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Locating where archaeological sites occur in intertidal sequences: the use of archaeoentomological data as a proxy for tidal regime

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ABSTRACT:

Intertidal archaeological deposits occur worldwide, particularly in the temperate latitudes. These deposits can contain archaeological sites that were constructed at the time these were terrestrial landscapes, but subsequently were inundated as a result of rising sea levels. Part of this process can include the development of salt marshes. There is a need, therefore, to identify where archaeological sites lie within the cline of past tidal regimes. This paper presents the results of a survey of UK archaeoentomological data recovered from intertidal deposits which was undertaken in order to identify patterns in archaeoentomological data that might indicate a deposit's position within a saltmarsh. Such an approach has potential to establish 'indicator groups' for saltmarsh zones, thereby facilitating archaeological interpretation of intertidal deposits. A statistical ordination of the archaeoentomological dataset has been undertaken to explore the security and strength of proposed archaeoentomological indicator groups for various ecological zones within saltmarsh/ intertidal environments and the results are presented here. These indicator groups also are crossed-checked against the known modern ecology of the various beetles included within each grouping, to determine if they make good 'ecological sense'. is the dataset discussed here is specific to Northern Europe, but the approach is applicable worldwide.

KEYWORDS: Saltmarsh: Estuary: Intertidal Archaeology: Archaeoentomology: Coleoptera: Tidal Zone

1. INTRODUCTION

In the last 30 years coastal and intertidal archaeology has received increased interest (e.g. Bell 2012; Firth 2011; Ford 2011). Intertidal archaeology was initially developed in the UK and

Northern Europe (e.g. Bell *et al.* 2000; Bell 2013; O'Sullivan 2001; Rasmussen 2007; Wilkinson and Murphy 1995), but there is increasing interest in maritime, and by extension coastal archaeology, worldwide, ranging from North America, Japan and Australia (e.g. Bell 2012; Catsambis *et al.* 2011; Croes 2005; Ford 2011; Matsui 1992). Intertidal and coastal deposits often preserve 'drowned forests', freshwater marshes and other terrestrial environments and several of these have been sampled for archaeoentomological remains. Examples include Bronze Age Goldcliff and Redwick, Gwent (Bell *et al.* 2000; Bell 2013) Minehead Bay, Somerset (Jones *et al.* 2005), Holme-next-the-Sea, Norfolk (Brennand and Taylor 2003), The Stumble, Essex (Wilkinson and Murphy 1995), and a variety of sites around the Humberhead Levels (van der Noort 2004). To describe the majority of these sites as 'coastal' archaeology is something of a misnomer, since they are in fact the remains of woods, fens and marshes that developed some distance from what would have then the contemporary coast and now happen to be exposed (often through erosion processes) on our modernforeshores. These deposits sometimes represent the remains of landscapes and ecologies of the wide continental plain, including areas such as 'Doggerland', that existed before being submerged through dramatic sea level rise, between *ca*. 9,500 – 6500 BC, following the last glaciation and resulting oscillations in sea levels (e.g. Coles 1998, 1999; Gaffney *et al.* 2010).

Some archaeological sites from these locations are, in a more literal sense, truly coastal. They are located or were constructed at what would have been the contemporary coast. Often these sites were specifically located in the intertidal zone between the land and the sea. These intertidal landscapes consisted of a complex mosaic of coastal woods, marshes, estuary creeks and saltmarshes. In some locations, as sea levels rose, saltmarshes would develop on the surface of pre-existing wood, fresh water or acidic 'peats' (Cott *et al.* 2012). Clear examples of such truly intertidal sites are the Bronze and Iron Age buildings and trackways at Goldcliff and Redwick, Gwent (Bell *et al.* 2000; Bell 2013), the Bronze Age trackway at Cold Harbour Pill, Gwent (Bell 2013), the Saxon mill race at Springhead, Kent (Barnett *et al.* 2012), the cattle footprint-filled channels at Walpole, Somerset (Shotter 2012) and the Bronze Age structure at Caldicot, Gwent (Naylor and Casledine 1997).

It is this type of truly coastal landscape, its archaeology and the insects associated with it that will be discussed in this paper. In the main, these archaeological sites are not embedded in freshwater 'peats' or part of 'wood peats', but are derived from material deposited directly into grey or blue estuarine clays. Often these deposits are situated directly at the boundary between marine clays and any underlying 'peats', or other terrestrial sediments, and represent the point in time when these intertidal sites were being inundated through rising sea levels. Such coastal environments are ecologically diverse and provided a wealth of food, resources and habitats to exploit.

If the role and function of these archaeological sites is to be understood, then it is clear that the location of archaeological sites within the coastal regime, and how this may have changed during the occupation of a site, needs to be resolved more precisely. For example, the Bronze

Age and Iron Age buildings at Goldcliff and Redwick are associated with cattle grazing (Bell *et al*. 2000; Bell 2013) but what landscapes were being grazed? and where precisely were these sites located within the saltmarsh? What was the nature of the saltmarsh crossed by the trackway at Cold Harbour Pill? and how often was this landscape flooded by sea water? Were these archaeological features in use before sea level rise and/or transgression, during or after?

Traditionally, these issues have been addressed through the analysis of foraminifera (e.g. Edwards and Horton 2000; Gehrels 1994; Gehrels *et al.* 2001, Haslett *et al.* 2001; Horton and Edwards 2005, Kemp *et al.* 2013), ostrocods (e.g. Boomer and Eisenhauer 2002; Frenzel and Boomer 2005), diatoms (Cameron and Dobinson 2000; Devoy 1979; Zong and Horton 1999) and, to a lesser extent, through plant macrofossils and pollen (e.g. Caseldine 2000; Caseldine *et al*. 2013; Shennan 1982). In terms of both ostracods and Foraminifera, these environmental proxies mainly have been used to reconstruct, with notable precision, relative sea level change on a large scale but rarely provide specific details for the local or immediate environment to assist landscape reconstruction at the fine-grained level of the immediate surroundings of the sampling site that is specifically required in order to help solve the archaeological questions posed above. Insect analysis, like plant macrofossils, can give a very detailed and local reconstruction, often of the nature of the surrounding landscape within 1000 m of the archaeological site itself (Smith *et al.* 2010; Hill 2016). Foraminifera and ostracods are strong indicators for the relative salinity of coastal waters, and the the general nature of tidal regimes, but do *not* allow direct reconstruction of the terrestrial environment, a detailed reconstruction of ground conditions or the nature of prevailing terrestrial vegetation. Insects, especially beetles, have been found to be sensitive indicators for salinity (Nayyar and Smith 2013b; Smith *et al.* 1997, 2000; Smith 2011, 2013b) and, in particular, useful proxies for reconstructing the nature of terrestrial landscapes and vegetation cover (e.g. Elias 1994, 2010; Smith 2012). Moreover, insects also can provide direct evidence for the nature of how humans have used landscapes in the past (e.g. Ellias 1994, 2000; Robinson 1981, 1983; Smith 2012); the use and the nature of habitation (i.e. archaeological buildings and features – e.g. Hall and Kenward 1990; Kenward and Hall 1995; Smith 2012); and the formation of archaeological deposits, including the disposal of settlement waste (e.g. Carrott and Kenward 2001; Hall and Kenward 2003; Kenward and Hall 1997; Smith 2012). The insect remains from samples associated directly with the Bronze and Iron Age buildings at Redwick (Smith 2012) and Goldcliff (Smith *et al.* 1997; 2000) clearly established that the same level of interpretation was possible at estuarine archaeological sites as at terrestrial, rural or urban locations.

There is now sufficient archaeoentomological data from intertidal sites available to support an exploration of data patterns in order to establish *indicator groups* (*sensu* Kenward and Hall 1997) for zones within saltmarsh. This paper presents the results of a survey of existing British archaeoentomological data from intertidal sites and their statistical analysis. Those indicator groups identified through statistical analysis are reviewed in terms of known ecological data. Finally, saltmarsh zone data from indicator groups are considered in terms of the archaeological contexts for a number of British intertidal archaeological sites. It is hoped that the methods, techniques and conclusions reached here can be used as model elsewhere in the world for the identification of tidal regimes at coastal archaeological sites. However, this approach is specific to the British Isles and its insect fauna and cannot be applied directly elsewhere in the world; instead, this approach will have to be locally adapted for insect taxa and salt marsh habitats occurring there.

2. THE SALTMARSH ENVIRONMENT

Saltmarshes are a relatively common worldwide coastal landform (e.g. Allen and Pye 1992; Chapman 1974; Scott *et al*. 2014) which normally consist of three to four distinct zones: pioneer marsh (mudflat) at its most seaward level, low saltmarsh, high saltmarsh further inland and a transitional zone toward the landward extreme of the marsh as it grades into fully terrestrial environments (Adnitt *et al.* 2007; Burd 1989; Dijkema 1984; JNCC 2004). Figure 1 outlines the major physical and vegetation zones found in saltmarshes in Northern Europe. The 'zonation' present is very strong in its nature leading to one of the most diverse but structured ecological gradients that can occur in a relatively small area (Adnitt *et al.* 2007). This is especially true for saltmarsh vegetation (outlined in Figure 1) which, despite some degree of geographic variation, occurs widely in Northern Europe and is clearly understood (e.g. Adam 1981; Adnitt *et al*. 2007; Burd 1989; Hemphill and Whittle 2002; Stark *et al.* 2002). This geological and plant succession is normally thought to be a response to relative elevation above sea level and to daily, monthly and yearly tidal influence and range. The pioneer marsh (normally referred to as 'mudflats' – the term which is also used in this paper) tends to occur from Mean High Water Neep tide to a higher point in the tidal range and are often flooded for 1-5 hours, twice daily, for majority of the year. Beyond this pioneer marsh is the low marsh, which often occurs between the final limit of mud flats up to around 50 cm above the Mean High Water tide line. This area is usually inundated daily. Beyond the low marsh is upper marsh, which tends to occur from around 50cm above the Mean High Water tide up to the Extreme High Water tide line, though this can be region dependant. The lower margins of this zone may be flooded daily when monthly tides are high. The higher margins of the upper marsh are only flooded once or twice a year. Beyond the upper marsh, at the most landward extreme of the saltmarsh environment, is an area (sometimes called 'drift line', 'transitional' or 'slack') which, normally, lies above the highest astronomical tide and is constantly supplied by fresh ground water. This area often is dominated by reed bed and a variety of freshwater carr woodlands. Ulrich and colleagues (2002) suggest that the divide between the low saltmarsh community dominated by *Puccinellia maritima* (Huds.) (common salt mash grass) and *Atriplex portulacoides* L. (sea purslane) and the high saltmarsh community, dominated by *Limonium* spp. (sea lavenders), *Festuca rubra* ssp. *litoralis* (G. Mey.) Auquier (coastal variety of red fescue) and *Juncus maritimus* Lam. (sea rush), seems to commonly occur about 50 cm above Mean High Tide.

