Principles of cross congruence do not apply in naturally disturbed dune slack habitats: Implications for conservation monitoring

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Title: **Principles of cross congruence do not apply in naturally disturbed dune slack habitats: implications for conservation monitoring.**

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Abstract

Cross congruence, where diversity or composition of multiple species follow similar patterns, underlies the use of indicator species in conservation practice. However, there are circumstances in which cross congruence has been shown to break down, for example after disturbance events. If cross congruence does not occur in habitats which experience natural disturbance, then conservation measures based on indicator species may yield misleading results. We assessed the degree of cross congruence among three biological taxa in dune slacks, which are temporary ponds found in coastal sand dunes. We also investigated the efficacy of a national monitoring assessment based on a single taxonomic group, plants, to predict the diversity and composition of two other taxonomic groups: snails and water beetles. We found no evidence of cross congruence among these three groups and the plant-based monitoring system did not predict the composition or diversity of snails or water beetles. The potential for dune slacks to support species of conservation interest was demonstrated here as eight snail species and two water beetle species listed as Near threatened or Vulnerable on the Irish Red Lists were found within the 24 sites surveyed, and the Irish populations of two of these are of international significance (*Vertigo angustior*, *Leiostyla anglica*). Some of these species of conservation interest were found in dune slacks which were of poor conservation status according to the monitoring methodology applied. Our results show that indicator species drawn from a single taxonomic group are not adequate to monitor the general habitat condition of dune slacks. Dune slacks are among many habitats of conservation interest which experience natural disturbance, and this research has implications for conservation practice in other habitats such as seasonal wetlands and fire-dependent habitats.

Highlights

- Conservation assessment protocols based on indicator species might be undermined in habitats which experience natural disturbances because cross-taxon congruence breaks down after disturbance events.
- We found that diversity of plants, snails and water beetles in dune slacks, a habitat characterised by regular disturbance, were not congruent. A habitat assessment based on plant indicator species failed to reliably distinguish between dune slack sites on the basis of the richness or composition of their snail and water beetle assemblages.
- Indicator species should be taken from a range of different taxonomic groups to enhance conservation assessments in habitats which experience natural disturbances.

Keywords

Cross-congruence; indicator species; dune slacks; invertebrates; snails; water beetles; plants; conservation; assessment

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1. Introduction

Global biodiversity decline has been associated with reductions in ecosystem productivity (Liang et al., 2016) and consequent ecosystem service provision (Cardinale et al., 2012), across many different habitat types. Identifying, preserving and restoring habitats of conservation interest have been recognised as means to slow biodiversity loss. These activities require knowledge of the status of organisms using the habitat, but resource constraints rarely allow exhaustive studies of all the living things within systems of interest (Heino, 2010). Using a small number of surrogate or indicator species to infer the conservation status or biological diversity of a habitat or area has been suggested as an achievable alternative (Lambeck, 1997; Landres et al., 1988; Hillard et al., 2017; Cheyne et al., 2016).

Using species as indicators or surrogates in this way assumes cross-congruence, where the diversity or composition of many taxa are linked, so that changes to the diversity or composition of the broader biological community can be determined by surveying the indicator species alone (Westgate et al., 2017; LIndenmayer et al., 2014; Hunter et al., 2016). Cross congruence has been shown to occur in nature and is very influential in conservation planning and policy (Gioria et al., 2010; Howard et al., 1998b; Lund & Rahbek, 2002; Wolters et al., 2006). However, there is a growing body of published data which indicates that relationships between diversity of different taxa are variable (Westgate et al., 2014). For example, taxa which are very strongly associated with a particular habitat type are likely to be more congruent than generalist species (Prendergast, 1997), but in highly heterogeneous habitats, cross congruence may be inflated due to species turnover between habitats, regardless of their conservation value (Ekroos et al., 2013). Therefore species are most effective as indicators of habitat conditions or diversity if they are used within a specific, homogeneous habitat. In addition, habitat scale can affect the strength of cross congruence (Hess et al., 2006), but this can be mitigated by using taxa with small body-sizes in habitats characterised by small patches (Wolters et al., 2006). Disturbance is an important factor (Heino, 2010), as was demonstrated in a survey of Canadian wetlands where weak cross-congruence was associated with historical human disturbance, and individual species varied in their response to stress gradients (Rooney and Bayley, 2012).

Despite the observed variability in the strength and occurrence of cross congruence, biological indicators and surrogate species are embedded in conservation policies all over the world (US EPA 2002; "Fauna Wetland Indicator Species List" 2018; Ramsar Convention Secretariat 2010), including international conservation policies such as the European Union (EU) Habitats Directive (Council Directive 92/43/EEC). The ultimate aim of the Habitats Directive is that all of the habitats and species of conservation interest achieve favourable conservation status (Evans and Arvela, 2011). Conservation status is assessed under four parameters: range, area, structure and functions and future prospects. The use of positive and negative indicator species is central to the habitat structure and functions assessment. The characteristic species listed in guidance documents are predominantly plants, and this appears to have had a strong influence on the choice of indicator species among signatory states, although the authors encourage the inclusion on non-plant species in the structure and functions assessment (European topic centre on biological diversity). Clearly since this principle is being applied for monitoring of high-level conservation objectives, its efficacy should be assessed, particularly in habitats which experience frequent natural disturbance.

Thus in this study, we specifically addressed two key questions:

1) is cross congruence maintained in habitats of conservation interest where natural disturbance occurs?

2) in a habitat which experiences natural disturbances, do indicator species provide reliable information regarding diversity and habitat use by the wider community of organisms?

We sought to answer these questions by comparing the composition and diversity of taxa with contrasting biological and habitat requirements in dune slacks, a habitat which experiences natural disturbance. We applied the EU Habitats Directive habitat monitoring guidelines for Irish dune slacks (Delaney et al., 2013) to assess dune slacks in Ireland and tested the ability of this assessment to discriminate between dune slacks on the basis of two invertebrate groups: water beetles and snails.

