD, Dd	tri	PC1	2.3	25.9	50.0

Table A.20: List of approaches ranked by score for balanced cross-validation results for the tibia (Subset B).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	79	Prefer	Form	DPL, Bd	bi	PC1	93.3	98.1	100.0
1	79	Prefer	Shape	Bp, LDp, GL	tri	PC1	94.4	97.6	100.0
1	79	Prefer	Shape	DPL, GL, Bd	tri	PC1	93.3	97.9	100.0
2	78	Prefer	Form	Bp, DPL, Bd	tri	PC1	93.3	97.2	100.0
2	78	Prefer	Form	DPL, SD, Bd	tri	PC1	93.3	97.5	100.0
2	78	Prefer	Shape	Bp, DPL, GL	tri	PC1	93.3	96.9	100.0
2	78	Prefer	Shape	Bp, GL, Bd	tri	PC1	93.3	97.8	100.0
2	78	Prefer	Size	Bp, DPL, Bd	tri	–	93.3	97.0	100.0
2	78	Prefer	Size	DPL, Bd	bi	–	93.3	97.7	100.0
3	74	Prefer	Form	Dp, DPL, Bd	tri	PC1	88.9	97.5	100.0
3	74	Prefer	Form	Dp, DPL	bi	PC1	88.9	97.4	100.0
3	74	Prefer	Shape	Bp, Dp, GL	tri	PC1	88.9	97.9	100.0
4	73	Prefer	Form	Bd, Dp	bi	PC1	88.9	96.3	100.0
4	73	Prefer	Form	Bp, Dp, DPL	tri	PC1	88.9	97.0	100.0
4	73	Prefer	Form	Dp, DPL, SD	tri	PC1	88.9	97.0	100.0
4	73	Prefer	Shape	Bd, GL	bi	PC1	90.0	95.7	100.0
4	73	Prefer	Shape	Dp, GL, Bd	tri	PC1	88.9	97.3	100.0
4	73	Prefer	Shape	LDp, GL, Bd	tri	PC1	88.9	97.2	100.0
4	73	Prefer	Size	Bd, Dp	bi	–	88.9	96.4	100.0
4	73	Prefer	Size	Bp, Dp, DPL	tri	–	88.9	96.7	100.0
4	73	Prefer	Size	Dp, DPL	bi	–	88.9	97.2	100.0
4	73	Prefer	Size	Dp, DPL, Bd	tri	–	88.9	97.2	100.0
4	73	Prefer	Form	Dp	uni	–	88.9	96.4	100.0
5	72	Prefer	Form	Bp, Dp, Bd	tri	PC1	88.9	95.9	100.0
5	72	Prefer	Form	Bp, Dp	bi	PC1	88.9	95.8	100.0
5	72	Prefer	Form	Bp, SD, Bd	tri	PC1	89.7	94.7	100.0
5	72	Prefer	Shape	GL, Bd, Dd	tri	PC1	90.0	94.9	100.0

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
5	72	Prefer	Size	Bp, Dp	bi	–	88.9	95.3	100.0
5	72	Prefer	Size	Bp, Dp, Bd	tri	–	88.9	95.8	100.0
5	72	Prefer	Size	Bp, SD, Bd	tri	–	89.7	94.6	100.0
6	71	Prefer	Form	Dp, DPL, LDp	tri	PC1	88.9	95.3	100.0
6	71	Prefer	Form	DPL	uni	–	86.7	97.1	100.0
7	70	Prefer	Form	Bp, DPL, SD	tri	PC1	86.7	96.5	100.0
7	70	Prefer	Form	DPL, Bd, Dd	tri	PC1	86.7	96.2	100.0
7	70	Prefer	Form	DPL, SD	bi	PC1	86.7	96.2	100.0
7	70	Prefer	Size	Dp, LDp, Bd	tri	–	88.3	93.9	100.0
7	70	Prefer	Size	DPL, Bd, Dd	tri	–	86.7	96.4	100.0
7	70	Prefer	Size	DPL, SD, Bd	tri	–	86.7	96.3	100.0
8	69	Prefer	Form	Bp, DPL	bi	PC1	86.7	95.4	100.0
8	69	Prefer	Form	DPL, LDp, Bd	tri	PC1	86.7	94.6	100.0
8	69	Prefer	Size	Bp, DPL	bi	–	86.7	95.2	100.0
8	69	Prefer	Size	Bp, DPL, SD	tri	–	86.7	94.7	100.0
9	68	Prefer	Form	Bp, Bd	bi	PC1	87.2	93.8	97.4
9	68	Prefer	Form	Bp, DPL, Dd	tri	PC1	86.7	94.3	100.0
9	68	Prefer	Shape	Bp, GL, Dd	tri	PC1	86.7	94.0	100.0
9	68	Prefer	Shape	Bp, GL	bi	PC1	86.7	94.5	100.0
9	68	Prefer	Size	Bp, Bd	bi	–	87.2	93.5	97.4
9	68	Prefer	Size	Bp, DPL, Dd	tri	–	86.7	94.2	100.0
9	68	Prefer	Size	DPL, Dd	bi	–	86.7	93.8	100.0
9	68	Prefer	Size	DPL, LDp, Bd	tri	–	86.7	94.4	100.0
10	67	Prefer	Form	Bp, SD	bi	PC1	87.2	92.7	97.4
10	67	Prefer	Form	DPL, Dd	bi	PC1	86.7	93.4	100.0
10	67	Prefer	Form	DPL, LDp, SD	tri	PC1	86.7	93.5	100.0
10	67	Prefer	Size	Bp, Bd, Dd	tri	–	87.2	92.6	97.4
10	67	Prefer	Size	Bp, SD	bi	–	87.2	92.0	97.4

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
10	67	Prefer	Size	DPL, GL, Bd	tri	–	86.7	93.4	100.0
11	66	Accept	Size	Bp, SD, Dd	tri	–	87.2	91.5	97.4
12	64	Accept	Form	Bp	uni	–	84.6	91.7	97.4
13	63	Accept	Form	Bp, Bd, Dd	tri	PC1	84.6	91.5	97.4
13	63	Accept	Form	Bp, SD, Dd	tri	PC1	84.6	90.9	97.4
13	63	Accept	Size	Bp, LDp, Bd	tri	–	83.3	92.1	100.0
14	62	Accept	Form	Bp, LDp, Bd	tri	PC1	83.3	91.7	100.0
14	62	Accept	Size	Bd, LDp	bi	–	83.3	91.0	100.0
14	62	Accept	Size	Bp, Dd	bi	–	84.6	90.4	94.9
15	61	Accept	Form	Bd, SD	bi	PC1	83.3	90.0	95.2
15	61	Accept	Shape	GL, SD, Bd	tri	PC1	83.3	90.5	96.7
15	61	Accept	Size	Bd, SD	bi	–	83.3	90.5	95.2
16	60	Accept	Form	Bp, DPL, LDp	tri	PC1	80.0	92.3	100.0
16	60	Accept	Form	Dp, DPL, Dd	tri	PC1	77.8	94.5	100.0
16	60	Accept	Form	Dp, SD, Bd	tri	PC1	77.8	95.2	100.0
16	60	Accept	Form	DPL, LDp, Dd	tri	PC1	80.0	92.3	100.0
16	60	Accept	Size	Bp, DPL, LDp	tri	–	80.0	92.3	100.0
16	60	Accept	Size	Dp, Bd, Dd	tri	–	77.8	94.8	100.0
16	60	Accept	Size	Dp, DPL, Dd	tri	–	77.8	94.4	100.0
16	60	Accept	Size	Dp, DPL, LDp	tri	–	77.8	95.0	100.0
16	60	Accept	Size	Dp, DPL, SD	tri	–	77.8	95.3	100.0
17	59	Accept	Form	Bp, Dd	bi	PC1	82.0	89.3	94.9
17	59	Accept	Form	Bp, Dp, LDp	tri	PC1	77.8	93.4	100.0
17	59	Accept	Form	Bp, Dp, SD	tri	PC1	77.8	94.3	100.0
17	59	Accept	Form	Dp, Bd, Dd	tri	PC1	77.8	94.1	100.0
17	59	Accept	Form	Dp, LDp, Bd	tri	PC1	77.8	93.8	100.0
17	59	Accept	Form	DPL, LDp	bi	PC1	80.0	91.8	100.0
17	59	Accept	Form	DPL, SD, Dd	tri	PC1	80.0	91.5	100.0

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
17	59	Accept	Size	Dp, SD, Bd	tri	–	77.8	93.6	100.0
17	59	Accept	Size	DPL, LDp	bi	–	80.0	91.8	100.0
17	59	Accept	Size	DPL, LDp, Dd	tri	–	80.0	91.8	100.0
17	59	Accept	Size	DPL, LDp, SD	tri	–	80.0	91.5	100.0
17	59	Accept	Size	DPL, SD	bi	–	80.0	92.1	100.0
18	58	Accept	Form	Dp, DPL, GL	tri	PC1	77.8	92.8	100.0
18	58	Accept	Form	Dp, SD	bi	PC1	77.8	92.9	100.0
18	58	Accept	Form	DPL, GL, Bd	tri	PC1	80.0	91.2	100.0
18	58	Accept	Size	Bp, Dp, Dd	tri	–	77.8	92.6	100.0
18	58	Accept	Size	Bp, Dp, LDp	tri	–	77.8	92.7	100.0
18	58	Accept	Size	Bp, Dp, SD	tri	–	77.8	92.6	100.0
18	58	Accept	Size	Bp, DPL, GL	tri	–	80.0	90.9	100.0
18	58	Accept	Size	Dp, DPL, GL	tri	–	77.8	93.3	100.0
19	57	Accept	Form	Bp, Dp, Dd	tri	PC1	77.8	92.2	100.0
19	57	Accept	Form	Bp, DPL, GL	tri	PC1	80.0	90.0	100.0
19	57	Accept	Form	Dp, LDp	bi	PC1	77.8	92.3	100.0
19	57	Accept	Form	Dp, LDp, SD	tri	PC1	77.8	92.4	100.0
19	57	Accept	Size	Dd, Dp	bi	–	77.8	91.7	100.0
19	57	Accept	Size	Dp, LDp	bi	–	77.8	92.0	100.0
19	57	Accept	Size	DPL, SD, Dd	tri	–	80.0	90.0	100.0
19	57	Accept	Size	SD, Bd, Dd	tri	–	81.0	88.3	95.2
19	57	Accept	Form	Bd	uni	–	81.0	89.2	95.2
20	56	Accept	Form	Dd, Dp	bi	PC1	77.8	91.1	100.0
20	56	Accept	Form	SD, Bd, Dd	tri	PC1	81.0	87.7	92.9
20	56	Accept	Size	Dp, GL, Bd	tri	–	77.8	91.4	100.0
20	56	Accept	Size	Dp, LDp, SD	tri	–	77.8	91.1	100.0
21	55	Accept	Form	Bd, LDp	bi	PC1	77.8	89.9	100.0
21	55	Accept	Form	Dp, GL, Bd	tri	PC1	77.8	90.2	100.0

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
21	55	Accept	Form	Dp, LDp, Dd	tri	PC1	77.8	90.3	100.0
21	55	Accept	Form	Dp, SD, Dd	tri	PC1	77.8	90.0	100.0
21	55	Accept	Shape	DPL, LDp, GL	tri	PC1	80.0	87.3	93.3
21	55	Accept	Size	Bp, Dp, GL	tri	–	77.8	89.8	100.0
21	55	Accept	Size	Dp, LDp, Dd	tri	–	77.8	90.4	100.0
21	55	Accept	Size	LDp, Bd, Dd	tri	–	77.8	90.3	100.0
22	54	Accept	Form	Bp, Dp, GL	tri	PC1	77.8	89.4	100.0
22	54	Accept	Form	Bp, LDp, Dd	tri	PC1	77.8	88.5	100.0
22	54	Accept	Form	LDp, Bd, Dd	tri	PC1	77.8	89.0	100.0
22	54	Accept	Form	LDp, SD, Bd	tri	PC1	77.8	88.6	100.0
22	54	Accept	Shape	Dp, LDp, GL	tri	PC1	77.8	88.6	100.0
22	54	Accept	Shape	DPL, GL	bi	PC1	80.0	86.3	93.3
22	54	Accept	Size	Bp, LDp	bi	–	77.8	88.5	100.0
22	54	Accept	Size	Bp, LDp, Dd	tri	–	77.8	89.0	100.0
22	54	Accept	Size	Dp, SD	bi	–	77.8	89.3	100.0
22	54	Accept	Size	Dp, SD, Dd	tri	–	77.8	88.6	100.0
22	54	Accept	Size	LDp, SD, Bd	tri	–	77.8	88.8	100.0
23	53	Accept	Form	Bp, LDp	bi	PC1	77.8	88.0	100.0
23	53	Accept	Form	Bp, LDp, SD	tri	PC1	77.8	88.0	100.0
23	53	Accept	Shape	DPL, GL, Dd	tri	PC1	79.7	86.1	93.3
23	53	Accept	Size	Bp, LDp, SD	tri	–	77.8	88.2	100.0
24	52	Accept	Size	Bd, Dd	bi	–	78.6	86.4	92.9
24	52	Accept	Size	Dd, SD	bi	–	78.6	86.0	92.9
25	51	Accept	Form	Bd, Dd	bi	PC1	78.6	85.4	92.9
25	51	Accept	Size	Bp, GL, Bd	tri	–	76.7	86.5	93.3
26	50	Accept	Size	Bp, GL, SD	tri	–	76.7	85.5	93.3
27	49	Accept	Form	Dd, SD	bi	PC1	76.2	85.2	92.9
27	49	Accept	Shape	Bp, GL, SD	tri	PC1	76.7	85.3	93.3

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
27	49	Accept	Size	DPL, GL	bi	–	73.3	88.6	100.0
28	48	Accept	Size	DPL, GL, Dd	tri	–	73.3	87.8	100.0
28	48	Accept	Size	DPL, LDp, GL	tri	–	73.3	87.5	100.0
29	47	Accept	Form	DPL, GL, Dd	tri	PC1	73.3	86.0	100.0
29	47	Accept	Form	DPL, GL	bi	PC1	73.3	86.8	100.0
29	47	Accept	Form	DPL, LDp, GL	tri	PC1	73.3	86.6	100.0
30	46	Accept	Form	DPL, GL, SD	tri	PC1	73.3	85.1	100.0
31	45	Accept	Form	Dd, LDp	bi	PC1	72.2	85.0	94.4
31	45	Accept	Form	LDp, SD, Dd	tri	PC1	72.2	85.1	94.4
31	45	Accept	Size	Dd, LDp	bi	–	72.2	85.5	94.4
31	45	Accept	Size	DPL, GL, SD	tri	–	73.3	83.9	100.0
31	45	Accept	Size	LDp, GL, Bd	tri	–	72.2	85.5	94.4
32	44	Accept	Form	Bp, GL, Bd	tri	PC1	73.3	82.9	93.3
32	44	Accept	Form	Bp, GL, SD	tri	PC1	73.3	83.4	93.3
32	44	Accept	Shape	LDp, Bd, Dd	tri	PC1	72.2	84.5	94.4
32	44	Accept	Shape	LDp, GL, Dd	tri	PC1	72.2	84.2	94.4
32	44	Accept	Size	Bp, LDp, GL	tri	–	72.2	84.5	94.4
32	44	Accept	Size	LDp, SD, Dd	tri	–	72.2	84.2	94.4
33	43	Accept	Form	LDp, SD	bi	PC1	72.2	83.5	94.4
33	43	Accept	Shape	Bd, Dd	bi	PC1	73.8	81.7	88.1
33	43	Accept	Shape	Dp, GL, Dd	tri	PC1	66.7	89.1	100.0
33	43	Accept	Shape	Dp, GL	bi	PC1	66.7	89.2	100.0
33	43	Accept	Shape	SD, GL	bi	PC1	73.3	82.6	93.3
33	43	Accept	Size	Bp, GL	bi	–	73.3	82.2	90.0
33	43	Accept	Size	Bp, GL, Dd	tri	–	73.3	82.5	90.0
33	43	Accept	Size	GL, SD, Bd	tri	–	73.3	82.2	90.0
33	43	Accept	Form	LDp	uni	–	72.2	83.5	94.4
34	42	Accept	Size	Dp, GL	bi	–	66.7	87.6	100.0

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
35	41	Accept	Form	Dp, LDp, GL	tri	PC1	66.7	86.9	100.0
35	41	Accept	Form	LDp, GL, Bd	tri	PC1	71.9	81.8	94.4
35	41	Accept	Size	Dp, LDp, GL	tri	–	66.7	86.7	100.0
36	40	Accept	Form	Dp, GL	bi	PC1	66.7	86.1	100.0
36	40	Accept	Shape	Bp, Bd, Dd	tri	PC1	71.8	80.5	87.2
37	39	Accept	Form	Dp, GL, SD	tri	PC1	66.7	84.8	100.0
37	39	Accept	Form	Dd	uni	–	71.4	80.1	88.1
38	38	Accept	Form	Bp, GL, Dd	tri	PC1	70.0	80.5	90.0
38	38	Accept	Size	Bd, GL	bi	–	70.0	81.0	90.0
38	38	Accept	Size	GL, Bd, Dd	tri	–	70.0	80.7	90.0
39	37	Accept	Form	GL, SD, Dd	tri	PC1	70.0	79.9	90.0
39	37	Accept	Shape	LDp, GL	bi	PC1	66.7	82.9	94.4
39	37	Accept	Size	Dp, GL, SD	tri	–	66.7	83.5	100.0
39	37	Accept	Size	GL, SD, Dd	tri	–	70.0	80.2	90.0
40	36	Accept	Form	Bp, GL	bi	PC1	70.0	78.6	86.7
40	36	Accept	Form	Bp, LDp, GL	tri	PC1	66.7	81.6	94.4
40	36	Accept	Form	GL, SD, Bd	tri	PC1	70.0	78.9	86.7
40	36	Accept	Shape	Dp, DPL, GL	tri	PC1	66.7	81.6	88.9
40	36	Accept	Size	LDp, SD	bi	–	66.7	81.5	94.4
41	33	Accept	Form	SD	uni	–	68.9	77.2	84.4
42	32	Accept	Form	GL, Bd, Dd	tri	PC1	66.7	77.7	86.7
42	32	Accept	Shape	GL, SD, Dd	tri	PC1	66.7	78.5	90.0
43	31	Accept	Form	DPL, GL, Dd	tri	PC2	66.7	76.5	86.7
44	30	Accept	Form	DPL, LDp, GL	tri	PC2	66.7	76.1	86.7
44	30	Accept	Form	DPL, GL	bi	PC2	66.7	76.2	86.7
45	29	Reject	Form	LDp, GL, Bd	tri	PC2	66.7	74.9	88.9
45	29	Accept	Size	SD, GL	bi	–	66.7	75.5	86.7
46	28	Accept	Size	LDp, GL, Dd	tri	–	61.1	79.3	94.4

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
47	27	Accept	Size	Dp, GL, Dd	tri	–	55.6	84.5	100.0
48	26	Accept	Form	Bd, GL	bi	PC1	63.3	75.2	86.7
48	26	Accept	Form	Dp, GL, Dd	tri	PC1	55.6	83.0	100.0
48	26	Accept	Shape	Bp, DPL, LDp	tri	PC2	60.0	78.5	93.3
48	26	Accept	Shape	Bp, DPL	bi	PC1	60.0	78.8	93.3
48	26	Accept	Shape	DPL, GL, SD	tri	PC1	60.0	78.6	93.3
49	25	Reject	Shape	SD, Bd, Dd	tri	PC1	64.3	73.1	81.0
50	24	Accept	Shape	Bp, Dp, Dd	tri	PC1	55.6	80.7	100.0
50	24	Accept	Size	LDp, GL, SD	tri	–	61.1	75.6	88.9
51	22	Reject	Shape	Bp, DPL, GL	tri	PC2	60.0	74.5	86.7
51	22	Reject	Shape	DPL, SD, Bd	tri	PC1	60.0	74.5	86.7
52	21	Accept	Form	LDp, GL, Dd	tri	PC1	55.6	78.5	94.4
52	21	Reject	Shape	Bp, Dd	bi	PC1	61.5	72.1	82.0
53	18	Reject	Shape	Bp, DPL, Dd	tri	PC2	60.0	70.7	86.7
53	18	Accept	Shape	Bp, LDp	bi	PC1	55.6	75.2	88.9
54	17	Reject	Shape	Bd, LDp	bi	PC1	55.6	73.7	88.9
54	17	Accept	Shape	Bp, DPL, Bd	tri	PC1	53.3	76.4	93.3
54	17	Reject	Shape	Bp, LDp, Bd	tri	PC1	55.6	74.0	88.9
55	14	Reject	Shape	Bp, DPL, Dd	tri	PC1	53.3	73.8	86.7
55	14	Reject	Shape	DPL, SD	bi	PC1	53.3	73.6	86.7
56	13	Reject	Form	Bp, GL, Bd	tri	PC2	56.7	68.8	76.7
56	13	Accept	Size	LDp, GL	bi	–	50.0	75.3	88.9
57	12	Reject	Form	Bp, DPL, GL	tri	PC2	53.3	71.5	80.0
57	12	Reject	Shape	Bp, LDp, Dd	tri	PC1	50.0	74.4	88.9
57	12	Reject	Size	Dd, GL	bi	–	53.3	71.3	83.3
58	11	Reject	Shape	Bp, DPL, SD	tri	PC1	53.0	70.8	86.7
58	11	Reject	Shape	LDp, GL, SD	tri	PC1	50.0	73.8	88.9
59	10	Accept	Shape	Dp, Bd, Dd	tri	PC1	44.4	78.6	100.0

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
59	10	Reject	Shape	DPL, GL, Bd	tri	PC2	53.3	69.3	80.0
60	9	Reject	Form	Bp, LDp, GL	tri	PC2	55.6	66.4	77.8
60	9	Reject	Shape	Dd, SD	bi	PC1	54.6	66.6	76.2
60	9	Accept	Shape	Dp, GL, SD	tri	PC1	44.4	77.1	100.0
60	9	Reject	Shape	DPL, Bd	bi	PC1	46.7	75.0	93.3
61	8	Reject	Form	Dd, GL	bi	PC1	50.0	70.7	83.3
61	8	Accept	Shape	Bp, Dp, DPL	tri	PC1	44.4	76.4	100.0
62	6	Reject	Form	LDp, GL, SD	tri	PC1	44.4	74.4	88.9
63	5	Reject	Form	LDp, GL	bi	PC1	44.4	72.8	88.9
63	5	Reject	Shape	Dp, DPL, Bd	tri	PC1	43.9	74.2	100.0
64	4	Reject	Shape	Dd, Dp	bi	PC1	44.4	71.9	100.0
64	4	Reject	Form	Bp, GL	bi	PC2	53.3	63.5	73.3
65	3	Reject	Form	Bp, GL, Dd	tri	PC2	50.0	66.2	73.3
65	3	Reject	Shape	Dd, GL	bi	PC1	53.3	62.7	73.3
65	3	Reject	Shape	Dp, GL, Bd	tri	PC2	44.4	71.4	88.9
66	2	Reject	Form	Dp, DPL, GL	tri	PC2	44.4	69.8	88.9
66	2	Reject	Form	Bd, GL	bi	PC2	53.3	60.9	70.0
67	0	Reject	Shape	DPL, Bd, Dd	tri	PC1	40.0	72.2	93.3
67	0	Reject	Form	GL	uni	–	43.3	69.4	83.3
68	-1	Reject	Form	Dp, Bd, Dd	tri	PC2	44.4	67.5	88.9
68	-1	Reject	Form	GL, Bd, Dd	tri	PC2	50.0	61.6	70.0
68	-1	Reject	Shape	Bp, Dp, Dd	tri	PC2	44.4	67.3	88.9
68	-1	Reject	Shape	Dp, LDp, Dd	tri	PC1	44.4	67.6	88.9
69	-2	Reject	Form	DPL, GL, Bd	tri	PC2	40.0	70.4	86.7
70	-3	Reject	Shape	Bp, SD, Dd	tri	PC1	46.1	63.5	74.4
71	-4	Reject	Form	SD, GL	bi	PC1	40.0	69.0	83.3
71	-4	Reject	Shape	DPL, SD, Dd	tri	PC1	40.0	69.1	93.3
72	-5	Reject	Shape	Dp, DPL, SD	tri	PC1	33.3	74.3	100.0

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
73	-7	Reject	Shape	Bd, Dp	bi	PC1	33.3	72.6	100.0
74	-8	Reject	Shape	Bp, LDp, SD	tri	PC2	44.4	60.4	72.2
74	-8	Reject	Shape	Dp, SD	bi	PC1	33.3	70.9	100.0
75	-9	Reject	Shape	Dp, SD, Bd	tri	PC1	33.3	70.3	100.0
75	-9	Reject	Shape	DPL, GL, SD	tri	PC2	40.0	63.8	80.0
75	-9	Reject	Shape	LDp, SD, Bd	tri	PC1	38.9	64.7	83.3
76	-10	Reject	Shape	Bp, Dp, Bd	tri	PC1	33.3	69.5	88.9
77	-11	Reject	Form	LDp, GL, Dd	tri	PC2	44.2	57.9	72.2
77	-11	Reject	Shape	Bp, Dp, GL	tri	PC2	33.3	68.1	88.9
77	-11	Reject	Shape	Bp, Dp, LDp	tri	PC2	33.3	68.2	100.0
78	-12	Reject	Shape	Bp, Dp	bi	PC1	33.3	67.4	88.9
79	-13	Reject	Form	Bp, Dp, GL	tri	PC2	33.3	66.8	88.9
79	-13	Reject	Shape	Dp, LDp, SD	tri	PC1	33.3	66.3	88.9
80	-14	Reject	Form	DPL, GL, SD	tri	PC2	33.3	65.0	80.0
80	-14	Reject	Shape	Dp, SD, Dd	tri	PC1	33.3	65.7	88.9
80	-14	Reject	Shape	DPL, LDp, Bd	tri	PC1	33.3	65.5	86.7
80	-14	Reject	Shape	LDp, SD, Dd	tri	PC1	33.3	65.4	83.3
81	-15	Reject	Form	Dp, GL, Dd	tri	PC2	33.3	63.9	88.9
81	-15	Reject	Shape	DPL, LDp, SD	tri	PC1	33.3	64.8	86.7
81	-15	Reject	Form	Dp, GL	bi	PC2	33.3	64.3	88.9
82	-16	Reject	Shape	Dp, LDp, Bd	tri	PC1	33.3	63.7	88.9
83	-17	Reject	Form	Dp, GL, SD	tri	PC2	33.3	62.9	88.9
83	-17	Reject	Shape	Bp, Dp, SD	tri	PC1	33.3	62.5	88.9
83	-17	Reject	Shape	LDp, SD, Bd	tri	PC2	38.9	56.5	72.2
83	-17	Reject	Shape	LDp, SD	bi	PC1	33.3	62.8	83.3
84	-18	Reject	Shape	Bp, Bd	bi	PC1	35.9	58.7	71.8
84	-18	Reject	Shape	Bp, Dp, LDp	tri	PC1	33.3	60.9	88.9
85	-19	Reject	Form	GL, SD, Bd	tri	PC2	36.7	56.6	70.0