The process by which the vegetation succession is determined and maintained has been studied quite intensely in Northern Europe. This is mainly due to growing concerns over the loss of saltmarshes to coastal development and erosion and research into their response to climate change (Adnitt *et al.* 2007; JNCC 2004). A series of survey and experimental projects has clearly established that the primary factor in the vegetation succession is the relative altitude above sea level, which has obvious implications for inundation and relative salinity (e.g. Bockleman *et al.* 2002; Pennings and Bentness 2001; Pennings *et al.* 2005) Research by Adnitt and colleagues (2007) suggests that this may determine 80% – 90% of the variation in plant species present. Clearly, the variation of plant communities within saltmarsh is affected by many factors including competition between plant species (Adnitt 2007; Costa *et al*. 2003; Pennings *et al.* 2005); wave form and aspect (Pennings and Bentness 2001); relative levels of saturation, anoxia, salinity and available oxygen (Davy *et al.* 2011; Moffett *et al.* 2010; Pennings *et al.* 2005) and sediment supply and budget (Pennings and Bentness 2001) or, indeed, a combination of many of these factors locally (Pennings and Calloway 1992; Silvestri *et al.* 2005).

A key objective for this paper is to establish if it is possible to use insects, particularly beetles from archaeological deposits, to identify the presence of the same, or similar, zonation within saltmarshes and to relate this directly to the archaeological record.

3. PREVIOUS MODERN STUDIES OF INSECTS FROM SALTMARSHES

A number of studies have been carried out on the insect faunas from modern saltmarshes which suggest that 'zonation' in insect faunas is present, but currently is not clearly defined. Dijkema (1984) has examined a large range of insect species and how their distribution changed within the saltmarsh environment. He found that around 100 insect species were associated with the pioneer phase, around 500 with the middle saltmarsh and at least 1300 with upper saltmarsh. He suggested at least 75% – 80% of the insect species found in mudflats and low marsh were halobionts (associated exclusively with saline conditions), 25% – 50% of insects were halobionts in high saltmarsh communities and only 5% – 10 % of insects were halobionts in the transitional zone at the landward edge of the saltmarsh. Dijkema's survey established that plant feeders (phytophages), detritivores and carnivores also increase in number as one moves inland. Several studies have shown similar patterns in terms of the distribution of a number of insect species and the proportions of halobionts for the Carabidae 'ground beetles' (e.g. Desender and Maelfait 1999; Forster 2000; Petillion *et al.* 2008; Ulrich *et al.* 2002) and it is likely that the same pattern presumably also is true for other beetle families. In terms of ground beetles in the UK there is clear evidence that the fauna associated with saltmarshes is restricted. Luff and Eyre (2000) suggest that 28 ground beetles appear to be associated with saltmarshes, with eight beetle species being true halobionts. For Staphylindidae or 'rove beetles', Hammond (2000) suggests that in the UK 54 species are predominantly coastal, with 17 specific to saltmarshes. Foster (2000) suggests that only 7% of the British water beetle fauna is coastal, with 38 species directly associated with brackish water and only six known to be true halobionts.

Saltmarsh insects seem to have a variety of strategies for surviving in a saline environment (e.g. Forster 2000; Luff and Eyre 2000). Several, such as the *Bledius* and *Heterocerus* species from the mudflats, are cryptic (live in burrows). These beetles live in air-filled burrows, more or less fulltime, by sealing the narrow entrance or relying on surface tension to keep out the rising tide. Others alter the times at which they leave their burrows to avoid the rising tide. For example, the ground beetle *Dicheirotrichus gustavi* Crotch is usually nocturnal, and is only active and emerges from its burrow in the evening; however, when the tide coincides with daylight hours it will remain in its burrow for several days. Several species, including many of the ground beetles and the rove beetles, will actively 'migrate' with the tides moving to drier ground either on foot or by flying when the saltmarsh they inhabit is inundated (Foster 2000; Hammond 2000; Luff and Eyre 2000; Ulrich *et al.* 2002). True halobionts not only tolerate saline water but also can cope with extreme variability in salinity. How they do this is not fully understood but some (e.g. Foster 2000; Luff and Eyre 2000) suggest that they have the ability to osmoregulate (or actively regulate the relative salinity in their body). This may also explain the rectal pads seen on many saltmarsh beetle species. W. Foster (2000) also observed that *Bledius* beetle species living on saltmarsh also seem to choose to eat algae that are low in salt at times of high environmental salinity. Certainly, the saltmarsh environment can lead to some fairly extreme adaptations. For example, *Bledius* females 'curate' their larvae and young and keep them in the burrow until almost adults (Foster 2000).

Many of these studies of saltmarsh insects aim to establish the extent of the fauna, its conservation status or its national distribution; there are very few studies that specifically investigate how insects respond to the ecological zonation seen in saltmarshes, as described above. Ulrich and colleagues (2002) study of saltmarshes from the North Sea and the Baltic found that two distinct high and low saltmarsh 'zones' could be identified based on ground beetle communities with the divide occurring at between 60 – 80 cm above MHT for the North Sea sites. The low marsh was characterised by *Pogonus chalceus* (Marsh.) and D. *gustavi* (with *P. chalceus* slightly lower in elevation) and high marsh by the presence of *Bembidion minimum* (F.), *B. normannum* Dej. and *Dyschirius salinus* Schaum. This is potentially an important distinction for the survey of archaeoentomological faunas reviewed in this article. Similarly, though it does not distinguish between the saltmarsh zones, the paper by Desender and Maelfait (1999) describing the coastal shoreline distributions of beetle faunas along the Estuary of the river Scheldt does draw some very clear distinctions between the faunas of saltmarsh, sun-exposed areas of sands and freshwater marshes that are relevant here.

There are a number of issues that actually prevent direct comparison between the results of these modern entomological surveys and archaeoentomological assemblages:

1) The insects in the modern surveys are collected by hand or from pitfall traps; whereas, the insects from the archaeological sites are collected as fragments from archaeological sediment during excavation.

2) The insects from the modern survey are a 'living fauna'; whereas, those from archaeological sites are most likely 'death assemblages'. Death assemblages can be expected to be very different in their nature from living insect communities, especially in terms of how they form and the area of landscape they represent (e.g. Kenward 1975, 1978; Smith 2012; Smith *et al.* 2010).

3) Modern surveys usually collect beetles during a very limited period of time or one particular season. The archaeoentomological faunas are collected over an unknown but probably much longer period of time. It is reasonable to assume that archaeentomological assemblages contain the remains of insects that have gathered over many seasons and years and are unlikely to represent one season or calendar year.

4) Many of the modern surveys of saltmarshes concentrate on specific Coleoptera families from the beetle fauna present (normally the Carabidae 'ground beetles'; The Hydrophilidae 'water scavenger beetles' and the Staphylinidae 'rove beetles'). The archaeological faunas are whole faunas that include a mixture of the full range of the beetles present

5) The modern insect faunas are usually identified to species level. This level of identification is not always possible with archaeological insects, which are recovered in fragments (usually head, thorax and elytra are sorted from flots) and often lack diagnostic features such as antenna, hairs, legs which frequently feature as criteria to distinguish morphologically similar taxa to species level in entomological keys.

6) The modern surveys often only include a list of the species encountered and do not indicate their relative numerical abundance (to be fair this is standard in most modern entomological surveys, which normally do not indicate relative abundance of taxa).

7) Finally, with modern assemblages, the beetles sampled are directly collected from an observed habitat using methods where collection biases are understood and can be addressed. However, with archaeoentomological assemblages the past environment is not known, and can only be understood through proxy indicators such as plant macrofossils, pollen or even the beetles themselves. Moreover, it is highly likely that archaeoentomological assemblages will be biased by factors such as preservation, taphonomy (how deposits form and are subsequently modified) and human activity.

4. METHODOLOGY AND ANALYSIS

In order to establish if similar saltmarsh zonation indicators may be detected in archaeological insect faunas, and if this could be used to interpret archaeological site location within a coastal landscape, the following approaches were used:

4.1 Sampling

Bulk samples were recovered from either estuarine clays or from underlying freshwater peats from a wide range of archaeological features from 15 archaeological sites. The location, dating, site type, nature of sampled material, details of publication and the number of samples analysed from the individual sites are outlined in Table 1. The site locations are illustrated in Figure 2.

