The extent and cause of 'unwelcome species' on the sand dunes of Sheskinmore Lough SPA, northwest Ireland

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MSc Conservation

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Abstract

Coastal sand dunes are a product of complex relationships between oceanic, geomorphic and ecological processes. Due to their position within the coastal zone, these formations are mostly transient in nature and are sensitive to biotic and abiotic changes. As a result, factors such as invasive species, recreational activity and climate change threaten to alter the dune environment and flora communities. Currently, there is little understanding of the impact that 'unwelcome' species such as *Pteridium aquilinum* (L.) Kuhn and *Rosa pimpinellifolia* (L.) have had upon the Sheskinmore Lough SPA dune system. Furthermore, an understanding of whether the distribution of 'unwelcome' species has been influenced by a local caravan site is required.

The fixed dune grassland of Sheskinmore Lough SPA was surveyed using four transects radiating away from the caravan site. Species data and environmental gradients were analysed to assess relationships between quadrats with 'unwelcome' species and quadrats without. GIS was used to gain a spatial understanding of the environmental parameters. No significant relationship between species diversity and distribution of 'unwelcome' species was found. *R. pimpinellifolia* has not established dense stands of vegetation and has not influenced levels of biodiversity or environmental gradients. By contrast, *P. aquilinum* has formed large delineated patches of growth in three locations of the study site. A bracken patch was identified adjacent to the caravan site, where phosphate levels and calcium carbonate quantities are high. The caravan site has evidently had an impact upon the surrounding environment.

A targeted management plan of removal has therefore been advised, which focuses on cutting and pulling *P. aquilinum* twice yearly to eradicate the unwelcome species. Immediate action is required before the bracken affects the edaphic and floristic environment. The transient nature of the dunes, combined with climate change, means that the management plan must adapt to the changing environment over time.

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1. Introduction

1.1 Sand dune formation

Coastal sand dunes are a product of complex relationships between oceanic, geomorphic and ecological processes. Due to their position within the coastal zone, these formations are mostly transient in nature and are subject to growth and decay. Sand dunes that have formed along the current coastline of Western Europe are a result of eustatic change during the Holocene. During the Last Glacial Maximum (LGM), 18,000 year ago, the North Sea was 100-120 metres below the present level (Provoost *et al*, 2011). As the ice sheets retreated, sea levels rose to their current position and copious amounts of sediment were released from ice caps , which initiated coastal dune formation. Sea level rise allowed for the deposition of sand by waves to create beaches and in turn, onshore winds transported sediments further inland to create the early stages of a dune system (Peterson *et al*, 2007). There is an alternative school of thought which hypothesises the creation of sand dunes during interglacial periods. As sea levels fell, the continental shelf was exposed at the coastline, revealing a larger surface area of sediment to be suspended by Aeolian activity. This sediment was transported onshore to create coastal sand dunes (Hansom, 1988; Pye and Tsoar, 2009). The latter theory is one which is considered by Wilson *et al* (2001) to be responsible for the formation of the ancient sand dunes of Northumberland, England.

Sediment supply is a crucial factor to the formation of coastal sand dunes. Erosion of cliffs and bluffs is a major source of sediment and is largely determined by changes in sea levels. Cliffs exposed to the attack of waves will release sediment to the ocean, which will ultimately be transported to estuaries and bays by longshore drift, where it will be deposited onto the coastline (Maun, 2009). River discharge is another major source for sediment and is most likely responsible for dune development within the close vicinity of river estuaries. Rivers would have contributed significantly to sediment deposition at the end of the LGM, when ice sheets began to retreat and release large volumes of sediment and meltwater into the hydrological system (Maun, 2009). In order to form the dunes, a prevailing wind must be present to transport the sand grains across the beach and an obstacle, such as driftwood or a plant, must intercept the wind to capture the suspended sand (Maun, 2009). This initial process ultimately forms the first stage to dune development: a shadow dune. These dunes are not a permanent feature. As a cloud of saltating sand is blown onshore, the wind is deflected to the sides of the obstacle. On the windward side, the velocity of wind increases, while the leeward side sees a decrease in wind velocity. Over a short period of time, sand accumulates on the leeward side until the obstacle is buried and the wind resumes a normal flow (Maun, 2009). At this point, the shadow dune ceases to exist.

The first stage to a permanent dune however, is created by the accumulation of sand around perennial plants such as *Ammophila arenaria* and *Elytrigia juncea.* Vegetation is highly influential to the morphology of embryo dunes, as their ability to survive burial and to expand either vertically or horizontally across the beach affects the size and shape of the developing dune. Rhizomes and stolons allow the plants to expand in a linear fashion, creating low, sinuous ridges of sand (Hesp, 1989). Plants which are able to grow shoots that exceed the height of the sand stabilise the sand further and encourage an accumulation of sediment around the shoots. In past studies, it has been found that grasses such as *A. arenaria* form broad, embryonic dunes which have gentle, leeward slopes (Heyligers, 1985). This is due to dense growth formation of the species, which significantly reduces airflow (Hesp, 2002). The stability of the dune is determined by a decrease in sand supply and wind velocity, as well as the extent of vegetation cover which colonises the dune (Álvarez-Molina *et al*, 2012). Foredunes present a challenging environment for plants as the lack of available water, shifting sands and minimal nutrients mean that only a select few, well adapted species are able to survive. While the dune is mobile, plant succession remains in its early stages.

With the establishment and gradual decline in mobility, the embryonic dune will establish a vegetation community and become a foredune. At this point, there is a significant increase in height, yet the size and shape of the foredune is dependent on variables such as wind velocity, sediment supply, plant stature and human activity (Maun, 2009). *A. arenaria* is a species well-known for stabilising sand dunes and is a common occurrence on the foredunes of Europe. These dunes are still influenced by the sea, yet the substantial growth of *A. arenaria* actively contributes towards a gradual accumulation of organic matter and humus (FSC, 2008). The equivalent species within this stage of succession native to North America is *Ammophila breviligulata*, which is also capable of stabilising foredunes. Successive dune ridges which follow on from the foredunes become less and less influenced by wind velocity and the volume of sand deposition. Older ridges, including grey dunes, are found further inland and are under direct influence of vegetation (Maun, 2009). They tend to be of a lower height than the foredunes since they receive minimal deposition of Aeolian sand, if any at all. The relief of the dunes becomes shallower and broader than the initial dune ridges, due to erosional factors such an animal and human activity, lack of sediment deposition and surface runoff (Maun, 2009). Grey dunes are defined by the CORINE biotope classification as “fixed coastal dunes with herbaceous vegetation” and are considered a priority in the EU Habitats Directive (Annex

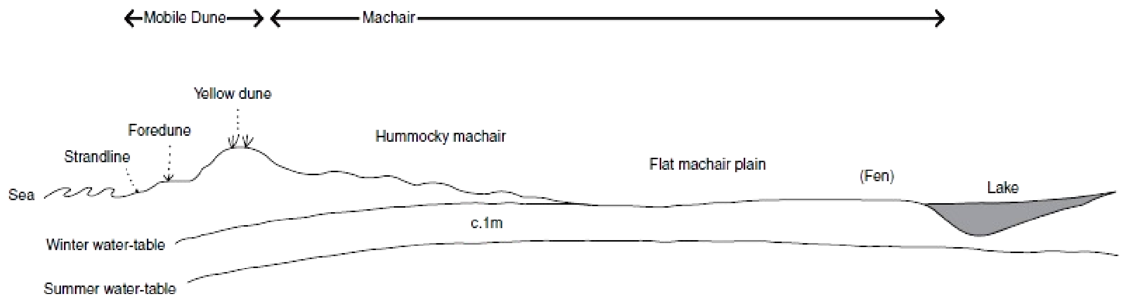

Figure 1.1: Schematic of a sand dune formation, with a machair habitat between the dunes and lake (Gaynor, 2006)

1). Their limited range and species richness warrant the protection status they have. Vegetation on grey dunes tends to vary considerably from north to south and from east west (JNCC, 2013), yet this is threatened by unmanaged scrub encroachment due to advancing succession and species invasion (Hantson *et al*, 2012).

A more unusual feature to the coastal dune formation is machair, which is found exclusively on the coasts of Scotland and Ireland (Gaynor, 2006). Machair demonstrates a unique geomorphological and ecological habitat which is designated as a priority habitat under the EU Habitats Directive. As Figure 1.1 shows, it is formed beyond the foredunes and is of a much lower, flatter topography than the preceding dunes. Its position means that it is of a mature age and close to the water table; plant communities are therefore transitional between wet and dry habitat. The presence of shell fragments give the soil high calcium carbonate values and thus a lime rich soil of a pH more than 7 (Gaynor, 2006). Not only does machair have an unusual natural formation, its history is intrinsically linked to human settlement. As far back as 8,000 years ago, people have used the land for domestic stock grazing, tillage and cultivation (Bassett and Curtis, 1985). Today, machair is used less intensively but is commonly used for grazing stock (Gaynor, 2006).

1.2 Vegetation development and succession on sand dunes

Sand dunes exhibit a fairly homogeneous vegetation community during the early stages of succession. For the foredunes to stabilise, they must be colonised by a plant community which is able to survive the harsh, saline and arid environment of the young dunes. Adaptations such as rhizomes and stolons enable pioneer species, such as psammophytes, to secure themselves to the loose sandy substrate, and to colonise elsewhere on the beach if they are detached during stormy conditions (Doody, 2012). Environmental stress is a major component to the foredune habitat, which in turn produces positive plant interactions through competition for

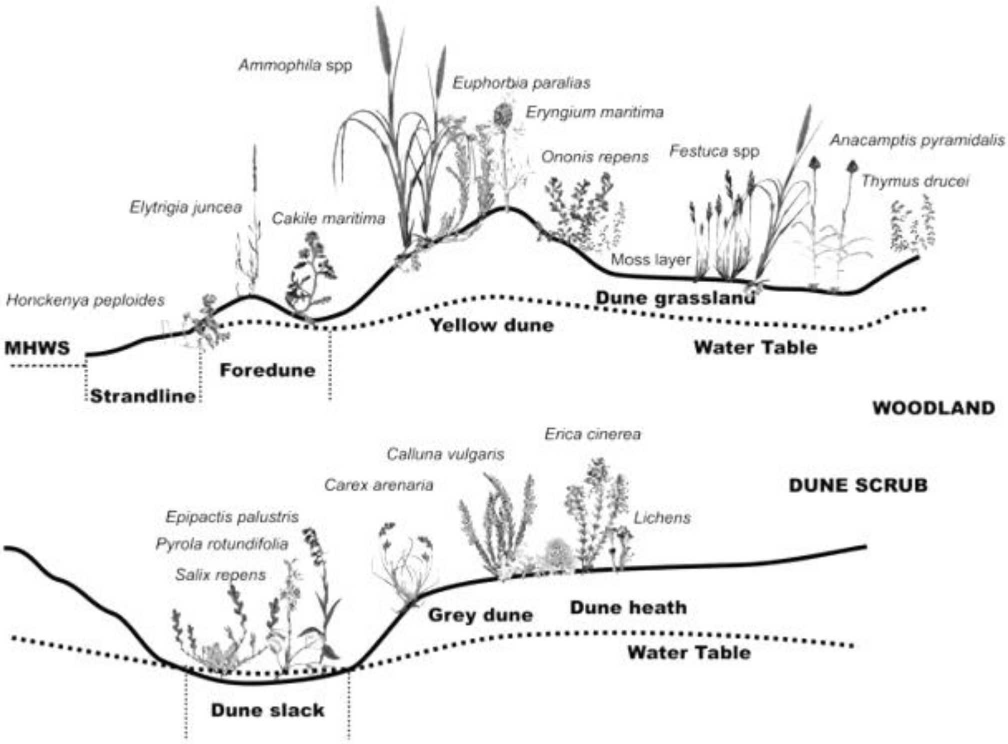

Figure 1.2: Diagram representing a basic example of succession on a sand dune formation, from the strandline through to the dune heath (Doody, 2012)

nutrients and water. This, plus the production of organic matter and humus, develops the vegetation community and advances the rate of succession through species replacement (Vallés *et al*, 2011). Figure 1.2 illustrates the linear stages of ecological succession on sand dunes, from the strandline through to the dune heath stage. However, succession is by far a linear and simple process. Due to the transient nature of coastal dunes, sands can shift and create micro-scale spatial zonation with plant communities. For instance, a dune ridge may have a composition of species on the windward side which could be totally different to the leeward slope, that may exhibit a more advanced seral plant community, due to a change in environmental conditions (Kim and Yu, 2009).

Heterogeneity becomes more prevalent on the grey dunes, where a substrate of organic matter has developed and a low level of nutrients maintains competition between plant species. Disturbances caused by storms, wind or oceanic currents can often encourage heterogeneity, as they open up patches of dune which allows for plants to colonise and fill ecological niches (Álvarez-Molina *et al*, 2012). As succession develops, dune grassland species establish and the habitat becomes more species-rich. A variety of grasses such as *A. arenaria, Festuca rubra* and *Festuca ovina* become typical of a dune grassland community. Beyond the initial set of dunes, where a wind shadow forms, herbaceous species such as *Jasione montana* and *Phleum arenarium* are able to establish and form a heterogeneous habitat (Isermann *et al*, 2007). Sand dune succession climaxes with scrub encroachment and woodland, when management such as grazing is not an influential factor. Natural colonisers to this seral community include *Salix repens*, *Corylus avellana* and *Betula pendula. Juniper communis* is also found in some dune climax communities (Doody, 2012). It is at this stage in succession, that 'problem species' and invasive plants often become an issue and threaten the native plant community.

1.3 Sand dune nutrient dynamics

In young, mobile dune systems, where vegetation is limited to species such as *A. arenaria,* nutrients are derived from salt spray and sand grains as they contain both organic and inorganic components (Ehrenfeld, 1990; Kim and Yu, 2009). Grass roots are the main source of organic material during decomposition and over time, organic matter and humus accumulates within the top layers of the soil (Provoost *et al*¸2004). At this point in early development, a high level of shell fragments remain in the soil which makes it very calcareous: up to 8% $CaCO_3$ can be detected. However, as the soil develops, humic acids are released. This, combined with excess precipitation, forces $CaCO_3$ to leach out of the soil (Provoost *et al*¸2004). As the rate of vegetation decomposition increases, ecological conditions become less calcareous. Soil pH has an intrinsic relationship with vegetation and tends to decrease with distance from the coastline, as the plant communities develop (Isermann, 2005). In general, foredunes have a neutral to alkaline pH of 6.5 to 8, while grey dunes are reasonably acidic and dune heaths are very acidic (Isermann, 2005). Soil pH can also vary on a small spatial scale, which affects the availability of base cations which in turn influences vegetation biodiversity. Decomposition is slowed by acidic soil conditions of less than pH 4, which contributes to the development of soil and ions during mineralisation (Provoost *et al*, 2004; Provoost *et al*, 2011). Spatial variability such as this may lead to a heterogenic plant community (Isermann, 2005).