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
85	-19	Reject	Shape	Bp, LDp, SD	tri	PC1	33.3	60.4	77.8
86	-20	Reject	Form	Bp, Dp, Dd	tri	PC2	33.3	59.5	77.8
86	-20	Reject	Form	Dp, LDp, Bd	tri	PC2	33.3	59.8	77.8
86	-20	Reject	Shape	Dp, DPL, Dd	tri	PC1	33.3	58.9	77.8
87	-21	Reject	Form	Bp, Dp, LDp	tri	PC2	33.3	58.0	88.9
87	-21	Reject	Form	Dd, Dp	bi	PC2	33.3	58.6	88.9
88	-22	Reject	Form	Bp, LDp, Bd	tri	PC2	33.3	57.9	77.8
88	-22	Reject	Form	Dp, DPL, Dd	tri	PC2	33.3	56.9	77.8
88	-22	Reject	Form	Dp, LDp, GL	tri	PC2	33.3	57.3	77.8
88	-22	Reject	Form	Bd, LDp	bi	PC2	33.3	57.8	77.8
89	-23	Reject	Form	Bp, GL, SD	tri	PC2	33.3	55.9	70.0
89	-23	Reject	Form	DPL, LDp, Bd	tri	PC2	33.3	56.7	80.0
90	-24	Reject	Form	Dp, GL, Bd	tri	PC2	33.3	55.7	77.8
90	-24	Reject	Shape	Dp, SD, Bd	tri	PC2	33.3	55.5	88.9
90	-24	Reject	Form	LDp, GL	bi	PC2	33.3	55.7	72.2
91	-25	Reject	Shape	Bp, SD, Bd	tri	PC2	33.3	54.0	66.7
91	-25	Reject	Shape	Bp, SD, Dd	tri	PC2	38.5	49.2	59.0
91	-25	Reject	Shape	Dp, DPL, LDp	tri	PC1	22.2	65.5	89.4
91	-25	Reject	Shape	DPL, LDp, SD	tri	PC2	33.3	54.2	73.3
91	-25	Reject	Form	Bd, Dd	bi	PC2	33.3	54.5	69.0
92	-26	Reject	Shape	Bp, DPL, LDp	tri	PC1	33.3	53.5	73.3
92	-26	Reject	Shape	Dp, LDp, Bd	tri	PC2	33.3	53.7	77.8
92	-26	Reject	Shape	DPL, Dd	bi	PC1	33.3	52.9	66.7
92	-26	Reject	Shape	DPL, LDp	bi	PC1	33.3	53.7	73.3
93	-27	Reject	Shape	DPL, LDp, Dd	tri	PC1	33.3	52.0	66.7
94	-29	Reject	Form	Bp, SD, Dd	tri	PC3	33.3	49.9	61.5
94	-29	Reject	Form	Bp, Dd	bi	PC2	33.3	50.3	61.5
95	-30	Reject	Form	Bp, Bd, Dd	tri	PC2	30.8	51.5	66.7

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
95	-30	Reject	Form	Bp, GL, SD	tri	PC3	30.0	52.3	63.3
95	-30	Reject	Shape	GL, SD, Dd	tri	PC2	30.0	52.6	66.7
96	-31	Reject	Form	LDp, Bd, Dd	tri	PC2	27.8	53.5	72.2
97	-32	Reject	Form	GL, SD, Dd	tri	PC2	30.0	50.6	63.3
97	-32	Reject	Form	LDp, SD, Bd	tri	PC3	27.8	53.1	72.2
97	-32	Reject	Form	SD, Bd, Dd	tri	PC3	30.9	49.5	62.0
98	-33	Reject	Form	Dd, GL	bi	PC2	30.0	49.3	63.3
98	-33	Reject	Form	Dd, SD	bi	PC2	33.3	46.7	54.9
98	-33	Reject	Form	SD, GL	bi	PC2	30.0	50.2	66.7
99	-34	Reject	Shape	Bp, GL, SD	tri	PC2	30.0	48.2	63.3
99	-34	Reject	Shape	Bp, SD	bi	PC1	30.8	48.2	59.0
99	-34	Reject	Shape	DPL, LDp, Bd	tri	PC2	26.7	52.3	73.3
100	-35	Reject	Form	Dp, LDp, Dd	tri	PC2	22.2	55.4	77.8
100	-35	Reject	Shape	Dp, GL, SD	tri	PC2	22.2	55.3	88.9
100	-35	Reject	Shape	Dp, LDp, SD	tri	PC2	22.2	56.0	77.8
101	-36	Reject	Form	Dp, DPL, LDp	tri	PC2	22.2	54.8	88.9
101	-36	Reject	Form	DPL, Bd, Dd	tri	PC2	26.7	49.6	73.3
101	-36	Reject	Form	LDp, GL, SD	tri	PC3	27.8	49.3	61.4
101	-36	Reject	Shape	Dp, SD, Dd	tri	PC2	22.2	54.0	77.8
102	-37	Reject	Form	DPL, SD, Dd	tri	PC3	26.7	49.3	66.7
102	-37	Reject	Form	SD, Bd, Dd	tri	PC2	30.9	44.9	54.8
102	-37	Reject	Shape	DPL, SD, Dd	tri	PC2	26.7	49.5	66.7
102	-37	Reject	Shape	SD, Bd, Dd	tri	PC2	30.9	45.1	54.8
103	-38	Reject	Shape	Dd, LDp	bi	PC1	27.8	47.0	66.7
103	-38	Reject	Shape	DPL, Bd, Dd	tri	PC2	26.7	47.9	66.7
103	-38	Reject	Shape	DPL, SD, Bd	tri	PC2	26.7	48.5	66.7
103	-38	Reject	Form	DPL, Dd	bi	PC2	26.7	48.4	66.7
104	-39	Reject	Form	Bp, DPL, Dd	tri	PC2	26.7	46.9	66.7

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
104	-39	Reject	Form	Bp, SD, Dd	tri	PC2	30.8	42.7	51.3
104	-39	Reject	Form	DPL, LDp, Dd	tri	PC2	26.7	46.6	66.7
104	-39	Reject	Shape	Bp, DPL, SD	tri	PC2	26.7	46.9	66.7
104	-39	Reject	Shape	Bp, LDp, Dd	tri	PC2	27.8	45.5	61.1
105	-40	Reject	Form	Dp, SD, Dd	tri	PC3	22.2	50.8	77.8
105	-40	Reject	Shape	Bp, SD, Bd	tri	PC1	28.2	44.8	53.9
105	-40	Reject	Shape	Dp, Bd, Dd	tri	PC2	22.2	50.4	77.8
105	-40	Reject	Shape	Dp, LDp	bi	PC1	22.2	50.9	77.8
105	-40	Reject	Shape	DPL, LDp, GL	tri	PC2	26.7	46.0	66.7
106	-41	Reject	Shape	Bp, Dp, SD	tri	PC2	22.2	49.9	77.8
106	-41	Reject	Shape	GL, Bd, Dd	tri	PC2	26.7	45.0	56.7
107	-42	Reject	Shape	Dp, DPL, Dd	tri	PC2	22.2	48.8	77.8
107	-42	Reject	Shape	Dp, DPL, GL	tri	PC2	22.2	48.6	77.8
107	-42	Reject	Shape	Dp, DPL	bi	PC1	22.2	48.3	77.8
108	-43	Reject	Form	GL, SD, Dd	tri	PC3	23.3	45.9	63.3
108	-43	Reject	Form	Bp, Bd	bi	PC2	28.2	41.1	53.9
108	-43	Reject	Form	Dp, LDp	bi	PC2	22.2	47.1	77.8
109	-44	Reject	Form	GL, SD, Bd	tri	PC3	26.7	42.4	53.3
109	-44	Reject	Shape	Dp, DPL, LDp	tri	PC2	22.2	46.6	66.7
110	-45	Reject	Form	Bp, SD, Bd	tri	PC3	25.6	42.2	53.9
110	-45	Reject	Form	Dp, LDp, SD	tri	PC3	22.2	45.6	66.7
111	-46	Reject	Form	Bp, LDp, SD	tri	PC3	22.2	44.3	66.7
111	-46	Reject	Form	LDp, GL, SD	tri	PC2	22.2	44.5	61.1
111	-46	Reject	Shape	Dp, LDp, GL	tri	PC2	22.2	44.8	66.7
111	-46	Reject	Shape	LDp, GL, SD	tri	PC2	22.2	44.2	61.1
112	-47	Reject	Form	Bp, DPL, LDp	tri	PC2	20.0	46.0	73.3
112	-47	Reject	Form	Bd, SD	bi	PC2	26.2	40.0	50.0
112	-47	Reject	Form	Bp, LDp	bi	PC2	22.2	43.5	66.7

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
112	-47	Reject	Form	Bp, SD	bi	PC2	25.6	39.7	48.7
112	-47	Reject	Form	DPL, LDp	bi	PC2	20.0	45.9	66.7
113	-48	Reject	Form	Bp, LDp, Dd	tri	PC3	22.2	42.6	61.1
113	-48	Reject	Form	Dp, SD, Dd	tri	PC2	22.2	42.2	66.7
114	-50	Reject	Form	DPL, LDp, SD	tri	PC3	20.0	42.3	66.7
114	-50	Reject	Shape	Bp, GL, Bd	tri	PC2	23.3	39.3	53.3
114	-50	Reject	Form	Bd, Dp	bi	PC2	22.2	40.6	66.7
114	-50	Reject	Form	DPL, Bd	bi	PC2	20.0	42.7	60.0
114	-50	Reject	Form	LDp, SD	bi	PC2	22.2	40.8	61.1
115	-51	Reject	Form	DPL, SD, Bd	tri	PC3	20.0	42.1	60.0
116	-52	Reject	Form	Bp, Bd, Dd	tri	PC3	23.1	38.1	51.3
116	-52	Reject	Form	Bp, DPL, Bd	tri	PC2	20.0	40.5	60.0
116	-52	Reject	Form	Bp, SD, Bd	tri	PC2	23.1	37.2	46.1
116	-52	Reject	Form	Dp, LDp, SD	tri	PC2	22.2	38.1	66.7
116	-52	Reject	Form	LDp, SD, Bd	tri	PC2	22.2	38.9	55.8
116	-52	Reject	Shape	GL, SD, Bd	tri	PC2	23.3	37.5	50.0
116	-52	Reject	Shape	LDp, GL, Bd	tri	PC2	22.2	38.8	55.6
117	-53	Reject	Shape	Bp, LDp, GL	tri	PC2	22.2	37.7	50.3
117	-53	Reject	Shape	DPL, LDp, Dd	tri	PC2	20.0	39.7	60.0
118	-55	Reject	Shape	Bp, GL, Dd	tri	PC2	20.0	37.6	53.3
119	-57	Reject	Form	Bp, LDp, Dd	tri	PC2	16.7	38.8	55.6
119	-57	Reject	Shape	Bp, Bd, Dd	tri	PC2	20.5	35.5	48.7
120	-60	Reject	Shape	Bd, SD	bi	PC1	19.1	33.8	45.2
121	-61	Reject	Form	Dp, SD, Bd	tri	PC3	11.1	40.6	66.7
122	-62	Reject	Form	DPL, LDp, Dd	tri	PC3	13.3	37.9	60.0
122	-62	Reject	Form	LDp, SD, Dd	tri	PC2	16.7	34.4	55.6
123	-63	Reject	Form	Dp, DPL, Bd	tri	PC2	11.1	38.6	66.7
124	-64	Reject	Shape	Dp, DPL, SD	tri	PC2	11.1	37.6	66.7

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
125	-65	Reject	Form	Bp, Dp, Bd	tri	PC2	11.1	36.5	66.7
125	-65	Reject	Form	Dp, DPL, LDp	tri	PC3	11.1	36.7	55.6
125	-65	Reject	Form	Dp, GL, Dd	tri	PC3	11.1	36.8	66.7
125	-65	Reject	Form	Dp, SD	bi	PC2	11.1	36.9	66.7
126	-66	Reject	Form	DPL, Bd, Dd	tri	PC3	13.3	33.1	53.3
126	-66	Reject	Form	DPL, LDp, SD	tri	PC2	13.3	33.7	53.3
126	-66	Reject	Form	DPL, SD, Dd	tri	PC2	13.3	33.0	53.3
126	-66	Reject	Shape	Bp, DPL, Bd	tri	PC2	13.3	33.6	53.3
126	-66	Reject	Shape	Dp, LDp, Dd	tri	PC2	11.1	35.4	66.7
126	-66	Reject	Shape	LDp, GL, Dd	tri	PC2	11.1	35.4	55.6
127	-67	Reject	Form	LDp, GL, Dd	tri	PC3	11.1	34.8	61.1
128	-68	Reject	Form	DPL, GL, SD	tri	PC3	6.7	37.8	66.7
128	-68	Reject	Shape	Dp, GL, Dd	tri	PC2	11.1	33.7	66.7
129	-69	Reject	Form	Bp, GL, Bd	tri	PC3	13.3	30.3	46.7
129	-69	Reject	Form	Dp, DPL, Dd	tri	PC3	11.1	32.7	55.6
129	-69	Reject	Form	Dp, DPL, GL	tri	PC3	11.1	32.7	55.6
129	-69	Reject	Form	Dp, DPL, SD	tri	PC3	11.1	32.6	55.6
129	-69	Reject	Shape	Bp, Dp, DPL	tri	PC2	11.1	32.2	55.6
129	-69	Reject	Form	Dp, DPL	bi	PC2	11.1	32.8	55.6
130	-70	Reject	Form	Dp, Bd, Dd	tri	PC3	11.1	31.7	55.6
130	-70	Reject	Form	LDp, SD, Dd	tri	PC3	11.1	32.0	55.6
130	-70	Reject	Shape	LDp, Bd, Dd	tri	PC2	11.1	31.3	55.6
130	-70	Reject	Shape	LDp, SD, Dd	tri	PC2	11.1	31.5	50.0
130	-70	Reject	Form	Dd, LDp	bi	PC2	11.1	31.6	55.6
131	-71	Reject	Form	Bp, LDp, SD	tri	PC2	11.1	30.4	50.0
131	-71	Reject	Form	Dp, GL, Bd	tri	PC3	11.1	30.1	55.6
131	-71	Reject	Form	LDp, Bd, Dd	tri	PC3	11.1	30.8	55.6
132	-74	Reject	Form	Bp, GL, Dd	tri	PC3	10.0	28.4	46.7

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
132	-74	Reject	Form	DPL, GL, Dd	tri	PC3	6.7	31.9	53.3
132	-74	Reject	Form	DPL, SD, Bd	tri	PC2	6.7	31.7	60.0
132	-74	Reject	Form	GL, Bd, Dd	tri	PC3	10.0	28.9	46.7
133	-75	Reject	Shape	DPL, GL, Dd	tri	PC2	6.7	31.5	53.3
134	-76	Reject	Form	Bp, DPL, SD	tri	PC3	6.7	29.7	53.3
134	-76	Reject	Form	DPL, SD	bi	PC2	6.7	30.4	60.0
135	-77	Reject	Form	DPL, LDp, Bd	tri	PC3	6.7	28.8	46.7
136	-78	Reject	Form	Bp, DPL, LDp	tri	PC3	6.7	28.5	53.3
136	-78	Reject	Form	Bp, DPL	bi	PC2	6.7	28.1	46.7
137	-79	Reject	Form	Bp, DPL, Bd	tri	PC3	6.7	27.4	46.7
137	-79	Reject	Form	Bp, DPL, GL	tri	PC3	6.7	26.6	46.7
137	-79	Reject	Form	Bp, LDp, GL	tri	PC3	5.6	28.6	50.0
137	-79	Reject	Form	DPL, GL, Bd	tri	PC3	6.7	26.9	46.7
137	-79	Reject	Shape	Bp, LDp, Bd	tri	PC2	5.6	28.1	50.0
138	-80	Reject	Form	Bp, DPL, Dd	tri	PC3	6.7	26.0	46.7
138	-80	Reject	Form	Bp, LDp, Bd	tri	PC3	5.6	27.5	44.4
138	-80	Reject	Form	Dp, LDp, Dd	tri	PC3	0.0	32.5	66.7
138	-80	Reject	Form	Dp, SD, Bd	tri	PC2	0.0	32.7	66.7
139	-82	Reject	Form	Bp, Dp, GL	tri	PC3	0.0	30.4	55.6
139	-82	Reject	Form	Dp, DPL, SD	tri	PC2	0.0	30.3	55.6
140	-83	Reject	Form	Bp, Dp, DPL	tri	PC3	0.0	30.1	55.6
140	-83	Reject	Form	Bp, Dp, LDp	tri	PC3	0.0	29.7	55.6
140	-83	Reject	Form	Bp, Dp, SD	tri	PC2	0.0	30.1	55.6
140	-83	Reject	Form	Bp, Dp, SD	tri	PC3	0.0	30.1	66.7
140	-83	Reject	Form	Dp, GL, SD	tri	PC3	0.0	29.8	66.7
140	-83	Reject	Form	DPL, LDp, GL	tri	PC3	0.0	29.6	53.3
140	-83	Reject	Shape	Bp, Dp, Bd	tri	PC2	0.0	29.7	55.6
141	-84	Reject	Form	Bp, Dp, Dd	tri	PC3	0.0	29.2	55.6

Table A.20: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
141	-84	Reject	Form	Bp, Dp	bi	PC2	0.0	28.7	55.6
142	-85	Reject	Form	Bp, Dp, Bd	tri	PC3	0.0	27.4	55.6
142	-85	Reject	Form	Bp, Dp, DPL	tri	PC2	0.0	27.9	66.7
142	-85	Reject	Form	Bp, DPL, SD	tri	PC2	0.0	27.6	53.3
142	-85	Reject	Form	Dp, LDp, GL	tri	PC3	0.0	27.7	55.6
143	-86	Reject	Shape	Dp, DPL, Bd	tri	PC2	0.0	26.6	55.6
144	-87	Reject	Form	Dp, DPL, Bd	tri	PC3	0.0	25.8	55.6
145	-89	Reject	Form	Dp, LDp, Bd	tri	PC3	0.0	24.1	55.6
145	-89	Reject	Form	LDp, GL, Bd	tri	PC3	0.0	24.0	44.4

A.3.9 Calcaneum

Table A.21: List of approaches ranked by score for balanced cross-validation results for the calcaneum (Subset A).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	54	Prefer	Form	GB, GLT, SDT	tri	PC1	90.6	92.9	96.9
1	54	Prefer	Form	GL, GLT, SDT	tri	PC1	90.6	93.0	96.9
1	54	Prefer	Size	GB, GL, SDT	tri	–	90.6	92.9	96.9
1	54	Prefer	Size	GLT, GDT, SDT	tri	–	90.6	93.0	96.9
2	53	Prefer	Form	SDT, GLT	bi	PC1	90.6	92.5	96.9
2	53	Prefer	Size	GLT, GBT, SDT	tri	–	90.6	92.8	96.9
2	53	Prefer	Size	SDT, GLT	bi	–	90.6	92.6	96.9
3	52	Prefer	Form	GB, GL, SDT	tri	PC1	90.6	91.9	93.8
4	50	Prefer	Size	GB, GBT, SDT	tri	–	87.5	92.5	96.9
4	50	Prefer	Size	GB, GLT, SDT	tri	–	87.5	92.7	96.9
5	49	Prefer	Form	GB, SDT	bi	PC1	87.5	91.1	93.8
5	49	Prefer	Form	GL, GLT, GDT	tri	PC1	87.5	91.7	96.9
5	49	Prefer	Form	SDT, GL	bi	PC1	87.5	91.4	96.9

Table A.21: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
5	49	Prefer	Size	GB, GDT, SDT	tri	–	87.5	92.0	96.9
5	49	Prefer	Size	GB, SDT	bi	–	87.5	91.5	93.8
5	49	Prefer	Size	GL, GBT, SDT	tri	–	87.5	91.1	93.8
5	49	Prefer	Size	GL, GDT, SDT	tri	–	87.5	91.2	93.8
5	49	Prefer	Size	GLT, GBT, GDT	tri	–	87.5	91.3	93.8
5	49	Prefer	Size	SDT, GL	bi	–	87.5	91.3	93.9
6	48	Prefer	Form	GL, GBT, SDT	tri	PC1	87.5	90.5	93.8
6	48	Prefer	Form	GLT, GBT, SDT	tri	PC1	87.5	90.3	93.8
6	48	Prefer	Size	GL, GLT, SDT	tri	–	87.5	90.3	93.8
6	48	Prefer	Form	SDT	uni	–	87.5	90.3	93.8
7	47	Prefer	Form	GB, GBT, SDT	tri	PC1	87.5	89.5	93.8
7	47	Prefer	Size	GB, GDT	bi	–	87.3	89.8	93.8
7	47	Prefer	Size	GB, GL, GDT	tri	–	87.5	89.7	93.8
8	45	Prefer	Shape	GB, SDT	bi	PC1	84.4	90.8	96.9
8	45	Prefer	Size	GL, GBT, GDT	tri	–	84.4	90.5	93.8
9	44	Prefer	Form	GBT, GDT, SDT	tri	PC1	84.4	89.3	93.8
9	44	Prefer	Form	GL, GBT, GDT	tri	PC1	84.4	89.3	93.8
9	44	Prefer	Form	GL, GDT, SDT	tri	PC1	84.4	89.9	93.8
9	44	Prefer	Form	GLT, GBT, GDT	tri	PC1	84.4	89.5	93.8
9	44	Prefer	Form	GLT, GDT, SDT	tri	PC1	84.4	89.2	93.8
9	44	Prefer	Form	SDT, GBT	bi	PC1	84.4	89.1	93.8
9	44	Prefer	Shape	GB, GDT, SDT	tri	PC1	84.4	90.0	93.8
9	44	Prefer	Size	GBT, GDT, SDT	tri	–	84.4	89.2	93.8
9	44	Prefer	Size	GDT, GL	bi	–	84.4	89.2	96.9
9	44	Prefer	Size	GDT, GLT	bi	–	84.4	90.1	96.9
10	43	Prefer	Form	GB, GBT, GDT	tri	PC1	84.4	88.8	93.8
10	43	Prefer	Form	GB, GL, GDT	tri	PC1	84.4	88.9	93.8
10	43	Prefer	Form	GB, GLT, GDT	tri	PC1	84.4	89.1	93.8

Table A.21: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
10	43	Prefer	Form	GBT, GDT	bi	PC1	84.4	89.0	93.8
10	43	Prefer	Size	GB, GBT, GDT	tri	–	84.4	88.7	90.6
10	43	Prefer	Size	GB, GLT, GDT	tri	–	84.4	88.3	93.8
10	43	Prefer	Size	GBT, GDT	bi	–	84.4	89.1	93.8
10	43	Prefer	Size	GL, GLT, GDT	tri	–	84.4	88.7	93.8
10	43	Prefer	Size	SDT, GBT	bi	–	84.4	89.0	93.8
11	42	Accept	Form	GB, GBT	bi	PC1	84.4	88.0	90.6
11	42	Accept	Form	GBT, GL	bi	PC1	84.4	87.5	90.6
11	42	Accept	Form	GDT, GLT	bi	PC1	84.4	87.5	93.8
11	42	Accept	Shape	GB, GDT	bi	PC1	84.4	87.5	93.8
11	42	Accept	Size	GL, SBT, SDT	tri	–	83.3	89.0	93.3
12	41	Accept	Form	GB, GDT, SDT	tri	PC1	84.2	86.7	93.8
12	41	Accept	Size	GLT, SBT, SDT	tri	–	83.3	87.5	90.0
13	40	Accept	Shape	GB, GBT, SDT	tri	PC1	81.2	88.7	93.8
13	40	Accept	Size	GB, SBT, SDT	tri	–	83.3	87.0	93.3
14	39	Accept	Form	GDT, GL	bi	PC1	81.2	88.0	96.9
14	39	Accept	Size	SDT, GDT	bi	–	81.2	87.3	93.8
15	38	Accept	Form	GB, GL, GBT	tri	PC1	81.2	86.4	90.6
15	38	Accept	Form	SDT, GDT	bi	PC1	81.2	87.0	93.8
15	38	Accept	Form	GDT	uni	–	81.2	87.0	93.8
16	37	Accept	Form	GB, GDT	bi	PC1	81.2	86.2	90.6
16	37	Accept	Shape	GB, GL, SDT	tri	PC1	81.2	85.4	90.6
16	37	Accept	Size	GB, GBT	bi	–	81.2	86.2	90.6
17	36	Accept	Form	GL, GLT, GBT	tri	PC1	81.2	84.7	90.6
17	36	Accept	Form	GL, SBT, SDT	tri	PC1	80.0	86.1	93.3
17	36	Accept	Form	GLT, SBT, SDT	tri	PC1	80.0	85.5	90.0
17	36	Accept	Shape	GB, GL, GDT	tri	PC1	78.1	87.7	93.8
17	36	Accept	Shape	GB, GLT, SDT	tri	PC1	81.2	84.6	87.5

Table A.21: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
17	36	Accept	Size	GBT, SBT, SDT	tri	–	80.0	86.0	93.3
17	36	Accept	Size	GL, GDT, SBT	tri	–	80.0	86.3	93.3
18	35	Accept	Form	GB, SBT, SDT	tri	PC1	80.0	85.4	93.3
18	35	Accept	Form	GBT, SBT, SDT	tri	PC1	80.0	84.9	93.3
18	35	Accept	Form	GDT, SBT, SDT	tri	PC1	80.0	85.0	93.3
18	35	Accept	Shape	GB, GBT, GDT	tri	PC1	78.1	87.1	93.8
18	35	Accept	Size	GBT, GL	bi	–	81.2	84.2	87.5
18	35	Accept	Size	GDT, SBT, SDT	tri	–	80.0	85.1	93.3
18	35	Accept	Size	GLT, GDT, SBT	tri	–	80.0	84.5	90.0
18	35	Accept	Size	SBT, SDT	bi	–	80.0	85.1	93.3
19	34	Accept	Form	GB, GLT, GBT	tri	PC1	78.1	85.4	90.6
20	33	Accept	Shape	GB, GLT, GDT	tri	PC1	78.1	84.9	90.6
20	33	Accept	Size	GLT, GBT, SBT	tri	–	80.0	83.5	86.7
21	32	Accept	Form	GBT, GLT	bi	PC1	78.1	83.7	90.6
21	32	Accept	Size	GBT, GDT, SBT	tri	–	76.7	85.6	93.3
21	32	Accept	Size	GL, GLT, GBT	tri	–	78.1	83.6	87.5
22	31	Accept	Form	SBT, SDT	bi	PC1	76.7	84.5	93.3
22	31	Accept	Shape	GB, GDT, SBT	tri	PC1	76.7	84.1	90.0
22	31	Accept	Size	GB, GL, GBT	tri	–	78.1	83.1	87.5
22	31	Accept	Size	GBT, GLT	bi	–	75.0	85.6	93.8
22	31	Accept	Form	GBT	uni	–	78.1	83.1	87.5
23	29	Accept	Shape	GL, GLT, SDT	tri	PC1	78.1	80.9	84.4
23	29	Accept	Size	GL, GBT, SBT	tri	–	76.7	82.2	90.0
24	28	Accept	Form	GL, GDT, SBT	tri	PC1	76.7	80.9	93.3
24	28	Accept	Shape	GB, SBT, SDT	tri	PC1	76.7	81.5	86.7
24	28	Accept	Size	GB, GDT, SBT	tri	–	76.7	81.5	86.7
24	28	Accept	Size	GB, GLT, GBT	tri	–	75.0	82.7	87.5
24	28	Accept	Size	GL, GLT, SBT	tri	–	76.7	81.2	86.7

