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Eco-hydrological interactions within a sand dune system in South East England

by

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Thesis submitted

For the Degree of Doctor of Philosophy

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Abstract

The research was undertaken at a sand dune system located along the South East coast of England, known as Sandwich Bay. Sandwich Bay has attracted a number of environmental designations, including Special Areas of Conservation and a Site of Special Scientific Interest due to the presence of rare habitats and flora found predominantly at this single site, such as *Himantoglossum hircinum* (lizard orchid) and *Orobanche caryophyllacea* (bedstraw broomrape). The research focus centred on concerns surrounding ecological change resulting in the loss of grey dunes, an Annex 1 priority feature. Sandwich Bay has been classed as a Special Site of Scientific Interest in unfavourable condition (Natural England, 2014), based primarily upon the loss of fixed grey dune habitats to neutral grasslands (SD8 to MG1/MG12 NVC classifications).

The aim was to identify causative factors that might account for the observed historic and any current changes in vegetation. The research was conducted between October 2011 and September 2014, and focused upon hydro-chemical interactions in the environment. Analysis was undertaken by the installation of 103 dipwells across the 520 ha site, in order to obtain groundwater samples. The hydro-chemical and botanical analysis indicated that the vegetation composition was not affected significantly by the chemical constituents within the groundwater. However vegetation composition was significantly modified by variable surface elevation and the related height of the water table. An additional investigation focused upon the identification of management techniques that are thought to be beneficial to dune vegetation restoration. Three management trials were located at three different sites, investigating four different management treatments. Analysis showed that there was a significant difference between the various management treatments and species composition. Vegetation analysis indicated that both cut and remove, and burning, as management treatments encouraged a greater diversity of species, particularly in sheltered eutrophic areas.

Acknowledgements

There is no such thing as a lone study; therefore I wish to acknowledge the assistance given financially, physically and academically to all of those involved in this research project.

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I wish to thank all of those involved with the dipwell installation and sample collection across Sandwich Bay, in the snow, rain, fog and the occasional sunshine, which helped to make this substantial project a success. I would like to thank particularly: Phil Buckley, Hazel Ellis, Martin Bailitis, Timothy Moore, Georgina Andrews, Tom Williams and David Cameron, all of whom came back on numerous occasions to support me.

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List of Abbreviations

CASI - Compact Airborne Spectrographic Imager

DEM - Digital Elevation Model

DSM - Digital Surface Model

DTM - Digital Terrain Model

GIS - Geographic Information Systems

IDW - Inverse Density Weighted

LiDAR - Light Detecting and Ranging

MAVIS - Modular Analysis of Vegetation Information System

MSS - Multi-Spectral Scanner Imagery

NVC - National Vegetation Classification of the UK

SSSI - Site of Special Scientific Interest

TIN - Triangulated Irregular Network

Chapter One

Eco-hydrological interactions within a sand dune system in South East England

1.1 Introduction

Distribution of sand dune systems

Coastal dunes are aeolian landforms that develop in coastal areas where an ample supply of loose, sand sized sediment is available to be transported inland by the ambient winds (Martínez & Psuty, 2008). Coastal sand dunes are unique systems that can be found in most biomes, covering ecological habitats ranging from polar to tropical latitudes, and from deserts to tropical rainforests (van der Maarel 1993a; Martínez & Psuty, 2008).

The sand dune distribution map (Figure 1.1) shows the worldwide locations of interspersed and developed sand dunes. Due to the broad distribution and ecological diversity (in terms of geomorphological dimensions, environmental heterogeneity, and species variability), sand dune ecosystems are diverse habitats and host a large number of niche environments, which change frequently, based upon successional states (Maun, 2009).

Sand dune systems have been used for many different purposes, including; coastal defence, water catchment, agriculture, mining, housing, and tourism (Carter, 1991; Geelen & Kemps, 2013; Stuyfzand, 1993; van der Maarel, 1993b). In addition, dune system areas serve as locations for groundwater recharge and assist in the retention of freshwater as a buffer against saltwater intrusion (Stuyfzand, 1993). There is also a growing body of opinion that sees the preservation of sand dune systems as desirable in itself, for scientific and ecological reasons (Maun, 2009).

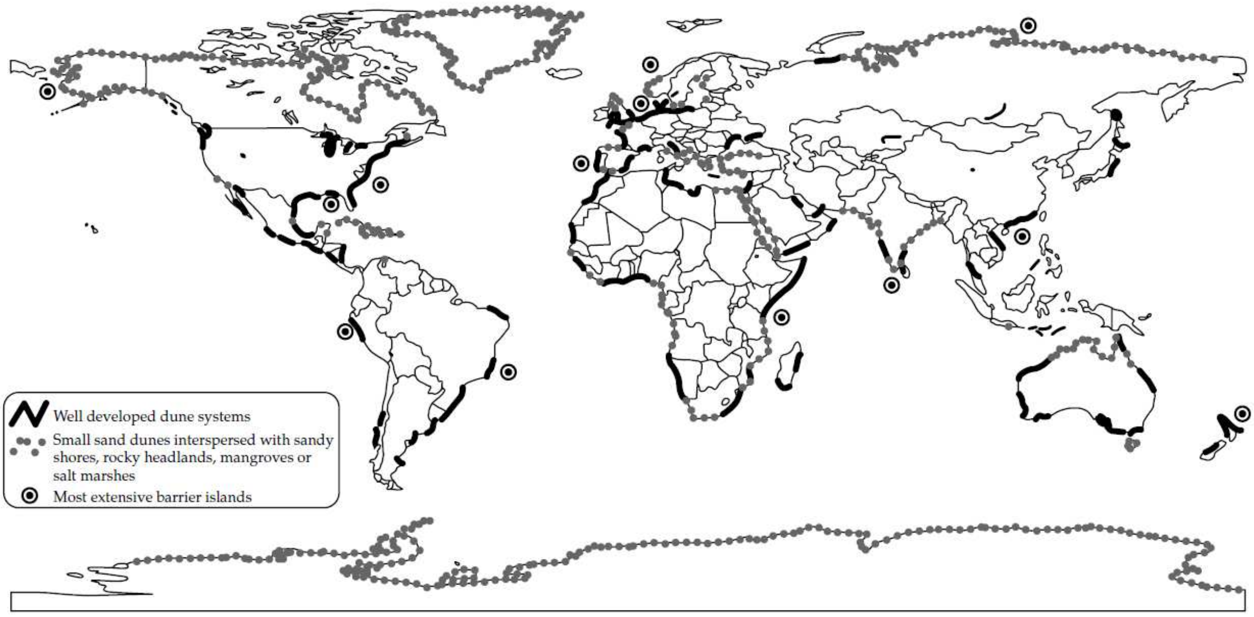


Figure 1.1 Main locations of sand dune formation along sea coasts of the world and along the Great Lakes (Figure taken from Maun, 2009 and Martínez & Psuty, 2008)

England and Wales have a number of dune systems (Figure 1.2). According to the Sand Dune Survey of Great Britain (Radley & Dargie, 1995), the total area of sand dunes in the United Kingdom is 70,998 ha, which equates to: 11,897 ha in England, 8,101 ha in Wales, 48,000 ha in Scotland and 3,000 ha in Northern Ireland. The UK has 2,762 golf courses, representing 8% of the world's golf courses (Saito, 2010; R&A, 2013), 208 of which are links golf courses residing on an estimated 24,960 ha of dunes, corresponding to 35.4% of the UK sand dunes (Taylor, 2012).

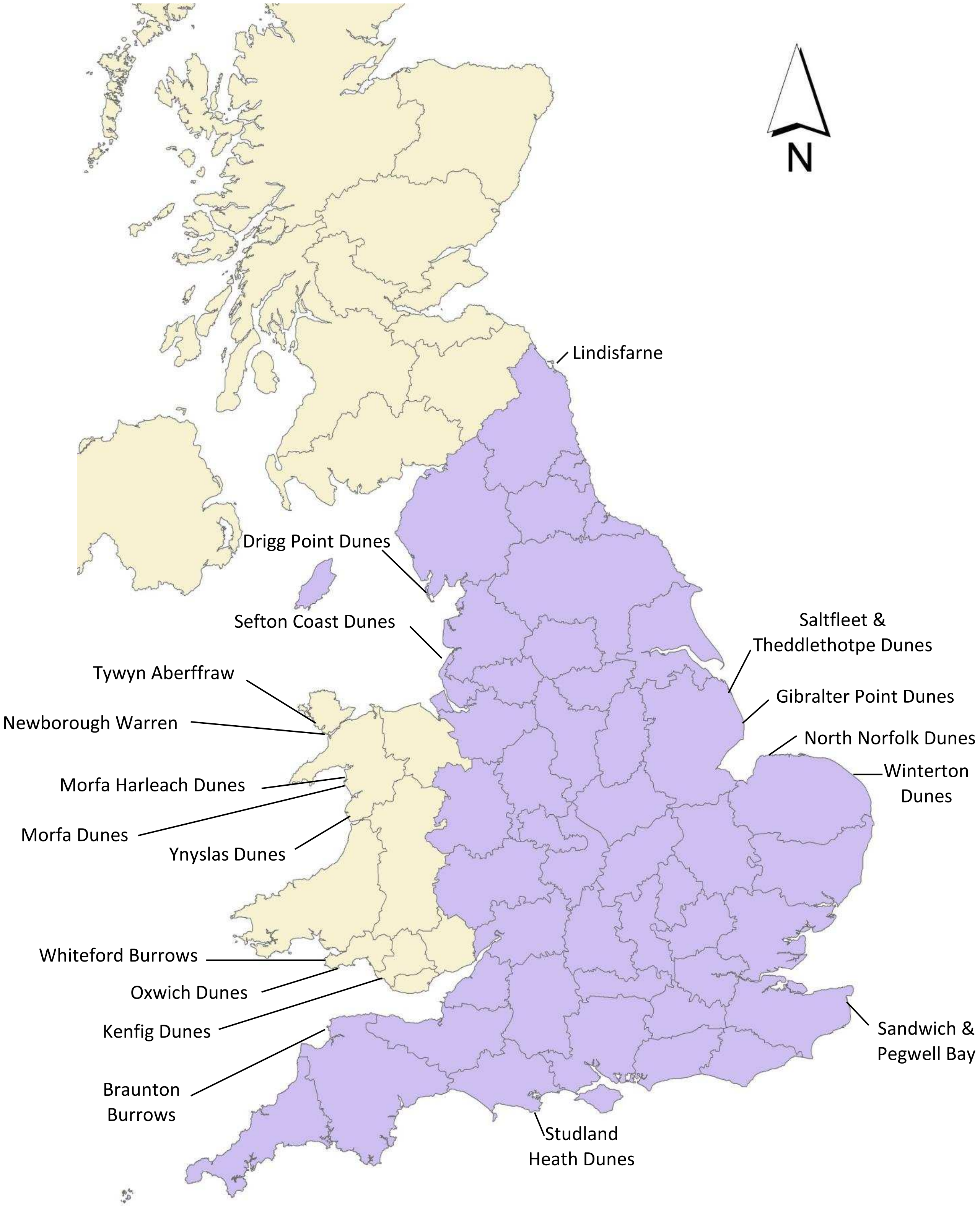


Figure 1.2 Coastal dune sites in England and Wales (map adapted from Clarke & Stratford, 2010)

Sand dune formation

The mechanics of sand dune formation can vary greatly. However, the selective forces which create them, such as erosion and deposition, are similar (Maun, 2009; Clarke & Stratford, 2010). Marine dune systems are formed along coasts in areas above the high-water mark of sandy beaches. For marine dune formation to take place, there are three requirements: a prevailing onshore wind above a certain threshold wind velocity; a continuous supply of sand; and an obstacle to reduce the velocity of wind to capture the sand load carried by the wind.

These three conditions occur to varying degrees on different beaches around the world and the pattern of sand dune formation differs accordingly to these conditions (Hardisty, 1990; Martínez & Psuty, 2007; Maun, 2009). An additional important factor in dune formation is beach width, in relation to beach morpho-dynamics and water levels, as high water levels and coastal progradation (an accreting shoreline extending seaward) will aid in the stabilisation of sediments, allowing accumulation in the absence of available vegetation (Maun, 2009; Pye & Blott, 2013).

Sand dune formation in rivers and lakes is the result of a different process; dune formation is common around river mouths during floods, where the sand is carried by the increased flow of water and deposited on banks and valleys, which are subsequently dried by the wind and shaped into dunes (Nordstrom *et al*., 1990). The ground water within sand dunes can vary between generally freshwater or brackish, the dune systems in Amsterdam are artificially recharged with freshwater, to push back the encroaching salinity gradient within the dune system as well as acting as a shallow aquifer for the purposes for drinking water (Stuyfzand, 1993). Therefore the extent of a particular salinity gradient varies between sand dunes based upon a number of factors, such as water extraction from the dune systems encouraging saline incursion or the mobility of the dunes (Stuyfzand, 1993; Maun, 2009).

Soil and vegetation ecology of sand dunes

Sand dune formation is influenced by the available energy within a system, which shapes the topographic processes. Based upon these processes, the relative diversity of dune complexes creates suitable conditions for a particularly wide range of rare flora. This diversity can be attributed to the presence of a range of successional stages that compose sand dune complexes (Jones *et al*., 2006), particularly those that have a high level of stress. These stresses can include low nutrient supply, exposure to salt spray, disturbance factors such as burial by sand (Huggett, 2011; Warren, 2013), and desiccation. As a result the vegetation of these early successional state dune systems is limited to only a few species of plants, usually those grasses which are well adapted to these stresses (McLachlan & Brown, 2006; Huggett, 2011). *Ammophila arenaria* (Marram grass) is the most common pioneer species (McLachlan & Brown, 2006, Maun, 2009), and is particularly well adapted to grow upwards through the accumulating sand (Warren, 2013).

As the dune system stabilises, the variety of vegetation increases and the pioneer species are replaced by species more typical of grassland habitats (Houston, 2008; Maun, 2009). Of the different stages observed along the dune system, semi-fixed or fixed grey dunes are of particular ecological importance (Houston, 2008; Maun, 2009; JNCC, 2013b), and are recognised as a priority feature by Natural England (Dargie, 2002; Dargie, 2009), since they are considered to be in danger of disappearing (Houston, 2008; Dargie, 2009; Williams, 2011*; pers.comm.*).

Figure 1.3 shows the observed profile of an example of successional states within a managed dune system; for example dune systems which have amenity pressures placed upon them. The youngest dunes are at the back of the beach and the oldest dunes are found further inland.

Grey dunes are so named, due to colonization by mosses and lichens, which create their characteristic grey colour (Hardisty, 1990; Bird, 2008, Maun, 2009).

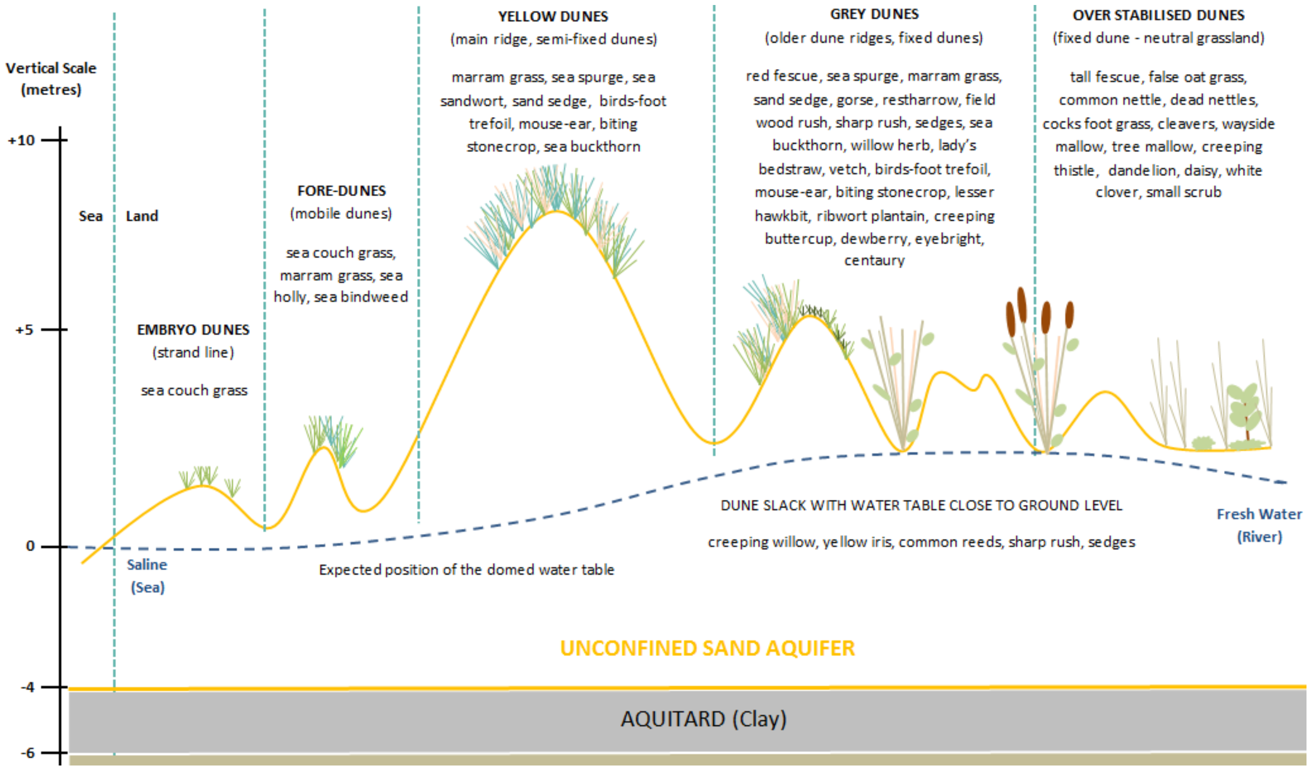


Figure 1.3 Observed profile of succession states of managed dune system at Sandwich Bay (Figure adapted from Maun, 2009; Ranwell & Boar, 1986)

With natural succession, the diversity and frequency of plant variation increases with increasing distance from the sea. In addition to this, the chemical and physical nature of the soil alters. This can be seen in Figure 1.4. Initially, diversity of plant species is relatively limited in the less-stable areas closest to the sea. As the dunes become stabilised, there is typically an increase in the range of species able to adapt and thrive within these environments. However, when the dunes become over-stabilised, the plant diversity begins to decrease. This is due to higher levels of organic matter retaining increased volumes of moisture, and a decrease in salinity and pH. Lower salinity levels and greater availability of nutrients within the soil create suitable conditions for competitive neutral vegetation to thrive (Geelen & Kemps, 2013; Grootjans *et al*., 1996).

Inland, the dune complexes are able to retain greater amounts of water due primarily to the increased plant cover i.e. fewer exposed areas of sand, and a relative increase in the amount of organic matter. Salinity levels are reduced through precipitation leaching sodium, as well as increased distance from the sea. The soil pH is also reduced, due to the increased humus layer and the greater retention of precipitation, which is slightly acidic, thus leading to leaching of calcium carbonate in the sandy soil.

Figure 1.4 illustrates successional dynamics in graphical form. Increasing stabilisation happens along a gradient (Maun, 2009; Ranwell & Boar, 1986), and the red dashed lines indicate the estimated maximum plant diversity within a sand dune system.

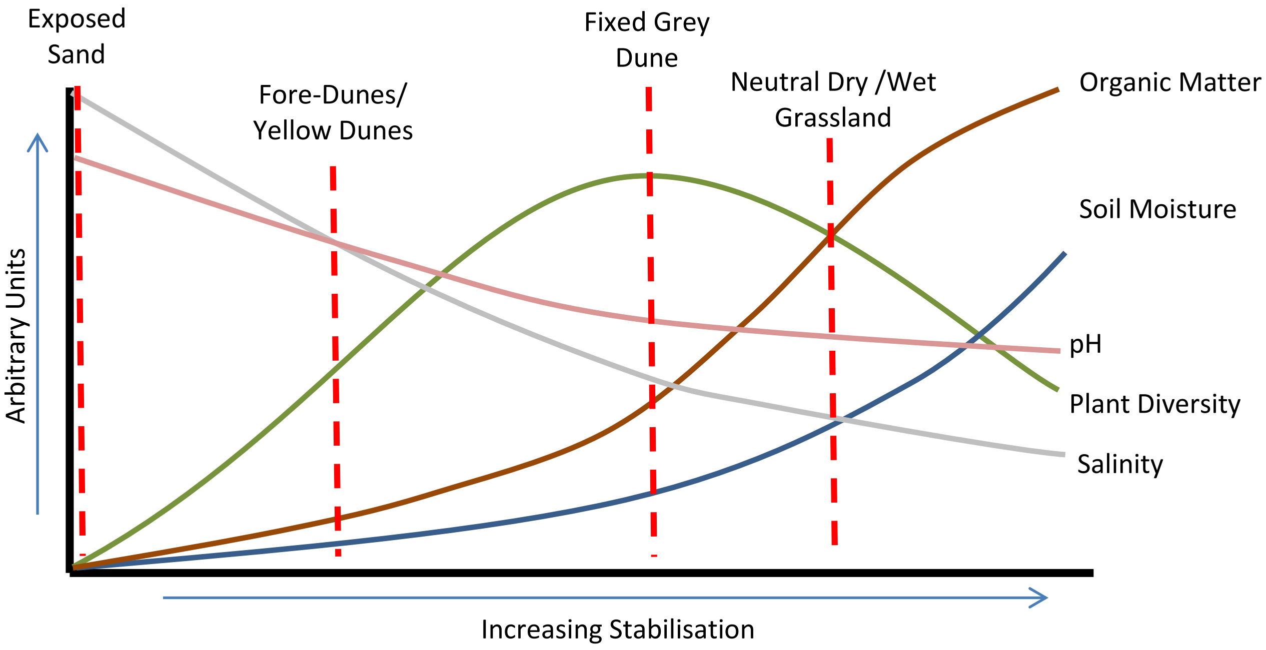


Figure 1.4 Graph showing dynamics of an observed gradient from beach to inland stabilised sand dunes (Figure adapted from Maun, 2009; Ranwell & Boar, 1986)

Sand dune communities are vegetation assemblages that reside within the newly formed or stabilised sand formations, such as those of grey dunes, classed under the National Vegetation Classification of the United Kingdom (NVC) as SD8. The SD8 plant composition is predominantly *Festuca rubra* (Red fescue) and *Galium verum* (Lady's bedstraw) dominated communities. However the ability of vegetation compositions to persist depends upon a number of factors. These include; hydrological regime (seasonal flux and relative water levels), pH buffering capacity (linear relationship between soil pH and the additional influx of acid or alkali to the soil), i.e. precipitation reducing the pH of the soil (Jones *et al*., 2006; Nelson & Su, 2010), nutrient levels, management techniques (grazing, mowing, burning and scrub clearing) and the age of the dune slacks (soil development). Part of the marine dune system that is of particular importance, and is in danger of being lost as a habitat, are dune slacks. Dune slacks are hollows between dune ridges where the water table is at, or just below, the sand surface (Maun, 2009).

Dune slacks are created in two ways. In the first, the sea retreats and the shoreline expands seaward, so that space becomes available for the formation of new embryo dunes closer to the sea, thus leaving a hollow between these and the first dune ridge. In the second, wind erosion creates deflation basins down to the capillary fringes between existing dune ridges (Maun, 2009). The environmental conditions in the slack differ from those within the dunes because of the coarse texture of the substratum, proximity to the water table and frequently higher soil moisture levels due to the lower elevations. The loss of slack habitats is associated with continuing stabilisation of the dune system, which has meant that competition from neutral vegetation is of particular concern, as an increase in their prevalence implies a reduction in diversity. These changes are considered to be the result of a rising water table, containing higher than normal amounts of plant nutrients (Etherington, 1967; Bossuyt *et al*., 2003; Dargie, 2009; Davy *et al*., 2010).

Urban sprawl, particularly in the South East of England, has also led to numerous habitats being lost, and therefore the surviving habitats, which can be found along the fringes of human infrastructure, have become particularly isolated and are greatly affected by local interactions. These interactions create plagioclimax communities (Maun, 2009). Despite the apparent abundance of sand dunes on every continent, there are relatively few coastal dune ecosystems that have not been severely degraded as a result of an excessive exploitation of natural resources, population expansion, and industrial growth (Martínez & Psuty, 2008).

The main focus of this study was on coastal dune environments, particularly dune systems that reside within a managed landscape and which have been recognised to be in poor condition in relation to loss of floral diversity. As Sandwich Bay is what is known as a managed landscape, the dune system is in a plagioclimax successional state, and the climax communities are composed of over-stabilised neutral swards and short scrub growth rather than woodland.

Due to the nature of this study involving complex interactions and differing methodological setup, the thesis will be written as partially independent investigations.

1.2 Background of the research interest

Short history and account of previous studies at Sandwich Bay, Kent

The Stour Estuary was designated as a Special Site of Scientific Interest (SSSI) in 1951 on the recommendation of the 1944 Nature Reserves Investigation Committee (Douthwaite, 1967). Originally, the designated area was split into two sections: one of these was located at Pegwell Bay, covering the salt marsh and cliff faces, the other at Sandwich Bay.

Pegwell Bay was designated due to the Pleistocene, Eocene and Cretaceous exposures within the cliff faces, which encouraged geological interest in the area. The sand dunes and dune grasslands of Sandwich Bay were designated due to their entomological and botanical importance (Douthwaite, 1967; Henderson, 1986b; Dargie, 2002).

The two separate areas were united in January 1966 in recognition of the ornithological importance of the intertidal flats between Pegwell Bay and Sandwich Bay (Douthwaite, 1967). According to research undertaken at Sandwich Bay (Douthwaite, 1967; Henderson, 1986b; Dargie, 2002), the grey dunes on the three golf courses (Princes Golf Club, Royal St George's golf club and the Royal Cinque Ports Golf Club) are botanically rich, due to the high levels of alkalinity in the dune soils, resulting in a strong calcicole element present in the dune flora.

Of the calcicole flora, the family Orchidaceae is well represented at Sandwich Bay. Some of the Orchidaceae recorded at Sandwich Bay include:

- Marsh Helleborine (*Epipactis palustris*) – common in wet pastures and low dunes
- Common Twayblade (*Listera ovata*) – found in moist areas
- Bee Orchid (*Ophrys apifera*) – although not seen in latter surveys of Sandwich Bay
- Lizard Orchid (*Himantoglossum hircinum*) – vast numbers of this otherwise rare species have been recorded around the dunes situated closest to the sea at Royal St George’s Golf Club and have recently been found in the southern reaches of Princes Golf Club, although they are rarer on Cinque Ports Golf Club
- Green-winged Orchid (*Orchis morio*) - found often within areas that are transitional between SD8 (*Festuca rubra – Galium verum*) and MG1 (*Arrhenatherum elatius*) NVC classifications
- Southern Marsh Orchid Complex (*Dactylorhiza praetermissa*) –found in wet areas
- Man Orchid (*Orchis anthropophorum*) – found in dry areas, although not seen in latter surveys of Sandwich Bay
- Pyramidal Orchid (*Anacamptis pyramidalis*) – found in dry areas

Douthwaite (1967) noted in his research on the site that there is a 'Southern' continental range of vegetation across the dunes and in some of the surrounding area. An example of this type of Mediterranean vegetation is *Juncus acutus* (sharp-flowered rush), perhaps the most conspicuous plant found at Sandwich Bay. *J. acutus* can be found in the low dunes and is particularly rare in the South East of England, being of Mediterranean origin. *J. acutus* has also been documented within the Welsh and North Devon Dune systems (Douthwaite, 1967), and along the South and South-Eastern coasts of Ireland (Preston *et al*., 2002).

The 1989 survey of Sandwich, as part of the 'Sand Dune Survey of Great Britain', was primarily interested in the production of a detailed vegetation map and an inventory of the extent of sand dune habitats (Doarks *et al*., 1990). By the authors' own admission (Doarks *et al.,* 1990), the survey was undertaken within a limited time frame, and a general vegetative and habitat extent census was the key output. However, it also produced a detailed account of vegetation status that Henderson (1986a), in his report, suggested would be essential to any future conservation of the area.

A follow-up survey (commissioned by English Nature), at Sandwich Bay, was undertaken in 2001. The survey was undertaken not only to compare change over time, but also to obtain additional data, which had been omitted from the1989 survey due to time constraints, such as areas that were classed as extensively managed (Dargie, 2002). The original quadrat locations from the 1989 survey were resampled as fixed points for comparison over time. Figure 1.5 shows the geographical locations of the golf clubs residing within Sandwich Bay.

It was accepted in the 2001 report that the accuracy of quadrat relocations has a ± 20m margin of error (Dargie, 2002). This margin of error was due to the lower accuracy of Global Positioning System (GPS) technology at the time of the original 1989 quadrat positioning. The GPS signal was downgraded by a process called 'selective availability' prior to May 2001 (Hulbert & French, 2001). This >20m error in GPS positioning meant the lower precision of species assemblages recorded in 1989 species maps will have an impact on continued analysis within the same site (Hulbert & French, 2001).

The analysis of vegetation change revealed a significant loss of fixed dune grassland (Dargie, 2002), categorised under the NVC as codes SD8 (*Festuca rubra–Galium verum*, fixed dune grassland), SD9 (*Ammophila arenaria–Arrhenatherum elatius*, dune grassland), SD10 (*Carex arenaria*, dune community), SD11 (*Carex arenaria–Cornicularia aculeata*, dune community), and SD12 (*Carex arenaria–Festuca ovina–Agrostis capillaris*, dune grassland) (Rodwell, 2000). The total amount of fixed grass dune species lost totalled 62 ha in 2001 (Dargie, 2009).

A more recent study undertaken in 2008 on just one of the golf course sites at Sandwich Bay (Royal St George's) showed that there was a continual trend in the loss of fixed grass dune species when compared with the same site in the 2001 survey. The vegetation change was from fixed grass dunes to dry neutral grassland habitat, which accounted for 49 ha of the vegetation change noted in the 2001 survey (Dargie, 2009).

Management methods intended to maintain or restore dune systems, aim to prevent over-stabilisation and eutrophication within dune systems and to prevent movement towards a successional state to wet woodland. The change from species diverse grey dune systems to neutral mesotrophic grasses is considered to be a normal successional progression (Maun, 2009; Ranwell & Boar, 1986), although Dargie (2009) noted that what may appear to be natural succession is more likely to be a reaction to increasing sea levels and leaching of nutrients from nearby agricultural processes, thus accelerating this change in vegetation.

In the North and West of England, the dunes are commonly found to host damp neutral grassland, with NVC classifications MG1 (*Arrhenatherum elatius*, dry neutral grassland), MG11 (*Festuca rubra–Agrostis stolonifera–Potentilla anserina*, wet grassland), MG12 (*Festuca arundinacea*, neutral grassland) and MG13 (*Agrostis stolonifera–Alopecurus geniculatus*, wet neutral grassland) (Rodwell, 2006; Dargie, 2000; Dargie, 2009, Jones *et al*., 2006. Until recently, these grassland communities were only found in South Eastern coastal regions in restricted locations (Dargie, 2002).

The fixed dune grassland found in the South East has been able to persist there due to the relatively dry regional climate, compared to that found in the North and West of England (Clarke & Stratford, 2010; Dargie, 2002). The successional change in vegetation types in the North and West of England is predominantly attributed to these areas being wetter regions (Jones *et al*., 2006, Dargie, 2013). An example of this vegetation change can be observed in westerly dune systems, such as Kenfig in Wales. The availability of water in a sand dune system is a driver of change (Clarke & Stratford, 2010; Dargie, 2009), and therefore easterly dune systems, such as those that at Sandwich Bay, should be more suitable for maintaining fixed grey dune vegetation communities.

The observed switch to damp neutral grassland condition, at Sandwich Bay is believed to be the result of increased retention of water in the dune system (Dargie, 2002). It has also been suggested that a change in vegetation may be linked to changing water table levels and associated increases in nutrition (Dargie, 2009).

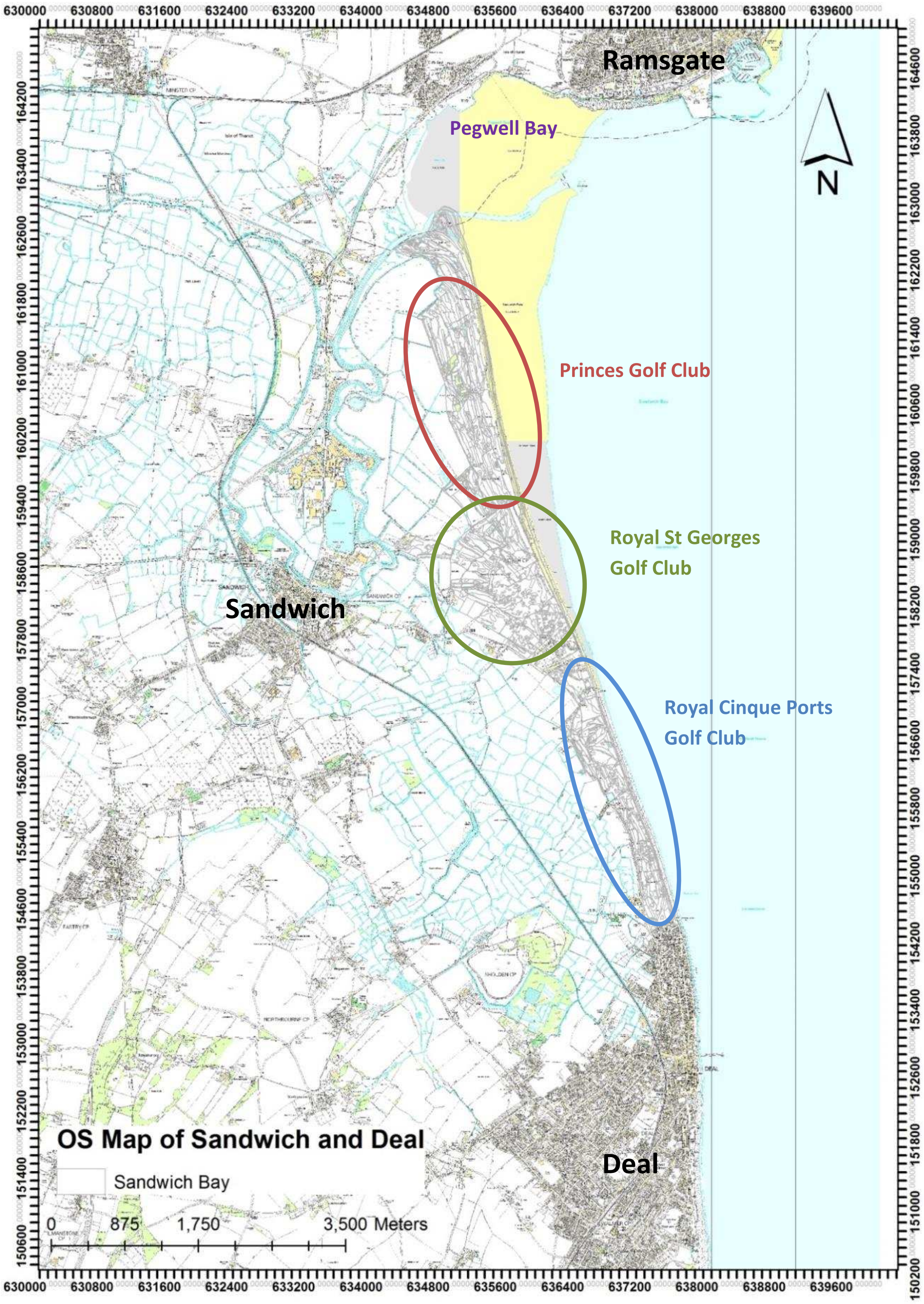


Figure 1.5 Ordnance survey map showing golf club locations (raster layers reproduced with permission from Natural England)

The increase in nutrients and retained moisture in the dune system may have led to an increase in the competitive exclusion of fixed grey dune grass species in favour of less diverse rank neutral vegetation (Clarke & Stratford, 2010; Dargie, 2002). Assumptions about community composition dynamics are based upon the 1989 survey (Doarks *et al.,* 1990), although these are unlikely to be accurate as a defined baseline measurement, since Dargie (2013*; pers.comm.*) has suggested that the changes in vegetation composition were probably already happening prior to the 1989 survey. The previous studies undertaken at Sandwich Bay involved mapping habitats and vegetation communities, and were mainly in the form of conventional field-based NVC surveys, rather than involving hydro-chemical analysis.

Research interest

The geographical area selected for this research was a sand dune complex area in Sandwich Bay, located on the South East coast of Kent, England. Sandwich Bay is the only area in the South East of England that has a fixed grey dune system. The sand dunes within this area form a relatively small system in comparison to complexes elsewhere in the world, such as the 'Kapenglop' dune slack complex on Schiermonnikoog Island, Netherlands, and closer sand dune complexes such as Camber Sands in East Sussex, which is a highly mobile, accreting, dune system. The dune system of Sandwich Bay is of particular importance due to its extensive areas of 'grey' dunes (Dargie, 2002) - a priority feature designated a Special Area of Conservation (SAC) under the EU habitats directive (92/43/EEC) (Rhind *et al*., 2006).

The most important feature of Sandwich Bay (JNCC, 2013), is the presence of the particular species found within the SD8 *Festuca rubra–Galium verum* classification of the NVC, also known as fixed dune grassland communities (Rodwell,2006), in particular, the nationally rare

Himantoglossum hircinum. Other rare plant species, which can be supported within this community composition, include *Oenothera stricta* (evening primrose), *Orobanche caryophyllacea* (bedstraw broomrape) and *Silene conica* (sand catchfly) (JNCC, 2013). However, the SD8 communities have rapidly declined to MG1 (neutral dry grassland), since the first complete NVC survey at Sandwich undertaken as part of the Sand Dune Survey of Great Britain in 1989 by the Nature Conservancy Council (Doarks *et al.,* 1990; Dargie, 2002). This survey was part of a series of strategic surveys of coastal habitats, and revealed that there have been changes in the vegetation communities over time, resulting in the loss of important habitats and raising conservation concern with regard to maintaining the dune system (Dargie, 2002).

Natural England believes that there is a serious need to investigate the causal influences on the vegetation change at Sandwich Bay (Williams, 2011*; pers.comm.*). Since the first complete sand dune survey of Great Britain in 1989, there has been a net loss of 64.4 ha of grey dune (Dargie, 2009), with the original species being supplanted by improved neutral grassland. Although a number of surveys have been undertaken at Sandwich Bay by different ecological consultancies, none have incorporated the use of a fixed point hydrological survey to identify and analyse the water chemistry and its potential influence on the landscape over an extended period of time. Of the different surveys, the most detailed, and arguably the one with the highest reliability in terms of vegetation classification (according to Natural England, partners to this study), was undertaken in 2001 (Williams, 2011*; pers.comm.*), with a revised survey by the same consultancy in 2008 at a single location - Royal St Georges Golf Club (RSGGC).

A number of hypotheses have been proposed by Dargie (2009) to explain the change in vegetation at Sandwich Bay. These include the role of natural succession, an increase in wetness within the dune complexes, and an increase of nutrients, either within the SSSI, or further afield, all of which were investigated within this study.

Dargie (2009) stressed the need to develop a more accurate way to collect data and review change at Sandwich Bay as a matter of urgency, if the link between vegetation change and dune relief was to be assessed in detail. In particular, the use of remote sensing, in the form of LiDAR and multispectral scanner imagery, at regular intervals would enable changes in vegetation height to be calculated, offering a different perspective when calculating rates of vegetation change. It is on the back of this final report that the study is underpinned by the recommendations of the 2009 report (Dargie, 2009).

1.3 Research questions

Nutrient levels and vegetation colonisation

Dune slacks are traditionally classed as oligotrophic habitats (Maun, 2009). Vegetative species found within these areas have therefore adapted to low levels of nutrient input (Grootjans *et al.*, 1996). Despite this, dune slacks often have rich and diverse vegetation. However, some of these species are highly sensitive to changes, particularly an influx of nutrients or a sustained increase in moisture levels. Plate.1.1 highlights the vulnerability of this environment to external inputs, including possible eutrophication of the surrounding area. Vegetation communities on dunes are controlled largely by water availability and chemistry (Anon, 2002; Jones, *et al.*, 2006). Changes in the water table and water chemistry are dependent on a number of factors, including nutrient deposition from the atmosphere (Jones *et al.*, 2004), diffuse pollution from various agricultural practices (NRA, 1992), and finally direct deposition of organic matter into watercourses or within the dunes themselves.

Plate 1.1 Grass clippings deposited on an area outside of play at Prince's Golf Club.

Coastal sand dune soils generally lack three macronutrients: nitrogen (N), phosphorous (P) and potassium (K) (Zhang, 1996; Jones *et al*., 2004; Ridge, 2002; Maun, 2009). Experiments by Willis & Yemm (1961), and Willis (1963) on the mineral nutrient status of Braunton Burrows sand dunes using turf transplant cultures and the growth of indicator plants for nutrient deficiency, showed that sparse growth of vegetation was a direct result of a nitrogen, phosphorus and, to a lesser extent, potassium deficiency, rather than other environmental stresses such as fluctuations in the water table. Similarly, Tilman (1986) showed that the introduction of additional nitrogen to the habitat resulted in a decrease in species diversity and relative floral composition, promoting a differential response in plant species to the total soil nitrogen concentration. This was part of an investigation into the role of nitrogen as a limiting nutrient in sandy soils at Cedar Creek Natural History Area, Minnesota. Houle's (1998) research showed a marked, but temporary, improvement in productivity of *Elymus mollis* (Sea lyme-grass), following the addition of nutrients on a dune system along Hudson Bay. However, as soon as the nutrient source was exhausted, the observed plant communities reverted to the original state, and the addition of macronutrients after the first application did not promote enhanced growth or change in relative vegetation composition (Houle, 1998; Maun, 2009).