1.2. Study System and target taxa

Dune slacks are damp depressions in sand dune systems ranging in size from a few square metres to several hectares. They arise from areas of low-lying bare sand such as former beaches or erosion features within larger sand dune systems. Unlike the dry dunes that surround them, the water table in dune slacks is close to the surface and it typically exceeds the slack floor when groundwater rises in late winter (Davy et al., 2006). Although dune slacks are dynamic and experience succession over their lifetime (Bossuyt et al., 2003; Smith, 2006), extreme habitat heterogeneity is rare within an individual dune slack at a single point in time unless there is a history of different management regimes or disturbance patterns within the slack (Adema et al., 2002). The clear delimitation between dune slacks and dry dune habitats and their relative lack of human disturbance correspond with the conditions in which strong cross congruence might be expected. Conversely, annual flooding and desiccation events act as natural disturbances and the presence of a dry phase and an aquatic phase means that the habitat experiences temporal heterogeneity. This natural disturbance could result in a breakdown of cross congruence despite the relatively low human impacts on most dune slacks.

The conservation value of dune slack habitats has been recognised under the EU Habitats Directive and they are designated as 2190 Humid dune slacks (Council Directive 92/43/EEC). They are recognised as being important refuges for some animal species and the inclusion of animal indicator species in the structure and functions assessment is encouraged (Evans and Arvela, 2011). Within the Atlantic biogeographical region of the EU, the typical species listed for Ireland (Delaney et al., 2013), the UK (Common standards monitoring guidance), France and Portugal do not contain any animal species (European topic centre on biological diversity), while Germany, the Netherlands and Belgium have included some bird species or the natterjack toad in their dune slack habitat assessments (European topic centre on biological diversity) but typical species for Denmark are not available.

The three taxa chosen for this study were plants (vascular plants and bryophytes), snails and water beetles. Both of the invertebrate taxonomic groups represent a subset of species within large phyla which share specific characteristics; snails (class Gastropoda, phylum Mollusca) have a shell into which their body can retract (Cameron, 2008) and water beetles (Order Coleoptera, Class Insecta, Phylum Arthropoda) live underwater for part of their lifecycle and so are likely to be caught in sweep-net samples (Foster et al., 2014). Vascular plants and bryophytes are currently used to assess habitat condition in dune slacks in accordance with the EU Habitats Directive in all of the signatory states. Water beetles and snails were chosen because they have small body size, because they are well described and can be identified to species, and because they are diverse groups which are sensitive to environmental changes (Bilton et al., 2006). Both have been demonstrated to exhibit cross-taxon congruence in ponds (Bilton et al., 2006; Gioria et al., 2010) and they are commonly found in temporary waterbodies in Britain and Ireland (Nicolet et al., 2004; Reynolds, 1985). However, because of differences in dispersal and lifecycles, water beetles and snails are likely to differ in their responses to flooding and desiccation. Although records suggest that dune slacks represent an important refuge for aquatic species due to the loss of inland wetland habitats (Cameron, 2008; Foster et al., 2014; Foster & Friday, 2011; Davidson, 2014), comprehensive surveys of aquatic invertebrates in dune slacks have not been carried out on a large scale in Europe or elsewhere. There is therefore no list of the aquatic invertebrates associated with good habitat condition in dune slacks.

2 Methods

2.1 Site selection

We used pre-existing habitat maps (Delaney et al., 2013; Ryle et al., 2004) to select twenty-four dune slacks across the Republic of Ireland (Figure 1). They were evenly distributed among the regions containing the greatest concentration of dune slacks in Ireland: counties Donegal, Mayo, Kerry, and the east coast from Dublin to Wexford. Selected slacks conformed to a similar range in area from small (0.2–0.29 ha) to large (6–8 ha) within each region. This research focussed on calcareous dune slacks with predominantly herbaceous vegetation and a shallow water table which were located inside EU Natura 2000 Special Areas of Conservation (SACs). Slacks with permanent water bodies, acidic conditions or very sparse vegetation were not included. We did not include any slacks where human interference in the substrate such as sand or sod removal was known to have occurred.

These exclusion criteria ensured that the most common dune slack types in Ireland were available for selection while variability in the history, anthropogenic disturbance and fundamental abiotic conditions affecting the slacks was limited. We selected only one slack from any sand dune system to ensure that all sites were independent.

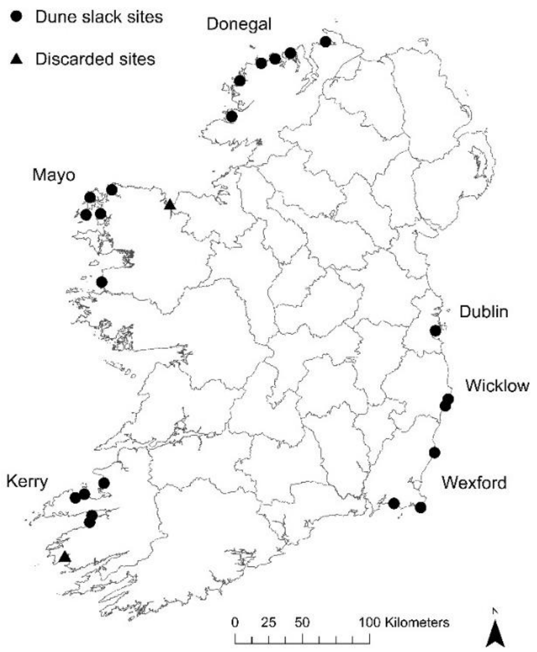

Figure 1 Dune slack sites included in this research. Reasons for discarding sites are given in section 3. NOTE: 1 COLUMN

2.2 Vegetation survey

We recorded vegetation in 2 m x 2 m quadrats from June to September 2015. Sampling intensity was deemed adequate when the number of new vascular plant species recorded in each new quadrat was equal to one or zero, resulting in 3 – 9 quadrats per site. We recorded plant species cover in percent digitally in the field using *Turboveg for Windows 2.120* (Hennekens and Schaminée, 2001) and nomenclature followed the Ireland2008v2 species list. If several vegetation communities, such as reed bed or *Salix repens* dunes, occurred in a single slack, at least one quadrat was placed in each microhabitat, but otherwise we placed the quadrats at random.