Table A.21: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
25	27	Accept	Form	GBT, GDT, SBT	tri	PC1	73.3	83.5	93.3
25	27	Accept	Form	GLT, GDT, SBT	tri	PC1	76.7	80.2	86.8
25	27	Accept	Shape	GL, GBT, GDT	tri	PC1	75.0	81.6	90.6
25	27	Accept	Shape	GL, GDT, SDT	tri	PC1	75.0	82.1	90.6
26	26	Accept	Form	GB, GDT, SBT	tri	PC1	76.7	79.8	86.7
27	25	Accept	Shape	GL, GBT, SDT	tri	PC1	75.0	79.6	84.4
28	24	Accept	Size	SBT, GLT	bi	–	73.3	80.5	90.0
29	23	Accept	Form	SBT, GDT	bi	PC1	73.3	80.0	90.2
29	23	Accept	Shape	GLT, GDT, SBT	tri	PC1	73.3	79.8	86.7
29	23	Accept	Shape	GLT, GDT, SDT	tri	PC1	71.9	80.7	87.5
29	23	Accept	Size	GB, GBT, SBT	tri	–	73.3	79.8	86.7
29	23	Accept	Size	SBT, GDT	bi	–	73.3	79.6	90.0
30	22	Accept	Form	GL, GBT, SBT	tri	PC1	73.3	78.2	83.3
30	22	Accept	Shape	GDT, GL	bi	PC1	71.9	80.3	90.6
30	22	Accept	Shape	GL, GLT, GDT	tri	PC1	71.9	79.9	90.6
30	22	Accept	Shape	SDT, GL	bi	PC1	71.9	80.0	84.4
30	22	Accept	Size	GL, GLT	bi	–	71.9	79.7	87.5
31	21	Accept	Form	GB, GBT, SBT	tri	PC1	73.3	77.9	83.3
31	21	Accept	Form	GL, GLT	bi	PC1	71.9	79.6	87.5
31	21	Accept	Form	GLT, GBT, SBT	tri	PC1	73.3	77.6	83.3
31	21	Accept	Form	SBT, GL	bi	PC1	73.3	78.0	83.3
31	21	Accept	Shape	GL, GDT, SBT	tri	PC1	70.0	80.8	90.0
31	21	Accept	Size	GB, GL, SBT	tri	–	73.3	77.3	83.3
31	21	Accept	Size	SBT, GL	bi	–	73.3	77.7	86.7
31	21	Accept	Form	GL	uni	–	74.2	77.0	78.8
32	20	Accept	Form	GB, GL, GLT	tri	PC1	71.9	77.7	81.2
32	20	Accept	Form	GB, GL	bi	PC1	73.3	76.3	80.0
32	20	Accept	Form	SBT, GBT	bi	PC1	73.3	77.1	83.3

Table A.21: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
32	20	Accept	Size	GB, GL	bi	–	73.3	76.5	80.0
32	20	Accept	Size	GB, GL, GLT	tri	–	71.9	78.1	84.4
33	19	Accept	Shape	SDT, GLT	bi	PC1	71.9	77.5	81.2
33	19	Accept	Form	GLT	uni	–	71.9	77.0	84.4
34	18	Accept	Form	GB, GLT	bi	PC1	71.9	75.9	84.4
34	18	Accept	Shape	GLT, GBT, SDT	tri	PC1	71.9	76.4	81.2
34	18	Accept	Size	GB, GLT, SBT	tri	–	70.0	78.0	83.3
34	18	Accept	Size	SBT, GBT	bi	–	70.0	78.1	90.0
35	17	Accept	Form	GL, GLT, SBT	tri	PC1	70.0	77.3	83.3
35	17	Accept	Form	SBT, GLT	bi	PC1	70.0	76.8	83.3
35	17	Accept	Shape	GB, GBT	bi	PC1	68.8	77.8	87.5
35	17	Accept	Shape	GDT, GLT	bi	PC1	68.8	78.1	87.5
35	17	Accept	Shape	GLT, GBT, GDT	tri	PC1	68.8	78.0	84.4
35	17	Accept	Size	GB, SBT	bi	–	70.0	76.8	83.3
36	15	Accept	Form	GB, GL, SBT	tri	PC1	70.0	75.5	80.0
36	15	Accept	Form	GB, GLT, SBT	tri	PC1	70.0	75.2	80.0
36	15	Accept	Shape	GB, GLT, SBT	tri	PC1	70.0	75.4	80.0
36	15	Accept	Shape	GBT, SBT, SDT	tri	PC2	70.0	75.2	80.0
37	14	Accept	Shape	GL, SBT, SDT	tri	PC1	66.7	77.7	83.3
37	14	Accept	Size	GB, GLT	bi	–	68.8	75.5	81.2
37	14	Reject	Form	SBT	uni	–	70.0	74.4	83.3
38	13	Reject	Shape	GB, GL, GBT	tri	PC1	68.8	74.6	81.2
39	10	Reject	Form	GB, SBT	bi	PC1	66.7	73.6	80.0
39	10	Reject	Shape	GB, GL, SBT	tri	PC1	66.7	73.6	80.0
40	8	Reject	Shape	GB, GBT, SBT	tri	PC1	66.7	71.5	80.0
41	7	Reject	Shape	GB, GLT, GBT	tri	PC1	65.6	71.1	75.0
41	7	Reject	Shape	GL, GBT, SBT	tri	PC1	63.3	73.8	80.0
41	7	Reject	Shape	GLT, SBT, SDT	tri	PC1	66.7	70.6	76.7

Table A.21: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
42	5	Reject	Shape	GBT, GDT, SDT	tri	PC1	65.6	69.0	75.0
42	5	Reject	Shape	GL, GLT, GBT	tri	PC1	65.6	69.3	75.0
43	4	Reject	Shape	GB, SBT	bi	PC1	63.3	71.0	76.7
43	4	Reject	Form	GB	uni	–	66.1	68.2	71.0
44	3	Reject	Shape	SBT, GL	bi	PC1	60.0	73.0	83.3
45	2	Reject	Shape	SDT, GBT	bi	PC1	62.5	69.1	75.0
46	-1	Reject	Shape	GL, GLT, SBT	tri	PC1	60.0	69.0	76.7
47	-2	Reject	Shape	GBT, GDT	bi	PC1	62.5	66.0	71.9
48	-3	Reject	Shape	GBT, GDT, SBT	tri	PC2	60.0	66.6	73.3
49	-5	Reject	Shape	GBT, GL	bi	PC1	59.4	65.7	71.9
49	-5	Reject	Shape	GBT, GLT	bi	PC1	59.4	65.7	75.0
50	-9	Reject	Shape	SBT, GBT	bi	PC1	56.7	64.2	70.0
50	-9	Reject	Form	GB, GBT	bi	PC2	53.1	68.0	78.1
51	-10	Reject	Shape	GLT, GBT, SBT	tri	PC1	56.7	63.2	70.0
51	-10	Reject	Shape	SBT, GLT	bi	PC1	56.7	63.2	70.0
52	-12	Reject	Shape	GBT, GDT, SBT	tri	PC1	56.7	61.7	66.7
52	-12	Reject	Form	GB, GL	bi	PC2	56.7	61.0	65.0
53	-14	Reject	Shape	GB, GL	bi	PC1	56.7	59.6	63.3
53	-14	Reject	Shape	GLT, GDT, SDT	tri	PC2	56.2	59.5	65.6
54	-15	Reject	Form	GLT, SBT, SDT	tri	PC2	53.3	61.3	66.7
54	-15	Reject	Shape	GB, GLT, SBT	tri	PC2	53.3	62.0	70.0
55	-17	Reject	Shape	GL, GDT, SDT	tri	PC2	53.1	59.9	65.6
56	-18	Reject	Form	GB, GLT, GBT	tri	PC3	53.1	58.6	65.6
56	-18	Reject	Shape	GB, GLT, GBT	tri	PC2	53.1	58.5	65.6
57	-20	Reject	Shape	GB, GLT, GDT	tri	PC2	53.1	56.6	62.5
58	-22	Reject	Form	GB, GL, GBT	tri	PC2	46.9	60.8	71.9
59	-23	Reject	Form	GL, GLT, GBT	tri	PC2	49.8	57.0	62.5
59	-23	Reject	Form	GL, SBT, SDT	tri	PC2	50.0	57.2	63.3

Table A.21: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
60	-24	Reject	Form	GLT, GDT, SBT	tri	PC3	46.7	59.0	73.3
61	-25	Reject	Form	GBT, SBT, SDT	tri	PC2	50.0	54.9	60.0
61	-25	Reject	Shape	GL, SBT, SDT	tri	PC2	50.0	55.3	60.0
61	-25	Reject	Form	SBT, SDT	bi	PC2	50.0	55.3	60.0
62	-26	Reject	Form	GB, GBT, SBT	tri	PC3	50.0	54.4	60.0
62	-26	Reject	Shape	GLT, SBT, SDT	tri	PC2	50.0	54.3	60.0
63	-28	Reject	Shape	GB, GL, GDT	tri	PC2	46.7	55.0	62.5
63	-28	Reject	Shape	GB, GL, SBT	tri	PC2	46.7	55.2	63.3
64	-29	Reject	Shape	GL, GLT, GDT	tri	PC2	46.9	54.1	62.5
65	-30	Reject	Shape	GB, GLT	bi	PC1	46.9	52.7	59.4
65	-30	Reject	Form	SBT, GBT	bi	PC2	46.7	53.7	60.0
66	-31	Reject	Shape	GB, GL, GLT	tri	PC1	46.9	52.3	59.4
67	-32	Reject	Shape	GB, SBT, SDT	tri	PC2	46.7	51.7	56.7
68	-34	Reject	Form	GB, GDT, SDT	tri	PC3	40.6	55.0	62.5
68	-34	Reject	Shape	GL, GLT, GBT	tri	PC2	43.8	52.6	59.4
68	-34	Reject	Form	SBT, GLT	bi	PC2	40.0	56.0	70.0
69	-35	Reject	Shape	GL, GLT, SDT	tri	PC2	43.6	51.7	59.4
70	-36	Reject	Form	GB, GLT, SBT	tri	PC3	36.7	56.8	66.7
70	-36	Reject	Form	GB, SBT, SDT	tri	PC2	43.3	50.5	56.7
70	-36	Reject	Form	GBT, GDT, SDT	tri	PC3	37.5	56.6	68.8
71	-37	Reject	Form	GB, GL, GDT	tri	PC3	40.6	52.1	62.5
71	-37	Reject	Form	GL, GBT, SBT	tri	PC2	36.7	56.4	63.3
72	-40	Reject	Form	SBT, GL	bi	PC2	33.3	56.6	70.0
73	-41	Reject	Form	GB, GLT, GDT	tri	PC3	40.6	48.1	56.2
74	-43	Reject	Form	GB, GL, SBT	tri	PC3	36.7	50.3	63.3
74	-43	Reject	Form	GBT, GDT, SBT	tri	PC2	30.0	57.4	66.7
74	-43	Reject	Form	GL, GDT, SBT	tri	PC3	30.0	56.7	66.7
75	-44	Reject	Form	GB, GDT, SBT	tri	PC2	33.3	52.9	60.0

Table A.21: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
75	-44	Reject	Shape	GL, GLT, SBT	tri	PC2	33.2	52.7	60.0
76	-45	Reject	Form	SDT, GDT	bi	PC2	31.1	53.8	65.6
77	-47	Reject	Form	GB, GL, GBT	tri	PC3	31.1	52.0	62.5
78	-49	Reject	Form	GLT, GBT, SBT	tri	PC2	26.7	54.8	66.7
78	-49	Reject	Shape	GB, GL, GBT	tri	PC2	28.1	52.9	62.5
79	-53	Reject	Shape	GB, GLT, SDT	tri	PC2	28.1	49.0	56.2
80	-54	Reject	Form	GL, GLT, SDT	tri	PC2	25.0	51.4	62.5
81	-55	Reject	Form	GDT, SBT, SDT	tri	PC3	20.0	54.6	63.3
81	-55	Reject	Shape	GB, GBT, GDT	tri	PC2	21.9	52.9	62.5
81	-55	Reject	Form	GDT, GL	bi	PC2	15.6	58.9	71.9
82	-56	Reject	Form	SBT, GDT	bi	PC2	20.0	53.8	66.7
83	-59	Reject	Shape	GB, GDT, SDT	tri	PC2	18.8	51.8	62.5
83	-59	Reject	Form	GDT, GLT	bi	PC2	18.8	52.6	65.6
84	-61	Reject	Form	GDT, SBT, SDT	tri	PC2	20.0	49.2	63.3
84	-61	Reject	Form	GL, GDT, SDT	tri	PC2	15.6	53.6	68.9
84	-61	Reject	Form	GLT, GBT, GDT	tri	PC2	18.8	50.3	59.4
85	-62	Reject	Shape	SBT, GDT	bi	PC1	16.7	51.2	66.7
86	-63	Reject	Shape	GB, GBT, SBT	tri	PC2	20.0	47.0	56.7
87	-64	Reject	Form	GB, GLT, GDT	tri	PC2	15.6	50.1	65.6
88	-65	Reject	Form	GLT, GBT, SBT	tri	PC3	16.5	48.5	60.0
88	-65	Reject	Form	GLT, GDT, SDT	tri	PC2	15.6	49.8	62.5
89	-66	Reject	Form	GB, GL, SDT	tri	PC2	15.6	48.0	59.4
89	-66	Reject	Form	GL, GDT, SBT	tri	PC2	13.3	50.6	63.3
89	-66	Reject	Shape	GB, GBT, SDT	tri	PC2	15.6	48.2	59.4
90	-67	Reject	Form	GBT, GDT, SBT	tri	PC3	13.3	49.3	60.0
90	-67	Reject	Shape	GDT, SBT, SDT	tri	PC2	16.7	46.1	56.7
90	-67	Reject	Form	GL, GLT	bi	PC2	12.5	50.7	65.6
91	-68	Reject	Form	GB, GBT, SDT	tri	PC2	15.6	46.4	56.2

Table A.21: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
92	-69	Reject	Form	GB, GL, SDT	tri	PC3	12.3	48.7	62.5
93	-70	Reject	Form	GB, GLT, SBT	tri	PC2	10.0	49.5	63.3
94	-71	Reject	Form	GB, GLT, SDT	tri	PC2	12.5	46.4	59.4
95	-72	Reject	Form	GL, GLT, SBT	tri	PC2	6.7	51.8	66.7
96	-73	Reject	Form	GB, GBT, SBT	tri	PC2	10.0	46.6	63.3
96	-73	Reject	Form	GBT, SBT, SDT	tri	PC3	10.0	46.8	56.7
96	-73	Reject	Form	GL, GBT, SBT	tri	PC3	6.7	50.1	63.3
96	-73	Reject	Form	GL, GLT, GDT	tri	PC2	12.5	44.7	65.6
97	-74	Reject	Form	GB, GBT, GDT	tri	PC3	9.4	46.2	62.5
98	-76	Reject	Form	GL, GLT, GDT	tri	PC3	9.4	45.0	59.4
99	-77	Reject	Shape	GB, GL, SDT	tri	PC2	6.2	47.1	62.5
99	-77	Reject	Shape	GL, GBT, SBT	tri	PC2	6.7	46.2	63.3
99	-77	Reject	Form	SDT, GLT	bi	PC2	9.2	43.9	59.4
100	-78	Reject	Shape	GDT, SBT, SDT	tri	PC1	6.7	45.2	63.3
100	-78	Reject	Shape	GL, GDT, SBT	tri	PC2	6.7	44.9	60.0
100	-78	Reject	Shape	SDT, GDT	bi	PC1	9.4	42.8	56.2
100	-78	Reject	Form	GB, GDT	bi	PC2	9.4	42.4	59.4
100	-78	Reject	Form	GB, SDT	bi	PC2	9.4	42.6	56.2
101	-79	Reject	Form	GB, GLT, SDT	tri	PC3	9.4	41.6	56.2
101	-79	Reject	Form	GL, GBT, GDT	tri	PC2	6.2	45.1	59.4
101	-79	Reject	Form	GL, GLT, GBT	tri	PC3	9.4	41.5	56.2
101	-79	Reject	Shape	GL, GBT, SDT	tri	PC2	6.2	44.6	62.5
102	-80	Reject	Form	GB, GBT, SDT	tri	PC3	9.4	40.7	56.2
102	-80	Reject	Form	GB, GDT, SDT	tri	PC2	9.4	40.5	56.2
102	-80	Reject	Form	GB, GL, GLT	tri	PC3	6.2	44.1	59.4
102	-80	Reject	Form	GB, GLT, GBT	tri	PC2	9.4	40.5	56.2
102	-80	Reject	Shape	GB, GL, GLT	tri	PC2	6.2	43.6	59.5
102	-80	Reject	Shape	GBT, SBT, SDT	tri	PC1	10.0	40.3	56.7

Table A.21: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
102	-80	Reject	Shape	GLT, GDT, SBT	tri	PC2	6.7	43.5	56.7
102	-80	Reject	Form	GB, SBT	bi	PC2	6.7	43.6	60.0
103	-81	Reject	Form	GB, GL, GLT	tri	PC2	9.4	40.0	62.5
103	-81	Reject	Form	GL, GDT, SDT	tri	PC3	6.2	42.7	59.4
103	-81	Reject	Form	GB, GLT	bi	PC2	9.4	39.9	53.1
103	-81	Reject	Form	SDT, GL	bi	PC2	9.4	39.4	56.2
104	-82	Reject	Form	GB, GDT, SBT	tri	PC3	6.7	41.6	56.7
104	-82	Reject	Form	GL, GBT, SDT	tri	PC2	9.4	38.7	59.4
104	-82	Reject	Form	GLT, GBT, SDT	tri	PC2	6.2	42.0	59.4
104	-82	Reject	Shape	GBT, GDT, SDT	tri	PC2	6.2	42.0	62.5
104	-82	Reject	Shape	GL, GLT	bi	PC1	6.2	42.0	56.2
104	-82	Reject	Form	GBT, GLT	bi	PC2	9.2	38.8	56.2
105	-83	Reject	Form	GB, GL, SBT	tri	PC2	3.3	43.5	60.0
105	-83	Reject	Shape	GLT, GBT, SBT	tri	PC2	6.7	40.3	63.3
105	-83	Reject	Shape	GLT, GBT, SDT	tri	PC2	9.2	38.0	50.0
106	-84	Reject	Form	GLT, GDT, SBT	tri	PC2	6.7	39.1	56.7
106	-84	Reject	Form	GBT, GL	bi	PC2	9.4	37.0	53.1
107	-85	Reject	Form	GB, SBT, SDT	tri	PC3	6.7	38.7	53.3
107	-85	Reject	Form	GL, GLT, SBT	tri	PC3	3.3	41.2	60.0
107	-85	Reject	Form	GL, GLT, SDT	tri	PC3	6.2	38.8	59.4
107	-85	Reject	Form	GLT, GDT, SDT	tri	PC3	3.1	41.4	56.2
107	-85	Reject	Form	GLT, SBT, SDT	tri	PC3	6.7	38.0	56.7
108	-86	Reject	Form	GL, GBT, SDT	tri	PC3	6.2	37.4	53.1
108	-86	Reject	Form	GL, SBT, SDT	tri	PC3	3.3	40.2	60.0
108	-86	Reject	Shape	SBT, SDT	bi	PC1	6.7	37.4	56.7
108	-86	Reject	Form	GBT, GDT	bi	PC2	6.2	37.2	53.1
109	-87	Reject	Form	GB, GBT, GDT	tri	PC2	3.1	40.1	59.4
109	-87	Reject	Form	GB, GL, GDT	tri	PC2	3.1	40.1	56.2

Table A.21: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
109	-87	Reject	Shape	GB, GDT, SBT	tri	PC2	3.3	39.7	60.0
110	-88	Reject	Form	GL, GBT, GDT	tri	PC3	3.1	38.6	53.1
111	-89	Reject	Form	GLT, GBT, SDT	tri	PC3	6.2	34.9	53.1
111	-89	Reject	Shape	GLT, GBT, GDT	tri	PC2	3.1	37.6	50.0
111	-89	Reject	Form	SDT, GBT	bi	PC2	3.1	38.0	56.2
112	-90	Reject	Form	GBT, GDT, SDT	tri	PC2	3.1	36.4	56.2
113	-91	Reject	Form	GLT, GBT, GDT	tri	PC3	3.1	35.6	50.0
113	-91	Reject	Shape	GL, GBT, GDT	tri	PC2	0.0	38.5	62.5

Table A.22: List of approaches ranked by score for balanced cross-validation results for the calcaneum (Subset B).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	73	Prefer	Form	GB, GL, SDT	tri	PC1	90.5	95.1	100.0
1	73	Prefer	Size	GB, GL, SDT	tri	–	90.5	95.0	100.0
2	71	Prefer	Form	GB, GLT, SDT	tri	PC1	88.9	94.4	100.0
2	71	Prefer	Size	GLT, GDT, SDT	tri	–	88.9	94.6	100.0
3	70	Prefer	Form	GL, GBT, SDT	tri	PC1	88.9	94.0	100.0
3	70	Prefer	Size	GL, GBT, SDT	tri	–	88.9	94.1	100.0
3	70	Prefer	Size	SDT, GLT	bi	–	88.9	94.2	100.0
4	68	Prefer	Form	GLT, GBT, SDT	tri	PC1	86.7	94.0	100.0
4	68	Prefer	Size	GLT, GBT, SDT	tri	–	86.7	94.1	100.0
5	67	Prefer	Form	GB, SDT	bi	PC1	85.7	93.9	100.0
5	67	Prefer	Form	GDT, GL	bi	PC1	85.7	93.6	100.0
5	67	Prefer	Form	GL, GDT, SDT	tri	PC1	85.7	94.3	100.0
5	67	Prefer	Form	SDT, GL	bi	PC1	85.7	94.4	100.0
5	67	Prefer	Size	GB, SDT	bi	–	85.7	93.8	100.0
5	67	Prefer	Size	GDT, GL	bi	–	85.7	93.6	100.0

Table A.22: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
5	67	Prefer	Size	GL, GDT, SDT	tri	–	85.7	94.2	100.0
5	67	Prefer	Size	SDT, GL	bi	–	85.7	94.4	100.0
6	66	Prefer	Form	GB, GDT, SDT	tri	PC1	85.7	93.2	100.0
6	66	Prefer	Form	GB, GL, GDT	tri	PC1	85.7	93.1	100.0
6	66	Prefer	Form	GL, SBT, SDT	tri	PC1	85.7	92.5	100.0
6	66	Prefer	Size	GB, GDT, SDT	tri	–	85.7	93.4	100.0
6	66	Prefer	Size	GB, GL, GDT	tri	–	85.7	93.2	100.0
7	65	Prefer	Form	GB, GBT, SDT	tri	PC1	83.3	93.9	100.0
7	65	Prefer	Form	GB, GDT	bi	PC1	85.7	92.0	100.0
7	65	Prefer	Form	GLT, GDT, SDT	tri	PC1	83.3	94.4	100.0
7	65	Prefer	Size	GB, GLT, SDT	tri	–	83.3	94.1	100.0
7	65	Prefer	Size	GL, SBT, SDT	tri	–	85.7	92.4	100.0
7	65	Prefer	Form	SDT	uni	–	85.7	92.1	100.0
8	64	Prefer	Form	GDT, GLT	bi	PC1	83.3	93.1	100.0
8	64	Prefer	Form	SDT, GBT	bi	PC1	83.3	92.9	100.0
8	64	Prefer	Form	SDT, GLT	bi	PC1	83.3	93.7	100.0
8	64	Prefer	Size	GB, GBT, SDT	tri	–	83.3	93.5	100.0
8	64	Prefer	Size	GDT, GLT	bi	–	83.3	93.2	100.0
8	64	Prefer	Size	GL, GBT, GDT	tri	–	83.3	93.2	100.0
9	63	Prefer	Form	GB, GBT, GDT	tri	PC1	83.3	92.2	100.0
9	63	Prefer	Form	GB, GLT, GDT	tri	PC1	83.3	92.4	100.0
9	63	Prefer	Form	GBT, GDT	bi	PC1	83.3	92.2	100.0
9	63	Prefer	Form	GBT, GDT, SDT	tri	PC1	83.3	92.8	100.0
9	63	Prefer	Form	GL, GBT, GDT	tri	PC1	83.3	92.7	100.0
9	63	Prefer	Form	GL, GLT, GDT	tri	PC1	83.3	92.7	100.0
9	63	Prefer	Form	GL, GLT, SDT	tri	PC1	83.3	92.6	100.0
9	63	Prefer	Form	GLT, SBT, SDT	tri	PC1	83.3	91.9	100.0
9	63	Prefer	Size	GB, GLT, GDT	tri	–	83.3	92.4	100.0

Table A.22: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
9	63	Prefer	Size	GBT, GDT, SDT	tri	–	83.3	92.7	100.0
9	63	Prefer	Size	GL, GLT, GDT	tri	–	83.3	92.8	100.0
9	63	Prefer	Size	GL, GLT, SDT	tri	–	83.3	92.8	100.0
9	63	Prefer	Size	SDT, GBT	bi	–	83.3	92.6	100.0
10	62	Prefer	Form	GBT, SBT, SDT	tri	PC1	83.3	91.1	100.0
10	62	Prefer	Size	GB, GBT, GDT	tri	–	83.3	91.8	100.0
10	62	Prefer	Size	GBT, GDT	bi	–	83.3	91.6	100.0
10	62	Prefer	Size	GBT, SBT, SDT	tri	–	83.3	91.0	100.0
10	62	Prefer	Size	GLT, SBT, SDT	tri	–	83.3	91.8	100.0
11	60	Accept	Form	GLT, GBT, GDT	tri	PC1	80.0	92.9	100.0
11	60	Accept	Form	SDT, GDT	bi	PC1	81.0	92.2	100.0
11	60	Accept	Size	GB, GDT	bi	–	81.0	91.9	100.0
11	60	Accept	Size	GLT, GBT, GDT	tri	–	80.0	93.0	100.0
11	60	Accept	Size	SDT, GDT	bi	–	81.0	92.1	100.0
12	59	Accept	Form	GB, SBT, SDT	tri	PC1	81.0	90.9	100.0
12	59	Accept	Form	GL, GDT, SBT	tri	PC1	81.0	90.5	100.0
12	59	Accept	Size	GB, SBT, SDT	tri	–	81.0	90.8	100.0
12	59	Accept	Size	GDT, SBT, SDT	tri	–	81.0	90.4	100.0
12	59	Accept	Size	GL, GDT, SBT	tri	–	81.0	90.8	100.0
13	58	Accept	Form	GDT, SBT, SDT	tri	PC1	81.0	90.2	100.0
13	58	Accept	Form	SBT, SDT	bi	PC1	81.0	89.7	100.0
13	58	Accept	Size	SBT, SDT	bi	–	81.0	89.7	100.0
14	57	Accept	Size	GB, GDT, SBT	tri	–	81.0	88.5	95.2
15	55	Accept	Form	GBT, GDT, SBT	tri	PC1	77.8	89.5	100.0
15	55	Accept	Form	GBT, GL	bi	PC1	77.8	89.6	100.0
15	55	Accept	Form	GLT, GDT, SBT	tri	PC1	77.8	90.1	100.0
15	55	Accept	Size	GBT, GDT, SBT	tri	–	77.8	89.8	100.0
15	55	Accept	Size	GBT, GL	bi	–	77.8	89.9	100.0