4.2 Basic identification

The bulk samples were prepared using the standard method of paraffin floatation outlined in Kenward *et al.* (1980). Waterlogged insect remains were sorted and identified under a low-power binocular microscope at magnifications between x15 – x45. Where achievable, the insect remains were identified to species level by direct comparison to specimens in the Gorham and Girling insect collections, housed in the Department of Classics, Ancient History and Archaeology at The University of Birmingham. The nomenclature used in this paper for the beetles is based on Lucht (1987) and is based on Stace (2010) for the plants.

4.3 Data Analysis

In order to establish whether the insects recovered from archaeological material can reliably indicate saltmarsh zone the site was located in, a number of analyses were undertaken:

1) ***Identifying if there are differences in species composition between archaeological sites***
The species lists from the individual archaeological sites were consulted and the presence and the relative numbers of individual species were noted. The aim of this analysis was to identify species which are significant in these faunas and which might therefore be considered as archaeological 'indicator species' (*sensu* Kenward and Hall 1997) for salt marsh landscapes. Obviously given the many taphonomomic and depositional issues that affect insect faunas in the past (i.e. Kenward 1975; 1978; Smith 2012) it would be a mistake to attempt to use these proportions directly to interpret the archaeological record. This is about establishing general trends here, not directly comparing specific data.

2) ***Assigning the archaeological data to ecological groupings***
Insect faunas from archaeological sites are now routinely assigned to 'ecological groupings' following the methodology outlined in Kenward (1978) and Robinson (1981, 1983). The ecological groups used here are based on a set devised specifically for use in the archaeological record. They are intentionally broad (often much broader than modern ecological groupings for insects) since they are designed to be used for comparison of death assemblages that may not have formed in the same ecologies or in the same taphonomic circumstances:

    1. freshwater aquatic ('a' group)
    2. fast-flowing waters ('ff' group)
    3. acidic waters ('aw' group)
    4. species associated with muddy watersides and waterside vegetation often reed bed ('ws' group)
    5. saline waters ('sw' group)
    6. coastal terrestrial ('c' group)

7. moorland (‘m’ group)
8. dung fauna (‘df’ group)
9. ‘house’ and settlement fauna (‘h’ group)

The membership of these groups is outlined in Kenward (1978), Kenward and Hall (1995), Smith and Howard (2004) and Smith and colleagues (Smith *et al.* 1997, 2000).

The proportions for groups ‘a’, ‘sw’, ‘aw’, ‘ff’ and ‘ws’ have been calculated as a percentage of the total minimum number of individuals (MNI) recovered for each sample. The proportions for groups ‘c’, ‘m’, ‘df’ and ‘h’ have been calculated as part of the terrestrial fauna recovered (this is calculated by removing the aquatic species (‘a’ +’sw’) from the MNI for the whole assemblage). In many archaeological samples, the terrestrial fauna can be ‘swamped’ by the aquatic fauna and the relative proportion of terrestrial beetles therefore can be adversely, and misleadingly, affected by variations in the aquatic fauna., As a result, the exclusion of aquatic species from the calculation for terrestrial species is necessary.

3) Use of statistical ordination to identify data patterns

In order to test the security of the two analyses suggested above, a statistical ordination was carried out on the entire dataset for the sites. A detrended correspondence analysis (hereafter DCA) using the CANOCO 4.5 programme (ter Braak and Šmilauer 2002) was carried out on a total of 59 insect faunas to determine if the faunas and the archaeological samples recovered were statistically distinct or clustered. The full data set consisted of 9131 individuals representing 451 taxa. An initial run of the DCA across the total fauna of all samples indicated that standard reciprocal averaging gave an undue importance to both rare individuals and individual taxa from samples where the total counts were low. This is a common problem encountered with reciprocal averaging (Gauch 1982). The dataset also tended to divide on aspects of the data regarded as unimportant for the present investigation (for example the presence or absence of synanthropic, woodland and/ or dung beetles).

As a result, it was decided to restrict the data used in the CANOCO DCA analysis in two ways:

1) Removing faunas in which less than 20 individuals were recovered and removing taxa which accounted for less than 10% of the total fauna (in essence this meant the removal of faunas that would normally <u>not</u> be considered archaeologically interpretable – Kenward 1978; Smith 2012).

2) Restricting the analysis to species that were included in relevant ecological groups, in this case the ‘a’, ‘sw’, ‘c’, ‘ws’ and ‘m’ ecological groupings.

These manipulations of the data reduced the dataset analysed to 4482 individuals representing 94 taxa from 44 assemblages, from 15 archaeological sites at 6 locations. The option to down weight species occurring infrequently was selected for the DCA.

This is of course a fairly heavy set of data manipulations for an ordination, and is the kind of 'tidying up' that is specifically not recommended by ter Braak and Šmilauer (2002). However, given the complexity and taphonomic problems for datasets produced by most archaeoentomolgoical and other environmental archaeology analyses, to some extent this approach is defendable and is common practice (previous examples of similar decisions to restrict archaeoentomological datasets are outlined in Smith 2012, 2013a). For the purposes of this exercise, the DCA ordination is intended to independently confirm and support the indicator groups and patterns identified subjectively, or by the use of less complex statistics, rather than be the sole or determining form of analysis.

5. RESULTS

Table 2 presents the range of species that are seen to be particularly indicative of saline waters, estuarine conditions, freshwater and waterside environments from the sites examined. The shading in the table represents the number of individuals encountered at a particular site.

Table 3 and Figures 3, 4 and 5 present the relative proportions of the ecological groups for each site.

Figure 6 presents the results of the CANOCO DCA ordination using the reduced dataset described above and represents the first and second axes of ordination. Figure 6a presents the DCA ordination for the species and Figure 6b for the samples from the archaeological sites. An annotated interpretation of the groups of insects and samples that resulted from this ordination is presented in Figures 6a–b.

6. DISCUSSION

The three analyses that have been undertaken all indicate that the insect remains from the archaeological sites have distinct habitat groups present. The differences in faunas, and which species seem to be significant, are summarised in detail in Table 4 (species in bold are thought to be particularly indicative). The relative proportions of the ecological groups present also are provided. Finally, an indication of where that particular site may have been located within the saltmarsh landscape is suggested.

These groupings appear to make both ecological and archaeological sense and the logic for this can be explained as follows:

6.1 Differences in taxa and the proportions of ecological groups of aquatic Coleoptera between the sites

Table 3 clearly illustrates that the individual sites fall into a number of distinct groups. These differences appear to relate to the occurrence and relative numbers of beetle species from saline, aquatic and waterside environments. Similar patterns are seen in the proportions of the ecological groups recovered (see Figures 3, 4 and 5).

The sites at Springhead and Caldicot are distinct from the other archaeological sites as a result of the presence of a range of water beetles, mainly elmid 'riffle beetles', which are usually associated with fast-flowing, well-oxygenated fresh waters, often flowing over sand and gravel substrates (ecological group 'ff'). These taxa only account for 1% of the fauna at Springhead, but account for 27.5% at Caldicot; however, they are completely absent at the other sites examined. In the archaeological record, elmid beetles have been found to be mainly associated with large river channels in the British lowlands during the Early and Mid-Holocene. Their distribution appears to contract with increased river channel alluviation from the Late Bronze Age/ Early Iron Age onwards (Osborne 1988; Smith 2000; Smith and Howard 2004). The other water beetles from these two sites are a fairly mixed blend of species ranging from freshwater and watersides to coastal and saltmarsh environments. Both Springhead and Caldicot were probably located on fast-flowing creeks or tidal inlets, where freshwater channels entered the saltmarsh zone on their way to the sea. On the Gwent Levels, these features are known as 'pills' which is an Anglicisation of the Welsh word '*pwl'*, meaning inlet, harbour or pool, but in this area specifically refers to freshwater channels. This 'pill' term at Caldicot may be particular significant in terms of the Saxon Mill at Springhead, since the Springhead faunas and archaeology suggest that both fresh river water and estuary tides may have been important in the operation of this mill (Barnett *et. al*. 2011).

Two of the trackways at Goldcliff (Trackways 4 and 6) contained no taxa that are associated with saltmarsh environments. These sites are dominated by a wide range of taxa that are associated with slow-flowing or stagnant freshwater (ecological group 'a' which account for 45.5% and 58.4% of the fauna respectively). The faunas also are dominated by a number of species, such as the reed beetle *Plateumaris braccata*, associated with *Phragmites* reed beds and other stands of emergent waterside vegetation (typically ecological group 'ws' which accounts for 29.3% and 18.9% respectively). This ecological group is present in much higher numbers at Goldcliff trackways 4 and 6 than in the other faunas. It is probable, therefore, that deposits from these two sites were located in the freshwater slack at the back of the saltmarsh, where there is a more limited saline influence.

The samples from Cold Harbour Pill and the two buildings at Redwick produced moderate numbers of taxa that are associated with coastal environments. This component of the terrestrial fauna mainly consists of a range of *Bembidion* species and the saltmarsh specialist *Pogonus chalceus.* The saline tolerant water beetles included limited numbers of *Ochthebius dilatatus* and *O. viridis*. Taken together both the coastal species and salt water species (ecological groups 'c' and 'sw') usually account for under 15% of the beetle fauna recovered. Notably, none of the species associated with saline mud flats were recovered at these sites. Similar proportions (< 15%) of species associated with freshwater and watersides also were recovered from the samples from Cold Harbour Pill and Redwick (see Table 3 and Figure 4). Indicators for reed bed are much less common than they were in the material from Trackways 4 and 6 at Goldcliff. Given that saline indicators are present, particularly *Pogonus chalceus*, and that mud flat species are essentially absent, it seems reasonable to suggest that these sites were originally located on high or low saltmarsh.