Based on the research highlighted, the first question to ask was; ‘Are there any relationships between nutrient levels and vegetation communities at Sandwich Bay?’

Water table

According to the research undertaken (Jones *et al*., 2006; Smits *et al*., 2002) there is an optimum successional state between 40 and 70 years after initial sand deposition that provides a suitable substrate for dune species. Therefore, according to Jones *et al*., (2006), soil development on the dune system may be less important than water chemistry in regard to vegetation change. Other studies have indicated that fixed grass dune species tolerate drought stress conditions better than mixed neutral wet grasses, and that there is a clear indication that the water table has a strong influence upon the vegetation cover (Grootjans *et al*., 1991; Grootjans *et al.,* 1996; Davy *et al*., 2006; Jones *et al.,* 2006; Kiehl & Isermann, 2007; Geelen & Kemps, 2013).

According to Jones *et al.,* (2006), there are seasonal extremes in the variability of the water table. For instance, super-saturation of the soil does not necessarily mean standing/surface water. However, the water table has to be within reach of the rooting zone. Thus a variable water table will result in significant differences in seasonal water availability. Based upon ground observations from this study at Sandwich Bay and guidance from Jones *et al.,* (2006), the dunes at Sandwich Bay may be classed as seasonally wet dunes.

Since the literature suggests that the development of neutral grassland is directly linked with the availability of water (Grootjans *et al*., 1991; Dargie, 2002, Dargie, 2009), identifying fluctuations in the water table, as well as in the chemical composition of the water, was very significant to any intended management objective. As an example, the source of water within the aquifer, derived from a freshwater gradient or saline incursion, would be crucial in the identification of where any potential sources of nutrients may be entering the dune complex.

In Dargie's 2009 report, it was noted that there was some evidence for an increase in the height of the water table at Sandwich Bay, possibly driven by a rise in sea levels, and this may be responsible for the changes in vegetation type. Historically, the dune systems in the South-East of England have not been studied in depth, either botanically of chemically. To understand the relationship between vegetation composition and relative water table height it was important to identify the type of dune systems in which we are interested. Table 1.1 shows the differences in dune system identification and the related seasonal water table heights.

Grootjans *et al*., (1991), noticed that dry conditions restricted, and in some cases reversed, vegetation succession within the 'Kapenglop' dune complex of Schiermonnikoog Island in the Netherlands. The literature suggested that variability in precipitation has a greater effect on the replenishment levels of the water table level than the influx of underground water into the aquifer. In addition to this, extreme or unusual weather conditions may influence the course of vegetation development, i.e. acidification by rainwater lensing (Jones *et al*., 2006). In part, the saturation of the grey dunes at Sandwich Bay in recent years seems to follow similar successional vegetation patterns as those observed in a wetter dune system, according to Dargie (2009).

Table 1.1 Differences between dune slacks and recorded available water (Table adapted from Ranwell, 1959 and Rodwell, 2000)

Dune description	Water table ranges	Estimated water table depths relative to ground level (cm)
Wet slack (semiaquatic)	• Predominantly flooded during winter • water levels during the summer still reach the rooting zone • water table remains at a constant height and rarely reduces below 50cm	November – April +20 – -60 cm April – August +20 – -90 cm August – November -10 – -90 cm (+ve – above ground, -ve – below ground level)
Transitional slack	• Summer water table remains within 1 metre from surface	November – April 0 – -90 cm April – August -10 – -120 cm August – November -50 – -120 cm
Dry slack	• Summer water level is between 1-2 metres from the surface	November – April -35 – -120 cm April – August -35 – -160 cm August – November -90 – -170 cm
Dune	• Summer water table is lower than 2 metres from the surface	No Data

When reviewing whether the hydrological regime plays an important role in determining vegetation growth, Shanmugam & Barnsley (2002) noted that it is essential to assess known attributes as part of its hydrological status. Jones (1993) developed a method to classify dune slacks at Kenfig National Nature Reserve, Wales, based upon their ability to retain water. The outlines of this sub-classification of hydrological status within dune slacks can be seen in Table 1.2.

Table 1.2 Dune slack classification based upon hydrological status (Table adapted from Shanmugam & Barnsley, 2002; and Jones, 1993)

Dune Slack Classification Type	Classification Description
Type 1	Dune slacks rarely flooded or have surface water during winter. Subdued response to prolonged periods of heavy rainfall.
Type 2	Slacks similar to type 1, but flood to a greater depth. The depth of flooding rarely exceeds 30 cm.
Type 3	Slacks are characterised by deep winter flooding.
Type 4	Slacks are characterised by exceptionally high levels of water and deep winter flooding.

Findings from Jones (1993) showed that there is a particular stage of variability, in terms of vegetation colonisation, at habitat type classifications 2 and 3, and that competitive exclusion of certain environmentally sensitive vegetation types is increasingly likely at these stages. One of the most interesting outcomes from Jones' (1993) research was that hydrological factors had little impact on the transitions between the later successional stages.

However, research undertaken at Sandwich Bay (Dargie, 2009) emphasised that hydrological factors were the main drivers behind vegetation community change. Based on the research summarised above, the second research question was: 'Does the variability in water table height affect vegetation composition?'

Geographical Information Systems

Cartographic processes are an integral and important part of monitoring changes in an ecological environment (Horning *et al*., 2010; Shanmugam & Barnsley, 2002; Zuidam *et al*., 1998), and recent technological developments in Geographical Information Systems (GIS), have increased the complexity of these habitat maps, allowing for a more integrated approach to the economic and political aspects of conservation of sensitive habitats (Martínez & Psuty, 2008).

Londo (1974) argued that vegetation maps, particularly those associated with succession, could be divided into either dynamo-genetical vegetation maps or regression maps. Dynamo-genetical vegetation maps show actual vegetation populations and their estimated state of development, plus the optimum levels of nutrients needed to avoid competitive succession and to exclude invasive plant species. Regression maps show the potential natural vegetation (Londo, 1974). An example of the use of regression maps is that they can be used when estimating the extent of plant cover in a habitat that is classed as having plagioclimax communities.

The problem with vegetation mapping is that it is subject to individual interpretation (Hearn *et al*., 2011), particularly between different survey classification systems and different observer's experience. This is a recognised problem where different surveys may interpret the same data in different ways (Hearn *et al*., 2011), or surveys undertaken by different individuals record different data. As an example, Dargie (2002) noted that the 1989 NVC survey of Sandwich Bay classified relatively large areas as consisting of one particular vegetation composition, while the 2001 survey identified various communities within the same area. This made it difficult to maintain consistency between the two data sets. Therefore the relative detail of the survey needs to be taken into consideration when interpreting change over time. This is also true of NVC surveys themselves, the classifications of which are based upon species compositions observed on the West coast of England, and the resulting classification system will not be completely compatible with the drier coastlines of the South East of England. Another limitation of this particular classification system is that the original baseline species floristic composition locations, for which the NVC guidelines were created around, were lost during the 1980s when hardcopy information was transferred into a digital format. This meant that revision of original NVC vegetation floristics based upon vegetation type, over an extended period of time was not possible; therefore the NVC floristic structure cannot be quantifiably revised.

Based on the research highlighted above, the third research question is an investigation into the reliability of land management using cartographic tools to spatially analyse species change, with particular focus upon management techniques; therefore, ‘Can land management techniques elicit vegetation change at Sandwich Bay?’

Remote sensing data

Light detection and ranging (LiDAR) and multispectral scanner imagery (MSS) are two remote sensing tools that collect spatial data. LiDAR is an active method, as it uses its own energy source, whereas MSS is a passive method, measuring reflected sunlight (Horning *et al.,* 2010). The use of remote sensing has already been integrated into some coastal studies (Zuidam *et al*., 1998). However, they record different types of data. As an ‘active’ method of remote sensing, LiDAR records surface characteristics such as texture and elevation, whereas MSS, which uses a ‘passive’ method, records different wavelengths of reflected sunlight (Horning *et al.,* 2010). This allows for a measure of ‘greenness’ which gives an estimate of variability in species composition and indicates areas that have greater retention of moisture.

Horning *et al.,* (2010), mentions a number of techniques which can be used when monitoring land cover to obtain usable ecological data based upon the relative colour wavelengths obtained by MSS data. One technique involved the use of the Principal Components Analysis (PCA) approach called the 'Tasselled Cap Transformation'. Using the Tasselled Cap Transformation coefficients gives the potential to compare MSS component images from various times of the year. It is thus possible to measure vegetation growth dynamics, commonly known as 'greenness', using the Normalised Difference Vegetation Index (NDVI) of vegetation productivity (Horning *et al*., 2010).

Another form of MSS, predominantly used for environmental monitoring, is CASI (Compact Airborne Spectrographic Imager). CASI is a multispectral mapping tool that measures reflected light from the visible and near infrared portion of the spectrum (between 400nm and 1000nm), which is split into multiple and discrete image bands, similar to Landsat data and SPOT-MLA Multispectral Linear Array data (Petchey *et al*., 2011).

CASI multispectral imagery combines orthorectified LiDAR data, which allows for a spatial resolution as low as 50cm (normally 1-2 metres), whereas SPOT-MLA has a fixed resolution of 20 metres and the Landsat has a lower resolution of 30 metres. The other benefit of using CASI data is the number of spectral bands that may be acquired - up to 288 different bandwidths ranging from 400 - 1000mm, which allows increased definition and visual differentiation between vegetation assemblages. This may be compared to conventional satellite programs which have limited spectral bands with fixed spectral ranges (Petchey *et al*., 2011).

Spectral digital imagery data can be used to study the various reflective characteristics of the ground surface, although remote sensing still has some issues with regard to resolution accuracy when interpreting detailed change at ground level (Horning *et al*., 2010), particularly with regard to open source datasets. MSS data spatial resolution can be improved when combined with LiDAR data, the main requirement for detailed interpretation is to link remote sensing with ground-based data collection, when assessing ecological change; Petchey *et al*., 2011).

LiDAR works by having a gyroscopic mounted laser which fires rapid pulses of laser light at a surface, while a sensor on the instrument measures the amount of time it takes for each pulse to bounce back. Repetition of this procedure in quick succession builds up a complex picture/map of the surface (Horning *et al*., 2010). This creates a high spatial-extent and high resolution image, and, as a result of the different angles at which the LiDAR lasers capture data, it is particularly useful in providing accurate relief profiles.

When obtaining LiDAR data, there are two different types of LiDAR data sets which are available: the Digital Terrain Model (DTM), which records the elevation of the land itself minus any buildings/structures, tree canopies and vegetation, and the Digital Surface Model (DSM), which takes into account everything that can be seen on the ground, such as the height of vegetation, buildings and various other structures.

The initial intended use of LiDAR to determine vegetation height and ground topography provided, at particular times of year, the ability to identify certain vegetation types based upon their height, for example, SD8 *Festuca rubra–Galium verum* fixed dune grassland, comprises of vegetation strands about 0.5 m in height, while rank vegetation such as MG1 *Arrhenatherum elatius* grassland can grow to 1.5m.

DTM data can also be transformed in ArcGIS to create what is called the digital elevation model (DEM). DEM allows for three-dimensional modelling of the landscape which can assist in groundwater level observations.

The initial base maps obtained at Sandwich Bay were partly created from digitised aerial photography imported into a vector-based GIS format. Incorporated into the meta-data are the previous NVC data recorded in 1989 and 2001. LiDAR, vegetation communities and hydro-chemical data obtained from the site will be incorporated into a cartographic image/raster to aid analysis of influencing factors. Figure 1.6 shows an example of the particular coastal model and the elements needed to geospatially analyse a coastal environment.

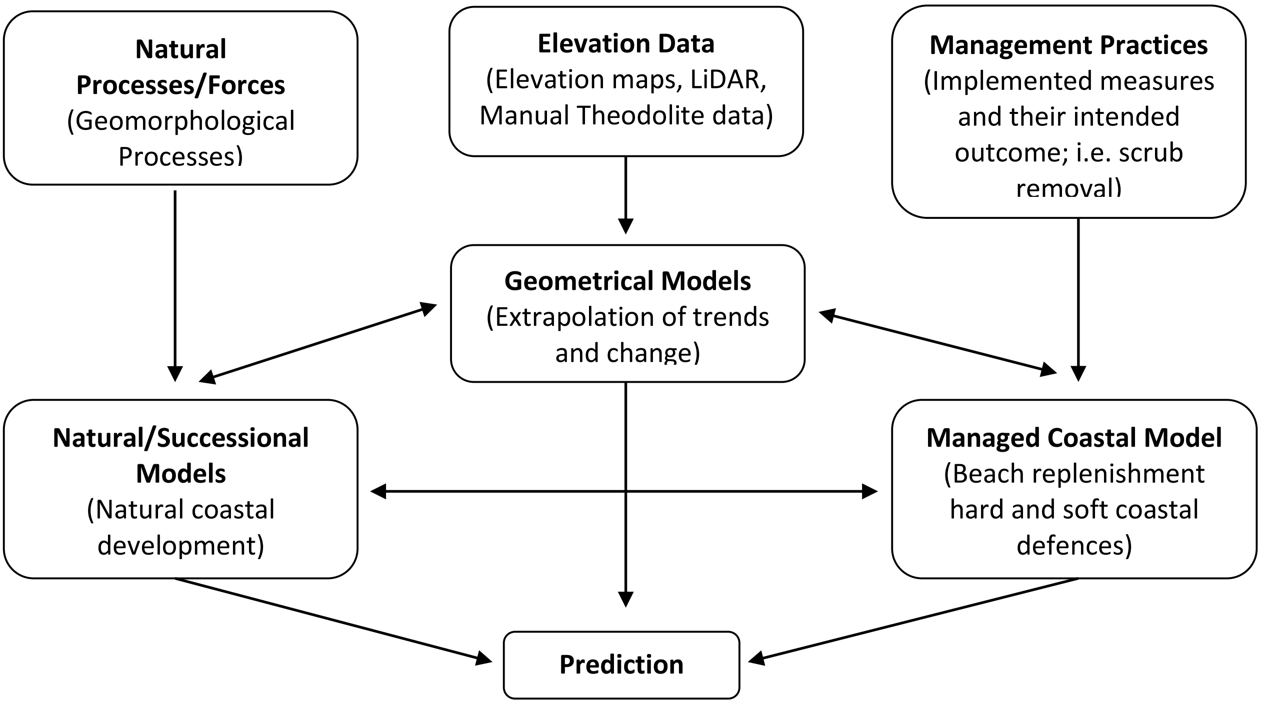


Figure 1.6 Flow Diagram modelling coastal behaviour in geospatial temporal GIS environment (Adapted from Zuidam *et al*., 1998)

Remote sensing has been used over the past 20 years with varying degrees of accuracy. When analysing vegetation assemblages using MSS within areas <30 m², remote sensing often has an element of inaccuracy (Horning *et al*., 2010).

Remote sensing can be a valuable tool so, based on the research discussed above, the fourth research question was; ‘Is the use of remote sensing data practical for NVC surveys?’

1.4 Aims of the research

Rationale behind current research

Although a number of studies have been undertaken at Sandwich Bay, none of them included analysis of the hydrological regime or long-term monitoring of the dune complexes. This issue was highlighted by Dargie’s report (2009) reflecting upon the changes noticed at Royal St George's Golf Club, in relation to the previous NVC studies undertaken at Sandwich Bay.

The comparisons between the NVC data recorded in 1989, 2001 and, in part, at Royal St Georges in 2008, showed that there was a trend towards the loss of fixed grass dune species such as *F. rubra* and *G. verum*, and calcareous dune grassland, which is of great importance in supporting rarer species such as *O. caryophyllacea* and *H. hircinum*.

The fixed grass dune habitat is of great importance to this site. The 1989 NVC survey showed that there were 198ha of SD8 classified habitat, but it was later found that this area had been reduced to 136ha, which was a total loss of 64.4ha, based upon the 2001 NVC survey undertaken by Dargie (2002) on behalf of English Nature.

Proposed research and aims

The study undertaken at Sandwich Bay focused upon the hydrological regime and in particular the hydro-chemical analysis of the dune systems at specific points. To achieve this, one hundred dipwell locations were installed to a maximum of 3 m depth, to obtain groundwater samples for hydro-chemical analysis. The dipwells were placed in assigned areas across the 520 ha site, which incorporated three golf courses. Judgement-quota sampling and a mixture of ground truthing alongside desktop spatial positioning, all aided in the dipwell distribution. In addition to the hydro-chemical analysis, three management trials were established in an effort to ascertain which management techniques would be the most beneficial for sward diversity, and these were then incorporated into the management regime of the golf courses.

The aims of the study were to:

1. Investigate the reasons for change in vegetation cover over time at Sandwich Bay;
2. Identify causative factors that might account for the observed historic and any current changes in vegetation;
3. Create a geographical model of vegetation changes that could be used as part of future NVC Surveys;
4. Identify possible management techniques that are beneficial to dune vegetation restoration.

After reviewing the literature, the initial null hypotheses will be based upon the identification of causative factors that may have elicited vegetative change. The null hypotheses are:

- There is no correlation between ground elevation and vegetation community cover;
- Varying concentrations of nutrients in the groundwater have no significant effect on vegetation communities;
- There is no significant relationship between vegetation colonisation and water availability;
- Land management techniques have no significant effect on vegetation colonisation patterns.

The strength of the study will be underpinned by the previous NVC survey data (1989 and 2001 surveys), as a baseline against the hydro-chemical analysis and the management trials. The hydro-chemical analysis and the management trials will, in part, be separate investigations but complementary to each other. Assessing the hydrological regime will enable an understanding of tolerances of different dune communities and the effects of water chemistry in maintaining stable populations.

The overall main aim of this study was to determine the role of water table dynamics and groundwater nutrient status in eliciting change in vegetation composition, and to evaluate the role of GIS, in developing a rapid methodology to model and monitor temporal and spatial change of vegetation types in dune complexes.

Optimisation of the current botanical NVC survey will allow for ease of standardising future survey techniques and provide a model for the use of GIS in the field. The research aims to collate and graphically display species change will increase the efficiency of repeat NVC field surveys, by allowing for an estimation of species change.

1.5 Chapter epilogue

The research follows recommendations from the last report undertaken in 2008 at Sandwich Bay (Dargie, 2009), which focused on Royal St George's Golf Club. This proposed that the vegetation change noted at Royal St George's was likely to be related to the underlying hydrology, in particular to the availability of water in the dune complexes, and its chemical constituents.

In order to fulfil these aims, it was necessary to make extensive use of archive datasets from the various surveys undertaken at Sandwich Bay in Kent. However, before these datasets could be used, it was necessary to learn more about how to get the most information from them, understanding the classification process used and other existing classification systems, limitations of interpretation, and assessment of the discrepancies and inaccuracies between datasets.

The following chapter reviews different classification methods, in comparison to the methods undertaken in the previous surveys of Sandwich Bay. The datasets from previous surveys are also scrutinised, and an appropriate methodology for botanical surveys undertaken in this study is described.

Chapter Two

Analysis of previously recorded datasets

2.1 Introduction to habitat and vegetation classifications

Review of different classification systems

Vegetation classifications are useful tools when disseminating knowledge of an area, particularly when highlighting any issues or concerns with regard to ecological irregularities. The rationale for using classifications is to provide a mechanism by which records from similar habitats, but geographically different locations, can be quantified along the baseline of vegetation compositions as accepted categories (Rodwell, 2000; Morris & Therivel, 2010). This allows translation of observed assemblages between different vegetation classification systems, and informed assessment of habitat condition.

It is possible to fit observations into different designated classifications (Morris & Therivel, 2010), although there may be a loss of detail involved in subsuming classifications within a broader class. However, failure to identify the limitations of classifications when analysing comparative vegetative populations can lead to errors such as undervaluation of habitats (Rodwell, 2006) and misinterpretation when disseminating or sharing data with others who were not involved in the initial data gathering processes (Dargie, 2002).

There are a range of different vegetation and habitat classifications that have been devised and used within the United Kingdom. These include:

- JNCC Phase 1 habitat classification: this is a hierarchical habitat classification system, which includes various sub-sections which take into account vegetation physiognomy (physical characteristics), environmental features or substratum (non-vegetative habitats), characteristic plant species and land use (Davy *et al.*, 2006; JNCC, 2007).
- UKBAP broad habitats and priority habitats: the underlying principle behind UKBAP is to identify priority habitats which are in special need of conservation, within the framework of broad habitat types (Morris & Therivel, 2010). This is a two-level habitat classification. An example, when looking at coastal areas, would be that habitats are broadly classed as ‘supralittoral sediment’ and the priority habitats would be ‘coastal sand dunes or coastal vegetative shingle’.
- The Integrated Habitat System (IHS) is a hierarchical classification of up to 4 levels, from Broad Habitat Types, through vegetation communities to habitat-specific features. It is an integrated approach to the management, collection and analysis of habitat data (Blair-Myers, 2011). During its development, the existence of prior habitat management classifications provided the necessary flexibility to incorporate other classifications such as phase 1, UKBAP and annex 1 (CORINE) systems (Morris & Therivel, 2010), which facilitated translation between different classifications. This is used by Kent County Council's habitat management team and is their preferred method of recording data.
- The National Vegetation Classification (NVC) focuses on semi-natural vegetation that is normally of higher conservation interest. For this reason, it is considered to be an essential tool for the main classification of terrestrial habitats deemed to be important from both the scientific and sensitivity points of view (Rodwell, 2006). One slight difference between NVC and other habitat classifications is that the NVC categorises

habitats based upon vegetation physiognomy and environmental attributes, as well as floristics. This is the preferred classification for environmentally sensitive and/or designated areas within the UK (Williams, 2011; *pers. comm*.).

- The Countryside Vegetation System (CVS) is a periodic vegetation census of the British Isles, and incorporates initial data from the countryside survey of 1990 as a baseline, as well as information from subsequent surveys in 2000 and 2007. The CVS is a large-scale random sampling system, characterising vegetation assemblages, normally within an area of 1 km², which is now used in designated land types based upon UKBAP broad habitat (Morris & Therivel, 2010). CVS are a broad classification system, which is efficient in the rapid classification of large areas of undesignated land. CVS are particularly useful when comparing classifications because it includes Ellenberg scores in its classification criteria, and thus has scientific validity because it can be species-specific.

There are two significant problems in any ecological survey: the ecological variability and the non-conformity between classifications (Morris & Therivel, 2010). Variability is representative of a localised point in a gradient or between designated habitat types (Morris & Therivel, 2010). An example of ecological variability in the landscape might be an isolated pocket of nutrients, promoting growth of competitive homogeneous species. One instance observed at Sandwich Bay was the result of direct nutrient inputs from a deposited spoil heap creating localised change in the vegetation community composition from SD8 to broader MG1 grassland, see Plate 1.1.

Within each of these classification systems, the interpretation of the vegetation in an area can be made more sensitive by sub-sectioning the land cover to a finer scale (Bossuyt *et al*., 2004). This was done with particular effectiveness in the previous surveys undertaken at Sandwich Bay, where there were numerous polygons normally containing only a single vegetation class.

It was also particularly useful for identifying areas that were in a transitional state from one vegetation class to another.

Interpretation differences between classification systems

The stages of vegetation classification in each of the different classifications systems follow the same initial procedure of walking the area to make a visual assessment of the various types of vegetation that are present and to note any areas which seem to differ (Dargie, 2012; *pers. comm*.). However, as different classification systems record vegetative cover as different indices, there is often a loss of detail when comparisons between classifications are investigated. For example, the Integrated Habitat System (IHS) records areas in a broader context, often merging observed vegetative cover into a general descriptive observation of a much larger area (Blair-Myers, 2011).

By contrast, the NVC classification focuses on a selection of smaller areas that are reviewed in detail and are deemed to be representative of the surrounding areas (Rodwell, 2000; Rodwell, 2006). Non-conformity, between habitat classifications in any ecological survey, may lead to misinterpretation between different classification systems (Gibson, 1998), and an example of this type of misunderstanding occurs when comparing Phase 1 habitat classification or Integrated Habitat System, which can be classed as more general vegetation classifications focusing upon species assemblages, with NVC classifications, which are species-specific abundance classification systems focusing upon community structure and indicator plants as a way of delineating classifications as a community-based system.

A typical difference between two classification systems can be illustrated with the following example. In the IHS classification there are up to 3 main vegetation codes that are each comprised of a sequence of habitat descriptors (Blair-Myers, 2011). For example, SS174.SC21Z.GL11 is ‘Damp dune pasture dune slack community (SS174) with scattered scrub (SC21Z) and golf course management (GL11)’.

The NVC equivalent to this would be SD16 + W2 + Fairway, Damp dune pasture dune slack community (SD16 *Salix repens - Holcus lanatus* dune, slack community), with scattered scrub (W2 *Salix cinerea - Betula pubescens - Phragmites australis*) and golf course management (which specifies whether it refers to a fairway, tee or buildings).

Within the NVC classifications, the code refers to a dominance or abundance of key species in a classification, so an example of this would be the wet woodland classification, ‘W2’ - the species typically found in this community include Grey Willow (*Salix cinerea*), Downy Birch (*Betula pubescens*) and Common Reed (*Phragmites australis*). However, the IHS classification, open/scattered native scrub, may not provide sufficient individual species detail when observing complex and often sensitive interactions with external influences in an environment. Another example is where the IHS classification, SS13 (Fixed dunes with herbaceous vegetation), has a number of corresponding NVC classifications (SD7 *Ammophila arenaria–Festuca rubra* semi-fixed dune community, SD8 *Festuca rubra–Galium verum* fixed dune grassland and SD9 *Ammophila arenaria–Arrhenatherum elatius* dune grassland) associated with it. Clearly, therefore, the IHS system does not take into account discrete differences in the individual classifications, therefore making it difficult to integrate this classification data into NVC.

Another example of differing vegetation classifications can be observed when comparing CVS and NVC classifications, and in particular the location of sample plots. With CVS, the sample plots are placed at random, while with NVC, the replicates are placed selectively within homogeneous strands, e.g. *Festuca rubra–Galium verum* dominated strands are indicative of SD8 NVC. Similarly, while the NVC is primarily concerned with semi-natural vegetation, CVS focuses on disturbed ground and over a wider area, with a particular focus on monitoring vegetation change. The main criteria, with regard to practical application of any of these surveys, are the limitations of time, cost and expertise that are needed to obtain a sufficiently accurate picture of plant composition change at ground level. For this reason, although NVC is highly detailed, the required intricacies of recording at this detailed level often limits its application in the field, compared to more general classifications which permit reduced survey time.

The Great Sand Dune Survey of Great Britain

Surveys of the sand dunes in Great Britain were undertaken from the late 1980s through to the mid-1990s, and this is often referred to as 'The Great Sand Dune Survey of Great Britain'. They were based on standard methods of mapping and classification using NVC (Rodwell, 2000) to categorise the vegetation communities. The surveys were designed to facilitate the selection of sites for conservation designation, such as Natura 2000, to identify 'Ecological Zones', and as a basis for monitoring future change (Radley, 1994; Dargie, 1993; Dargie 1995).

The results highlighted the enormous diversity of coastal sand dune vegetation, with more than 120 distinct types of vegetation assemblages recorded across the spectrum of the NVC (Dargie, 1995). They also illustrated the considerable range of variation that existed between different geographical areas (Rodwell, 2000). The close relationship between dune vegetation and physical processes was a theme in the reports, as was the influence of changing patterns in vegetation composition due to land use (Rodwell, 2000; Rodwell, 2006).

The report identified four main issues in coastal dune management for nature conservation (Rodwell, 2000):

- The importance of understanding the role of instability in dune conservation;
- The need for management of the recreational use of these areas;
- The methods for managing successional change, for example, the loss of diverse habitat to broad species – e.g. the replacement of SD8 *Festuca rubra–Galium verum* fixed dune grassland by MG1 *Arrhenatherum elatius* dry neutral grassland;
- The importance of naturalness.

NVC is primarily a method of selective sampling in apparently homogeneous strands of vegetation, which aims to ensure that the results are representative of the specific community type. The floristic data are recorded within the confines of a quadrat that is of a suitable size to obtain representative samples of the community's vegetation species. Normally, a 2m x 2m quadrat is deemed sufficient for relatively short herbaceous vegetation (Rodwell, 2006). NVC recording is undertaken by visually identifying vegetation types within the quadrat and then visually estimating the Domin cover/abundance values for each of these species (Rodwell, 2006). This includes all vascular plants, as well as bryophytes and lichens. The recommended replication of quadrats is five, to give a true representation of the vegetation cover (Rodwell, 2000; Dargie, 2009, Williams, 2011*; pers.comm.*). Braun-Blanquet constancy classes are used to weight the frequency of the individual species, and give an estimate of the dominance of a particular individual species within the quadrat. Dargie (2009) adopted a method of transforming Domin scores into percentages that can be analysed in a spreadsheet, see Table 2.1

Table 2.1 Domin cover abundance values and Braun-Blanquet constancies (adapted from Morris & Therivel, 2010; Rodwell *et al*., 2000; Rodwell, 2006; Dargie, 2009)

Domin Scale of Cover Abundance			
Domin Value	Category when cover is < 4%	% Cover	Transformation Spread Sheet Cover %
1	Few individuals	<4%	0.25
2	Several individuals	<4%	1.52
3	Many individuals	<4%	4.35
4		4-10%	9.19
5		11-25%	16.42
6		26-33%	26.37
7		34-50%	39.37
8		51-75%	55.72
9		76-90%	75.68
10		91-100%	99.53

Braun-Blanquet Constancy Classes for Grouped Quadrats	
% of quadrats in which species is present	Species Constancy
1 to 20%	I
21 to 40%	II
41 to 60%	III
61 to 80%	IV
81 to 100%	V

NVC Limitations

The original NVC classifications did not represent all possible habitats found throughout the entire United Kingdom, as there were obvious areas where baseline habitats were either not sampled or under-sampled during the final stages of the NVC project compilation (Dargie, 2009; Rhind *et al.,* 2006). For example, no quadrat data for the South East of England were recorded or incorporated into the original NVC project publication when it was being finalised (Dargie, 2009). In addition the baseline plant community composition was not modelled on dry dune systems, such as those found in the South East of England. The original NVC quadrat locations, from which the NVC guidelines were modelled upon, were lost during the digitisation of hard copy records in the early 1990s (Dargie, 2009), therefore it is not possible to reassess the original community compositions and adjust for variations over time.

Rodwell (2000) found that the fixed grey dune vegetation (*F. rubra – G. verum* community), which is classed as SD8, represented the dominant fixed dune grassland in the United Kingdom. Rhind *et al*., (2006) argued that *F. rubra - G.verum* dominated communities are indicative of conditions which are far too calcareous for grey dune development, and that the *Luzula campestris* sub-community, classed as SD8b, supports the more acidophilous lichens and mosses, such as *Cladonia coccifera* and *Polytrichum juniperinum*, which, according to Rhind *et al*., (2006), are absent in *F. rubra – G. verum*-dominated communities. The use of sub-categories thus allows for finer detail and greater clarity in interpreting plant hydro-chemical relations. The classification of what comprises a 'grey dune' is important, as it has been noted by Rodwell, (2000) and Dargie (2000) that certain grey dune species can actually be present in other NVC classifications. Therefore, sub-communities assist in describing the intricacies of plant community composition, particularly with respect to acidic dune grassland, such as those found along the East coast of Scotland (Rhind *et al*., 2006).

Grey dune formation is not necessarily restricted to the SD8 NVC classification, since vegetation floristic compositions, which have been modelled on the West coast of England, will not necessarily match perfectly to dune systems found in Wales, Scotland and in the South-East of England (Dargie, 2000; Rodwell *et al*., 2000; JNCC, 2011). Rhind *et al*., (2006), argued that it is rare that a real quadrat sample will precisely match the floristic composition expected from an ideal NVC community. To give weight to this argument, the dune system of Morfa Dinlle in Anglesey, Wales, was not recognised as a grey dune system in the original sand dune survey report (Duckworth *et al*., 1995), primarily because Morfa Dinlle was more appropriately described as 'acid grassland' in NVC terminology. However, it was later categorised as a form of SD11 *Carex arenaria–Cornicularia aculeata* dune community (Dargie, 1995), the grassland of which was characterised by abundant lichens, including *Cladonia* species, often referred to as lichen heath.

It is necessary to record vegetation present in the dune complexes correctly to make sure that interpretation is not the limiting factor in documenting vegetation change. This is particularly important where certain classification are locally rare, for example, SD11b *Festuca ovina* sub community is mainly restricted to one locality, in this case the dunes of East Anglia, with very infrequent smaller areas in the Tentsmuir dune complexes in Scotland (Rhind *et al*., 2006). As a result, revision of the original NVC publications is not easily done (JNCC, 2011), since the successional states of the plant compositions of the different NVC indexes cannot be accounted for accurately.

Although there are obvious errors in the classification system, particularly with respect to the generalisation that vegetation compositions would be similar, independently of differing location, the NVC was selected as the primary plant community identification system for the purposes of this study, in order to maintain consistency with the previous surveys undertaken at Sandwich Bay, as these datasets will be referenced to analyse vegetation classification change over time. It is recognised that NVC surveys are still the most reliable and widely recommended format for this type of habitat, due to the level of detail which may be acquired, and the surveying methods, which scrutinise the vegetation cover at ground level.

2.2 Methodology

Sandwich Bay Vegetative Datasets

To ensure consistency and comparability between the different datasets recorded at Sandwich Bay, the study used the same NVC surveying techniques as those used in the 1989 and 2001 surveys. Identifying vegetation cover by grouping individuals and categorising them, based upon abundance and key species, was the main method of vegetation analysis for the study.

There are a number of different vegetation classifications in use, but the methods used in the NVC surveys, which are looked at in depth in this chapter, are generally considered to be less biased and more detailed than similar systems, such as Phase 1 habitat surveys and IHS surveys.

Figure 2.1, shows the end product of the 2001 survey for the entirety of Sandwich Bay (Dargie, 2002). The colour banding reflects the community structure laid out in the NVC protocols. For example, colour banding 17 (dark pink), indicates a change to neutral or wet neutral grassland (MG1 *Arrhenatherum elatius* dry neutral grassland / MG12 *Festuca arundinacea* wet neutral grassland). 2001 was hydrologically a very wet year in southern UK, and while in comparison 1989 was the second driest year when observing weather data between 1980 – 2013, this would have encouraged an increase in the change of vegetation swards to wetter species.

The initial basis of this study involved compiling and analysing available historic data sets, with particular focus upon the complete vegetation censuses of 1989 (Doarks *et al*., 1990) and 2001 (Dargie, 2002). The two surveys from 1989 and 2001 were selected as they were complete surveys of Sandwich Bay which incorporated all three of the golf courses selected as the study areas. The 2008 dataset and independently recorded datasets commissioned by Kent County Council were not included, mainly due to the latter datasets not covering the entirety of Sandwich Bay, although the 2008 dataset (Dargie, 2009), was used as a guide in the identification of plant species present at Sandwich Bay, and provided an indication of perceived trends within the dune systems.

Other species datasets were recorded at Sandwich Bay independently of English Nature, but were not available from the Kent County Council habitat team, due to the inconsistencies in comparisons with previous records from English Nature obtained at the site, the resulting inconsistencies meant the reliability of the newly acquired species data was considered questionable (Blair-Myers, 2011).

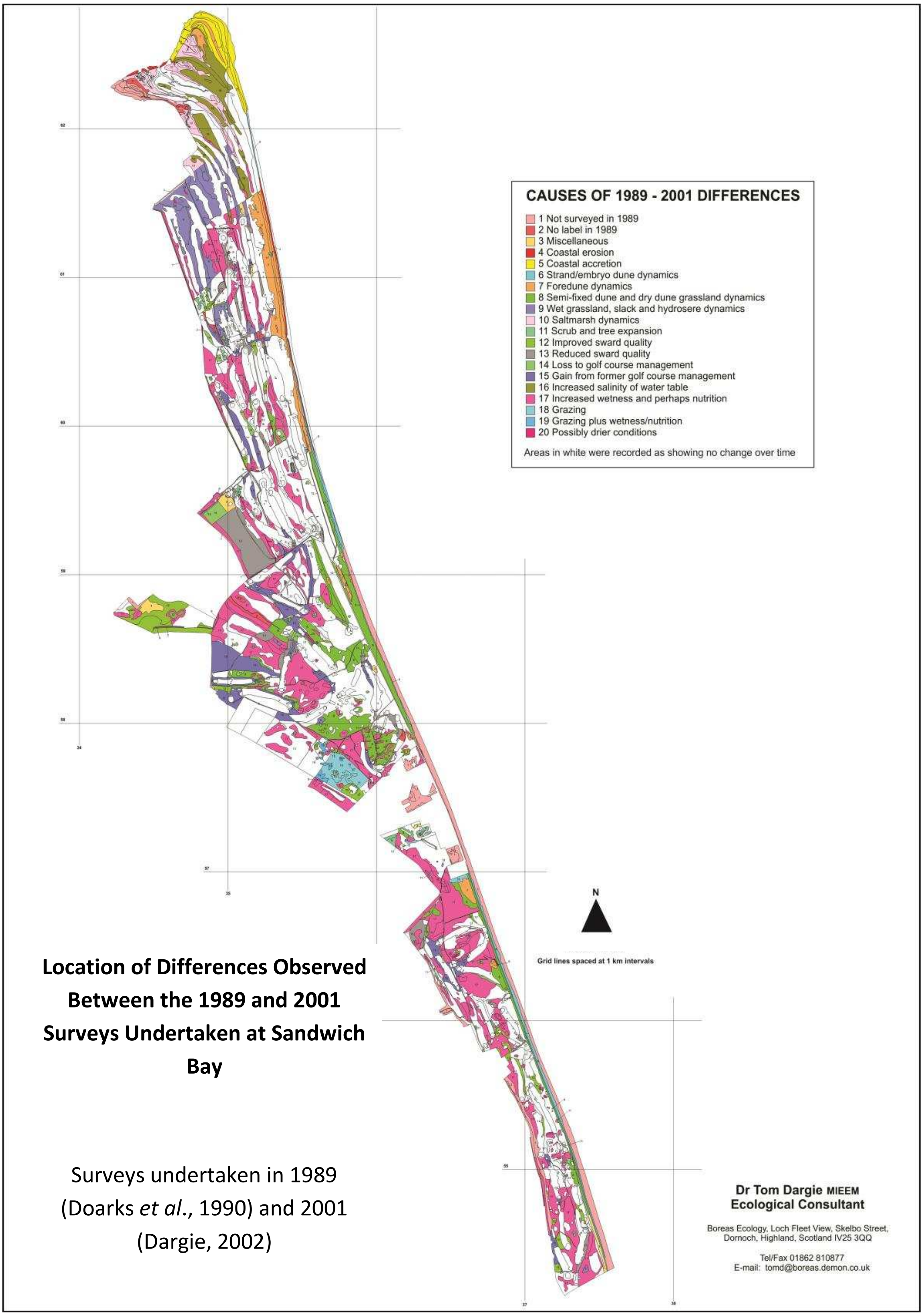


Figure 2.1 Map showing the comparison between the 1989 and 2001 datasets (Map taken from Dargie, 2002)

Analysis of dataset methodology

Natural England (at the time English Nature) commissioned an additional survey to revisit quadrat locations in the 2001 and 2008 surveys, with additional quadrats introduced by Dargie (2002) to incorporate species-rich habitats, which had been omitted from the original quadrat locations selected in the 1989 survey, the spatial locations of the permanent quadrats positioned during the original 1989 survey of the coastal area are shown in Figure 2.2. These three surveys were the source of the historical data used in this study, and to gain an idea of plant community change over time, it was essential to undertake NVC surveys following the same protocols as those used previously, which were outlined in the NVC publications (Rodwell, 2000; Rodwell *et al*., 2000; Rodwell, 2006).

Natural England considered the 2001 data to be the most complete and accurate survey undertaken at Sandwich Bay. While there was another survey undertaken in 2008, it focused on a single golf course, Royal St George's Golf Club. Therefore, as a complete survey, the 2001 dataset was referred to predominantly for the study. There is a gap of 12 years between the full NVC surveys in 1989 and 2001, and a sensitive environment can change significantly as a result of relatively small inputs often over a relatively short space of time. Sandwich Bay has been recognised to be under threat by lack of monitoring (Williams, 2011*; pers.comm.*).

Figure 2.3, shows a simple map assembly of Sandwich Bay, illustrating the dynamics of the shift from fixed and semi-fixed dune grass swards (SD) towards neutral grassland (MG) community composition, observed between the 1989 and 2001 surveys. This was an important reference document when positioning dipwells for the hydro-chemical analysis, as well as furnishing the 2001 dataset, which was central to this study.