Table A.22: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
15	55	Accept	Size	GLT, GDT, SBT	tri	–	77.8	89.7	100.0
16	54	Accept	Form	GB, GL, GBT	tri	PC1	77.8	88.7	100.0
16	54	Accept	Size	GB, GL, GBT	tri	–	77.8	89.0	100.0
16	54	Accept	Size	GL, GBT, SBT	tri	–	77.8	88.6	100.0
17	53	Accept	Form	GB, GBT	bi	PC1	77.8	87.9	100.0
17	53	Accept	Form	GL, GBT, SBT	tri	PC1	77.8	88.1	100.0
17	53	Accept	Form	GL, GLT, SBT	tri	PC1	77.8	87.7	100.0
17	53	Accept	Size	GB, GBT	bi	–	77.8	88.3	100.0
17	53	Accept	Size	GL, GLT, SBT	tri	–	77.8	87.5	100.0
17	53	Accept	Form	GBT	uni	–	77.8	88.2	100.0
18	52	Accept	Form	GB, GBT, SBT	tri	PC1	77.8	86.8	100.0
18	52	Accept	Form	GB, GDT, SBT	tri	PC1	76.2	88.6	95.5
18	52	Accept	Form	SBT, GLT	bi	PC1	77.8	87.3	94.4
18	52	Accept	Size	GB, GBT, SBT	tri	–	77.8	87.1	100.0
18	52	Accept	Size	SBT, GLT	bi	–	77.8	87.2	94.4
19	51	Accept	Form	SBT, GDT	bi	PC1	76.2	87.3	100.0
19	51	Accept	Size	SBT, GDT	bi	–	76.2	87.0	95.2
20	50	Accept	Form	SBT, GL	bi	PC1	76.2	86.9	95.2
20	50	Accept	Size	SBT, GL	bi	–	76.2	86.6	95.2
21	49	Accept	Form	GB, GL	bi	PC1	76.9	84.5	92.3
21	49	Accept	Form	GB, GL, SBT	tri	PC1	76.2	85.7	95.2
21	49	Accept	Form	GBT, GLT	bi	PC1	73.3	88.0	100.0
21	49	Accept	Form	GLT, GBT, SBT	tri	PC1	73.3	88.2	100.0
21	49	Accept	Size	GB, GL, SBT	tri	–	76.2	85.5	95.2
21	49	Accept	Size	GB, GLT, GBT	tri	–	73.3	88.3	100.0
21	49	Accept	Size	GBT, GLT	bi	–	73.3	88.7	100.0
21	49	Accept	Size	GL, GLT, GBT	tri	–	73.3	88.5	100.0
21	49	Accept	Size	GLT, GBT, SBT	tri	–	73.3	88.3	100.0

Table A.22: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
21	49	Accept	Form	GDT	uni	–	76.2	85.6	95.2
22	48	Accept	Form	GB, GLT, GBT	tri	PC1	73.3	87.6	100.0
22	48	Accept	Form	GB, SBT	bi	PC1	76.2	84.1	95.2
22	48	Accept	Form	GL, GLT, GBT	tri	PC1	73.3	87.7	100.0
22	48	Accept	Size	GB, GL	bi	–	76.9	84.1	92.3
22	48	Accept	Size	GB, SBT	bi	–	76.2	84.4	95.2
22	48	Accept	Form	GL	uni	–	76.2	84.6	92.9
23	46	Accept	Form	SBT, GBT	bi	PC1	72.2	86.4	100.0
23	46	Accept	Size	SBT, GBT	bi	–	72.2	86.8	100.0
24	45	Accept	Form	GB, GLT, SBT	tri	PC1	72.2	85.6	94.4
24	45	Accept	Form	GL, GLT	bi	PC1	72.2	85.1	94.4
24	45	Accept	Size	GB, GLT, SBT	tri	–	72.2	85.8	94.4
25	44	Accept	Form	GB, GL, GLT	tri	PC1	72.2	84.7	94.4
25	44	Accept	Size	GB, GL, GLT	tri	–	72.2	84.8	94.4
25	44	Accept	Size	GL, GLT	bi	–	72.2	84.9	94.4
25	44	Accept	Form	GLT	uni	–	72.2	84.2	94.4
26	43	Accept	Form	GB, GLT	bi	PC1	72.2	83.3	94.4
27	42	Accept	Size	GB, GLT	bi	–	72.2	82.7	94.4
28	38	Accept	Form	GB	uni	–	71.8	79.3	87.2
29	35	Accept	Form	SBT	uni	–	66.7	81.1	95.2
30	9	Reject	Form	GLT, GDT, SBT	tri	PC2	55.6	66.0	77.8
31	8	Reject	Form	GB, GDT, SBT	tri	PC2	52.4	68.5	81.0
32	6	Reject	Form	GL, GDT, SBT	tri	PC2	52.4	66.7	81.0
33	3	Reject	Shape	GLT, GDT, SBT	tri	PC1	50.0	65.5	77.8
34	2	Reject	Form	GL, GDT, SDT	tri	PC2	47.6	66.7	81.0
35	1	Reject	Form	GB, GDT, SDT	tri	PC2	47.6	66.6	81.0
36	-1	Reject	Shape	GL, SBT, SDT	tri	PC1	47.6	64.3	81.0
37	-5	Reject	Shape	GLT, GBT, SBT	tri	PC1	46.7	61.2	80.0

Table A.22: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
38	-7	Reject	Form	GL, SBT, SDT	tri	PC2	42.9	63.0	81.0
38	-7	Reject	Form	GLT, GDT, SDT	tri	PC2	44.4	61.4	77.8
38	-7	Reject	Shape	GB, GLT, GBT	tri	PC1	40.0	65.3	80.0
38	-7	Reject	Shape	GBT, GLT	bi	PC1	40.0	65.3	80.0
38	-7	Reject	Shape	GL, GDT, SBT	tri	PC1	42.9	62.5	76.2
39	-8	Reject	Shape	GB, SDT	bi	PC1	47.6	57.3	66.7
39	-8	Reject	Shape	GL, GBT, SBT	tri	PC1	44.4	60.1	72.2
40	-9	Reject	Form	GL, GBT, SBT	tri	PC2	44.4	59.6	77.8
40	-9	Reject	Shape	GL, GLT, GBT	tri	PC1	40.0	63.9	80.0
40	-9	Reject	Shape	GL, GLT, SBT	tri	PC1	44.4	59.1	77.8
41	-10	Reject	Shape	GLT, GBT, GDT	tri	PC1	40.0	62.8	80.0
41	-10	Reject	Shape	GLT, SBT, SDT	tri	PC1	44.2	58.6	72.2
41	-10	Reject	Shape	SBT, GL	bi	PC1	42.9	59.9	76.2
42	-11	Reject	Shape	GL, GLT, GDT	tri	PC1	38.9	62.4	77.8
43	-12	Reject	Form	GB, GBT, SBT	tri	PC2	44.4	55.9	72.2
43	-12	Reject	Form	GDT, GL	bi	PC2	38.1	62.2	81.0
44	-13	Reject	Form	GLT, GBT, SBT	tri	PC2	40.0	59.6	80.0
44	-13	Reject	Shape	GB, GL, GDT	tri	PC2	42.9	56.5	71.4
44	-13	Reject	Shape	GDT, GL	bi	PC1	38.1	61.5	81.0
44	-13	Reject	Shape	GDT, GLT	bi	PC1	38.9	60.5	77.8
44	-13	Reject	Shape	GL, GDT, SDT	tri	PC1	38.1	61.7	76.2
45	-15	Reject	Form	GLT, SBT, SDT	tri	PC2	38.9	58.9	77.8
45	-15	Reject	Shape	GB, GL, SBT	tri	PC2	42.9	55.0	66.7
46	-16	Reject	Shape	GB, GL	bi	PC1	41.0	55.3	64.1
46	-16	Reject	Shape	GB, GL, SDT	tri	PC1	38.1	58.9	71.4
47	-17	Reject	Shape	GB, GBT, SDT	tri	PC1	44.4	51.7	61.1
47	-17	Reject	Shape	SBT, GLT	bi	PC1	38.9	56.7	77.8
47	-17	Reject	Form	GB, GDT	bi	PC2	33.3	61.9	81.0

Table A.22: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
48	-18	Reject	Form	GLT, GBT, GDT	tri	PC2	33.3	61.7	80.0
48	-18	Reject	Shape	GB, GLT, GDT	tri	PC1	33.3	61.8	77.8
48	-18	Reject	Form	SBT, GL	bi	PC2	38.1	56.4	71.4
49	-19	Reject	Form	GB, SBT, SDT	tri	PC2	38.1	55.1	76.2
49	-19	Reject	Shape	GB, GL, GBT	tri	PC1	38.9	54.7	72.2
49	-19	Reject	Shape	GBT, GL	bi	PC1	38.9	54.5	66.7
50	-20	Reject	Form	GB, GBT, GDT	tri	PC2	33.3	59.0	77.8
50	-20	Reject	Form	GL, GBT, GDT	tri	PC2	33.3	59.3	77.8
50	-20	Reject	Shape	GLT, GDT, SDT	tri	PC1	33.3	59.6	72.2
51	-23	Reject	Form	GB, GL, SDT	tri	PC2	33.3	56.2	71.4
51	-23	Reject	Shape	GB, GLT, SDT	tri	PC1	33.3	56.8	72.2
51	-23	Reject	Form	GB, SDT	bi	PC2	33.1	56.5	76.2
52	-24	Reject	Form	GL, GBT, SDT	tri	PC2	33.3	54.9	72.2
52	-24	Reject	Shape	GB, GLT, SBT	tri	PC1	33.3	55.7	72.2
52	-24	Reject	Form	GB, SBT	bi	PC2	38.1	50.7	66.7
53	-25	Reject	Shape	GB, GL, SBT	tri	PC1	33.3	54.8	71.4
54	-26	Reject	Shape	GB, SBT, SDT	tri	PC1	28.6	58.0	76.2
54	-26	Reject	Shape	SDT, GL	bi	PC1	33.3	52.9	71.4
54	-26	Reject	Form	SBT, GLT	bi	PC2	33.3	53.2	72.2
54	-26	Reject	Form	SDT, GL	bi	PC2	33.3	53.7	71.4
55	-27	Reject	Shape	GB, GL, SDT	tri	PC2	33.3	52.6	71.4
55	-27	Reject	Form	GDT, GLT	bi	PC2	27.8	57.9	77.8
56	-28	Reject	Shape	GB, GL, GLT	tri	PC1	33.3	51.1	66.7
57	-29	Reject	Form	GB, GBT, SDT	tri	PC2	27.8	55.5	77.8
57	-29	Reject	Form	GB, GLT, GDT	tri	PC2	27.8	55.8	77.8
57	-29	Reject	Shape	GL, GBT, GDT	tri	PC1	27.8	55.9	77.8
58	-31	Reject	Form	GB, GLT, SDT	tri	PC2	27.8	53.6	72.2
58	-31	Reject	Form	GBT, GDT, SDT	tri	PC2	33.3	48.1	61.1

Table A.22: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
58	-31	Reject	Shape	GB, GDT, SDT	tri	PC1	33.3	48.3	61.9
58	-31	Reject	Shape	GB, GL, GBT	tri	PC2	33.1	48.4	61.1
59	-32	Reject	Form	GB, GL, SBT	tri	PC2	28.6	52.4	71.4
59	-32	Reject	Form	GBT, SBT, SDT	tri	PC3	33.3	47.8	61.1
59	-32	Reject	Shape	GB, GL, GDT	tri	PC1	28.6	52.5	76.2
59	-32	Reject	Shape	GLT, GBT, SDT	tri	PC2	26.7	54.0	73.3
59	-32	Reject	Form	GBT, GDT	bi	PC2	33.3	47.4	61.1
60	-33	Reject	Form	GB, GLT, SBT	tri	PC2	27.8	52.3	66.7
60	-33	Reject	Form	GL, GLT, SDT	tri	PC2	27.8	52.0	72.2
60	-33	Reject	Shape	GB, GDT, SBT	tri	PC1	33.3	46.0	61.9
61	-34	Reject	Form	GB, GL, GDT	tri	PC2	28.6	50.5	76.2
61	-34	Reject	Form	GL, GLT, GDT	tri	PC2	27.8	51.0	72.5
61	-34	Reject	Form	GL, GLT, SBT	tri	PC2	27.8	51.3	72.2
61	-34	Reject	Shape	GL, GBT, SDT	tri	PC1	27.8	50.8	66.7
61	-34	Reject	Shape	GL, GLT, SDT	tri	PC1	27.8	50.4	66.9
62	-35	Reject	Shape	GB, GBT, SBT	tri	PC1	27.8	49.5	77.8
62	-35	Reject	Shape	GB, SBT	bi	PC1	28.6	49.0	71.4
63	-36	Reject	Shape	GB, GLT, SDT	tri	PC2	27.8	49.3	66.7
64	-37	Reject	Shape	GB, GBT	bi	PC1	27.8	48.4	66.7
64	-37	Reject	Shape	GB, GLT	bi	PC1	27.8	48.2	61.1
64	-37	Reject	Shape	GB, GLT, SBT	tri	PC2	27.8	48.0	66.7
65	-38	Reject	Form	GBT, GDT, SBT	tri	PC3	27.8	46.9	61.1
65	-38	Reject	Form	GLT, GBT, SDT	tri	PC2	26.7	48.1	66.7
65	-38	Reject	Form	SBT, GBT	bi	PC2	27.8	47.0	61.1
66	-39	Reject	Form	GB, GLT, GBT	tri	PC2	26.7	46.7	66.7
66	-39	Reject	Shape	GB, GDT	bi	PC1	28.6	45.6	61.9
66	-39	Reject	Shape	GB, GLT, GDT	tri	PC2	27.8	45.5	66.7
66	-39	Reject	Shape	GLT, GBT, GDT	tri	PC2	26.7	47.2	66.7

Table A.22: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
66	-39	Reject	Shape	GLT, GBT, SDT	tri	PC1	26.7	46.6	66.7
66	-39	Reject	Shape	SDT, GLT	bi	PC1	27.8	45.7	66.7
66	-39	Reject	Form	SDT, GLT	bi	PC2	27.8	45.6	66.7
67	-40	Reject	Form	GBT, GLT	bi	PC2	26.7	46.4	66.7
68	-44	Reject	Shape	GBT, GDT, SDT	tri	PC2	22.2	46.0	61.1
68	-44	Reject	Form	GB, GBT	bi	PC2	27.8	40.8	55.6
69	-45	Reject	Shape	GL, GBT, GDT	tri	PC2	22.2	45.1	61.4
70	-47	Reject	Shape	GL, GBT, SDT	tri	PC2	22.2	43.1	61.1
71	-48	Reject	Shape	GDT, SBT, SDT	tri	PC2	23.8	41.0	57.1
72	-49	Reject	Form	GB, GL, GBT	tri	PC2	22.2	41.2	55.6
72	-49	Reject	Shape	GB, GBT, GDT	tri	PC1	22.2	41.9	61.1
73	-50	Reject	Form	GDT, SBT, SDT	tri	PC3	23.8	39.0	57.1
73	-50	Reject	Form	GL, GLT, GBT	tri	PC2	20.0	42.5	60.0
73	-50	Reject	Shape	GB, GBT, GDT	tri	PC2	22.2	40.5	55.6
73	-50	Reject	Shape	GBT, SBT, SDT	tri	PC2	22.2	40.6	55.6
73	-50	Reject	Shape	GLT, GBT, SBT	tri	PC2	20.0	42.7	60.0
73	-50	Reject	Shape	SDT, GDT	bi	PC1	23.8	38.8	52.4
74	-51	Reject	Shape	GBT, SBT, SDT	tri	PC1	22.2	39.8	61.1
74	-51	Reject	Form	GBT, GL	bi	PC2	22.2	39.8	55.6
75	-52	Reject	Shape	GB, GBT, SDT	tri	PC2	22.2	38.6	55.6
75	-52	Reject	Shape	GBT, GDT	bi	PC1	22.2	38.2	50.0
76	-55	Reject	Shape	GB, SBT, SDT	tri	PC2	19.1	38.3	57.1
76	-55	Reject	Shape	GLT, GDT, SDT	tri	PC2	22.2	36.0	55.6
76	-55	Reject	Form	SDT, GBT	bi	PC2	22.2	35.1	50.0
77	-56	Reject	Shape	GB, GDT, SDT	tri	PC2	19.1	37.9	52.4
77	-56	Reject	Shape	GB, GLT, GBT	tri	PC2	20.0	37.1	53.3
77	-56	Reject	Shape	SBT, GBT	bi	PC1	16.7	40.0	55.6
77	-56	Reject	Shape	SBT, SDT	bi	PC1	19.1	37.7	52.4

Table A.22: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
77	-56	Reject	Form	SDT, GDT	bi	PC2	19.1	37.9	52.4
78	-57	Reject	Shape	GBT, GDT, SBT	tri	PC2	16.7	39.0	55.6
78	-57	Reject	Shape	GBT, GDT, SDT	tri	PC1	16.7	39.4	55.6
78	-57	Reject	Form	SBT, SDT	bi	PC2	19.1	36.4	52.4
79	-58	Reject	Form	GB, GBT, GDT	tri	PC3	16.7	37.7	61.1
79	-58	Reject	Form	GL, SBT, SDT	tri	PC3	19.1	36.0	52.4
79	-58	Reject	Shape	GL, GBT, SBT	tri	PC2	16.7	38.5	55.6
80	-60	Reject	Shape	SDT, GBT	bi	PC1	16.7	35.8	55.6
81	-61	Reject	Form	GBT, SBT, SDT	tri	PC2	16.7	35.4	55.6
81	-61	Reject	Form	GL, GBT, GDT	tri	PC3	16.7	34.9	61.1
82	-62	Reject	Form	GB, GL, GDT	tri	PC3	14.3	36.8	57.1
83	-63	Reject	Form	GB, GL, SBT	tri	PC3	14.3	35.4	61.9
84	-64	Reject	Shape	GL, SBT, SDT	tri	PC2	14.3	34.6	52.4
85	-65	Reject	Form	GB, GL	bi	PC2	15.4	32.0	46.1
86	-67	Reject	Shape	GL, GDT, SDT	tri	PC2	14.3	31.5	47.6
87	-68	Reject	Form	GB, GLT, SBT	tri	PC3	11.1	33.3	55.6
87	-68	Reject	Form	GL, GDT, SDT	tri	PC3	14.3	30.9	47.6
88	-69	Reject	Form	GB, GL, GBT	tri	PC3	11.1	32.9	55.6
88	-69	Reject	Form	GLT, GDT, SDT	tri	PC3	11.1	32.9	50.0
88	-69	Reject	Shape	GL, GLT	bi	PC1	11.1	32.5	50.0
89	-70	Reject	Form	GB, GLT, SDT	tri	PC3	11.1	31.8	55.6
89	-70	Reject	Shape	GL, GLT, SBT	tri	PC2	11.1	31.4	55.6
89	-70	Reject	Shape	GLT, SBT, SDT	tri	PC2	11.1	31.5	55.6
90	-71	Reject	Form	GL, GLT, SBT	tri	PC3	11.1	30.7	50.0
90	-71	Reject	Form	GLT, SBT, SDT	tri	PC3	11.1	30.3	50.0
90	-71	Reject	Shape	GBT, GDT, SBT	tri	PC1	11.1	30.8	50.0
91	-72	Reject	Form	GB, GL, SDT	tri	PC3	9.5	31.0	52.4
91	-72	Reject	Form	GB, SBT, SDT	tri	PC3	9.5	30.9	47.6

Table A.22: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
91	-72	Reject	Form	GBT, GDT, SBT	tri	PC2	11.1	29.8	50.0
91	-72	Reject	Form	GL, GLT	bi	PC2	11.1	29.5	50.0
92	-74	Reject	Form	GLT, GBT, GDT	tri	PC3	6.7	31.8	60.0
92	-74	Reject	Shape	GB, GBT, SBT	tri	PC2	11.1	27.8	44.4
93	-75	Reject	Form	GB, GDT, SBT	tri	PC3	9.5	27.7	42.9
94	-76	Reject	Shape	GDT, SBT, SDT	tri	PC1	9.5	27.1	42.9
94	-76	Reject	Shape	GL, GLT, SDT	tri	PC2	5.6	30.8	50.0
95	-77	Reject	Form	GB, GDT, SDT	tri	PC3	9.5	26.6	42.9
95	-77	Reject	Form	GB, GL, GLT	tri	PC2	5.6	30.2	55.6
95	-77	Reject	Form	GB, GLT, GDT	tri	PC3	5.6	30.6	55.6
95	-77	Reject	Form	GL, GDT, SBT	tri	PC3	9.5	25.9	42.9
95	-77	Reject	Form	GL, GLT, SDT	tri	PC3	5.6	30.2	55.6
95	-77	Reject	Shape	GL, GDT, SBT	tri	PC2	9.5	26.4	42.9
95	-77	Reject	Form	GB, GLT	bi	PC2	5.6	30.0	50.0
96	-78	Reject	Form	GB, GLT, GBT	tri	PC3	6.7	27.6	46.7
96	-78	Reject	Form	GL, GBT, SDT	tri	PC3	5.6	28.7	50.0
96	-78	Reject	Form	GLT, GBT, SDT	tri	PC3	6.7	27.8	53.3
96	-78	Reject	Shape	GB, GDT, SBT	tri	PC2	9.5	25.3	42.9
97	-79	Reject	Form	GLT, GDT, SBT	tri	PC3	5.6	28.0	50.0
97	-79	Reject	Shape	GL, GLT, GDT	tri	PC2	5.6	27.7	50.0
98	-80	Reject	Form	GB, GBT, SBT	tri	PC3	5.6	27.1	50.0
98	-80	Reject	Form	GB, GBT, SDT	tri	PC3	5.6	27.6	50.0
98	-80	Reject	Form	GBT, GDT, SDT	tri	PC3	5.6	26.8	50.0
98	-80	Reject	Form	GL, GLT, GDT	tri	PC3	5.6	27.3	50.0
98	-80	Reject	Shape	GB, GL, GLT	tri	PC2	5.6	27.2	50.0
98	-80	Reject	Shape	GLT, GDT, SBT	tri	PC2	5.6	26.9	50.0
99	-82	Reject	Form	GB, GL, GLT	tri	PC3	5.6	25.2	44.4
99	-82	Reject	Shape	GL, GLT, GBT	tri	PC2	6.3	24.1	46.7

Table A.22: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
100	-83	Reject	Shape	SBT, GDT	bi	PC1	4.8	24.6	42.9
101	-84	Reject	Form	GDT, SBT, SDT	tri	PC2	4.8	23.4	42.9
101	-84	Reject	Form	SBT, GDT	bi	PC2	4.8	24.3	42.9
102	-87	Reject	Form	GL, GBT, SBT	tri	PC3	0.0	25.4	44.4
103	-88	Reject	Form	GLT, GBT, SBT	tri	PC3	0.0	24.9	46.7
104	-89	Reject	Form	GL, GLT, GBT	tri	PC3	0.0	23.7	46.7

A.3.10 Metapodia

A.3.10.1 MT2

Table A.23: List of approaches ranked by score for balanced cross-validation results for the MT2 (Subset A).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	58	Prefer	Shape	Bd, GL	bi	PC1	93.8	93.8	93.8
2	37	Prefer	Form	Bd, GL	bi	PC2	83.3	83.3	83.3
3	20	Prefer	Form	GL	uni	–	75.0	75.0	75.0
4	12	Reject	Form	Bd, GL	bi	PC1	70.8	70.8	70.8
4	12	Reject	Form	Bd	uni	–	70.8	71.4	72.9
5	-18	Reject	Size	Bd, GL	bi	–	56.2	56.2	56.2

Table A.24: List of approaches ranked by score for balanced cross-validation results for the MT2 (Subset B).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	67	Prefer	Shape	Bd, GL	bi	PC1	86.7	92.9	100.0
2	48	Prefer	Form	GL	uni	–	76.7	84.0	93.3
3	38	Prefer	Form	Bd	uni	–	70.0	80.4	90.0

Table A.24: *(continued)*

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
4	30	Prefer	Form	Bd, GL	bi	PC1	66.7	76.5	86.7
5	-4	Reject	Size	Bd, GL	bi	–	40.0	69.0	80.0
6	-5	Reject	Form	Bd, GL	bi	PC2	50.0	58.0	66.7

A.3.10.2 MT3

Table A.25: List of approaches ranked by score for balanced cross-validation results for the MT3 (Subset A).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	61	Prefer	Shape	Bd, GL	bi	PC1	95.7	95.7	95.7
2	40	Prefer	Form	Bd, GL	bi	PC1	84.8	85.2	87.0
2	40	Prefer	Form	Bd	uni	–	84.8	85.6	87.0
3	13	Reject	Form	GL	uni	–	69.6	73.0	76.1
4	1	Reject	Form	Bd, GL	bi	PC2	65.2	66.0	67.4
5	-11	Reject	Size	Bd, GL	bi	–	58.7	60.6	60.9

Table A.26: List of approaches ranked by score for balanced cross-validation results for the MT3 (Subset B).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	68	Prefer	Shape	Bd, GL	bi	PC1	87.5	93.7	100.0
2	61	Prefer	Form	Bd	uni	–	83.3	90.5	95.8
3	43	Prefer	Form	GL	uni	–	73.3	82.8	90.0
4	39	Prefer	Form	Bd, GL	bi	PC2	70.8	81.3	91.7
5	4	Reject	Size	Bd, GL	bi	–	45.8	70.6	83.3
6	-10	Reject	Form	Bd, GL	bi	PC1	37.5	64.8	79.2

A.3.10.3 MT4

Table A.27: List of approaches ranked by score for balanced cross-validation results for the MT4 (Subset A).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	62	Prefer	Form	Bd, GL	bi	PC1	95.8	95.8	95.8
1	62	Prefer	Shape	Bd, GL	bi	PC1	95.8	95.8	95.8
2	58	Prefer	Form	Bd	uni	–	93.8	94.0	95.8
3	16	Reject	Form	GL	uni	–	72.9	72.9	72.9
4	-5	Reject	Form	Bd, GL	bi	PC2	62.5	62.5	62.5
5	-9	Reject	Size	Bd, GL	bi	–	60.4	60.4	60.4

Table A.28: List of approaches ranked by score for balanced cross-validation results for the MT4 (Subset B).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	76	Prefer	Shape	Bd, GL	bi	PC1	92.6	96.0	100.0
2	72	Prefer	Form	Bd	uni	–	88.9	95.5	100.0
3	56	Prefer	Form	Bd, GL	bi	PC2	81.5	87.6	92.6
4	43	Prefer	Form	GL	uni	–	73.3	82.0	90.0
5	24	Reject	Size	Bd, GL	bi	–	63.0	73.5	85.2
6	-7	Reject	Form	Bd, GL	bi	PC1	40.7	65.1	77.8

A.3.11 Astragalus

Table A.29: List of approaches ranked by score for balanced cross-validation results for the astragalus (Subset A).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	-3	Reject	Form	GL	uni	–	61.7	65.3	68.3

Table A.30: List of approaches ranked by score for balanced cross-validation results for the astragalus (Subset B).