Goldcliff buildings 1, 6 and 8 and trackways 1130, 1330, 1311, 1108 and the palaeochannel at Walpole form a distinct group from the other archaeological sites. Taxa from saline water and coastal environments account for at least 15% of the fauna recovered from these sites, with the proportions of saline taxa often exceeding 20% of the overall assemblage (see Table 3 and figure 3). This suggests that saltwater/ coast conditions were a dominant aspect of the local landscape. The exception to this is Building 1 at Goldcliff where only 1.8% of the fauna falls into these ecological groups. This is easy to explain as the deposit was from the internal surface of the building's floor and its archaeoentomological fauna was dominated instead by members of 'house fauna' (Smith *et al.* 1997, 2000).

Perhaps more significant are the specific taxa recovered at these sites. The faunas contain several individuals which are all normally associated with saline mud and mud flats in the pioneer zone of saltmarshes (Clarke 1973; Lott 2009; Tottenham 1954); such as, *Bledius spectabilis, B. occidentalis, Heterocerus fossor, H. flexuosus, H, ?obsoletus* and H*. maritimus*. The two species of Hydrophilidae recovered (*Cercyon litoralis* and *Cercyon depressus*) normally are associated with decaying seaweed (Hansen 1987) and are recovered only at these sites. In addition, the faunas also contain a wide range of species know to inhabit pioneer mudflats at low tide, as well as high and low saltmarsh; such as, *Dyschirius aeneus, D. salinus, Pogonus chalceus, Dicheirotrichus gustavi* and a range of *Bembidion* species. Saline water beetles such as *Ochthebius dilatatus, O. marinus* and *O. viridis* are common at these sites as well.

Interestingly, despite the presence of taxa clearly signalling saline conditions at Goldcliff, there are still relatively large amounts of freshwater and waterside species (ecological groups 'a' and 'ws') recovered. This result requires some explanation. Certainly, several of the species of 'freshwater' beetles can, and often do, occur on saltmarshes, suggesting a degree of tolerance to salinity (e.g. Foster 2000). Several of the waterside plants indicated by the beetles recovered, such as *Phragmites* water reed and sea club rush (*Bolboschoenus maritimus* L.), will occur on either low or high saltmarsh, as well as freshwater areas. Their presence also may result from two well-known archaeological problems.

Kenward (1975, 1978) has clearly demonstrated that the formation of death assemblages of insects in the archaeological record is complex and can routinely incorporate significant proportions of species that are allochthonus (taxa that originated at a distance from location in which it is deposited) to the deposit in which they are found. Annoyingly, Kenward's study established that this often can include beetles from freshwater turning up in deposits far away from such an environment. Equally, many of the samples from these sites were taken from directly above or even at, the transition between the underlying marsh/ wood/ acidic peats and the overlying estuarine clays. It is, therefore, likely that there may have been some mixing of these deposits either during formation or in sampling.

Unfortunately, the distinction identified by Desender and Maelfait (1999) to divide between low and high saltmarsh using ground beetles (i.e. low saltmarsh characterised by the presence of *Pogonus chalceus* and *Dicheirotrichus gustavi*: high saltmarsh characterised by the presence of *Bembidion minimum, B. normannum* and *Dyschirius salinus*) was not observable in these archaeological assemblages. These species either occur in low numbers or, when more numerous, occur across most of the archaeological faunas regardless of whether the deposits appear to have formed on mudflats, low or high saltmarsh (based on other aspects of the faunas recovered). The modern ecology and collection records for these taxa in Britain also suggest that there is an overlap in habitat for these highly mobile ground beetles (e.g. Luff 2007).

Archaeologically the presence of all of these taxa occurring together is not surprising. It is thought that archaeological insects tend to come from a 1000 m area around the sampling site (e.g. Hill 2016; Smith *et al.* 2010). Although a relative small total area, this potentially could include all of these tidal regimes within a saltmarsh. Many of these species are very mobile and will move up and down the tidal sequence on a seasonal timescale, if not daily. This would inevitably lead to beetles occurring in death assemblages potentially representing quite a wide area of habitats. The archaeological factors that complicate the formation of insect death assemblages discussed above would also be a factor here and, of course, both live and dead beetles can be carried by the tide or freshwater floods into deposits which they do not really represent.

6.2 Differences in taxa and proportions of ecological groups of terrestrial Coleoptera between sites

There are some interesting distinctions between the sites in terms of the terrestrial insect faunas recovered (Table 3 and Figure 5). Although this may relate to these sites' location within the saltmarsh, it also is likely that this could relate to other factors; such as, surrounding landscape or human behaviour.

Many of the sites at Goldcliff and Redwick contain small numbers of species that are associated with moorland (ecological group 'm'). This group accounts for 2.8% of the terrestrial fauna at

Goldcliff building 6 to 19.3% at Redwick building 2. The moorland group includes the ground beetle *Bradycellus ruficollis,* which typically is found on sandy ground amongst heather in heathland and moorland (Lindroth 1974; Luff 2007); the weevil *Micrelus ericae,* which feeds only on heathers (*Erica* spp. and *Calluna vulgaris* L.); and *Plateumaris discolor* which is associated with cotton grass (*Eriophorum angustifolium* Honck.). The small predaceous diving beetle *Hydroporus melanarius* is normally associated with dark acidic pools in peat bogs (Foster *et al.* 2014). The presence of these species at the Gwent Levels sites is not surprising. Here, lowland raised peat bog appears to be one of the landscapes that is commonly inundated due to rising sea levels in the Middle Iron Age (Bell *et al.* 2000; Bell 2013). The sites examined on the Gwent Levels (Goldcliff, Redwick, Caldicot, Cold Harbour Pill) all show evidence that the underlying peat was being eroded during inundation with elements of this material, including insect remains, becoming incorporated into the overlying estuarine clays. In addition, these sites also contain moderate amounts of a range of species that are associated with cattle and other grazing animals (ecological group 'df' in Table 3 and Figure 5); such as, the *Aphodius* dung beetles, but also can include individuals of the 'dor beetle' *Geotrupes* and the *Onthophagus* beetles. The presence of such dung beetles can be related to the substantial archaeological evidence recovered at these sites for seasonal cattle grazing during the Late Bronze Age and the Early Iron Age (Bell 2013; Bell *et al.* 2000).

Perhaps even more striking is the presence of substantial proportions of insects that are normally associated with human settlement and housing (ecological group 'h') at some of these saltmarsh sites. This can account for between 5% – 10% of the fauna recovered but does reach 20% of the terrestrial fauna in Building 1 at Goldcliff. This 'house fauna' includes several species that are seen as particularly strong synanthropes; such as, the 'woodworm' *Anobium punctatum*, the 'hairy fungus beetle' *Typhaea stercorea* and the 'spider beetle' *Ptinus fur*. Smith and colleagues (Smith 2013b; Smith *et al.* 2000) have suggested that these synanthropes most likely were brought to site in stored hay and quickly developed into breeding populations in fodder and other materials stored in the buildings during their use.

6.3 The Detrended Correspondence Analysis (DCA) Ordination

The results of the CANOCO Detrended Correspondence Analysis (DCA) ordination are shown in Figures 6a and 6b. It is clear that there is a strong separation seen in both the species and the sample ordinations. For the species ordination (Figure 6a) there are a clear number of distinct groupings:

1) The taxa that constitute the saline waters ('sw') and coastal terrestrial ('c') groupings fall into a discreet cluster in the lower middle of the plot (labelled 1). This grouping includes a range of very strong terrestrial halophile species; such as, *Pogonus chalceus, Bembidion minimum, B. varium, Dyschirius salinus, Bledius occidentalis, Heterocerus fenestratus, H. maritimus, H. ?obsoletus;* and

the salt water tolerant hydraenid beetles *marinus, O. viridis* and the hydrophilid *Cercyon depressus*. A small number of saline tolerant species do not fall into this group but, instead, cluster with a range of fresh water indicators towards the upper middle of the diagram. However, these are species; such as, *Bembidion assimile, B. semipuctatum, B. fumigatum*, and *Ochthebius dilatatus,* which are closely associated with salt marshes, but can occur in a range of freshwater habitats (Foster *et al.* 2014; Lindroth 1974; Luff 2007).

2) The species associated with fast-flowing water, mainly consisting of a range of elmids, primarily occur together in the upper right hand corner of the plot and some of these taxa plot out on top of each other (labelled 2).

3) There is also a group of species that cluster towards the middle right hand side of the diagram, which may indicate a general preference for 'reed beds' (labelled 3). This includes species such as *Agonum thoreyi*, *Odacantha melanura, Silis ruficollis and Plateumaris braccata* which are very characteristic of this environment. Notably the 'duckweed' weevil *Tanysphyrus lemnae* and the 'whirligig' beetles *Gyrinus* spp. which have long been thought to be associated with open areas of water in reed beds in the archaeological record, also plot out in this area of the diagram (e.g. Girling 1979; Smith and Howard 2004).

4) Towards the top left hand side of the diagram is a much wider group of taxa that are associated with fresh water environments (labelled 4).

5) There is a linear spread of species towards the middle and upper left hand side of the diagram that consist of a range of species that are indicators for acid bogs and heathlands. There are all members of the moorland ('m') and acidic waters ('aw') ecological grouping such as *Bradycellus ruficollis, Hydroporus striola, H. melanarius, Acidota crenata, Haltica ericeti and Micrelus ericae*.

6) There are also two notable 'outliers' towards the bottom of the left-hand side of the diagram. These are the staphylinids *Trogophloeus pusillus* and *T. fuliginosus.* These were initially included in the ordination since they are species that are commonly associated with wet mud and decaying vegetation by watersides (Tottenham 1954; Lott 2009). However, both species are also commonly found in the archaeological record in deposits that come from wet yards, house floors and passageways where they are often closely associated with a range of synanthropic 'house' fauna (Kenward and Hall 1995; Carrott and Kenward 2001; Smith 2012) and it may be that these two species should have been excluded from this analysis along with the other members of the synanthropic fauna.