2.3 Invertebrate surveys

We collected snail samples once during the dry phase from July to September 2014 and twice during the flooded phase in March and April 2015. During the dry phase, we removed all leaf litter, vegetation and loose soil within a 25 cm x 25 cm quadrat adjacent to each vegetation quadrat. We sampled snails at nine points evenly distributed in the dune slack during the flooded phase by using a 0.5 mm mesh net to collect all loose material within a box quadrat (23 cm x 27 cm) following O'Connor et al. (2004). All material collected was dried and gastropods were isolated by passing the material through a 0.5 mm sieve (Long et al*.,* 2012). Individuals which had more than three complete whorls and a developed mouth were treated as adults and identified to species following Cameron (2008). Juveniles could not be identified reliably for all species, and so were not considered during the analysis. Nomenclature followed Anderson (2005).

Water beetles were not surveyed during the dry phase as they do not remain in the habitat when water is not present (Reynolds, 2003). In accordance with O'Connor et al. (2004) a high sided quadrat measuring 40 cm x 35 cm was placed adjacent to each of the aquatic snail quadrats in March and April 2015. Loose material was collected with a 0.5 mm net and placed in a tray where the beetles were removed and stored in alcohol for identification. Identification was carried out using Foster and Friday (2011), Foster et al. (2014) and Friday (1988).

When comparing the diversity and composition patterns of water beetles with those of plants and snails, we considered only those sites which flooded in the winter of 2014/2015 as water beetles were only surveyed in flooded sites.

2.4 Quantifying diversity

Species-area curves approached the asymptote for plants at most sites, but water beetles and snails were sparsely distributed at some sites and this resulted under-sampling of waterbeetles at 56% and under-sampling of snails at 40% of sites. We used the iNEXT package for R (R Development Core Team, 2013; Chao et al*.,* 2014) to standardise samples and calculate Hill numbers corresponding to species richness (H_0) and diversity (inverse Simpson's concentration: H_2) (Chao et al*.,* 2014). Inverse Simpson's concentration is a useful complement to species richness because it is highly sensitive to dominance (Jost et al., 2011). Standardisation was achieved by first estimating the coverage of the sample (the likelihood that any individual taken from the total species pool at a site will belong to one of the species included in the sample) at each site based on relative abundance (Chao and Jost, 2012). The species richness or diversity was then rarefied or extrapolated to correspond to 50% coverage to facilitate comparisons between sites. Fifty percent is the minimum coverage required for an accurate comparison between groups, and did not require extrapolating beyond the threshold for accuracy (extrapolation to twice the number of samples actually recorded) (Chao and Lee, 1992). Estimated species richness represents a minimum value, whereas the metric corresponding to Simpson's diversity is relatively unbiased (Chao et al., 2014). At sites where four or fewer individuals were present, the diversity index calculations should be interpreted with caution as they may not be an accurate reflection of diversity. We consulted the Irish Red Lists to determine the IUCN threat status category in Ireland for each species of plant, snail and water beetle we found (Byrne et al., 2009; Foster et al., 2009; Lockhart et al., 2012; Wyse Jackson et al., 2016).

2.5 Data analysis

We performed data analyses in R (R Development Core Team 2013) with the aid of the data analysis package Vegan (Oksanen et al., 2016). We used Kendall rank order correlation to test whether a relationship could be detected between species richness and diversity of plants, snails and water beetles in dune slack sites. A non-parametric method was appropriate because sample sizes were uneven and the data distribution was non-normal (Dytham, 2003). We visualised the composition of snail and plant species records at each site with non-metric multidimensional scaling (NMS) which is a reliable method for zero-rich data (Kent, 2011). Beetles were sparsely distributed and many species occurred only once within the dataset. To compensate, we aggregated the beetle records to genus level before performing NMS. This is reasonable since water beetle species within genera play ecologically similar roles according to data describing their functional traits (Tachet et al., 2010). We calculated the mean number of each species/genus recorded per quadrat at each site and log-transformed the result ($\log_{10}(x + 1)$) to reduce the influence of extreme values (McCune & Grace, 2002). We removed species/genera of plants or invertebrates which only occurred once in the dataset prior to running the NMS, and any site which was left with no species or a single species was also removed. Removing singleton species or sites with a single species is recommended in ordination as they do not contribute useful information for generating a matrix of similarity (McCune & Grace, 2002). We set the number of axes to be generated in each case to 2 and the number analysis runs with different random start configurations to 20. We used Procrustean rotation to assess how similar the NMS plots for plants, snails and water beetles were and assessed the significance of any similarities with the permutational test PROTEST.

2.6 Cross-applicability of a conservation assessment based on plant communities

We applied the 2190 Humid Dune Slacks Annex I habitat assessment used in Ireland (Delaney et al. 2013) to data recorded in the field for each slack. The assessment was designed to be applied over the entire dune slack habitat within a sand dune system, and we modified it for application in a single dune slack. We retained all of the structure and functions criteria with the exception of the criterion specifying the acceptable quantity of bare ground (Table 1), as lack of bare ground within an individual dune slack is not an indication of habitat degradation. We assessed the presence of positive indicator species listed on the habitat assessment protocol (Delaney et al. 2013), which is dominated by plants of the species-rich pioneer phase. We also assessed the presence of negative indicator species which are typical of agricultural activities, abandonment and nutrient enrichment. We considered the cover of bryophytes, scrub, non-native species and forb species and environmental factors such as disturbance due to human activities and coastal defences which have altered the sediment processes of the dune system. Ground water chemistry, flood duration and dune slack morphology are not taken into account as part of the structure and functions assessment.

We used the non-parametric Mann-Whitney U statistic to compare the diversity (estimated richness: H_0; and diversity: H_2) of snails and beetles at sites which failed with those that passed the habitat assessment. PERMANOVA analyses were carried out to compare the distributions of plants, snails and water beetle species in sites which passed and failed the 2190 Humid Dune Slacks habitat assessment (distance measure: Bray Curtis, 1000 permutations).