Rank	Score	Verdict	Variable	Metrics	NVars	PC	5%	Mean	95%
1	36	Prefer	Form	GL	uni	–	71.1	77.4	84.4

A.4 Predictive LDA Tables

Table A.31: List of identification approaches used for metrical identification of archaeological hare bones, Subset A. Arranged by element (anatomical order) and mean CVP (decreasing).

Element	Variable	Metrics	PC	Lower	Mean	Upper
MAND	Shape	m1, m4, m5a	PC1	83.3	86.9	90.5
MAND	Shape	m1, m5a	PC1	81.8	84.1	88.6
MAND	Shape	m1, m5, m5a	PC1	81.8	84.0	86.4
MAND	Shape	m1, m2, m5a	PC1	79.5	83.5	86.4
MAND	Shape	m3, m4, m5a	PC1	80.4	83.3	87.0
MAND	Form	m1, m2, m5a	PC2	77.3	82.0	86.4
MAND	Form	m1, m5a	PC2	77.3	81.7	86.4
MAND	Shape	m2, m3, m5a	PC1	77.1	81.5	87.5
MAND	Shape	m1, m3, m5a	PC1	77.3	81.5	86.4
MAND	Shape	m3, m5a	PC1	77.1	81.1	87.5
MAND	Shape	m2, m4, m5a	PC1	76.1	80.7	84.8
MAND	Form	m2, m4, m5a	PC2	76.1	80.5	87.0
MAND	Form	m4, m5a	PC2	76.1	80.0	84.8
SCAP	Form	GLP, HS	PC1	88.5	94.0	98.1
SCAP	Size	GLP, HS	–	88.5	92.7	96.2
SCAP	Size	BG, GLP, HS	–	90.4	91.8	94.2
SCAP	Form	BG, GLP, HS	PC1	88.5	91.2	94.2
SCAP	Form	GLP	–	87.9	91.0	93.9

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
SCAP	Form	GLP, DHA	PC1	88.9	90.9	92.6
SCAP	Size	BG, GLP, DHA	–	87.0	90.8	94.4
SCAP	Form	BG, GLP, DHA	PC1	87.0	90.7	94.4
SCAP	Size	BG, HS	–	86.5	89.3	92.3
SCAP	Size	BG, GLP, SLC	–	86.4	89.0	90.9
SCAP	Form	GLP, HS, DHA	PC1	86.5	88.8	94.2
SCAP	Form	BG, GLP	PC1	86.4	88.6	90.9
SCAP	Size	GLP, SLC, HS	–	84.6	88.5	92.3
SCAP	Size	BG, GLP	–	86.4	88.3	90.9
SCAP	Form	BG, HS	PC1	84.6	88.3	92.3
SCAP	Size	GLP, DHA	–	85.2	87.5	90.7
SCAP	Form	BG, DHA	PC1	85.2	87.5	90.7
SCAP	Size	BG, DHA	–	85.2	87.5	90.7
SCAP	Form	BG, GLP, SLC	PC1	84.8	87.4	90.9
SCAP	Form	GLP, SLC, HS	PC1	82.7	87.4	92.3
SCAP	Size	GLP, HS, DHA	–	82.7	86.5	92.3
SCAP	Size	BG, SLC, HS	–	82.7	86.3	90.4
SCAP	Size	GLP, SLC, DHA	–	81.5	86.1	90.7
SCAP	Size	GLP, SLC	–	80.3	85.9	89.4
SCAP	Form	BG, SLC, HS	PC1	82.7	85.8	88.5
SCAP	Form	GLP, SLC, DHA	PC1	81.5	85.0	90.7
SCAP	Form	BG, HS, DHA	PC1	80.8	84.5	88.5
SCAP	Size	BG, HS, DHA	–	80.8	83.5	86.5
SCAP	Form	BG	–	78.8	83.2	87.9
SCAP	Form	GLP, SLC	PC1	80.3	83.2	87.9
SCAP	Size	BG, SLC, DHA	–	79.6	82.8	87.0
SCAP	Form	BG, SLC, DHA	PC1	79.6	82.8	87.0
SCAP	Form	BG, SLC	PC1	78.8	81.5	84.8

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
SCAP	Form	SLC, HS	PC1	76.9	80.6	84.6
SCAP	Size	BG, SLC	–	77.3	80.5	86.4
SCAP	Size	SLC, DHA	–	78.6	80.1	82.1
SCAP	Size	SLC, HS, DHA	–	76.9	80.1	82.7
HUM	Shape	Dp, GL, Dd	PC1	97.6	98.0	100.0
HUM	Shape	Bp, Dp, GLC	PC1	95.2	97.3	97.6
HUM	Size	Bd, Dp	–	95.2	96.6	98.4
HUM	Shape	Bp, Dp, GL	PC1	95.2	96.4	97.6
HUM	Form	Bd, Dp	PC1	93.5	95.6	96.8
HUM	Shape	Bp, GL	PC1	92.9	95.2	97.6
HUM	Size	Bp, Dp, Bd	–	93.2	95.1	95.5
HUM	Form	Bp, Dp, Bd	PC1	93.2	95.0	95.5
HUM	Size	Bp, Dp, Dd	–	93.2	94.4	97.7
HUM	Shape	Bp, GLC	PC1	92.9	94.3	97.6
HUM	Form	Dp, GL, Bd	PC1	91.7	94.3	96.7
HUM	Form	Bp, Dp, Dd	PC1	93.2	94.3	97.7
HUM	Shape	Dp, GL, GLC	PC1	91.9	94.3	96.8
HUM	Shape	Dp, GLC	PC1	91.9	93.9	96.8
HUM	Shape	Dp, GL, Bd	PC1	90.0	93.6	96.7
HUM	Shape	Dp, GL	PC1	90.3	93.0	95.2
HUM	Size	Dd, Dp	–	90.9	92.9	95.5
HUM	Form	Dd, Dp	PC1	90.9	92.9	95.5
HUM	Size	Bp, Dp, HTC	–	90.9	92.6	95.5
HUM	Shape	GLC, SD, Dd	PC2	90.5	91.9	92.9
HUM	Shape	Dd, GLC	PC1	90.9	91.8	93.2
HUM	Size	Dd, Bp	–	90.9	91.6	93.2
HUM	Form	Dp, Bp	PC1	90.9	91.6	93.2
HUM	Form	Dd, Bp	PC1	88.6	91.5	93.2

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
HUM	Size	Dp, Bp	–	90.9	91.5	93.2
HUM	Shape	GL, GLC, Dd	PC1	90.9	91.5	93.2
HUM	Shape	Dd, GL	PC1	90.9	91.5	93.2
HUM	Shape	Dp, GL, HTC	PC1	90.5	91.5	92.9
HUM	Form	Bp, Dp, GLC	PC1	90.5	91.4	92.9
HUM	Form	Bp, Dp, GL	PC1	90.5	91.2	92.9
HUM	Form	Bp, Dp, HTC	PC1	88.6	90.7	93.2
HUM	Form	Dp	–	89.4	90.7	92.4
HUM	Shape	HTC, GL	PC1	88.6	90.7	93.2
HUM	Shape	GL, GLC, HTC	PC1	88.6	90.7	93.2
HUM	Shape	HTC, GLC	PC1	88.6	90.5	90.9
HUM	Form	Bd, Bp	PC1	88.6	90.3	93.2
HUM	Size	Bd, Bp	–	88.6	90.3	93.2
HUM	Form	Bd, Dd	PC1	89.6	90.1	91.7
HUM	Size	Bd, Dd	–	89.6	90.0	91.7
HUM	Form	Bp	–	84.1	89.1	90.9
HUM	Size	HTC, Dp	–	86.4	89.1	90.9
HUM	Form	Dp, GL	PC1	87.1	89.1	91.9
HUM	Shape	Bd, GLC	PC1	86.7	88.9	91.7
HUM	Shape	GL, GLC, Bd	PC1	86.7	88.7	91.7
HUM	Size	HTC, Bd, Dd	–	87.5	88.1	89.6
HUM	Size	HTC, Bp	–	86.4	88.0	93.2
HUM	Shape	Bd, GL	PC1	83.3	87.9	91.7
HUM	Form	HTC, Bd, Dd	PC1	87.5	87.9	89.6
HUM	Form	HTC, Bp	PC1	86.4	87.9	93.2
HUM	Form	Dp, GL, Dd	PC1	85.7	87.9	92.9
HUM	Size	Bp, Dp, SD	–	86.4	87.2	88.6
HUM	Form	Dp, GLC	PC1	83.9	87.1	90.3

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
HUM	Form	Bp, Dp, SD	PC1	86.4	87.1	88.6
HUM	Form	Bd	–	81.2	86.8	90.6
HUM	Form	Bp, GLC	PC1	85.7	86.6	88.1
HUM	Form	Bp, GL	PC1	85.7	86.5	88.1
HUM	Form	Bd, GL	PC1	83.3	86.2	90.0
HUM	Size	Bd, HTC	–	85.4	86.2	87.5
HUM	Form	Bd, GLC	PC1	83.3	86.0	90.0
HUM	Form	Bd, HTC	PC1	85.4	85.8	87.5
HUM	Size	Dp, GL, Bd	–	83.3	85.5	90.0
HUM	Size	Bp, SD	–	81.8	84.5	86.4
HUM	Size	Dd, SD	–	82.6	84.5	87.0
HUM	Form	HTC, Dp	PC1	81.8	84.5	88.6
HUM	Form	Bp, SD	PC1	81.8	84.1	86.4
HUM	Form	Dp, GL, HTC	PC1	81.0	83.9	85.7
HUM	Size	Dp, SD	–	81.8	83.6	86.4
HUM	Shape	Dp, GL, SD	PC2	79.0	82.9	87.1
HUM	Form	SD, HTC, Bd	PC1	80.4	82.5	84.8
HUM	Size	SD, HTC, Bd	–	80.4	82.2	84.8
HUM	Size	Bd, SD	–	78.1	81.6	84.4
HUM	Form	GL, GLC, Bd	PC1	78.3	81.2	85.0
HUM	Size	Bp, Dp, GL	–	78.6	81.0	83.3
HUM	Form	GL, GLC, Dd	PC2	79.5	80.9	84.1
HUM	Size	Dd, HTC	–	77.1	80.8	85.4
HUM	Size	SD, HTC, Dd	–	78.3	80.7	84.8
HUM	Size	Dp, GL, HTC	–	76.2	80.7	85.7
HUM	Size	Bp, Dp, GLC	–	78.6	80.7	83.3
HUM	Form	SD, HTC, Dd	PC1	78.3	80.2	82.6
RAD	Form	Bp, SD, Dd	PC1	95.8	99.1	100.0

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
RAD	Form	Dd, SD	PC1	91.7	98.7	100.0
RAD	Size	Bp, Dd	–	95.8	98.3	100.0
RAD	Size	Bp, SD, Dd	–	95.8	98.2	100.0
RAD	Form	Bp, Dd	PC1	95.8	97.9	100.0
RAD	Form	Dd, Bd, SD	PC1	91.7	97.9	100.0
RAD	Form	Bp, GL, Dd	PC1	95.8	97.4	100.0
RAD	Form	Bp, Dp, Dd	PC1	90.9	97.0	100.0
RAD	Size	Dd, SD	–	91.7	96.7	100.0
RAD	Shape	Bp, GL, Bd	PC1	96.3	96.5	98.2
RAD	Form	Bp, GL	PC1	94.6	96.2	98.2
RAD	Size	Dd, Bd, SD	–	91.7	96.2	100.0
RAD	Form	Bp, SD, Dp	PC1	92.9	96.1	100.0
RAD	Size	Bp, SD, Dp	–	92.9	96.0	100.0
RAD	Form	Bp	–	95.5	95.6	97.0
RAD	Form	Bp, Bd, Dd	PC1	91.7	95.6	100.0
RAD	Size	Bp, Dp, Dd	–	90.9	95.4	100.0
RAD	Form	Dp, Dd	PC1	90.9	94.8	100.0
RAD	Size	Bp, Bd, Dd	–	87.5	94.8	100.0
RAD	Shape	Bp, GL, Dp	PC1	91.7	94.5	100.0
RAD	Form	Dp, GL, Dd	PC1	90.9	94.4	100.0
RAD	Form	Dd, GL	PC1	91.7	94.2	100.0
RAD	Size	Bp, GL, Dd	–	87.5	94.0	100.0
RAD	Form	GL, Dd	PC1	91.7	94.0	100.0
RAD	Form	Dd	–	91.7	94.0	95.8
RAD	Size	Dp, Dd	–	90.9	94.0	100.0
RAD	Shape	Bp, GL	PC1	92.9	94.0	98.2
RAD	Size	Dp, Bd, Dd	–	86.4	93.9	100.0
RAD	Form	Dp, Bd, Dd	PC1	86.4	93.8	100.0

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
RAD	Form	Bp, Dp	PC1	89.3	93.6	100.0
RAD	Form	Bp, GL, SD	PC1	92.6	93.4	94.4
RAD	Size	Dp, SD	–	89.3	93.3	96.4
RAD	Form	Bp, GL, Bd	PC1	88.9	92.9	96.3
RAD	Form	Dp, SD	PC1	89.3	92.8	96.4
RAD	Form	Bp, Bd	PC1	91.4	92.7	93.1
RAD	Form	Bd, Dd	PC1	87.5	92.7	100.0
RAD	Size	Bp, SD	–	90.9	92.7	93.9
RAD	Size	Bp, Dp	–	89.3	92.5	96.4
RAD	Form	Bp, Dp, Bd	PC1	86.4	92.5	100.0
RAD	Size	Bp, Dp, Bd	–	86.4	92.1	95.5
RAD	Form	Bp, SD	PC1	90.9	92.1	93.9
RAD	Size	Bd, Dd	–	87.5	92.0	95.8
RAD	Size	Bp, GL	–	91.1	91.8	92.9
RAD	Form	Bp, GL, Dp	PC1	87.5	91.7	95.8
RAD	Shape	Bp, GL, Dd	PC1	91.7	91.7	91.7
RAD	Size	Dp, GL, Dd	–	86.4	91.6	95.5
RAD	Form	Bp, SD, Bd	PC1	91.1	91.6	92.9
RAD	Form	Dp, GL, SD	PC1	87.5	91.6	95.8
RAD	Size	Bp, SD, Bd	–	91.1	91.5	92.9
RAD	Shape	Bp, GL, SD	PC1	90.7	91.0	92.6
RAD	Shape	Bp, Bd, Dd	PC1	83.3	90.8	95.8
RAD	Size	Bp, GL, Dp	–	83.3	90.6	95.8
RAD	Size	Bp, Bd	–	89.7	90.1	93.1
RAD	Shape	Dd, GL	PC1	87.5	89.8	91.7
RAD	Shape	GL, Dd	PC1	87.5	89.8	91.7
RAD	Form	Dp, Bd, SD	PC1	81.8	89.5	95.5
RAD	Shape	Bd, Dd	PC1	83.3	89.3	95.8

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
RAD	Size	Dp, Bd, SD	–	81.8	88.9	95.5
RAD	Shape	Dp, GL, SD	PC1	87.5	88.8	91.7
RAD	Size	Bp, GL, SD	–	87.0	88.5	90.7
RAD	Shape	Dp, GL, Dd	PC1	81.8	87.7	90.9
RAD	Shape	Dp, GL	PC1	79.2	87.6	91.7
RAD	Size	Dp, Bd	–	81.8	87.3	90.9
RAD	Shape	Dp, GL, Bd	PC1	77.3	87.2	95.5
RAD	Form	Dp, Bd	PC1	81.8	87.0	95.5
RAD	Size	Dd, GL	–	79.2	87.0	91.7
RAD	Size	GL, Dd	–	79.2	86.9	95.8
RAD	Shape	Dd, Bd, SD	PC2	79.2	86.7	95.8
RAD	Form	Bd, SD	PC1	85.7	86.5	87.5
RAD	Shape	GL, SD	PC1	85.2	85.9	87.0
RAD	Shape	SD, GL	PC1	85.2	85.9	87.0
RAD	Size	Dp, GL, SD	–	79.2	85.5	91.7
RAD	Size	Bp, GL, Bd	–	83.3	85.4	88.9
RAD	Form	Dp	–	75.0	85.2	92.9
RAD	Form	Dp, GL, Bd	PC1	77.3	85.0	90.9
RAD	Shape	Bp, Dp, Bd	PC1	77.3	84.5	90.9
RAD	Shape	Bp, Bd	PC1	82.8	83.8	84.5
RAD	Size	Bd, SD	–	82.1	83.3	85.7
RAD	Form	Dp, GL	PC1	70.8	81.6	91.7
RAD	Form	SD	–	74.2	80.3	81.8
RAD	Shape	Dp, Bd, Dd	PC1	72.7	80.1	86.4
RAD	Form	GL, SD	PC1	75.9	80.1	83.3
ULN	Form	BPC, SDO, GL	PC1	100.0	100.0	100.0
ULN	Shape	BPC, SDO, GL	PC1	95.8	97.9	100.0
ULN	Form	SDO, GL	PC1	97.9	97.9	97.9

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
ULN	Size	BPC, SDO	–	96.4	97.0	100.0
ULN	Form	BPC, SDO	PC1	96.4	96.9	98.2
ULN	Size	BPC, DPA, SDO	–	96.4	96.9	98.2
ULN	Form	BPC, DPA, SDO	PC1	96.4	96.8	98.2
ULN	Size	BPC, SDO, GL	–	95.8	96.3	100.0
ULN	Shape	BPC, DPA, GL	PC1	96.2	96.2	96.2
ULN	Form	SDO	–	94.6	96.1	98.2
ULN	Form	DPA, SDO	PC1	94.6	96.0	98.2
ULN	Size	DPA, SDO	–	94.6	96.0	98.2
ULN	Shape	DPA, SDO, GL	PC1	95.8	95.8	95.8
ULN	Shape	SDO, GL	PC1	95.8	95.8	95.8
ULN	Form	DPA, SDO, GL	PC1	93.8	95.7	97.9
ULN	Form	BPC, DPA, GL	PC1	94.2	94.2	94.2
ULN	Form	BPC, GL	PC1	92.3	92.3	92.3
ULN	Size	SDO, GL	–	91.7	92.1	93.8
ULN	Size	DPA, SDO, GL	–	91.7	92.1	93.8
ULN	Size	BPC, DPA	–	90.3	91.4	93.5
ULN	Form	BPC, DPA	PC1	90.3	91.3	93.5
ULN	Shape	BPC, GL	PC1	90.4	90.4	90.4
ULN	Size	BPC, DPA, GL	–	90.4	90.4	90.4
ULN	Form	BPC	–	89.1	90.2	92.2
ULN	Form	DPA, GL	PC1	86.5	86.5	86.5
ULN	Shape	DPA, GL	PC1	86.5	86.5	86.5
ULN	Form	DPA	–	83.9	86.5	88.7
ULN	Size	BPC, GL	–	84.6	84.6	84.6
ULN	Shape	DPA, SDO	PC1	82.1	84.6	87.5
ULN	Shape	BPC, DPA, SDO	PC2	78.6	82.0	85.7
PEL	Form	LFo, GL	PC1	88.6	89.2	90.9

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
PEL	Size	LFo, GL	–	86.4	88.3	90.9
PEL	Form	GL	–	87.0	88.0	91.3
PEL	Form	LFo, SH, GL	PC1	86.4	87.2	88.8
PEL	Size	LFo, SH, GL	–	86.4	86.8	88.6
PEL	Size	SH, GL	–	84.8	85.6	87.0
PEL	Form	SH, GL	PC1	84.8	85.6	87.0
PEL	Size	SB, SH, GL	–	78.3	81.2	84.8
PEL	Form	LFo	–	80.3	80.3	80.3
PEL	Form	SH, LFo	PC1	79.0	80.3	82.3
PEL	Size	SH, LFo	–	79.0	80.1	82.3
FEM	Shape	Bp, DC, GLC	PC1	95.2	96.1	98.4
FEM	Shape	Bp, DC, GL	PC1	93.5	95.1	96.8
FEM	Shape	Bp, BTr, GLC	PC1	91.1	93.9	94.6
FEM	Shape	Bp, GL, GLC	PC1	92.2	93.7	95.3
FEM	Shape	Bp, GLC	PC1	90.6	93.1	95.3
FEM	Shape	Bp, GLC, Bd	PC1	90.7	92.9	96.3
FEM	Form	Bp, DC, Bd	PC1	90.4	92.7	96.2
FEM	Size	Bp, Bd	–	87.0	92.2	96.3
FEM	Shape	Bp, BTr, GL	PC1	91.1	92.1	94.6
FEM	Shape	Bp, GL, Bd	PC1	88.9	92.0	94.4
FEM	Size	Bp, DC, Bd	–	86.5	92.0	96.2
FEM	Shape	Bp, GL	PC1	89.1	91.9	93.8
FEM	Form	Bp, Bd	PC1	87.0	90.9	94.4
FEM	Shape	DC, GLC, Bd	PC1	88.9	90.8	92.6
FEM	Shape	Bp, BTr, DC	PC1	87.5	90.5	92.9
FEM	Shape	Bp, BTr	PC1	87.5	90.4	92.9
FEM	Shape	BTr, DC, SD	PC1	87.9	90.0	93.1
FEM	Size	Bp, DC, SD	–	87.1	89.8	91.9

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
FEM	Form	Bp, DC, SD	PC1	87.1	89.7	91.9
FEM	Size	Bp, DC	–	87.1	89.7	93.5
FEM	Form	DC, Bd	PC1	87.0	89.5	92.6
FEM	Form	Bp, DC	PC1	87.1	89.5	91.9
FEM	Shape	Bp, BTr, Bd	PC1	87.0	89.3	91.3
FEM	Size	DC, Bd	–	87.0	89.2	92.6
FEM	Shape	DC, GLC	PC1	87.5	89.1	90.6
FEM	Form	Bp, BTr, DC	PC1	85.7	88.7	92.9
FEM	Shape	DC, GL, Bd	PC1	84.6	88.6	92.3
FEM	Form	Bp, GL, Bd	PC1	85.2	88.5	90.7
FEM	Form	Bp, GLC, Bd	PC1	85.2	88.4	90.7
FEM	Size	DC, SD	–	86.4	88.3	90.9
FEM	Shape	DC, GL, GLC	PC1	85.5	88.3	90.3
FEM	Shape	DC, GL	PC1	85.5	88.2	90.3
FEM	Form	Bp, DC, GL	PC1	85.5	88.1	90.3
FEM	Form	Bp, DC, GLC	PC1	85.5	87.9	90.3
FEM	Form	Bp	–	84.4	87.5	90.6
FEM	Shape	BTr, DC, Bd	PC1	83.3	87.4	91.7
FEM	Size	DC, SD, Bd	–	83.3	87.4	92.6
FEM	Form	DC, SD, Bd	PC1	83.3	87.0	90.7
FEM	Form	BTr, DC, Bd	PC1	83.3	86.8	89.6
FEM	Form	DC	–	83.3	86.8	90.9
FEM	Shape	BTr, DC, GLC	PC1	84.5	86.6	89.7
FEM	Form	DC, GLC, Bd	PC1	81.5	86.5	90.7
FEM	Form	Bp, GL	PC1	82.8	86.4	89.1
FEM	Form	DC, GL, Bd	PC1	80.8	86.4	90.4
FEM	Shape	BTr, DC, GL	PC1	83.9	86.3	89.3
FEM	Shape	Bp, BTr, SD	PC1	83.9	85.9	89.3

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
FEM	Size	Bp, BTr, DC	–	82.1	85.7	91.1
FEM	Form	Bd	–	81.7	85.6	90.0
FEM	Form	Bp, GLC	PC1	82.8	85.6	87.5
FEM	Form	Bp, BTr, Bd	PC1	82.6	85.5	89.1
FEM	Shape	BTr, SD	PC1	80.0	84.8	88.3
FEM	Size	Bp, DC, GL	–	80.7	84.6	88.7
FEM	Size	Bp, GL, Bd	–	79.6	84.6	88.9
FEM	Shape	BTr, DC	PC1	81.0	84.5	87.9
FEM	Size	Bp, DC, GLC	–	80.7	84.3	88.7
FEM	Size	Bp, GLC, Bd	–	79.6	84.3	87.0
FEM	Form	DC, SD	PC1	81.8	83.9	86.4
FEM	Size	DC, GL, Bd	–	78.8	83.0	88.5
FEM	Form	DC, GLC	PC1	81.2	83.0	85.9
FEM	Form	Bd, GLC	PC1	78.6	82.8	87.5
FEM	Form	DC, GL	PC1	79.0	82.4	85.5
FEM	Form	BTr, DC	PC1	77.6	82.3	86.2
FEM	Size	DC, GLC, Bd	–	77.8	82.2	87.0
FEM	Size	BTr, DC, Bd	–	79.2	82.2	85.4
FEM	Form	Bd, GL	PC1	77.8	82.1	85.2
FEM	Form	BTr, DC, SD	PC1	77.6	81.9	86.2
FEM	Size	Bp, SD	–	78.1	81.5	84.4
FEM	Shape	BTr, GL, SD	PC1	76.8	81.3	85.7
FEM	Size	Bd, GLC	–	76.8	81.2	85.7
FEM	Size	Bd, GL	–	77.8	81.2	85.2
FEM	Form	Bp, GL, SD	PC1	78.1	81.1	84.4
FEM	Shape	BTr, GLC, SD	PC1	77.6	81.0	84.5
FEM	Form	BTr, DC, GLC	PC1	77.6	81.0	84.5
FEM	Form	DC, GL, SD	PC1	77.4	80.8	85.5