This analysis, at least, has suggested that it may be possible to refine the broad, and perhaps crude, ecological groupings 'saline waters', 'coastal terrestrial' and 'waterside' into further 'functional' sub-groups (see Hill 2016 for one such suggested scheme). However, given the very complex nature of death assemblages, which differ in both time, space and taphonomy, the extent to which this may be be warranted in the long term needs to be considered.

The species ordination has therefore separated the taxa into a sequence of environments running broadly right to left across the diagram with species indicative of fast-flowing water at the right, through freshwater and reed bed species, to saltmarsh and peat bog and heath at the left. Given that in these environments local conditions can be quite ‘mixed’ and we are dealing with the vagaries of the archaeological record (for example at Iron Age Goldcliff the saltmarsh deposits becoming mixed with the underlying peat as the result of cattle ‘trampling’ (Bell *et al*. 2000)), the strength of this ordination is striking and encouraging.

In terms of the DCA ordination by samples (Figure 6b), these results generally support the distinctions between the sites discussed above. The samples from Cold Harbour Pill and Redwick, the two sites thought to represent high and low saltmarshes, cluster together in the top left hand corner of the plot. Sites which, based on the ecology of the insect species present, appear to be from pioneer mudflats are clustered together in the lower left hand area of the plot. This cluster includes the three buildings from Goldcliff, trackways 1130, 1330, 1311, 1108 at Goldcliff and the site at Walpole. Though perhaps less clearly clustered the samples from the potential tidal channel sites at Springhead and Caldicot do seem to cluster together in the middle right of the diagram. Just below this is a cluster of samples from the two trackways at Goldcliff (Trackway 4 and 6) which were thought to be from freshwater slack.

7. Conclusion

This paper set out to establish whether it is possible to use the insect remains from intertidal archaeological sites to determine where they may have been located within the past tidal regime of ancient saltmarshes. The ecological data from the individual species, the summary statistics based on their ecological grouping and the ordination suggest that this is feasible. Though a distinction between low and high saltmarsh proved difficult, this is likely to be due to the limited number of archaeological sites examined (N = 6) and the affect of tidal movement on insects (both dead and alive/ during site formation and since). Nevertheless, the insect faunas reliably separated freshwater slack from saltmarsh, from mudflat, from tidal creek. Although this survey was speculative (i.e. were there any patterns to the data), these different faunas theoretical could be developed (with further data from other archaeological sites in Britain and elsewhere) as ‘indicator groups’ for these separate environments in the archaeological record (*sensu* Hall and Kenward 1997). One way to validate the conclusions drawn here would be to carry out a series of modern calibration studies in a range of saltmarsh biomes. Ideally this would use insect ‘death assemblages’ taken directly from sediment samples to see if the results presented here are replicable when collected from modern environments (for methodology see Smith *et al.* 2010).

The conclusions presented here are quite timely. Due to modern climate change and coastal erosion due to sea level rise, many more of these important foreshore archaeological sites worldwide are likely to be exposed over the next few decades (i.e. Bell 2012, 2013; Bell *et al.* 2000;). Though many of these intertidal sites will be from terrestrial peats, some will be from sites that were originally located within estuarine and saltmarsh landscapes. Understanding their location and use is of paramount research and archaeological importance. Insect remains, as one of the strongest environmental archaeological proxy indicators, clearly have a vital role to play here, not just in northern Europe, but internationally.

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Table 1. Site details, dates and publication.

SITE NAME	LOCATION	DESCRIPTION	DATE	PUBLICATION	NUMBER OF SAMPLES AT EACH SITE
Springhead	Northfleet, Essex, England	Saxon mill race and shoot	Late 7th or Early 6th century	Smith 2011	7
Goldcliff (Buildings 1, 6 and 8)	Gwent Levels, Newport, Gwent, Wales	Building 1: a range of floor deposits from rectangular timber structure. Building 6 and 8: materials from palaeochannels filled with cattle foot prints around timber structures	Building 6: dendrochronology indicates wood cut in 273 BC. Buildings 1 and 8: radiocarbon dated between 400–100 cal BC.	Smith *et al.* 1997, 2000	22
Goldcliff, Trackway 1130	Gwent Levels, Newport, Gwent, Wales	Corduroy and brushwood trackway	391–116 cal. BC	Smith *et al.* 1997, 2000	3
Goldcilff, Trackway 1330	Gwent Levels, Newport, Gwent, Wales	Brushwood trackway	165–129 cal. BC	Smith *et al.* 1997, 2000	1
Goldcliff, Trackway 1311	Gwent Levels, Newport, Gwent, Wales	Brushwood trackway	366–41 cal. BC	Smith *et al.* 1997, 2000	1
Goldcliff, Trackway 1108	Gwent Levels, Newport, Gwent, Wales	Brushwood trackway	Dendrochronological date of 336–318 BC	Smith *et al.* 1997, 2000	4
Redwick Building 4	Gwent Levels, Newport, Gwent, Wales	From edge of channel alongside rectangular building structure	Sample appear to be slightly younger than structure which is dated to 1601–1261 cal. BC and 1376–929 cal. BC	Smith 2013b	3
Redwick Building 2	Gwent Levels, Newport, Gwent, Wales	Occupation deposits around rectangular timber structure. Pit thought occupation layers of site	1379–940 cal. BC 1389–1129 cal. BC	Tetlow 2013	4
Cold Harbour Pill	Gwent Levels, Newport, Gwent, Wales	Section through timber aliment at site 9	Trackway undated but presumed similar to dates of the buildings	Nayyar and Smith 2013	4
Walpole Landfill site	Walpole, nr. Pawlet, Bridgewater, Somerset, England	Estuarine clays from palaeochannels filled with cattle foot prints	Neolithic	Shotter 2012	3
Caldicott	Nr Caldicot Castle, Gwent, Wales	Palaeochannel deposits associated with timber and worked wood	Series of radiocarbon dates place activity in the 2nd millennium BC	Osborne 1997	1

Table 2. The coastal, saline, aquatic and waterside Coleoptera recovered from the archaeological sites examined. The shading and the key below the table outlines their relative occurrence at each site.

	Springhead	Goldcliff Building 1	Goldcliff Building 6	Goldcliff Building 8	Goldcliff Trackway 4	Goldcliff Trackwa y 6	Goldcliff Trackway 1130	Goldcliff Trackway 1330	Goldcliff Trackway 1311	Goldcliff Trackway 1108	Redwick Building 4	Redwick Building 2	Cold Harbour Pill	Walpole Channels	Caldicot
Freshwater Aquatics															
Hygrotus inaequalis (F.)															
Hydroporus scalesianus Steph															
H. tessellatus Drap.															
Graptodytes cf. granularis (L.)															
Gyrinus spp.															
Ochthebius bicolon Germ.															
Ochthebius minimus (F.)															
Coelostoma orbiculare (F.)															
Cymbiodyta marginella (F.)															
Chaetarthria seminulum (Hbst.)															
Helodidae Gen. & spp. Indet.															
Saltmarsh and Coastal Species															
Dyschirius aeneus (Dej.)															
Dyschirius salinus Schaum															
Bembidion varium (Ol.)															
B. fumigatum (Duft.)															
B. assimile Gyll.															
Bembidion minimum (F.)															
Bembidion iricolor Bedel															
Pogonus chalceus (Marsh.)															
Dicheirotrichus gustavi Crotch.															
Stenolophus skrimshiranus Steph.															
Agonum viduum (Panz.)															
Cercyon litoralis (Gyll.)															
C. depressus Steph.															
Omalium laeviusculum Gyll.															
Bledius spectabilis Kr.															
B. occidentalis Bondr.															
Heterocerus flexuosus Steph.															
Heterocerus fossor Kiesw.															
Heterocerus fossor Kiesw.or H. flexuosus Steph.															
H. ?obsoletus Curt.															
H. maritimus Guer spp.															
Saline water															
Ochthebius dilatatus Steph.															
Ochthebius marinus (Payk.)															
O. viridis Peyrhff.															
Moorland															
Bradycellus ruficollis (Steph.)															
Hydroporus melanarius Strum.															
Plateumaris discolor (Panz.)															
Haltica c.f. ericeti allard															
Micrelus ericae (Gyll.)															
Fast flowing freshwater															
Stictotarsus duodecimpustulatus (F.)															
Potamonectes depressus (F.)															
Orectochilus villosus (Müll.)															
Elmis aenea (Müll.)															