3 Results

The data recorded from quadrats at each site have been submitted to the Irish National Biodiversity Data Centre. We excluded one site from the project because it was inaccessible for much of the year and another because, on inspection, it did not contain dune slack habitat. Six of the sites failed to flood during the monitoring year, so while snails and plants were collected at 22 sites, water beetles sampling was carried out at 16 sites. Plants were the most species rich group with 195 species, followed by snails (33 species) and water beetles (23 species). Abundance of beetles and snails collected at each site was very variable. No beetles were found at three sites and fewer than four individuals were collected at seven of the remaining sites. More than four snails were sampled at 18 sites, and no snails were recovered at one site.

There was no significant correlation between estimated richness (H_o) and diversity (H_2) of plant, snail and water beetle assemblages within a site (Table 2).

The best fit NMS plots for plants had a stress value of 0.15, for snails 0.14 and for beetles 0.09, and stress values of less than 0.2 indicate a good two-dimensional representation of multivariate data (Clarke, 1993). The procrustean rotation plots for plants and snails show that that there is considerable distance between the locations of sites in the ordination plot when it was at the optimal or closest matching rotation (Figure 2) and no evidence for cross-congruence was detected (sum of squares = 0.85, Procrustes correlation = 0.39, p = 0.13).

Nor was there evidence of cross congruence between water beetle assemblages and those of plants (sum of squares = 0.74, Procrustes correlation = 0.51, p = 0.23) or snails (sum of squares = 0.80, Procrustes correlation = 0.45, p = 0.39).

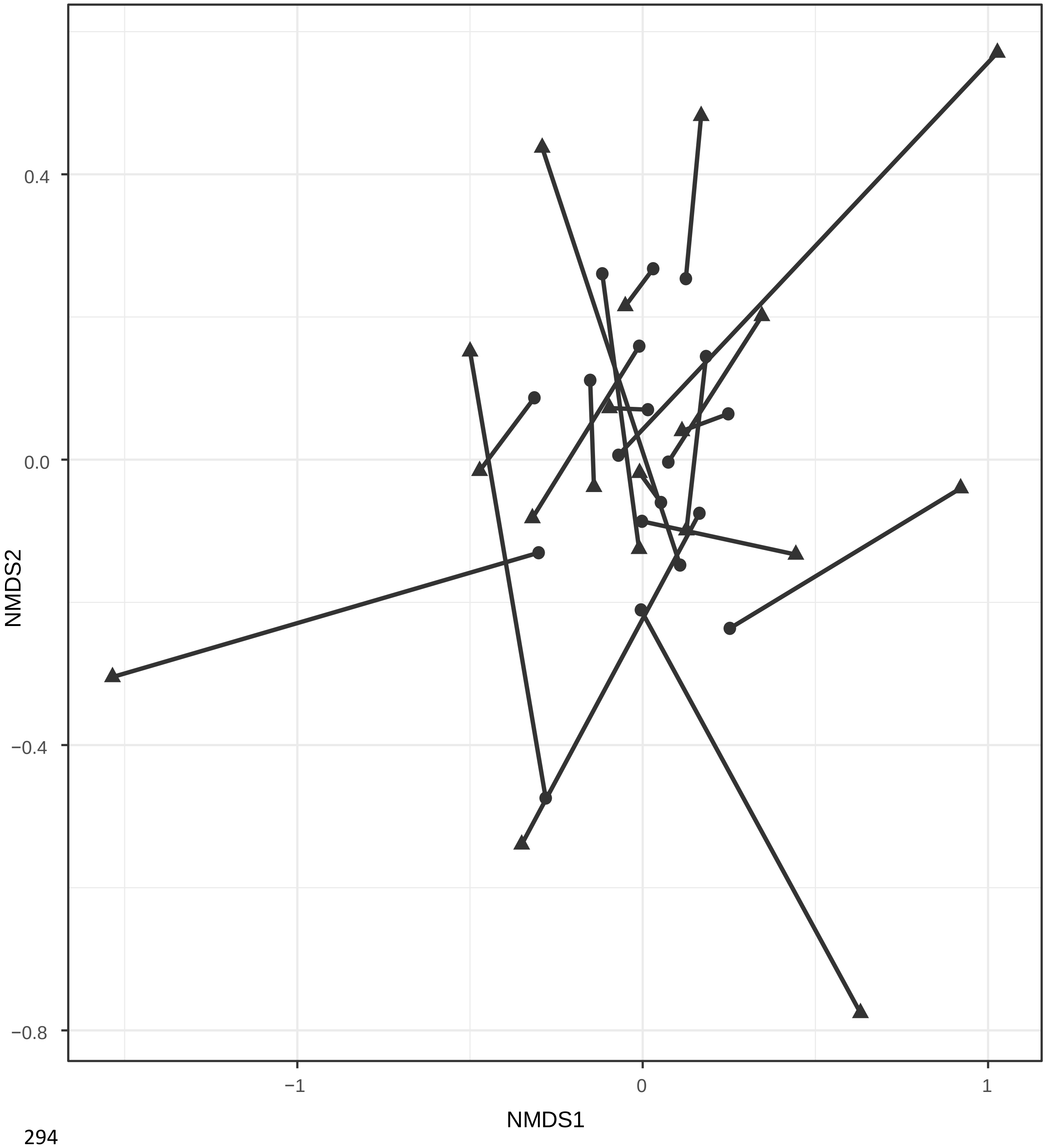

Figure 2 Ordination plot of plant assemblages at the sites surveyed (triangles). Triangles which are located close to each other in ordination space represent sites with similar plant composition. The ordination plot for snail species (dots) has been rescaled, rotated and superimposed on the plant assemblage ordination in the configuration showing the greatest possible similarity between plots as

described by their plant and snail assemblages. Each site is represented as a dot (snail assemblage) and a triangle (plant assemblage) joined by a line. The presence of long lines in relation to the NMS axis lengths shows that the configuration of plant and snail assemblages within the sites surveyed were not similar.