The two key nutrients to coastal sand dunes are nitrogen and phosphorus (Kooijman *et al*¸1998). Nitrogen is predominantly sourced from the decomposition of plants, which means that total nitrogen content is highly correlated with organic matter (Provoost *et al*¸2004). By contrast, the availability of phosphorus is regulated by soil pH. The optimum pH for phosphorus availability is 5; as soils become more alkaline, phosphorus becomes locked into calcium phosphate which can limit biomass production (Provoost *et al*¸ 2004; Provoost *et al*¸2011).

A surplus of nutrients can have a detrimental effect upon species richness of a dune grassland. A high deposition of nitrogen for instance, can lead to vigorous growth of *A. arenaria*, which greatly increases biomass production (Provoost, 2011). Yet due to limited light penetration and intense competition, the grass can outcompete slower growing herbs and shrubs, which ultimately reduces species richness (Roem and Berendse, 2000). This has been described by Grime (2006), who constructed a hump-shaped curve of species richness against productivity. Thus, species richness tends to occur on a site with limited nutrient availability but where environmental stress is not overwhelming.

1.4 Causes and Impacts of problem species

Coastal sand dunes are vulnerable to invasive species. Both native and alien invasive species can be equally damaging and cause a significant decline in plant biodiversity. An extensive wealth of literature has explored the causes and consequences behind the spread of invasive species on coastal dune systems. Grey dunes are particularly susceptible to invasion as they are host to a suitable environment for herbs and shrubs. In addition, they are effectively one stage away from the climatic climax of the dune succession, where a scrub habitat dominates.

One major theory to the recent spread of invasive species and scrub encroachment on coastal sand dunes is that the outbreak of Myxomatosis in the 1950s is largely accountable (Binggeli *et al*, 1992; Provoost *et al,* 2011). Rabbit populations were almost eradicated in the UK, which ultimately affected the habitats they grazed in. It was noted by White (1961) that following the outbreak of February 1954, grass encroachment at Blakeney Point, Norfolk increased from 14-43% to 80-89%, while moss species declined. Rabbits did not return to the area until 1959.

Sea buckthorn (*Hippophae rhamnoides*) is a particularly vigorous invasive species which is capable of growing in nutrient-poor soils with high pH values (Isermann *et al*, 2007). The dense stands the species creates tend to reach heights of three metres in the UK (Binggeli *et* al, 1992) and can quickly outcompete lower-growing herbs, grasses and shrubs. Studies on the impacts to native dune species have yielded mixed results. Binggeli *et al* (1992) for instance, found that dune species richness significantly decreased and rare species were displaced by *H. rhamnoides.* These changes resulted in a shift towards a woodland community. However, this meant that woodland bird species such as the warbler and dunnock benefited as they were able to breed in the scrub, while woodland species such as sycamore and elder thrived in the new ecosystem. Similarly, Isermann *et al* (2007) discovered associated positive impacts with *H. rhamnoides* cover, as the number of herbaceous species increased with its presence. However, they also found that when the cover exceeded a certain threshold, species richness declined

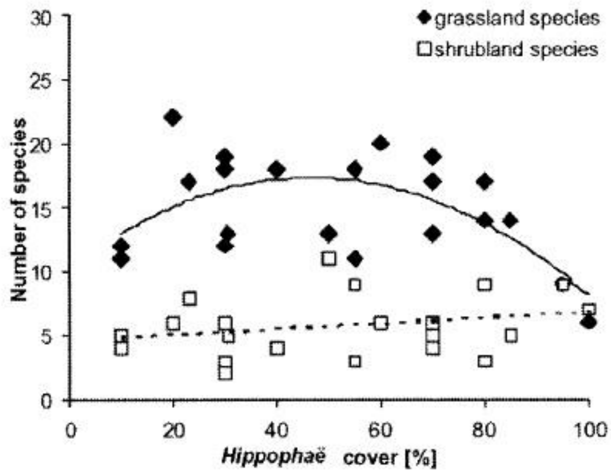

Figure 1.3: Diagram to illustrate the effect of *H. rhamnoides* on the species richness of the Norderney coastal sand dunes, East Frisian Islands (Isermann *et al,* 2007)

significantly (Figure 1.3). This could be explained by nitrogen levels, which were extremely high in older stands of *H. rhamnoides* and twice the amount than the younger stands.

By comparison, a survey of coastal sand dunes on the Korean peninsula and Cheju Island, revealed that invasive plants have replaced the native species of the dunes and were flourishing along the edges of the habitat, particularly towards the climax woodland community (Kim, 2004). The mean species number per m^2 declined significantly from 10 to 3 species during the period of 1983 to the 2004. It has become a concern that these invasive species have replaced the role of native species within the ecosystem as they are highly reproductive and effectively stabilise the dune system. Degradation of the sand dune itself seemed to be related to disturbance from a nearby beach resort as the invasive plants were most prolific within disturbed soils.

Studies suggest that the occurrence of invasive and problem species on coastal sand dunes appear to only have a detrimental impact when they are left unmanaged, and are able to establish significantly dense stands. Many of these studies focus on well-known invasive plants such as *H. rhamnoides*, which has a noticeable appearance on the landscape and is extremely difficult to control when large stands establish. However, there is limited literature on the impacts of burnet rose (*Rosa pimpinellifolia* L.) which is capable of covering the dune landscape with expansive swathes of growth. Very often native species such as this can easily be disregarded as a problem as it has long been a part of the habitat. By contrast, bracken (*Pteridium aquilinum,* (L.) Kuhn) is a recognised native invasive species. It is often found in habitats of mid-succession, where it occupies a niche between heathland or grassland and woodland (Marrs *et al*, 2000; Stewart *et al*, 2008). There is substantial research on the management of *P. aquilinum* as it is adept at outcompeting the less robust members of the plant community, as well as altering the edaphic environment. The species is well adapted to successful establishment. It harbours an extensive rhizome system which consists of large carbohydrate and nutrient reserves, as well as toxic chemicals within the plant tissue which prevent decay and herbivory (Marrs *et al*, 2000). As a result, management of *P. aquilinum* is a challenge but a necessary step to take for the sake of habitat conservation. The ecology and interactions of *P. aquilinum* and *R. pimpinellifolia* with the complex dune environment need to be understood in order to effectively manage these species for the benefit of biodiversity.

1.5 Aims of this Study

The aim of this study is to establish the cause and extent of 'unwelcome' species within Sheskinmore SAC, paying particular attention to the grassland surrounding the caravan site. The study will focus on *Pteridium aquilinum* and *Rosa pimpinellifolia,* which have established populations across Sheskinmore SAC. An understanding of the factors which influence the expansion of such species will help to construct a targeted management plan of removal. To establish these factors, the objectives to this study are as follows:

1. To examine differences in biodiversity between plots of unwelcome species and plots without unwelcome species.

2. To assess whether environmental factors have an influence over the growth of unwelcome species.

3. To establish whether the caravan site has had an impact upon the natural vegetation communities within the near vicinity.

4. To evaluate potential options for the management of unwelcome dune species across the dune system.

2. Study Site

2.1 Regional Setting

Over the past 22,000 years, the coasts of north-west Ireland have been moulded by geomorphic processes that still have a bearing on the landscape today. The Midlandlian glaciation heavily eroded the basement rocks, scouring the land as the ice sheet advanced and retreated. It also deposited large quantities of clastic sediments onto the present-day coastline and shelf, in the form of glaciofluvial sands and gravels (Carter and Wilson, 1993). As a result, the dune fields of Donegal predominantly consist of glacial material which have been deposited throughout the Pleistocene era. These dunes only began to take their present-day form 6,000 years ago, during the mid-Holocene sea-level peak. As the sea levels fell, sediment was transferred from the shore inland by Aeolian processes, to form ridges and dunes. The sedimentary budget has since been profoundly negative, resulting in considerable morphological changes to many dune systems of north-west Ireland (Carter and Wilson, 1993). The country currently consists of 190 Holocene coastal dunes, which span 6,000km of coastline (Curtis, 1991). In particular, County Donegal is host to 40% of all Irish sand-dunes (Wilson and Braley, 1997).

2.2 Climate

Located in the Atlantic biogeographic region, the climate of north-west Ireland is incredibly influential over the morphology of the sand dunes. A substantial proportion of coastline erosion can be attributed to prevailing winds from the southwest (Gaynor, 2006). North Atlantic frontal depressions, combined with warm south-westerly air-streams create a varied climate across the region, particularly on the coast where annual hourly wind speeds have been recorded to be as high as $8ms^{-1}$ (Barrett-Mold and Burningham, 2010) on more than 57 days per year (Cross, 2005).

The coastline is also shaped by the behaviour of the ocean. It is known to lie within the mixed 'wave-tide dominated' coastal energy spectrum where the mean tidal range is 3.5m at springs and 1.6m at neaps (Burningham, 2008). Waves have been recorded to reach 1.9m closer to inshore, 30km west of Loughros Bay (Burningham, 2008).

The mean monthly temperatures for the region are relatively narrow in range due to the influence of the Atlantic Ocean. The mean annual temperature for 1981 – 2010 has been

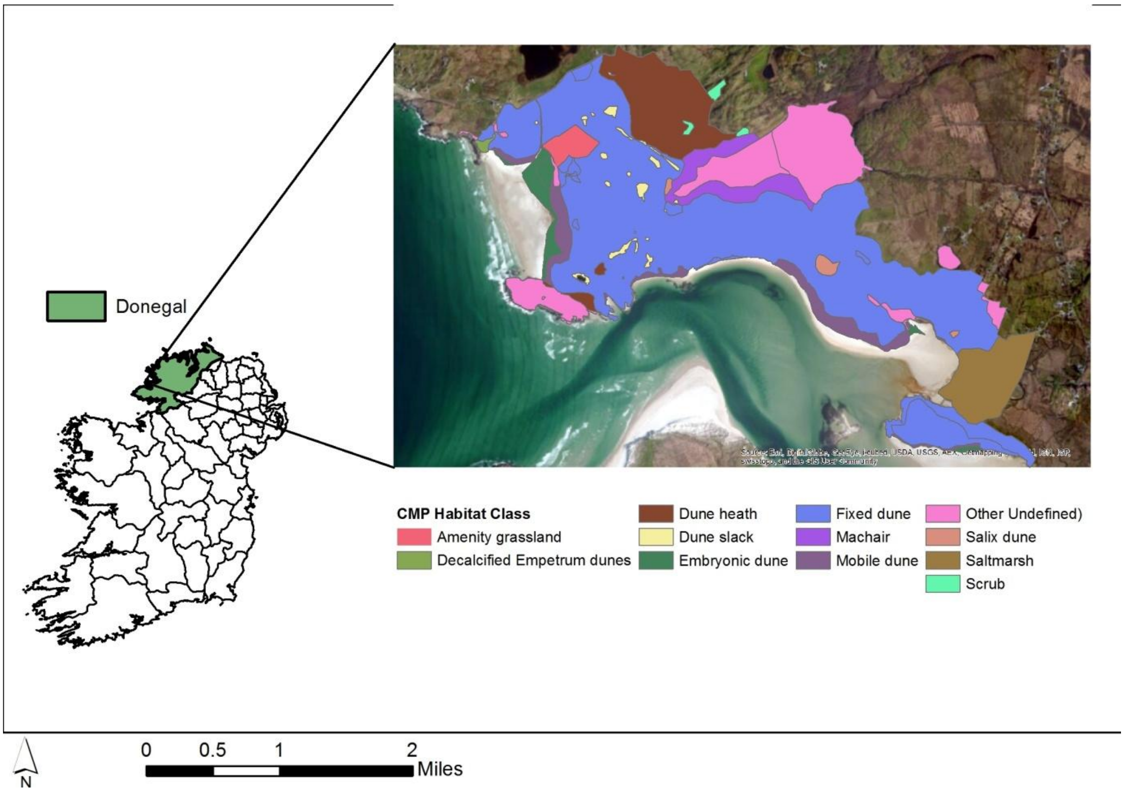

Figure 2.1: A map of the West of Ardara/Maas Road site, with CMP habitat classes defined and depicted. The caravan site is located where 'Amenity grassland' has been identified in red (Aerial photography courtesy of ESRI ArcGIS 10.1. Ireland and UK shapefile courtesy of GADM. CMP shapefile courtesy of Ryle *et al*¸2009).

recorded to be between 9 - 10°C (Irish Meteorological Service). Rainfall is more excessive, with annual values of 1,200 to 1,400mm per year (Irish Meteorlogical Service).

2.3 Sheskinmore Lough SPA

Sheskinmore Lough SPA is part of a larger site known as West of Ardara/Maas Road, which is designated with SAC status. Covering 16.5 hectares, Sheskinmore Lough SPA is a mosaic of habitats comprising of lacustrine, swamp, fen and grassland environs. Figure 2.1 is a map of West of Ardara/Maas Road, showing the different habitat types found on on-site. The habitat classed as 'Amenity Grassland' also denotes the location of the caravan site.

The shallow lake at Sheskinmore Lough is fed by the the Duvoge and Abberachrin rivers, and is host to a number of aquatic plants, in particular *Phragmites australis* (Common Reed) (NPWS, 2005). Surrounding the lake are areas of fen which consist of *Schoenus nigricans* (Bog rush) and *Carex* spp. (Sedge) as part of the local vegetation community (NPWS, 2005).