	Springhead	Goldcliff Building 1	Goldcliff Building 6	Goldcliff Building 8	Goldcliff Trackway 4	Goldcliff Trackway 6	Goldcliff Trackway 1130	Goldcliff Trackway 1330	Goldcliff Trackway 1311	Goldcliff Trackway 1108	Redwick Building 4	Redwick Building 2	Cold Harbour Pill	Walpole Channels	Caldicot
Oulimnius spp.	<5														>20
Riolus spp.	<5														
Limnius volckmari (Panz.)															<5
Normandia nitens (P. Müller)															<5
	Waterside / freshwater marsh														
B. semipuctatum (Donv.)		<5			five - ten	<5	<5								
A. thoreyi Dej.					<5	<5									
Odacantha melanura (L.)	<5	<5			<5		<5					<5	<5		
Dromius linearis (Ol.)		<5	<5	<5						<5	<5				<5
Cercyon tristis (Ill.)	five - ten	>20	<5		<5		<5								
Cercyon convexiusculus Steph.	<5		<5		<5	five - ten	<5				five - ten	five - ten			
L. heeri (Fauv.)												five - ten	five - ten		eleven - 20
Lesteva longelytrata (Goeze)	eleven - 20						<5					<5	five - ten		
Platystethus cornutus (Grav.)		<5	<5	<5								<5		<5	>20
Paederus spp.	eleven - 20	eleven - 20	<5	<5	five - ten	<5	<5	<5		<5		<5			<5
Silis ruficollis (F.)	<5	<5			<5	<5	<5								<5
Heterocerus marginatus (F.)															>20
H.?fenestratus (Thunb.)		<5	<5												
Plateumaris braccata (Scop.)	<5				>20	>20	>20	<5		<5			<5		
Plateumaris sericea (L.)	<5	five - ten													
Bagous spp.	<5	<5	<5	<5				<5	<5					<5	
Notaris spp.	five - ten	<5				<5					<5			<5	
Thyrogenes spp.	<5	<5						<5							
Limnobaris pilistriata (Steph.)		<5		<5				<5			<5	<5			
Corylophus cassidoides (Marsh.)		<5								five - ten	<5	five - ten	five - ten		<5
Dromius longiceps Dej.					five - ten	<5	<5					<5		<5	

Key to shading:

<5	grey
five - ten	diagonal hatching
eleven - 20	chequered
>20	black

Table 3. The relative proportions of the various ecological groups for the coleopteran recovered from the saltmarsh archaeological sites

SITES / ECOLOGICAL GROUPING	Springhead	Goldcliff Building 1	Goldcliff Building 6	Goldcliff Building 8	Goldcliff Trackway 4	Goldcliff Trackway 6	Goldcliff Trackway 1130	Goldcliff Trackway 1330	Goldcliff Trackway 1311	Goldcliff Trackway 1108	Redwick Building 2	Redwick Building 4	Cold Habour Pill	Walpole	Caldicot
saline water	0.9%	1.3%	10.3%	15.2%	0.0%	0.0%	3.1%	16.0%	6.5%	9.9%	0.5%	0.0%	5.7%	23.1%	1.0%
coastal species	1.9%	0.5%	7.7%	10.0%	0.0%	0.0%	7.0%	17.7%	22.2%	9.1%	5.5%	9.2%	11.9%	30.3%	4.8%
freshwater	20.4%	6.1%	17.8%	26.7%	45.4%	58.4%	54.4%	40.7%	37.0%	26.4%	15.9%	9.1%	5.2%	3.8%	27.5%
acid water	0.0%	0.0%	0.2%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
fast-flowing	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	24.2%
waterside species	13.3%	7.4%	3.9%	3.3%	29.3%	18.9%	13.3%	4.9%	6.5%	6.6%	6.4%	7.3%	7.5%	9.4%	6.7%
dung fauna	6.2%	1.0%	9.2%	3.2%	8.8%	1.5%	4.7%	3.2%	3.7%	2.4%	4.6%	7.1%	6.3%	0.0%	7.2%
moorland	0.0%	0.0%	2.8%	6.8%	0.0%	0.0%	0.0%	1.6%	3.7%	0.0%	19.3%	10.9%	3.3%	0.0%	0.0%
house fauna	8.8%	20.7%	11.3%	7.8%	1.7%	3.1%	2.3%	6.5%	0.0%	10.6%	3.3%	0.0%	0.5%	0.0%	0.3%

Table 4. Summary of the main differences between the faunas investigated and an interpretation of where the sites may lie in the saltmarsh environment

Springhead and Caldicot	**Particularly Indicative taxa**	**% and (range) of saltmarsh and coastal**	**%other ecological grouping**	**Tidal River or stream channel**
Wide range of species from watersides and reed bed	*Odacantha melanura, Dromius linearis*, range of Dytisicidae, *Gyrinus* spp., **Hydrophilidae**, ***Ochthebius minimus, O. bicolon***, *Platystethus cornutus*, ***Paederus*** spp., **Helodidae**, freshwater ***Heterocerus*** spp., *Plateumaris braccata, P. sericea*, *Bagous* spp., *Thyrogenes* spp., ***Notaris*** **spp.**		*Aquatic*: Springhead 20.4% Caldicot 27.5% *Waterside:* Springhead 13.3% Caldicot 6.2%	
Limited coastal and salt water faunas (saline tolerant rather than strongly halophilic, water beetles associated with temporary saline pools).	***Bembidion varium***, *B. iricolor*, ***B. fumigatum***, *B. assimile*, ***Pogonus chalceus***, ***Ochthebius dilatatus***, ***O. marinus***	*Coastal*: Springhead 1.9% (0.0-5.0) Caldicot 4.8% *Saline:* Springhead 0.9% (0.0-2.9) Caldicot 1.0%		
Moderate to large number of individuals associated with fast flowing water	*Stictotarsus duodecimpustulatus*, ***Potamonectes depressus, Orectochilus villosus, Elmis aenea, Oulimnius*** spp. *Limnius volckmari, Normandia nitens*		*Fast flowing*; Springhead: 1.0% Caldicot 24.2%	
Limited dung and house faunas	*Geotrupes* and *Aphodius* species. *Lyctus linearis*, *Atomaria* spp., *Lathridius minutus, Ptinus fur*		Dung fauna: Springhead 6.2% Caldicot 7.2% House fauna: springhead 8.6%	
Goldcliff Trackways 4, 6				**Freshwater marsh in slack at back of saltmarsh**
Dominated by freshwater and waterside species mainly associated with *Phragmites* reed bed	***Bembidion semipuctatum***, *Agonum thoreyi, Odacantha melanura, Dromius longiceps, Hygrotus inaequalis, H. scalesianus*, ***Ochthebius bicolon***, ***O. minimus***, **Hydrophilidae**, ***Paederus*** spp., ***Cyphon*** spp. ***Plateumaris braccata***, *Notaris* spp.		Aquatic: Trackway 4 45.0% Trackway 5 58.4% Waterside: Trackway 4 29.0% Trackway 6 18.9%	
No saltmarsh species, Limited dung fauna, limited house fauna	*Aphodius* species.		Dung fauna: Trackway 4 8.8% Trackway 6 1.5%	
Cold Harbour Pill and Redwick Building 4 and 2				**Upper Saltmarsh**
Moderate numbers of a wide range of freshwater and waterside species (less evidence for thick stands of reeds)	*Odacantha melanura*, ***Graptodytes granularis***, ***Gyrinus*** *spp.*, ***Ochthebius minimus***, ***Coelostoma orbiculare***, Aquatic *Cercyon, Chaetarthria seminulum, Lesteva heeri, Platystethus cornutus*, ***Helodidae***, ***Corylophus cassidoides***, *Plateumaris braccata*		Aquatic: Redwick 2 15.9% Redwick 4 9.1% Cold H P 5.2% Waterside: Redwick 2 6.4% Redwick 4 7.3% Cold HP 7.5%	
Moderate numbers of coastal species; a few species associated with salt water (but no species associated with open saline mud)	***Bembidion varium, B. fumigatum, B. assimile, B. minimum***, *Pogonus chalceus*, ***Ochthebius dilatatus, O. viridis***.	*Saline*: Redwick 2 0.5% (0.0-1.9%) Redwick 4 0.0% Cold HP 5.7% (0.0-8.6%) *Coastal*:Redwick 2 5.5% (3.7-10.6%) Redwick 4 9.2% (5.2-18.5%) Cold HP 11.9% (0.0-22.8%)		
Moderate moorland bog Limited dung fauna Small house fauna	***Bradycellus ruficollis***, *Hydroporus melanarius*, ***Micrelus ericae*** *Geotrupes* spp. *Aphodius* spp. *Atomaria* spp.		Moorland: Redwick 2 19.3% Redwick 4 10.9% Cold HP 3.3% Dung: Redwick 2 4.6% Redwick 4 7.1% Cold H P 6.3% House Redwick 2 3.3% Redwick 4 0.0% Cold HP 0.5%	
Goldcliff Buildings 1, 6, 8, Trackways 1130, 1330, 1311, 1108 and Walpole				**Low saltmarsh and mud flats**
Dominated by a wide range of coastal species, saline waters and species associated with open saline mud	*Dyschirius aeneus, D. salinus*, ***Bembidion varium***, *B. fumigatum B. assimile*, ***B. minimum***, ***Pogonus chalceus, Dicheirotrichus gustavi, Ochthebius dilatatus, O. marinus, O. viridis***, *Cercyon litoralis*, ***C. depressus***, *Bledius spectabilis, B. occidentalis*, ***Heterocerus fossor, H. flexuosus***, *H, maritimus*.	*Saline*: Goldcliff B1 1.3% (0.0-6.1%) Goldcliff B6 10.3% (1.4-14.9%) Goldcliff B8 15.2% (0.0-26.9%) Trackway 1130 3.1% (2.7-7.5%) Trackways 1330 1.6% Trackways 1311 6.5%		