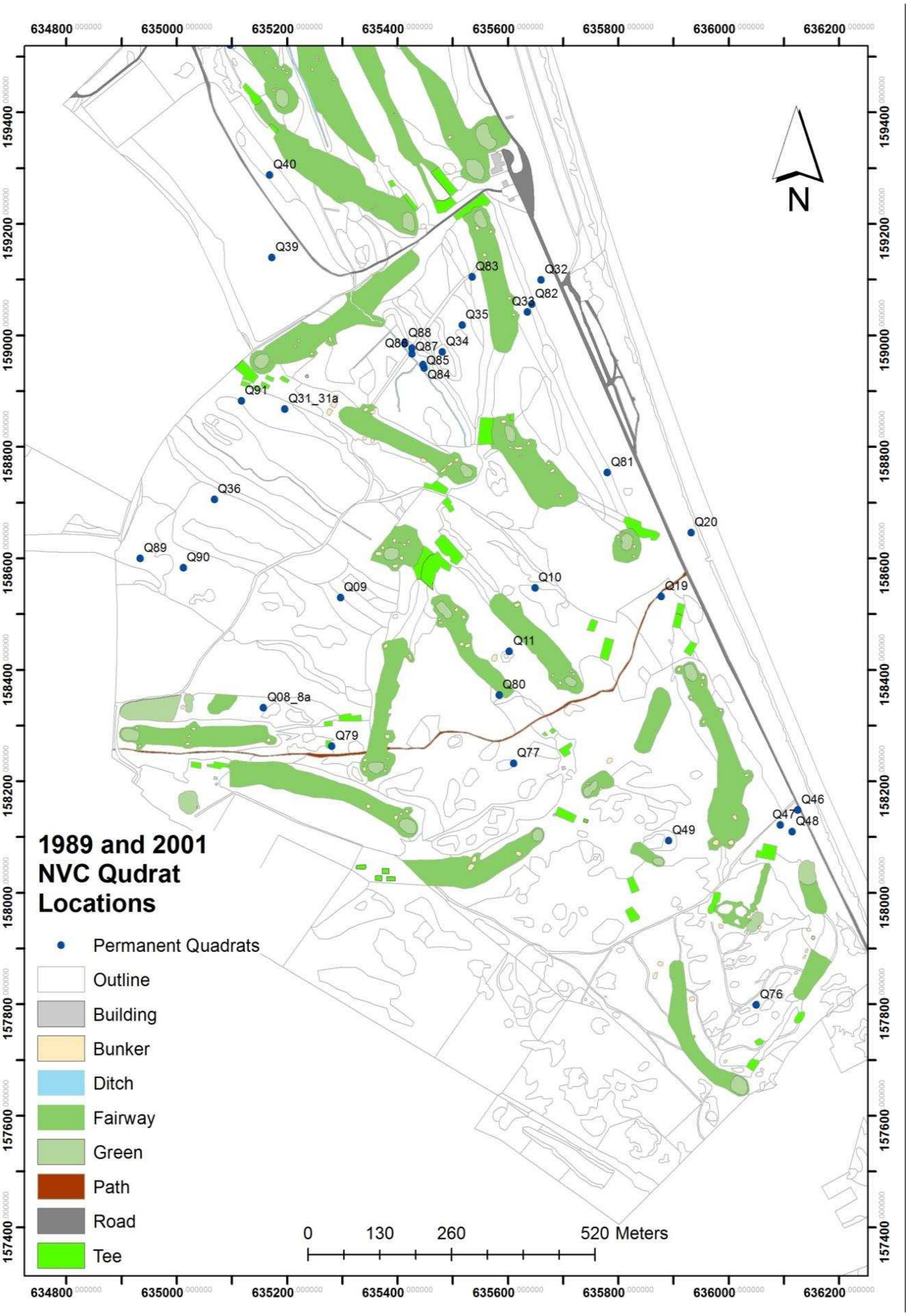


Figure 2.2 Map of Permanent Quadrats located at Royal St Georges Golf Club (vector layers reproduced with permission from Natural England) (Doarks *et al*., 1990; Dargie, 2002)

Figure 2.3 Map showing the dynamics of fixed and semi-fixed dune grassland from 1989 - 2001

Although human interaction can have a significant effect on the environment, there are also a number of natural interactions that contribute to long-term vegetation change (Dargie, 2009; Grootjans *et al*., 1991; Grootjans *et al*., 1996). Thus, although it is important to note human intervention within the landscape, it should not be the only area of focus.

Repeat recording of vegetation cover

Due to the complexity of the study, and the range of activities undertaken during the study time constraints, it was impractical to undertake a full census of the vegetation cover across Sandwich Bay. After exploring various options and following personal communication with Dr Dargie, it was deemed feasible to record NVC vegetation cover at each of the dipwell sites, rather than using the existing quadrat locations that were assessed in the 1989 and 2001 studies.

Recording the vegetation cover within a 2 x 2 metre quadrat situated at a distance of one metre from each dipwell point allowed for the possibility of relating the chemical concentrations in the groundwater to the vegetation composition at ground level. A one metre separation from the dipwell pipe and quadrat minimised the impact of dipwell-installation on the vegetation assemblages recorded within the quadrat. With the addition of historic NVC data, this would provide an understanding of the vegetation cover and how it has changed over time, as well as any correlation between the observed vegetation cover and the related water chemistry and water-table fluctuations at specific points. Recording vegetation cover near dipwell locations did not impact the quadrat analysis in the long term, as the dipwell installation affected a relatively localised area, although the disturbance around the localised area during installing the dipwells did have had an effect on the vegetation within the dipwell radius, for the first year.

It was readily acknowledged that interpretations made by different botanists may be subjective, so it is possible that there are differences in identification of vegetation classes between the data recorded in 1989 and that recorded in 2001, due to the assessment being made by different observers, for example, the presence of a sub-community of *Tortula ruraliformis*, a bryophyte typical of sandy ground, would change the classification of an area from SD8a, a typical *F. rubra - G. verum* fixed dune grassland sub-community, to SD8c.

To ensure a sufficient level of accuracy and confidence in the recorded data, it was essential to gain an understanding of the processes involved from experts with extensive knowledge of both coastal dune complexes, and also of the site that is the focus of the study. Under the guidance of experienced botanists (Dr Tom Dargie and Phil Williams; Senior Ecologist Natural England), the initial vegetation cover was recorded in detail at each of the field trial areas located at the three golf courses. These were located in parts of the courses that were not currently included in course management or in amenity use in any way.

The species identified, together with the previous recorded data set for Royal St George's from 2008 (Dargie, 2009), allowed for a baseline of 241 individual terrestrial bryophyte and vascular of species recorded at Sandwich Bay. Collaboration with Dr Dargie confirmed that the species recorded in this research were a good representation of the species present and the community composition's spatial ranges, lending confidence to the accuracy of the survey interpretation undertaken at Sandwich Bay.

2.3 Discussion

Review of real time ecological field surveys

Ecological surveys should be undertaken at least twice in the growing season (Dargie, 2012 *pers.comm*.; Rodwell *et al.,* 2000)

As plant species flower and seed at different time periods, it was important to identify the time period where species recognition could be replicated over a number of years. Sampling repetition when observing vegetation composition change was, therefore, particularly essential in more sensitive coastal environments, as these ecosystems have a high degree of seasonality (Dargie, 2009; Rodwell *et al*., 2000; Rodwell, 2006). As an example, salt marsh vegetation flowers relatively late in the summer, while the sand dune flora appears to have two distinct growing seasons, one in late-spring and the other midway through summer.

After enquiring about the strategic time implications of vegetation analysis, it was decided that the month of June would be most suitable for identifying the late spring flowering vegetation layer, for example *Anthoxanthum odoratum*, and the early to mid-summer flowering species, for example, *G. verum*. However, climatic conditions, particularly low light levels and excess amounts of waterlogging, can affect the growing timeframes of some observed species (Cheng & Ouazar, 2005; Rhind *et al*., 2006).

In addition to the climatic and meteorological factors affecting accurate vegetation data collection, coastal zones presented a number of additional challenges with regards to ecological sampling, particularly when they include areas that are highly mobile as a result of natural forces, such as the embryo dunes located north of Sandwich Bay. Besides the mobility of a sand dune system, pressures from human infrastructure, amenity management and reclamation of areas which have not been in management before, make it difficult to draw conclusions from long-term observations. Short-term disturbances, which are more localised, such as disturbance by humans via un-adopted paths, can also greatly affect repeat systematic sampling and identification as well (Morris & Therivel, 2010; Jones, 2009).

As a result, vegetative sampling had to be carried out at different times of the year, in order to build up a full picture and, although it was possible to obtain reliable data on the species cover by just sampling during one of these growing seasons or in the interim, the accuracy was greatly improved when the vegetative cover was in flower and/or in seed (Rodwell, 2006).

Another consideration when analysing the data sets, apart from the addition of new data, is that besides the interactions directly from pedestrian traffic, and the halting of succession (plagioclimax communities) through the management techniques at the golf courses, it was also necessary to consider other widespread interactions that were not necessarily situated in the area of study (Large, 2001), such as beach replenishment further along the coast.

Research focus

The research undertaken at Sandwich Bay involved a multidisciplinary approach to fulfil the requirements of the study, which included comparing and contrasting observations of historical vegetative cover with newly acquired vegetative data, relating remote sensing data (LiDAR) with vegetation classifications within Geographical Information Systems (GIS), the observation of vegetation re-colonisation under different treatments, and the chemical analysis of ground water and its relation to vegetation growth. LiDAR was obtained from the Geomatics group, (department linked with the Environment Agency), and was the sole source of remote sensing data used in this study. This is described in detail in chapter 4. MSS data were not used as it was considered to have insufficient resolution for the needs of this research.

Dargie (2002) noted that there were some inconsistencies in the 1989 survey of Sandwich Bay, particularly with regard to noted omissions in the data (Doarks *et al*., 1990). For example, areas that were in active management for amenity purposes, known as areas ‘in play’, were not necessarily recorded. These omissions from the 1989 survey did not account for the subtle intricacies of areas between swards managed for amenity and the less intensely managed areas of the rough, which although ‘in play’ can be just as diverse and ecologically important as the areas which are not under any management. In the 2001 survey data, these areas were recorded, thus showing the link between semi-improved grass swards and neutral grassland.

The 1989 and 2001 NVC datasets were used in the initial stages that formed the outline of the study undertaken. The 2008 survey at Royal St Georges was excluded as a working dataset in the analysis of the study, since it did not represent areas outside of the confines of RSGGC. The 2008 dataset was used solely to compare and contrast NVC data that were recorded during this project, since it provided the most recent species records at the site, and provided the initial basis for the NVC surveys undertaken.

Due to time limitations during the study, particularly in the first year, where time was at a premium, due to late access permission to the golf courses, it was accepted that focusing solely on the areas around the dipwells meant that merging the data recorded as a part of this study, with the 1989, 2001 and 2008 survey data would be difficult due to the incompleteness of the surveys undertaken in 2012 and 2013, as these were focused upon the dipwells located at specific locations, rather than the complete vegetation censuses of Sandwich Bay. This meant that vegetation analysis was undertaken on a much smaller scale than the previous surveys undertaken.

The following chapter focuses upon the installation of the dipwells and methodologies involved in obtaining consistent water samples over an extended period of time.

Chapter Three

Hydrological installation

3.1 Hydrological interactions at Sandwich Bay

Hydrological interactions within aquifers

To understand the hydrological interactions that occur at Sandwich Bay, it is necessary to understand the underlying geology, and in particular, how the groundwater flows in the aquifer. Consequently, gaining an understanding of the different types of aquifers and establishing the relative porosity of the underlying sediments was an important initial step in undertaking a hydrological study.

There are three main types of aquifers:

- Unconfined aquifers, which are also known as, water table aquifers. In these cases the upper surface of the aquifer is the same as the water table;
- Confined aquifers occur where the permeable sediments are situated below an aquitard or confined between two aquitards. Clay-rich deposits, such as those in farm land near Maidstone, Kent, are good examples of a clay aquitard that impedes water movement into the aquifer, often resulting in localised surface flooding of the area;
- A semi-confined aquifer is where aquitards are permeable and permit significant movement of water to the aquifer.

The golf courses at Sandwich Bay are located within an unconfined aquifer. Unconfined aquifers are the most easily accessible of the three types of aquifer. However, due to this accessibility, they can easily become contaminated, and the transport of contaminating material or nutrients is more likely to occur in this case than it is with confined and semi-confined aquifers (Maun, 2009), which are often found at greater depths (Simpson *et al*., 2006; Sival *et al*., 1997). Aquitards are confining layers of nonporous materials, such as clay, that tend to reduce the possibility of contamination of the underlying aquifers due to their low permeability (Simpson *et al.,* 2006), which impedes water movement, more so than larger-pore sediments such as sand. See Figure 3.1 for a profile of a typical unconfined sand aquifer.

Groundwater flows at different rates, depending on the porosity of the sediments in the surrounding area, such that in more open substrates, such as sand or gravel aquifers, groundwater can flow horizontally at a rate of several metres per day (Simpson *et al*., 2006).

The exact path along which the water flows, can be complex (Jones *et al*., 2006), but the majority of the water will take the path of least resistance, flowing through the most permeable sediments (Grootjans *et al*., 1988). Unconfined aquifers have a potentially higher recharge than confined aquifers (Simpson *et al*., 2006). Therefore an accumulation of water from the chalk bedrock, which may have come from several kilometres away through the aquifer, as well as other sources such as the River Stour, precipitation, and surface run-off, will replenish available fresh water in the aquifer.

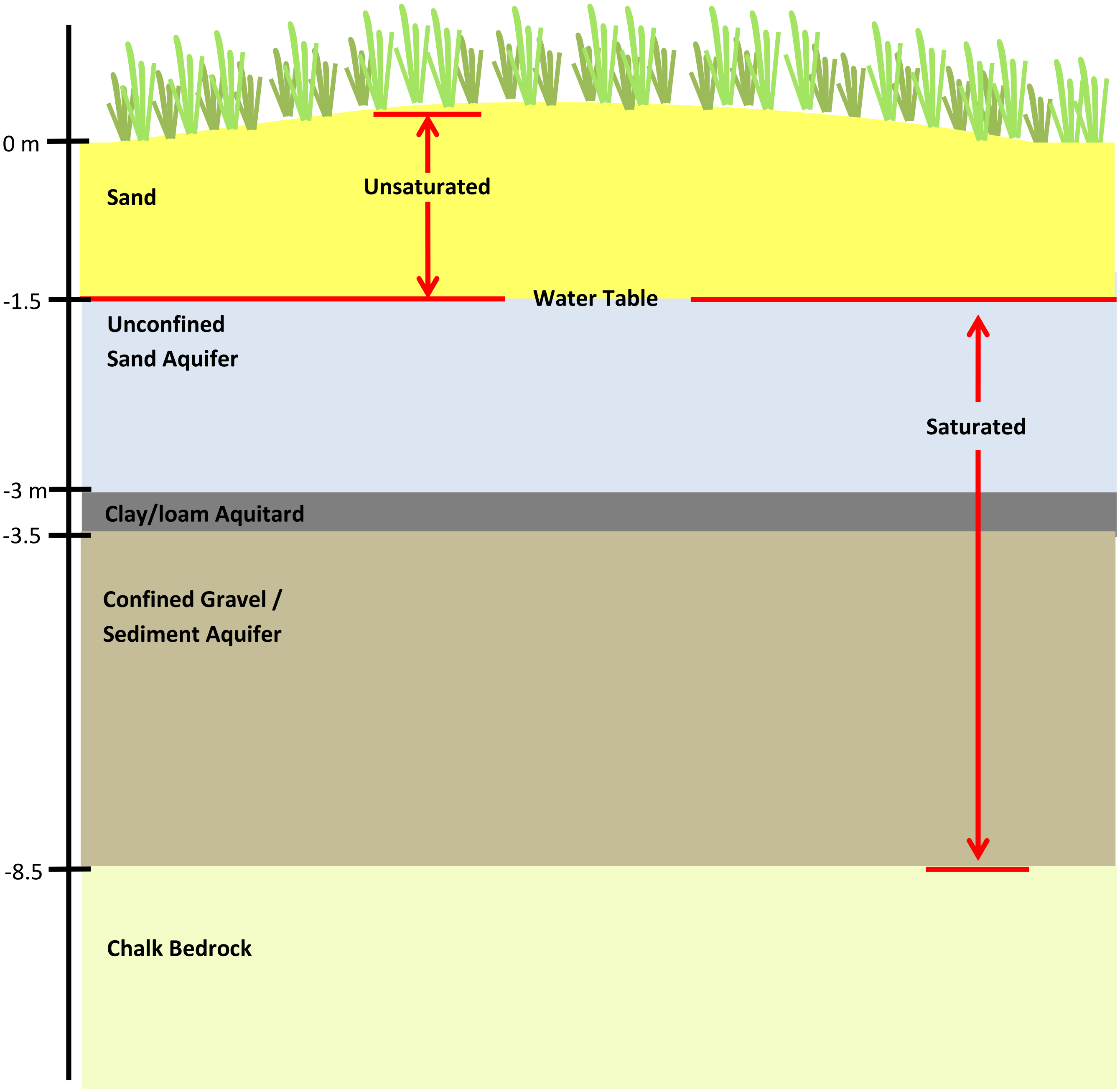


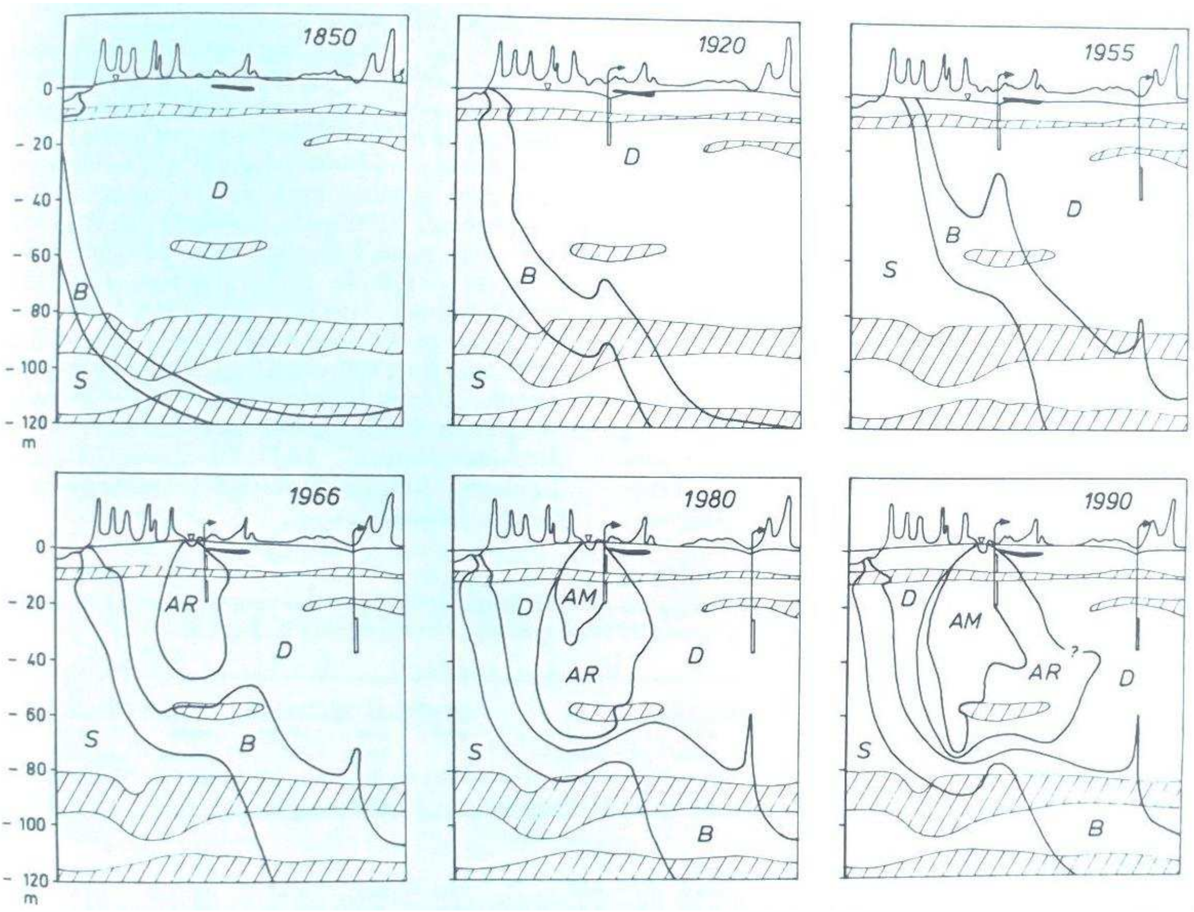
Figure 3.1 Profile view of a sand aquifer as found at Sandwich Bay (Adapted from Simpson *et al.*, 2006)

The unconfined aquifer found at Sandwich Bay is replenished by precipitation, as well as the underlying groundwater movement. Additionally, the unique topography of Sandwich Bay means that the dune systems actually slope down inland rather than towards the sea, and this, together with the fact that Sandwich Bay consists of a dune system that is the result of an accreting coastline and a water table that is affected by tidal processes, contributes to the groundwater containing high levels of sodium chloride and hence being classed as brackish ground water.

Salinisation dynamics and coastal positioning

In sand dune and shingle hydrology, there is a particularly complex interaction between the saline incursions from the ocean and the freshwater influx from the nearby landmasses (Grootjans *et al*., 1988; Maun, 2009; Stuyfzand, 1993). Salinisation of dune complexes can happen in a number of ways. These include an increasing/rising sea level, interruption of the freshwater gradient in the dune system through actions such as water extraction, or diversion of the freshwater sources that recharge the aquifer (Stuyfzand, 1993). An example of the hydrological dynamics of salinisation occurred in a dune system in Amsterdam, which has been exploited for drinking water purposes. This can be seen in Figure 3. 2.

In the Amsterdam case study, drinking water had been extracted from the upper aquifer over the period 1850 – 1950, and the demand on the aquifer resulted in a saline incursion from the North Sea into the sand dune aquifer. For the dune systems to be maintained and used as a reservoir for drinking water, they needed to be artificially recharged (Stuyfzand, 1993), and the artificial recharge of freshwater into the aquifer deterred the saline water infiltration and partially reversed the incursion.



AR = Artificial recharge using River Rhine water, AM = Artificial recharge using River Meuse water, D = fresh Dune water, B = Brackish water (Cl^- 300 – 10,000 mg/l) and S = North Sea water.

Figure 3.2 Salinisation dynamics cross-section of the West-Meijendel dunes, Scheveningen, Netherlands (Figure taken from Stuyfzand, 1993)

These dune systems are still in use today as reservoirs for drinking water, so water from the Rhine is pumped into the top aquifer and left for six weeks to remove parasites and pathogens (Geelen & Kemps, 2013). The resulting water has an increased level of phosphates (Geelen & Kemps, 2013), but is suitable for drinking purposes after filtration.

Capillary action within substrata

The phreatic surface (often known as the water table) is the level in the soil where the hydraulic pressure of water in the soil pores is equal to the pressure of the atmosphere. However, water can rise far above the phreatic surface due to the capillary attraction of the soil pores.

The water content in the unsaturated zone (seen in Figure 3.1) is held in place by surface adhesive forces (Cheng & Ouazar, 2005), and it rises above the water table by capillary action to saturate a small zone above the phreatic surface, called the capillary fringe. This saturation, held under tension and termed tension saturation, (Simpson *et al.*, 2006), is not the same saturation as that found below the water table level, as water content in a capillary fringe decreases with increasing distance from the phreatic surface (Simpson *et al.*, 2006; Sundaram *et al.*, 2009; Stuyfzand, 1993).

The height of the water column, known as capillary head (Lambe & Whitman, 1969), is strongly affected by the permeability of the soil, particularly with regards to sandy soils, which have larger pore sizes (Cheng & Ouazar, 2005). In these cases, the capillary head will be significantly less than in other substrates with smaller pores, such as clay. This means that water will drain more freely in sediments such as sand. The capillary rise observed in sandy soils may be anywhere between 0.3 m - 0.8 m above the water table level, while with other soils, such as clay, the capillary rise may be anywhere between 1.8 m – 3 m or even more (Simpson *et al.*, 2006; Sundaram *et al.*, 2009). Dargie (2012) noted that the observed presence of the capillary fringe close to ground level would have a direct relationship with the vegetation community composition. It was therefore surmised that the year-round presence of a saturated capillary fringe within a depth of ≤30 cm from ground level would result in those vegetation communities which preferred wetter conditions becoming established in those areas (Stuyfzand, 1993).

Different hydrological methodologies

There are a number of methods for hydrological monitoring, each with different strategic benefits, of which the simplest was obtaining water samples from ground level, while the more difficult hydrological monitoring methods took account of relatively inaccessible sources of water, located below the surface at distances greater than two metres.

Different Water Sampling Techniques

- Surface water collection – this is the easiest and simplest method of water collection. However, it can contain contamination from surface run-off. With surface water collection in a permeable environment, it can also be difficult to obtain samples on a regular basis.
- Boreholes – these comprise a vertical hole into the ground that is sheathed with a retaining pipe of any diameter and length. Samples are taken from the ground water or deeper in an aquifer.
- Dipwells - this is an English term for a shallow borehole with an often narrow-diameter pipe, not intended to yield large volumes of water at any one time.
- Lysimeters – these are similar to boreholes. They are used when investigating the practicability of water extractions concerned with volume or a constant flow, and the associated replenishment rates surrounding an extraction point (Kubiak *et al*., 1988; Sundaram *et al*., 2009).

The rate of replenishment of water in a borehole is based upon the relative height of the water-table, rather than the volume of water extracted during the sampling process (Stuyfzand, 1993). Although ascertaining water replenishment rates would be useful in monitoring water allocation and efficiencies within the dune systems, there were no extraction processes in use in the dune system at Sandwich Bay, as the nearby River Stour is the direct extraction point from which the golf courses obtain water for the irrigation systems. This study was not primarily concerned with the replenishment rates, particularly as the technique used was a simple random sampling methodology (Barnett, 2002). Thus measuring the rate at which the sample was replaced was not necessary, unlike with unrestricted random sampling methodologies (Barnett, 2002) where the boreholes are pumped for a length of time before a water sample is collected (Whiteman *et al.*, 2013). It was not possible to extract large volumes of water from the dipwells at Sandwich Bay, due to the fact that the dune systems are classed as a dry dune system (Jones, 1993), compared to those situated in Wales. Initial investigations into the replenishment rates were investigated by bailing the dipwells and measuring the replenishment rates, based upon a single observation period it took roughly three hours to replace one litre of water within a single dipwell. Since the samples collected were small in volume, but taken at regular intervals, it was determined that the installation of dipwells was the most suitable methodology for this project.

3.2 Materials and methods

Current land use

The area around Sandwich Bay is predominantly devoted to a mixture of agriculture, amenity, and residential use, as well as a local nature reserve. The areas selected for the study were managed amenity areas, since these comprise the majority of the landscape and ground access. Consideration was given to the idea of installing sampling points in the nature reserve located in the northern part of Sandwich Bay. However, restrictions with regards to ground-nesting birds and general disturbance of the area during the initial installation of the dipwells meant that the reserve area was omitted from the sampling range. Thus it was decided that, as the analysis focused predominantly upon areas in a managed landscape, the dipwells, positioned in areas which were out of play or managed with regard to low stocking rotation of livestock (cattle and sheep grazing), were sites that could be considered typical of agricultural management. There were also a number of dipwells situated in smaller areas, which were located some distance away from any kind of management, such as wooded areas behind greens and tees, to see if the water samples obtained from these areas differed from water samples taken from the managed areas. These water samples were considered to be representative of unmanaged dune-systems and could therefore be treated as a potential baseline.

Dipwell positioning

The selection of suitable sampling locations was achieved using two observational techniques. The first consisted of visually ground truthing the site and identifying areas of varying vegetation cover. The second technique involved comparing and contrasting the historic NVC data (1989 and 2001 NVC surveys), in a desk-based geographical form, by creating NVC attributes that compared and displayed changes between fixed grass dune species , identified as SD (Shingle, strandline and sand-dune communities), to MG (mesotrophic grasses), and *vice-versa*. Other community codes were not omitted from the analysis, but were merged together as a single category to visually demonstrate the spatial cover between the two main categories MG and SD, which can be seen in Figure 3.3.

A number of factors were taken into account when siting the dipwells, to allow for continued analysis and sample collection. One of the primary initial considerations was the permeability of the sediments. Following past research (Jones, 1993) into sand-dune complexes and relative hydrological dynamics, initial observations of Sandwich Bay suggested that, to maintain a viable sampling regime, it would be necessary to obtain water samples from depths of up to three metres below ground level, where this was practicable (Jones, 1993; Ranwell, 1959; & Rodwell, 2000).

The dipwell sampling sites were chosen using judgement-quota sampling (Barnett, 2002). Judgement-quota sampling is a non-probability, non-random sample selection technique where units are selected based upon previous data, and confined within a number limitation (Barnett, 2002). The aim of this type of survey technique was to subjectively choose sampling sites that represent a portion of chosen NVC categorisations (SD8/MG1), orientated spatially to ensure even distribution, with a set number of dipwells to be installed within classifications across a specified area. The historic NVC data and ground truthing data were consulted to ensure that the spatial distribution of the dipwell sampling sites was taken into consideration to avoid spatial replication of data, while at the same time obtaining suitable replication of differing NVC classification types based upon the 2001 dataset.

The two main weaknesses of Judgmental Sampling are to do with the authority (data or knowledge) and the sampling process; both of which pertain to the reliability and bias of the sampling technique (Barnett, 2002). Additionally, it was assumed that the historical data represented accurately the plant cover at the time of that study, even though the methodology of collecting the data was arguably subjective, in that the individual surveyor's interpretation of the site (Hearn *et al.*, 2011) affected the classification assignment of vegetation composition. It was further assumed that past vegetation types in the area had an effect on the present vegetation cover, even though the data were recorded more than 10 years prior to this study, and in an area as sensitive to changes as the fixed sand dunes. Consequently the vegetation type recorded from that time may potentially have less resemblance to the vegetation now present at those locations than was assumed.

The vegetation composition dynamics fluctuate between mainly SD and mainly MG vegetation classes. Since the main interest of this site is focused upon grey dunes (SD8), as a priority Annex 1 habitat feature, the research focus was predominantly upon the dynamics of these two vegetation classifications.

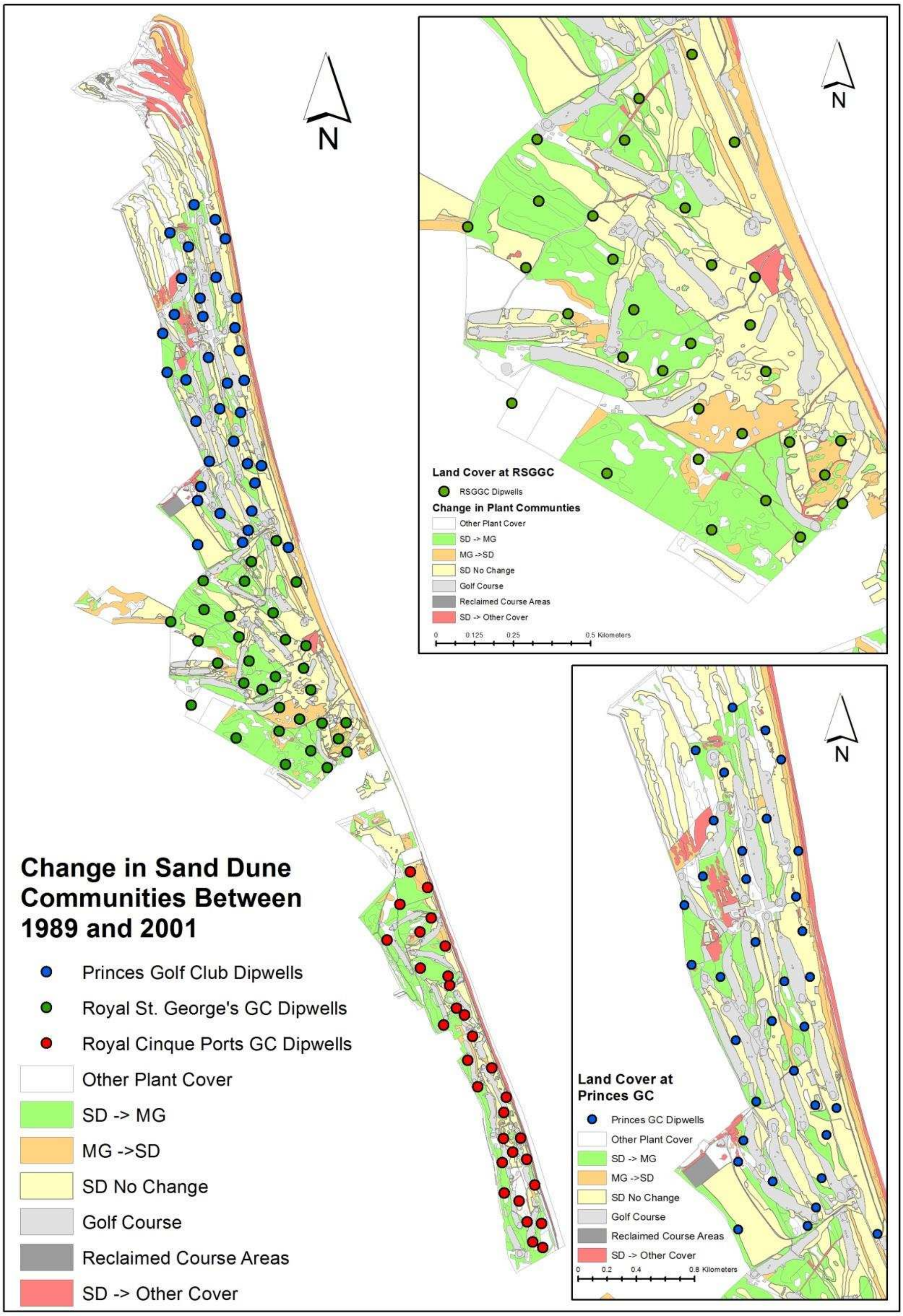


Figure 3.3 Map showing the distribution of dipwells installed across Sandwich Bay displaying created NVC attributes

Dargie (2009) observed that the main pathways of change incorporate NVC community classes SD8 *Festuca rubra–Galium verum* fixed dune grassland; MG1 *Arrhenatherum elatius* dry neutral grassland and MG12 *Festuca arundinacea* wet neutral grassland. There are 13 communities prefixed "MG", and 19 communities prefixed "SD", one shingle, two strandline, and 16 sand dune communities (Rodwell, 2006). The NVC number allocations (SD7 to SD8) represent successional states in chronological order, which relate to vegetation composition change and to possible increases in nutrients and/or moisture levels. There are also sub-communities, identified by lower case letters that denote subtle differences in the community structure.

The areas investigated at Sandwich Bay comprised the three golf courses. Of these, the courses which show the most ecologically interesting vegetation assemblages were Royal St George's and Princes Golf Club. By contrast, the sand dunes at the Royal Cinque Ports appeared to be predominantly homogeneous, having a less-diverse range of fixed dune species, with mixed grasses of lesser botanical interest dominating. Royal Cinque Ports Golf Club is narrower than the other two courses, and has fewer available areas that are not in amenity management. This may account for the uniform species composition observed both in the data from this study and in the historic data. As a consequence, and to ensure an even distribution of dipwells across Sandwich Bay, permission was sought and granted to extend the sample range laterally on to neighbouring farmland, thus widening the sample area. Dipwell locations on Walnut Tree Farm were chosen to increase the sampling range at the point where RCPGC narrows to accommodate existing infrastructure such as the caravan site and public house.

Dipwell installation procedure

The installation was undertaken with the aid of a two-man hydraulic auger that was used to drill down to the water table. The holes were drilled to 3.5m depth with an auger bit of 200mm diameter. Due to the wet sediment slumping from the sides of the hole created, it was necessary for each extension of the auger drill bit to be pulled up at various stages, particularly at the end, to remove a core of sediment. This minimised the amount of sediment refilling the borehole which had been dug. Once the maximum depth of the auger had been reached and the auger bit removed, the dipwell pipe was immediately inserted into the hole and pushed in manually until resistance was met. At this stage it was important to drive the dipwell as far into the ground as possible before the sediments around the pipe solidified. Therefore a wooden-ended striking top with handles was placed over the top and driven in using a wooden mallet to ensure that the top of the dipwell was positioned as close as possible to ground level, so that the full length of the pipe was below ground level (Plate 3.1). This allowed for sample collection from a maximum depth of 3 m.

Plate 3.1 Dipwell installation using the two-man hydraulic auger

The dipwells were constructed using relatively simple materials. Commercial dipwells consist of a polyurethane pipe, with slit perforations along the full length of the pipe, a screening fine mesh filter either inside or outside the pipe to reduce the amount of sediment infiltrating the pipe, and a firmly fixed threaded end cap. As this project had a limited budget, a slightly adapted form of the commercially available pipes was employed, though with no loss of efficiency.

Black polyurethane pipes of 40 mm diameter and 3m in length were sourced, and in conformity with Stuyfzand's (1993) recommendations, perforations were made along the lower 30 cm length of the polypropylene pipe using a 3 mm high-speed steel drill bit. Unlike commercial dipwell installations, the pipes were not sheathed with the fine mesh to impede sedimentation from infiltrating the dipwell. The rationale behind omitting a mesh filter was that the flow rate of the groundwater in the dune system at Sandwich Bay was estimated to be lower than those observed in wetter climates, and the cost of the additional materials would have meant that fewer dipwells were installed.

The main concern during the dipwell installation was the mobility and compaction of the wet sediments. Various designs of wooden tips were fixed to the bottom of the pipes and trialled, to investigate which shape was easiest for inserting the pipe into the ground. It was determined that a triangular configuration point, with an internal recess to aid fixation to the pipe, was a better design than a conical, flat or rounded point (Plate 3.2).

To ensure minimal contamination of the water samples from the materials used, particularly tannins from the wooden points, the internal protrusion of the wooden points were wrapped in a stabilised industrial food-grade polyurethane sheet, secured with 2.5 x 4mm stainless steel screws.

Plate 3.2 Shaped wooden points and perforations in the dipwell

To measure the rate of sediment infiltration into the pipe, the first trial dipwells were installed and then removed to see how much material had accumulated during the installation. It was discovered that sedimentation infiltration through the perforations was an issue.

To counteract the accumulation of sediment in the pipe during installation, in the absence of a mesh lining, the use of a 32mm diameter internal pipe was trialled. The internal sheathing of the 40mm pipe, using a 32 mm diameter polypropylene pipe, greatly reduced the amount of sediment infiltration during the initial installation of the dipwell, and, once settled, could be removed at a later stage to allow water sample collection.

After piloting non-sheathed and sheathed dipwells, it was found that sheathed dipwells had significantly less sedimentation during installation. An inadvertent benefit of this dipwell modification was that it resulted in increased rigidity of the dipwell pipe, which facilitated installation, as well as providing a visible indication of the influx of ground water into the dipwell by the relative moisture height on the internal pipe, as seen in Plate 3.3.

Plate 3.3 Internal 32mm diameter sheathing pipe being removed from the dipwell and visual water table level observation

Plastic and wooden end caps were positioned on top of the pipes to reduce the likelihood of contamination from debris and organic matter during and after installation.

Jones *et al*., (2006), recommended that after installing dipwells, a period of one month should be allowed, to settle the water pressure and permit equalisation in the disturbed area, before sampling from the dipwell is undertaken. A cross-section of the dipwell installation can be seen in Figure 3.4, which illustrates how table measurements are gathered in relation to undulating dune systems.

According to Stuyfzand (1993), depending on the relative depth of the dipwells, the positioning of the perforations, and the relative porosity of the substrate, the age of the water when it reaches the discharge point may be no more than a few months (Stuyfzand, 1993), or even weeks, depending upon the season (Maun, 2009; Simpson *et al*., 2006).

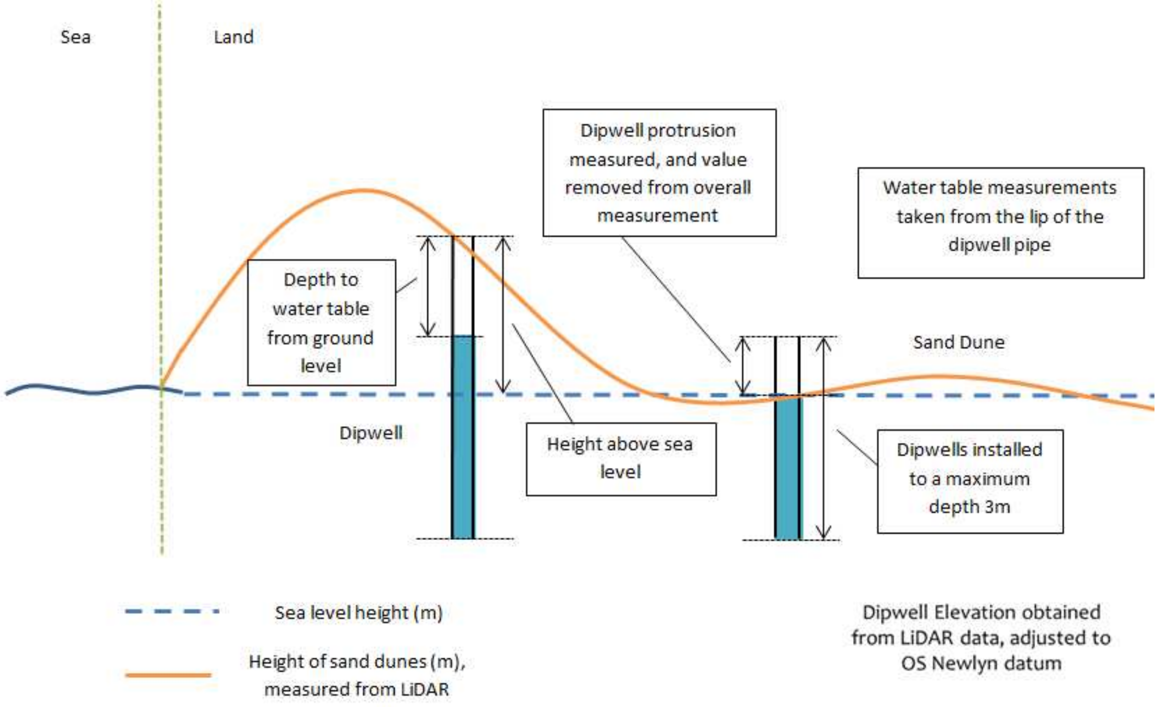


Figure 3.4 Dipwell cross-section and water table measurement

Sample collection longevity

Installation of the dipwells was undertaken during the months of February – May 2012, though ideally this should have been done at the driest possible time of year (June – September), when the water table is at its lowest levels, to ensure that the dipwells were installed to sufficient depth, at a suitable location, to allow for year round water sample collection.