Of particular note are the grassland communities, which cover a range of NVC types across the dune system. Atlantic decalcified fixed dunes are of particular interest as they are also

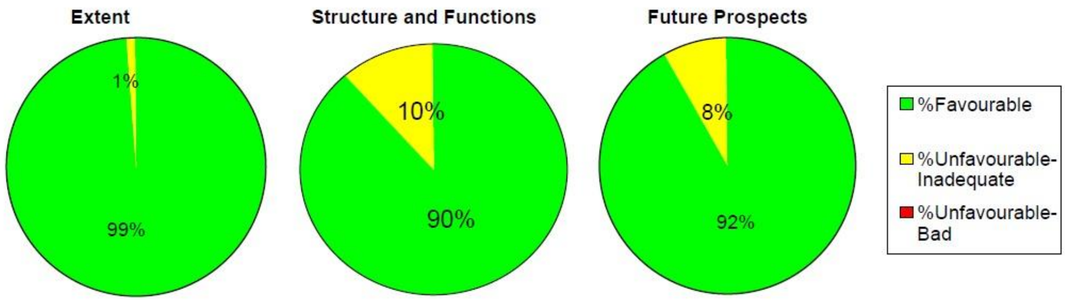

Figure 2.2: The assessment of Atlantic decalcified fixed dunes in Ireland (Ryle *et al*, 2009)

considered to be classified as 'dune heath', which is a rare occurrence in Ireland (Ryle *et al,* 2009). Figure 2.2 illustrates the conservation status of Atlantic decalcified fixed dunes in Ireland, as assessed by the Coastal Monitoring Project (CMP) surveys. As the assessment charts show, the extent of the habitat in Ireland is in favourable condition. During these surveys, *Juniper communis* (Common Juniper) was recorded on site, which was a noteworthy observation as this habitat was previously listed as Annex 1 "*Juniperus communis* formations on heaths or calcareous grassland" (Ryle *et al*, 2009). The site is also host to a small area of calcareous grassland, with a rich variety of orchid populations including *Neotinea maculate* (Dense-flowered Orchid). This merges into the machair south-east of the caravan site, within the nature reserve.

In general, Sheskinmore Lough SPA consists of marram dunes, fixed dunes and decalcified dune heath. Characteristic species which are found frequently across the range of habitats include *Ammophila arenaria, Carex arenaria, Festuca rubra, Achillea millefolium, Galium verum, Lotus corniculatus* and *Viola palustris* (NPWS, 2005). However, the species communities are potentially subject to change due to trampling and erosion, since the caravan site is situated in a prime location, providing easy access across the Magheramore dune system and Tramore Beach. This has been recognised in the CMP Report, where the Structure and Prospects of the habitat somewhat failed in their assessment, as they were classified to be in 'unfavourable-inadequate' condition (Figure 2.2). The reason given is attributed to recreational activities applying pressure onto the habitat (Ryle *et al*, 2009).

Many faunal attributes are found at the site, including a frequent occurrence of Choughs (an Annex 1 species of the EU Birds Directive) which use the area to graze and socialise. As many as 100 individuals have been observed in the sky at any one time (NPWS, 2005). In addition to this, waterfowl species can also be observed, including Teal, Mallard and Lapwing. The grasslands are valuable habitat to the Red Data Book species *Draba incana* (Hoary Whitlow

Grass), the rare *Vertigo geyeri* (Whorl-snail), *Euphydryas aurinia* (Marsh Fritillary) and the *Cupido minimus* (Small Blue Butterfly) (NPWS, 2005).

Specifically, the site of interest to this study is the grassland surrounding the caravan site (see Figure 2.1). This is located on the grey dunes of Sheskinmore Lough, identified as 'Fixed dune' on the map, with transects approaching both wet grassland and granitic intrusions, located southeast of the caravan site.

3. Methodology

3.1 Field Sampling

The study area was initially analysed using recent aerial photography from ArcMap (ESRI ArcGIS 10.1) to identify areas with possible problem species. Investigation into the coastal dunes at Sheskinmore Lough SPA revealed confined locations of *P. aquilinum* (bracken) and *R. pimpinellifolia* (Burnet Rose) close to the caravan site. It was therefore decided to adopt a stratified random sampling approach by surveying four transects which radiated out from the caravan site. As Figure 3.1 shows, the transects followed four different compass directions, in order to disqualify the age of sand dunes as an influencing factor over the results. Each transect was divided by 10 survey points, at intervals of 40 metres. At every survey point, the quadrat was thrown randomly twice: once into an area of problem plant species and once into an area absent of problem species. This provided 10 pairs of contrasting vegetation plots. Therefore a total of 80 survey plots were recorded, 20 on each transect.

Fieldwork was conducted over eight days in June. Quadrats measuring 1m^2 were used for the flora surveys, since the vegetation was predominantly grassland. Most plant species were

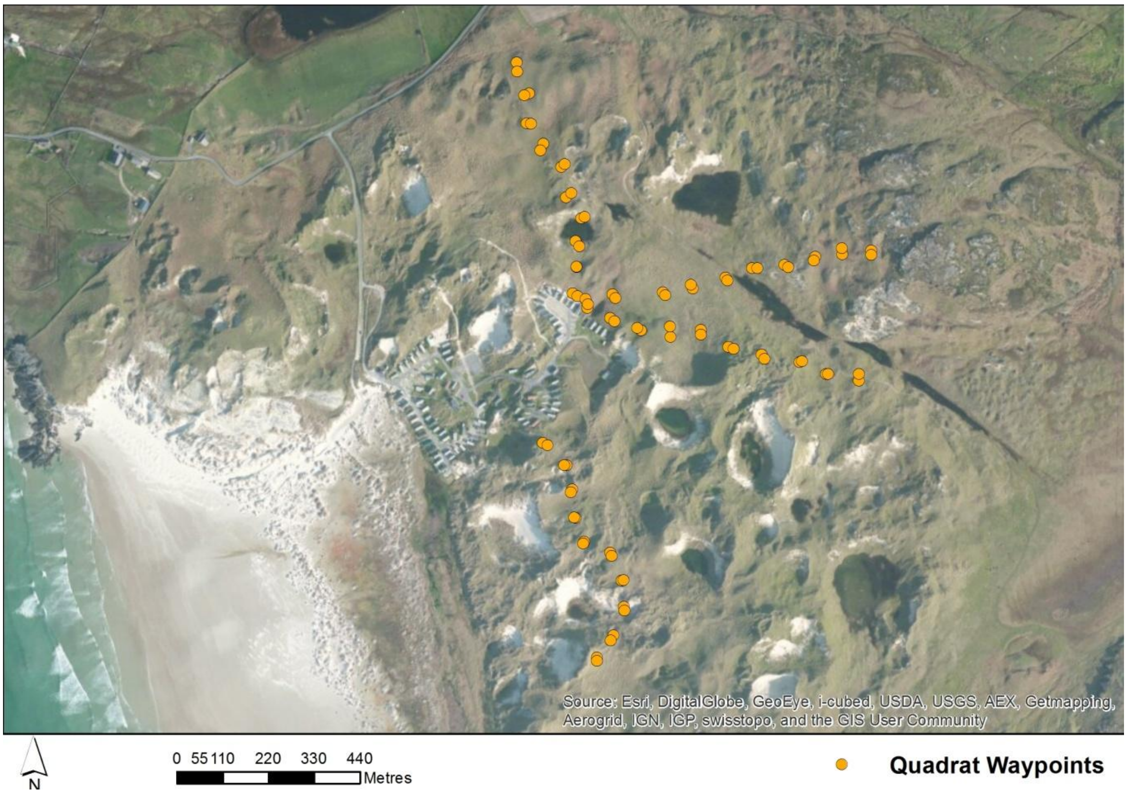

Figure 3.1: Aerial photograph showing the positions of quadrats along each of the four transects at Sheskinmore SPA. Transects were aligned according to compass directions: north, north-east, south-east and south. Pairs of quadrats can clearly be seen. (Esri ArcGIS 10.1 Aerial Photography)

identified out in the field using Rose (2006) and Fitter (1984); unknown species were sampled and photographed to be later identified. Moss and lichen were recorded but not identified to species level, while bare ground, including sand cover, was accounted for in the survey. Percentage cover was estimated in 5% steps and the DAFOR scale was used to assess abundance for each species. GPS coordinates were recorded for each plot.

A soil sample was taken from each quadrat from the upper mineral layer to a 5cm depth using a hand shovel. The samples were protected in air-tight plastic bags and stored in a refrigerator for later analysis. A photo log of the plots and plant species was kept throughout the entire survey.

3.2 Analytical Procedures

The soil samples were analysed for a number of environmental variables to investigate how influential edaphic factors are on species composition.

The moisture content for each sample was calculated by using the loss on drying method. Sub-samples of 1.5g were weighed out into crucibles and placed into an oven to dry overnight at a temperature of 105°C. They were then reweighed to obtain the percentage dry weight. Standard methods for loss on ignition (LOI) were subsequently employed. The sub-samples were placed into a furnace for two hours at 550°C and reweighed to calculate the loss of organic content within the sediment sub-samples. Finally, carbonate content was calculated by returning the sub-samples to the furnace at a temperature of 950°C for a further four hours. Carbon dioxide is lost in this process when the carbonates are converted to oxides; this therefore provides a good indicator of the original carbonate content within the sediment samples. After reweighing, the difference between the final ash sample and the LOI weight was calculated and multiplied by 1.36 to obtain carbonate content. This provides the difference between the molecular weights of CO_2 and CO_3, which was finally expressed as a percentage of the dry weight.

Sediment samples were also tested for pH, conductivity, nitrate and phosphate content. A sub-sample of 10g from every quadrat was weighed into a beaker and 100ml of deionised water was added to the sample. The mixed solution was left to steep for 30 minutes. The resulting supernatant was tested using pH and conductivity meters. After filtering, the solution samples were tested for nitrates (Cadmium Reduction Method) and phosphates (Amino Acid Method) using the Hach Lange DR 2800 spectrophotometer. An initial analysis of the raw data revealed a number of outliers; it was therefore decided to retest these particular samples to investigate whether the outliers were a product of inaccurate testing or extreme actual values. The new values were used and incorporated into the dataset.

3.3 GIS Analyses

The spatial context was analysed using aerial photography from ArcMap (ESRI ArcGIS 10.1). Obtained environmental and vegetation data from the transect survey was used to explore relationships between parameters and observe trends in data across the survey area. Data generated by TABLEFIT software was also used to explore the flora communities that had been observed in each quadrat.

3.4 Statistical Analyses

Species data was initially analysed using the TWINSPAN method in WinTWINS (V2.3) software (Hill and Šmilauer, 2005). This is an indicator species analysis which uses qualitative data to create a dichotomy throughout the species data in order to classify them into groups. The abundance of every species is preserved by using the concept of pseudo-species, whereby a species can be signified by a number of pseudo-species at each pre-determined cut-level of the analysis (Lepš and Šmilauer, 2003). The resulting dichotomy presents communities of species that characterise the groups they have been divided into. From this it is possible to infer common ecological preferences for each community.

Communities were investigated using TABLEFIT, a programme which measures the goodness-of-fit of four ecological indices with the quadrat data (Hill, 1996). This is achieved by matching the relevé data to NVC types and CORINE values. Five possible ecological communities are presented for each relevé. The overall goodness of fit value, G, is used to attain the associative NVC type and the CORINE value. When two possible communities held the same value for G, the 'compositional satisfaction' index, G1, was used to determine the outcome (Hill, 1996).

Normal distribution of data was tested for each environmental variable by running the Kolmogorov-Smirnov Test. Significant deviation away from the normal distribution was discovered for the nitrate and phosphate data. These variables were therefore log transformed ($\log_{10}(\chi + 1)$) and tested for normality again. A persisting absence of a normal distribution for these variables meant that the most appropriate test for correlation was the non-parametric Spearman Rank. Calcium carbonates and % organic matter were highly correlated with the remaining variables, so they were removed from further analyses. All tests up until this point were conducted on SPSS 17.0. The remaining environmental parameters were z-transformed to ensure equal weighting.

Species richness was calculated for every quadrat, as was the Simpson's Index of Diversity, where the result was equal to 1 - D. The latter was chosen as the most appropriate index for this study as it proved to be more robust and unbiased than the Shannon index when dealing with less than 1000 sampled individuals (Mouillot and Leprêtre, 1999).

Quadrats from all four transects were split into two groups: those which contained problem species and those which did not. To test for significant differences between the two groups, a t-test was performed on the normally-distributed pH data. Since phosphates and nitrates were not normally distributed, a non-parametric equivalent, the Mann Whitney-U test, was performed instead. The values obtained from the Simpson's Index of Diversity were also interrogated by the t-test to investigate differences between the two groups of quadrats.

A multiple linear regression (MLR) was performed to examine relationships between diversity patterns and the environmental variables. Only data which was not correlated could be examined against the Berger-Parker index, Simpson's Index of Diversity and species richness. Therefore conductivity, phosphates, nitrates, % moisture loss and pH were interrogated by the MLR.

A multivariate data analysis was used to explore the relationships between environmental parameters, quadrats containing problem species and species composition. Moss and lichen were not included in this process. The software programme CANOCO 4.5 was used for analysis. A Detrended Correspondence Analysis (DCA) was subsequently used to establish the gradient length of the first axis. The gradient indicates the beta diversity in the community (Lepš and Šmilauer, 2003). It was found to be 3.228 standard deviation units. Since this value was significantly lower than 4 s.d. units, it was decided that a Principle Components Analysis (PCA) and Redundancy Analysis (RDA) were most appropriate techniques for this data, as the gradient lengths were low enough to suggest a linear trend. The z-transformed variables for the environmental data was used to ensure equal weighting for the ordinations.

The PCA analysis was used to identify similarities and variation between species in conjunction with environmental parameters. An RDA was performed to show the variability between all three pieces of information: plots, environmental parameters and species. For clarity, rare species were removed from the analysis (those which covered less than 15% of the quadrat) as it was found that the RDA plot was more interpretable without them. It has been found by Legendre and Legendre (1998) that rare species do not contribute towards the vegetation structure and can actually skew the ordination alignment. The ordination was rerun without the outliers, where it was found that 10.2% of total variability in the species data could be explained by the first axis.

Species response curves were used to analyse whether the problem species of interest, *R. pimpinellifolia* and *P. aquilinum,* responded positively to an increase or decrease in environmental gradients. A quadratic degree with a poisson distribution was used. This method is an effective way of illustrating whether these two species have an optimal range for particular environmental parameters or whether they tend to be more generalist in ecological preference.

4. Results

4.1 Dune Ecology

4.1.1 Vegetation Assemblages

A total of 76 vascular plant species were identified across all four transects. Plots with an occurrence of problem species were found to have 58 of the identified species, while plots absent of problem species recorded all 79 species present. All were terrestrial species except for one marginal plant, *Hydrocotyle vulgaris* (Marsh Pennywort).

Species richness had little variability between the problem species quadrats and those without problem species. Quadrats with problem species ranged from 7 to 24, with an average value of 13.8. These are similar results to the plots without problem species, which had a range of 6 to 22 species per plot, with an average value of 14. Comparatively, the Simpson's Index of Diversity also exhibited little variation, since the range of values for problem quadrats were from 0.72 to 0.93, with an average value of 0.85. Non-problem quadrats similarly resulted in values between 0.64 to 0.94, with also an average value of 0.85. Evidently, there is a slightly larger range in values for the latter group of quadrats. These results are displayed in Figure 4.1.