Twelve sites passed and 10 sites failed the habitat assessment based on vascular plants. No significant difference was detected in the estimated species richness (H_0) of snails (U = 61, $p < 0.67$) or water beetles ($U = 17$, $p = 0.71$) or in the diversity (H_2) of snails ($U = 62$, p = 0.62) or water beetles ($U = 17$, $p > 0.71$) recorded at sites which passed and failed the assessment (Figure 3). The species compositions of snails (F= 0.67, $p = 0.79$) and beetles ($F = 1.55$, $p = 0.17$) did not differ significantly at sites which passed and failed the habitat assessment. NOTE: 1 COLUMN

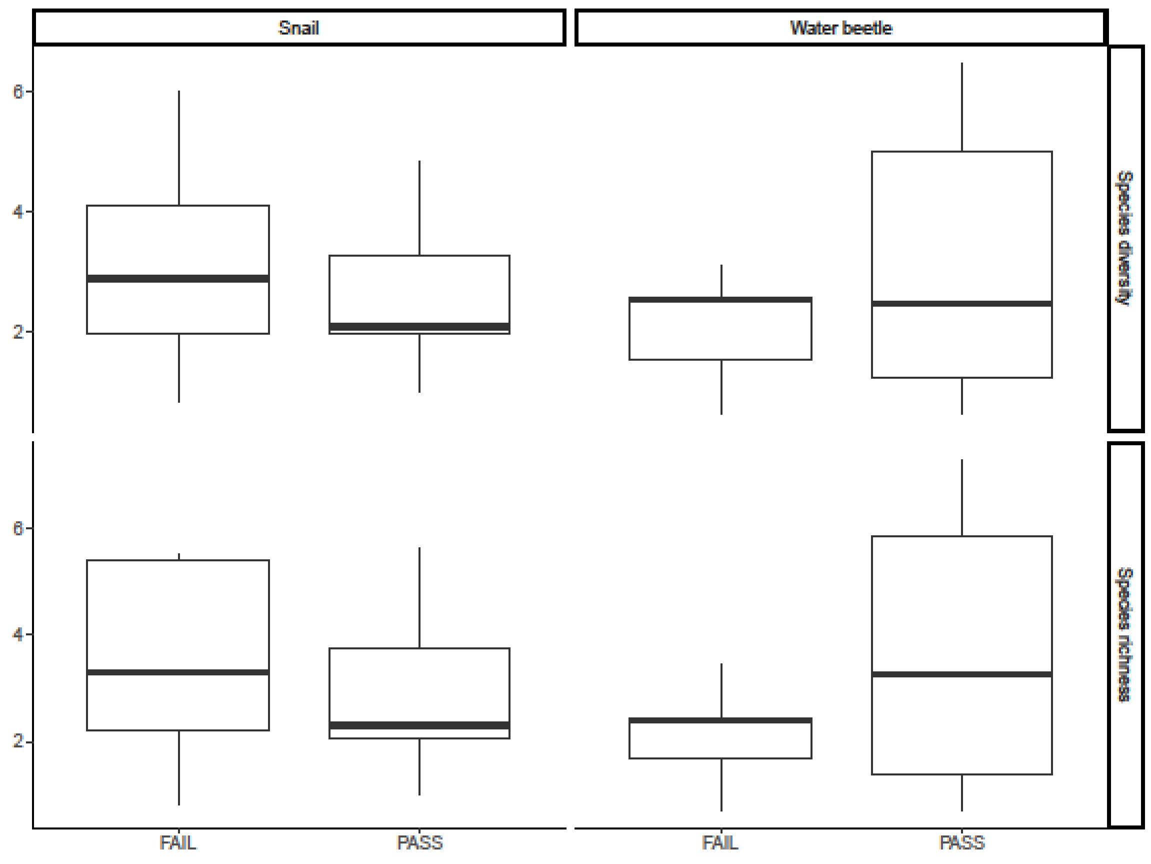

Figure 3 Diversity (Inverse Simpson's concentration, H_2) and richness (H_0) of snail and water beetle species in sites which passed and failed the conservation assessment. The bold horizontal line indicates the median value and boxes represent the interquartile range. The total range of values recorded is shown as a vertical line above and below the box. NOTE: 2 COLUMNS

Snail species of conservation concern were found at eleven sites which passed and seven sites which failed the habitat assessment. Of these species, six were listed as Vulnerable and two as Near Threatened on the Irish Red List for snails (Byrne et al., 2009). Among water beetles, *Enochrus halophilus* is listed as Vulnerable and was found in a site which passed the assessment while *Dryops similaris* is listed as Near Threatened and was found in a site which failed the habitat assessment (Foster et al., 2009). The remaining species were listed as being of Least Concern. All of the plant species found were of Least Concern according to the Irish Red List for vascular plants and bryophytes (Lockhart et al., 2012; Wyse Jackson et al., 2016).

4 Discussion

The dune slacks we surveyed generally contained diverse plant communities of wetlands and sandy places which are typical of the habitat in Ireland and Britain (Fossitt, 2000; Rodwell et al., 2000). There are no published records of large scale surveys of aquatic invertebrate species in temperate dune slacks, and the number of coleopteran and gastropod species recorded in other temporary water bodies can be highly variable. That being said, snail abundance and diversity were high in relation to some other temporary waterbodies (Nicolet et al., 2004; Porst and Irvine, 2009), although this may be partly due to having surveyed both during the wet and dry phases rather than focussing on one or the other. In comparison to surveys of other temporary freshwaters in Ireland and Britain, the dune slacks we surveyed were relatively poor in water beetle species (Nicolet, 2004; Collinson et al., 1995; Porst and Irvine, 2009). Plants and snails were more abundant than water beetles in the dune slacks we surveyed and the results of analyses carried out on them should carry greater weight.

Although we minimised factors associated with reduced cross-congruence by using invertebrates with a small body size, conducting the research in a specific habitat type and selecting sites within a conservation network to minimise the likelihood of human impacts (Prendergast, 1997; Wolters et al., 2006; Rooney and Bayley, 2012), we did not find evidence of cross-congruence in estimated diversity or in composition among plants, snails and water beetles in Irish dune slacks. The taxa may be subject to different community assembly processes due to their differing biology, or they may respond differently to the abiotic forces affecting the dune slacks (Saetersdael & Gjerde, 2011). A likely explanation is that the three taxonomic groups respond differently to the natural disturbance of periodic flooding due to differences in their biological requirements. A fluctuating water table is required to maintain the typical plant community of dune slacks (Davy et al., 2006, Currelli et al., 2013, Grootjans et al., 1991), whereas the end of the flooded phase is a major disturbance for water beetles, and dune slacks must be recolonised each flood season. A thorough investigation of the role of community assembly forces including habitat filtering is beyond the scope of this paper.