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
FEM	Size	Bd, SD	–	75.0	80.8	83.9
FEM	Size	Bp, BTr, Bd	–	76.1	80.6	84.8
FEM	Form	DC, GLC, SD	PC1	78.1	80.5	84.4
FEM	Form	BTr, DC, GL	PC1	76.8	80.5	83.9
FEM	Form	BTr, GL, Bd	PC2	76.1	80.5	84.8
FEM	Form	Bp, GLC, SD	PC1	78.1	80.5	82.8
FEM	Form	BTr, Bd	PC2	77.1	80.3	83.3
FEM	Size	Bp, GL	–	76.6	80.2	84.4
FEM	Size	Bp, GLC, SD	–	76.6	80.2	82.8
FEM	Form	Bp, SD	PC1	76.6	80.2	84.4
FEM	Size	Bp, GL, SD	–	76.6	80.2	82.8
FEM	Form	Bp, GL, GLC	PC1	76.6	80.0	84.4
TIB	Shape	DPL, GL, Dd	PC1	97.5	99.9	100.0
TIB	Shape	Bp, Dp, GL	PC1	97.2	99.2	100.0
TIB	Shape	DPL, LDp, GL	PC1	97.5	98.8	100.0
TIB	Shape	DPL, GL	PC1	97.5	98.7	100.0
TIB	Shape	Bp, DPL, GL	PC1	97.5	98.0	100.0
TIB	Shape	DPL, GL, SD	PC1	97.5	98.0	100.0
TIB	Size	DPL, Bd	–	97.5	97.9	100.0
TIB	Form	DPL, Bd	PC1	97.5	97.9	100.0
TIB	Form	DPL, GL, Bd	PC1	97.4	97.7	100.0
TIB	Shape	LDp, GL, Bd	PC1	97.5	97.4	97.5
TIB	Shape	DPL, GL, Bd	PC1	97.4	97.4	97.4
TIB	Form	DPL, GL	PC1	95.0	97.3	100.0
TIB	Shape	Bp, GL, Bd	PC1	96.4	97.3	98.2
TIB	Shape	Dp, GL, Dd	PC1	97.2	97.2	97.2
TIB	Shape	Dp, GL	PC1	97.2	97.2	97.2
TIB	Shape	Dp, LDp, GL	PC1	97.2	97.2	97.2

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
TIB	Shape	Dp, DPL, GL	PC1	97.1	97.2	100.0
TIB	Shape	Dp, GL, Bd	PC1	97.1	97.1	97.1
TIB	Shape	Dp, GL, SD	PC1	94.4	97.0	97.2
TIB	Shape	Bp, LDp, GL	PC1	95.2	96.8	100.0
TIB	Form	DPL, SD, Bd	PC1	94.7	96.1	97.4
TIB	Form	Dp, DPL, LDp	PC1	94.1	96.1	100.0
TIB	Form	Dp, GL	PC1	94.4	96.0	100.0
TIB	Form	Bp, Dp, DPL	PC1	94.1	96.0	100.0
TIB	Form	Bp, Dp	PC1	94.7	96.0	100.0
TIB	Form	Bp, DPL, Bd	PC1	95.0	96.0	97.5
TIB	Form	Bp, DPL, GL	PC1	95.0	96.0	97.5
TIB	Form	Bp, Dp, Bd	PC1	94.4	96.0	100.0
TIB	Form	Dp, DPL	PC1	94.1	96.0	100.0
TIB	Form	Dp	–	94.7	96.0	97.4
TIB	Form	Bd, Dp	PC1	94.4	96.0	100.0
TIB	Size	Dp, DPL	–	94.1	96.0	100.0
TIB	Size	Bp, DPL, Bd	–	95.0	96.0	97.5
TIB	Size	Bp, Dp, Bd	–	94.4	96.0	100.0
TIB	Size	Bp, Dp, DPL	–	94.1	96.0	100.0
TIB	Size	Dp, DPL, Bd	–	93.8	96.0	100.0
TIB	Form	Dp, DPL, GL	PC1	94.1	96.0	100.0
TIB	Form	Dp, SD, Bd	PC1	94.4	95.9	100.0
TIB	Form	Dp, DPL, SD	PC1	94.1	95.9	100.0
TIB	Size	Dp, DPL, SD	–	94.1	95.9	100.0
TIB	Form	Dp, DPL, Bd	PC1	93.8	95.9	100.0
TIB	Size	Bd, Dp	–	94.4	95.9	97.2
TIB	Form	Bp, DPL, SD	PC1	92.5	95.9	97.5
TIB	Size	DPL, Bd, Dd	–	95.0	95.9	97.5

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
TIB	Form	DPL, Bd, Dd	PC1	95.0	95.8	97.5
TIB	Form	Dp, GL, Bd	PC1	94.1	95.7	100.0
TIB	Form	DPL, LDp, SD	PC1	95.0	95.7	97.5
TIB	Size	DPL, SD, Bd	–	92.1	95.7	97.4
TIB	Size	Bp, Dp	–	92.1	95.7	100.0
TIB	Form	Dp, Bd, Dd	PC1	94.4	95.4	97.2
TIB	Form	Dp, DPL, Dd	PC1	91.2	95.4	100.0
TIB	Form	Bp, Dp, GL	PC1	91.7	95.2	100.0
TIB	Size	Dp, Bd, Dd	–	91.7	94.9	97.2
TIB	Size	Dp, DPL, LDp	–	91.2	94.7	97.1
TIB	Form	DPL	–	93.2	94.5	97.7
TIB	Shape	Bd, GL	PC1	92.9	94.1	96.4
TIB	Shape	Bp, GL, Dd	PC1	92.6	93.9	96.3
TIB	Shape	GL, Bd, Dd	PC1	92.6	93.8	96.3
TIB	Form	Bp, DPL	PC1	93.2	93.7	95.5
TIB	Size	Bp, DPL	–	93.2	93.7	95.5
TIB	Size	Bp, DPL, Dd	–	92.9	93.6	95.2
TIB	Form	DPL, LDp, Bd	PC1	92.5	93.5	95.0
TIB	Size	Bp, DPL, SD	–	92.5	93.5	95.0
TIB	Form	DPL, SD	PC1	92.5	93.5	95.0
TIB	Form	DPL, Dd	PC1	92.9	93.5	95.2
TIB	Form	Bp, DPL, Dd	PC1	92.9	93.4	95.2
TIB	Size	DPL, Dd	–	92.9	93.4	95.2
TIB	Size	Dp, SD, Bd	–	91.7	93.4	97.2
TIB	Form	DPL, GL, Dd	PC1	92.5	93.4	95.0
TIB	Form	DPL, GL, SD	PC1	90.0	93.3	95.0
TIB	Form	DPL, LDp, GL	PC1	90.0	92.9	95.0
TIB	Size	Dp, DPL, Dd	–	91.2	92.8	97.1

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
TIB	Form	Dd, Dp	PC1	92.1	92.7	94.7
TIB	Size	Dp, DPL, GL	–	91.2	92.6	94.1
TIB	Form	DPL, LDp, Dd	PC1	90.5	92.4	92.9
TIB	Size	Bp, SD, Bd	–	90.0	92.0	95.0
TIB	Form	Dp, LDp, Bd	PC1	88.9	92.0	97.2
TIB	Size	DPL, LDp, Bd	–	90.0	92.0	95.0
TIB	Size	Dp, LDp, Bd	–	88.9	91.8	94.4
TIB	Form	Dp, GL, Dd	PC1	88.9	91.7	94.4
TIB	Form	Bp, Bd	PC1	90.3	91.7	91.9
TIB	Size	Bp, Bd	–	88.7	91.6	91.9
TIB	Size	DPL, GL, Bd	–	86.8	91.5	94.7
TIB	Form	Bp, Dp, Dd	PC1	89.5	91.4	94.7
TIB	Shape	Bp, GL	PC1	89.3	91.4	92.9
TIB	Form	Dp, LDp, SD	PC1	86.8	91.0	94.7
TIB	Size	Dd, Dp	–	89.5	90.9	94.7
TIB	Size	Bp, Dp, SD	–	89.5	90.8	92.1
TIB	Form	Bp, Dp, SD	PC1	89.5	90.8	94.7
TIB	Form	Bp, SD, Bd	PC1	88.3	90.7	93.3
TIB	Form	DPL, LDp	PC1	88.6	90.6	93.2
TIB	Size	Bp, Dp, Dd	–	89.5	90.6	92.1
TIB	Form	DPL, SD, Dd	PC1	87.5	90.4	92.5
TIB	Size	DPL, SD	–	87.5	90.3	92.5
TIB	Form	Bp, Bd, Dd	PC1	88.3	90.2	93.3
TIB	Size	DPL, LDp, SD	–	85.0	89.9	95.0
TIB	Form	Dp, LDp	PC1	86.8	89.8	94.7
TIB	Form	Dp, GL, SD	PC1	86.1	89.8	94.4
TIB	Size	Bp, DPL, LDp	–	88.6	89.8	93.2
TIB	Form	Bp, DPL, LDp	PC1	88.6	89.7	93.2

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
TIB	Form	Bp, Dp, LDp	PC1	86.8	89.7	94.7
TIB	Size	Bp, Bd, Dd	–	86.7	89.5	91.7
TIB	Size	Bp, Dp, LDp	–	86.8	89.3	92.1
TIB	Form	Dp, SD	PC1	86.8	89.1	94.7
TIB	Form	Bp	–	85.5	88.9	91.9
TIB	Size	Dp, LDp, SD	–	86.8	88.4	92.1
TIB	Form	Bp, SD, Dd	PC1	86.2	88.1	91.4
TIB	Form	Bp, GL, Bd	PC1	87.5	88.0	89.3
TIB	Form	Bp, LDp, Bd	PC1	86.4	88.0	93.2
TIB	Form	Dp, LDp, GL	PC1	83.3	87.9	94.4
TIB	Size	Bp, SD	–	83.3	87.9	93.3
TIB	Size	Bp, SD, Dd	–	84.5	87.9	91.4
TIB	Size	Bp, LDp, Bd	–	86.4	87.8	90.9
TIB	Size	DPL, LDp	–	86.4	87.8	90.9
TIB	Size	Dp, LDp	–	84.2	87.5	92.1
TIB	Size	Dp, GL, Bd	–	85.3	87.5	91.2
TIB	Form	LDp, Bd, Dd	PC1	86.4	87.4	88.6
TIB	Size	LDp, Bd, Dd	–	86.4	87.4	88.6
TIB	Size	DPL, LDp, Dd	–	85.7	87.3	90.5
TIB	Form	Dp, LDp, Dd	PC1	84.2	86.8	89.5
TIB	Size	Dp, SD	–	84.2	86.7	92.1
TIB	Form	Bd, LDp	PC1	84.1	86.6	88.6
TIB	Size	Bd, LDp	–	84.1	86.6	88.6
TIB	Form	Bp, Dd	PC1	83.3	86.6	90.0
TIB	Size	DPL, SD, Dd	–	85.0	86.0	90.0
TIB	Size	Bp, Dd	–	83.3	86.0	88.3
TIB	Form	Bp, SD	PC1	83.3	85.7	88.3
TIB	Size	Bp, Dp, GL	–	83.3	85.6	88.9

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
TIB	Form	Bd	–	83.3	85.4	87.9
TIB	Size	Bp, DPL, GL	–	82.5	85.4	90.0
TIB	Form	Bp, LDp	PC1	83.3	85.3	85.4
TIB	Shape	Dp, LDp	PC1	81.6	85.3	89.5
TIB	Shape	Dp, LDp, Bd	PC1	80.6	85.2	88.9
TIB	Size	Bd, SD	–	82.8	85.2	87.6
TIB	Form	Dp, SD, Dd	PC1	84.2	85.2	89.5
TIB	Form	Bp, LDp, Dd	PC1	84.8	85.1	87.0
TIB	Shape	Bp, Dp, Dd	PC1	81.6	85.1	89.5
TIB	Size	Bp, LDp, Dd	–	84.8	85.0	87.0
TIB	Shape	Dp, LDp, SD	PC2	79.0	85.0	89.5
TIB	Size	Dp, LDp, Dd	–	81.6	84.4	86.8
TIB	Form	Bp, LDp, SD	PC1	81.8	84.3	86.4
TIB	Size	Dp, LDp, GL	–	80.6	84.2	88.9
TIB	Form	Bd, GL	PC1	82.1	84.0	87.5
TIB	Form	Bp, GL, Dd	PC1	79.6	83.9	87.0
TIB	Shape	Bp, GL, SD	PC2	80.4	83.9	87.5
TIB	Size	Dp, SD, Dd	–	81.6	83.9	86.8
TIB	Form	LDp, GL, Bd	PC1	77.5	83.9	90.0
TIB	Size	DPL, GL	–	77.5	83.7	87.5
TIB	Form	Bp, GL, SD	PC1	80.4	83.7	87.5
TIB	Form	Bp, GL	PC1	80.4	83.7	87.5
TIB	Shape	DPL, Dd	PC1	81.0	83.4	85.7
TIB	Shape	DPL, LDp, Dd	PC1	81.0	83.4	85.7
TIB	Form	Bd, SD	PC1	79.7	83.4	87.5
TIB	Form	LDp, SD, Bd	PC1	81.0	83.3	85.7
TIB	Size	SD, Bd, Dd	–	79.0	83.3	88.7
TIB	Shape	Bp, Dp, LDp	PC1	76.3	83.3	89.5

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
TIB	Shape	LDp, GL	PC1	81.0	83.1	88.1
TIB	Shape	LDp, GL, SD	PC2	81.0	83.1	88.1
TIB	Form	Bp, LDp, GL	PC1	81.0	83.0	85.8
TIB	Shape	Dp, DPL, LDp	PC1	73.5	82.9	88.2
TIB	Size	Bp, LDp	–	81.2	82.5	85.4
TIB	Shape	Dp, SD, Dd	PC2	79.0	82.5	84.2
TIB	Size	Dp, GL	–	77.8	82.5	86.1
TIB	Size	LDp, SD, Bd	–	78.6	82.4	85.7
TIB	Size	Bp, LDp, SD	–	79.5	82.3	84.1
TIB	Shape	DPL, Bd, Dd	PC1	80.0	82.2	85.0
TIB	Shape	LDp, GL, Dd	PC1	81.0	82.1	85.7
TIB	Size	DPL, GL, Dd	–	80.0	82.0	85.0
TIB	Shape	Dd, Dp	PC1	79.0	82.0	84.2
TIB	Shape	Bp, DPL, Dd	PC1	78.6	81.8	85.7
TIB	Form	SD, Bd, Dd	PC1	75.8	81.8	87.1
TIB	Shape	GL, SD, Bd	PC2	75.0	81.5	87.5
TIB	Form	GL, Bd, Dd	PC1	77.8	81.3	83.3
TIB	Shape	DPL, LDp	PC1	79.5	81.1	84.1
TIB	Shape	Dp, DPL, Dd	PC1	76.5	81.1	88.2
TIB	Shape	Bp, DPL, LDp	PC1	79.5	81.1	84.1
TIB	Size	Dp, GL, Dd	–	75.0	81.0	86.1
TIB	Size	DPL, LDp, GL	–	77.5	80.9	85.0
TIB	Form	GL, SD, Bd	PC1	76.8	80.7	85.7
TIB	Shape	Bp, Dp, DPL	PC1	73.5	80.7	85.3
TIB	Shape	Dp, Bd, Dd	PC1	77.8	80.5	86.1
TIB	Shape	DPL, LDp, Bd	PC1	77.5	80.3	82.5
TIB	Shape	Dp, LDp, Dd	PC1	79.0	80.2	84.2
TIB	Shape	DPL, SD, Dd	PC2	77.5	80.1	82.5

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
CALC	Form	GL, GLT, SDT	PC1	90.6	93.0	96.9
CALC	Size	GLT, GDT, SDT	–	90.6	93.0	96.9
CALC	Size	GB, GL, SDT	–	90.6	92.9	96.9
CALC	Form	GB, GLT, SDT	PC1	90.6	92.9	96.9
CALC	Size	GLT, GBT, SDT	–	90.6	92.8	96.9
CALC	Size	GB, GLT, SDT	–	87.5	92.7	96.9
CALC	Size	SDT, GLT	–	90.6	92.6	96.9
CALC	Size	GB, GBT, SDT	–	87.5	92.5	96.9
CALC	Form	SDT, GLT	PC1	90.6	92.5	96.9
CALC	Size	GB, GDT, SDT	–	87.5	92.0	96.9
CALC	Form	GB, GL, SDT	PC1	90.6	91.9	93.8
CALC	Form	GL, GLT, GDT	PC1	87.5	91.7	96.9
CALC	Size	GB, SDT	–	87.5	91.5	93.8
CALC	Form	SDT, GL	PC1	87.5	91.4	96.9
CALC	Size	GLT, GBT, GDT	–	87.5	91.3	93.8
CALC	Size	SDT, GL	–	87.5	91.3	93.9
CALC	Size	GL, GDT, SDT	–	87.5	91.2	93.8
CALC	Form	GB, SDT	PC1	87.5	91.1	93.8
CALC	Size	GL, GBT, SDT	–	87.5	91.1	93.8
CALC	Shape	GB, SDT	PC1	84.4	90.8	96.9
CALC	Form	GL, GBT, SDT	PC1	87.5	90.5	93.8
CALC	Size	GL, GBT, GDT	–	84.4	90.5	93.8
CALC	Form	GLT, GBT, SDT	PC1	87.5	90.3	93.8
CALC	Form	SDT	–	87.5	90.3	93.8
CALC	Size	GL, GLT, SDT	–	87.5	90.3	93.8
CALC	Size	GDT, GLT	–	84.4	90.1	96.9
CALC	Shape	GB, GDT, SDT	PC1	84.4	90.0	93.8
CALC	Form	GL, GDT, SDT	PC1	84.4	89.9	93.8

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
CALC	Size	GB, GDT	–	87.3	89.8	93.8
CALC	Size	GB, GL, GDT	–	87.5	89.7	93.8
CALC	Form	GB, GBT, SDT	PC1	87.5	89.5	93.8
CALC	Form	GLT, GBT, GDT	PC1	84.4	89.5	93.8
CALC	Form	GBT, GDT, SDT	PC1	84.4	89.3	93.8
CALC	Form	GL, GBT, GDT	PC1	84.4	89.3	93.8
CALC	Size	GBT, GDT, SDT	–	84.4	89.2	93.8
CALC	Form	GLT, GDT, SDT	PC1	84.4	89.2	93.8
CALC	Size	GDT, GL	–	84.4	89.2	96.9
CALC	Form	SDT, GBT	PC1	84.4	89.1	93.8
CALC	Size	GBT, GDT	–	84.4	89.1	93.8
CALC	Form	GB, GLT, GDT	PC1	84.4	89.1	93.8
CALC	Size	SDT, GBT	–	84.4	89.0	93.8
CALC	Form	GBT, GDT	PC1	84.4	89.0	93.8
CALC	Size	GL, SBT, SDT	–	83.3	89.0	93.3
CALC	Form	GB, GL, GDT	PC1	84.4	88.9	93.8
CALC	Form	GB, GBT, GDT	PC1	84.4	88.8	93.8
CALC	Size	GL, GLT, GDT	–	84.4	88.7	93.8
CALC	Shape	GB, GBT, SDT	PC1	81.2	88.7	93.8
CALC	Size	GB, GBT, GDT	–	84.4	88.7	90.6
CALC	Size	GB, GLT, GDT	–	84.4	88.3	93.8
CALC	Form	GB, GBT	PC1	84.4	88.0	90.6
CALC	Form	GDT, GL	PC1	81.2	88.0	96.9
CALC	Shape	GB, GL, GDT	PC1	78.1	87.7	93.8
CALC	Shape	GB, GDT	PC1	84.4	87.5	93.8
CALC	Form	GDT, GLT	PC1	84.4	87.5	93.8
CALC	Size	GLT, SBT, SDT	–	83.3	87.5	90.0
CALC	Form	GBT, GL	PC1	84.4	87.5	90.6

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
CALC	Size	SDT, GDT	–	81.2	87.3	93.8
CALC	Shape	GB, GBT, GDT	PC1	78.1	87.1	93.8
CALC	Size	GB, SBT, SDT	–	83.3	87.0	93.3
CALC	Form	SDT, GDT	PC1	81.2	87.0	93.8
CALC	Form	GDT	–	81.2	87.0	93.8
CALC	Form	GB, GDT, SDT	PC1	84.2	86.7	93.8
CALC	Form	GB, GL, GBT	PC1	81.2	86.4	90.6
CALC	Size	GL, GDT, SBT	–	80.0	86.3	93.3
CALC	Form	GB, GDT	PC1	81.2	86.2	90.6
CALC	Size	GB, GBT	–	81.2	86.2	90.6
CALC	Form	GL, SBT, SDT	PC1	80.0	86.1	93.3
CALC	Size	GBT, SBT, SDT	–	80.0	86.0	93.3
CALC	Size	GBT, GLT	–	75.0	85.6	93.8
CALC	Size	GBT, GDT, SBT	–	76.7	85.6	93.3
CALC	Form	GLT, SBT, SDT	PC1	80.0	85.5	90.0
CALC	Shape	GB, GL, SDT	PC1	81.2	85.4	90.6
CALC	Form	GB, SBT, SDT	PC1	80.0	85.4	93.3
CALC	Form	GB, GLT, GBT	PC1	78.1	85.4	90.6
CALC	Size	GDT, SBT, SDT	–	80.0	85.1	93.3
CALC	Size	SBT, SDT	–	80.0	85.1	93.3
CALC	Form	GDT, SBT, SDT	PC1	80.0	85.0	93.3
CALC	Shape	GB, GLT, GDT	PC1	78.1	84.9	90.6
CALC	Form	GBT, SBT, SDT	PC1	80.0	84.9	93.3
CALC	Form	GL, GLT, GBT	PC1	81.2	84.7	90.6
CALC	Shape	GB, GLT, SDT	PC1	81.2	84.6	87.5
CALC	Form	SBT, SDT	PC1	76.7	84.5	93.3
CALC	Size	GLT, GDT, SBT	–	80.0	84.5	90.0
CALC	Size	GBT, GL	–	81.2	84.2	87.5

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
CALC	Shape	GB, GDT, SBT	PC1	76.7	84.1	90.0
CALC	Form	GBT, GLT	PC1	78.1	83.7	90.6
CALC	Size	GL, GLT, GBT	–	78.1	83.6	87.5
CALC	Form	GBT, GDT, SBT	PC1	73.3	83.5	93.3
CALC	Size	GLT, GBT, SBT	–	80.0	83.5	86.7
CALC	Size	GB, GL, GBT	–	78.1	83.1	87.5
CALC	Form	GBT	–	78.1	83.1	87.5
CALC	Size	GB, GLT, GBT	–	75.0	82.7	87.5
CALC	Size	GL, GBT, SBT	–	76.7	82.2	90.0
CALC	Shape	GL, GDT, SDT	PC1	75.0	82.1	90.6
CALC	Shape	GL, GBT, GDT	PC1	75.0	81.6	90.6
CALC	Shape	GB, SBT, SDT	PC1	76.7	81.5	86.7
CALC	Size	GB, GDT, SBT	–	76.7	81.5	86.7
CALC	Size	GL, GLT, SBT	–	76.7	81.2	86.7
CALC	Shape	GL, GLT, SDT	PC1	78.1	80.9	84.4
CALC	Form	GL, GDT, SBT	PC1	76.7	80.9	93.3
CALC	Shape	GL, GDT, SBT	PC1	70.0	80.8	90.0
CALC	Shape	GLT, GDT, SDT	PC1	71.9	80.7	87.5
CALC	Size	SBT, GLT	–	73.3	80.5	90.0
CALC	Shape	GDT, GL	PC1	71.9	80.3	90.6
CALC	Form	GLT, GDT, SBT	PC1	76.7	80.2	86.8
CALC	Shape	SDT, GL	PC1	71.9	80.0	84.4
MT2	Shape	Bd, GL	PC1	93.8	93.8	93.8
MT2	Form	Bd, GL	PC2	83.3	83.3	83.3
MT3	Shape	Bd, GL	PC1	95.7	95.7	95.7
MT3	Form	Bd	–	84.8	85.6	87.0
MT3	Form	Bd, GL	PC1	84.8	85.2	87.0
MT4	Form	Bd, GL	PC1	95.8	95.8	95.8

Table A.31: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
MT4	Shape	Bd, GL	PC1	95.8	95.8	95.8
MT4	Form	Bd	–	93.8	94.0	95.8

Table A.32: List of identification approaches used for metrical identification of archaeological hare bones, Subset B. Arranged by element (anatomical order) and mean CVP (decreasing).