To analyse any significant differences among the two groups of data in terms of the Simpson's Index of Diversity, a t-test was run. This resulted in a P value of 0.370, which is greater than 0.05 so the null hypothesis was accepted; there is no significant difference in diversity between quadrats with problem species and quadrats without.

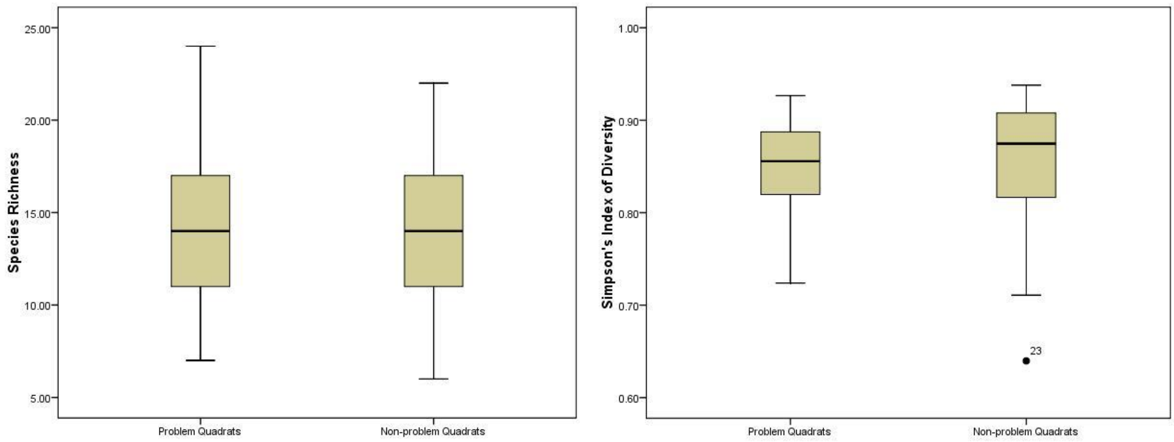

Figure 4.1: Boxplots to show the range and variability in data for species richness and Simpson's Index of Diversity. Quadrats have been split between problem plots and non-problem plots.

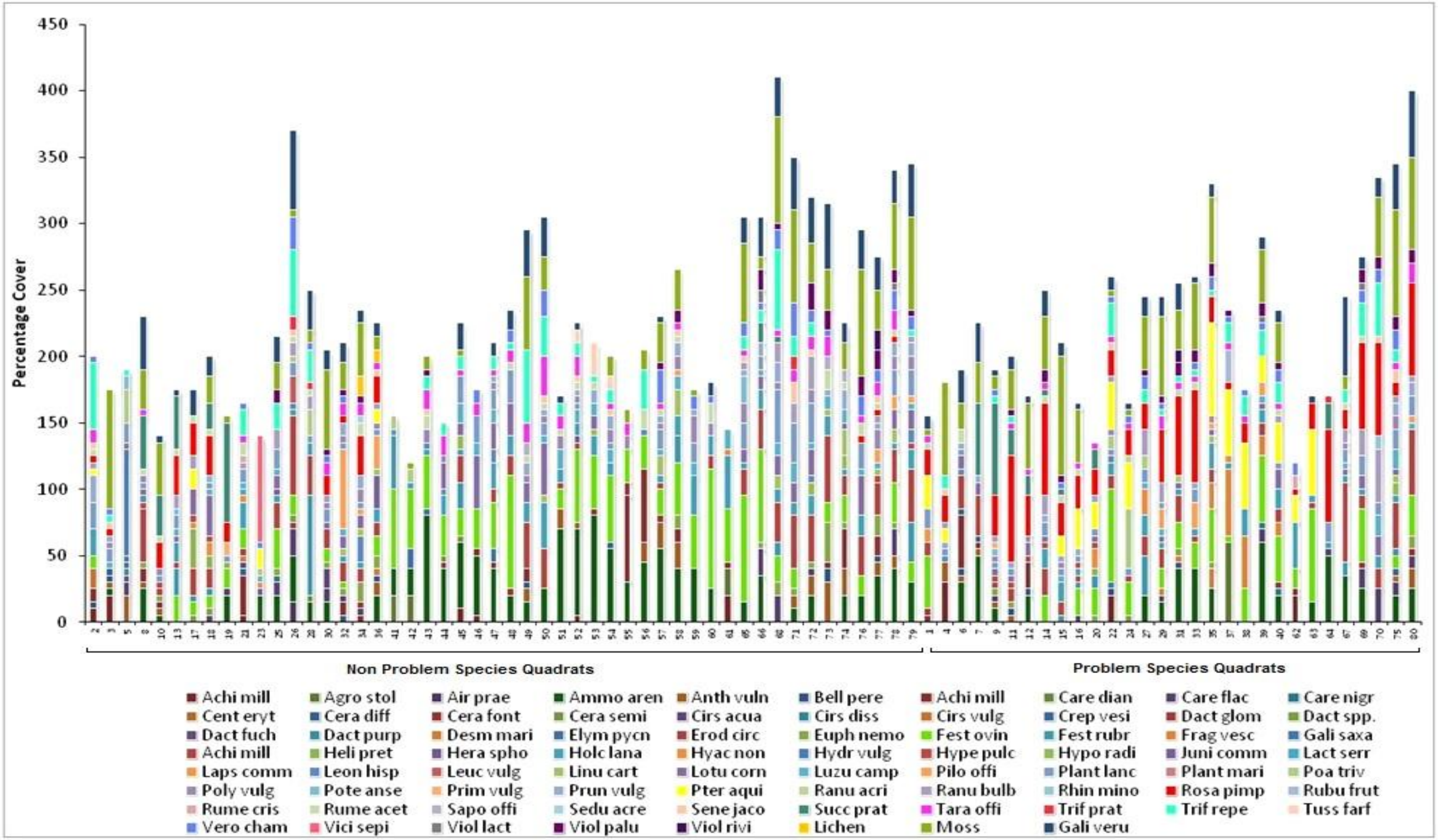

Figure 4.2: Species present in each vegetation quadrat, by percentage cover and split between quadrats without problem species and quadrats with such species.

Figure 4.2 illustrates the contribution each species made to the quadrats; quadrats have been split into groups of problem species present and the occurrence of no problem species. It can be seen that *R. pimpinellifolia, P. aquilinum, G. verum* and *A. arenaria* are the dominant species within the problem species quadrats. By comparison, a wider range of species were found to contribute towards the grassland community within plots that lacked the problem species: *A. arenaria, Festuca ovina, G. verum, Holcus lanatus, Lotus corniculatus, Plantago lanceolata, Thymus polytrichus* and *Trifolium repens* all made a regular occurrence within these relevés. *F. ovina* and *A. arenaria* clearly dominate the plant communities which lack problem species, while *G. verum* is present in the majority of quadrats.

The indicator species analysis (Wintwins, TWINSPAN) revealed distinct communities and dichotomies between plant communities (Figure 4.3). The first division has clearly separated dune grassland communities, C1, and communities more consistent with marginal or disturbed ground (C2) , with *P. aquilinum* as the primary species for this particular community. C1 consists of species which would be expected from fixed dunes with herbaceous vegetation: *A. arenaria, L. corniculatus, P. vulgaris* and moss. The second subdivision to this community has split *S. pratensis* (C3) from *H. lanatus, T. polytrichus* and *V. chamaedrys* (C4). The latter group of species are plants which commonly occur on the grey dune grassland and are again typical amongst the herbaceous vegetation. *S. pratensis* is a species which is plentiful across the mildly acidic dune grassland, and occurred as the dominant species within quadrats (Figure

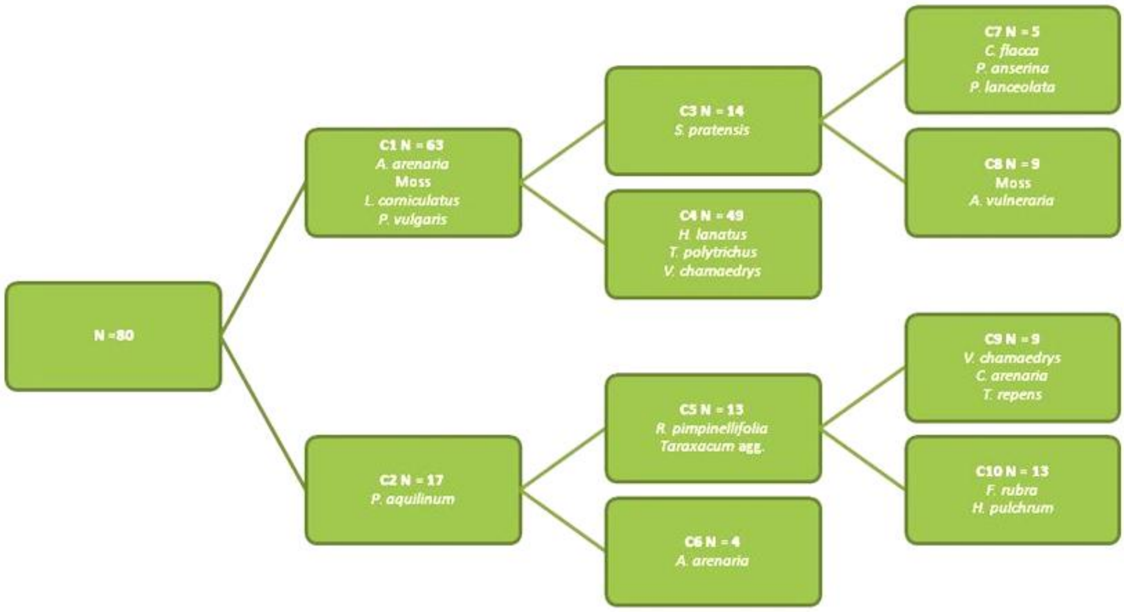

Figure 4.3: Indicator species analysis (Wintwins, TWINSPAN) presenting inferred communities across the study site.

Figure 4.4: A photo of a quadrat from the northerly transect, which comprised of 75% coverage of *S. pratensis.*

4.4). The community of *S. pratensis* has been further divided into one community consisting of *C. flacca, P. anserina* and *P. lanceolata* (C7)*.* This assemblage of species is indicative of disturbed ground, particularly the occurrence of *P. anserina* which can grow in poor conditions, and *C. flacca,* which is able to grow in a wide range of soils. The final division to this major branch ends with *A. vulneraria*, which is a common sight across sand dune grassland. This is a wild flower which is normally found on disturbed but not heavily grazed land (Raven, 2012).

The second major branch, starting at C2 with *P. aquilinum,* consists of species that are predominantly aligned with quadrats that were recorded with problem species. This community has been subdivided into one branch consisting of *A. arenaria* (C6), a grass which is highly dominant in a dune habitat, and a second branch comprised of *R. pimpinellifolia* and *T. officinale* (C5)*.* The latter two species are those which could be considered 'undesirable' to the dune grassland. *R. pimpinellifolia* is a common occurrence across the grassland, while *Taraxacum* agg. is capable of out-competing grass and is a sign of disturbed ground (Raven, 2012). This community forms the final division to the indicator species analysis. *F. rubra* and *H. pulchrum* are of one community (C10) while *V. chamaedrys, C. arenaria* and *T. repens* form C9.

Both communities are typical of dune grassland and consist of species which were commonly recorded throughout the survey.

The indicator species analysis was conducted in conjunction with a TABLEFIT analysis. This allowed for comparison between communities of species as generated by TWINSPAN, and CORINE communities inferred from species composition per quadrat, based on goodness-of-fit values. Table 4.1 shows the NVC classifications and CORINE values that are to be found across the study site. It can be seen that most of the CORINE classifications reflect the communities established using TWINSPAN, such as Atlantic Ammophila dune and Northern fixed dune, which the majority of quadrats have been defined as. Three quadrats have been defined as 'Acid-soil bramble thicket'. Species present in these plots include *P. aquilinum, Fragaria vesca, Rubus fruiticosus, R. pimpinellifolia* and *Vicia sepium*. All these species are specimens which are often found on disturbed ground or growing in poor soils. They are also capable of forming dense thickets, which was the case for the three quadrats that have been defined under the CORINE classification.

CORINE Code	CORINE Name	NVC Code	NVC Name	# Quadrats Present
C16.2121	Atlantic Ammophila dune	SD6	Ammophila arenaria	13
C16.2121	Atlantic Ammophila dune	SD7	Ammoph aren-Fest rubra	2
C16.221	Northern fixed dune	SD12	Car are-Fes ovi-Agr cap	27
C16.221	Northern fixed dune	SD10b	Carex arenaria	1
C16.2211	Calc north fixed dun	SD8	Fest rubra-Galium verum	7
C16.34	Moist slack grass/rush	SD17	Poten anse-Carex nigra	1
C18.2	Vegetated Sea Cliff	MC 9	Fest rubra-Holcu lanat	4
C18.2	Vegetated Sea Cliff	MC12	Fest rubra-Hyacin non-s	1
C31.831	Acid-soil bramble thicket	W25	Pte aq-Rub fr underscb	3
C34.3216	Tall Mesobrom calc grass	CG4	Brachypodium pinnatum	1
C34.3216	Tall Mesobrom calc grass	CG6	Avenula pubescens	3
C34.3216	Short Mesobr calc grass	CG2c	Fest ovina-Avenula prat	1
C34.3216	Mesobr calc grass	CG7	Fest ovi-Hier pil-Thym	3
C34.3216	Short Mesobr calc grass	CG2c	Fest ovina-Avenula prat	7
C34.32162	Brachypodium calc grass	CG4c	Brachypodium pinnatum	1
C34.331	Brit Xerobr calc grass	CG1	Fest ovina-Carlina vulg	1
C35.12	Agrostis-Festuca grass	U4b	Fes ovi-Agr cap-Gal sax	1
C35.22	Perennial open silic grass	U1d	Fes ovi-Agr cap-Rum	1
C37.241	Tall rush pastures	MG10	Holc lana-Junc effusus	1

Table 4.1: NVC classifications and CORINE values, generated by TABLEFIT, based upon species assemblage in each quadrat.