Sandwich Bay is classed as a dry dune system, where the water table height varies from one to three metres below the surface, year-round (Ranwell, 1959; Rodwell, 2000). The dune system is categorised as type I and type II according to Jones (1993), where the water table height is close to ground level, or higher only during winter flooding, based upon dune slack categorisation (Shanmugam & Barnsley, 2002; Jones, 1993), see Table 1.1 and 1.2. The summer down-draw in English dune slacks is considered to be around 1.5 m (Dargie, 2014 *pers. comm.*). Therefore, as a guide, water samples below 1.5 m were classed exclusively as groundwater samples, rather than being an interaction between groundwater and surface water infiltration.

Fortunately, the year prior to the installation of these dipwells had been particularly dry (2011) with an equally dry spring (2012). This permitted an estimation of the likelihood of obtaining year-round water samples, even though installation of the dipwells was not during the driest part of the year.

3.3 Sample collection applications

Water collection strategies

Obtaining a water sample from an aquifer can be achieved in a number of ways. The main issue, compared to collecting water samples from an open source, was the inaccessibility of the water sample (Sundaram *et al*., 2009). Table 3.1 lists various types of water-sampling equipment that were considered for use during the study, along with their advantages and disadvantages.

After careful consideration and practical experimentation with a number of different water collection devices, it was decided that the bailer would be the most suitable device due to its portability, and because its design caused the least amount of disturbance to the water column within the dipwell.

The bailer displaced the water inside the dipwell, retrieving a water sample, which was then poured into a clean, labelled, plastic bottle. The sample was then taken back to the laboratory for filtration and chemical analysis. However, it was noted that when there was a low volume of water in a dipwell, the design intention for the bailer to displace the water meant it was not possible to obtain a water sample, and the resulting dipwell was thus classified as dry.

Table 3.1 Table of advantages and disadvantages of different groundwater sampling equipment, investigated for the study (adapted from Sundaram *et al.,* 2009)

SAMPLING AND PURGING EQUIPMENT	ADVANTAGES	DISADVANTAGES
Bailer	∗ Can be constructed simply from a variety of materials ∗ Size can be varied to suit the sampling point ∗ Easy to clean and disinfect ∗ No external power required ∗ Inexpensive ∗ Low surface area to volume ratio ∗ Easy to transport ∗ Operates by displacing water ∗ Performs well in silty/sandy environments	∗ Time-consuming ∗ Non-continuous flow ∗ Personnel are susceptible to exposure to any contaminants in the sample ∗ Can be difficult to determine the point in the water column that the sample represents ∗ Impractical to remove stagnant water in a deep bore hole ∗ Possible sample aeration when bottled ∗ Causes considerable disturbance to water column ∗ Possible contamination from surface and residue from inside the pipe can enter the water column while obtaining a sample ∗ Risk of cross-contamination between bore holes
Syringe devices	∗ Problems with aeration are limited ∗ Contained vessel reduces atmospheric contamination ∗ Can be made of any material ∗ Inexpensive ∗ Highly portable and simple to operate ∗ Can be used in small diameter bore holes ∗ Sample can be collected at various depths, with aid of extensions ∗ Can be used as a sample container ∗ Size can be varied to suit the sampling point ∗ Easy to clean and disinfect ∗ No external power required	∗ Not suitable for large volume samples ∗ Cannot be used for evacuating stagnant water ∗ Limited to water with small suspended solids ∗ Larger abrasive sediments can affect water retention, partially around the plunger ∗ Use of pipe extensions can limit the amount of sample drawn into the syringe ∗ Risk of cross-contamination between bore holes ∗ Can be difficult to determine the point in the water column that the sample represents
Submersible pump	∗ Constructed from various materials ∗ Readily available ∗ High pumping rates are possible for evacuation of large volumes ∗ Provides a continuous sample over extended periods ∗ 12V pumps are relatively portable	∗ Conventional units cannot pump sediment-laden water ∗ Small diameter pumps can be expensive ∗ Limited with regards to the size of the pump, most are too large for field work ∗ May overheat if not submerged ∗ High risk of cross-contamination between bore holes ∗ Not easy to clean or disinfect ∗ Needs power source
Inertial pump	∗ Performs well in silty/sandy environments ∗ Inexpensive ∗ Highly portable and simple to operate ∗ No external power required	∗ Suitable only for small-diameter bores holes ∗ Time consuming ∗ Non-continuous flow ∗ Works optimally with deep installations ∗ Low flow capacity ∗ Risk of cross-contamination between bore holes ∗ Causes considerable disturbance to water column ∗ Needs to be primed with water to operate
Diaphragm pump	∗ Preforms well in silty/sandy environments ∗ Inexpensive ∗ Highly portable and simple to operate ∗ No external power required	∗ Not easy to clean or disinfect ∗ Time consuming ∗ Non-continuous flow ∗ High risk of cross-contamination between bore holes ∗ Needs large water samples to be taken to make it efficient ∗ Works better when primed

Water collection and water table height equipment designs

Traditional bailer designs are based upon a weighted pipe lowered on a chain or rope, which displaces the water into the collection cup. The equipment used during this study was intended to be as portable and lightweight as possible, while allowing precise control of the sampling device.

The bailer was constructed from a 200 x 32 mm diameter piece of polyurethane plastic tube, the open end of which was sealed using ultraviolet light stabilised industrial epoxy resin and a rubberised damp-coursing material, to enable the water sample to be retained. This plastic tube was attached to a collapsible fibreglass pole, as can be seen in Plate 3.4. The 32 mm diameter tube allowed 4mm clearance around the bailer, which reduced the likelihood of larger sediments or contaminants being collected.

Plate 3.4 Bespoke bailer used in the study

Accurate measurement of the water table height, in the close confines of the dipwell, involved investigation into a number of designs, from simple floating graduated measurements, such as a rule inserted into a polystyrene plug, to slightly more complex open electrical circuits that audibly indicated when the water table was reached. With input from Phil Buckley and Hazel Ellis, it proved possible to construct an open electrical circuit, which utilised the electrical conductance of the groundwater to close the circuit, resulting in an audible and visual indication of when the water table was reached. Figure 3.5 shows the circuit design.

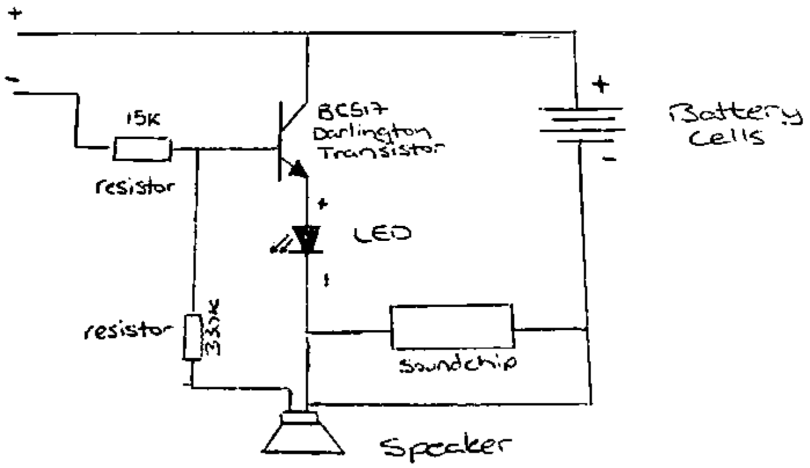


Figure 3.5 Open electrical circuit schematic

This open-circuit device was constructed using a combination of waste materials and simple audio equipment. Measurement of the depth of the water-table was achieved by the use of a 3m length of wire with a male 3.5mm double headphone jack. The wire was attached to the collapsible fibreglass pole. This ensured that there was minimal flexing in the wire when measuring the height of the water table in the dipwell, thus ensuring accurate measurements.

3.4 Chapter epilogue

103 dipwells were successfully installed across the 520 ha dune system that comprises Sandwich Bay. The installation depth varied from the full 3 m depth, down to 2 m in places where the substrata proved too difficult to penetrate. A number of dipwells were retrieved and reinserted elsewhere when a dipwell was unsuccessful in providing access to the water table, such that all 103 dipwells had a depth of water ≥ 2m at the time of installation. During the sample-collection timeframe, seven dipwells were vandalised, two dipwells did not yield any water samples, and six dipwells could not be found again, so that a total of 88 dipwells remained intact for the duration of the study. Besides these losses, some dipwells did not yield enough water for chemical analysis at various sampling times during the study.

For the purposes of this study, vegetation analysis formed a core link between the hydro-chemical and geographical analysis. The next chapter investigates the effect of elevation, meteorological data, geographically-estimated vegetation composition and related hydro-chemical interactions on vegetation composition.

Chapter Four

Geographical and hydrological analysis of vegetation variation

Introduction

4.1 Geographical introduction

Geographical analysis

Geographical analysis has been incorporated into a number of different disciplines in recent years: for example law enforcement and the construction industry (Horning *et al.,* 2010) and, when incorporating ecological data, particularly vegetation maps, has become a significant part of ground-based surveys of the environment (Hearn *et al.*, 2011). Using GIS allows for a visual representation of spatial and numerical data, which is visually more accessible than numerical data alone. Additionally, modern methods of geographical analysis have allowed for increased refinement and ease of categorisation when gathering raw data (Hobma, 1995; Horning *et al.,* 2010).

Different data sources are available for geographical analysis. These include historical datasets, aerial photography and LiDAR (Blair-Myers, 2011; *pers.comm.*; Petchey *et al.,* 2011). The logical stages of geographical conceptualisation, and the various available elements for this study were arranged into a flow diagram to illustrate the process of analysing the spatial variation of vegetation composition specific to this study, (Figure 4.1).

Habitat attributes and aerial photography are often the first steps in an ecological census of a site that has not been previously surveyed. The initial stages of mapping the environment involved a desktop-based survey using aerial photography to isolate areas that showed a visual change in the landscape, such as colour pigmentation (Blair-Myers, 2011; *pers.comm.*). An example of this was observed during the re-digitisation of potential habitat assemblages from updated aerial photography undertaken by Kent County Council, where areas of sea buckthorn on sand dunes stood out as a colour change in the landscape. During the height of the growing season, the aerial photography showed these areas of sea buckthorn as a purple/dark-green colour, as opposed to the normal whitish-grey colour of the exposed stem when the plants are not in leaf. These areas, once identified, were then isolated as a geographical polygon, which was later confirmed by ground-truthing (Blair-Myers, 2011; *pers.comm.*).

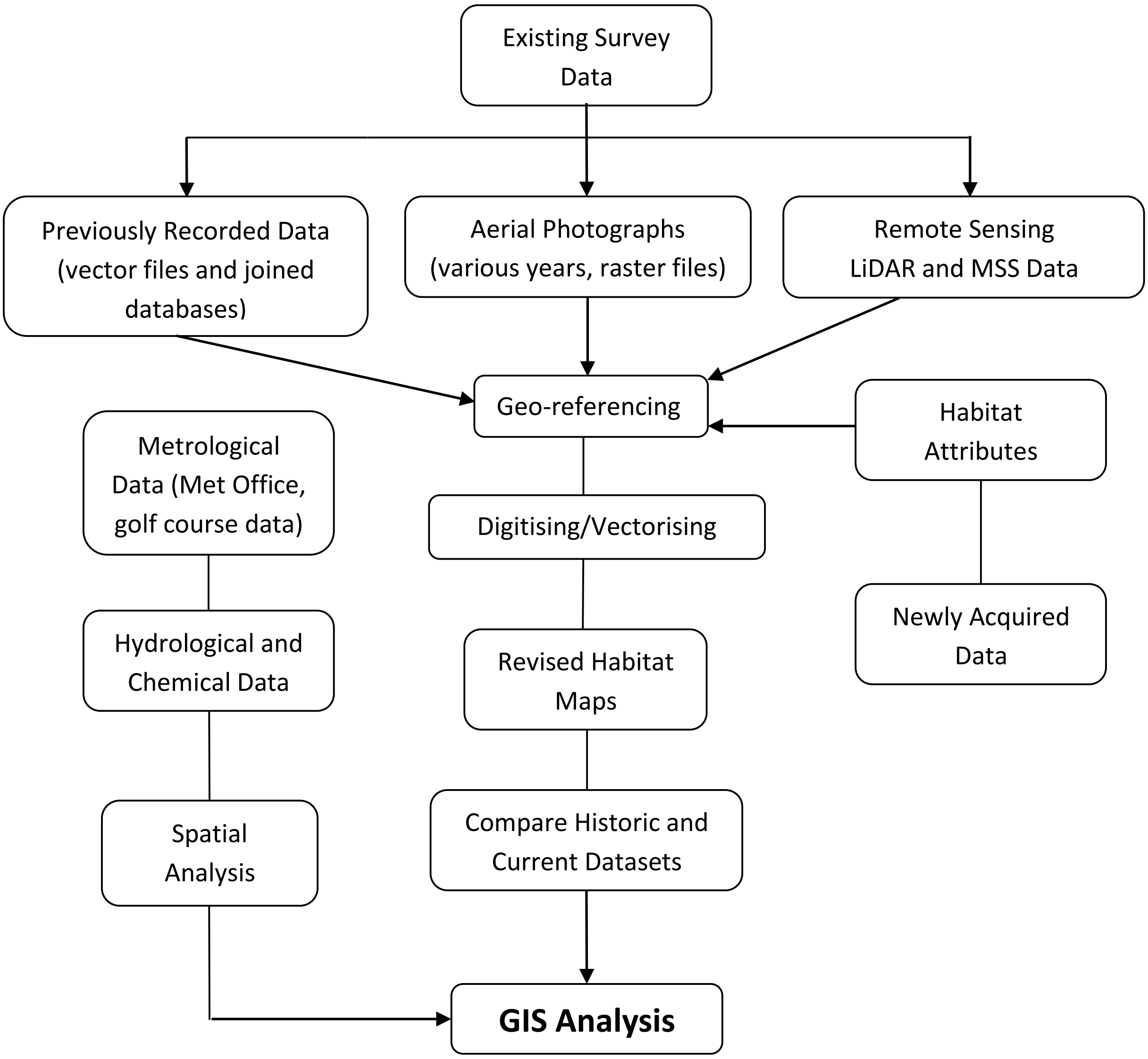


Figure 4.1 Flow diagram showing conceptualisation of geographical elements related to the study (Adapted from Shanmugam & Barnsley 2002)

Practical applications of remote sensing

There are two main types of remote sensing available to ecologists. Elevation data, derived from Light Detection and Ranging (LiDAR), and colorimetry data, derived from Multi-Spectral Scanner imagery (MSS).

MSS data captures images of energy reflected and emitted from the Earth, at various wavelengths in the electromagnetic spectrum, with the visible wavelengths displayed in the form of differing colour banding (Hobma, 1995; Horning *et al*., 2010). This colour banding can aid in descriptive observations of changes in the environment: for example, changes in chlorophyll content (greenness) that may be due to areas of sustained moisture or eutrophication (Horning *et al*., 2010).

The most accessible open-source MSS data are available from the U.S. Geological Survey satellites, known as Landsat (Pavlopoulos *et al*., 2009; Horning *et al*., 2010). However, after viewing the Landsat data (MSS data), it was decided that the colour-banding detail was insufficient for the needs of this study, as resolution was often low, and available high resolution data was either incomplete, historical, or not relevant to the area in question.

Metternicht & Zinck (2003) suggested that raw remote-sensing data needs substantial transformation or high resolution, to enable accurate feature recognition. Previous studies of Sandwich Bay had shown that a very small localised change in vegetation cover may sometimes be <5 m². However, MSS data at their highest resolution were only accurate to approximately 30 m² (Horning, *et.al*. 2010; USGS, 2014), which was a concern, as it could lead to biased interpretation in feature recognition of the MSS images, due to the coarseness of the resolution.

LiDAR data were available at a resolution of one metre, which enabled accurate positioning of height dependent quadrats and was useful in aiding analysis of the vegetation dynamics in relation to the relative water table height. There are two different sets of LiDAR data available: A digital terrain model (DTM), which measures the physical height of the ground, and a digital surface model (DSM), which measures the canopy layer and vegetation height (Pavlopoulos *et al*., 2009; Weng, 2011; Horning, *et.al*. 2010).

LiDAR provides accurate measurements and is able to map areas that are difficult to access (Horning *et al.,* 2010). Further, it has demonstrated the capability to accurately estimate important vegetation structural characteristics such as forest canopy height (Hudak *et al.,* 2002). Research undertaken by Genç *et al.,* (2004) used LIDAR data to estimate vegetation structure in wetland areas, based upon the known height classifications of specific species. On the other hand, Hopkinson *et al*., (2003) found that LiDAR data showed inaccuracies of measurement when assessing taller vegetation, such as tree canopy height in afforested areas. The research undertaken by Hopkinson *et al*., (2003) found that LiDAR was both underestimating and overestimating height, depending on the vegetative species within the canopy being measured. The literature suggests, overall, that the use of LiDAR gave accurate figures when estimating vegetation structure and assemblages <5 metres in height. There is therefore a relatively high degree of confidence in the accuracy of LiDAR in determining species differentiation, based upon height, particularly when observing lower-lying open vegetation such as grasses. Sandwich Bay predominantly has low-lying vegetation, and therefore LiDAR was appropriate for the analyses of the vegetation structures in this study.

The topography of the land can be a key factor in determining the range of plant communities present at a site (Horning *et al.,* 2010), particularly with regard to environmental stresses on plant communities, such as frequent extended periods of flooding, where the plant communities will redevelop at higher elevations (Dargie, 2012; *pers. comm*.; Jones, 2014; *pers. comm*.). This dispersal of vegetation is particularly apparent in wet dune slacks (Curreli *et al*., 2013; Jones, 2014; *pers. comm*.), where plant species, such as *Mentha aquatic*, are found dispersed along the higher reaches of wet dune slacks.

DSM data allow for the estimation of vegetation cover on the landscape, and by the subtraction of DTM values, it is possible to work out the height of the vegetation (Horning *et al.,* 2010). Analysis of these two different LiDAR datasets, obtained over a number of years at one specific location, combined with specific species knowledge about the site, may allow an estimation of vegetation redevelopment range in the landscape.

The Environment Agency collects the LiDAR data annually, typically between October – March as a part of their routine collection of sampling data, and any additional LiDAR data collection outside of these periods is conducted as a result of commercial requests or enquiries related to specific projects (Brownett, 2014*; pers. comm*.). Aerial photography is also flown annually, but has a differing time period for the data-capture (March – September) (Brownett, 2014*; pers. comm*.).

Since the regular collection of LiDAR data does not coincide with the growing season (unless specifically commissioned), the use of DSM in the estimation of vegetation structure will be inaccurate (Hobma, 1995; Horning, *et.al*. 2010; Williams, 2012; *pers. comm*.; Brownett, 2014*; pers. comm*.). In addition to this, not all areas are captured every year, and this is particularly true of Sandwich Bay (Brownett, 2014*; pers. comm*.).

As a result, observing continued progressive change in vegetation colonisation, using DSM data, was not feasible, due to the infrequency with which data were collected at Sandwich Bay. However, the DTM datasets, comprising a snapshot in time, were adequate for the research purposes of this study, because elevation would not vary depending on the growing season.

The rationale for using the DTM data was based upon the 2009 report on Sandwich Bay (Dargie, 2009). One of the questions raised by the report centred upon the possibility that an increase in water table height, identified by indicator species, could be a driver for observed change in the vegetation structure. In this study, to investigate the question raised by the 2009 report, DTM data were deemed a suitable measurement of the possible flux of dune elevation, over time, and these could be correlated to the relative water table height, based upon the height of the dunes above sea level. Thus the DTM data could be directly related to the water table heights taken from each dipwell (Figure 3.4). In addition to this, the DTM dataset could be related to vegetation classifications and their relative elevation, based upon where NVC classes reside.

4.2 Hydrological analysis introduction

Hydro-chemical investigation

Dune systems are often nutrient deprived (Martínez & Psuty, 2008; Maun, 2009), which means indicators such as plant height, and even colouration, can vary from one dune system to the next, based upon the available nutrients and the amount of water in the system. Examples of this are the dune systems found on the South-East coast of England, which are far drier than those found along the West coast of Wales (Clarke & Stratford, 2010), due to the climate. This is illustrated by the variation in plant assemblages between these two dune systems.

Although dune systems may have similar vegetation assemblages, similar elevation, and been shaped by similar coastal processes, there are a number of interactions which make each dune system unique in its own right. The geographical location and the amount of energy in the system contribute to shaping the dune system, together with many other factors; for example, the availability of fresh water.

Therefore, although every dune system is visually similar, there are many processes at work which make it difficult to compare them directly. This implies that a comparative analysis between dune systems will be inaccurate when observing dune systems in detail.

This is also partially true when comparing descriptive data of plant assemblages in habitats, since various external influences on vegetation growth, such as those relating to drought stress, nutrient deficiency, weather dynamics and topography, imply that each site will have its own unique plant composition.

The species distribution within the dune system can be significantly influenced by a constant influx or a long-term retention of water. Consequently, of the features that reside within the dune system, dune slacks have been the subject of most research in recent years (Stratford, 2011). Dune slacks are a seasonal coastal wetland habitat, whose plant assemblages and soil properties are strongly linked to a fluctuating water table (Curreli *et al*., 2013). Climate change is predicted to cause major shifts in sand dune hydrological regimes, though relatively little is known about the tolerances that plant communities will have in respect of this potential change, and their precise hydrological requirements are poorly quantified (Curreli *et al.,* 2013; Jones *et al*., 2013).

Previous studies at Sandwich Bay suggested that an increased rate-of-change in vegetation might be driven by an excess of nutrients in the system and increased retention of moisture (Dargie, 2009). One of the main areas of interest in this study was to investigate whether the chemical constituents in the groundwater affected the vegetation at ground level and, where there were indicators of increased water retention over long periods of time, what were the driving factors behind this retention of water.

It was known that in unconfined aquifers, the flow rate of water through the system can be relatively high, with estimates of between 5m to 50 m per day (Stuyfzand, 1993; Maun, 2009). However in a dune system such as that found at Sandwich Bay, the estimated flow rate through the system is likely to be 0.3m per day (Clarke, 2014*; pers. comm.*). The research was not focused upon the flow rate of water through the dune system due to equipment constraints, but it did involve the measurement of the water-table height, and therefore it was important to observe the effects of tidal variation/flux in the dune systems, and the change in species composition in relation to water table height.

Groundwater chemical constituents

Groundwater normally contains seven major ions: Ca^{+2}, Mg^{+2}, Cl^{-1}, HCO_3^{-1} Na^{+1}, K^{+1}, and SO_4^{-2} (Akbar *et al*., 2008; Cheng & Ouazar, 2005; Stuyfzand, 1993). The chemical parameters of groundwater play a significant role in the classification and assessment of water quality (Cheng & Ouazar, 2005; Sadashivaiah *et al*., 2008). Nitrogen in the system is also an important component, and can be derived from both inorganic and organic sources. Nitrogen exists in three ionic states: ammonia (NH_4^+), nitrates (NO_3^-) and nitrites (NO_2^-) (Baird & Cann, 2012; Stuyfzand, 1993). These three states occur as a result of oxidation (Baird & Cann, 2012), and Total Oxidised Nitrogen (TON) is a measure of the sum of these three states. The order in which oxidation occurs is based upon the reactivity of the chemical constituents. Ammonia is oxidised first into nitrites, which are then rapidly oxidised to nitrates. The oxidisation of ammonia is the main source of nitrites (Baird & Cann, 2012; Stuyfzand, 1993), and therefore nitrites, in aqueous form, represent an unstable state of nitrogen in an aquatic environment, since they readily combine with oxygen to form nitrates.

These conversion stages can accelerate eutrophication processes in aquatic systems (Stuyfzand, 1993). Dissolved inorganic nitrogen is readily available to plants because it exists in the form of nitrates. Analysis of the difference between nitrate and nitrite concentrations can aid in the identification of organic or inorganic pollutants entering the system, since high concentrations of nitrites suggest that they are being replenished from an external source.

Jones *et al*., (2006) discusses the phenomenon of rainwater 'lensing', with particular reference to the acidity of rainwater. Pools of rainwater gather in low-lying areas and the acidity causes the vegetation to differ from the surrounding areas. The pH of rainwater is around 5.6, and it is generally assumed that rainwater is more acidic than groundwater in areas where there are aquifers (Baird & Cann, 2012; Cheng & Ouazar, 2005). Slight acidification of the surrounding localised area, due to precipitation remaining on the surface, may therefore constitute a causal factor in vegetation change (Pye & Tsoar, 2009; Zunzunegui *et al.,* 1998). It has been observed at Prince's Golf Club that, during the wetter winter months, there can be large pockets of surface water on the fairways inland from the shore. The prolonged presence of surface water decreases the pH in these seasonally flooded areas, and plant identification has shown that isolated areas of SD12 *Carex arenaria–Festuca ovina–Agrostis capillaris* (dune grassland) composition, which tend to favour these slightly acidic soils have increased their range in these areas.

Meteorological data

The key drivers in eco-hydrological change in a stabilised dune system are variations in rainfall, coastal erosion, and long-term trends in the form of rising sea-levels (Stratford *et al.,* 2013). Because external influences, such as climatic and meteorological conditions, can affect vegetation growth, it was essential to collect local weather data, which were recorded both at Princes Golf Course and at an independent meteorological station located in Broadstairs (Rogers, 2014). In addition to local data, historical meteorological data, obtained from the Met Office (recorded at Manston airport, Thanet) were used to determine meteorological conditions for the time periods during which the surveys were undertaken at Sandwich Bay, focusing upon extended periods of dry and wet conditions before and during the time when the surveys were performed.

Historic vegetation analysis

In the previous analyses undertaken at Sandwich Bay that focused upon the vegetation community dynamics, based upon the historic datasets, there was an observed trend in vegetation communities away from diverse fixed dune grassland to neutral grassland (Dargie, 2009), as can be seen in Figures 4.2 and 4.3.

Comparisons between the different survey years confirmed that there was indeed a trend in the observed change from fixed dry dune grassland to dry neutral and wet neutral grassland (Dargie, 2009).

Vegetation analysis was an integral part of the investigation, and therefore the initial results focused upon vegetation composition within a 1 m distance of the dipwells, which were then related to the groundwater samples.

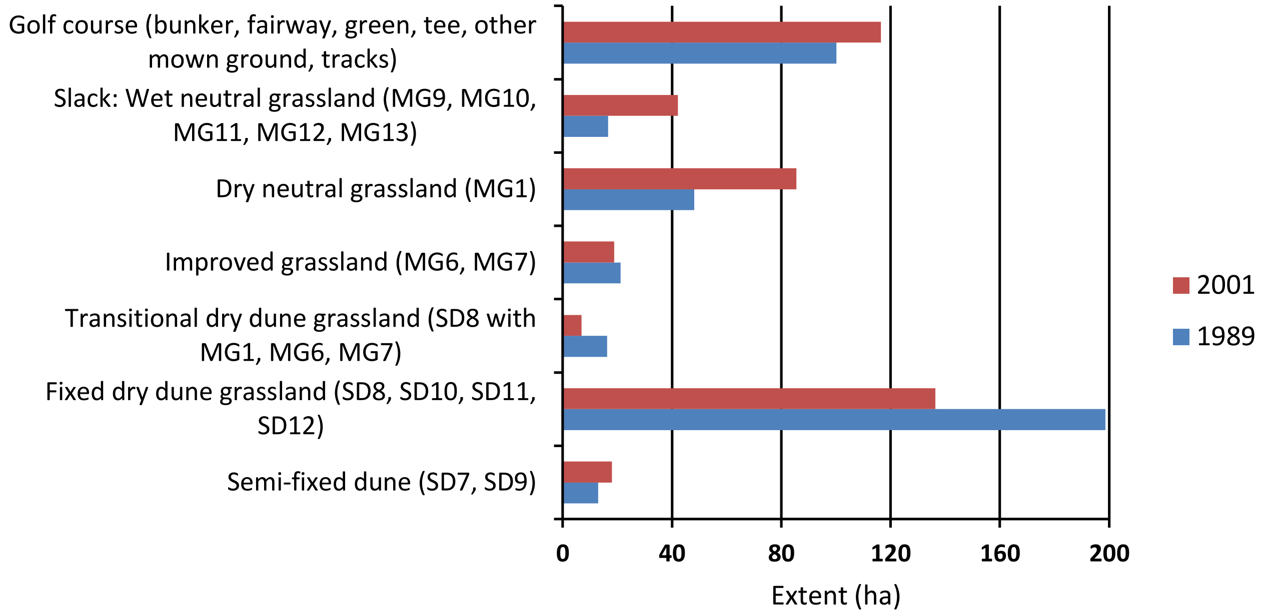


Figure 4.2 Graph showing the differences in the extent of vegetation communities between the 1989 and 2001 data sets at Sandwich Bay (graph taken from Dargie & Earl, 2013)

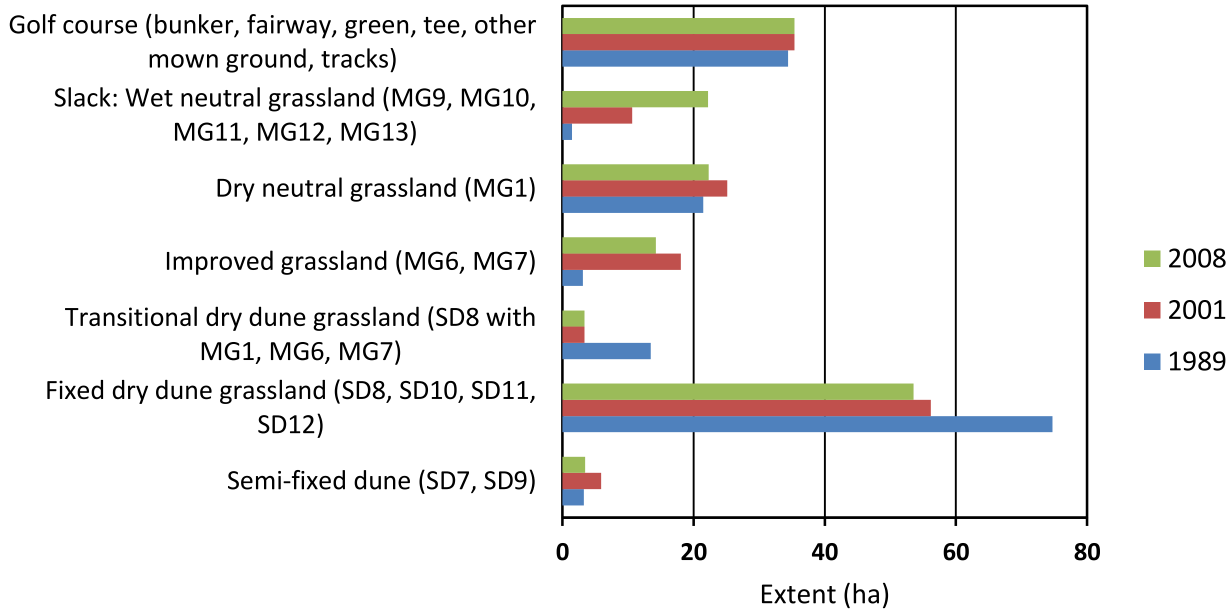


Figure 4.3 Graph showing the differences in the extent of vegetation communities between the 1989, 2001 and 2008 at RSGGC (graph taken from Dargie & Earl, 2013)

The successional state of vegetation change observed between the survey periods 1989, 2001 and 2008 all indicate that there is an ongoing trend in species composition change, possibly driven by retained moisture within the dune systems, following an observed trend that may have been happening already within the dune systems during the first NVC survey 1989 (Dargie, 2009).

4.3 Vegetation description tools

Review of existing available NVC tools

Software is available which can provide an estimation of the vegetation class based upon NVC survey raw data. The two main open-source programs that are currently in use today are TABLEFIT and MAVIS (Modular Analysis of Vegetation Information System) (Kent, 2012; Williams, 2013; *pers. comm*.). Each of these programs uses a species-recognition database to identify individuals, or group of individuals, to work out the appropriate NVC classification based upon the inputted data. The MAVIS incorporates the MATCH program for vegetation analysis, and has been the preferred open-source program for habitat analysis in Natural England (Williams, 2013; *pers. comm*.). It combines a number of habitat classification systems, including Ellenberg scores and NVC, to analyse quadrat data to give an estimation of NVC classifications.

MAVIS provides a range of coefficient values to express the degree of confidence in its estimate of community type, an example would be, ‘NVC: MG7 53.75’. A coefficient of >50 shows a high degree of confidence in the analysis, although, due to the amount of species overlap between similar communities, it is not possible to simply infer that the highest MAVIS coefficient will indicate the correct community. The results should only be used as a guide, and consulting of the published floristic tables and descriptions in the NVC volumes are needed to decide which community is most representative of the observed data. These programs are limited in that they do not take into account the transition between vegetation classes, habitats which are under sampled, and in particular, they do not necessarily account for errors in the original vegetation classifications that ultimately arise from lack of revision. Thus even the use of an unbiased program still requires an interpretation that incorporates multiple information sources.

One of the highlighted issues with MAVIS is that it weights each plant species equally as a default value, and does not reflect the importance of key species in a classification. It uses cover values of 1% whenever specific percentage cover values are not specified (Smart, 2000). However, in the MAVIS guidance documents, these default values are not displayed, and such analyses can therefore be misleading (Williams, 2013; *pers. comm*.).

An example of this was the recent extension of an existing SSSI, called Chattenden Woods and Lodge Hill (April 2013), which now includes a former Ministry of Defence training camp. The site was of particular importance as a habitat for 65 breeding pairs of nightingales. Investigation by an experienced team of botanists from Natural England identified the sward cover to be of botanical interest (Williams, 2013; *pers. comm.*), and based upon ground observations, the swards found were classed as MG5 *Cynosurus cristatus – Centaurea nigra* (unimproved grassland), making this site unsuitable for a proposed development of an additional 5000 houses by Medway Council.

However, the coefficients generated by MAVIS are open to interpretation, when analysing homogenous strands. This was the case with the sward identified as unimproved grassland (MG5) by Natural England. The independently surveyed quadrat data were reanalysed by parties in favour of the development, and MAVIS showed that the quadrat analysis was in fact classed as MG6 - *Lolium perenne – Cynosurus cristatus* (semi-improved grassland), even though a typical indicator species *Lolium perenne* (rye grass) of MG6 sward was not present (Williams, 2013; *pers.comm*.).

Although MAVIS is a competent program that can be used to categorise species assemblages, in order to maintain an element of consistency with previous studies when analysing the species compositions, the methods developed in the 2009 report (Dargie, 2009) were employed..

Review of Ellenberg gradients in plant analysis

Ellenberg gradients and indicator scores were developed as a way of evaluating plant species, based upon their environmental status and the specific ranges that these species inhabit. Ellenberg scores are based upon the published list of species of European flora, designed by Heinz Ellenberg (Thompson *et al*., 1993; Hill *et al*., 1999; Smart & Scott, 2004). Ellenberg defined seven major scales (Hill *et al*., 1999): Light (L), Moisture (F), Reaction (R) (either soil pH or water pH), Nitrogen (N) (a general indicator of soil fertility), Salinity (S) (salt tolerance), Temperature (T), and Continentality (K). Two of the scales, those for temperature and continentality, are generally omitted from studies conducted in oceanic climates, such as those of the British Isles (Hill *et al*., 1999), as these values are defined as being geographic rather than climatic.

The scales, or gradients, have numerical values ranging from 1 - 12 (10 – 12 are for species in aquatic environment), to convey the optimal set of conditions that particular species are typically found to occupy, see Table 4.1. Ellenberg scores position a species along different gradients, based upon a synthesised scoring system developed from experimental laboratory work (Smart & Scott, 2004), field observations, and descriptive analyses of particular species. An example of Ellenberg scoring for an individual species is *F. rubra*, which has an Ellenberg score of 8 for light, 5 for wetness, 6 for pH, 5 for available plant nutrients and 2 for salinity.

The validity of the Ellenberg values, as a definitive scoring system for individual plants at species level, has been questioned (Thompson *et al*., 1993; Smart & Scott, 2004; Lawesson *et al.,* 2003). Ellenberg's studies concentrated upon Central European populations, and thus the scoring system might be considered inappropriate as a measure of species performance in the British Isles (Wamelink *et al.,* 2002; Smart & Scott, 2004).

Ellenberg scores exist for a range of different plant species, including 1791 vascular plants found in Great Britain (Hill *et al*., 1999). There are, however, limitations with regards to the Ellenberg scores, particularly with regards to rare plant species, such as *Orobanche caryophyllacea*.

Schaffers & Sykora (2000) noted that, when assessing the reliability of Ellenberg indicator values, particularly moisture and nitrogen, Ellenberg moisture values correlated accurately with average groundwater levels, but Ellenberg N values correlated weakly when assessing soil/groundwater chemistry. However, Ellenberg N values did have a strong correlation with biomass production (Schaffers & Sykora, 2000). Therefore relating Ellenberg N scores for nutrient values obtained from quadrats would have an element of inaccuracy, when comparing them to the Ellenberg N values for nutrient concentrations obtained from the water table. For this reason, NVC vegetation classes were deemed to be the preferred variables when analysing the hydro-chemical parameters rather than Ellenberg scores directly.

Curreli *et al,*. (2013) and Jones (2014*; pers. comm.*) observed that a fluctuating water table will generally only affect the vegetation in closest proximity to it, and therefore the dune slacks have been the focal point of sand dune investigations in recent years, particularly in relation to hydrological and chemical changes (Jones,2014*; pers. comm*.). As part of the investigation into the possibility of a significant difference between elevation (proximity to the water table) and NVC class, a number of NVC classes recorded at Sandwich Bay were subdivided into wet-environment indicator species classifications, including mesotrophic grassland communities MG12 *Festuca arundinacea* (wet neutral grassland) and MG13 *Agrostis stolonifera – Alopecurus geniculatus* (wet neutral grassland), and the dune-slack communities SD13 *Sagina nodosa – Bryum pseudotriquetrum* (dune-slack community), SD14 *Salix repens – Campylium stellatum* (dune-slack community), SD16 *Salix repens – Holcus lanatus* (dune-slack community) and SD17 *Potentilla anserina – Carex nigra* (dune-slack community), which were then analysed against LiDAR data to observe differing elevation between NVC types.

Table 4.1 Ellenberg indicator scales and definitions of values for five Ellenberg gradients (Table adapted from Dargie, 2009)

Ellenberg Score	Ellenberg Indicator Gradients				
	L - Light	F - Moisture	R – Reaction/pH	N — Nitrogen	S – Salt
0					Absent from saline sites; if in coastal situations, only accidental and non-persistent if subjected to saline spray or water (85% of British flora)
1	Plant in deep shade	Indicator of extreme dryness, restricted to soils that often dry out for some time	Indicator of extreme acidity, never found on weakly acid or basic soils	Indicator of extremely infertile sites	Slightly salt-tolerant species, rare to occasional on saline soils but capable of persisting in the presence of salt. Includes dune and dune slack species where groundwater is fresh but where some salt-spray inputs are likely
2	Between Ellenberg scores 1 and 3	Between Ellenberg scores 1 and 3	Between Ellenberg scores 1 and 3	Between Ellenberg scores 1 and 3	Species occurring in both saline and non-saline situations, for which saline habitats are not strongly predominant
3	Shade plant, mostly <5% relative illumination, seldom >30% relative illumination when	Dry site indicator, more often found on dry ground than in moist places	Acidity indicator, mainly on acid soils, but exceptionally also on nearly neutral ones	Indicator of mostly infertile sites	Species most common in coastal sites but regularly present in fresh water or on non-saline soils inland (includes strictly coastal species occurring in sites such as cliff crevices and sand dunes that are not obviously salt- affected)
4	Between Ellenberg scores 3 and 5	Between Ellenberg scores 3 and 5	Between Ellenberg scores 3 and 5	Between Ellenberg scores 3 and 5	Species of salt meadows and upper saltmarsh, subject to at most only very occasional tidal inundation. Includes species of brackish conditions
5	Semi-shade plant, rarely in full light, but with generally >10% relative illumination when trees are in leaf	Moist site indicator, mainly on fresh water-saturated soils of average dampness	Indicator of moderately acid soils, only occasionally found on very acid or on neutral to basic soils	Indicator of moderately infertile sites	Species of the upper edges of saltmarsh, where not inundated by all tides. Includes obligate halophytes of cliffs receiving regular salt spray
6	Between Ellenberg scores 5 and 7	Between Ellenberg scores 5 and 7	Between Ellenberg scores 5 and 7	Between Ellenberg scores 5 and 7	Species of middle saltmarsh
7	Plant generally in well-lit places, but also occurring in partial shade	Dampness indicator, mainly on constantly moist or damp soils, but not on wet soils	Indicator of weakly acid to weakly basic conditions; never found on very acid soils	Indicator of sites of intermediate fertility	Species of lower saltmarsh
8	Light-loving plant, rarely found where relative illumination in summer is <40%	Between Ellenberg scores 7 and 9	Between Ellenberg scores 7 and 9	Between Ellenberg scores 7 and 9	Species more or less permanently inundated in sea water
9	Plant in full light, found mostly in full sun	Wet site indicator, often on water-saturated, badly aerated soils	Indicator of basic pH, always found on calcareous or other high pH soils	Plant often found in richly fertile places	Species of extremely saline conditions, in sites where sea water evaporates, precipitating salt
10		Indicator of shallow water sites that may lack standing water for extensive periods		Between Ellenberg scores 9 and 11	
11		Plant rooting under water, but at least for a time exposed above, or plant floating on the surface		Indicator of extremely rich soil fertility, such as cattle resting places or near organically-	
12		Submerged plant, permanently or almost constantly under water			

Sandwich Bay NVC quadrats and pseudo-replicate NVC data

The quadrats positioned in 1989 at Sandwich Bay were distributed to take into account the variation in the dune systems, which included humid dune slacks and fixed grey dune habitats, while avoiding areas under extensive management by the golf courses (Doarks *et al*., 1990). In addition to the 63 permanent quadrats located in 1989, Dargie (2002) added a further 28 quadrats to facilitate a better understanding of localised changes in the landscape, because the previous quadrats located in 1989 were distributed in a sparse and often clumped distribution.