Element	Variable	Metrics	PC	Lower	Mean	Upper
MAND	Form	m5a	–	73.3	80.8	88.9
SCAP	Size	BG, GLP, HS	–	87.9	94.1	100.0
SCAP	Form	GLP, HS	PC1	87.9	94.0	100.0
SCAP	Size	GLP, HS	–	87.9	93.9	100.0
SCAP	Form	BG, GLP, HS	PC1	87.9	93.8	100.0
SCAP	Form	GLP	–	88.2	93.5	98.0
SCAP	Size	BG, GLP, DHA	–	87.9	93.4	100.0
SCAP	Form	BG, GLP, DHA	PC1	87.9	93.4	100.0
SCAP	Form	BG, GLP	PC1	87.5	92.1	95.8
SCAP	Size	BG, GLP	–	87.5	92.0	95.8
SCAP	Size	BG, HS	–	86.1	92.0	97.2
SCAP	Size	BG, GLP, SLC	–	87.5	92.0	95.8
SCAP	Size	GLP, SLC, HS	–	84.8	91.9	97.0
SCAP	Form	BG, GLP, SLC	PC1	87.4	91.8	97.9
SCAP	Form	GLP, SLC, HS	PC1	84.8	91.8	97.0
SCAP	Form	BG, HS	PC1	86.1	91.7	97.2
SCAP	Form	GLP, DHA	PC1	84.8	91.7	97.0
SCAP	Form	BG, DHA	PC1	86.1	91.3	97.2
SCAP	Form	GLP, HS, DHA	PC1	83.3	91.3	96.7
SCAP	Size	GLP, DHA	–	84.8	91.2	97.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
SCAP	Size	BG, DHA	–	83.3	91.1	97.2
SCAP	Size	GLP, HS, DHA	–	83.3	90.6	96.7
SCAP	Size	BG, SLC, HS	–	83.3	90.4	97.2
SCAP	Form	BG, SLC, HS	PC1	83.3	90.3	97.2
SCAP	Size	GLP, SLC, DHA	–	81.8	89.9	97.0
SCAP	Size	GLP, SLC	–	83.3	89.7	95.8
SCAP	Form	GLP, SLC, DHA	PC1	81.8	89.6	97.0
SCAP	Size	BG, HS, DHA	–	81.8	89.5	97.0
SCAP	Form	BG, HS, DHA	PC1	81.8	89.4	97.0
SCAP	Form	BG	–	82.3	89.2	94.1
SCAP	Form	GLP, SLC	PC1	83.3	89.1	93.8
SCAP	Size	BG, SLC, DHA	–	80.6	88.9	94.6
SCAP	Form	BG, SLC, DHA	PC1	80.6	88.8	97.2
SCAP	Size	BG, SLC	–	82.3	87.9	94.1
SCAP	Form	BG, SLC	PC1	82.3	87.5	94.1
SCAP	Form	SLC, HS, DHA	PC1	78.8	87.0	93.9
SCAP	Size	SLC, HS, DHA	–	78.8	87.0	93.9
SCAP	Size	HS, DHA	–	78.8	86.7	93.9
SCAP	Form	HS, DHA	PC1	78.8	86.5	93.9
SCAP	Size	SLC, HS	–	77.8	86.5	94.4
SCAP	Form	SLC, HS	PC1	77.8	86.3	94.4
SCAP	Form	HS	–	77.8	86.2	94.4
SCAP	Size	SLC, DHA	–	77.8	85.9	94.4
SCAP	Form	DHA	–	77.8	84.9	91.7
SCAP	Form	SLC, DHA	PC1	77.8	84.8	91.7
HUM	Form	Bd, Dp	PC1	92.9	97.3	100.0
HUM	Size	Bd, Dp	–	92.9	97.0	100.0
HUM	Shape	Dp, GL, Dd	PC1	88.9	96.6	100.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
HUM	Size	Bp, Dp, Bd	–	88.9	95.0	100.0
HUM	Form	Bp, Dp, Bd	PC1	88.9	94.8	100.0
HUM	Size	Bp, Dp, HTC	–	88.9	94.8	100.0
HUM	Form	Bp, Dp, HTC	PC1	88.9	94.7	100.0
HUM	Form	Dd, Dp	PC1	88.9	94.2	100.0
HUM	Size	Bd, Bp	–	88.9	94.2	100.0
HUM	Form	Bp, Dp, Dd	PC1	83.3	94.2	100.0
HUM	Size	Dd, Dp	–	83.3	94.2	100.0
HUM	Size	Bp, Dp, Dd	–	83.3	94.1	100.0
HUM	Form	Bd, Bp	PC1	83.3	94.0	100.0
HUM	Form	Dp	–	88.1	93.7	97.6
HUM	Shape	Dd, GL	PC1	83.3	93.4	100.0
HUM	Form	Dd, Bp	PC1	83.3	93.0	100.0
HUM	Size	Dd, Bp	–	83.3	92.8	100.0
HUM	Size	HTC, Bp	–	83.3	92.7	100.0
HUM	Size	Dp, Bp	–	83.3	92.7	100.0
HUM	Size	Bd, Dd	–	83.3	92.5	100.0
HUM	Form	Dp, Bp	PC1	83.3	92.5	100.0
HUM	Shape	GL, GLC, Dd	PC1	83.3	92.5	100.0
HUM	Form	HTC, Bp	PC1	83.3	92.4	100.0
HUM	Size	HTC, Dp	–	83.3	92.2	100.0
HUM	Shape	Bp, Dp, GLC	PC1	83.3	92.1	100.0
HUM	Form	Bd, Dd	PC1	83.3	92.0	100.0
HUM	Shape	Bp, Dp, GL	PC1	83.3	91.9	100.0
HUM	Shape	Bd, GLC	PC1	87.2	91.8	97.4
HUM	Form	HTC, Dp	PC1	83.3	91.7	100.0
HUM	Shape	Dd, GLC	PC1	83.3	91.5	100.0
HUM	Shape	GL, GLC, Bd	PC1	84.6	91.2	97.4

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
HUM	Shape	Dp, GL, Bd	PC1	84.6	91.2	97.4
HUM	Form	Bd	–	85.4	91.2	95.8
HUM	Form	Bp	–	83.3	90.9	100.0
HUM	Shape	Bd, GL	PC1	84.6	90.9	97.4
HUM	Shape	Bp, GL	PC1	77.8	90.8	100.0
HUM	Size	Dp, GL, Bd	–	84.6	90.7	97.4
HUM	Form	Bp, Dp, SD	PC1	83.3	90.6	100.0
HUM	Size	Bp, Dp, SD	–	83.1	90.5	100.0
HUM	Shape	Bp, GLC	PC1	77.8	90.4	100.0
HUM	Size	HTC, Bd, Dd	–	83.3	90.3	100.0
HUM	Form	HTC, Bd, Dd	PC1	77.8	89.8	100.0
HUM	Form	Dp, SD	PC1	83.3	89.5	95.2
HUM	Size	Bd, HTC	–	77.8	89.5	100.0
HUM	Size	Dp, SD	–	83.3	88.7	95.2
HUM	Form	Bp, SD	PC1	77.8	88.7	100.0
HUM	Form	Bd, HTC	PC1	77.8	88.5	100.0
HUM	Shape	GLC, SD, Bd	PC1	82.0	88.4	94.9
HUM	Size	Bp, Dp, GL	–	77.8	88.2	100.0
HUM	Form	Dp, GL, Bd	PC1	82.0	88.0	94.9
HUM	Size	Bp, Dp, GLC	–	77.8	87.8	100.0
HUM	Size	SD, HTC, Bd	–	77.8	87.8	100.0
HUM	Size	Bp, SD	–	77.8	87.7	100.0
HUM	Form	Dd, SD	PC1	77.8	87.6	100.0
HUM	Size	SD, HTC, Dd	–	77.8	87.5	94.4
HUM	Form	SD, HTC, Bd	PC1	77.8	87.3	100.0
HUM	Form	Dd	–	77.8	87.2	100.0
HUM	Form	Dd, HTC	PC1	77.8	87.1	100.0
HUM	Size	Dd, SD	–	77.8	87.1	94.4

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
HUM	Form	Bp, Dp, GL	PC1	77.8	87.1	94.4
HUM	Size	Dd, HTC	–	77.8	86.8	94.4
HUM	Size	Dp, GL, Dd	–	77.8	86.8	94.4
HUM	Form	Bp, Dp, GLC	PC1	77.8	86.8	94.4
HUM	Form	SD, HTC, Dd	PC1	72.2	86.7	94.4
HUM	Size	Dp, GL, HTC	–	72.2	86.6	100.0
HUM	Form	Dp, GL, HTC	PC1	72.2	85.8	94.4
HUM	Form	Dp, GL, Dd	PC1	72.2	85.5	94.4
HUM	Size	Dp, GL, SD	–	76.9	84.7	92.3
HUM	Form	HTC, SD	PC1	72.2	84.6	94.4
HUM	Size	Bd, SD	–	77.1	84.6	91.7
HUM	Size	Bp, GL	–	72.2	84.4	94.4
HUM	Size	Bp, GLC	–	72.2	84.0	94.4
HUM	Size	HTC, SD	–	72.2	83.9	94.4
HUM	Form	HTC	–	72.2	83.7	94.4
HUM	Form	Dp, GL, SD	PC1	76.9	83.6	89.7
HUM	Shape	Dp, GL	PC1	76.9	83.6	89.7
HUM	Form	Bd, SD	PC1	77.1	83.6	89.6
HUM	Shape	Dp, GL, GLC	PC1	76.9	83.5	89.7
HUM	Size	Bd, GL	–	76.9	83.5	89.7
HUM	Size	Bd, GLC	–	74.4	83.0	89.7
HUM	Size	GLC, SD, Bd	–	74.4	82.9	92.3
HUM	Size	GLC, SD, HTC	–	72.2	82.7	94.4
HUM	Form	Bp, GL	PC1	66.7	82.4	94.4
HUM	Size	Dp, GL	–	74.4	82.2	89.7
HUM	Shape	Dp, GLC	PC1	74.4	82.1	87.2
HUM	Form	GLC, SD, HTC	PC1	72.2	82.0	94.4
HUM	Size	GLC, SD, Dd	–	72.2	81.9	94.4

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
HUM	Form	Bp, GLC	PC1	66.7	81.9	94.4
HUM	Size	Dp, GLC	–	74.4	81.3	89.7
HUM	Shape	Dp, GL, HTC	PC1	66.7	81.0	94.4
HUM	Form	Dp, GL	PC1	71.8	80.5	89.7
HUM	Form	GLC, SD, Dd	PC1	66.7	80.2	94.4
HUM	Form	Dp, GLC	PC1	71.8	80.2	87.2
HUM	Form	GLC, SD, Bd	PC1	71.8	80.2	87.2
RAD	Size	Bp, SD, Dd	–	95.2	98.9	100.0
RAD	Form	Bp, Dd	PC1	95.2	98.6	100.0
RAD	Form	Bp, SD, Dd	PC1	95.2	98.4	100.0
RAD	Size	Bp, Dd	–	95.2	98.3	100.0
RAD	Size	Dd, SD	–	90.5	97.8	100.0
RAD	Size	Bp, SD, Dp	–	90.5	97.1	100.0
RAD	Size	Dd, Bd, SD	–	90.5	97.1	100.0
RAD	Shape	Bp, GL, Dp	PC1	90.5	97.0	100.0
RAD	Form	Bp, SD, Dp	PC1	90.5	97.0	100.0
RAD	Form	Bp	–	93.8	96.9	100.0
RAD	Size	Bp, Dp, Dd	–	90.5	96.8	100.0
RAD	Form	Dd, SD	PC1	90.5	96.7	100.0
RAD	Shape	Bp, GL, Bd	PC1	92.9	96.6	100.0
RAD	Size	Bp, Bd, Dd	–	90.5	96.2	100.0
RAD	Form	Bp, Bd, Dd	PC1	90.5	96.0	100.0
RAD	Form	Dd, Bd, SD	PC1	90.5	95.9	100.0
RAD	Size	Bp, GL, Dd	–	90.5	95.9	100.0
RAD	Form	Bp, Dp, Dd	PC1	90.5	95.8	100.0
RAD	Size	Dp, Dd	–	90.5	95.8	100.0
RAD	Shape	Bp, GL	PC1	90.5	95.7	100.0
RAD	Size	Bp, Dp	–	90.5	95.6	100.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
RAD	Size	Dp, Bd, Dd	–	90.5	95.5	100.0
RAD	Shape	Bp, GL, SD	PC1	90.5	95.2	100.0
RAD	Form	Bp, Dp	PC1	90.5	94.9	100.0
RAD	Size	Bp, SD	–	91.7	94.9	97.9
RAD	Form	Dp, Dd	PC1	90.5	94.8	100.0
RAD	Form	Dp, SD	PC1	90.5	94.7	100.0
RAD	Size	Bp, Dp, Bd	–	90.5	94.6	100.0
RAD	Size	Dp, SD	–	90.5	94.5	100.0
RAD	Form	Dp, Bd, Dd	PC1	90.5	94.4	100.0
RAD	Shape	Bp, GL, Dd	PC1	90.5	94.3	100.0
RAD	Form	Bp, SD	PC1	89.6	94.1	97.9
RAD	Size	Bp, GL	–	90.5	94.1	97.6
RAD	Form	Bp, Dp, Bd	PC1	90.5	93.9	100.0
RAD	Size	Bd, Dd	–	85.7	93.8	100.0
RAD	Size	Dp, GL, Dd	–	90.5	93.8	100.0
RAD	Size	Bp, Bd	–	88.1	93.6	97.6
RAD	Size	Bp, SD, Bd	–	88.1	93.5	97.6
RAD	Form	Bp, GL, Dd	PC1	85.7	93.5	100.0
RAD	Form	Bp, SD, Bd	PC1	88.1	93.2	97.6
RAD	Size	Bp, GL, Dp	–	85.7	93.1	100.0
RAD	Form	Dd	–	85.7	93.1	100.0
RAD	Shape	Bp, Bd, Dd	PC1	85.7	93.0	100.0
RAD	Size	Dp, Bd, SD	–	85.7	93.0	100.0
RAD	Form	Bd, Dd	PC1	85.7	92.9	100.0
RAD	Form	Dp, Bd, SD	PC1	85.7	92.8	100.0
RAD	Shape	Dd, GL	PC1	85.7	92.8	100.0
RAD	Shape	GL, Dd	PC1	85.7	92.8	100.0
RAD	Shape	Dp, GL, Dd	PC1	85.7	92.7	100.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
RAD	Shape	Bd, Dd	PC1	85.7	92.5	100.0
RAD	Size	Bp, GL, SD	–	88.1	92.2	97.6
RAD	Form	Bp, Bd	PC1	88.1	92.0	97.6
RAD	Form	Bp, GL, Dp	PC1	85.7	91.8	100.0
RAD	Form	Dp, Bd	PC1	85.7	91.1	95.2
RAD	Size	Dp, Bd	–	85.7	91.0	95.2
RAD	Size	GL, Dd	–	81.0	90.8	100.0
RAD	Size	Dd, GL	–	81.0	90.8	100.0
RAD	Shape	Dp, GL, Bd	PC1	81.0	90.4	100.0
RAD	Size	Dp, GL, SD	–	81.0	90.4	95.2
RAD	Form	Bp, GL	PC1	83.3	90.3	95.2
RAD	Size	Bp, GL, Bd	–	85.7	89.9	95.2
RAD	Form	Bp, GL, SD	PC1	85.7	89.8	95.2
RAD	Form	Dp	–	81.0	89.4	95.2
RAD	Form	Dp, GL, Dd	PC1	81.0	89.0	95.2
RAD	Shape	Dp, Bd, Dd	PC1	81.0	88.6	95.2
RAD	Shape	Bp, Dp, Bd	PC1	81.0	88.6	95.2
RAD	Size	Bd, SD	–	83.3	88.6	92.9
RAD	Form	Dp, GL, SD	PC1	81.0	88.4	95.2
RAD	Form	Bd, SD	PC1	83.3	88.4	93.0
RAD	Shape	Dd, Bd, SD	PC1	76.2	87.3	95.2
RAD	Shape	Dp, GL, SD	PC1	81.0	87.3	95.2
RAD	Shape	Dp, GL	PC1	76.2	86.8	95.2
RAD	Form	Bp, GL, Bd	PC1	81.0	86.5	92.9
RAD	Form	SD	–	78.4	86.3	92.2
RAD	Size	Dp, GL, Bd	–	76.2	86.2	95.2
RAD	Size	GL, SD	–	78.6	85.6	92.9
RAD	Size	SD, GL	–	78.6	85.6	92.9

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
RAD	Form	Dp, GL, Bd	PC1	76.2	84.2	90.5
RAD	Form	GL, SD	PC1	76.2	83.7	90.5
RAD	Shape	Bp, Bd	PC1	76.2	83.7	90.5
RAD	Form	SD, GL	PC1	76.2	83.5	90.5
RAD	Shape	Bp, SD, Bd	PC1	76.2	81.9	88.1
RAD	Size	Dp, GL	–	71.4	81.2	90.5
RAD	Form	Dd, GL	PC1	71.4	80.9	90.5
RAD	Form	GL, Dd	PC1	71.4	80.4	90.5
RAD	Shape	GL, SD	PC1	73.8	80.3	85.7
RAD	Shape	SD, GL	PC1	73.8	80.3	85.7
ULN	Size	BPC, SDO	–	95.6	98.3	100.0
ULN	Form	BPC, SDO	PC1	95.6	98.2	100.0
ULN	Size	BPC, DPA, SDO	–	95.6	98.1	100.0
ULN	Form	BPC, DPA, SDO	PC1	95.6	98.0	100.0
ULN	Size	BPC, SDO, GL	–	95.2	97.9	100.0
ULN	Form	DPA, SDO	PC1	93.3	97.4	100.0
ULN	Form	SDO	–	93.3	97.3	100.0
ULN	Size	DPA, SDO	–	93.3	97.1	100.0
ULN	Form	BPC, SDO, GL	PC1	92.9	96.7	100.0
ULN	Shape	BPC, DPA, GL	PC1	92.9	96.4	100.0
ULN	Shape	BPC, SDO, GL	PC1	92.9	96.1	100.0
ULN	Size	DPA, SDO, GL	–	90.5	95.1	100.0
ULN	Form	DPA, SDO, GL	PC1	90.5	94.8	97.6
ULN	Size	SDO, GL	–	90.5	94.3	97.6
ULN	Form	BPC, DPA	PC1	88.9	94.1	97.8
ULN	Size	BPC, DPA	–	88.9	94.1	97.8
ULN	Form	SDO, GL	PC1	88.1	92.4	97.6
ULN	Form	BPC	–	86.3	92.3	96.1

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
ULN	Shape	SDO, GL	PC1	88.1	92.2	95.2
ULN	Shape	BPC, GL	PC1	88.1	92.1	97.6
ULN	Size	BPC, DPA, GL	–	88.1	92.1	97.6
ULN	Shape	DPA, SDO, GL	PC1	85.7	91.6	97.6
ULN	Form	DPA	–	84.4	90.7	95.6
ULN	Shape	DPA, GL	PC1	85.7	90.2	95.2
ULN	Form	BPC, DPA, GL	PC1	83.3	89.1	95.2
ULN	Size	BPC, GL	–	83.3	88.1	92.9
ULN	Size	DPA, GL	–	80.8	85.7	92.9
ULN	Form	BPC, GL	PC1	78.6	84.7	90.5
ULN	Form	DPA, GL	PC1	76.2	81.5	88.1
PEL	Size	LFo, GL	–	85.2	92.2	100.0
PEL	Form	GL	–	85.2	92.1	100.0
PEL	Form	LFo, GL	PC1	85.2	91.9	100.0
PEL	Size	LFo, SH, GL	–	85.2	91.0	96.3
PEL	Size	SH, GL	–	85.2	90.6	96.3
PEL	Form	LFo, SH, GL	PC1	81.5	90.4	96.3
PEL	Form	SH, GL	PC1	81.5	90.3	96.3
PEL	Form	LFo, SB, GL	PC1	77.8	86.8	96.3
PEL	Size	LFo, SB, GL	–	77.8	86.8	96.3
PEL	Size	SB, SH, GL	–	77.8	86.7	92.8
PEL	Form	SB, SH, GL	PC1	77.8	86.6	92.8
PEL	Size	SB, GL	–	77.8	85.9	92.6
PEL	Size	SH, LFo	–	79.5	85.9	92.3
PEL	Form	SH, LFo	PC1	79.5	85.8	92.3
PEL	Size	SB, LFo	–	78.6	85.8	92.9
PEL	Form	SB, LFo	PC1	78.6	85.5	92.9
PEL	Form	SH	–	78.6	85.4	92.9

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
PEL	Size	LFo, SB, SH	–	76.9	85.1	92.3
PEL	Form	LFo, SB, SH	PC1	76.9	84.6	92.3
PEL	Form	SB, GL	PC1	77.8	84.5	92.6
PEL	Form	LFo	–	76.2	84.0	90.5
PEL	Form	SB, SH	PC1	76.2	82.7	90.5
PEL	Size	SB, SH	–	76.2	82.3	88.1
FEM	Form	Bp, DC, Bd	PC1	89.7	94.7	100.0
FEM	Size	Bp, DC, Bd	–	89.7	94.5	100.0
FEM	Size	Bp, Bd	–	88.1	94.2	100.0
FEM	Form	Bp, Bd	PC1	88.1	93.8	97.6
FEM	Size	Bp, DC	–	87.2	93.4	97.4
FEM	Form	Bp, DC	PC1	87.2	93.4	97.4
FEM	Form	Bp, DC, SD	PC1	87.2	93.0	97.4
FEM	Size	Bp, DC, SD	–	87.2	92.8	97.4
FEM	Size	DC, Bd	–	87.2	92.8	97.4
FEM	Form	DC, SD, Bd	PC1	87.2	92.6	97.4
FEM	Form	DC, Bd	PC1	87.2	92.4	97.4
FEM	Size	DC, SD, Bd	–	84.6	92.2	97.4
FEM	Form	DC	–	84.6	91.2	97.4
FEM	Form	Bp	–	85.7	90.9	97.6
FEM	Form	DC, SD	PC1	84.6	90.8	97.4
FEM	Size	DC, SD	–	84.6	90.6	97.4
FEM	Form	Bp, BTr, DC	PC1	83.3	90.4	97.2
FEM	Form	Bd	–	83.3	90.3	95.2
FEM	Size	Bp, BTr, DC	–	83.3	89.9	97.2
FEM	Form	Bp, DC, GL	PC1	82.0	89.5	94.9
FEM	Form	Bp, GL, Bd	PC1	82.0	89.5	94.9
FEM	Size	Bp, GL, Bd	–	82.0	89.5	94.9

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
FEM	Size	Bp, GLC, Bd	–	82.0	89.4	94.9
FEM	Size	Bp, DC, GL	–	82.0	89.4	94.9
FEM	Form	Bp, DC, GLC	PC1	84.6	89.3	94.9
FEM	Form	Bp, GLC, Bd	PC1	82.0	89.1	94.9
FEM	Size	Bp, DC, GLC	–	82.0	88.9	94.9
FEM	Size	BTr, DC, Bd	–	80.6	88.8	94.4
FEM	Size	DC, GL, Bd	–	82.0	88.5	94.9
FEM	Size	DC, GLC, Bd	–	82.0	88.4	94.9
FEM	Form	BTr, DC, Bd	PC1	80.6	88.4	94.4
FEM	Form	Bp, SD	PC1	81.0	88.1	95.2
FEM	Form	DC, GL, Bd	PC1	82.0	87.9	94.9
FEM	Form	DC, GLC, Bd	PC1	82.0	87.8	94.9
FEM	Size	Bp, SD	–	81.0	87.7	95.2
FEM	Size	Bd, GL	–	79.5	87.2	94.9
FEM	Form	Bp, BTr, Bd	PC1	79.5	87.2	92.3
FEM	Size	Bd, GLC	–	79.5	87.0	94.9
FEM	Form	Bp, GLC	PC1	79.5	86.9	92.3
FEM	Size	Bp, BTr, Bd	–	79.5	86.8	92.3
FEM	Size	Bd, SD	–	78.6	86.7	92.9
FEM	Form	Bp, GL	PC1	79.5	86.7	94.9
FEM	Form	Bd, GL	PC1	79.5	86.6	94.9
FEM	Form	Bp, GL, SD	PC1	79.5	86.4	92.3
FEM	Form	Bd, SD	PC1	78.6	86.4	92.9
FEM	Size	Bp, GL	–	79.5	86.4	94.9
FEM	Size	Bp, GLC	–	79.5	86.3	92.3
FEM	Form	Bp, GLC, SD	PC1	79.5	86.2	92.3
FEM	Form	Bd, GLC	PC1	79.5	86.2	92.3
FEM	Form	BTr, DC, SD	PC1	77.8	86.2	94.4

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
FEM	Size	BTr, DC, SD	–	77.8	86.2	94.4
FEM	Size	Bp, GL, SD	–	79.5	86.0	92.3
FEM	Size	DC, GL, SD	–	79.5	85.7	92.3
FEM	Size	GL, SD, Bd	–	76.9	85.6	92.3
FEM	Size	Bp, GLC, SD	–	76.9	85.5	92.3
FEM	Size	DC, GLC, SD	–	76.9	85.5	92.3
FEM	Form	DC, GL, SD	PC1	76.9	85.4	92.3
FEM	Form	DC, GLC, SD	PC1	76.9	85.2	92.3
FEM	Form	GL, SD, Bd	PC1	76.9	85.0	92.3
FEM	Size	DC, GL	–	76.9	84.9	92.3
FEM	Size	DC, GLC	–	76.9	84.8	92.3
FEM	Form	Bp, BTr, SD	PC1	76.9	84.8	92.3
FEM	Size	GLC, SD, Bd	–	76.9	84.7	92.3
FEM	Size	GL, GLC, Bd	–	76.9	84.6	92.3
FEM	Form	DC, GL	PC1	76.9	84.6	92.3
FEM	Form	DC, GLC	PC1	76.9	84.5	92.3
FEM	Size	Bp, BTr, SD	–	76.9	84.4	92.3
FEM	Form	BTr, DC	PC1	77.8	84.3	91.7
FEM	Form	GLC, SD, Bd	PC1	76.9	84.2	92.3
FEM	Size	BTr, DC	–	75.0	84.2	91.7
FEM	Form	Bp, GL, GLC	PC1	76.9	83.6	89.7
FEM	Size	Bp, GL, GLC	–	76.9	83.6	92.3
FEM	Form	GL, GLC, Bd	PC1	76.9	83.3	92.3
FEM	Form	Bp, BTr	PC1	74.4	83.0	89.7
FEM	Form	Bp, BTr, GL	PC1	75.0	82.9	91.7
FEM	Size	BTr, DC, GL	–	75.0	82.9	91.7
FEM	Form	BTr, DC, GLC	PC1	75.0	82.7	91.7
FEM	Form	BTr, DC, GL	PC1	75.0	82.7	91.7