4.1.2 Environmental Factors

There is considerable variation throughout the environmental parameters when comparing quadrats with problem species and quadrats without (see Appendix 2). The values for pH demonstrate a clear difference between the two groups of quadrats, with a high average value of 8.39 for quadrats without problem species, compared to a more neutral value of 7.96 for quadrats with problem species. A t-test confirmed a significant difference between the two groups of data, with a P value of 0.01. By comparison, no significant differences were found for phosphates and nitrates, which are evidently similar in range and average values, as shown by Figure 4.5. The calcium carbonate content of the soil displayed a significant difference between the two groups, with a P value of 0.00 when the Mann-Whitney U Test was run (data was not normally distributed). Evidently, the average value for the problem species quadrat is 0.27%, while the non-problem species quadrats exhibited a mean value of 0.53%, both of which are relatively low. The remaining environmental parameters which were analysed - organic matter content, moisture content and conductivity - were not significantly different between the two groups of quadrats and do not display a large range in data.

Environmental variables were tested for strength in relationship against three ecological indices of diversity, by running an MLR. The results confirmed that Simpson's Index of Diversity, Berger-Parker Index and species richness are not significantly correlated with the environmental variables; specifically, the environmental parameters do not have an influence over the indices tested (results in Appendix 1).

In order to confine the focus down to species level, species response curves were generated to test whether the extent of *P. aquilinum* and *R. pimpinellifolia* were affected by particular environmental gradients. It was found that *R. pimpinellifolia* responds to the levels of pH and nitrates within the soil. The species steadily increases with an increase in nitrates. In terms of pH, *R. pimpinellifolia* rises and peaks, then decreases sharply after crossing a threshold in pH values. By contrast, *P. aquilinum* decreases with moderate values of nitrates and then rises

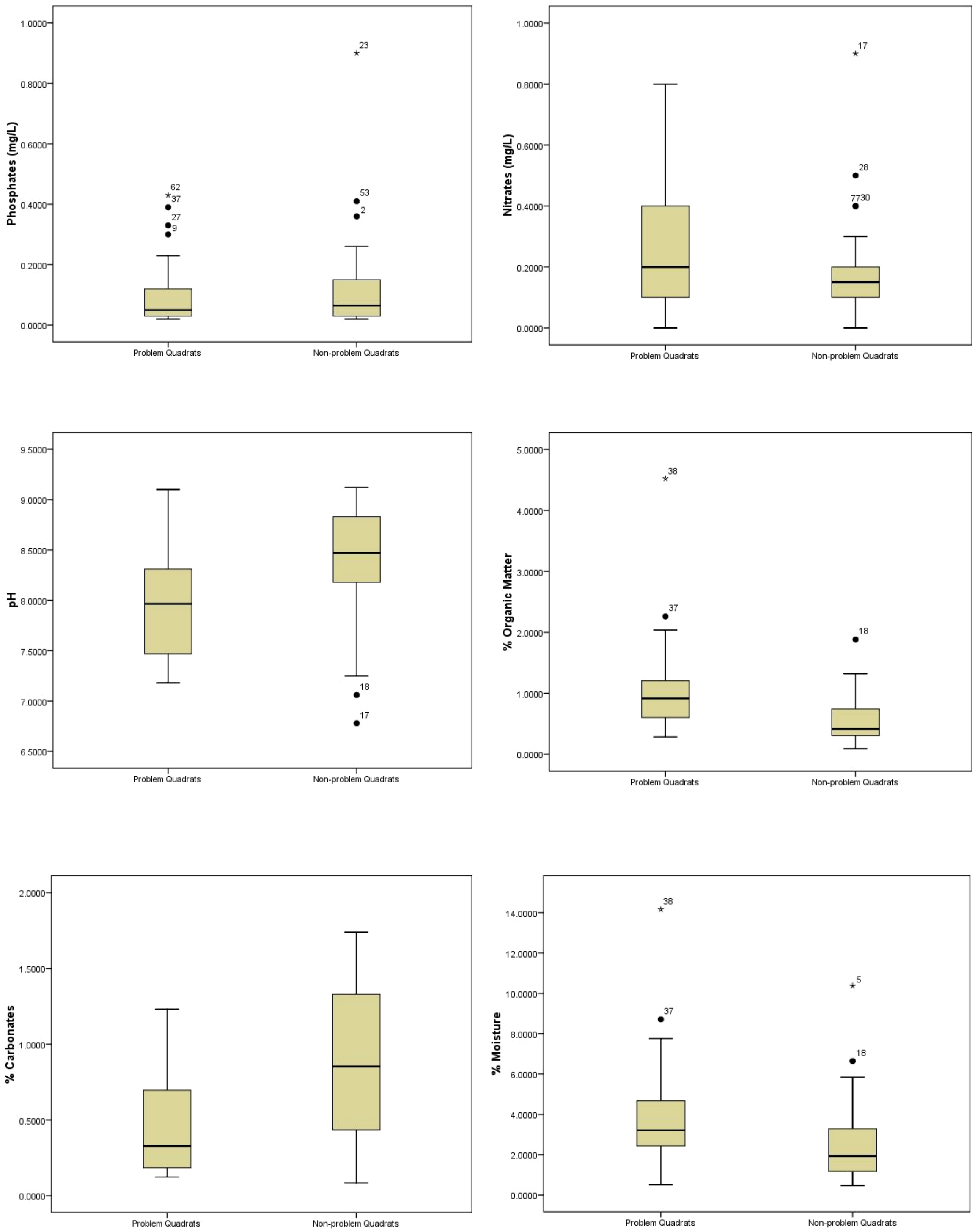

Figure 4.5: Box plots to show the variability between problem quadrats and non-problem quadrats, for the tested environmental variables.

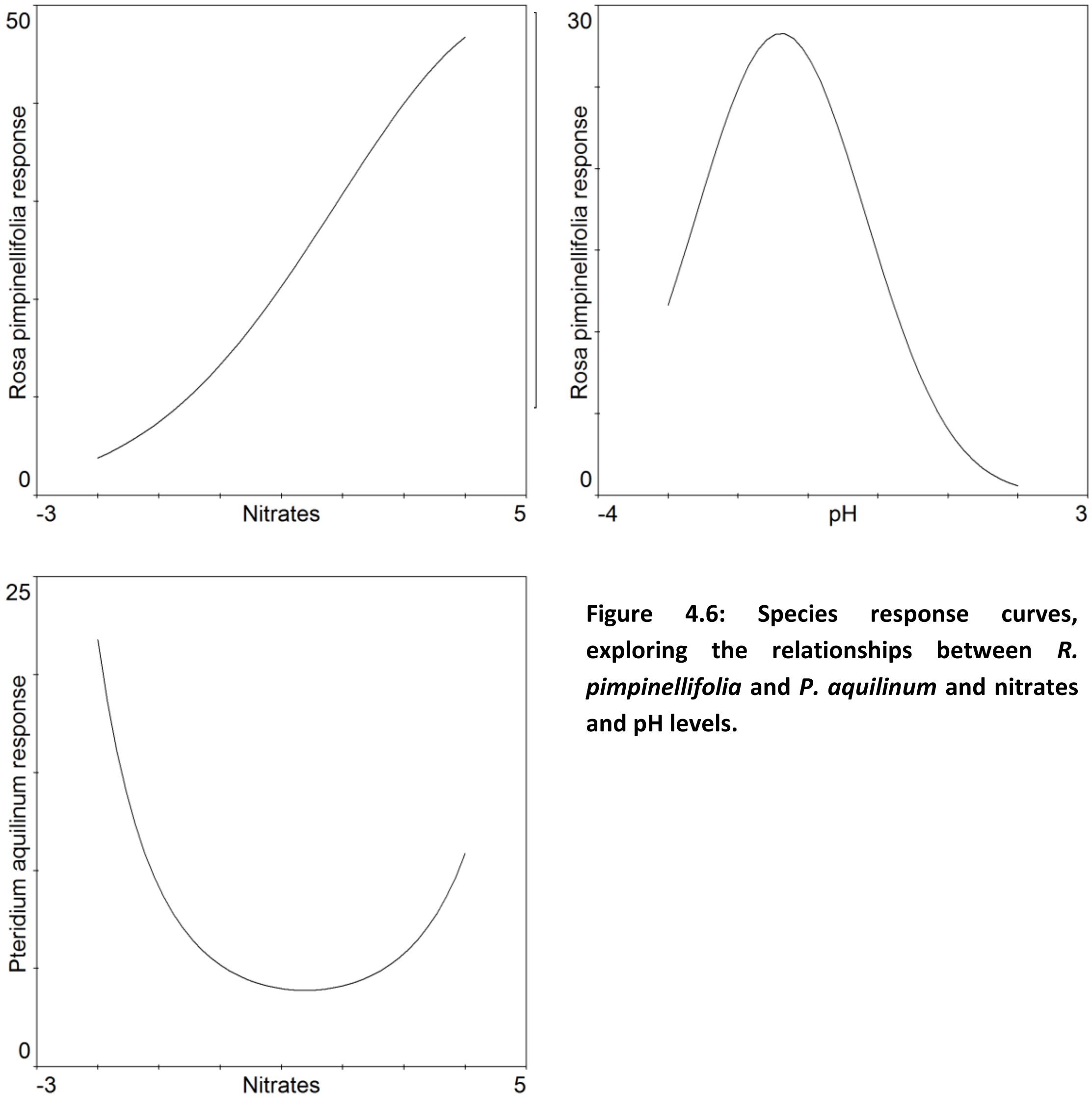

Figure 4.6: Species response curves, exploring the relationships between *R. pimpinellifolia* and *P. aquilinum* and nitrates and pH levels.

sharply in the presence of higher nitrate values. These curves are demonstrated in Figure 4.6 and all had p-values of less than 0.05.

The results of the PCA curve are presented in Figure 4.7 and demonstrate scores for both environmental gradients and species. Two axes were interpreted as follows: axis one, Eigenvalue of 0.190 and a variance of 19% explained; axis two, Eigenvalue of 0.139 and a variance of 33% explained. It can be seen that a number of environmental parameters are highly correlated with the axes. For instance, water loss (g), organic content and nitrates are positively correlated with axis 1, while pH and calcium carbonates are highly negatively correlated. Axis 2 positively correlates with phosphates, conductivity and water loss (g). It can be seen that *R. pimpinellifolia* prefers damper soils with high organic content, but with lower pH values and calcium carbonate values. This is in contrast to *P. aquilinum*, which appears to have a preference to more saline conditions (high conductivity values), yet is not correlated to any other environmental parameters. There is a clear clustering of species which have a

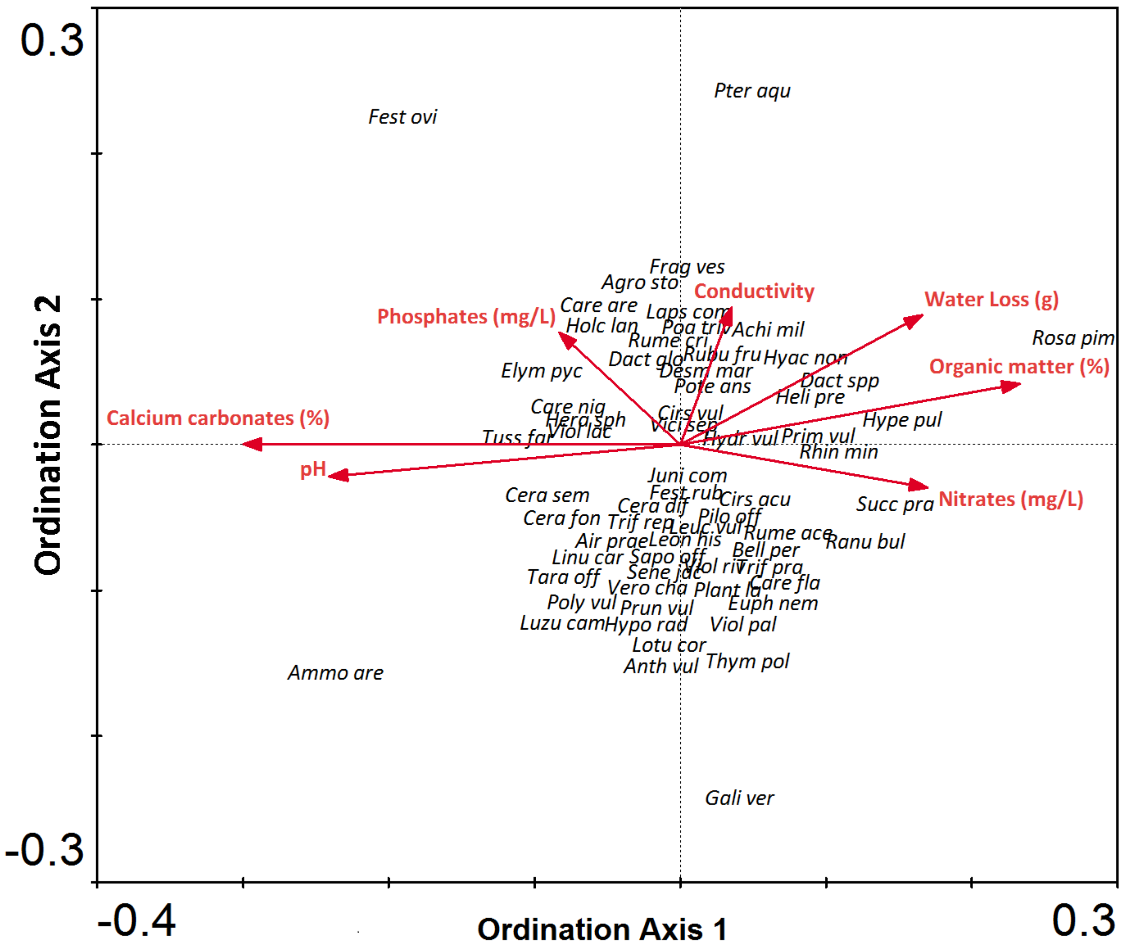

Figure 4.7: PCA of vegetation and environmental parameters across the study site (species abbreviations in Appendix 3)

preference for both higher pH values and nitrates. These are predominately plants which would typically be found in a fixed dune with herbaceous vegetation, where the sward is low and species diversity is high. Indeed, species such as *E. nemorosa, A. vulneraria, B. perennis, R. bulbosus* and *F. rubra* were recorded along the north-east and south-east transects where pH values were alkaline-neutral but gradually becoming more acidic. There is also a positive clustering of species on axis 2, which exhibit an equal preference for higher phosphates, conductivity and water loss (g) values. These are species which contribute towards a scrubbier plant community, such as *H. lanatus, C. vulgare, R. crispus, F. vesca* and *R. fruticosus.* Interestingly, *F. ovina* is a species clearly separated from any clustering and appears to have a preference for higher phosphate values and lower nitrate values. *G. verum,* being a species which occurred regularly throughout the transects, has an equal preference to higher pH and nitrate values. *A. arenaria* is also a species separated away from clustering, and according to the PCA, occurs where soil conditions have a lower moisture content and lower organic matter.