Because plant, snail and water beetle species are not cross-congruent in dune slacks, managing the habitat to protect or restore a specific plant community will not necessarily protect the snails and water beetles found there. For example, three of the six sites which were not observed to flood in 2014/2015 passed the conservation assessment. According to data from Met Éireann, the Irish meteorological service, rainfall in 2014 exceeded the annual average of the preceding 30 years in all of the regions where we selected sites, so lower than average water tables were not expected during the survey period. Four of the sites which failed to flood were on the east coast of Ireland where water resources are thought to experience greater pressure due to urban and tourist developments (Ryle et al., 2009, Delaney et al., 2013), and so reduced frequency or duration of flooding could be linked to human activities. Drying out is a major threat to European dune slacks (Grootjans and Stuyfzand, 1998) and it is of concern that this monitoring system failed to identify sites that no longer flood on an annual basis and therefore do not reliably provide habitat for aquatic species. This could lead to missed opportunities for conservation interventions and subsequent loss of species from some sites. In addition, annual flooding has been shown to be important for the long term maintenance of the calcareous wetland vegetation community of dune slacks elsewhere in Europe. By the time major vegetation changes are noted, the dune slack system may have been damaged beyond the point of restoration to its normal functioning (Grootjans et al., 1991). These results suggest that the use of a set of indicator species composed entirely of plants is inadequate to protect the long-term functioning of dune slack habitats.

There is no reference list of invertebrates associated with ideal conditions in dune slacks, but species classified as Vulnerable on the Irish Red Lists were found at six of the ten sites which failed the habitat assessment. Although these are not necessarily dune slack specialists, two were aquatic species and four were wetland species (Foster et al., 2009; Byrne et al., 2009), so they are likely to be particularly associated with the humid conditions in dune slacks rather than the sand dune habitat as a whole. Because eight of the species of conservation interest occurred at sites which failed the conservation assessment, they may be subjected to conservation measures which are not designed to protect them (e.g. NPWS, 2014).

The presence of eight snail species and two water beetle species listed as Near Threatened or Vulnerable on Irish Red Lists indicates that dune slacks provide important habitat for invertebrates whose populations are in decline. The Irish populations of two of the species recorded here are of international significance (*Vertigo angustior*, *Leiostyla anglica*). Many of the wetland and aquatic species on the Irish Red List were formerly found throughout Ireland but are now most commonly found in coastal locations (Byrne et al., 2009, Foster et al., 2009), and the importance of coastal wetlands as refuges for declining species is not merely an Irish phenomenon. Globally, wetland losses are estimated at between 54% and 57 % since 1700, most losses have occurred since 1900 and loss has occurred at a greater rate inland than in coastal regions (Davidson, 2014). Coastal wetlands such as dune slacks, Mediterranean temporary ponds and marshes therefore represent important refuges for freshwater wetland species affected by habitat loss. Measures such as the creation of areas of conservation in line with the EU Habitats Directive have the potential to prevent further biodiversity loss on an international scale (Hochkirch et al. 2013) but guidance on the choice of monitoring tools including indicator species should take the dual aquatic and terrestrial aspects of wetlands into account to avoid the implementation of inappropriate conservation measures.

The increasingly precarious position of much life on earth has been highlighted in the publication of the World Wildlife Fund's Living Planet Report (World Wildlife Fund, 2016), a report that echoes themes in academic literature (Cardinale et al., 2012; Díaz et al., 2006). Wetlands and their dependent taxa are among many that have suffered losses. Large-scale interventions to conserve habitats and species such as the Habitats Directive are to be welcomed but it is important to test them and ensure that the resources invested in conservation yield the best possible result. In contrast to the results reported here, the species recommended for protection under Annexes II and IV of the Habitats Directive have proved to be potentially reliable umbrella species in conservation planning (Lund, 2002). This is likely to relate to the fact that Articles II and IV include a wide range of taxa, so the conservation sites chosen on the basis of these species would contain a range of environmental conditions suitable for a variety of taxonomic groups. Our results show that choosing indicator species from more than a single taxonomic group would improve the sensitivity of monitoring schemes in dune slacks. Further research is required to determine whether this is also the case in other habitats which experience disturbance as part of their natural functioning.