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
FEM	Form	Bp, BTr, GLC	PC1	75.0	82.6	88.9
FEM	Size	Bp, BTr	–	74.4	82.6	89.7
FEM	Size	DC, GL, GLC	–	74.4	82.5	89.7
FEM	Size	BTr, DC, GLC	–	75.0	82.5	88.9
FEM	Size	Bp, BTr, GL	–	75.0	82.3	91.7
FEM	Size	BTr, GLC, Bd	–	75.0	82.3	88.9
FEM	Form	DC, GL, GLC	PC1	74.4	82.2	89.7
FEM	Size	Bp, BTr, GLC	–	72.2	82.0	88.9
FEM	Size	BTr, GL, Bd	–	75.0	81.9	88.9
FEM	Size	SD, GLC	–	71.8	81.3	89.7
FEM	Size	SD, GL	–	74.4	81.1	89.7
FEM	Form	SD, GL	PC1	74.2	81.0	89.7
FEM	Form	SD, GLC	PC1	71.8	80.9	87.2
FEM	Form	GL, GLC, SD	PC1	71.8	80.8	89.7
FEM	Form	BTr, GLC, Bd	PC1	72.2	80.8	88.9
FEM	Shape	GL, GLC, Bd	PC1	71.8	80.7	87.2
FEM	Size	GL, GLC, SD	–	71.8	80.6	87.2
FEM	Size	BTr, Bd	–	71.8	80.4	87.2
FEM	Form	BTr, GL, Bd	PC1	72.2	80.3	88.9
FEM	Shape	Bd, GL	PC1	71.8	80.3	87.2
FEM	Size	BTr, GLC, SD	–	72.2	80.1	86.2
FEM	Form	SD	–	72.9	80.0	87.5
TIB	Form	DPL, Bd	PC1	93.3	98.1	100.0
TIB	Shape	DPL, GL, Bd	PC1	93.3	97.9	100.0
TIB	Shape	Bp, Dp, GL	PC1	88.9	97.9	100.0
TIB	Shape	Bp, GL, Bd	PC1	93.3	97.8	100.0
TIB	Size	DPL, Bd	–	93.3	97.7	100.0
TIB	Shape	Bp, LDp, GL	PC1	94.4	97.6	100.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
TIB	Form	DPL, SD, Bd	PC1	93.3	97.5	100.0
TIB	Form	Dp, DPL, Bd	PC1	88.9	97.5	100.0
TIB	Form	Dp, DPL	PC1	88.9	97.4	100.0
TIB	Shape	Dp, GL, Bd	PC1	88.9	97.3	100.0
TIB	Shape	LDp, GL, Bd	PC1	88.9	97.2	100.0
TIB	Size	Dp, DPL, Bd	–	88.9	97.2	100.0
TIB	Size	Dp, DPL	–	88.9	97.2	100.0
TIB	Form	Bp, DPL, Bd	PC1	93.3	97.2	100.0
TIB	Form	DPL	–	86.7	97.1	100.0
TIB	Form	Dp, DPL, SD	PC1	88.9	97.0	100.0
TIB	Size	Bp, DPL, Bd	–	93.3	97.0	100.0
TIB	Form	Bp, Dp, DPL	PC1	88.9	97.0	100.0
TIB	Shape	Bp, DPL, GL	PC1	93.3	96.9	100.0
TIB	Size	Bp, Dp, DPL	–	88.9	96.7	100.0
TIB	Form	Bp, DPL, SD	PC1	86.7	96.5	100.0
TIB	Form	Dp	–	88.9	96.4	100.0
TIB	Size	Bd, Dp	–	88.9	96.4	100.0
TIB	Size	DPL, Bd, Dd	–	86.7	96.4	100.0
TIB	Form	Bd, Dp	PC1	88.9	96.3	100.0
TIB	Size	DPL, SD, Bd	–	86.7	96.3	100.0
TIB	Form	DPL, Bd, Dd	PC1	86.7	96.2	100.0
TIB	Form	DPL, SD	PC1	86.7	96.2	100.0
TIB	Form	Bp, Dp, Bd	PC1	88.9	95.9	100.0
TIB	Form	Bp, Dp	PC1	88.9	95.8	100.0
TIB	Size	Bp, Dp, Bd	–	88.9	95.8	100.0
TIB	Shape	Bd, GL	PC1	90.0	95.7	100.0
TIB	Form	Bp, DPL	PC1	86.7	95.4	100.0
TIB	Size	Bp, Dp	–	88.9	95.3	100.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
TIB	Size	Dp, DPL, SD	–	77.8	95.3	100.0
TIB	Form	Dp, DPL, LDp	PC1	88.9	95.3	100.0
TIB	Form	Dp, SD, Bd	PC1	77.8	95.2	100.0
TIB	Size	Bp, DPL	–	86.7	95.2	100.0
TIB	Size	Dp, DPL, LDp	–	77.8	95.0	100.0
TIB	Shape	GL, Bd, Dd	PC1	90.0	94.9	100.0
TIB	Size	Dp, Bd, Dd	–	77.8	94.8	100.0
TIB	Form	Bp, SD, Bd	PC1	89.7	94.7	100.0
TIB	Size	Bp, DPL, SD	–	86.7	94.7	100.0
TIB	Size	Bp, SD, Bd	–	89.7	94.6	100.0
TIB	Form	DPL, LDp, Bd	PC1	86.7	94.6	100.0
TIB	Form	Dp, DPL, Dd	PC1	77.8	94.5	100.0
TIB	Shape	Bp, GL	PC1	86.7	94.5	100.0
TIB	Size	DPL, LDp, Bd	–	86.7	94.4	100.0
TIB	Size	Dp, DPL, Dd	–	77.8	94.4	100.0
TIB	Form	Bp, Dp, SD	PC1	77.8	94.3	100.0
TIB	Form	Bp, DPL, Dd	PC1	86.7	94.3	100.0
TIB	Size	Bp, DPL, Dd	–	86.7	94.2	100.0
TIB	Form	Dp, Bd, Dd	PC1	77.8	94.1	100.0
TIB	Shape	Bp, GL, Dd	PC1	86.7	94.0	100.0
TIB	Size	Dp, LDp, Bd	–	88.3	93.9	100.0
TIB	Form	Bp, Bd	PC1	87.2	93.8	97.4
TIB	Size	DPL, Dd	–	86.7	93.8	100.0
TIB	Form	Dp, LDp, Bd	PC1	77.8	93.8	100.0
TIB	Size	Dp, SD, Bd	–	77.8	93.6	100.0
TIB	Size	Bp, Bd	–	87.2	93.5	97.4
TIB	Form	DPL, LDp, SD	PC1	86.7	93.5	100.0
TIB	Form	Bp, Dp, LDp	PC1	77.8	93.4	100.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
TIB	Form	DPL, Dd	PC1	86.7	93.4	100.0
TIB	Size	DPL, GL, Bd	–	86.7	93.4	100.0
TIB	Size	Dp, DPL, GL	–	77.8	93.3	100.0
TIB	Form	Dp, SD	PC1	77.8	92.9	100.0
TIB	Form	Dp, DPL, GL	PC1	77.8	92.8	100.0
TIB	Form	Bp, SD	PC1	87.2	92.7	97.4
TIB	Size	Bp, Dp, LDp	–	77.8	92.7	100.0
TIB	Size	Bp, Dp, SD	–	77.8	92.6	100.0
TIB	Size	Bp, Dp, Dd	–	77.8	92.6	100.0
TIB	Size	Bp, Bd, Dd	–	87.2	92.6	97.4
TIB	Form	Dp, LDp, SD	PC1	77.8	92.4	100.0
TIB	Form	Bp, DPL, LDp	PC1	80.0	92.3	100.0
TIB	Form	Dp, LDp	PC1	77.8	92.3	100.0
TIB	Form	DPL, LDp, Dd	PC1	80.0	92.3	100.0
TIB	Size	Bp, DPL, LDp	–	80.0	92.3	100.0
TIB	Form	Bp, Dp, Dd	PC1	77.8	92.2	100.0
TIB	Size	Bp, LDp, Bd	–	83.3	92.1	100.0
TIB	Size	DPL, SD	–	80.0	92.1	100.0
TIB	Size	Bp, SD	–	87.2	92.0	97.4
TIB	Size	Dp, LDp	–	77.8	92.0	100.0
TIB	Size	DPL, LDp	–	80.0	91.8	100.0
TIB	Form	DPL, LDp	PC1	80.0	91.8	100.0
TIB	Size	DPL, LDp, Dd	–	80.0	91.8	100.0
TIB	Size	Dd, Dp	–	77.8	91.7	100.0
TIB	Form	Bp, LDp, Bd	PC1	83.3	91.7	100.0
TIB	Form	Bp	–	84.6	91.7	97.4
TIB	Size	Bp, SD, Dd	–	87.2	91.5	97.4
TIB	Form	DPL, SD, Dd	PC1	80.0	91.5	100.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
TIB	Size	DPL, LDp, SD	–	80.0	91.5	100.0
TIB	Form	Bp, Bd, Dd	PC1	84.6	91.5	97.4
TIB	Size	Dp, GL, Bd	–	77.8	91.4	100.0
TIB	Form	DPL, GL, Bd	PC1	80.0	91.2	100.0
TIB	Size	Dp, LDp, SD	–	77.8	91.1	100.0
TIB	Form	Dd, Dp	PC1	77.8	91.1	100.0
TIB	Size	Bd, LDp	–	83.3	91.0	100.0
TIB	Size	Bp, DPL, GL	–	80.0	90.9	100.0
TIB	Form	Bp, SD, Dd	PC1	84.6	90.9	97.4
TIB	Size	Bd, SD	–	83.3	90.5	95.2
TIB	Shape	GL, SD, Bd	PC1	83.3	90.5	96.7
TIB	Size	Bp, Dd	–	84.6	90.4	94.9
TIB	Size	Dp, LDp, Dd	–	77.8	90.4	100.0
TIB	Size	LDp, Bd, Dd	–	77.8	90.3	100.0
TIB	Form	Dp, LDp, Dd	PC1	77.8	90.3	100.0
TIB	Form	Dp, GL, Bd	PC1	77.8	90.2	100.0
TIB	Form	Bd, SD	PC1	83.3	90.0	95.2
TIB	Form	Dp, SD, Dd	PC1	77.8	90.0	100.0
TIB	Size	DPL, SD, Dd	–	80.0	90.0	100.0
TIB	Form	Bp, DPL, GL	PC1	80.0	90.0	100.0
TIB	Form	Bd, LDp	PC1	77.8	89.9	100.0
TIB	Size	Bp, Dp, GL	–	77.8	89.8	100.0
TIB	Form	Bp, Dp, GL	PC1	77.8	89.4	100.0
TIB	Form	Bp, Dd	PC1	82.0	89.3	94.9
TIB	Size	Dp, SD	–	77.8	89.3	100.0
TIB	Shape	Dp, GL	PC1	66.7	89.2	100.0
TIB	Form	Bd	–	81.0	89.2	95.2
TIB	Shape	Dp, GL, Dd	PC1	66.7	89.1	100.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
TIB	Size	Bp, LDp, Dd	–	77.8	89.0	100.0
TIB	Form	LDp, Bd, Dd	PC1	77.8	89.0	100.0
TIB	Size	LDp, SD, Bd	–	77.8	88.8	100.0
TIB	Form	LDp, SD, Bd	PC1	77.8	88.6	100.0
TIB	Size	DPL, GL	–	73.3	88.6	100.0
TIB	Shape	Dp, LDp, GL	PC1	77.8	88.6	100.0
TIB	Size	Dp, SD, Dd	–	77.8	88.6	100.0
TIB	Size	Bp, LDp	–	77.8	88.5	100.0
TIB	Form	Bp, LDp, Dd	PC1	77.8	88.5	100.0
TIB	Size	SD, Bd, Dd	–	81.0	88.3	95.2
TIB	Size	Bp, LDp, SD	–	77.8	88.2	100.0
TIB	Form	Bp, LDp	PC1	77.8	88.0	100.0
TIB	Form	Bp, LDp, SD	PC1	77.8	88.0	100.0
TIB	Size	DPL, GL, Dd	–	73.3	87.8	100.0
TIB	Form	SD, Bd, Dd	PC1	81.0	87.7	92.9
TIB	Size	Dp, GL	–	66.7	87.6	100.0
TIB	Size	DPL, LDp, GL	–	73.3	87.5	100.0
TIB	Shape	DPL, LDp, GL	PC1	80.0	87.3	93.3
TIB	Form	Dp, LDp, GL	PC1	66.7	86.9	100.0
TIB	Form	DPL, GL	PC1	73.3	86.8	100.0
TIB	Size	Dp, LDp, GL	–	66.7	86.7	100.0
TIB	Form	DPL, LDp, GL	PC1	73.3	86.6	100.0
TIB	Size	Bp, GL, Bd	–	76.7	86.5	93.3
TIB	Size	Bd, Dd	–	78.6	86.4	92.9
TIB	Shape	DPL, GL	PC1	80.0	86.3	93.3
TIB	Shape	DPL, GL, Dd	PC1	79.7	86.1	93.3
TIB	Form	Dp, GL	PC1	66.7	86.1	100.0
TIB	Form	DPL, GL, Dd	PC1	73.3	86.0	100.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
TIB	Size	Dd, SD	–	78.6	86.0	92.9
TIB	Size	Bp, GL, SD	–	76.7	85.5	93.3
TIB	Size	LDp, GL, Bd	–	72.2	85.5	94.4
TIB	Size	Dd, LDp	–	72.2	85.5	94.4
TIB	Form	Bd, Dd	PC1	78.6	85.4	92.9
TIB	Shape	Bp, GL, SD	PC1	76.7	85.3	93.3
TIB	Form	Dd, SD	PC1	76.2	85.2	92.9
TIB	Form	DPL, GL, SD	PC1	73.3	85.1	100.0
TIB	Form	LDp, SD, Dd	PC1	72.2	85.1	94.4
TIB	Form	Dd, LDp	PC1	72.2	85.0	94.4
TIB	Form	Dp, GL, SD	PC1	66.7	84.8	100.0
TIB	Size	Dp, GL, Dd	–	55.6	84.5	100.0
TIB	Shape	LDp, Bd, Dd	PC1	72.2	84.5	94.4
TIB	Size	Bp, LDp, GL	–	72.2	84.5	94.4
TIB	Shape	LDp, GL, Dd	PC1	72.2	84.2	94.4
TIB	Size	LDp, SD, Dd	–	72.2	84.2	94.4
TIB	Size	DPL, GL, SD	–	73.3	83.9	100.0
TIB	Size	Dp, GL, SD	–	66.7	83.5	100.0
TIB	Form	LDp, SD	PC1	72.2	83.5	94.4
TIB	Form	LDp	–	72.2	83.5	94.4
TIB	Form	Bp, GL, SD	PC1	73.3	83.4	93.3
TIB	Form	Dp, GL, Dd	PC1	55.6	83.0	100.0
TIB	Form	Bp, GL, Bd	PC1	73.3	82.9	93.3
TIB	Shape	LDp, GL	PC1	66.7	82.9	94.4
TIB	Shape	SD, GL	PC1	73.3	82.6	93.3
TIB	Size	Bp, GL, Dd	–	73.3	82.5	90.0
TIB	Size	GL, SD, Bd	–	73.3	82.2	90.0
TIB	Size	Bp, GL	–	73.3	82.2	90.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
TIB	Form	LDp, GL, Bd	PC1	71.9	81.8	94.4
TIB	Shape	Bd, Dd	PC1	73.8	81.7	88.1
TIB	Shape	Dp, DPL, GL	PC1	66.7	81.6	88.9
TIB	Form	Bp, LDp, GL	PC1	66.7	81.6	94.4
TIB	Size	LDp, SD	–	66.7	81.5	94.4
TIB	Size	Bd, GL	–	70.0	81.0	90.0
TIB	Size	GL, Bd, Dd	–	70.0	80.7	90.0
TIB	Shape	Bp, Dp, Dd	PC1	55.6	80.7	100.0
TIB	Form	Bp, GL, Dd	PC1	70.0	80.5	90.0
TIB	Shape	Bp, Bd, Dd	PC1	71.8	80.5	87.2
TIB	Size	GL, SD, Dd	–	70.0	80.2	90.0
TIB	Form	Dd	–	71.4	80.1	88.1
CALC	Form	GB, GL, SDT	PC1	90.5	95.1	100.0
CALC	Size	GB, GL, SDT	–	90.5	95.0	100.0
CALC	Size	GLT, GDT, SDT	–	88.9	94.6	100.0
CALC	Form	GB, GLT, SDT	PC1	88.9	94.4	100.0
CALC	Size	SDT, GL	–	85.7	94.4	100.0
CALC	Form	SDT, GL	PC1	85.7	94.4	100.0
CALC	Form	GLT, GDT, SDT	PC1	83.3	94.4	100.0
CALC	Form	GL, GDT, SDT	PC1	85.7	94.3	100.0
CALC	Size	GL, GDT, SDT	–	85.7	94.2	100.0
CALC	Size	SDT, GLT	–	88.9	94.2	100.0
CALC	Size	GL, GBT, SDT	–	88.9	94.1	100.0
CALC	Size	GLT, GBT, SDT	–	86.7	94.1	100.0
CALC	Size	GB, GLT, SDT	–	83.3	94.1	100.0
CALC	Form	GL, GBT, SDT	PC1	88.9	94.0	100.0
CALC	Form	GLT, GBT, SDT	PC1	86.7	94.0	100.0
CALC	Form	GB, GBT, SDT	PC1	83.3	93.9	100.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
CALC	Form	GB, SDT	PC1	85.7	93.9	100.0
CALC	Size	GB, SDT	–	85.7	93.8	100.0
CALC	Form	SDT, GLT	PC1	83.3	93.7	100.0
CALC	Form	GDT, GL	PC1	85.7	93.6	100.0
CALC	Size	GDT, GL	–	85.7	93.6	100.0
CALC	Size	GB, GBT, SDT	–	83.3	93.5	100.0
CALC	Size	GB, GDT, SDT	–	85.7	93.4	100.0
CALC	Size	GDT, GLT	–	83.3	93.2	100.0
CALC	Size	GL, GBT, GDT	–	83.3	93.2	100.0
CALC	Form	GB, GDT, SDT	PC1	85.7	93.2	100.0
CALC	Size	GB, GL, GDT	–	85.7	93.2	100.0
CALC	Form	GDT, GLT	PC1	83.3	93.1	100.0
CALC	Form	GB, GL, GDT	PC1	85.7	93.1	100.0
CALC	Size	GLT, GBT, GDT	–	80.0	93.0	100.0
CALC	Form	GLT, GBT, GDT	PC1	80.0	92.9	100.0
CALC	Form	SDT, GBT	PC1	83.3	92.9	100.0
CALC	Form	GBT, GDT, SDT	PC1	83.3	92.8	100.0
CALC	Size	GL, GLT, SDT	–	83.3	92.8	100.0
CALC	Size	GL, GLT, GDT	–	83.3	92.8	100.0
CALC	Form	GL, GLT, GDT	PC1	83.3	92.7	100.0
CALC	Form	GL, GBT, GDT	PC1	83.3	92.7	100.0
CALC	Size	GBT, GDT, SDT	–	83.3	92.7	100.0
CALC	Size	SDT, GBT	–	83.3	92.6	100.0
CALC	Form	GL, GLT, SDT	PC1	83.3	92.6	100.0
CALC	Form	GL, SBT, SDT	PC1	85.7	92.5	100.0
CALC	Size	GL, SBT, SDT	–	85.7	92.4	100.0
CALC	Form	GB, GLT, GDT	PC1	83.3	92.4	100.0
CALC	Size	GB, GLT, GDT	–	83.3	92.4	100.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
CALC	Form	GB, GBT, GDT	PC1	83.3	92.2	100.0
CALC	Form	GBT, GDT	PC1	83.3	92.2	100.0
CALC	Form	SDT, GDT	PC1	81.0	92.2	100.0
CALC	Form	SDT	–	85.7	92.1	100.0
CALC	Size	SDT, GDT	–	81.0	92.1	100.0
CALC	Form	GB, GDT	PC1	85.7	92.0	100.0
CALC	Form	GLT, SBT, SDT	PC1	83.3	91.9	100.0
CALC	Size	GB, GDT	–	81.0	91.9	100.0
CALC	Size	GB, GBT, GDT	–	83.3	91.8	100.0
CALC	Size	GLT, SBT, SDT	–	83.3	91.8	100.0
CALC	Size	GBT, GDT	–	83.3	91.6	100.0
CALC	Form	GBT, SBT, SDT	PC1	83.3	91.1	100.0
CALC	Size	GBT, SBT, SDT	–	83.3	91.0	100.0
CALC	Form	GB, SBT, SDT	PC1	81.0	90.9	100.0
CALC	Size	GL, GDT, SBT	–	81.0	90.8	100.0
CALC	Size	GB, SBT, SDT	–	81.0	90.8	100.0
CALC	Form	GL, GDT, SBT	PC1	81.0	90.5	100.0
CALC	Size	GDT, SBT, SDT	–	81.0	90.4	100.0
CALC	Form	GDT, SBT, SDT	PC1	81.0	90.2	100.0
CALC	Form	GLT, GDT, SBT	PC1	77.8	90.1	100.0
CALC	Size	GBT, GL	–	77.8	89.9	100.0
CALC	Size	GBT, GDT, SBT	–	77.8	89.8	100.0
CALC	Size	GLT, GDT, SBT	–	77.8	89.7	100.0
CALC	Form	SBT, SDT	PC1	81.0	89.7	100.0
CALC	Size	SBT, SDT	–	81.0	89.7	100.0
CALC	Form	GBT, GL	PC1	77.8	89.6	100.0
CALC	Form	GBT, GDT, SBT	PC1	77.8	89.5	100.0
CALC	Size	GB, GL, GBT	–	77.8	89.0	100.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
CALC	Form	GB, GL, GBT	PC1	77.8	88.7	100.0
CALC	Size	GBT, GLT	–	73.3	88.7	100.0
CALC	Form	GB, GDT, SBT	PC1	76.2	88.6	95.5
CALC	Size	GL, GBT, SBT	–	77.8	88.6	100.0
CALC	Size	GL, GLT, GBT	–	73.3	88.5	100.0
CALC	Size	GB, GDT, SBT	–	81.0	88.5	95.2
CALC	Size	GB, GLT, GBT	–	73.3	88.3	100.0
CALC	Size	GLT, GBT, SBT	–	73.3	88.3	100.0
CALC	Size	GB, GBT	–	77.8	88.3	100.0
CALC	Form	GBT	–	77.8	88.2	100.0
CALC	Form	GLT, GBT, SBT	PC1	73.3	88.2	100.0
CALC	Form	GL, GBT, SBT	PC1	77.8	88.1	100.0
CALC	Form	GBT, GLT	PC1	73.3	88.0	100.0
CALC	Form	GB, GBT	PC1	77.8	87.9	100.0
CALC	Form	GL, GLT, SBT	PC1	77.8	87.7	100.0
CALC	Form	GL, GLT, GBT	PC1	73.3	87.7	100.0
CALC	Form	GB, GLT, GBT	PC1	73.3	87.6	100.0
CALC	Size	GL, GLT, SBT	–	77.8	87.5	100.0
CALC	Form	SBT, GLT	PC1	77.8	87.3	94.4
CALC	Form	SBT, GDT	PC1	76.2	87.3	100.0
CALC	Size	SBT, GLT	–	77.8	87.2	94.4
CALC	Size	GB, GBT, SBT	–	77.8	87.1	100.0
CALC	Size	SBT, GDT	–	76.2	87.0	95.2
CALC	Form	SBT, GL	PC1	76.2	86.9	95.2
CALC	Size	SBT, GBT	–	72.2	86.8	100.0
CALC	Form	GB, GBT, SBT	PC1	77.8	86.8	100.0
CALC	Size	SBT, GL	–	76.2	86.6	95.2
CALC	Form	SBT, GBT	PC1	72.2	86.4	100.0

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
CALC	Size	GB, GLT, SBT	–	72.2	85.8	94.4
CALC	Form	GB, GL, SBT	PC1	76.2	85.7	95.2
CALC	Form	GB, GLT, SBT	PC1	72.2	85.6	94.4
CALC	Form	GDT	–	76.2	85.6	95.2
CALC	Size	GB, GL, SBT	–	76.2	85.5	95.2
CALC	Form	GL, GLT	PC1	72.2	85.1	94.4
CALC	Size	GL, GLT	–	72.2	84.9	94.4
CALC	Size	GB, GL, GLT	–	72.2	84.8	94.4
CALC	Form	GB, GL, GLT	PC1	72.2	84.7	94.4
CALC	Form	GL	–	76.2	84.6	92.9
CALC	Form	GB, GL	PC1	76.9	84.5	92.3
CALC	Size	GB, SBT	–	76.2	84.4	95.2
CALC	Form	GLT	–	72.2	84.2	94.4
CALC	Size	GB, GL	–	76.9	84.1	92.3
CALC	Form	GB, SBT	PC1	76.2	84.1	95.2
CALC	Form	GB, GLT	PC1	72.2	83.3	94.4
CALC	Size	GB, GLT	–	72.2	82.7	94.4
CALC	Form	SBT	–	66.7	81.1	95.2
MT2	Shape	Bd, GL	PC1	86.7	92.9	100.0
MT2	Form	GL	–	76.7	84.0	93.3
MT2	Form	Bd	–	70.0	80.4	90.0
MT3	Shape	Bd, GL	PC1	87.5	93.7	100.0
MT3	Form	Bd	–	83.3	90.5	95.8
MT3	Form	GL	–	73.3	82.8	90.0
MT3	Form	Bd, GL	PC2	70.8	81.3	91.7
MT4	Shape	Bd, GL	PC1	92.6	96.0	100.0
MT4	Form	Bd	–	88.9	95.5	100.0
MT4	Form	Bd, GL	PC2	81.5	87.6	92.6

Table A.32: *(continued)*

Element	Variable	Metrics	PC	Lower	Mean	Upper
MT4	Form	GL	–	73.3	82.0	90.0

A.5 Digital Appendices

The majority of this thesis' appendices are provided electronically. Within the root directory, the accompanying files are arranged in five main folders. The 'Rmd' directory contains the HTML output of RMarkdown documents referred to in this text. These are provided at this directory level for ease of access, but the source code is also provided elsewhere (see 'repo', details below). The 'data' directory contains cleaned CSV data files purposefully placed here for ease of access, like the RMarkdown documents. Likewise, the 'img' directory contains PNG output of the dendrograms and maps from the abandoned cluster analysis for the synthesis in Chapter 2 (again, source code in 'repo', details below). The "pdf" folder contains the lagomorphs metrics recording guide associated with the methods for Chapters 3 and 4 (described in Chapter 3).

The final folder in the root directory is called 'repo'. It contains (slimmed down and tidied) versions of the two Git repositories I used to perform data analysis:

easterpr_speciation Files associated with osteometrics - for speciation and creation of the log ratio standards

easterpr_zooarch Files associated with zooarchaeology - the synthesis in Chapter 2 and the zooarchaeological data analysis in Chapter 5

A third repository for Chapter 6 is omitted because it almost exclusively pertains to the PAS dataset, which cannot be freely distributed. The other repositories are provided with the caveat that I am an entirely self-taught R and Git user, and the creation of these repositories happened concurrently with the growth of my skills in both. I would do many things differently now compared to when these analyses began. Though I have strived for reproducibility, it is inevitable that this will not be the case consistently, as my code has not been tested or optimised for running on any system other than macOS, and some file paths could be broken, having taken them out of the context of

my own computer. Much of the code is also dependent on other files which are either not mine to distribute; too large to include here; or not ready for public release (more details below). In short, the 'repo' part of this appendix is provided 'as is' to allow for scrutiny of this work by inspection of my code, but no guarantees are provided that it will run as intended. I advise readers to check all directories for associated README files. Note that many of the data files found within the repositories duplicate those of the 'data' folder in the root directory.

In particular, my implementation of the `mevolCVP()` and `pldam()` analysis was built using complex `for` and `if` loops, and references between different scripts using the `source()` function. This is primarily because I was unaware of the **purrr**, **callr**, and **here** packages at the time, and so was unable to confidently write functions that could handle the complexity required. A much more convoluted approach was implemented instead; instructions for running the code are provided in README files. Note, however, that `mevolCVP()` and `pldam()` are neither publicly available through CRAN and Github, nor mine to freely distribute. They are are therefore omitted from the repositories but can be obtained by contacting Allowen Evin.

I intend to make upgrades to the code before submitting the speciation method for publication, at which point the upgraded repository will appear publicly on my Github account. With that in mind, some significant upgrades have been applied to the repositories already. The directory structure is much improved and, as much as possible, I have identified and replaced traditional file paths with `here::here()` commands. Theoretically, this means that the code should run without issue, once the required dependencies are acquired. I have also edited the majority of files containing commands that create maps, replacing the original EDINA Digimap shapefiles with commands from the **rnaturalearth** package. This means running the code in these files will produce slightly different maps to those that appear in this text, though their substance remains the same. Shapefiles for the UK geology maps in Chapter 2 have also been omitted to save space, though the code still depends on them.

A.5.1 Rmd - List of RMarkdown Documents

I have referenced in this text several RMarkdown documents that expand on analyses performed in order to produce this thesis, but which were not essential to include at

length. The text in these documents does not supersede anything I have written in this thesis; they should be regarded as incomplete, albeit tidied, research notes that are provided only to supply supporting evidence. All the files given here are in HTML format; their RMarkdown source can be found by researching the "repo" directory for .Rmd files with the same name.

synthesis_bib.html Containing an interactive (i.e. searchable) table of NISP values for the synthesis in Chapter 2, with citations and an indication of whether the original report was consulted. A dedicated bibliography is provided in the same file. cvp_veto.html

Notes on vetoing approaches that had "original" CVP scores that lay outside the 5% to 95% intervals for "balanced" measurement_error.html

Notes on the inter-/intra- observer error study

A.5.2 Repository Omissions and Dependencies

A few changes were made to the original repositories before bundling them into this digital appendix. Firstly, plot and map image files (the cluster analysis images are exceptions and are supplied elsewhere) were deleted to save space. All those images appear in the thesis text, so their inclusion was not necessary and they can be recreated by running the code.

Some code in "easterpr_zooarch" depends on a personal R package ("zooarchr") I wrote to handle common zooarchaeological tasks using my own preferred workflows, but which was never intended for public release. Function calls dependant on "zooarchr" in the R and Rmarkdown files will fail. This is particularly true of the size change analysis in Chapter 5, which uses multiple functions of my own creation. Nevertheless, the samp_lsi_*() functions are provided in the "zooarchr" subdirectory of "easterpr_zooarch" for the purposes of scrutiny.

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