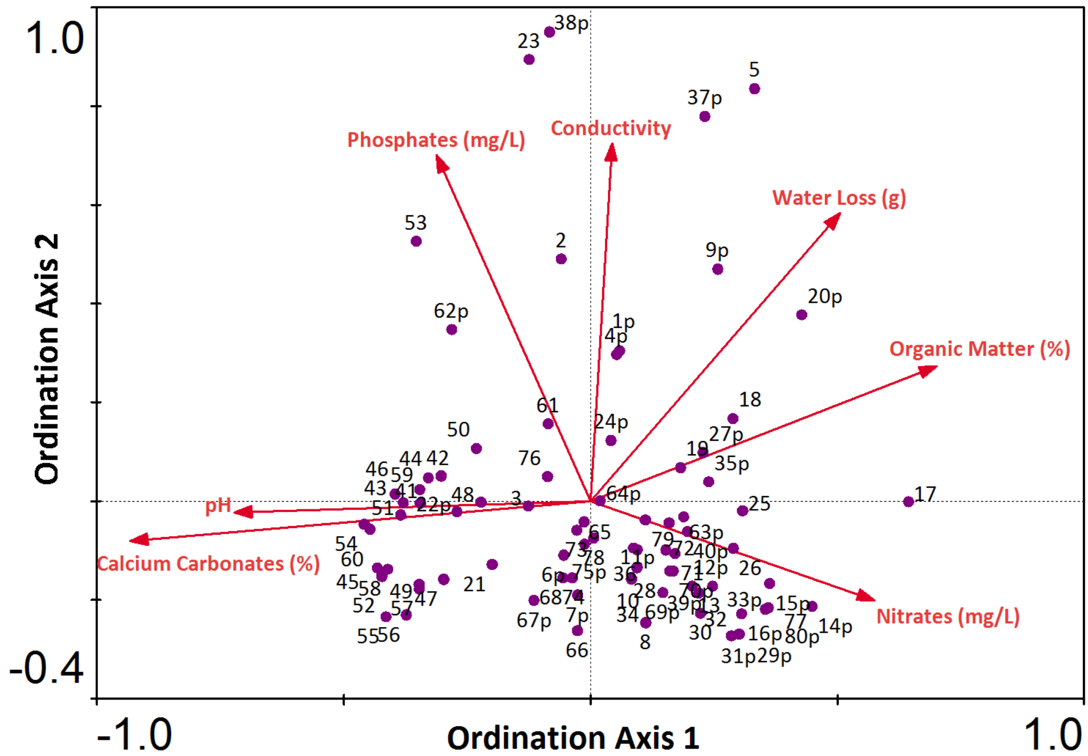

Figure 4.8: RDA of environmental parameters and plots. Problem species plots have been differentiated by the letter 'p' after the plot number.

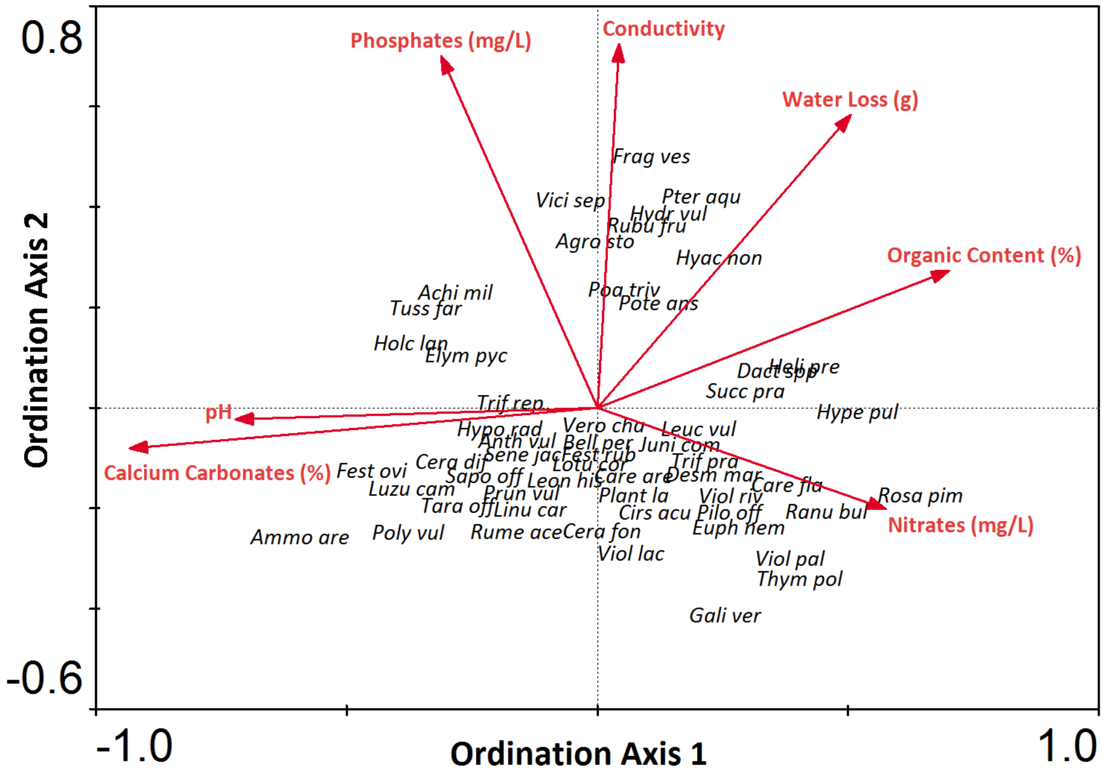

Figure 4.9: RDA of environmental parameters and species across the study site.

The RDA plots have been split into two biplots, rather than creating a triplot of environmental variables, samples and species, for clarity purposes. In Figure 4.8, Plots 37 and 38 are clearly separated from significant clustering , as they are located at the positive end of Axis 2. These quadrats were situated in an area of dense, scrubby vegetation, predominantly consisting of *F. vesca, A. stolonifera, R. fruiticosus* and *P. aquilinum* (Figure 4.9). In addition, plot 23 is also located within this small cluster. Although not a quadrat with problem species, it was situated in a dense patch of *V. sepium* which had low plant biodiversity. These plots appear to prefer conditions of greater salinity and phosphate levels and in soils of higher moisture content. A clustering of plots towards the negative end of Axis 1 are noticeably absent of problem species plots. A large cluster of plots appear on the negative end to Axis 2 and are a significant combination of problem species plots and non-problem species plots, which tend towards higher nitrate content in the soil. However, the cluster does not differentiate between the two groups of quadrats and so a significant relationship between problem species plots and nitrates cannot be gleaned from this observation.

4.2 Wider Dune Environment

Superimposing the key results onto an aerial photograph of the study site allows the viewer to gain a spatial appreciation of environmental gradients and change in vegetation communities. Figure 4.10 demonstrates this as it can be seen that the CORINE biotopes change with distance and coastal dune age. There is a clear radial area surrounding the caravan site which has been classified as Calcareous North Fixed Dune and consists of a low sward of herbaceous vegetation. Closer to the caravan site, communities become a combination of Perennial Open Siliceous Grassland and Agrostis-Festuca Grass. Looking at Figure 4.11, this corresponds with a higher density in *P. aquilinum* and lower species richness values. There are three significant patches of *P. aquilinum* which occur throughout the transects: one at the caravan site, one at the far end of the northern transect and one at the end of the northeast transect. The latter patch is located on the granitic outcrop, which is visible on the aerial photograph. *R. pimpinellifolia* does not appear to grow in delineated patches and is apparent throughout most of the inland transects. The southern transect is void of problem species altogether, and since it is located on along a dune system of uniform age, has a well defined community. Atlantic Ammophila dune and Perennial Open Siliceous grassland are the dominant plant communities

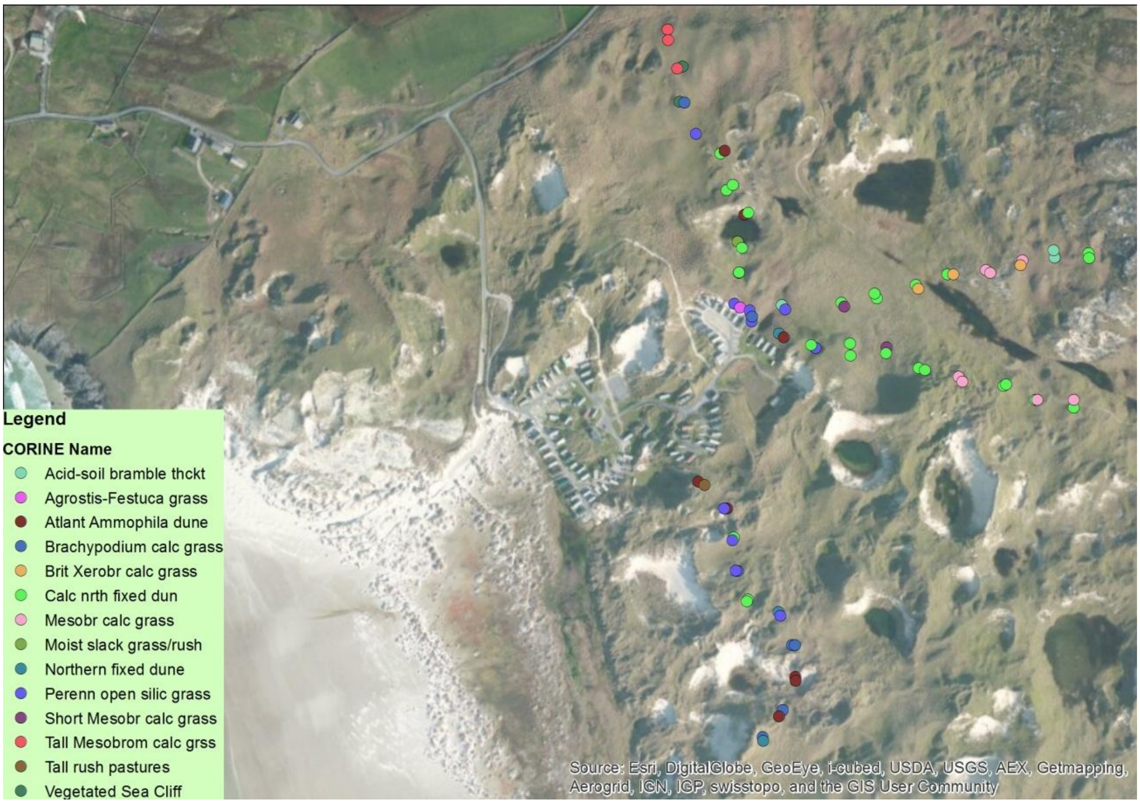

Figure 4.10: Classification of quadrat vegetation data based upon the CORINE biotope system, as determined by TABLEFIT.

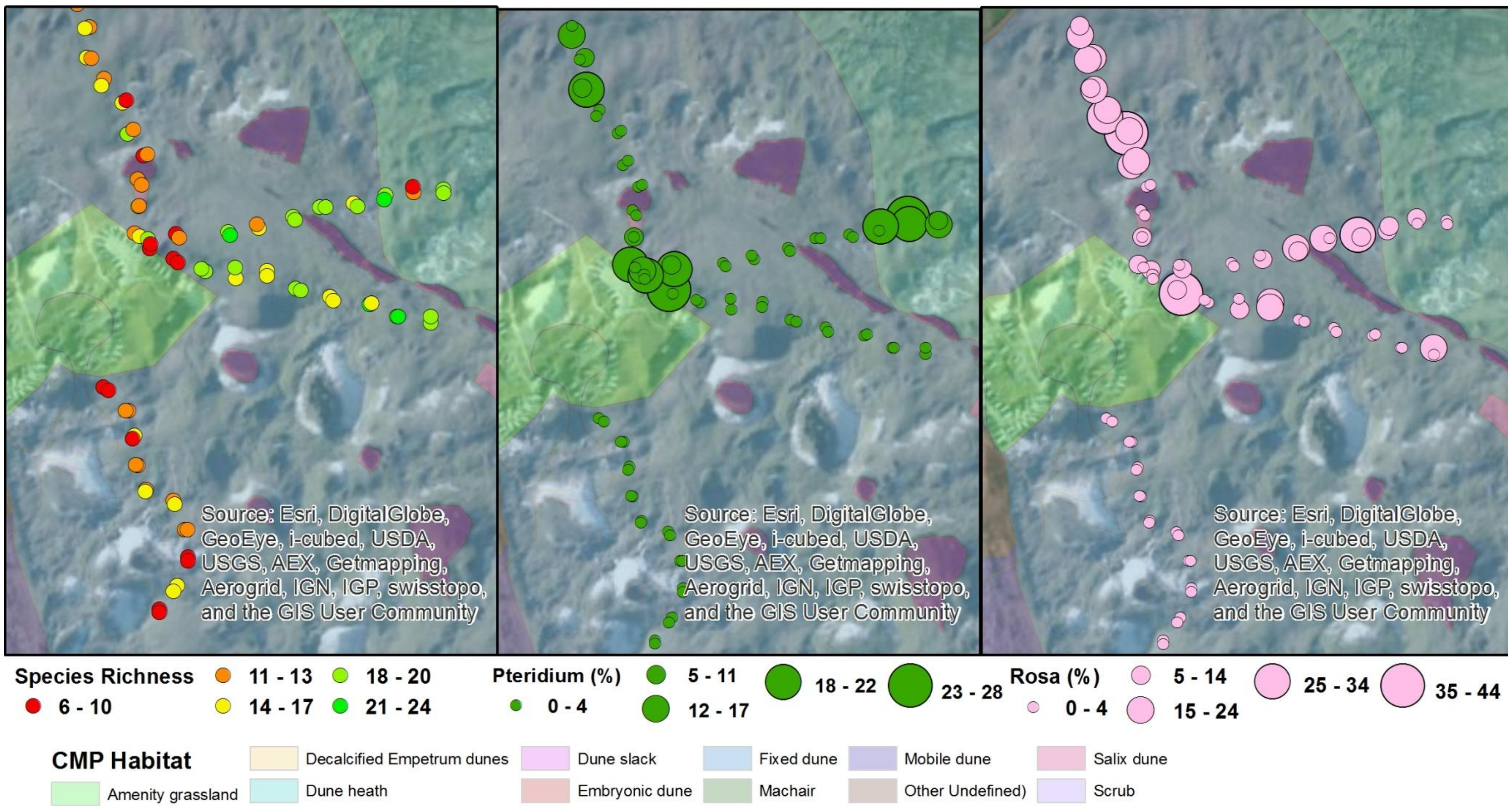

Figure 4.11: Species richness, *P.aquilinum* % coverage and *R. pimpinellifolia* % coverage across study site transects. CMP-assessed habitat classifications overlay the aerial photograph.