		Trackways 1108 9.9% (1.7-13.6%) Walpole 23.1% (6.6-34.4%) *Coastal*:Goldcliff B1 0.5% (0.0-7.1%) Goldcliff B6 7.7% (0.0-12.0%) Goldcliff B8 10.0% (0.0-16.3%) Trackway 1130 7.0% (3.1-7.5%) Trackways 1330 17.7% Trackways 1311 22.2% Trackways 1108 9.1% (7.1-12.7%) Walpole 30.3% (29.4-50%)		
Moderate proportions of a diverse range of freshwater fauna	*Odacantha melanura, Dromius longiceps, Hygrotus inaequalis,* ***H. tessellatus****, H. scalesianus,* ***Ochthebius minimus, O. bicolon, various Hydrophilidae,*** *Platystethus cornutus,* ***Paederus* spp**., Silis ruficornis, **Helodidae**, *Heterocerus fenestratus*, ***Plateumaris braccata, P. sericea***, *Bagous* spp., *Notaris* spp., *Thyrogenes* spp., *Limnobaris pilistriata*, ***Corylophus cassidoides*.**		*Aquatic*: Goldcliff B1 6.1% Goldcliff B6 17.8% Goldcliff B8 26.7% Trackway 1130 54.4% Trackways 1330 40.7% Trackways 1311 37.0% Trackways 1108 26.4% Walpole 3.8% *Waterside:*Goldcliff B1 7.4% Goldcliff B6 3.9% Goldcliff B8 3.3% Trackway 1130 13.3% Trackways 1330 4.9% Trackways 1311 6.5% Trackways 1108 6.6% Walpole 9.4%	
Moderate proportions of a limited range of Moorland species Moderate proportions of a wide range of dung beetles Large number of individuals of a range of house fauna particularly in the buildings at Goldcliff	***Bradycellus ruficollis*, *Hydroporus melanarius***, *Plateumaris discolor*, ***Micrelus ericae*** *Geotrupes* spp., *Onthophagus* spp., *Aphodius erraticus, A. contaminatus,* ***A. sphacelatus, A. prodromus***, *A. fimetarius, A. ater, A. plagiatus,* ***A. granarius*.** ***Anobium punctatum, Typhaea stercorea, Cryptophagus* spp., *Lathridius minutus* (group),** *Atomaria, Ptinus fur*.		*Moorland*: Goldcliff B1 0.0% Goldcliff B6 2.8% Goldcliff B8 6.8% Trackway 1130 0.0% Trackways 1330 1.6% Trackways 1311 3.7% Trackways 1108 0.0% Walpole 0.0% *Dung*: Goldcliff B1 1.0% Goldcliff B6 9.2% Goldcliff B8 3.2% Trackway 1130 4.7% Trackways 1330 3.2% Trackways 1311 3.7% Trackways 1108 2.4% Walpole 0.0% *Dung*: Goldcliff B1 20.7% Goldcliff B6 11.3% Goldcliff B8 7.8% Trackway 1130 2.3% Trackways 1330 6.5% Trackways 1311 0.0% Trackways 1108 10.6% Walpole 0.0%	

Figure 1. Typical zonation in saltmarshes

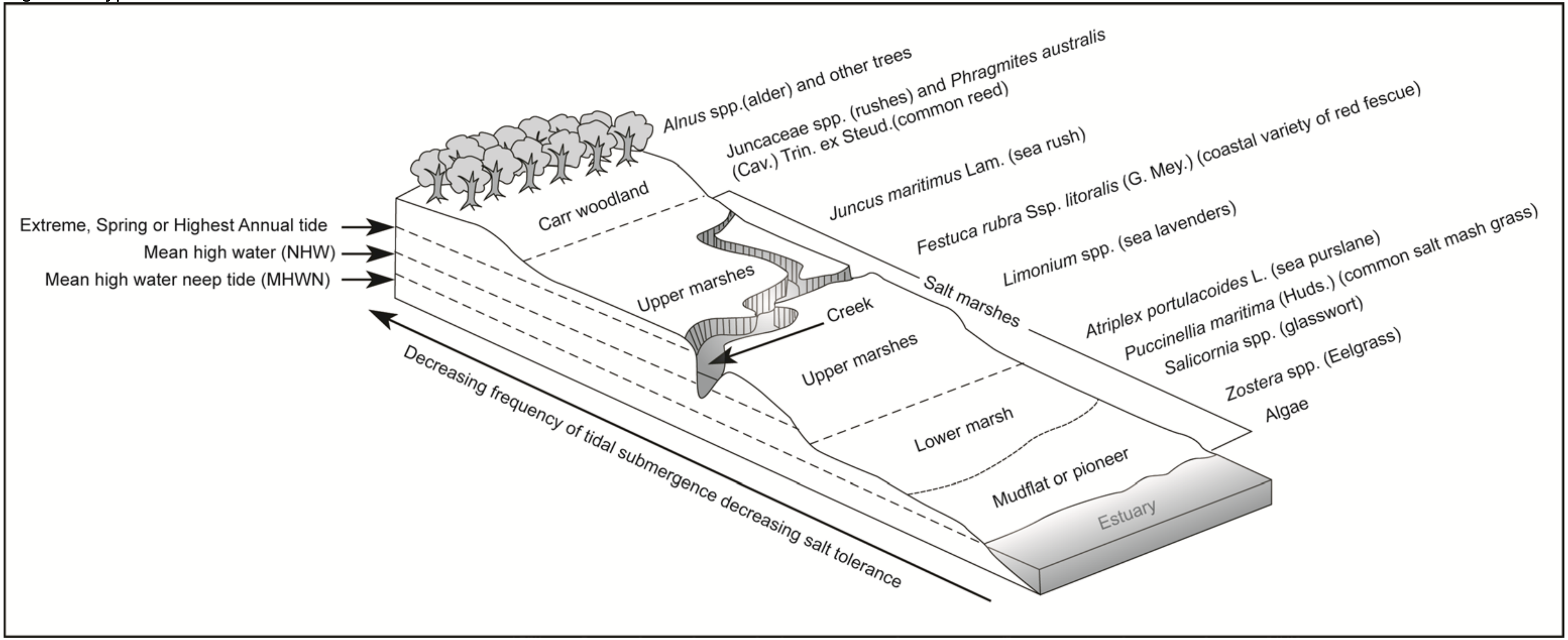

Figure 2. Location of the sites discussed

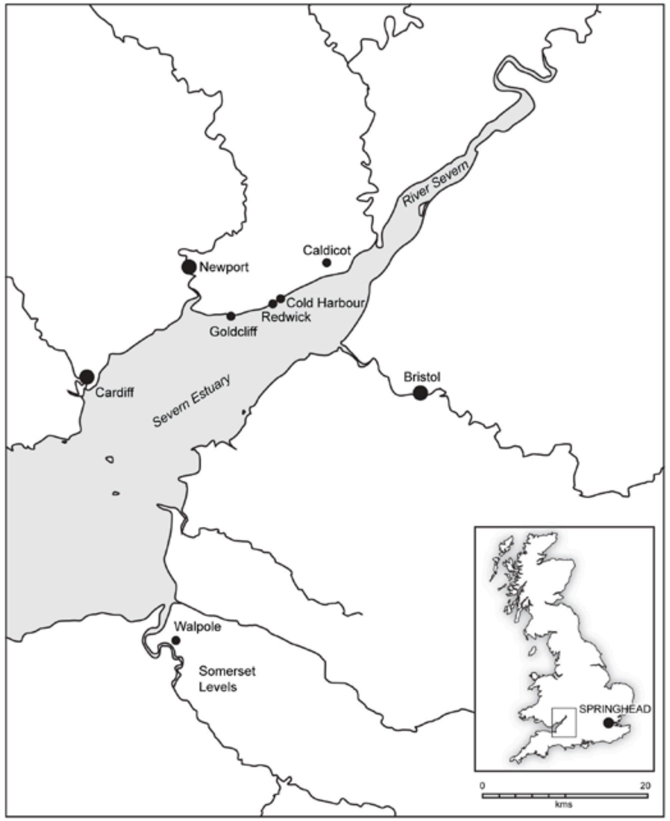

Figure 3. The relative proportions of the saltmarsh and coastal ecological groupings