The current study added a further 103 quadrat locations, based around the installed dipwells, and these were positioned in lower-lying areas than the majority of the original 1989 and 2001 NVC quadrats. The vegetation was analysed in accordance with the standard protocols for NVC surveys in open grassland areas using a 2 x 2m quadrat (Rodwell, 2006), to allow for standardisation and compatibility between the datasets.

To maintain consistency with previous surveys, quadrat analysis was undertaken not only using the NVC floristic tables and text guidelines, but also the addition of computer simulated floristic data to create pseudo-quadrat extents for each of the NVC classifications (Dargie, 2009). This allowed for an estimation of NVC type extent based upon an 25 estimated successional states, derived from the original NVC type floristics', increasing the accuracy of real-time NVC categorisation, while still being within the guidelines of the published NVC documentation.

This approach was used in addition to NVC floristic tables to allow for certain inconsistencies and lack of revision of the original NVC specific guidelines for these habitats. The rationale behind this was the impossibility of revising the original NVC quadrat locations, because during the transfer of hard copy records to electronic format, sometime in the late 80s and early 90s, the original quadrat location records, upon which the NVC guidelines were based, were lost (Dargie, 2012; *pers. comm.*).

This meant that the original locations could not be revisited and the classification system could not be updated based upon the successional state of the original sward composition. Dargie (2009) solved the problem caused by the lack original data by employing an ordination method that involved computer-simulated pseudo-quadrat data, derived from the original NVC floristic tables (Rhind *et al.,* 2006, Dargie, 2009), which projected an estimated range of states for each of the NVC classes. This pseudo-random quadrat approach simulated species data for 25 quadrats per NVC community, using the original published NVC floristic tables as a baseline, together with published domin scores and constancy (frequency) classes (ranging from I to V), and range and average number of species per quadrat (Rhind *et al*., 2006; Dargie & Earl,2013). In conjunction with quadrat data collected in the field, this provided an estimate of floristic composition using a transformation spreadsheet, allowing for quadrat analysis along the differing Ellenberg gradients that may affect plant growth, such as available water and plant nutrients.

Prediction ellipses allow for an estimation of potential NVC classes range based upon species composition, and when this data is imported into a cartographic program it allows for a visual representation and analysis of changes in the location of vegetation species within a quadrat. This gave the opportunity for easy repetition and analysis of vegetation types over successive surveys/years, and made a positive enhancement of repeat surveys/analysis of individual sites, as well as an estimation of the effect on species composition due to changes in management techniques.

Materials and methods

4.4 Geographical methods

NVC model using Ellenberg scores and pseudo-quadrats

NVC methodology focuses upon the analysis of vegetation structure within apparent homogeneous stands. Representative samples are located through subjective interpretation by the surveyor (Rodwell, 2006). NVC analysis within areas predominantly comprising of short herbaceous vegetation and dwarf-shrub, such as Sandwich Bay, uses a 2 x 2 m quadrat system, the assemblages are classified based upon species composition, using a floristic table. Samples that were subjectively selected from heterogeneous areas, or obviously defined vegetative boundaries, are acceptable as long as the overall survey is spread across a larger area to permit a broader understanding of the habitats that exist within the area under observation.

In contrast to IHS surveys and phase 1 habitat surveys, it is imperative when conducting NVC surveys to record the species within the quadrat at ground level in addition to species which predominantly rise just above ground level. As a result, when estimating species cover (including bare ground), the estimated cover can exceed one hundred percent. Quadrats which have less than one hundred percent cover often reflect species which have not necessarily been recorded, but might be present within the quadrat. For example, NVC surveys undertaken in late May, at the start of the growing season, might not necessarily count species such as *Arrhenatherum elatius*, which often flower/seed mid-to-late June. A list of NVC communities found at Sandwich Bay is provided in the appendices.

Two NVC surveys of Sandwich Bay were conducted annually in the years 2012 and 2013, with the two-metre square quadrats placed at 1 m distance from of each of the dipwells, in order to provide a comparison of annual vegetation change. Additionally one survey was conducted across Sandwich Bay in 2013 (in areas where access was granted), recording the species composition at the original 1989 quadrat locations. Once the field data were recorded, an Excel equation-based spreadsheet was used to input the raw quadrat data, which was then transformed into quadrat species composition Ellenberg scores that were plotted as non-spatial geographical grid references.

Domin scores were collected in the field and then converted into cover-percentages using a conversion table (Table 2.1). These cover-percentages were normalised, and then converted to species specific Ellenberg scores (Appendix 2). An example of the resulting outputs can be seen in Table 4.2. The Ellenberg gradient results were then ploted as an ordination using ESRI ArcGIS 10, with Ellenberg F and N values on the X and Y axes. These two Ellenberg parameters have been shown to have the most effect upon the vegetation change (Maun, 2009; Dargie, 2009).

Table 4.2 Example of the data held in Excel for the NVC surveys

Dipwell Number	Total Plant Cover (%), out of 200%	Total Coverage (%), out of 200%	Num-ber of Taxa	Ellenberg L (light)	Ellenberg F (moisture)	Ellenberg R (reaction /pH)	Ellenberg N (nutrients)	Ellenberg S (salinity)
1	110.973	114.973	7	7.975	5.553	6.399	5.254	2.009
2	120.194	120.194	13	7.705	4.666	6.371	4.502	1.545
3	122.447	122.447	12	7.050	5.643	6.542	6.218	0.192
4	108.365	118.365	11	7.938	4.778	6.338	4.347	1.425
5	100.019	100.019	12	7.223	5.410	6.330	5.546	0.560
6	122.725	122.725	11	6.998	5.684	6.265	5.699	0.025
7	114.483	116.483	11	7.222	4.543	5.811	4.126	1.094

The pseudo-quadrat values of NVC estimates (Dargie 2009) were then used to create ellipses for each NVC classification. These ellipses were then superimposed over the Ellenberg transformed quadrat data from Sandwich Bay.

Layer manipulation of differing NVC classification ellipses allowed for determination of which ellipse best portrayed the quadrat, and figure 4.4 shows the NVC ellipses. The NVC guidelines were then consulted to confirm the interpretation of the vegetation classifications. Changes in vegetation community composition were quantified by comparing the position on the ordination for each Sandwich quadrat in June 2012 with the position of the same quadrat in June 2013.

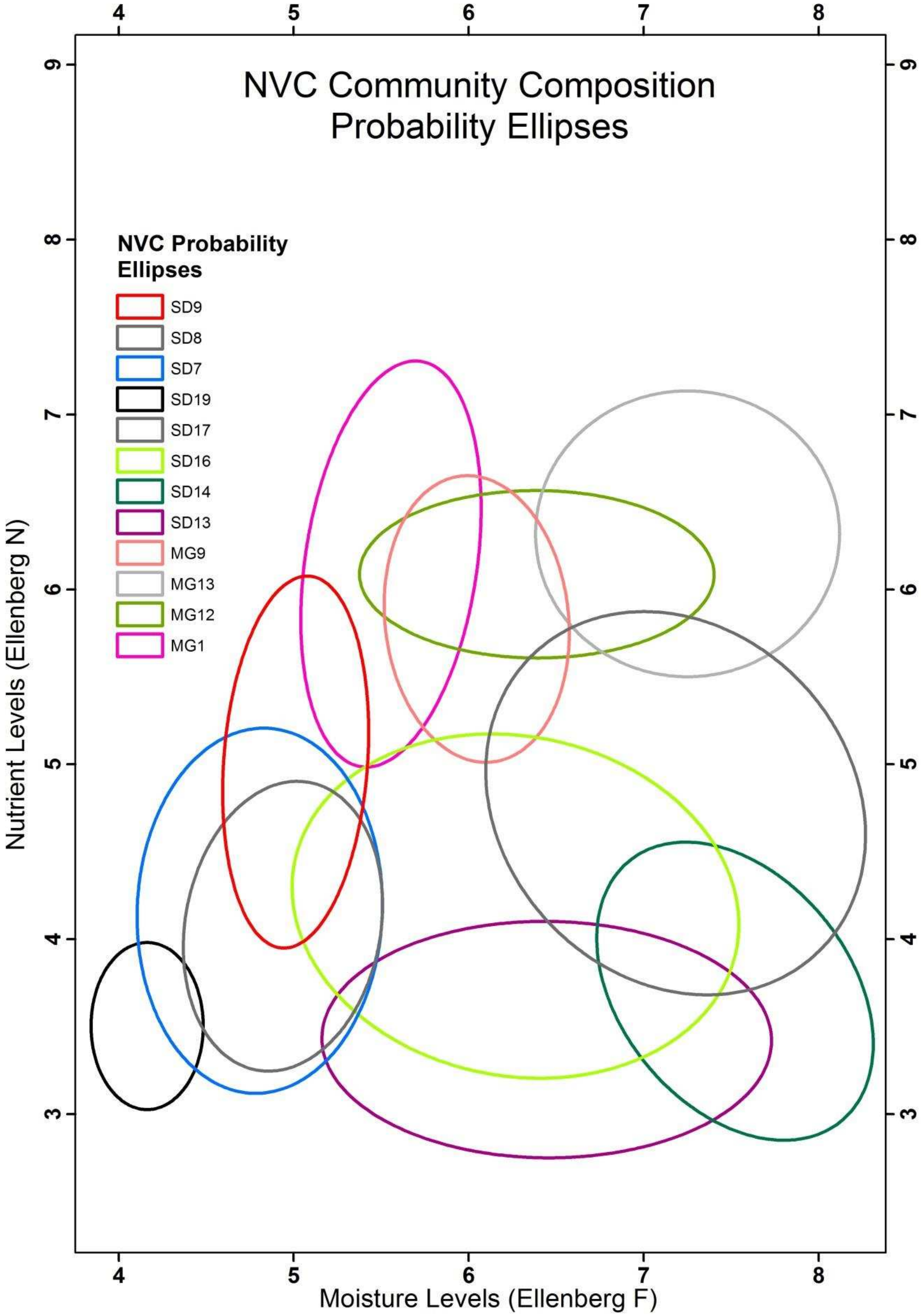


Figure 4.4 Pseudo-quadrat prediction ellipses (adapted from Dargie, 2009)

Further interpretation of the pseudo-quadrat data displayed in the probability ellipses, was performed using contingency table chi-square analysis (Zar, 2010). The analysis was performed by placing gridlines over the Ellenberg F and N gradient intervals, counting the number of quadrat occurrences within rows (Ellenberg N) and columns (Ellenberg F), for both the June 2012 and June 2013 data. . For each Ellenberg gradient a contingency table was created with Ellenberg score in columns and each year as the rows.

Geographical analysis of hydro-chemical data and vegetation data

DTM data, obtained from LiDAR, were used to measure the elevations of specific NVC communities and to compare NVC classifications with elevation as the determining factor.

Hydro-chemical data were inputted into the computational package ArcGIS, as grid-referenced vector point data, for analysis using interpolation. The interpolation method employed a spatial algorithm, called Inverse Distance Weighted analysis (IDW). IDW is a technique that estimates cell values of the hydro-chemical data, in the raster, at set sample points derived from the vector data. These cell values were displayed as chemical distributions estimated by zonation around the vector data.

4.5 Hydro-chemical materials and methods

Water sampling methodologies and strategies

The water-table height and water samples from every dipwell were collected once a month for a period of six months, from June 2012 – November 2012. After November 2012 the sampling resolution was changed to quarterly sampling, from March 2013 – June 2014, based upon standard sampling time-frames (Large *et al.*, 2007). Monthly water sample collection was impracticable due to the vast amount of time it took to collect and analyse the samples at such regular intervals. Table 4.3 shows a template spreadsheet used during water sample collection.

Quadrat locations were recorded using GPS equipment [Magellan MobileMapper CX], linked to North Foreland light house, Kent, to obtain differential GPS accuracy of plus/minus 2 metres. For orientation on the ground, maps of the golf courses were used, with dipwell locations plotted.

The water table measurements were taken prior to a water-sample being obtained, as the sampling method displaced the water column. The water table level was recorded using an open-circuit device, which provided audible and visual indications once the water table was reached. The length of wire fed into the dipwell was then measured, using a tape measure, to record the depth to the water table from ground-level. To standardise this measurement, the uppermost lip of the dipwell was the reference point, and measurements of the pipe protrusion in relation to ground level were also recorded. Recording the height of the water-table allowed assessment of the seasonal water available to the dune system.

Barometric pressures were also recorded upon arrival at the site on the sample days, using a portable self-calibrating sensor [Casio ProTrek PTR-400]. These values were then compared to data obtained from Rogers (2014). Barometric pressure has an influence on the relative water table heights (Sundaram *et al.,* 2009), and it was therefore important to record this data, as it was not possible to collect water samples from the entire dipwell network in a single day, and comparisons between dipwells at different locations had to take barometric pressures into consideration .

Table 4.3 Template spreadsheet used in raw data collection

RSGGC Surveyor .... Date.. Time ....

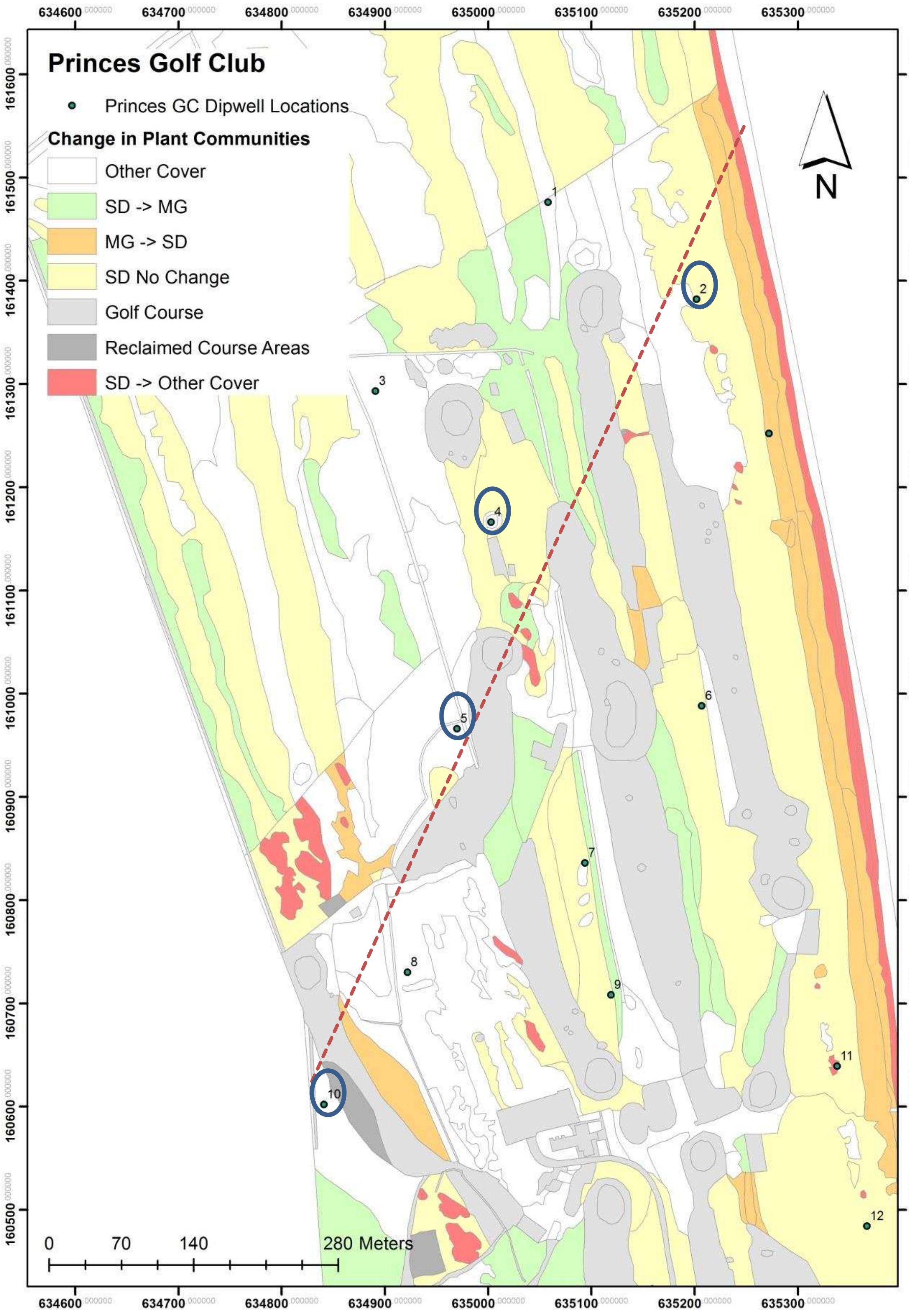
Bore Hole Number	Location	E	N	NVC	pH	EC	Pipe Protrusion cm	Water table cm
36	wp325	635620	159179	SD8a				
37	wp326 (418)	635450	159036	MG1a				
38	wp329	635120	158904	MG1a				
39	wp319	635403	158901	MG1a				
40	wp315	635758	158895	SD8a				
41	wp426	635126	158704	MG1a(20)+MG1/MG12(80)				
42	wp301	635599	158683	MG1a				
43	wp298	635301	158657	SD8a				
44	wp425	634896	158621	MG1a				
45	wp378	635365	158517	MG1a				
46	wp281	635084	158490	SD8a				
47	wp388	635684	158499	SD7b(60)/SD8a(40)				
48	wp308	635824	158458	SD8a				
49	wp333	635433	158353	MG1a(5)+SD8a(95)				
50	wp331	635220	158340	SD9a				
51	wp395	635808	158304	SD8a				
52	wp348	635616	158245	MG1a(5)+SD8a(95)				
53	wp340	635397	158201	MG12a				
54	wp423	635526	158156	MG11a				
55	wp396	635859	158154	MG1a				
56	wp352	635643	158033	MG10/MG11				
57	wp428	635038	158051	MG7				
58	wp261	635782	157953	MG11(70)+M28(30)				
59	wp358	635935	157926	SD8a(90)+SD9a(10)				
60	wp362	636101	157929	SD8a(90)+SD9a(10)				
61	wp421	635641	157870	W2a (woodland area cut)				
62	wp429	635346	157824	MG10/MG13				
63	wp371	636049	157819	SD8a(90)+SD9a(10)				
64	wp372	635859	157737	Mown track				
65	wp367	636106	157728	MG1a				
66	wp430	635684	157642	MG7c(70)+MG10b(10)+SD8a(20)				
67	wp368	635970	157619	MG1b/MG11a				

Water table measurements

Water table height was recorded in centimetres, with an accuracy of ± 0.5 cm. Stuyfzand (1993) stated that tidal fluctuations will have an effect on the water level in the dipwells, due both to the relative proximity to the sea, and to the sand dunes being an unconfined aquifer.

To estimate the effects of tidal flux upon the relative height of the groundwater in the dipwells, an experimental investigation into the tidal flux was undertaken in September 2013, as part of this study. This consisted of a 12 hour continuous tidal-fluctuation observation along a one kilometre long transect during a spring tide (full moon). The tidal influence observation transect was sited at the northern end of Sandwich Bay and incorporated four dipwells. A repeat analysis was undertaken during March 2014 along the same transect during a spring tide (full moon) to ensure consistency between the measurements allowing for the estimation of seasonal variability, Figure 4.5.

The water table heights were recorded on-the-hour, every hour, and measurements began roughly 1 hour before low tide, to observe decreasing height in the groundwater and to check that tidal fluctuations were indeed a factor to be considered. The results from the initial observation showed that there was a 4 cm (±0.5 cm) variation in water table height between high and low tide, and this difference was observed in the dipwells along the entirety of the 1 km transect. The repeat tidal observation undertaken in March 2014 showed a similar variation in the water table height. This tidal fluctuation had to be taken into account when recording water table heights, to allow for variations in the height of the water table based upon either spring or neap tidal influences in the groundwater within the dune system.



Key: Red dotted line shows transect, chosen repeat sample dipwells circled in blue

Figure 4.5 Map showing the hydrological fluctuation observation transect at Princes Golf Club

Water sample collection and aseptic techniques

The water was collected using a bailer, attached to the end of a collapsible fibreglass pole (Plate 4.1). The collection bottles (labelled with indelible ink for each individual dipwell) were, where possible, washed through with the water sample first and a secondary sample were then taken, to a maximum volume of 300 ml.

During water sample collection, it was necessary to ensure that there was the least possible amount of contamination between dipwells. To ensure this, all of the field equipment used in the sample collection was duplicated, to make sure there were at least two sets of everything required. It was also important that contamination in the dipwells, particularly by microbial matter (bio-fouling), often found at coastal water sampling locations (Maun, 2009), should be eliminated. Where biofouling was present, the water was emptied out of the dipwell using the bailer, allowing the groundwater to recharge and refresh the dipwell before the next sample collection.

Plate 4.1 Dipwell sample collection using bailer

To prevent contamination being transferred between dipwells by the equipment used, after each sample collection the probe and bailer were rinsed a minimum of three times using distilled water. Where it was evident that bio-fouling or any other contaminant was present, a 2% solution of Decon 90 was applied to the equipment, and it was then washed six times with distilled water before sampling recommenced. Consideration of possible *in situ* contamination included: residue of earlier samples remaining in sampling containers; contamination from the different dipwell locations and from the ground layer during sampling; residual water in or on poles, wires, and handles from the equipment used to obtain a water sample; contamination of bottle caps or tops by dust or water; and from hands, fingers, gloves and general handling.

Dipwell samples were processed within 24 hours to reduce chemical degradation (Rice *et al.,* 2012). The glassware, speed-filters, and the bottles in which the water samples were contained, were all shared equipment. Therefore, to ensure that no contamination between samples occurred, samples were processed in small batches and isolated. All equipment, including the sample bottles, were decontaminated using the 2% Decon 90 solution, then washed six times through with distilled water (Rice *et al.,* 2012; Buckley, 2006). This ensured that any residual contamination from previous samples would be diluted to very low levels, and would not affect the chemical analysis of the retained sample.

The water samples were first filtered using general analytical-grade 185mm circular filter papers with the aid of a speed filter. Plate 4.2 shows the filtration process. A minimum of 100 ml was required for all water analyses, which including a 50 ml secondary sample as backup if needed. All water sample bottles were then labelled in indelible ink with the location references and date.

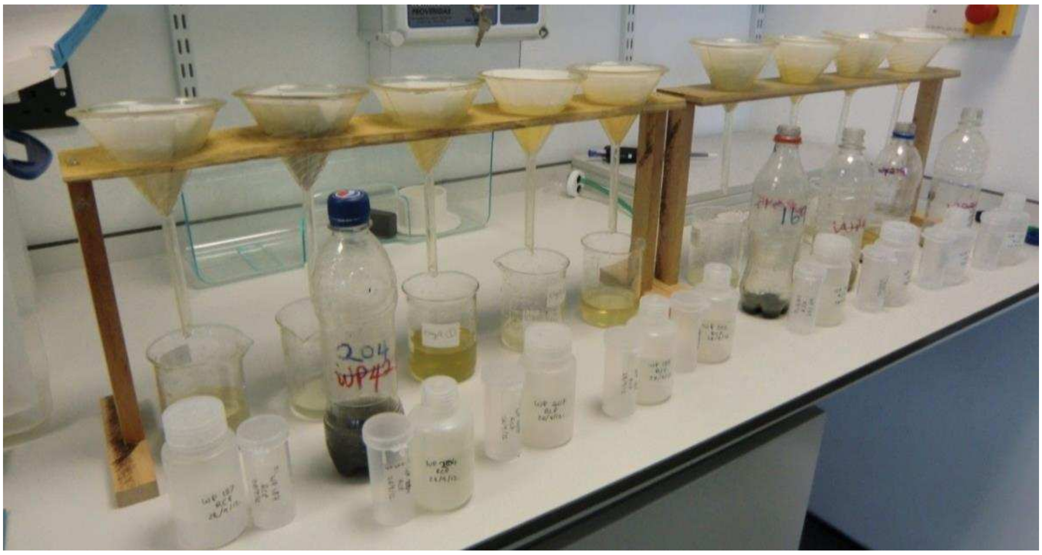


Plate 4.2 Filtration process and equipment

All water samples were filtered and frozen within 24 hours to ensure that any degradation of the chemical components was limited, particularly as the samples were not preserved by any additional chemical treatment.

Chemical analysis and analytical equipment

Water samples were collected and analysed using portable infield probes for electrical conductance (EC) (µs) [Hanna HI 98312], and hydrogen-ion concentration (pH) [Hanna HI 98127]. Major cations, such as sodium (Na^+) and potassium (K^+), and plant nutrients, such as nitrates and nitrites in the form of total oxidised nitrogen (TON), ammonia (NH_3), and phosphate (PO_4), were analysed using dedicated lab-based analytical equipment as itemised below.

Burkard Series 2000 automatic chemical analysers (auto-analyser) were used to quantify TON, NH_3, and PO_4. The three chemical parameters were analysed simultaneously, based upon the setup indicated by Moody (2000).

Because the water samples were obtained from the sand dune aquifer, and the fact that the dune systems were formed by accretion rather than windblown sand onto a nearby landmass, there was an element of brackishness to the water samples, and this was confirmed by using an electrical conductivity meter [Hanna HI-98312] to compare the groundwater to that in the River Stour (freshwater source) and to seawater (English Channel). Hydrological analysis confirmed that the dune systems are classed as brackish, as the salinity levels ranged between 154 - 279 mg/l NaCl, compared to surface sample waters taken from the River Stour/ditch which ranged from 73 – 361 mg/l NaCl and the Sea water which ranged between 4320 – 8156 mg/l NaCl.

The Burkard series 2000 auto-analyser can be used to analyse both fresh and salt water: however the methods are slightly different in orientation and sometimes require different reagents (Moody, 2000). As the groundwater could be classed as having a saline content, it was decided that the procedure would be undertaken using the estuarine methodology to analyse the water samples from the dune system (Moody, 2000).

A Jenway Model PFP7 flame photometer was used to measure sodium chloride (NaCl) and potassium chloride (KCl) levels, in accordance with the guidelines indicated by Jenway (2008).

Vegetation ordinations

Two main data sets were used in the ordination: species recorded during NVC quadrat analysis, and the hydro-chemical data gathered from the dipwells. Direct gradient analysis is known as environmental ordination, while indirect gradient analysis is known as vegetation ordination (Kent, 2012). Analysis of the vegetation was undertaken using the software package *Primer 6* [Version 6.1.2] to examine the ecological data, and in particular the relationships between orientated species quadrats and the related NVC types. Observing the variation in species composition related to variations associated with environmental/biotic factors (Kent, 2012).

Primer 6 was used to create similarity indices, which allowed for the interpretation of botanical data by creating resemblance matrices that showed the relative similarity between quadrats in terms of species composition. The two main approaches employed were Analysis of Similarities (ANOSIM), and non-metric multidimensional scaling (nMDS).

ANOSIM is a non-parametric analysis, similar to multivariate analysis of variance, such as MANOVA, which analyses the differences between environmental data that are paired with species data (Kent, 2012). The nMDS analysis is an ordination method that, depending upon the data analysed, will show how similar samples or environmental variables are to each other. This is shown in graph form and is expressed as distance between points. When analysing species data, the emphasis is on how similar species compositions are to each other, and therefore the index used was Bray and Curtis similarity. When analysing chemical data, the index used was Euclidean distance.

The nMDS ordinations take into consideration the best possible fit of the data within a given number of dimensions by displaying a stress value. The stress value indicates how difficult it was to display the analysis in two or more dimensions. Stress values of ≥0.30; indicate an unreliable representation of the data.

Results and discussion

4.6 Geographical analysis results and discussion

Probability ellipses

Comparisons between 2012 and 2013 showed that there was a change in NVC classification at some of the dipwells. When reviewing the combined NVC classifications, there did appear to be an overall trend towards increasing eutrophication and higher moisture levels in the quadrat samples over time (Figures 4.6 and 4.7). Analysis of the probability ellipses was undertaken using a contingency table chi-squared test, using counts of the number of quadrat occurrences within rows (Ellenberg N) and columns (Ellenberg F), as specified by Zar (2010). Table 4.4 displays the results from the r x c contingency table chi-squared analysis.

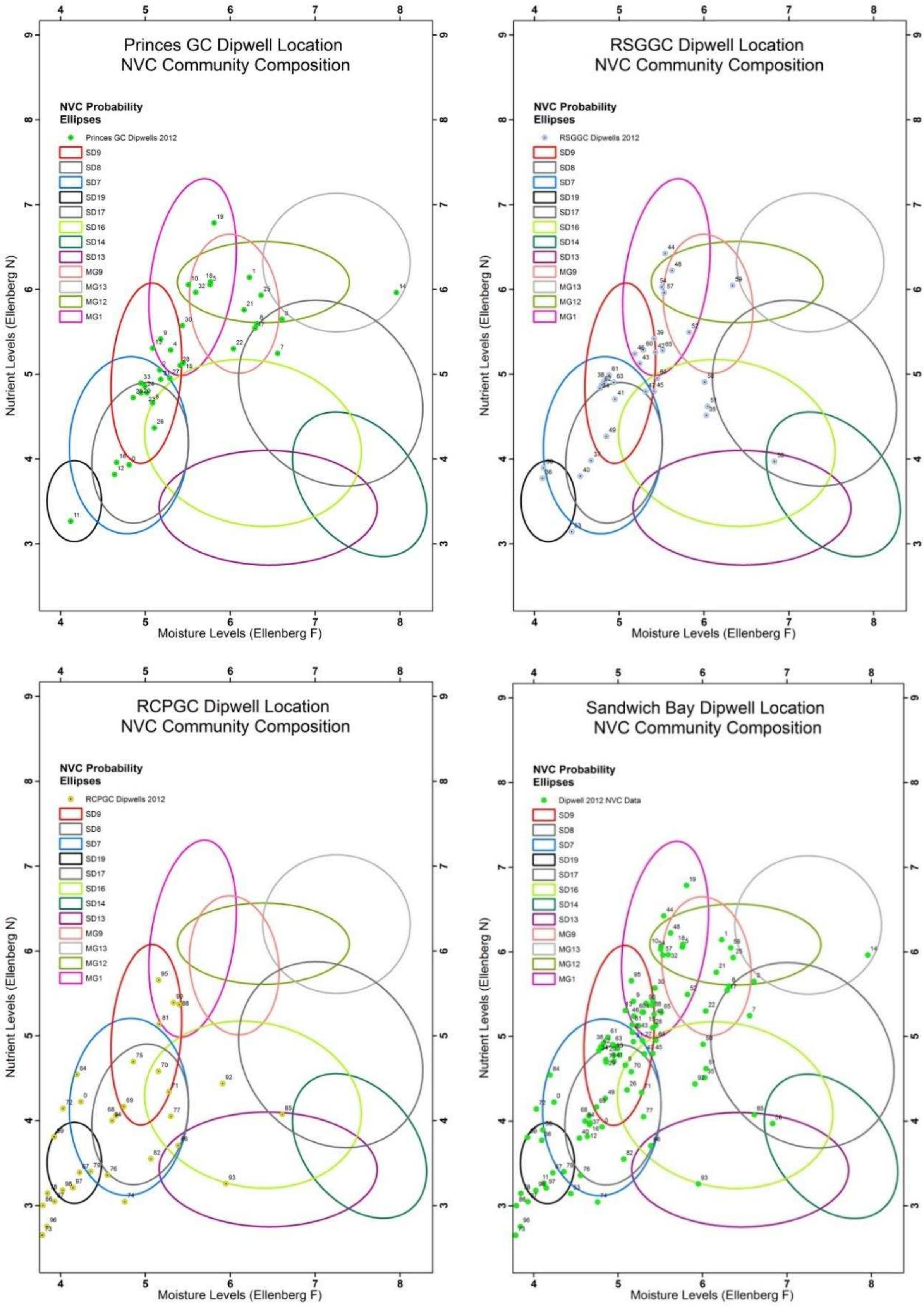


Figure 4.6 Probability ellipse results for dipwell quadrats recorded in 2012, at each golf course and combined (numbers identify dipwell label)

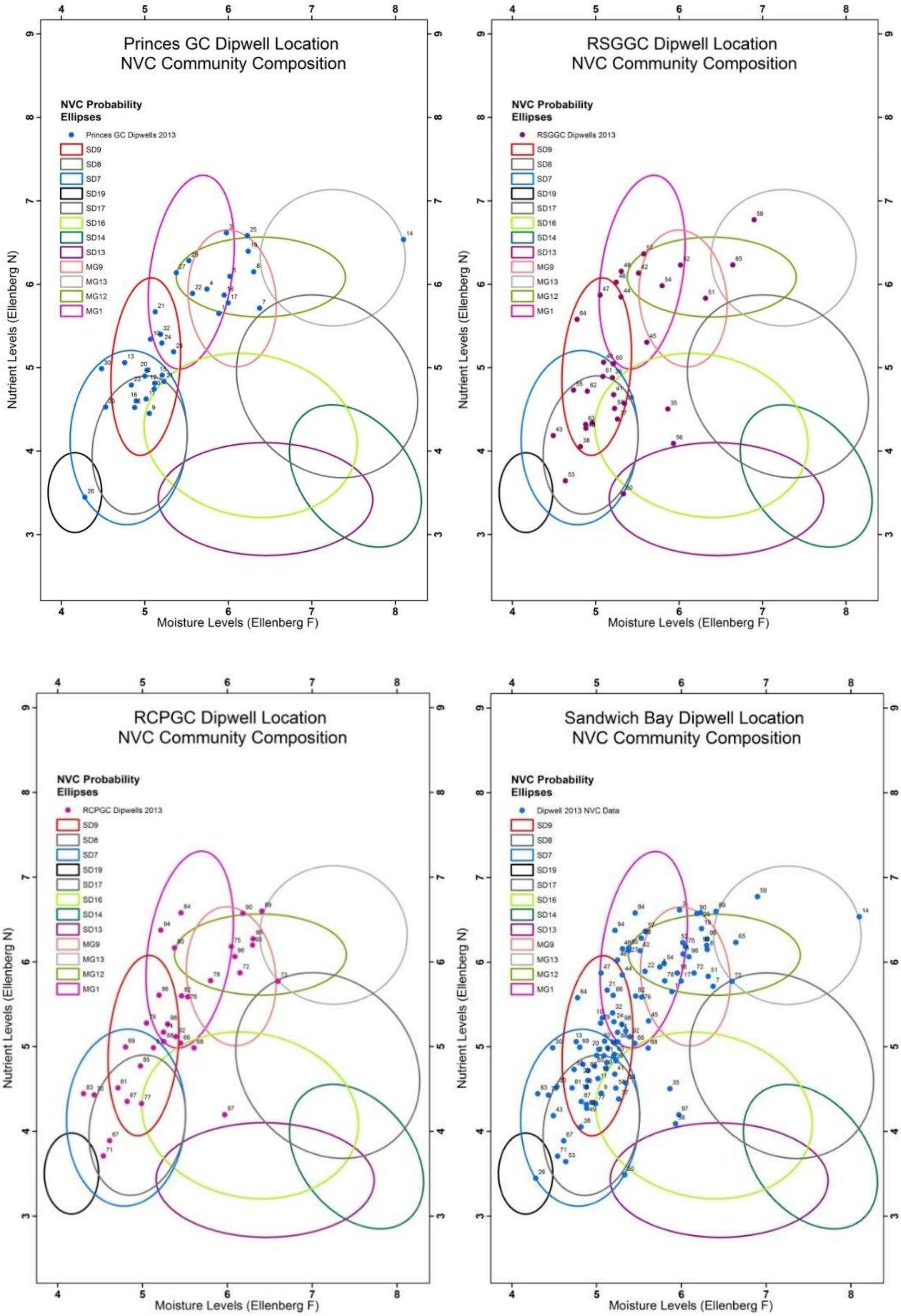


Figure 4.7 Probability ellipse results for dipwell quadrats recorded in 2013, at each golf course and combined (numbers reflect dipwell label)

To test the null hypothesis that there was no significant relationship between vegetation colonisation and water availability, an r x c contingency table chi-squared analysis of quadrat ordinations was performed to test the null hypotheses, specific to this statistical test:

H_0: there was no independence between Ellenberg F (moisture) gradient for moisture between years, in relation to quadrat ordinations

H_0: there was no independence between Ellenberg N (nutrient) gradient for nutrients between years, in relation to quadrat ordinations

Table 4.4 showed that there was a statistical difference between the years 2012 and 2013 for Ellenberg F, at each of the golf courses when analysing the data sets independently based upon site. The null hypothesis could therefore be rejected, as there was a significant difference between years for Ellenberg F, which affected NVC classifications based upon vegetation analysis. The combined analysis for Sandwich Bay however, did not show a significant difference between the years 2012 and 2013, therefore accepting the null hypothesis, when observing combined Ellenberg F results.

Table 4.4 r x c contingency table chi-squared analysis of quadrat ordinations between years 2012 and 2013, against Ellenberg F and N gradients

Location	Ellenberg	df	α level 0.05	χ2 value
Princes GC	F	1	3.841	18.555*
Princes GC	N	2	5.991	1.301
RSGGC	F	1	3.841	16.757*
RSGGC	N	2	5.991	0.914
RCPGC	F	1	3.841	15.587*
RCPGC	N	2	5.991	19.645*
Sandwich Bay	F	2	5.991	5.149
Sandwich Bay	N	3	7.815	20.817*

If χ^2 < α-value then accept the null hypothesis
If χ^2 > α-value then reject the null hypothesis (significant chi-squared values *)

Contingency table chi squared analysis showed that RCPGC is the only location that demonstrated a significant difference between nutrient values (N) over the two years. The combined quadrats for all of the golf courses showed that there was a significant difference between years and nutrients (N), but not between year and moisture (F). This may be due to the fact that chi-squared analysis does not permit directional variation, as each golf course showed significant differences when analysed individually, but not when analysed as a combined data-set.

Figure 4.8 shows the change in NVC vegetation composition observed at Princes Golf Course between the years 2012 and 2013. Although there were some quadrats in the ordination that had improved in species composition towards more diverse swards, the overall estimated trend in species change indicated that there was an increase in nutrients and moisture, i.e. a change towards generalist homogeneous strands , based upon quadrat ordination analysis.

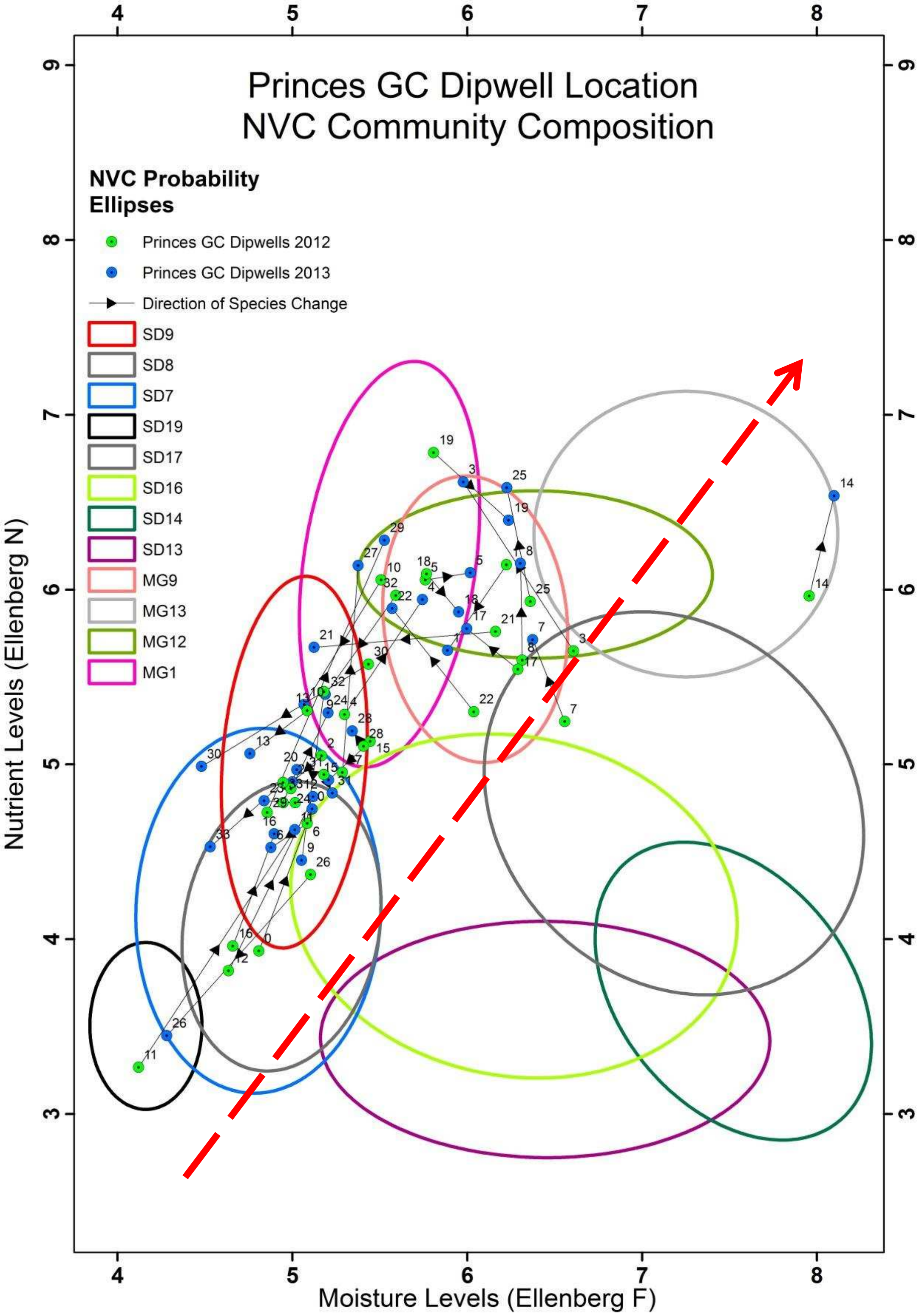


Figure 4.8 Trajectory analysis of combined probability ellipse results for the years 2012 and 2013 at Princes Golf Club (large red dotted arrow indicates the observed trend)

The ordination analyses were used to construct a vegetation composition frequency chart and this, together with the historic NVC data relating to the dipwell locations, allowed for comparisons between the different time periods, (Figure 4.9). The figure displays the change in vegetation compositions over time from neutral dry (MG1 *Arrhenatherum elatius*) to wet neutral (MG12 *Festuca arundinacea* and MG13 *Agrostis stolonifera – Alopecurus geniculatus*) grassland, and this was particularly apparent once it was realised that the MG13 species composition had appeared for the first time in 2012, and increased in frequency by 2013. There was an increase in SD8 vegetation composition observed between survey years 2012 and 2013.