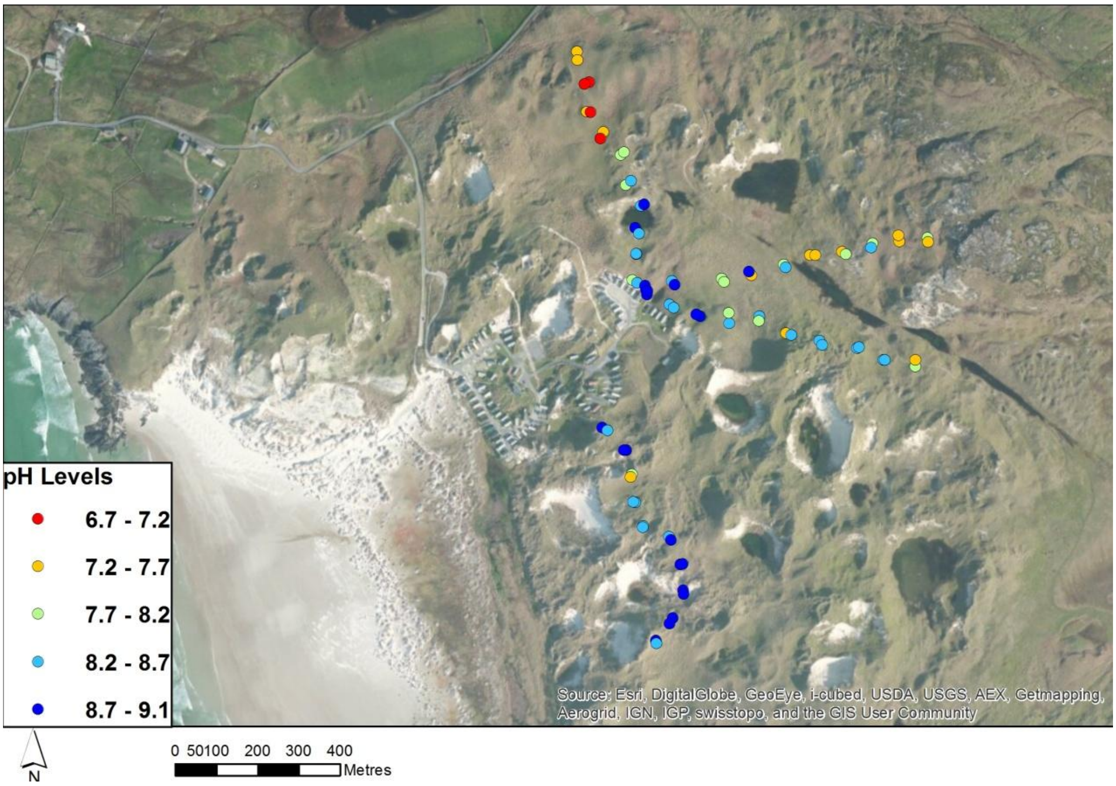

Figure 4.12: pH values for each quadrat throughout the study site.

along this transect. It is also characterised by alkaline soils and a low species richness, which is explained by the dominance of *Ammophila arenaria.*

Figure 4.12 illustrates that the values of pH do not correspond to areas of *P. aquilinum*, yet communities with alkaline values – with exception to the calcareous foredune - tend to have a higher species richness. However, it can clearly be seen that pH values become more acidic as vegetation succession advances and the dune decalcifies.

Calcium carbonate values are clearly correlated to the high pH levels along the southern transect, as Figure 4.13 demonstrates. Levels of $CaCO_3$ are also relatively high surrounding the caravan site. Levels of nitrate are moderately low throughout the transects, with exception to outliers which occur at intervals along the north, northeast and southeast transects. There is a clear clustering of higher phosphate values, 0.43 - 0.9mg/L, around the caravan site and on the granitic outcrop where there is substantial *P. aquilinum* growth. The remaining quadrats exhibit low levels of 0.02 - 0.16mg/L of nitrate by comparison.

The problem species *P. aquilinum* and *R. pimpinellifolia* only occur in mature grassland communities within the dune system, beyond the foredunes. The caravan site appears to have had a local impact upon the grassland communities, as it can be seen that species richness is noticeably poor within the immediate vicinity, while *P. aquilinum* is dominant.

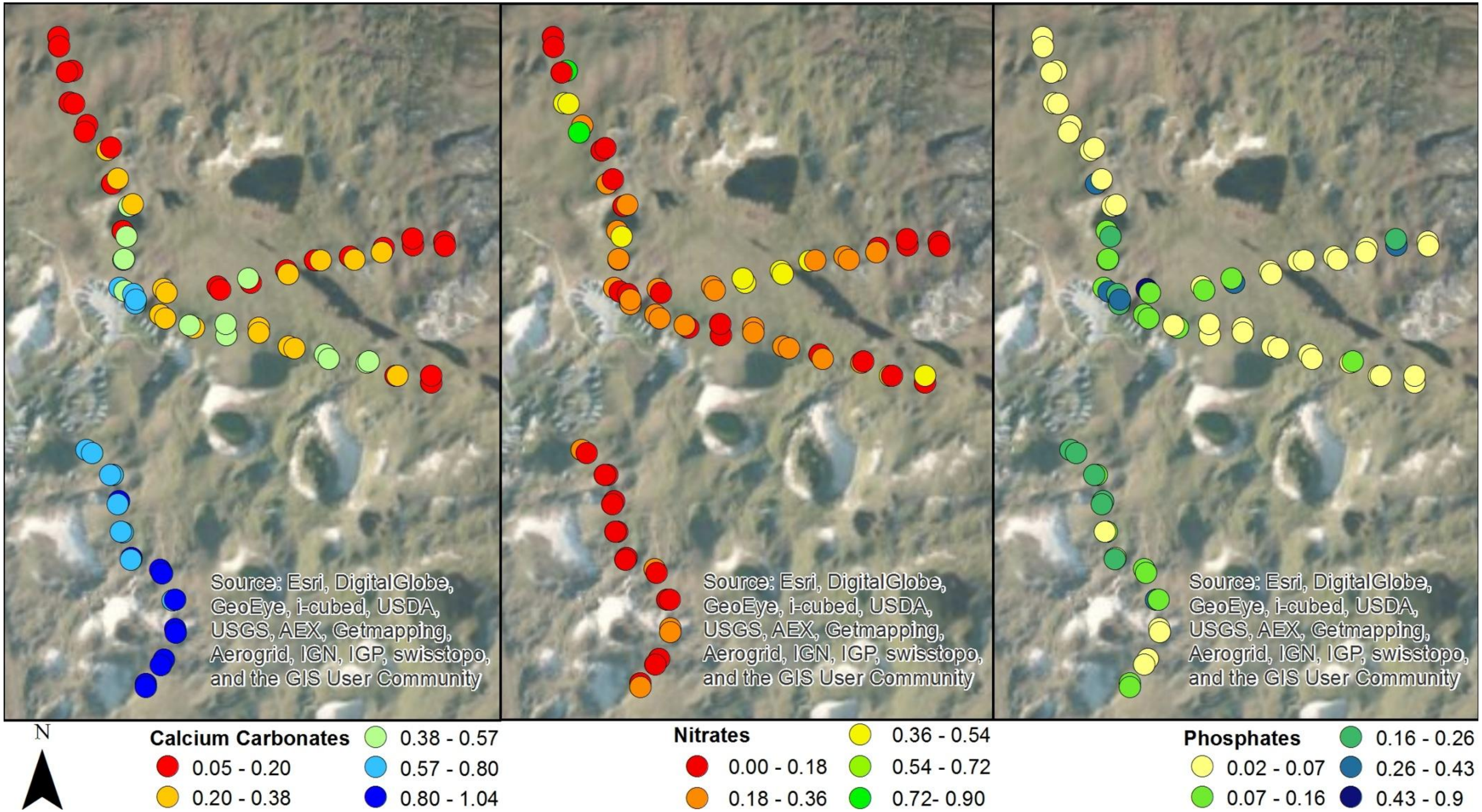

Figure 4.13: The distribution of calcium carbonate % values, nitrate and phosphate values.

5. Discussion

5.1 Ecology of dune grassland

The presence of *P. aquilinum* and *R. pimpinellifolia* appear to not yet have had a significant detrimental impact upon the species richness and biodiversity of Sheskinmore SPA. However, it is clear that many of the quadrats containing problem species are dominated by these plants, as well as vegetation typical of a scrubland community. This has been shown by the indicator species analysis which formed a secondary sub-community of *P. aquilinum*, with species of scrub communities, such as *R. pimpinellifolia* and *Taraxacum* agg. Furthermore, when comparing the location of bracken patches with the NVC classifications, it can be seen that plant communities indicative of lower conservation value are prevalent. Specifically, the *Pteridium aquilinum-Rubus fruticosus* underscrub was identified where the habitat is particularly encroached by bracken and bramble tickets, on the granitic outcrop of the northeast transect.

Although it was found that quadrats without problem species had significantly higher pH values, this could be attributed to the location of these quadrats, rather than the species composition. The majority of quadrats lacking such problem species occurred on the southerly transect which was located along the foredune behind Tramore Strand. The location of this foredune within the coastal dune system suggests that the alkaline pH values can be attributed to a high calcium carbonate percentage within the substrate, as decalcification due to carbonate leeching has not yet reached a substantial level to make a significant difference to edaphic conditions. Interestingly however, high calcium carbonate values were also recorded within the immediate vicinity of the caravan site. Decalcification occurs when humic acids are released during soil development and the levels of calcium carbonates drop below 0.3% (Provoost *et al,* 2004). Soil development is reliant upon the decomposition of plant material and a gradual development in succession to provide growing plant material. Considering this, it is possible that the activities of the caravan site have retarded soil development and consequently affected species composition. Since *P. aquilinum* thrives within mid-successional niches and disturbed ground, this would explain the extent of bracken in this area.

However, this is not the case for the large patches of *P. aquilinum* at the far end of the north transect and the northeast transect. These are two areas which are distanced from the walking paths with no evidence of human activity. They are also relatively inaccessible to grazing stock due to steep or rocky terrain. The measured environmental parameters do not reveal any significant relationships with these bracken communities. Further research would be required to determine the exact variables that influence the distribution of *P. aquilinum* in these areas.

Levels of phosphates and nitrates were all comparatively low throughout the quadrats, which is in agreement with expected nutrient levels, since dune systems are generally deficient (Richards and Burningham, 2011). No significant relationships were established between the distribution of problem species and the availability of soil nutrients. Nevertheless, the level of phosphates is particularly high around the caravan site, which again suggests that recreational activity has impacted upon the soil conditions within the immediate vicinity.

R. pimpinellifolia did not demonstrate any significant relationships with environmental gradients throughout the transects. Its distribution is fairly scattered across the grey dune grassland, with only a few noticeable areas devoid of the species. Its growth is dwarfed and did not exhibit any tendencies for outcompeting other grassland species for light or space. Favourable environmental conditions included a higher soil moisture content, high organic matter and lower calcium carbonate levels. These are preferences which are consistent with habitat conditions of the mature, acidic grey dune grassland.

Herbaceous species such as *Linum catharticum, Prunella vulgaris* and *Polygala vulgaris* favour conditions of higher pH values and proportionally high nitrate levels. The latter species in particular is indicative of infertile, neutral, short grassland (Raven, 2012). This is in agreement to the distribution of *Polygala vulgaris* recorded in this particular survey, especially as average nitrate levels were low.

The distribution of *A. arenaria* is very separate to that of *P. aquilinum*. No favoured environmental gradients were found to be in common between the two species. The former species occupies a well-defined niche, generally occurring on the foredunes where they stabilise the well-drained, saline, nutrient-poor substrate. By contrast, *P. aquilinum* appears to prefer soils which are substantially higher in moisture content with moderate-high nutrient levels. As a result, bracken was not found to be invasive across *A. arenaria* grassland.

Quadrats defined by the CORINE system as 'Calcareous North Fixed Dune' communities were generally found within the flat grassland plain, accessible to stock and with evidence of light grazing activity. Species richness was found to be fairly high in this habitat, with up to 25 species recorded in the majority of quadrats. In addition to this, there were areas of grassland where phosphate and nitrate values were moderately higher. Elevated nutrient levels could be attributed to the presence of livestock. Healthy species diversity has been demonstrated by previous studies (Plassman *et al*, 2010; Tahmasebi Kohyani *et al*, 2008; Harkel Matthijs and Meulen, 1996) that lightly grazed land is generally species-rich, as long as the seed bank harbours such potential. Grazing herbivores effectively reduce phytomass in a grassland, which opens up the sward to light and space, allowing for successful germination and establishment of seedlings which are less competitive (Jutila and Grace, 2002). In addition to this, trampling and dung can immediately change gap availability in the grassland sward, as well as add resources to the ecosystem which ultimately alters competitive hierarchies (Tahmasebi Kohyani *et al*, 2008). As a result, habitat niches are created, which forms a mosaic of vegetation communities.

Three clustered quadrats, located at the end of the north transect, have been defined under the CORINE system as 'Tall Mesobromic Calcicolous Grassland', which consists of grass species that are able to outcompete lower growing herbs and create a tall sward. These quadrats were situated in an area of dense bracken, low species richness and low nutrient availability. It is therefore evident that despite there being little correlation between low diversity and problem quadrats, on a micro scale, vegetation communities have been altered and made less diverse by the encroachment of *P. aquilinum*.

Species and communities have therefore been affected by the varying environmental variables across the transects. Problem species have had a less significant impact, but to a certain degree which does require attention. The caravan site has clearly had an influence over edaphic conditions and the resultant plant community.

5.2 Invasive species management at Sheskinmore Lough SPA

This study has demonstrated that *P. aquilinum* requires a targeted management plan in order to remove the species from the grassland. It is evidently growing in areas which are inaccessible to livestock, which suggests that it is capitalising on the mid-successional vegetation community and using these patches as refuges. Although species richness across the dune system in Sheskinmore Lough SPA has not yet appeared to have been affected, a proactive approach, to start as soon as possible, would be beneficial to the grassland in order to prevent any further potential damage to the ecosystem. Over time, affected grassland communities will become bracken habitat, where herbaceous ground flora will be out-competed and soil fertility will increase due to the accumulation of litter which consists of carbohydrate and nutrient reserves (Plassman *et al*, 2010; Pakeman and Marrs, 1992). Increased soil fertility could make future restoration of the dune grassland a challenge, since diversity increases when nutrients are low (Pakeman and Marrs, 1992). Therefore, immediate removal of bracken would decrease the probability of this scenario occurring.