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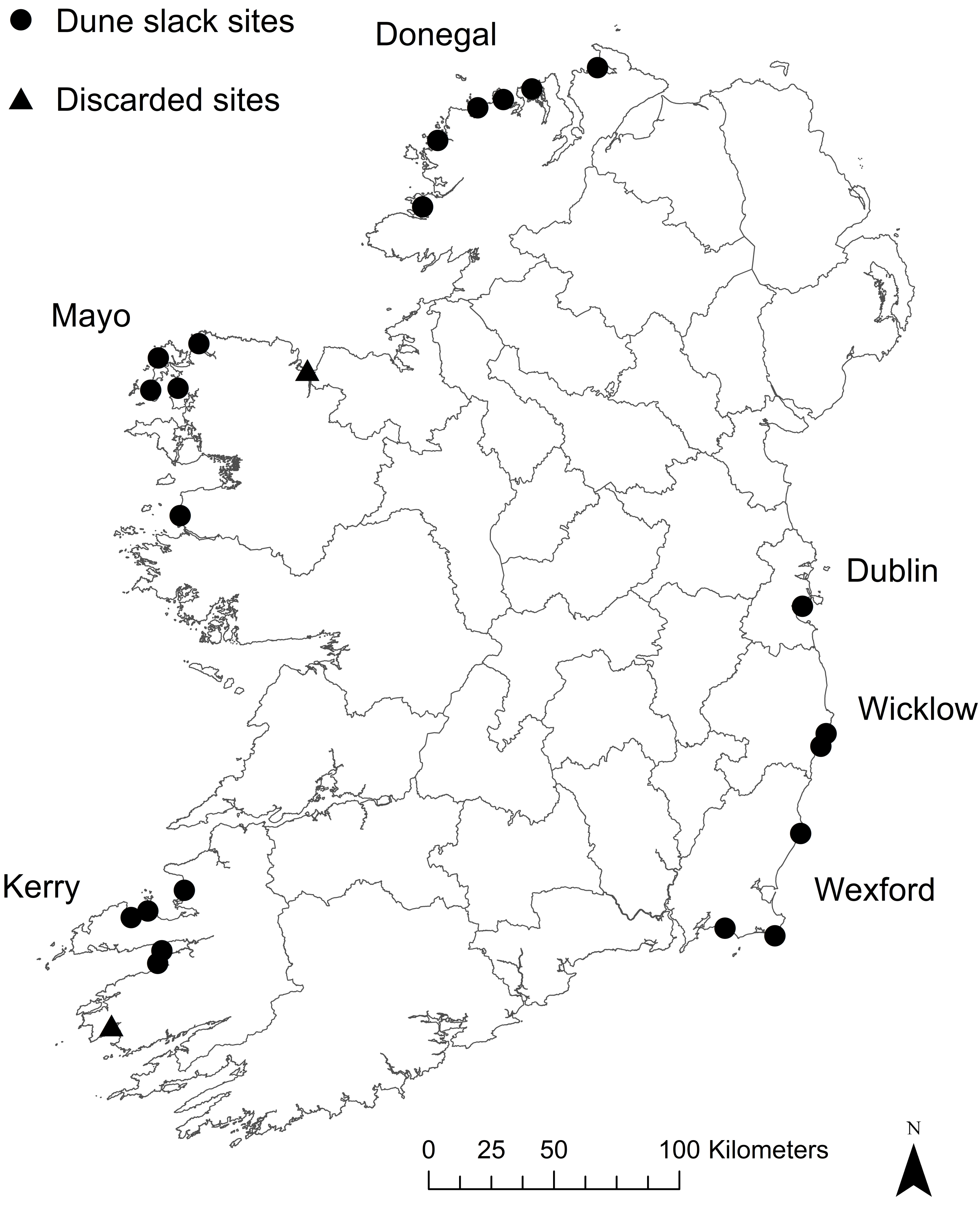
Table 1 Habitat assessment criteria modified from Delaney et al. (2013) for application at a single dune slack. NOTE: 2 COLUMNS

Assessment Criterion	Pass requirement
Positive indicator species	Four species present in over 40% of quadrats and two further species present in more than 20% of quadrats. At least three positive indicator species must be present in every quadrat.
Negative indicator species	No species present in more than 60% of quadrats or with a cover within a quadrat of greater than 25%. Combined cover of negative indicators 5% or less.
Cover of scrub	Scrub present in no more than 40% of quadrats and combined cover of 5% or less
Cover of Salix repens	A mean of less than 40% cover in quadrats
Frequency of bryophytes	Present in more than 20% of quadrats
Non-native species	No non-native species present in more than 20% of quadrats
Forb: grass cover ratio	Forb cover over 30%, grass cover below 70%
Disturbance	Impacts such as trampling, vehicle damage etc. affecting no more than 20% of habitat
Coastal defences	No anthropogenic impacts on the substrate/mobility of the system resulting from coastal defence works put in place or modified subsequent to the site's designation as an SAC, or from sediment extraction in the same period.

Table 2 Correlation tests for relationships between estimated species richness, diversity and composition of snails, plants and beetles. NOTE: 2 COLUMNS

Test	Subjects	Z-score	Tau	P value
Kendall rank correlation of estimated species richness (H_o)	Plants and snails	-0.33	-0.05	0.74
	Plants and beetles	0.62	0.13	0.54
	Snails and beetles	-0.24	-0.05	0.81
Kendall rank correlation of estimated diversity (H_2)	Plants and snails	-0.76	-0.11	0.45
	Plants and beetles	0.37	0.08	0.71
	Snails and beetles	-0.24	-0.05	0.81