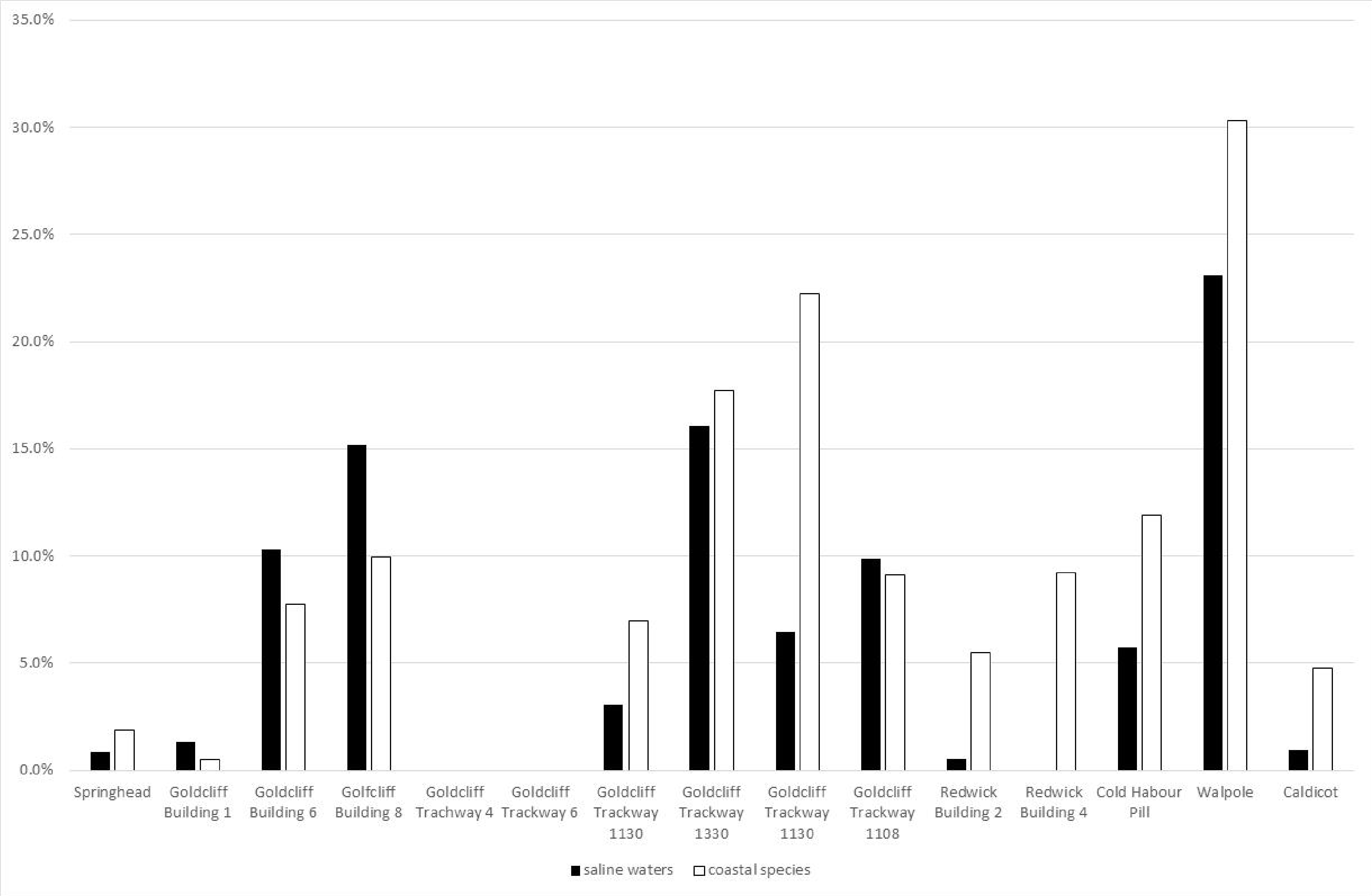

Figure 4. The relative proportions of the non-saline water ecological groupings

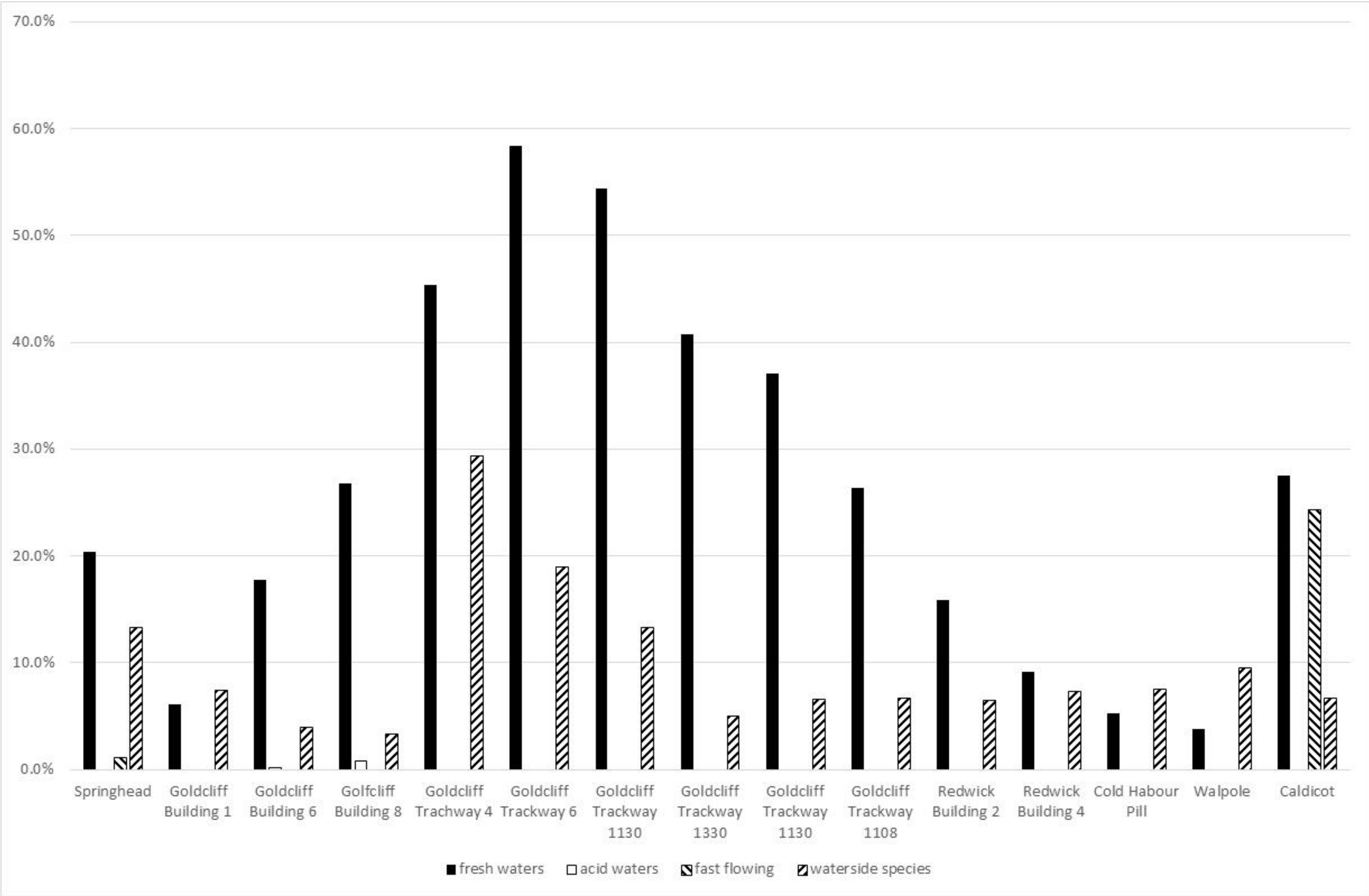

Figure 5. The relative proportions of the terrestrial ecological groups

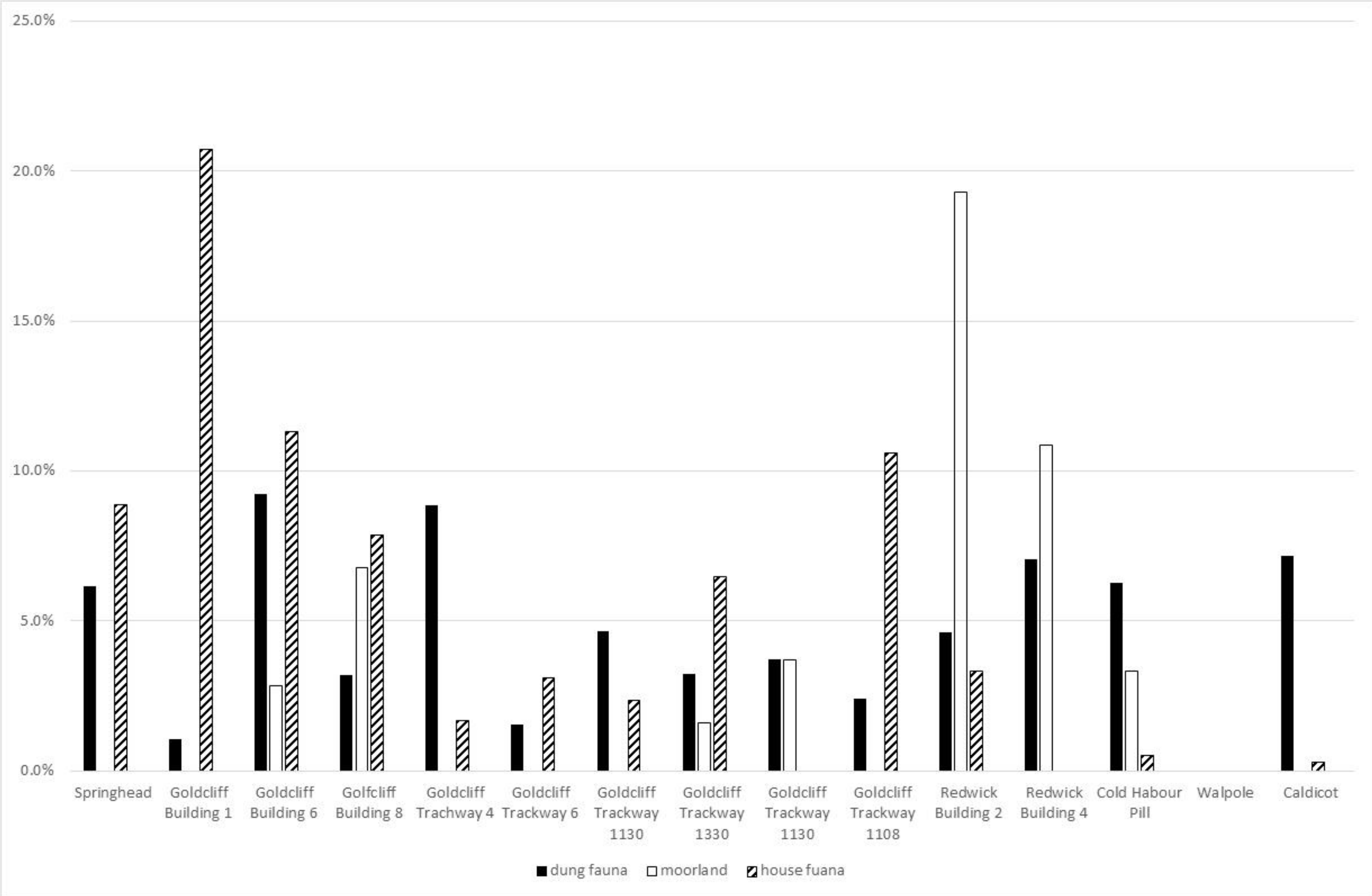

Figure 6: The CANOCO DCA ordinations. Figure 6a is the ordination by species. Figure 6b is the ordination by sample