The grassland immediately surrounding the caravan site needs to be closely monitored for any further change. It is possible that over time, recreational activity will have a spatially wider impact upon the dune grassland, to the point where hard restoration is required. Although the majority of recreation is clearly directed towards Tramore Strand, there is evidence of light erosion and disposal of litter and building materials, all of which can alter soil conditions and vegetation composition.

There is little evidence that *R. pimpinellifolia* has a negative impact across the dune grassland and so therefore does not require immediate management. Plant growth is currently dwarfed and scattered. In a report on Irish Machair survey sites (Bleasdale *et al,* 1996), it was noted that *R. pimpinellifolia* contributes towards the understorey of grassland species, thus stabilising the high dunes at Sheskinmore Lough SPA. The spread of *P. aquilinum* has been highlighted as a concern while *R. pimpinellifolia* has not. This suggests that the extent and intensity of *R. pimpinellifolia* growth has not increased over time but does need continual monitoring.

There are many long-term studies which have investigated the most appropriate treatments for invasive plant removal on coastal dunes (Kollman *et al,* 2009; Stewart *et al*, 2008). Biological control through the use of alien insects has historically been suggested (Lawton, 1990) but would be an inappropriate form of management in the present-day, given our current knowledge of deliberately introducing alien species and risking a new invasion. The use of bracken herbicide, asulam, has been another alternative option in the recent past, but it has since been banned across the EU from September 2011 and is only available during emergency authorisation (Briggs, 2013). Chemical control would most likely be inappropriate for a dune grassland in any case , given its fragile ecosystem and biodiversity. Måren *et al* (2008) found that the use of asulam had unintended effects upon species of a coastal heathland in Western Norway. They also found that mechanical control was equally effective and more beneficial to the restoration of heathland over time. Cutting bracken has been proven to be a successful treatment, as part of a long-term management plan . Marrs *et al* (2000) found that the most effective treatment was a twice yearly cut over the course of six years. The result was that the fronds had reached only 40% of the untreated levels, 12 years after the last treatment.

Considering this, cutting the bracken would be the most appropriate option for Sheskinmore Lough SPA. A twice-yearly cut would ensure that new fronds and growth are inhibited and closely monitored. It is appreciated that population – and therefore manpower – is scarce in the area for such a task. An option would be to establish a community voluntary group, consisting of local residents and annual visitors to the dunes. Not only would this attract people who already have an interest in conservation, it would also help to educate visitors and make them more environmentally aware of the SAC. A similar scheme exists in the UK in the form of The Conservation Volunteers (TCV). TCV visit local parks and reserves to do practical conservation management. As well as completing a substantial amount of conservation work, community spirit is nurtured through the feeling of accomplishment. This strategy is also an affordable and efficient option when there is a need to manage large areas.

Currently, a light grazing regime is implemented on the flat grassland which was recorded to have high species diversity, midway along the northeast and southeast transects. This is an effective tool for grassland management and is one which is appropriate for the site. The extent of bracken needs to be monitored, as it is poisonous and carcinogenic to stock (Pakeman and Marrs, 1992) . Thus, if the current populations expand into grazed grassland, the grazing potential is severely reduced, which in turn affects the plant species diversity.

5.3 Wider conservation implications for invasive species on coastal dunes

Given the complex mosaic of habitats and environmental interactions which form the coastal dune environment, it is very difficult to predict the behaviour of invasive species and apply the model to other coastal dune systems. Numerous studies have suggested that management experiments should be established at individual sites in order to determine the best treatment for the control of invasive species such as *P. aquilinum* (Stewart *et al*, 2008; Cox *et al,* 2008). Since coastal dune habitats are so transient in nature, management plans need to recognise this and adapt to the changing environment. This is particularly important given the climate change which is currently occurring. Sea level rise would have a particularly significant impact as it could potentially cause the beaches to migrate inland, thereby eroding foredunes and altering the course of plant succession. In addition, ocean acidification will reduce the rates of calcification, which will in turn affect the calcium metabolism of marine organisms (Defeo *et al*, 2009). This will ultimately affect the edaphic conditions of sand dunes.

Future scenarios such as this need to be considered when constructing management plans. Changing environments will undoubtedly impact upon the vegetation of coastal sand dunes, which includes invasive species. Although it is difficult to predict how invasive species will react to such change, the most effective treatments will be those which adapt to the changing environment.

6. Conclusion

Species biodiversity has not yet been affected by the encroaching *P. aquilinum* or *R. pimpinellifolia*. There appears to be no significant change in nutrient levels across the grassland as a result of these ‘unwelcome’ species. However, the dune grassland of Sheskinmore Lough SPA has clearly been affected by the caravan site, where species composition has formed a community which is comparable to under scrub vegetation. The zone of influence does not extend far since grassland 40 metres away from the caravan site is composed of species expected from a fixed dune community.

R. pimpinellifolia has not established dense stands of vegetation. By contrast, *P. aquilinum* has formed significant patches of growth which is a cause for concern. These areas have potential to expand and alter soil conditions and vegetation communities. Therefore, a targeted management plan of removal is required to control the bracken and prevent any damage to the fixed dune flora composition. Cutting and pulling bracken is a highly recommended strategy for removal and has proven to be successful.

Given the evolving nature of the coastal dune system, and the impacts that climate change could potentially have, the management plan needs to be adapted to the changing environment. Predicting the distribution of invasive and ‘unwelcome’ species in response to such environmental changes is difficult, hence the need for a flexible long-term management plan.

Further research is required to determine the environmental variables that influence the growth of bracken stands outside of the influence of the caravan site. This would contribute towards a greater understanding of the most appropriate treatment required for bracken removal and will help prevent future growth. Close monitoring of ‘unwelcome’ species is required to ensure that permanent damage to the fixed dune ecosystem is not made.

Autocritique

If I could do this project again and improve on it, I would survey many more transects which radiate out from the caravan site. I would also extend the transects by 200 metres so that they cover a wider area, well into the bracken stands. I would repeat the survey at least three times over the course of a year (or two) to see whether changes in environmental parameters are weather dependant. . This way, I would hope to gain a more comprehensive understanding of the change in vegetation composition and environmental variables across the study site.

In addition, I would also analyse the change in bracken extent over time, using GIS, in order to try and predict future expansion. However, all of this is based upon the assumption that I would have a lot more time to complete the project!

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Appendix 1: MLR Results

Dependent Variable: Species Richness

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	186.456	5	37.291	2.207	.063[a]
	Residual	1199.908	71	16.900		
	Total	1386.364	76			

a. Predictors: (Constant), pH, PO43- log10, NO-3 log 10, Conductivity, Water Loss (g)

b. Dependent Variable: Species Richness

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	16.595	8.883		1.868	.066
	Conductivity	-.367	.535	-.085	-.685	.496
	PO43- log10	-1.711	.665	-.305	-2.571	.012
	NO-3 log 10	.203	.497	.048	.408	.684
	Water Loss (g)	.088	.243	.048	.362	.719
	pH	-.362	1.032	-.049	-.351	.726

a. Dependent Variable: Species Richness

Dependent Variable: Simpson's Index of Diversity

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.023	5	.005	1.498	.201[a]
	Residual	.219	71	.003		
	Total	.242	76			

a. Predictors: (Constant), pH, PO43- log10, NO-3 log 10, Conductivity, Water Loss (g)

b. Dependent Variable: Simpson

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.010	.120		8.413	.000
	Conductivity	-.003	.007	-.058	-.461	.646
	PO43- log10	-.014	.009	-.194	-1.598	.114
	NO-3 log 10	.000	.007	-.015	-.127	.899
	Water Loss (g)	-.002	.003	-.086	-.636	.527
	pH	-.018	.014	-.186	-1.301	.197

a. Dependent Variable: Simpson

Dependent Variable: Berger-Parker Index

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	18.522	5	3.704	1.428	.225[a]
	Residual	184.180	71	2.594		
	Total	202.702	76			

a. Predictors: (Constant), pH, PO43- log10, NO-3 log 10, Conductivity, Water Loss (g)

b. Dependent Variable: Berger-Parker

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	8.984	3.480		2.581	.012
	Conductivity	.093	.210	.056	.443	.659
	PO43- log10	-.512	.261	-.239	-1.964	.053
	NO-3 log 10	-.077	.195	-.048	-.395	.694
	Water Loss (g)	-.081	.095	-.115	-.848	.399
	pH	-.544	.404	-.193	-1.346	.183

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	8.984	3.480		2.581	.012
	Conductivity	.093	.210	.056	.443	.659
	PO43- log10	-.512	.261	-.239	-1.964	.053
	NO-3 log 10	-.077	.195	-.048	-.395	.694
	Water Loss (g)	-.081	.095	-.115	-.848	.399
	pH	-.544	.404	-.193	-1.346	.183

a. Dependent Variable: Berger-Parker

Appendix 2: Average Values for Environmental Parameters

		pH	Conductivity (µS)	% Organic Matter	%Moisture	%CaCO3	Phosphate (mg/L)	Nitrates (mg/L)
Quadrats with Problem Species	**Min**	7.18	14.35	0.28	0.51	0.07	0.02	0.00
	Max	9.10	41.80	4.52	14.16	0.74	0.43	0.80
	Mean	7.96	22.91	1.08	3.87	0.27	0.11	0.25
Quadrats without Problem Species	**Min**	6.78	12.70	0.09	0.47	0.05	0.02	0.00
	Max	9.12	48.40	1.88	10.37	1.04	0.90	0.90
	Mean	8.39	23.11	0.58	2.49	0.53	0.12	0.19

Appendix 3: Species List and Abbreviations at Sheskinmore Lough SPA

Achillea millefolium	Achi mill	Yarrow
Agrostis stolonifera	Agro stol	Creeping Bent
Aira praecox	Air prae	Spike Hairgrass
Ammophila arenaria	Ammo aren	Marram Grass
Anthyllis vulneraria	Anth vuln	Kidney Vetch
Bellis perennis	Bell pere	Daisy
Carex arenaria	Care aren	Sand Sedge
Carex diandra	Care dian	Lesser Panicled Sedge
Carex flacca	Care flac	Glaucous Sedge
Carex nigra	Care nigr	Common Sedge
Centaurium erythraea	Cent eryt	Common Centaury
Cerastium diffusum	Cera diff	Sea Mouse-ear
Cerastium fontanum	Cera font	Common Mouse-ear
Cerastium semidecandrum	Cera semi	Little Mouse-ear
Cirsium acuale	Cirs acua	Dwarf Thistle
Cirsium dissectum	Cirs diss	Meadow Thistle
Cirsium vulgare	Cirs vulg	Spear Thistle
Crepis vesicaria	Crep vesi	Beaked Hawk's-beard
Dactylis glomerata	Dact glom	Cock's-foot
Dactylorhiza sp.	Dact spp.	Orchid Species
Dactylorhiza fuchsii	Dact fuch	Common Spotted-orchid
Dactylorhiza purpurella	Dact purp	Northern Marsh Orchid
Desmazeria marina	Desm mari	Stiff Sand-grass
Elymus pycnanthus	Elym pycn	
Erodium circutarium	Erod circ	Common Stork's-bill
Euphrasia nemorosa	Euph nemo	Common Eyebright
Festuca ovina	Fest ovin	Sheeps Fescue
Festuca rubra	Fest rubr	Red Fescue
Fragaria vesca	Frag vesc	Wild Strawberry
Galium saxatile	Gali saxa	Heath Bedstraw
Galium verum	Gali veru	Lady's Bedstraw
Helictotrichon pretense	Heli pret	Downy Oat-grass
Heracleum sphondylium	Hera spho	Hogweed
Holcus lanatus	Holc lana	Yorkshire Fog
Hyacinthoides non-scripta	Hyac non	Bluebell
Hydrocotyle vulgaris	Hydr vulg	Marsh Pennywort
Hypericum pulchrum	Hype pulc	Slender St John's-wort
Hypochaeris radicata	Hypo radi	Common Cat's Ear
Juniperus communis	Juni comm	Juniper
Lactuca serriola	Lact serr	Prickly Lettuce
Lapsana communis	Laps comm	Nipplewort
Leontodon hispidus	Leon hisp	Rough Hawkbit

Leucanthemum vulgare	Leuc vulg	Oxeye Daisy
Linum carthaticum	Linu cart	Fairy Flax
Lotus corniculatus	Lotu corn	Bird's Foot Trefoil
Luzula campestris	Luzu camp	Field Wood Rush
Pilosella officinarium	Pilo offi	Mouse-ear Hawkweed
Plantago lanceolata	Plant lanc	Ribwort Plantain
Plantago maritima	Plant mari	Sea Plantain
Poa trivialis	Poa triv	Rough Meadow Grass
Polygala vulgaris	Poly vulg	Common Milkwort
Potentilla anserina	Pote anse	Silverweed
Primula vulgaris	Prim vulg	Primrose
Prunella vulgaris	Prun vulg	Self-heal
Pteridium aquilinum	Pter aqui	Bracken
Ranunculus acris	Ranu acri	Meadow Buttercup
Ranunculus bulbosus	Ranu bulb	Bulbous Buttercup
Rhinanthus minor	Rhin mino	Yellow Rattle
Rosa pimpinellifolia	Rosa pimp	Burnet Rose
Rubus fruticosus	Rubu frut	Bramble (Blackberry)
Rumex crispus	Rume cris	Curled Dock
Rumex acetosa	Rume acet	Common Sorrel
Saponaria officinalis	Sapo offi	Soapwort
Sedum acre	Sedu acre	Biting Stonecrop
Senecio jacobaea	Sene jaco	Ragwort
Succisa pratensis	Succ prat	Devil's-bit Scabious
Taraxacum officinale agg	Tara offi	Dandelion
Thymus polytrichus	Thym poly	Wild Thyme
Trifolium pratense	Trif prat	Red Clover
Trifolium repens	Trif repe	White Clover
Tussilago farfara	Tuss farf	Coltsfoot
Veronica chamaedrys	Vero cham	Germander Speedwell
Vicia sepium	Vici sepi	Bush Vetch
Viola lactea	Viol lact	Pale Dog-violet
Viola palustris	Viol palu	Marsh Violet
Viola riviana	Viol rivi	Common dog violet