However, it was noted that using observations from differing time periods, particularly where there had been extended periods of time between surveys, meant that it could be difficult to draw reliable conclusions about the extent of vegetation change.

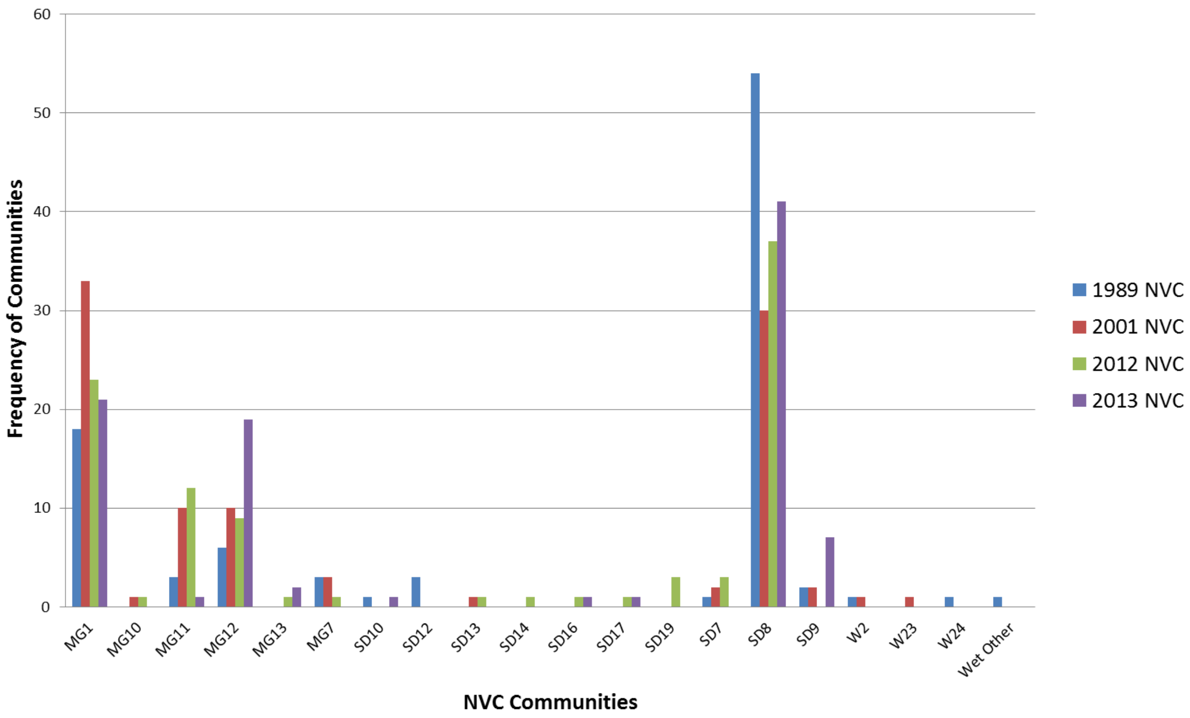


Figure 4.9 Bar chart showing the frequency of NVC classifications recorded within 1 m distance of the dipwells

Meteorological analysis

When attempting to assess the change in vegetation communities, it proved difficult to pinpoint exactly when the change in vegetation composition started, particularly as it is unknown whether this progression at Sandwich Bay had begun before the 1989 survey. It is, however, possible that the observed change has been predominantly driven by the increased amount of precipitation in the intervening years since the 1989 survey (Figure 4.10), so to evaluate this possibility, historical meteorological data were investigated. This data were obtained from the Met Office website (Met Office, 2014) and provided records of precipitation rates and sunlight hours either side of the surveys undertaken at Sandwich Bay, as can be seen in Figure 4.10.

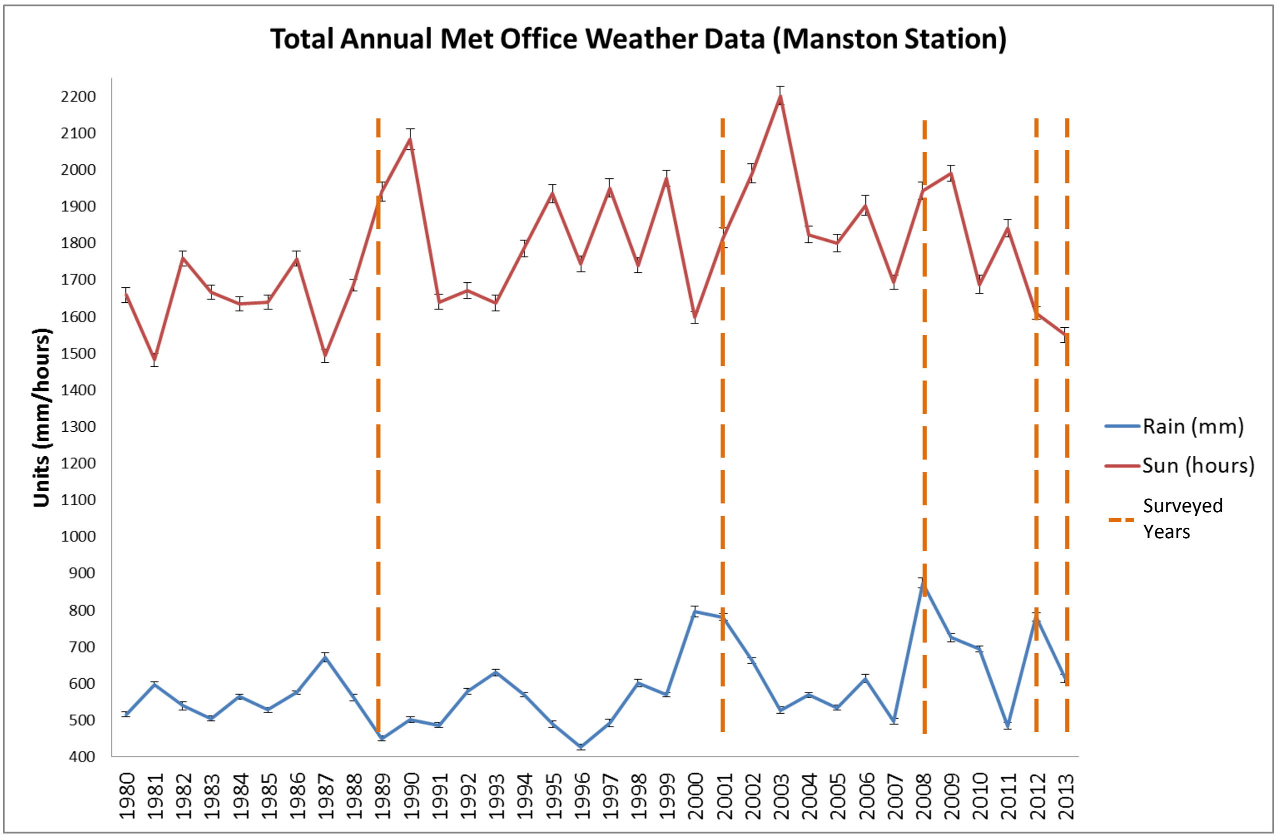


Figure 4.10 Total annual meteorological data from 1980 – 2013, recorded at Manston weather station, Thanet (data obtained from Met Office, 2014)

Comparisons between the vegetation communities (Figure 4.9) and the meteorological data obtained from the Met office (Figure 4.10) indicated that, prior to the 1989 survey undertaken at Sandwich Bay, the average annual precipitation between the years 1980 – 1988 was approximately 562.2mm. However in the 1989 survey year the total annual precipitation was 450.5mm, the second lowest annual rainfall between the years 1980 – 2013. This can be compared to the survey undertaken in 2001 where the total annual precipitation was 781.4mm. The increased amount of precipitation in the intervening years between 1989 survey and the 2001 survey will have contributed towards the increased frequency of more competitive dry and wet neutral grasses, such as MG1 *Arrhenatherum elatius* (dry neutral grassland), MG11 *Festuca rubra–Agrostis stolonifera–Potentilla anserina* (grassland) and MG12 *Festuca arundinacea* (wet neutral grassland), resulting in the inevitable loss of diverse vegetation types, such as SD8 *Festuca rubra–Galium verum* (fixed dune grassland).The total annual precipitation for the years 2012 (782.5 mm) and 2013 (614.1 mm), indicates that there is an total annual average rainfall increase of 275.5 mm of rainfall, based upon the combined total average rainfall during the survey years 2001, 2012 and 2013, compared to the total rainfall during the 1989 survey year.

This would have resulted in a natural progression of change in vegetation cover, based upon available water in the dune system, selecting for broader more competitive species. These findings were confirmed in the 2008 survey undertaken at Royal St George's golf club (Dargie, 2009), where there had indeed been a continual trend of increased moisture in the dune systems based upon vegetation analysis.

According to the research undertaken by Tilman (1993), decreased availability of light could also have contributed to a decrease in vegetation diversity. The meteorological data indicates that there is a continuing trend in the increase of both sunlight hours and rainfall, over the period from 1980 – 2013, suggesting that the amount of available water within a system is the driver for change in plant species composition.

The later surveys, undertaken in 2012 and 2013, indicated that there had been a gradual increase in desirable vegetation communities, such as SD8 *Festuca rubra–Galium verum* (fixed dune grassland), and over the same time-period there was also a successional change from dry neutral grassland (MG1) to wet neutral grassland (MG12 and MG13). This indicated that, although there has been a reversion of MG1 to SD8, there has also been a successional change from MG1 to MG12. However, Tilman (1987 & 1993) stated that species richness is dependent upon both the amount of organic material in soils and the available light, and these factors have a greater impact upon species heterogeneity than the amount of moisture in the system. However, the r x c contingency table Chi-Square analysis indicates that the varying amount of moisture in the system does in fact have an impact upon vegetation composition at Sandwich Bay.

Observations from the meteorological data collected from Princes Golf Club, seen in figure 4.10, indicate relative constancy in the water table height under stable meteorological conditions (Figure 4.12). More extreme weather conditions, as recorded in the spring of 2014, affected localised areas (surface flooding) on the golf course, and this may have implications for long-term change in vegetation, such as increased acidification from surface precipitation (Jones, 2009). Pearson's correlation coefficient was calculated on the meteorological data and water table heights, and it was found that the only significant correlation was between temperature and water table height (r^2 = 0.709, P = 0.010).

One of the proposed questions from Dargie's report (2009), was whether an increase in sea level was responsible for the observed increase in moisture levels and the observed change in vegetation, or was the amount of precipitation the determining factor? This was investigated using Pearson's correlation coefficient calculated on the dipwell water sample chemical data. It was found that there was a significant correlation between NaCl and the water table height ($r^2 = 0.221$, $P = 0.039$). Further analysis using a Mann-Whitney U test showed there to be a significant difference ($P < 0.001$), in both mean NaCl and mean water table height, between SD and MG communities. However analysis of the meteorological data indicated (Figure 4.10) that an increasing amount of rainfall over successive years would lead to an increase in the flow of fresh water into the dune system, reducing the salinity levels in the groundwater. Table 4.5 shows the variability between water samples collected from the dipwells, freshwater sources and the sea, indicating that precipitation/freshwater gradient has possibly contributed to the reduction in salinity within the dipwells.

Table 4.5 Seasonal NaCl concentrations

Sample (NaCl mg/l)	Summer 2012	Autumn 2012	Winter 2012	Spring 2013	Summer 2013	Autumn 2013	Winter 2013	Spring 2014
All Dipwells Average	208.79	237.82	279.19	179.90	178.78	183.09	165.37	154.10
Sea water	6402.92	5394.91	8156.04	6152.94	6065.46	6240.43	5890.49	5043.31
River Stour	-	-	361.45	220.43	165.15	267.99	177.90	192.49
RSGGC Ditch	-	-	289.16	73.48	115.61	76.57	197.67	77.00

This indicated that although the recharge of the water table is affected by precipitation, saline incursion or freshwater influx from the River Stour had a significant effect on the species composition residing in close proximity to the water table. Gradual sea level rise will result in an increase in the water table levels within the dune system, however coastal accretion will reverse this process (Clarke & Sanitwong Na Ayuttaya, 2010); therefore the dry fixed dune species found at Sandwich Bay should be able to persist within the environment, as long as the coastline is accreting. Figure 4.11 illustrates the water cycle observed at Sandwich Bay.

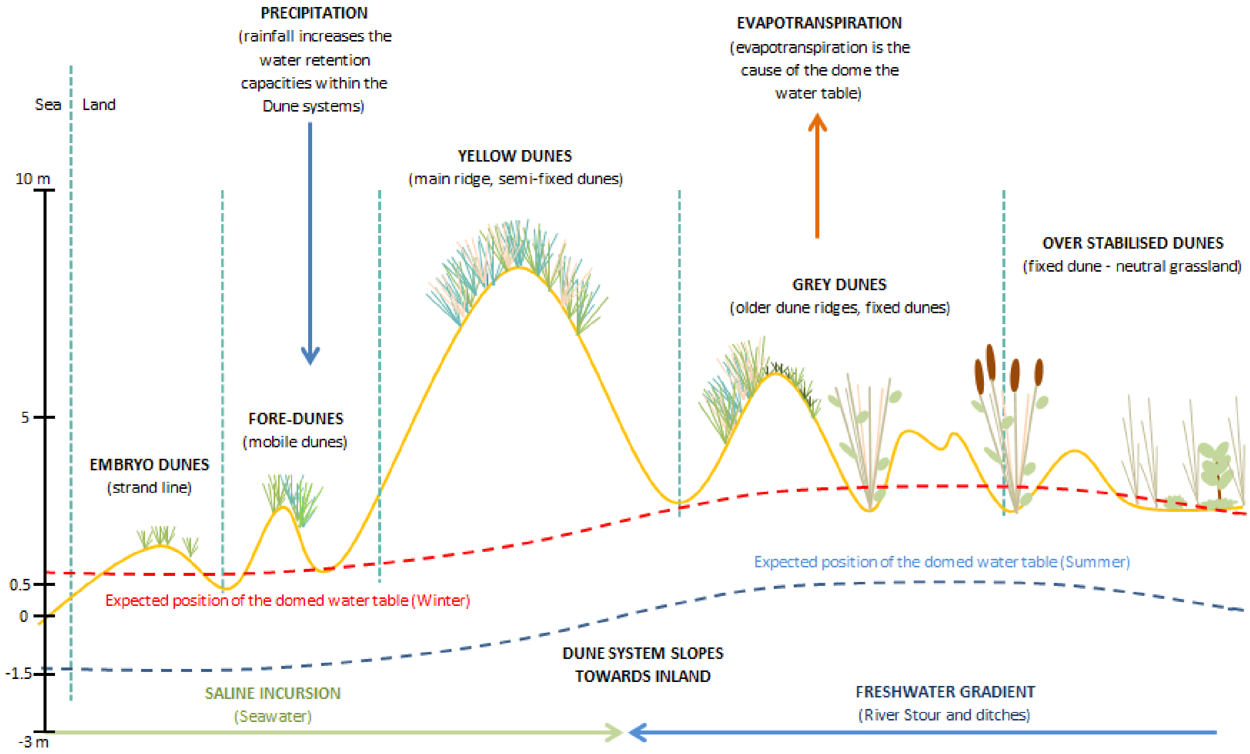


Figure 4.11 Water cycle observed at Sandwich Bay cross-section

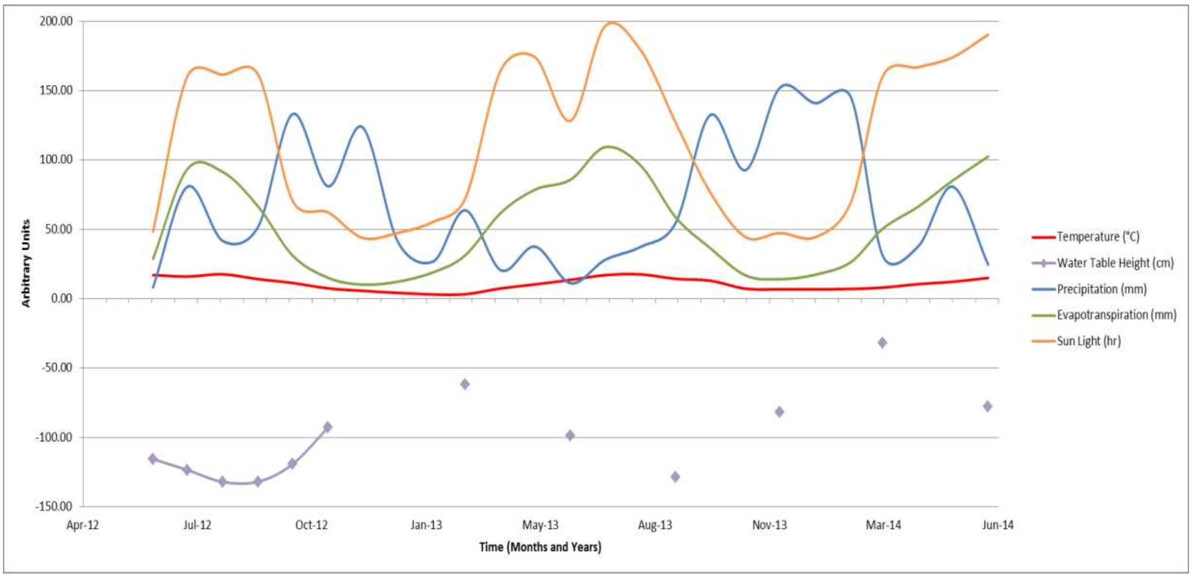


Figure 4.12 Princes Golf Club weather station data. Total monthly precipitation, temperature and evapotranspiration rates, mean temperature, and water table height at dipwells, for the duration of the study (June 2012 – June 2014)

LiDAR analysis

The dune system at Sandwich Bay is the result of an accreting coastline and appears to be highly mobile. As a result, elevation was considered to be one of the key factors required to quantify the vegetation dynamics at Sandwich Bay.

Two different LiDAR timeframe datasets were available for the project for the years 2010 and 2013. Comparisons between the two years indicated that there were quantifiable fluctuations between the two different LiDAR timeframes (Figure 4.13). However limitations in the available LiDAR data meant that the only vegetation dataset which could be compared against LiDAR with accuracy was the 2013 NVC dataset.

Analysis of DTM LiDAR data was undertaken using the raster calculator in the ArcGIS toolbox, by overlaying the elevation data and subtracting the newest dataset from the older dataset. This created a loss-and-gain elevation raster image, which can be seen in Figure 4.13.

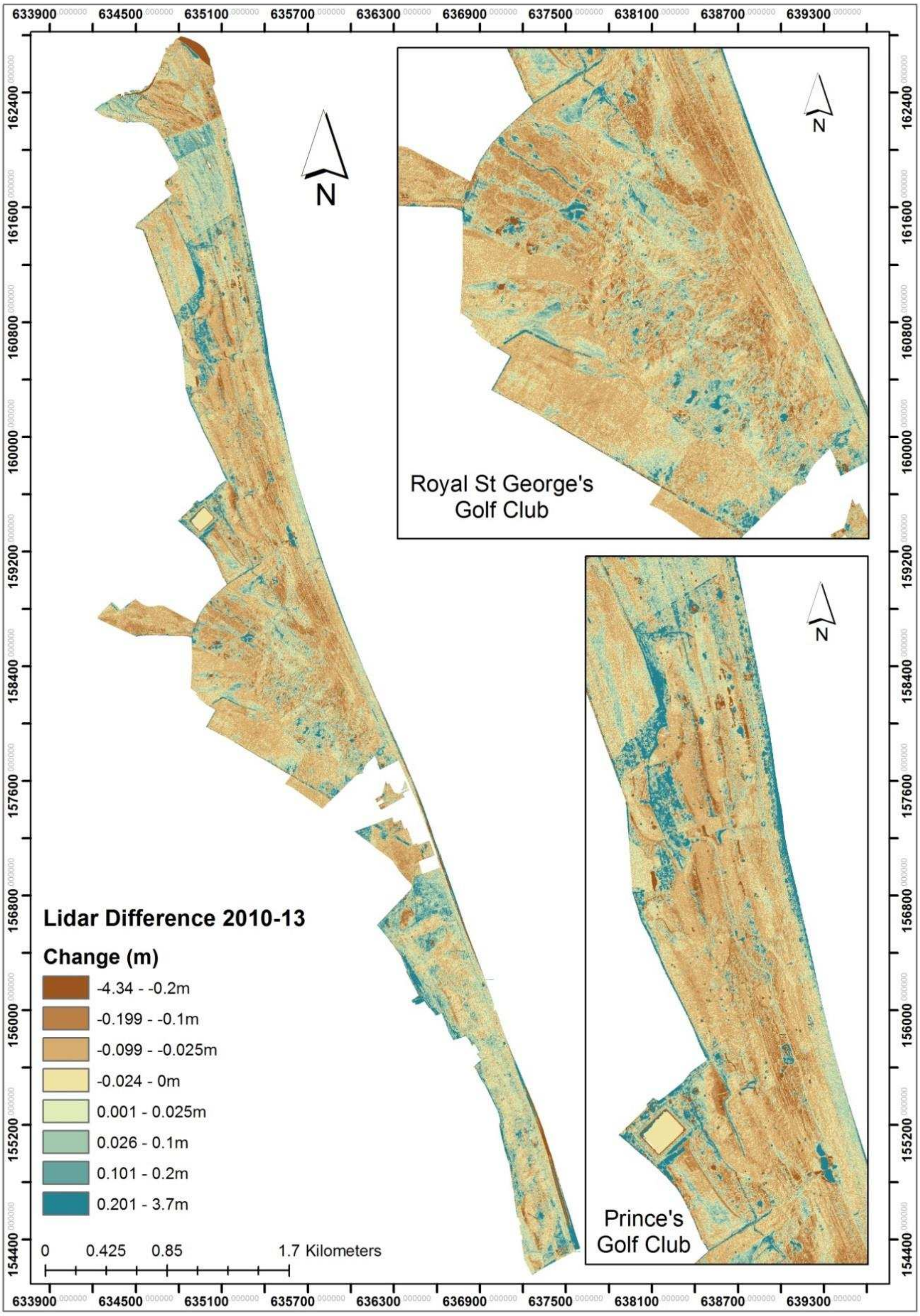


Figure 4.13 Cartographic analysis of LiDAR elevation data between the time periods of 2010 and 2013 (raw data supplied by the Environment Agency Geomatics group)

The 2013 dipwell location based NVC survey classifications were simplified by removing NVC sub-classes: for example SD8a and SD8b were amalgamated as SD8. Differences in elevation height for these amalgamated classifications was then analysed using a Kruskal-Wallis test. Classifications that had fewer than 3 NVC replicates per survey year were omitted from the analysis (Zar, 2010). For completeness a box and whisker plot depicting elevation of all classifications recorded in 2013 was also plotted (Figure 4.14).

There was a difference in elevation between the SD and MG classifications used in the analysis (Figure 4.15), and a Kruskal-Wallis test found this difference to be significant (p = 0.005).

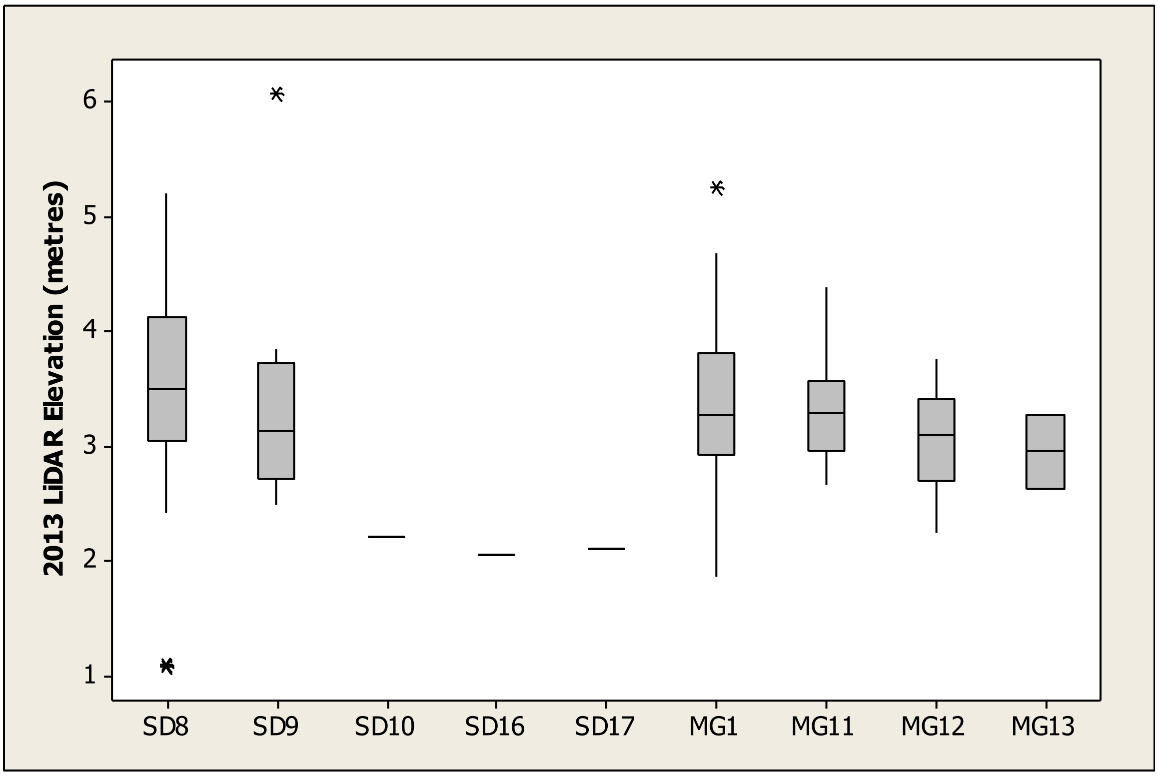


Figure 4.14 Box and Whisker plot showing all NVC types, recorded in 2013 (height derived from Newlyn OS datum)

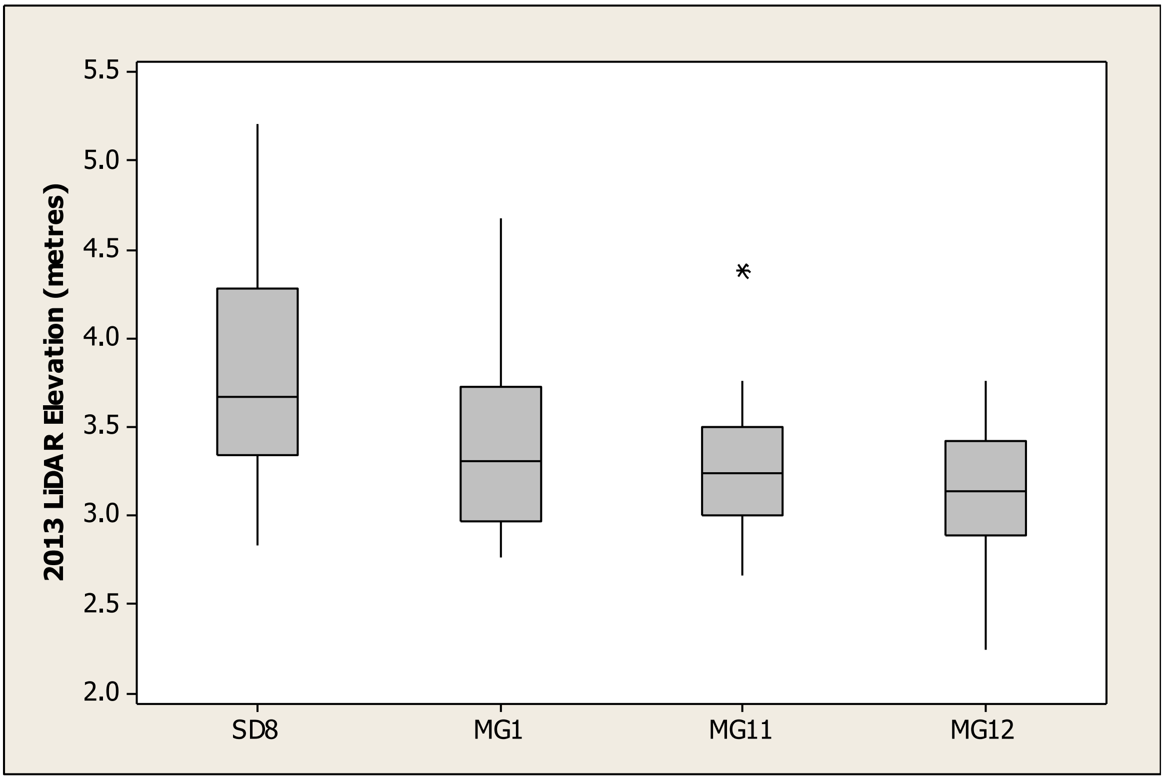


Figure 4.15 Box and Whisker plot showing ≥3 NVC replicates for 2013

4.7 Hydro-chemical analysis results and discussion

Spatial hydrological analysis

Water infiltrates the sand dune complexes at Sandwich Bay from three main sources: freshwater from precipitation, fresh/brackish water from the River Stour, and saline influx from the English Channel. Although the groundwater is brackish, its proximity to the River Stour and the dune topography means that there are large seasonal fluctuations in sodium chloride (NaCl) readings.

The spatial elements of these chemical interactions were investigated using Pearson's correlation coefficient, which was calculated on the average physico-chemical values for each dipwell water sample, and the 2013 LiDAR data and dipwell proximity to the mean high tide mark (according to LiDAR). The results of the spatial chemical analysis can be seen in Table 4.6.

Table 4.6 Spatial correlation analysis of combined physico-chemical values

Physico-chemical	**Dipwell**	**LiDAR DTM Height**	**Distance to high tide**
pH	(r^2 = -0.317) *P* = 0.003*	(r^2 = -0.022) *P* = 0.836	(r^2 = 0.249) *P* = 0.019*
NaCl	(r^2 = 0.101) *P* = 0.347	(r^2 = -0.272) *P* = 0.010*	(r^2 = 0.098) *P* = 0.363
KCl	(r^2 = -0.027) *P* = 0.806	(r^2 = -0.322) *P* = 0.002*	(r^2 = 0.115) *P* = 0.285
PO_4	(r^2 = -0.016) *P* = 0.881	(r^2 = -0.162) *P* = 0.133	(r^2 = 0.208) *P* = 0.052
TON	(r^2 = 0.052) *P* = 0.632	(r^2 = 0.321) *P* = 0.002*	(r^2 = -0.126) *P* = 0.242
NH_3	(r^2 = 0.096) *P* = 0.376	(r^2 = -0.089) *P* = 0.410	(r^2 = -0.026) *P* = 0.813
Water Table Height	(r^2 = -0.193) *P* = 0.072	(r^2 = 0.862) *P* = 0.000*	(r^2 = -0.142) *P* = 0.187

(Significant differences (< 0.05) are indicated with *)

Pearson's correlation coefficient analysis for the combined physic-chemical parameters measured for the duration of the study compared to spatial analysis, indicated that pH decreased, in a southerly direction across Sandwich Bay, while at the same time pH decreased from west to east towards the sea. NaCl and KCl concentrations both significantly negatively correlated with dune elevation, while TON concentrations were significantly positively correlated with dune elevation (Table 4.6).

IDW analysis identified several trends and patterns in physico-chemical conditions during the research time period. These trends and patterns can be seen in Figures 4.16 – 4.21, and the seasonal fluctuation of the water table can be seen in Figure 4.22.

Figure 4.16 displays the pH levels recorded throughout the duration of the study. This figure indicates that dune systems at Sandwich Bay are more alkali towards the Northern end of Sandwich Bay, for the quarterly survey periods' summer 2012 – winter 2013.

Figure 4.17 focuses upon sodium chloride (NaCl) levels. These maps showed several periods where high NaCl levels coincided with periods of low precipitation, such as that indicated during the summer of 2012. Figure 4.17 also indicates areas of Sandwich Bay that are most susceptible to saline incursion, such as those found towards the southern end of Sandwich Bay, at Royal Cinque Ports Golf Club, which was particularly apparent during the redevelopment coastal defences in Deal. In addition to this, it is possible to see the effects of the tidal surge of spring 2014, which flooded the northern end of Sandwich Bay at the upper end of Princes Golf Club and the nature reserve.

Figure 4.18 shows the seasonal variability of KCl. A significant drop in KCL at St Georges from spring 2013 to autumn 2013 coincided with a reduction in application of irrigation water abstracted from the river Stour. The other two golf courses either side of Royal St Georges did not alter their irrigation regime and showed no particular difference in KCl concentrations over the same time period.

Figure 4.19 show the total oxidised nitrogen concentrations. Course redevelopment involving extensive landscaping at Princes Golf Club led to an upwelling of nutrients between spring 2013 and summer 2013. Royal St Georges Golf Club has the highest dunes in Sandwich Bay, which is comparable with the IDW maps, indicating a pattern of higher TON at higher elevations.

Figure 4.20 shows the seasonal phosphate concentrations. Spatial analysis of Princes Golf Club between spring 2013 - autumn 2013 highlight several anomalies. For examples, two dipwells had their end caps removed which allowed for detritus and fauna (snails), to enter the dipwell. This also happened at a further three dipwells in autumn 2013 at Princes Golf Club. A particularly large spike in observed phosphate concentrations occurred during spring 2013 at the Northern end of Royal Cinque Ports Golf Club. This spike was due to re-establishment of pasture at Walnut Tree Farm, resulting in an application of phosphate to aid establishment of newly sown commercial grade grassland swards.

Figure 4.21 shows the seasonal ammonia concentrations. Ammonia concentrations indicated by the IDW maps indicate that during summer 2012 and spring 2014 ammonia concentrations were at their lowest across the whole of Sandwich Bay. Spatially the lowest ammonia levels observed were consistently within the confines of Royal St Georges Golf Club. The effects of agricultural practices opposite Royal Cinque Ports Golf Club can be seen from winter 2012 – summer 2013. For example, the effects of overwintering cattle in a single field with the addition of silage, was indicated by a high persistent concentration of NH_3 affecting the dune systems adjacent. There is also an uncharacteristic anomaly found at Royal St George's Golf Club, as direct result from agricultural practices.

Figure 4.22 shows water table heights. Analysis of the IDW maps confirmed that the dune systems at Sandwich Bay are classed as a dry sand dune system, with the water table consistently fluctuating between 1.5m – 3m below ground level. Spring 2013 was the driest period within the survey timeframe, with groundwater levels between 2m – 3m below surface level, while in contrast spring 2014 was the wettest quarter during research period with water levels exceeding 0.5m above ground level in some locations. This excessive amount of rainfall during spring 2014 affected all of the physico-chemical parameters recorded during the time period with the exception of potassium chloride and sodium chloride, which remained relatively constant throughout the time period.

The accuracy of water table measurements might be improved by the use of submersible data loggers, which can be left in situ and which will record the changes in water level, barometric pressure, and electrical conductivity, allowing an assessment of the salinity gradient at different tidal fluxes and as a result of seasonal change. At the start of this study submersible data loggers were not available, but towards the end of the study (June, 2014), the Centre of Ecology and Hydrology sponsored the installation of two data loggers at Royal St George's Golf Club, located at dipwells 46 and 50 (Appendix Three).