Dune slack sites
Discarded sites
Donegal
Mayo
Dublin
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Kerry
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0
25
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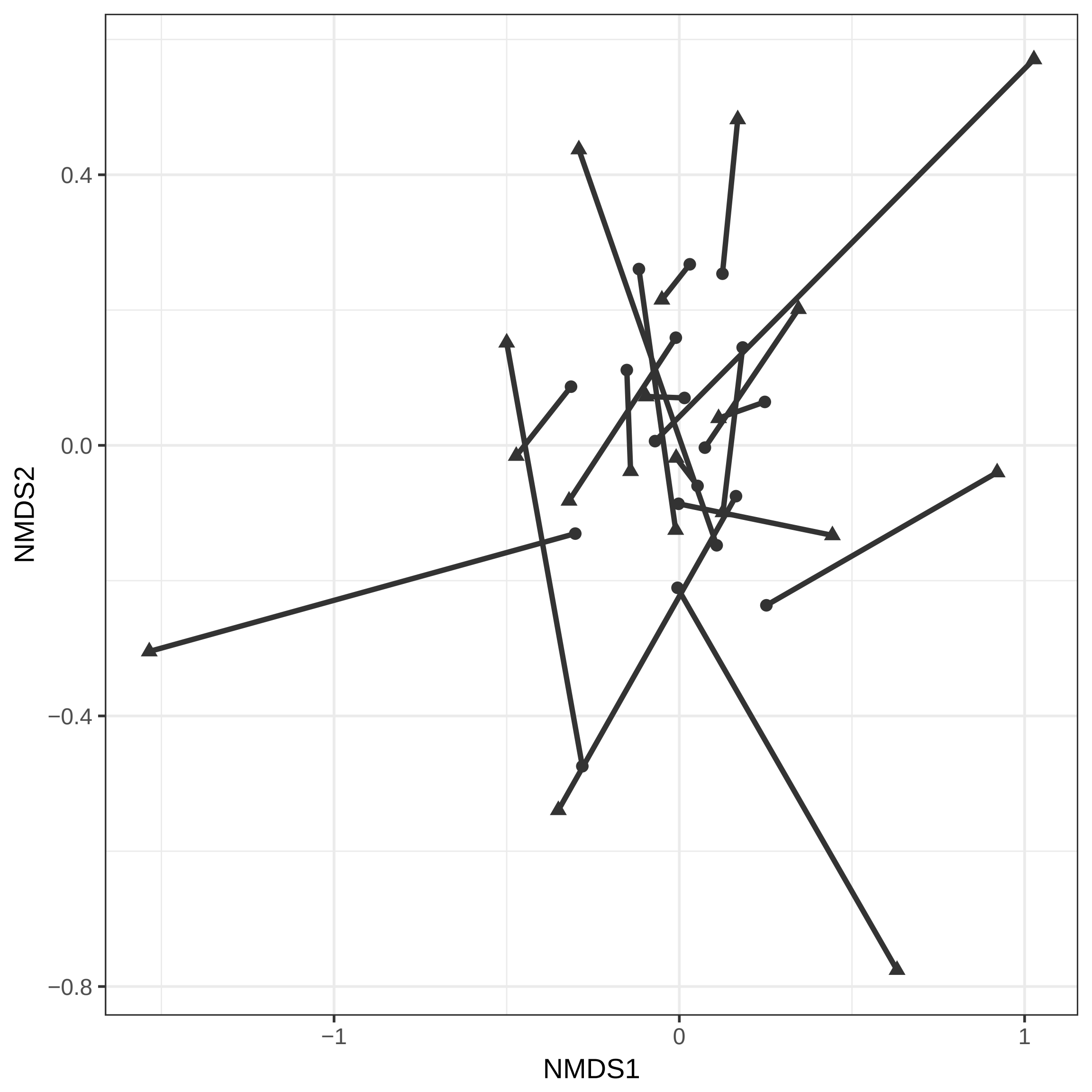
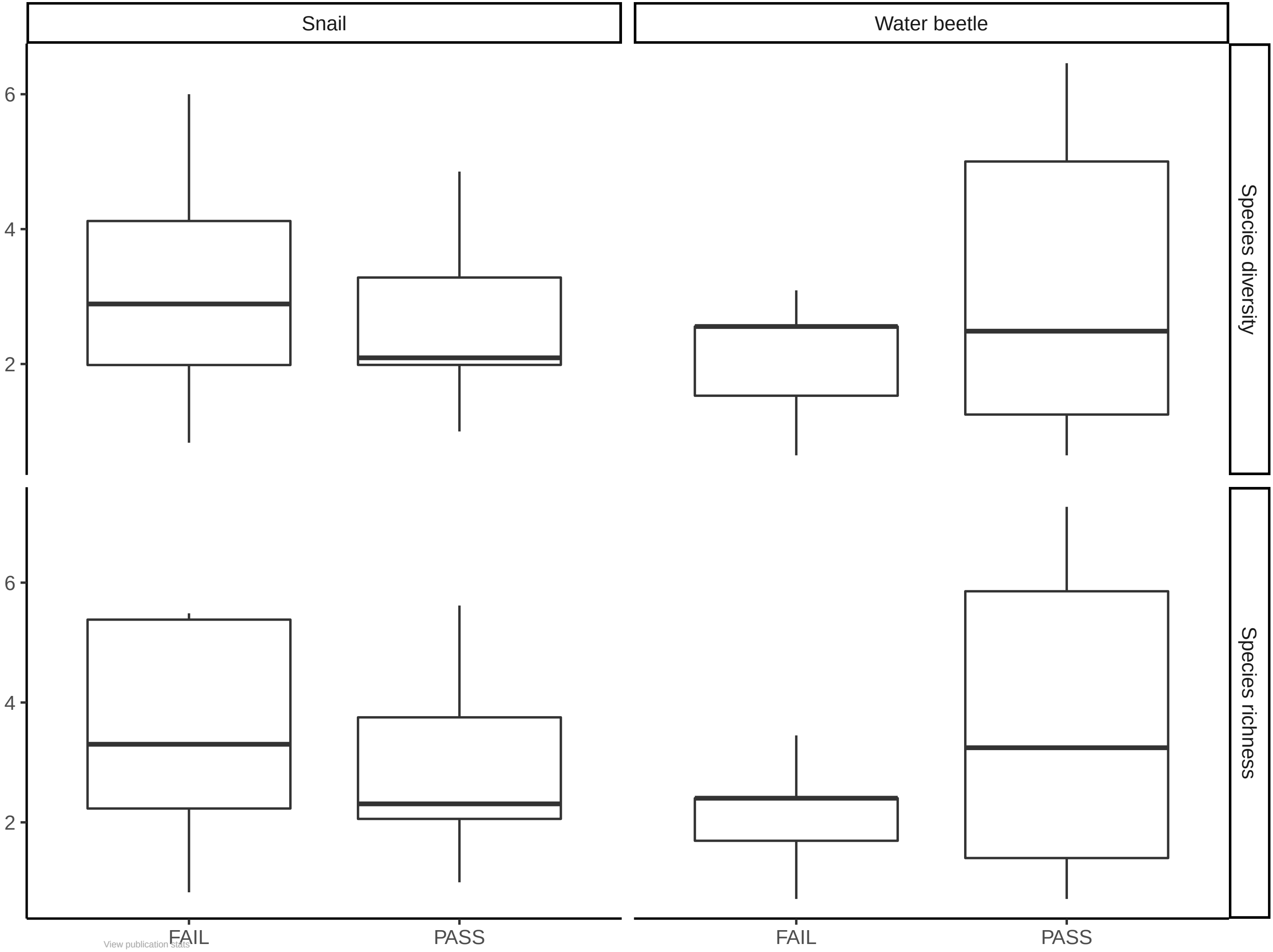


0.4
0.0
−0.4
−0.8
−1
0
1
NMDS1
NMDS2


Snail
Water beetle
Species diversity
Species richness
6
4
2
6
4
2
FAIL
PASS
FAIL
PASS