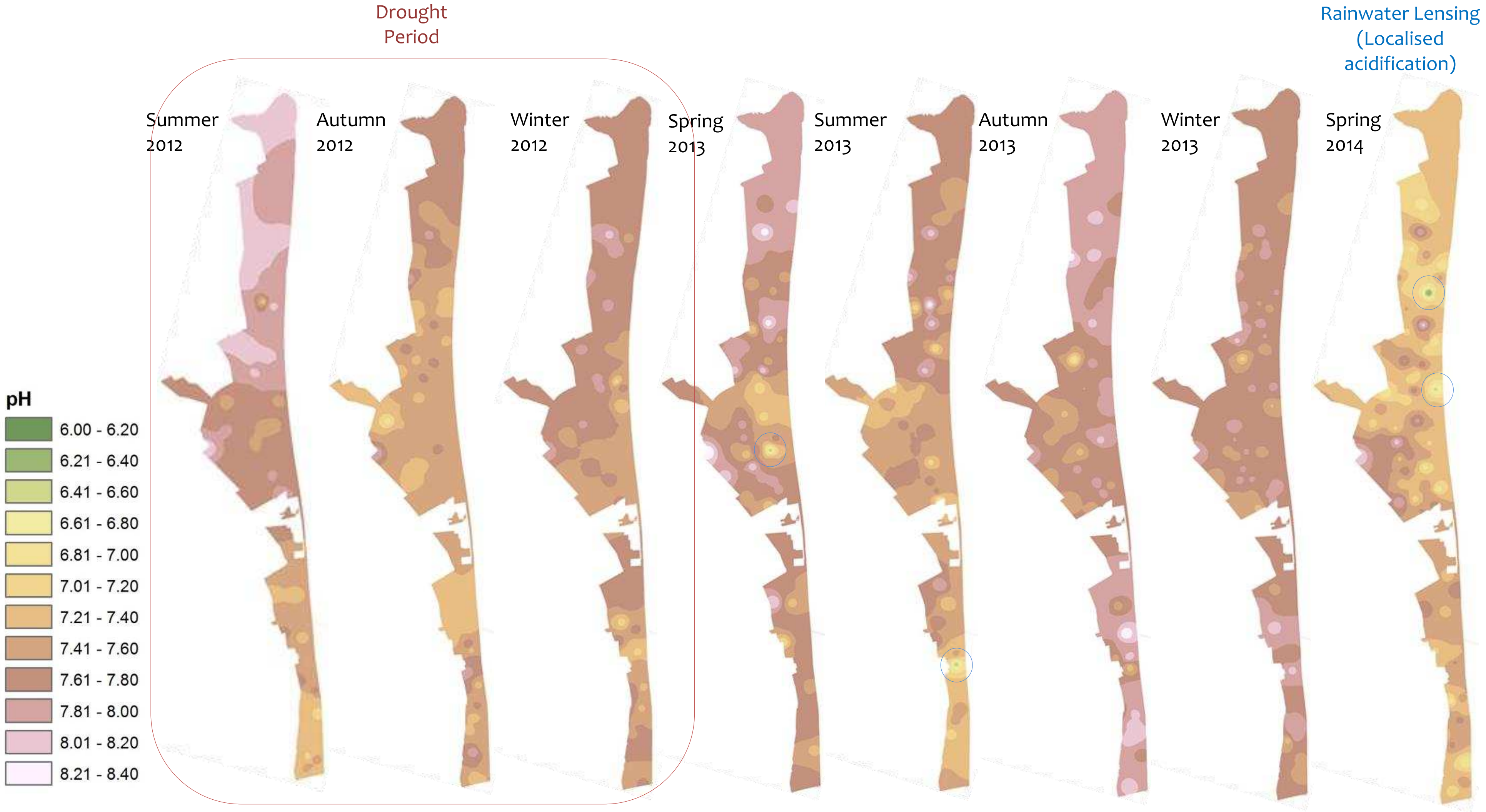
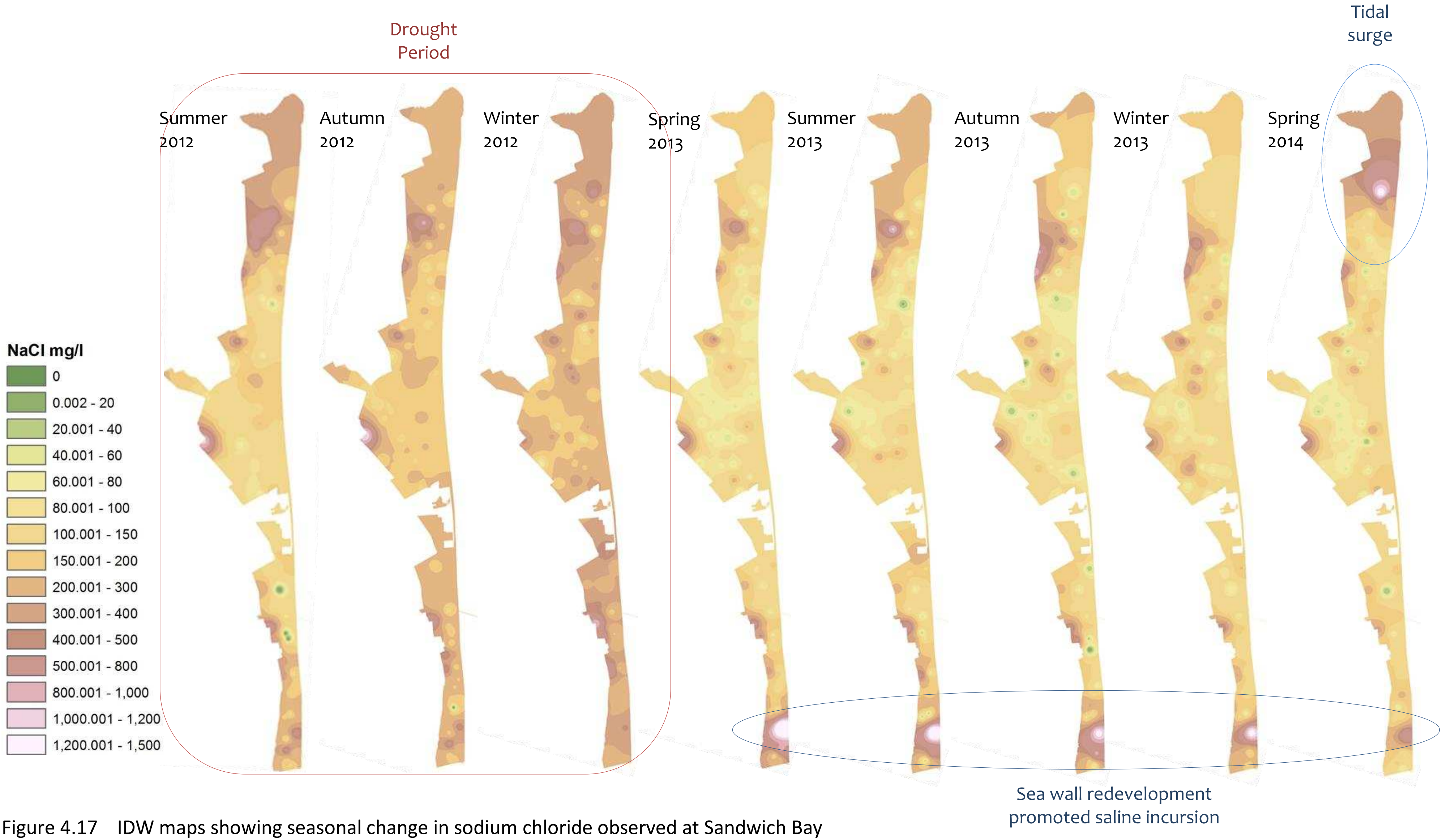


Figure 4.16 IDW maps showing seasonal change in pH observed at Sandwich Bay



Drought Period

Tidal surge

Sea wall redevelopment promoted saline incursion

Figure 4.17 IDW maps showing seasonal change in sodium chloride observed at Sandwich Bay

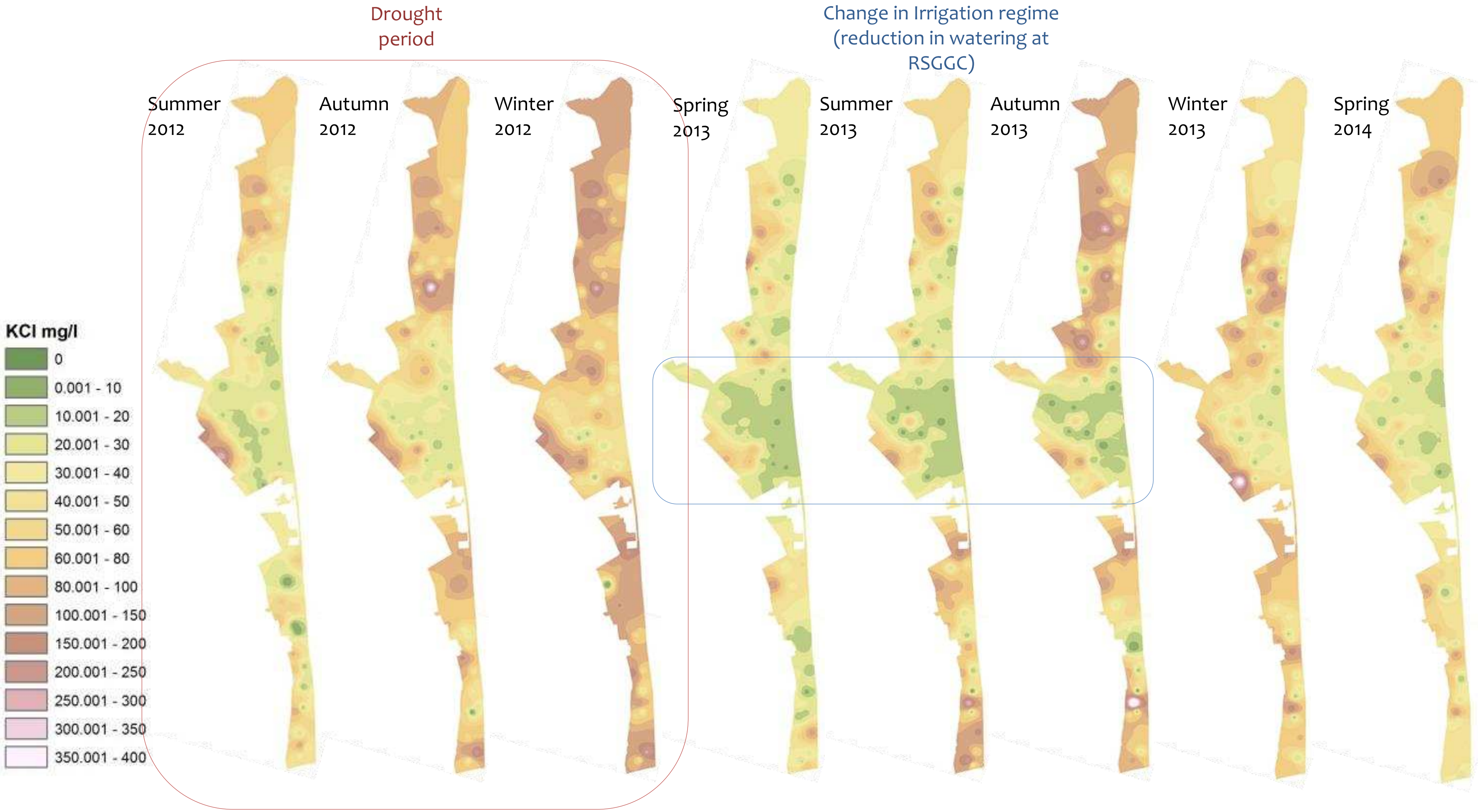


Figure 4.18 IDW maps showing seasonal change in potassium chloride observed at Sandwich Bay

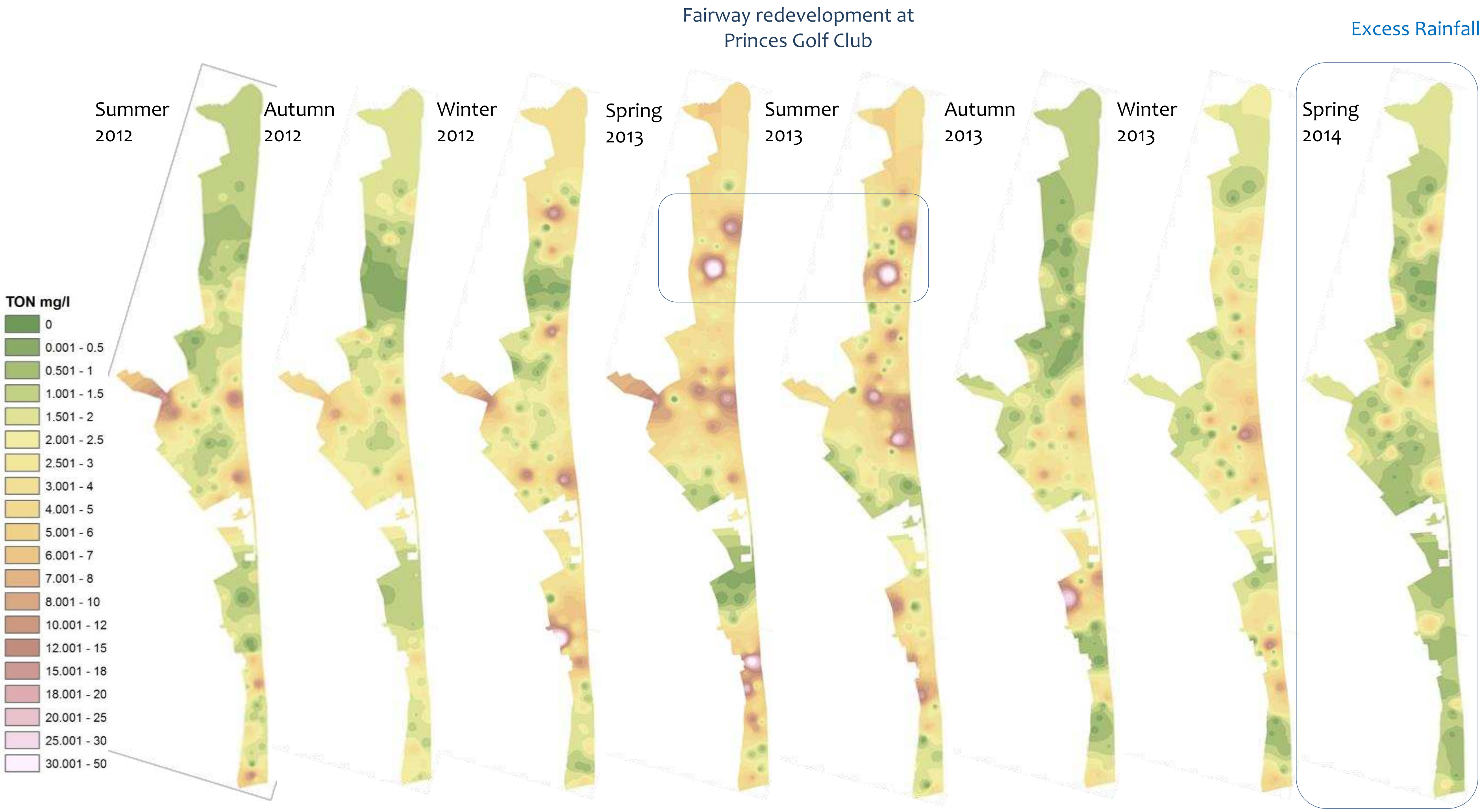


Figure 4.19 IDW maps showing seasonal change in total oxidised nitrogen observed at Sandwich Bay

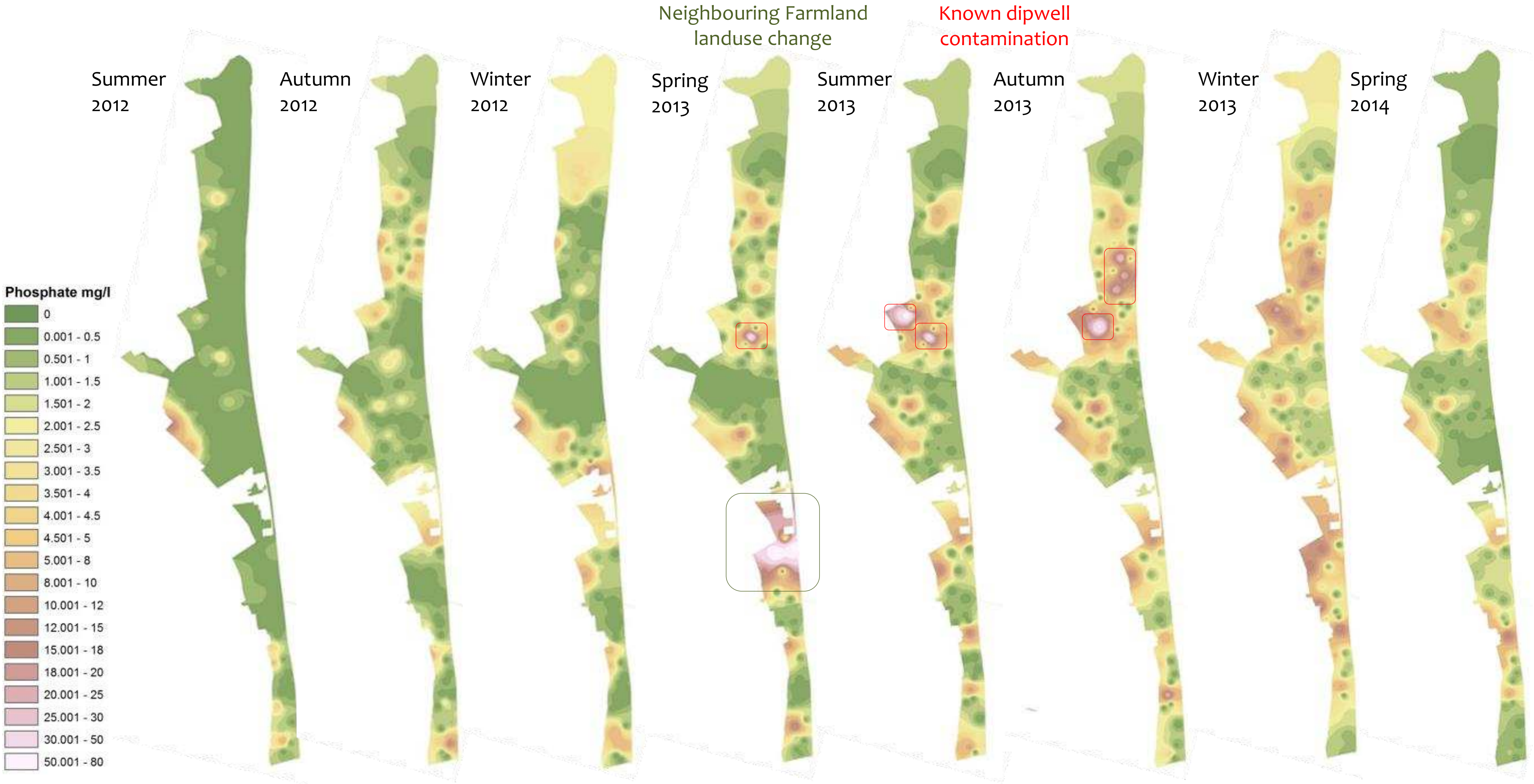


Figure 4.20 IDW maps showing seasonal change in phosphate observed at Sandwich Bay

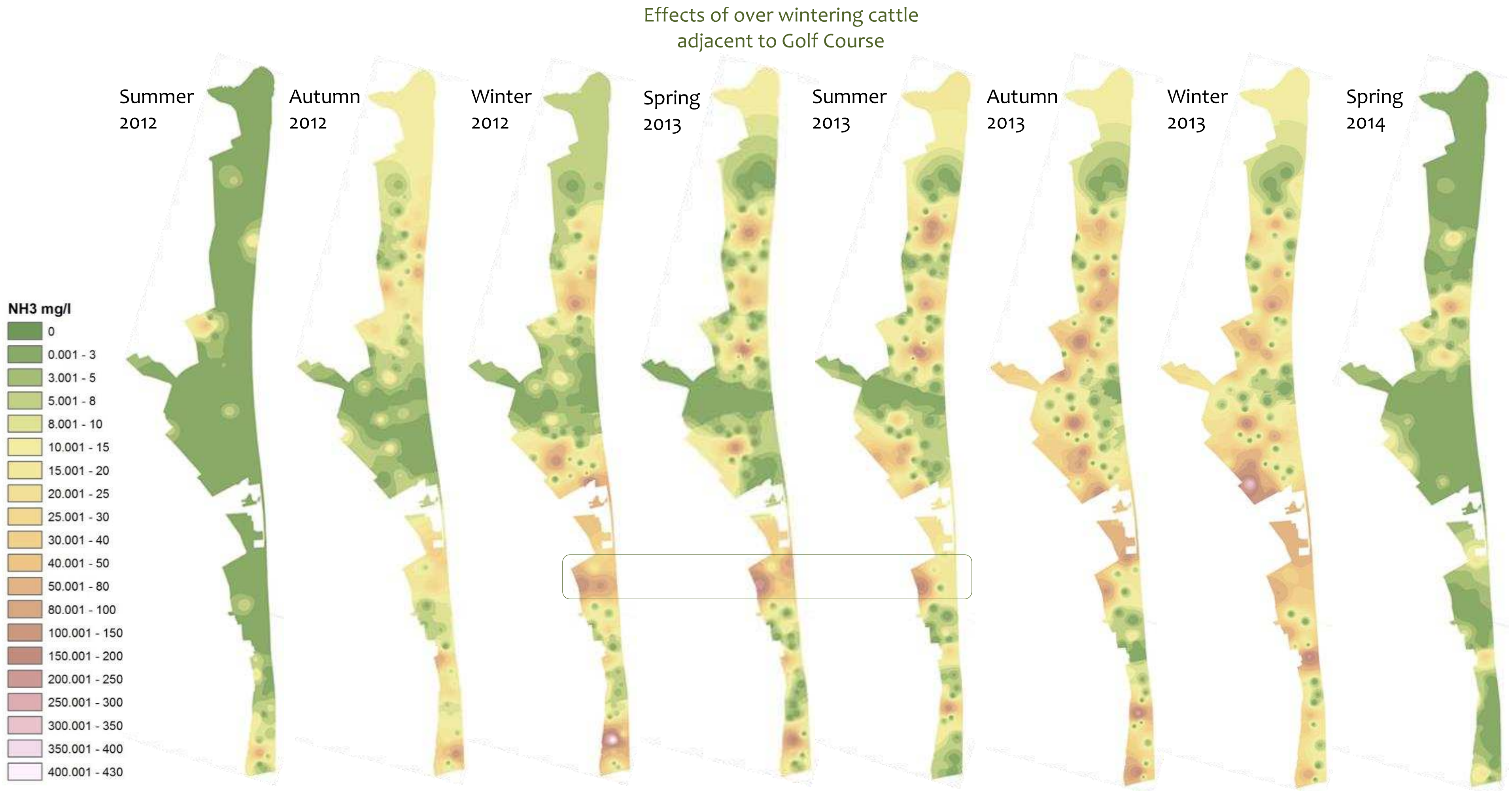


Figure 4.21 IDW maps showing seasonal change in ammonia observed at Sandwich Bay

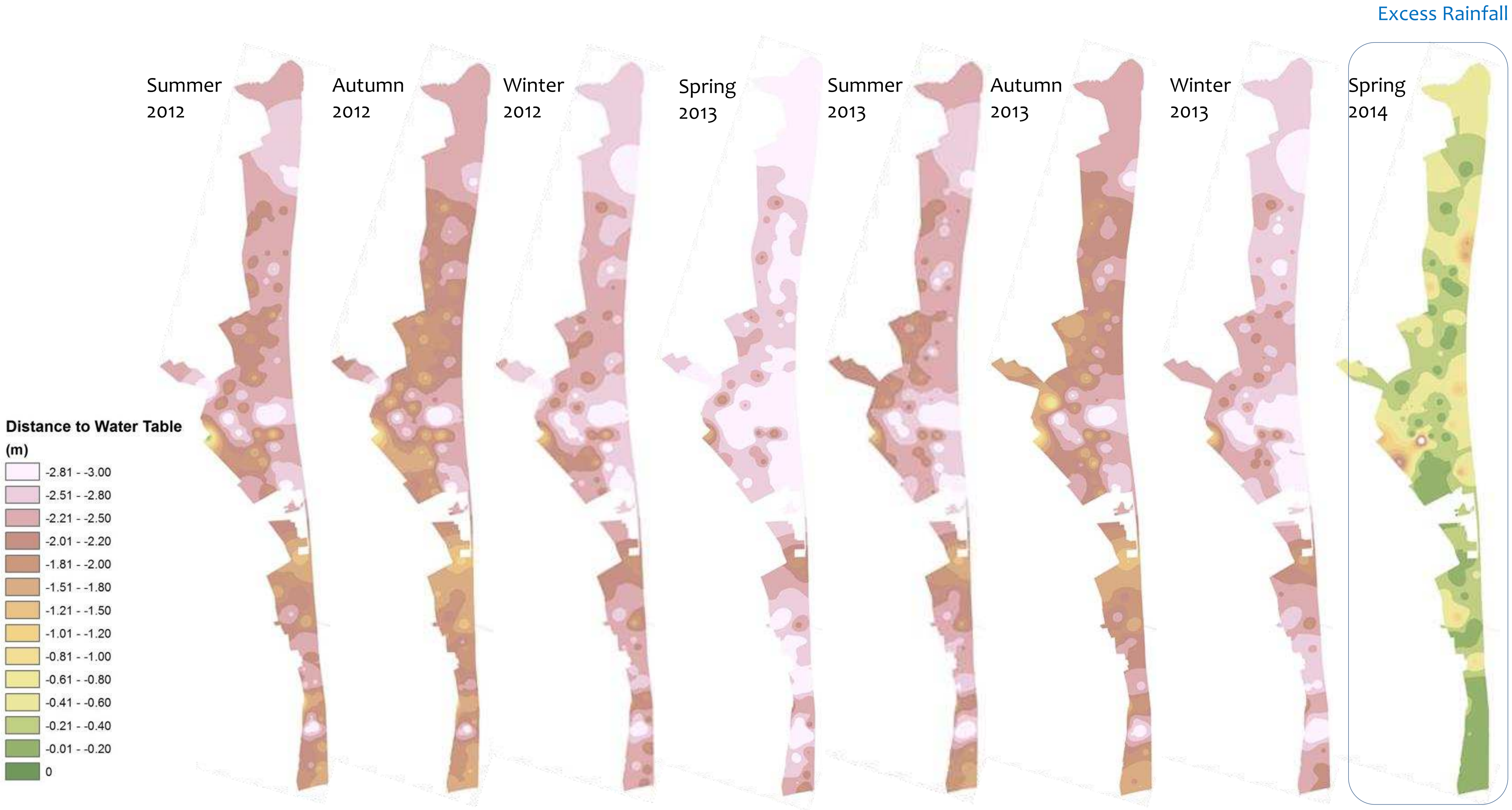


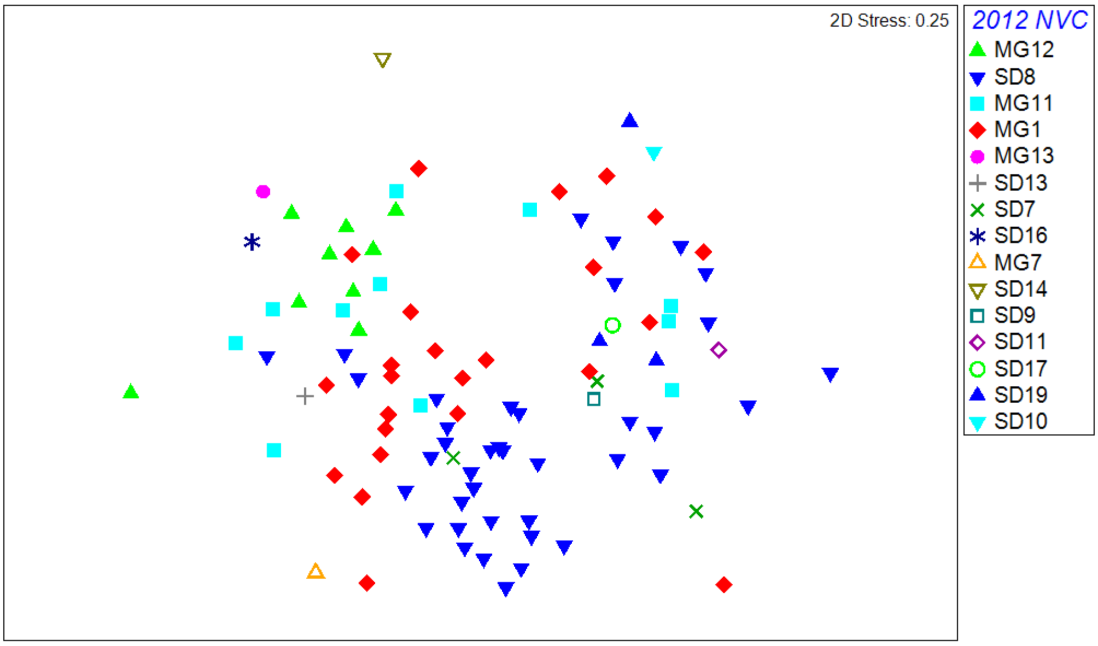
Figure 4.22 IDW maps showing seasonal change in the water table (distance to the water table from ground level), observed at Sandwich Bay

Vegetation description, analysis and quality testing of NVC

The ordinations for the 2012 and 2013 quadrats can be seen in Figure 4.23. This study focused on the changes between the NVC classes SD8 and MG1 vegetation compositions, and therefore separate nMDS ordinations were created to obtain Bray-Curtiss similarities between these communities and these can be seen in Figure 4.24.

Comparisons between the 2012 and 2013 nMDS ordinations, in Figure 4.24, indicated that there had been a change towards a more marked division between the two compositions. In 2012 there were some outliers, while in 2013 there was a distinct separation of the vegetation compositions.

Because the NVC system was developed for westerly areas of the UK, quality testing was carried out to validate the use of the NVC system in a south-east UK dune system. This analysis focused on SD8 and MG1 NVC communities. Bubble plots were produced to display the relationship between three specific indicator species indicative of the two NVC classification groups, based upon the 2013 NVC data: *A. elatius* to represent MG1, and *F. rubra* and *G. verum* for SD8 (Figure 4.25). Although there are overlaps in the ordination, there was distinct separation of species percentage cover between these classes.



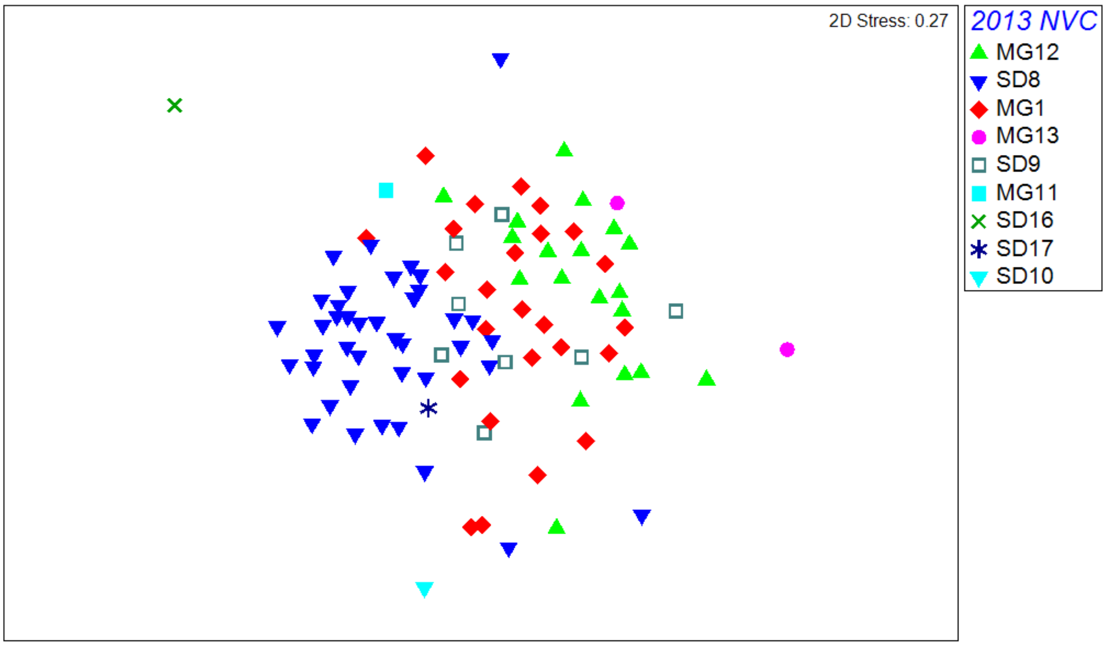
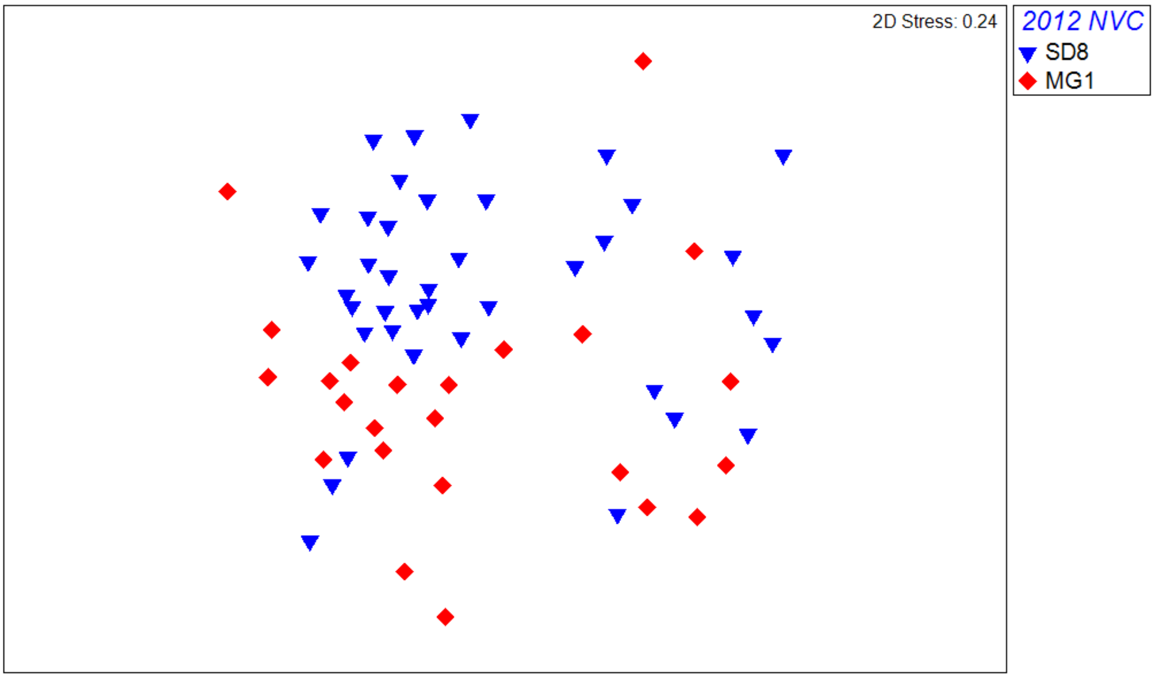


Figure 4.23 nMDS plots depicting species composition with NVC identification factors for (top) 2012 and (bottom) 2013



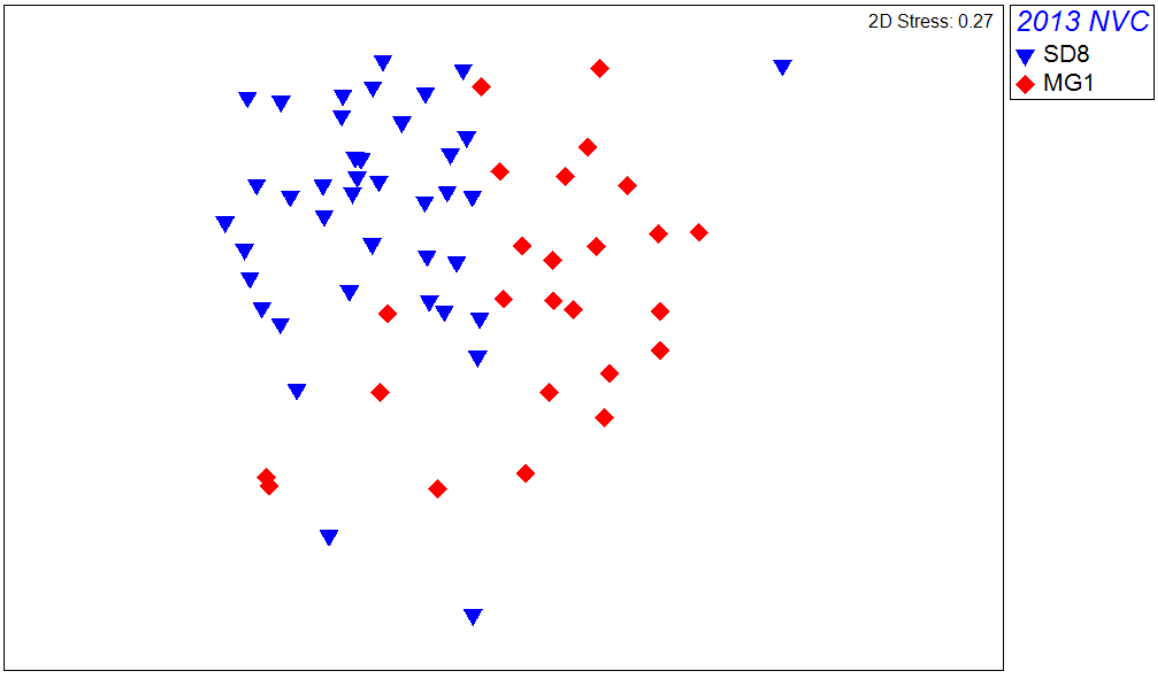


Figure 4.24 nMDS plots depicting species composition with SD8 and MG1 for (top) 2012 and (bottom) 2013.

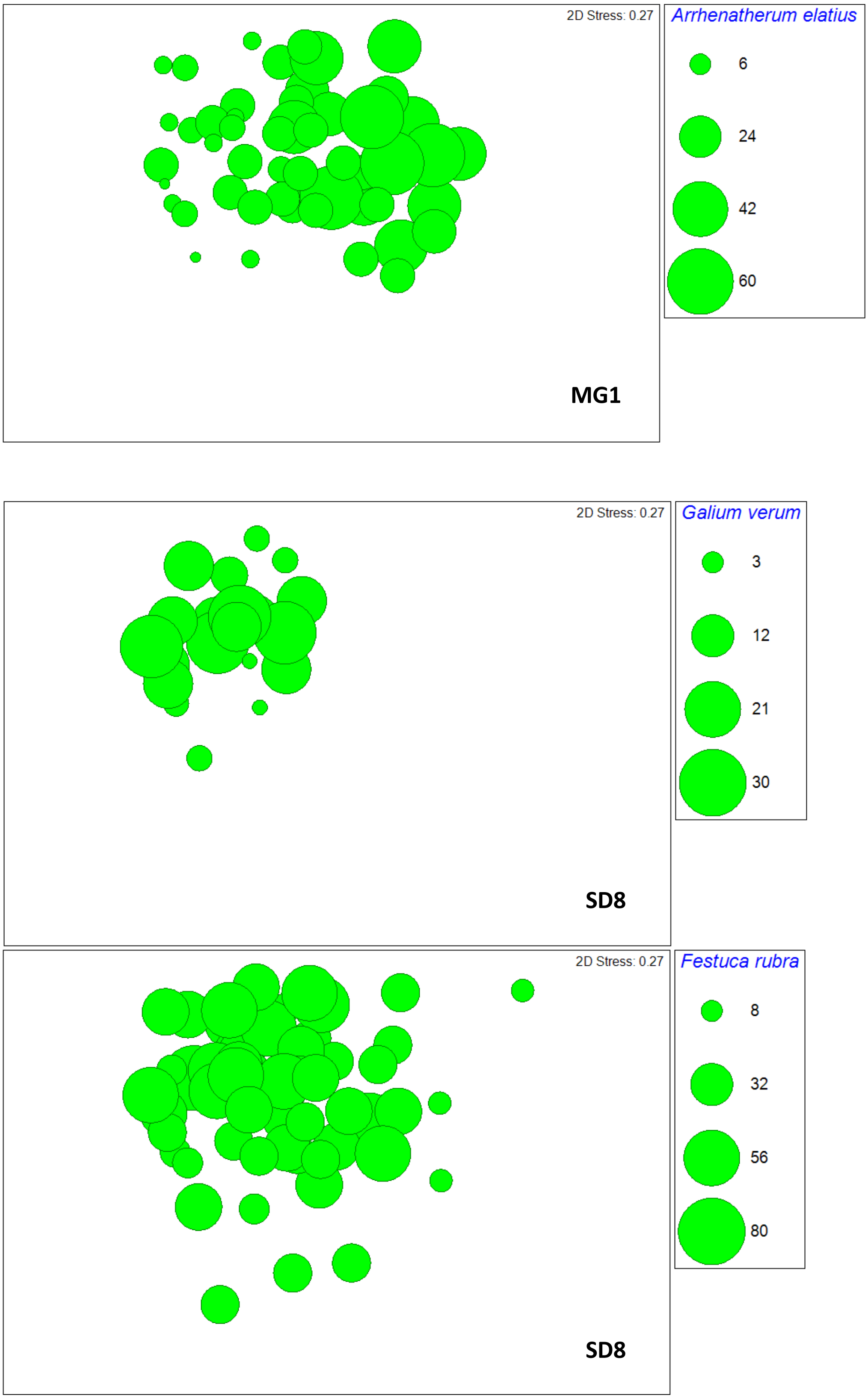


Figure 4.25 2013 species-specific nMDS bubble plot ordination plots displaying abundance values

Although there is a clear distinction between species composition and between NVC types, there is an element of overlap between individual species within different classifications, which can be seen in the nMDS plots (Figures 4.24 and 4.25). Analysis between key NVC types (SD8 and MG1), was undertaken to see if these overlaps were significantly different as individual species composition within quadrats.

The null hypothesis being tested was:

H_0: there is no significant difference in quadrat species composition, between vegetation classifications SD8 and MG1

An ANOSIM analysis was performed on the quadrat data, for the two NVC classes MG1 and SD8 and indicated a significant difference between the two vegetation types for both 2012 ($P = 0.004$) and 2013 ($P = 0.001$) data.

Therefore, the null hypothesis was rejected, as the ANOSIM analysis showed that there was a significant difference in quadrat species compositions between vegetation classifications SD8 and MG1. This confirmed that, even though there are overlaps in species present between differing NVC types, there was a significant difference between classifications, based upon species composition.

Hydro-chemical analysis

One important element in this investigation was to relate the hydro-chemical properties of the groundwater to the vegetation found in close proximity to the locations where the water samples were taken. Chemical measurements for different NVC communities between June

2012 and June 2013 were analysed. The aim of this was to determine whether the groundwater had a direct effect upon the vegetation at ground level.

Dipwells that had >1 missing water sample collection, over the duration of the study, have been excluded from the analyses, and therefore the analyses include 88 of a potential 99 dipwells, that successfully produced a water sample from the first data collection.

To test the null hypothesis that varying concentrations of nutrients in the groundwater have no significant effect on vegetation communities, a non-parametric Kruskal-Wallis analysis was performed to test the null hypothesis, specific to this statistical test:

H_0: the median ranks of chemical concentrations are the same, in relation to NVC classification

The results (Table 4.7) showed that the only significant statistical difference ($P = 0.032$) was in KCl concentrations between NVC classification type for the year 2012. The null hypothesis can therefore be rejected, for the KCl hydro-chemical values for 2012 only. However, the null hypothesis cannot be rejected for the other hydro-chemical values, which did not have significant values, and thus the median rank of other hydro-chemical values is the same across NVC classifications.

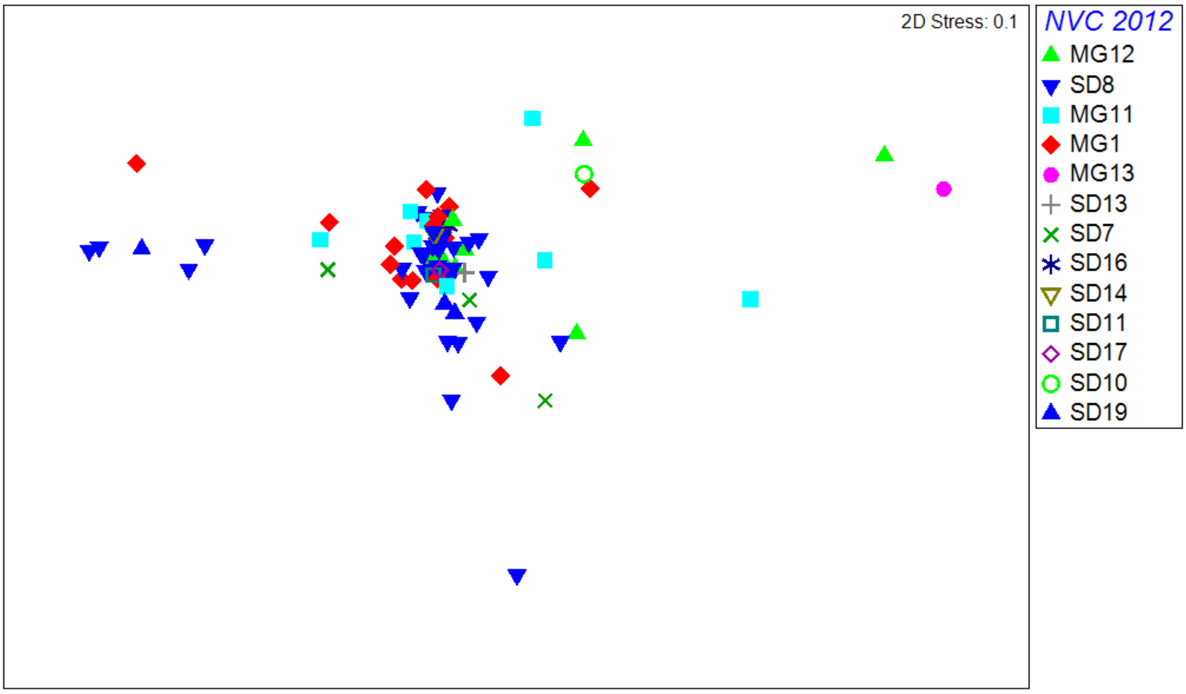
Table 4.7 Kruskal-Wallis analysis of chemical parameters and NVC communities

Chemical	Summer 2012	Summer 2013
NaCl	$P = 0.415$	$P = 0.623$
KCl	$P = 0.032$*	$P = 0.213$
PO_4	$P = 0.797$	$P = 0.197$
TON (NO_3)	$P = 0.055$	$P = 0.884$
NH_3	$P = 0.456$	$P = 0.141$

(Significant values are marked with *)

Chemical data obtained from different sites was transformed in to a Euclidean distance matrix. A non-metric multidimensional scaling plot was then generated from this matrix (Buckley, 2014; *pers. comm.*). Ordinations were calculated from the June 2012 chemical analysis, across all NVC classes as variable factors, and repeated for the June 2013 dataset (Figure 4.26). The same analysis was undertaken for the NVC classes MG1 and SD8 only, to ascertain any differentiation in chemical parameters between these vegetation compositions (Figure 4.27).

Trajectory analysis was under taken on chemical parameters for species compositions that have changed NVC type between SD8 and MG1, between the survey years June 2012 and June 2013. Black arrows indicate a change from Homogenous strands to heterogeneous strands (NVC types MG1 to SD8), while red arrows indicate a change from to heterogeneous strands to homogenous strands (NVC types SD8 to MG1), Figure 4.28.



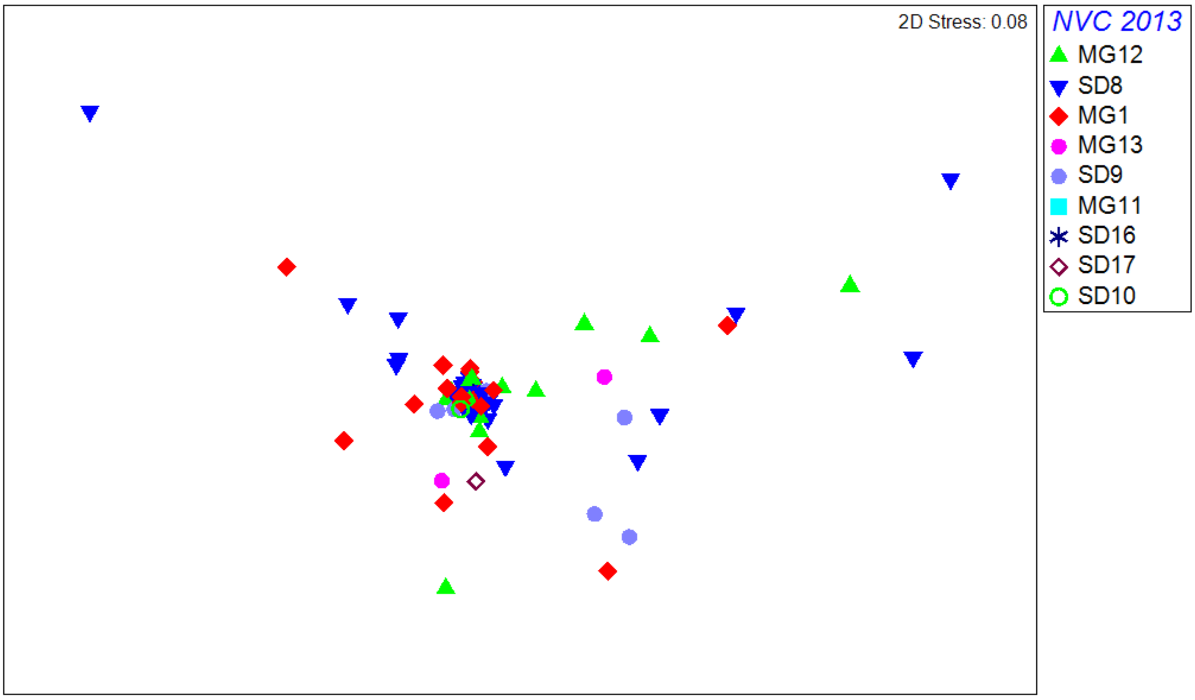
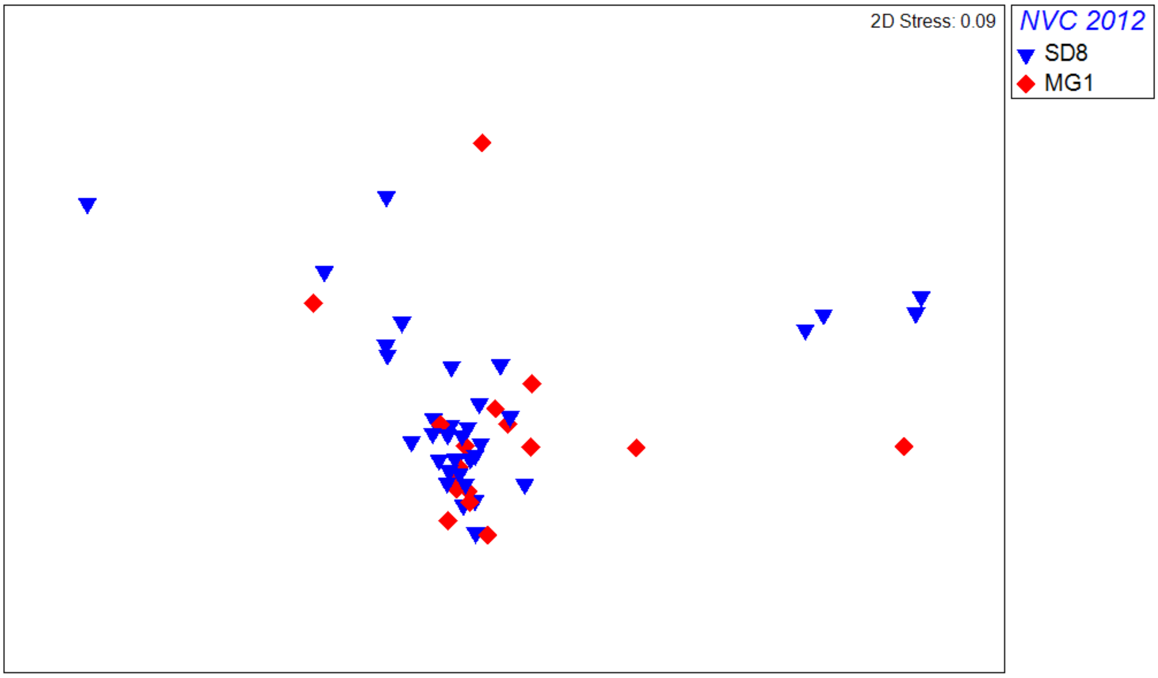


Figure 4.26 nMDS plots using combined chemical parameters, delineated by NVC classes relating to 2012 (top) and 2013 (bottom).



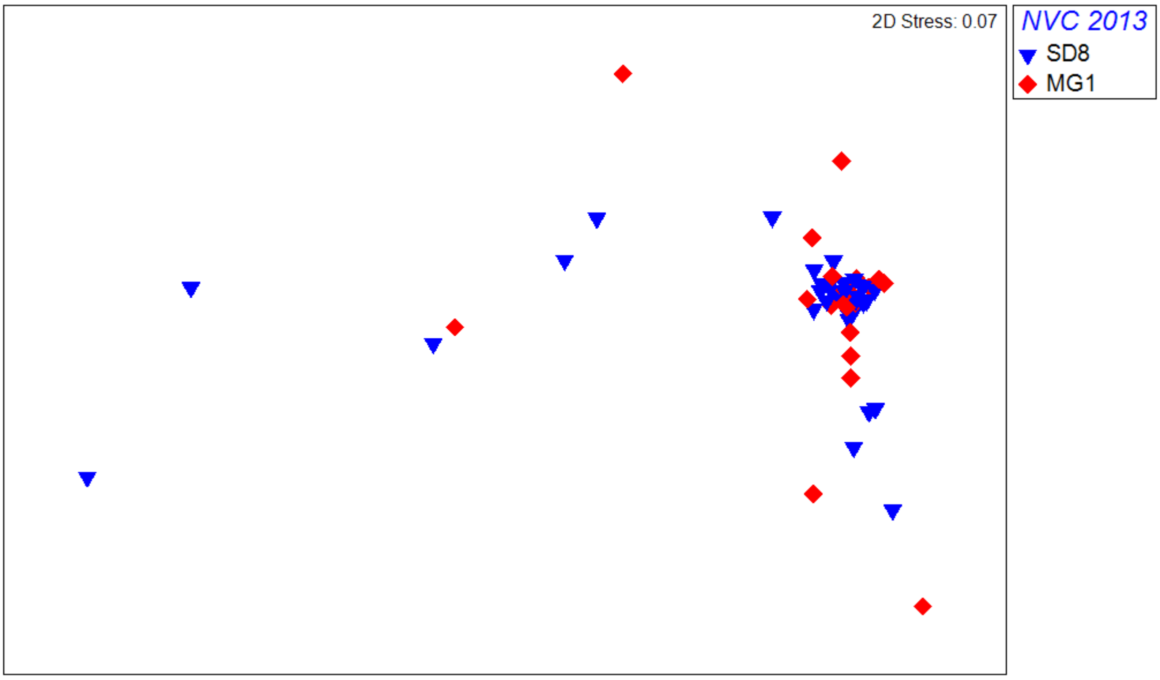


Figure 4.27 nMDS plots using combined chemical parameters, delineated by NVC typesSD8 and MG1 relating to 2012 (top) and 2013 (bottom).

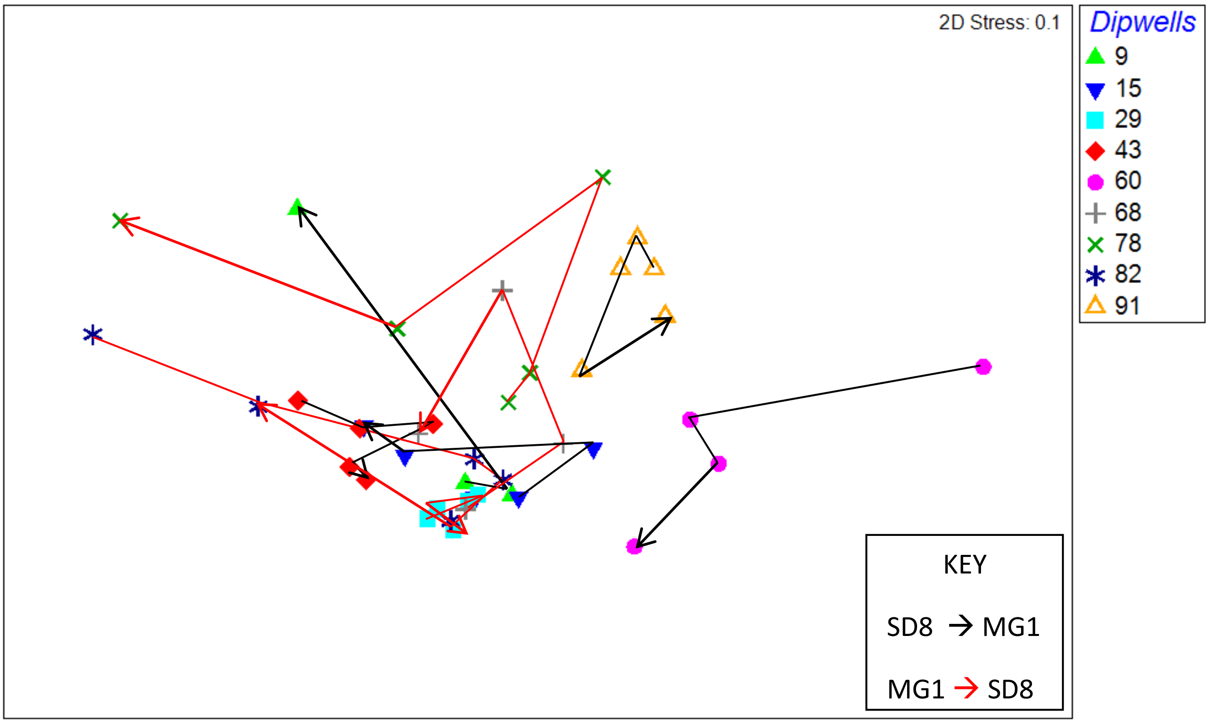


Figure 4.28 nMDS trajectory analysis of chemical parameters in NVC types SD8 and MG1, which have changed between the survey years 2012 and 2013

The nMDS ordinations showed that the combined chemical parameters were similar for different vegetation classifications, ANOSIM analysis found no significant difference in chemical variables between NVC types for June 2012 (Global R = 0.104*;* *P* = 0.073) and June 2013 (Global R = 0.068*;* *P* = 0.114). This indicated that there is the possibility of an even distribution of chemical constituents in the dune systems, or that the groundwater chemical composition is not an influential factor in ground level vegetation dynamics.

Further tests of the null hypothesis, that varying concentrations of nutrients in the groundwater have no significant effect on vegetation communities, were undertaken using a non-parametric Kruskal-Wallis analysis. This test was performed on the dipwell quadrat data, focusing specifically on NVC classes with ≥3 replicates. These NVC classes were: SD8 *Festuca rubra – Galium verum* (fixed dune grassland), MG1 *Arrhenatherum elatius* (dry neutral grassland), MG11 *Festuca rubra – Agrostis stolonifera – Potentilla anserina* (wet grassland) and MG12 *Festuca arundinacea* (wet neutral grassland).

The results showed that there was no significant difference between chemical parameters for the selected NVC classifications. Therefore, the null hypothesis cannot be rejected in this case.

Results indicate that the NVC communities at Sandwich Bay are not necessarily significantly determined by the hydro-chemical constituents of the groundwater. The vegetation observed at Sandwich Bay resides in a relatively dry and stabilised dune system. Curreli *et al*., (2013), noted that the water table needs to be relatively close to the vegetation to have an important chemical effect. Jones (2014; *pers. comm*.) stated that, in a dry dune system, there is a bio-geographical island effect upon the vegetation, which is influenced by precipitation and direct deposition of nutrients at ground level, rather than nutrients from the groundwater itself (Maun, 2009).

Due to the small number of dune slack community replicates (SD13, 14 16 and 17) (figure 4.9), analysis of these communities was limited. MG classifications indicative of wet mesotrophic grassland communities MG12 *Festuca arundinacea* (wet neutral grassland) and MG13 *Agrostis stolonifera – Alopecurus geniculatus* (wet neutral grassland) were amalgamated to form a single 'MG wet' classification. Similarly the dune-slack communities SD13 *Sagina nodosa – Bryum pseudotriquetrum* (dune-slack community), SD14 *Salix repens – Campylium stellatum* (dune-slack community), SD16 *Salix repens – Holcus lanatus* (dune-slack community) and SD17 *Potentilla anserina – Carex nigra* (dune-slack community) were also amalgamated to form an 'SD wet' classification. Differences in these classifications in water table height and physico-chemical variables were then compared using Mann-Whitney U tests.

The hypotheses tested were:

H_0: There is no difference in the ranks of chemical parameters between the two vegetation classifications

H_0: There is no difference in the ranks of water table height between the two vegetation classifications

There was a difference in water table height for the two NVC classifications for both 2012 (p = 0.0012) and 2013 (p = 0.0237) (Figure 4.29). The null hypothesis can therefore be rejected for water table height, and thus there is a difference in the ranks of water table height between the two vegetation types, SD and MG, for both years 2012 and 2013.

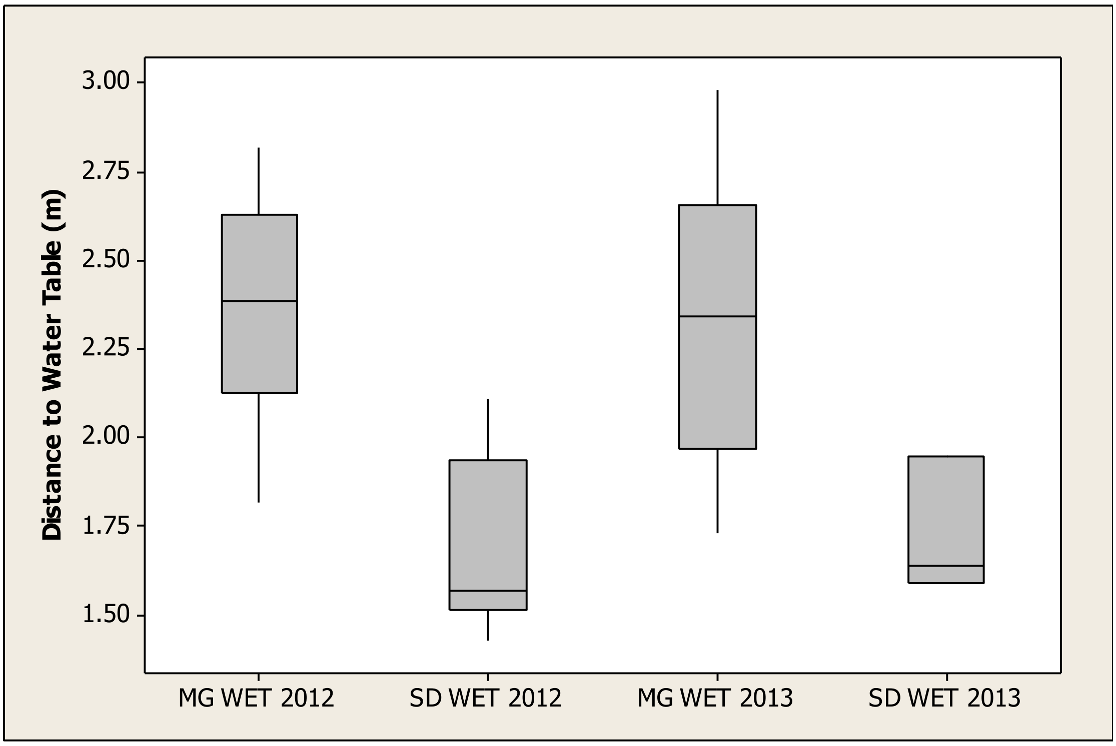


Figure 4.29 Box and whisker plot showing relative distance to the water table from ground level, between mesotrophic grassland communities and dune-slack communities in 2012 and 2013

Results from the analyses (Table 4.8) showed that there was a significant difference in the pH (*P* = 0.0307) between MG wet communities and SD wet communities, for the year 2012. Therefore, we can reject the null hypothesis for pH in the year 2012, and acknowledge difference in the ranks of pH between the two vegetation types, SD and MG. However, the null hypothesis cannot be rejected for the other chemical parameters, since there is no difference in the ranks of chemical parameters between the two vegetation types, SD and MG.

Table 4.8 Mann-Whitney U test showing p-values for physico-chemical value differences between mesotrophic grassland communities and dune-slack communities

Chemical parameters	MG Vs. SD 2012	MG Vs. SD 2013
pH	0.0307*	0.3872
NaCl	0.3508	0.3394
KCl	0.0685	0.4507
P04	0.8242	0.5949
TON	0.1002	0.5136
NH3	0.5636	0.8801
Water table height	0.0012*	0.0237*

(Significant differences (< 0.05) are indicated with *)

The finding that chemical parameters in the groundwater do not necessarily have a significant effect upon the vegetation structure may imply that unknown causative factors, such as atmospheric precipitation, may play a larger contributing role towards vegetation dynamics than expected. Another possible cause is that the aquifer is unconfined, resulting in a relatively even distribution of nutrients throughout the dune system, and making it difficult to determine specific significant links between vegetation composition and nutrients.

4.8 Conclusion

Geographical analysis

The geographical element in this study focused upon vegetation composition successional states along the gradients of nutrients and moisture, indicated by transformed Ellenberg scores (Dargie, 2009). The results of NVC ordinations (Figures 4.6 – 4.8), demonstrated a species change along the axes of nutrients and moisture (Rhind & Sanderson, 2006; Dargie, 2009), which promoted the change from diverse vegetation classes to homogeneous strands. Contingency table Chi-square analysis (Table 4.4) indicated that Ellenberg moisture levels were the significant parameter when investigating individual golf courses. However, the combined quadrat analysis using contingency tables analysis, which included all of the golf courses, showed that Ellenberg nutrient levels were the significant parameter in the change in NVC communities. Research undertaken by Schaffers & Sykora (2000) noted that Ellenberg scores in nutrients were not necessarily comparable to hydro-chemical data, particularly Ellenberg N, which is classed as a measure of bio-mass, rather than a measure of chemical concentration.

Analysis of LiDAR showed that there was a definite correlation between terrain height and plant community cover (Figures 4.14 and 4.15). Jones *et al.,* (2009) found that elevation, or relative distance from the water table, was not the only influential factor. There were other external influences which can affect plant assemblages, such as grazing pressures and wind desiccation (Jones *et al.,* 2009), that were not accounted for in the analysis.

Research interests in coastal areas that have dune systems are predominantly focused upon dune slacks, which are a priority feature of the Annex 1 habitat directive. These areas are classed as being of particularly high ecological value (Jones *et al.,* 2013). While Sandwich Bay has occurrences of humid dune slacks, the dune system is mostly composed of grey dunes, which are another priority feature (Natural England, 2014).

Secondary analysis was undertaken to assess those vegetation classes indicative of wetter areas, such as dune slack communities (SD13 *Sagina nodosa – Bryum pseudotriquetrum*, SD14 *Salix repens – Campylium stellatum*, SD16 *Salix repens – Holcus lanatus* and SD17 *Potentilla anserina – Carex nigra*), and the higher successional mesotrophic grassland communities (MG12 *Festuca arundinacea* and MG13 *Agrostis stolonifera – Alopecurus geniculatus*). Statistical analysis did not show any significant difference in elevation for these different communities.

Statistical analysis of NVC classifications predominantly found at this site (SD8 *Festuca rubra – Galium verum*, MG1 *Arrhenatherum elatius*, MG11 *Festuca rubra – Agrostis stolonifera – Potentilla anserina* and MG12 *Festuca arundinacea*), see Table 4.6 and Figure 4.15, indicated that there was correlation between ground elevation and vegetation community cover. Results show that assessment of plant composition in relation to elevation and relative water table height in a relatively stable system, such as that found in a managed landscape, could utilise LiDAR elevation to provide informed analysis of vegetation composition and potential habitat change.

Hydro-chemical analysis

Hydro-chemical analysis was undertaken to investigate the influence of chemical parameters on the flux in vegetation classes. Analysis of historic data indicated that SD8 fixed dune grassland was changing quite rapidly to MG1 and MG12 (Dargie, 2009).

It was found that increased moisture leads to high rates of diversity loss and increase in competitive species. According to the analysis, nutrient levels in the ground water have less influence on vegetation assemblages than moisture levels. Research undertaken on other dune systems found that an element of disturbance (wind desiccation or erosion) or stress (drought or waterlogging) affects the accumulation of the litter layer, encouraging species diversity (Tilman, 1987; Tilman, 1993; Jansen et al., 2004).

Analysis of the dipwell water-sample data from this study indicated that the chemical parameters were not the causal factor in facilitating change in vegetation communities, specifically SD8 and MG1. The relative water table height was, however, an explanatory variable for the observed NVC classification change. Analysis of meteorological data indicated that there was a relationship between mean rates of precipitation and water table height. Analysis of tidal fluxes across a single transect indicated that there was a ± 4cm variation between high and low tide during a spring tide, and that there was a significant correlation with the groundwater-influenced NaCl concentrations ($r^2 = 0.221$, $P = 0.039$). NaCl concentrations were seasonally consistent between the dipwells and had similar NaCl concentrations to the River Stour (Table 4.5), with only a few dipwells indicating isolated anomalies where NaCl concentrations differ dramatically, such as those highlighted in Figure 4.17, suggesting that the NaCl concentration fluctuation was based upon climatic conditions, such as periods of drought, or the tidal surge in Spring 2014.

IDW map observations indicated that, although there were a few dipwells which indicated higher concentrations of phosphates, ammonia and total oxidised nitrogen, there was a level of consistency in chemical distributions seasonally. Table 4.7 illustrates that the chemical distribution was consistent in relation to analysis between NVC types for the years 2012 and 2013, except for KCl in 2012. Analysis of NVC types affected by close proximity to the water table (Table 4.8 and Figure 4.29) did indicate that, of the hydro-chemical parameters, the most significant was the variability in the water table. Figures 4.14 and 4.15 illustrate that, while there is variability in NVC types found at differing elevation; the change in the water table levels was consistently the significant determinant that affected species composition.

The following chapter investigates the implementation of management trials, which aimed to address the concerns highlighted in this chapter, in relation to competitive change from heterogeneous to homogeneous vegetation assemblages. These active management treatments at ground level were intended to observe the effects of biomass removal and the effects of moisture retention in the soils by the implementation of accepted management techniques (Bossuyt, 2007; Grootjans *et al.,* 1997; Jansen *et al.,* 2004; Moreno-Casasola, 1986; Perumal & Maun, 2006; Plassmann *et al.,* 2010), intended to encourage diversity in the vegetation layer.

Chapter Five

Management Trials

5.1 Management trial introduction

Different types of management techniques

The over-stabilisation of dune systems can be observed on many dune systems in North-West Europe (Jones *et al*., 2009), including that at Sandwich Bay. Over-stabilisation leads to lower diversity of typical dune species and an accumulation of available soil nutrients and organic matter, as well as the ability to retain increased levels of moisture (Martínez, & Psuty, 2008; Maun, 2009). Figure 1.4 in Chapter One outlines these stabilisation dynamics.

A number of studies have been undertaken to determine the best management methods for sand dunes that are considered to be environmentally sensitive. A variety of accepted treatments have been put in place in coastal areas, including burning, grazing, burial, turf stripping and cut–and-remove (Bossuyt, 2007; Grootjans *et al*., 1997; Jansen *et al*., 2004; Moreno-Casasola, 1986; Perumal& Maun, 2006; Plassmann *et al*., 2010). There is also a recent study that looked at burial methods and inverting swards (Jones *et al*., 2009).

All of these management treatments aim to reduce available nutrients and remove the accumulation of organic matter in the system. However, the treatments are not necessarily creating a long-term new habitat, but instead are maintaining and potentially restoring plant communities to a sparsely-vegetated sward layer.

Recent thinking has led to the idea of remobilisation of sand dunes as a management practice (Pye & Blott, 2012). Remobilisation of sand dunes involves destabilising the dune systems by exposing bare sand, permitting the unrestrained movement of sand across the dune system.

This is quite the opposite of the standard practice of stabilising dune systems, which has been in active operation since the early 1970s and is still currently being undertaken, for example, at Camber Sands in East Sussex in 2009. Destabilising dune systems is, however, often employed as a management technique in sand dune areas used for amenity use. It frequently involves top-dressing the fairways and greens with sand to encourage the finer grasses, such as fescues (*Festuca spp*.) that need a more open soil structure and reduced organic matter content, thus eliciting an artificial mobility of sand into the area.

The main purpose behind mobilising sand in a dune system is to promote the development of pioneer plants that rely upon bare ground, which then has a knock-on effect on the different successional stages throughout the dune system (Pye & Blott, 2012; Waternet, 2013). This approach is deemed to be most beneficial on fixed dune systems that have an eroding coast line. There are two types of remobilisation: 'fore-dune' schemes, which involves excavating ridges into the fore-dunes and reconnecting the beach with the interior of the dunes, which allows sand and wind to feed into the dune system; and 'within-dune' schemes, based on turf stripping, targeted at areas with maximum wind exposure, and allocating target areas close to, or adjacent to, existing areas of instability (Weaver, 2011; Waternet, 2013; Pye & Blott, 2013).

There are specific drivers of coastal change that affect dune systems. These can be listed as mobility and stability drivers (Ranwell & Boar, 1986; Hardisty, 1990; Martínez, & Psuty, 2008; Maun, 2009; Pye & Blott, 2013). Dune mobility drivers include high wind speeds, low rainfall, high temperatures/high rates of evaporation, low nutrient availability, high rates of littoral sand supply, coastal erosion, high visitor pressure and lack of dune management methods. Dune stability drivers include low wind speeds, high rainfall and/or high moisture retention, low temperatures/low rates of evaporation, nutrient excess (which promotes plant growth), low rates of littoral sand supply, coastal progradation (an accreting shoreline extending seaward), low visitor pressure and effective management measures.

Although these drivers are not necessarily determinants of whether a sand dune system is stable or not, they do define certain pressures and sets of conditions that are relevant when evaluating the relative stability of the dune system. Remobilisation of dune systems, where it is feasible, may encourage various successional stages in the dune systems (Maun, 2009; Pye & Blott, 2013), particularly if the variability of an existing seed bank persists.

There is a further distinction to be made between schemes that are based on mechanical interventions to stimulate mobility, and schemes that focus on removing structures and past interventions. Examples of this include planting Christmas trees, or installing fences on the dune systems, as observed at Camber Sands, where they have increased stabilisation and constrained potential mobility.

However, mobilisation of dune systems is already in place where conditions are suitable, even to a limited extent. An example of this was observed on the dune systems at Kenfig Barrows in Wales, where remobilisation is possible due to its position on a peninsula, surrounded on three sides by the Irish Sea (Pye & Blott, 2013). Here, the energy is available to realise the potential for mobilisation of sand particles as a management technique, with strong inshore winds and relatively dry, high, dune systems that are sparsely vegetated due to wind desiccation.

The conditions at Sandwich Bay are diametrically opposed because it has a mixture of eroding coastline (southern end) and accreting coastline (northern end) along the bay. The dune systems are lower, and therefore the eddying effect of the wind, which aids the destabilisation and increased desiccation of vegetation (Maun, 2009) in the dune systems, is not always present. Additionally, this dune system is a managed landscape, where relative moisture levels are maintained throughout the dry seasons, thus halting any natural mobilisation of sediments by the wind.

Management trials at Sandwich Bay

Management trials are experiments on pieces of land designed to ascertain the effects of different treatments on a region of interest. They typically take into effect existing gradients, such as land slope or soil depth, that could affect the response being investigated. The treatments are applied in a grid-based assignment, typically with at least one treatment per row and per column (Mead & Curnow, 1983).

Management trials were set up at Sandwich Bay, as part of this study, to investigate re-colonisation rates for 'desired' vegetation after applying different treatments, with the aim of identifying a preferred method for the golf courses to manage the land.

5.2 Materials and methods

Locating management trials

Three management trials were setup; one on each of the three golf courses located at Sandwich Bay. These management trials were positioned to take into account an element of natural disturbance, such as wind desiccation. In addition, it was necessary to have a viable seed-bank of desired vegetation swards nearby. Due to restrictions of play, sites were dictated by the requirements of the golf course, rather than using published criteria or standardised spatial distribution. As a consequence, it proved impossible to standardise factors that could affect variability, such as distance from the high-tide mark or elevation.

There was, however, a conscious attempt to locate an area that was not too undulating, for ease of access, and which also incorporated areas of dry neutral grassland, classed as MG1 *Arrhenatherum elatius* (dry neutral grassland) under the NVC classifications, and a viable seed bank of fixed grey dune vegetation (SD8 *Festuca rubra–Galium verum*) nearby, if not actually within the management trials. The objective of the management trials was to investigate the feasibility of reverting neutral grassland to fixed dune grass species using accepted management practices (Pye & Blott, 2012).

The chosen management areas, based on the viability of a potential seed bank (Bakker *et al.*, 2000; Bossuyt *et al*., 2004; Marchante *et al*., 2011), meant that SD8 *Festuca rubra–Galium verum* fixed dune grassland vegetation was present within a 100 metre radius of each of the management trials, based upon the 2001 NVC data. Ensuring that there was a viable seed bank within 100 m radius of the management trials meant that seed dispersal and vegetative encroachment would have ensured that desirable species recolonisation would have been feasible, this was considered to a suitable standardisation method of SD species propagule delivery into your trial plots. The areas allocated for the management trials were classed as redundant or not incurrent use by the golf courses, with regard to amenity; thus there were already some successional stages of low scrub growth in places (Figure 5.1).

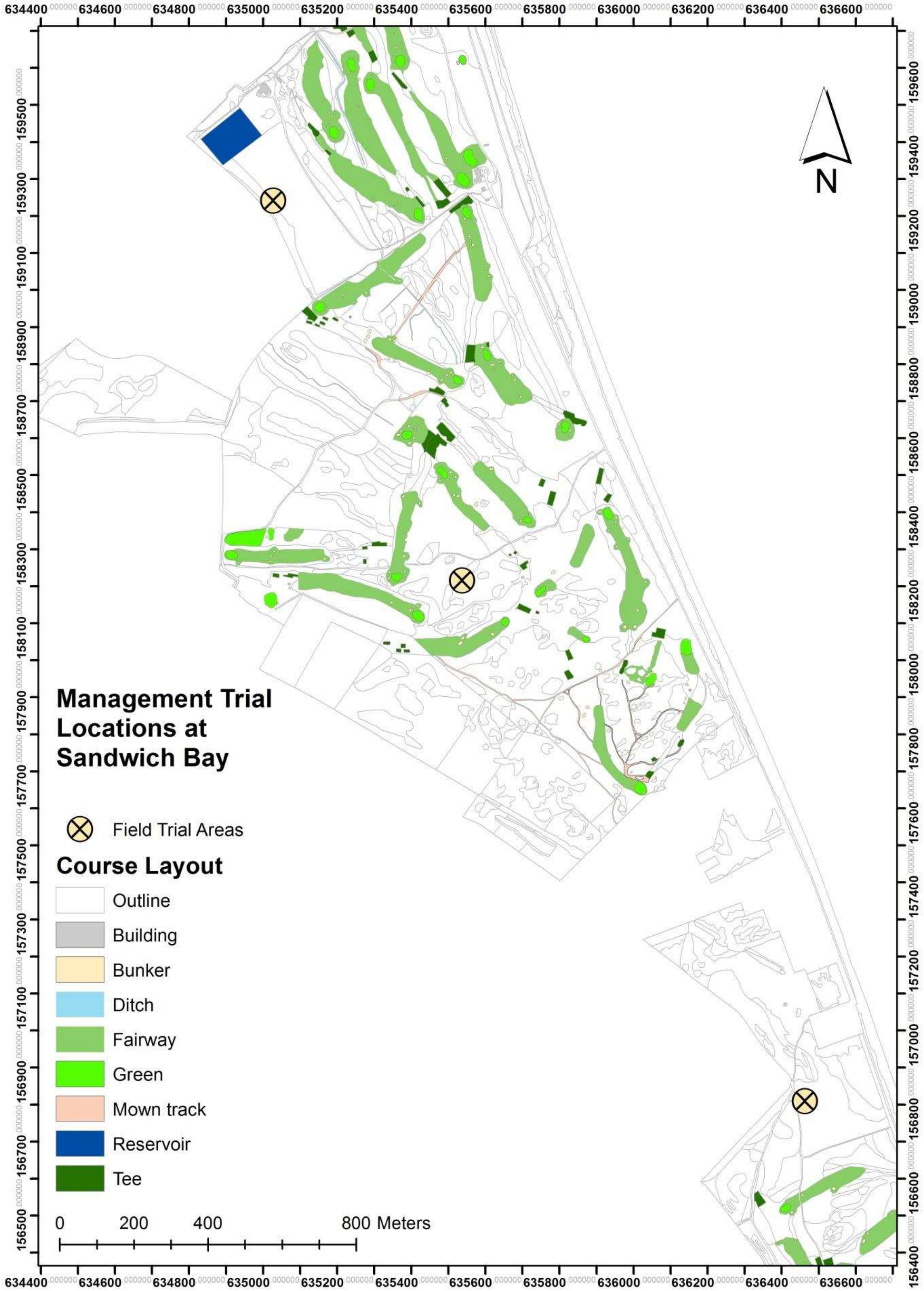


Figure 5.1 Map showing management trial locations across Sandwich Bay

Management trial positioning and chosen treatments

As with the hydrological investigation, it was imperative that any management trials would need to remain undisturbed for the duration of the study, if not longer, so that observations could be continued for as long as possible to allow for a greater understanding of the vegetation re-colonisation rates (Bakker *et al*., 1996; Large *et al*., 2007; Smits *et al*., 2002).

Jones *et al*., (2009) found that the location and proximity to other external influences or disturbances, whether this be human or animal interaction (herbivory), natural erosion processes by the wind, or scrub shelter, or some combination of these, can all have an influence upon vegetation re-colonisation rates beyond those due to the management techniques. Jones *et al*., (2009) noted in their research that in areas exposed to disturbance, particularly by the wind, this replaced the physical conditions of the management trial, which involved sward inversion/burial, as the dominant influence on plant growth and establishment observed over an extended period of time.

The aims of the management treatments were to remove organic matter from the localised area, to be repeatable, and to coincide with existing course management.

The management regimes already in place across Sandwich Bay's landscape include cut and removal of vegetation material. Therefore, by default, this management technique was considered for the management trials. Cut and remove reduces the amount of organic matter present. If this is not removed, the organic matter decomposes, recycling nutrients back into the system, creating a dense organic humus layer that retains water, and which is unfavourable for desired SD8 species.

Another management treatment is grazing. Low stocking rates and high rotational grazing provides the same benefits as cut and remove. A standard stocking unit per hectare is ten sheep, so with a high rotational/low stocking regime there might be ten sheep on an area greater than five hectares, and these would be frequently moved to different areas. Moderate grazing is the recommended management regime on sensitive sites (Ranwell & Boar, 1986). Although this is a common practice on SSSI and local nature reserves, animal welfare issues meant that it would not be feasible in this trial to confine animals to a small allocated area.

More invasive actions, such as burning, or scraping off the surface layer, remove this accumulation of organic matter far more effectively than the cut and remove treatment. Burning removes the often dense layers of grass/thatch, but leaves the root systems intact, whilst scraping can bring areas back to bare ground, void of an organic layer and root system. However, burning and scraping are specialised treatments, often involving costly techniques. Thus burning and scraping are not commonly practiced, but were chosen as two treatments for the management trials.

Latin Square Design

On agricultural land there is often a soil fertility gradient running in one direction down one of the dimensions of the field (Snedecor & Cochran, 1974). For this study, a Latin square design was chosen, which allows for blocking in two directions, where rows represent blocking in one direction and the columns represent blocking in the other direction (Mead & Curnow, 1983) (Figure 5.2.2.1). Although there was no known gradient of soil fertility in the management trial areas chosen, the Latin square design was useful as it allowed for the possibility of soil-fertility gradients, or any other variable gradient, such as a dominant wind direction, to be taken into account when randomly allocating treatments to the management trial areas (Snedecor & Cochran, 1974). The idea was that each block contained similar experimental units, to which the treatments were applied, allowing for more precise comparison of similar units by reducing the influence of environmental factors that may vary spatially in a particular direction (Kiefer & Wynn, 1981; Mead & Curnow, 1983). Blocking thus reduced the amount of variability in the treatment response that could be explained by unknown environmental variable gradients, in two different directions.

Each management trial consisted of four treatments, each replicated four times, allocated such that each treatment was applied once in every row and column, as can be seen in Figure 5.2. This totalled 16 units per management trial, each measuring 5 x 5 metres in size. A 1 metre margin separated each treatment unit, which acted as a buffer to prevent one treatment affecting the adjacent treatment units, for example, to prevent incidental seed dispersal when applying the cut and remove treatment. It was recognised, however, that there was a possibility of re-colonisation of the units from seed produced within the buffer strips as well (Bakker *et al*., 2005; Marchante *et al*., 2011; Studer-Ehrensberger *et al*., 1993). Therefore, to preserve the purpose of the buffer strips, they were cut manually twice a year to ensure that vegetation maturity was stunted in these areas, so that they would act as catchments rather than as a seed bank for the units.

The management trials were located at three different sites. This meant the design had 3 blocks, which accounted for variation that could be explained by the location, where each treatment is equally represented within each location block.

The total dimension of the management trials was 25 x 25 metres square, giving 625m^2 area in total for each site. Fortunately, there were few constraints on the amount of land that could be used for the experiment, which enabled a trial design to be set up that was large enough to be able to detect differences in vegetation re-colonisation between treatment units. The only restriction was on where the management trial sites could be located.

The treatments allocated within the Latin square design were:

- Treatment A - Cut-and- Collect (to be done on an annual basis)
- Treatment B – Burning (one-off treatment)
- Treatment C - Sward removal (scraping down to bare sand by mechanical means, approximately 8-12 inches depth, one-off treatment)
- Treatment D - Control (after initial setup, these areas were left untouched for the duration of the study)

The treatments were randomly allocated, using a random number generator, where a number represents a treatment, ensuring that the order of the treatments was not repeated within blocks (Snedecor & Cochran, 1974). This randomisation removed the possibility of experimenter bias in the allocation of treatments, ensuring that the trial was 'fair' (Mead and Curnow, 1983).

NVC classifications were used as an indicator of re-colonisation rates (Rodwell, 2006) within different treatment units, in order to quantify the effectiveness of each management technique. The pros and cons of each management technique were assessed to determine the most appropriate method available to the custodians of these sensitive areas.

The management trials were set up during the latter half of 2012, and all treatments were applied by early 2013. The sites were monitored on an annual basis, to record re-colonisation of vegetation and NVC cover class, during June 2013 and 2014. The management trials were recorded in line with the recommended NVC methodology undertaken previously during the 2001 and 2008 NVC surveys at Sandwich Bay (Dargie, 2001; Dargie, 2009).

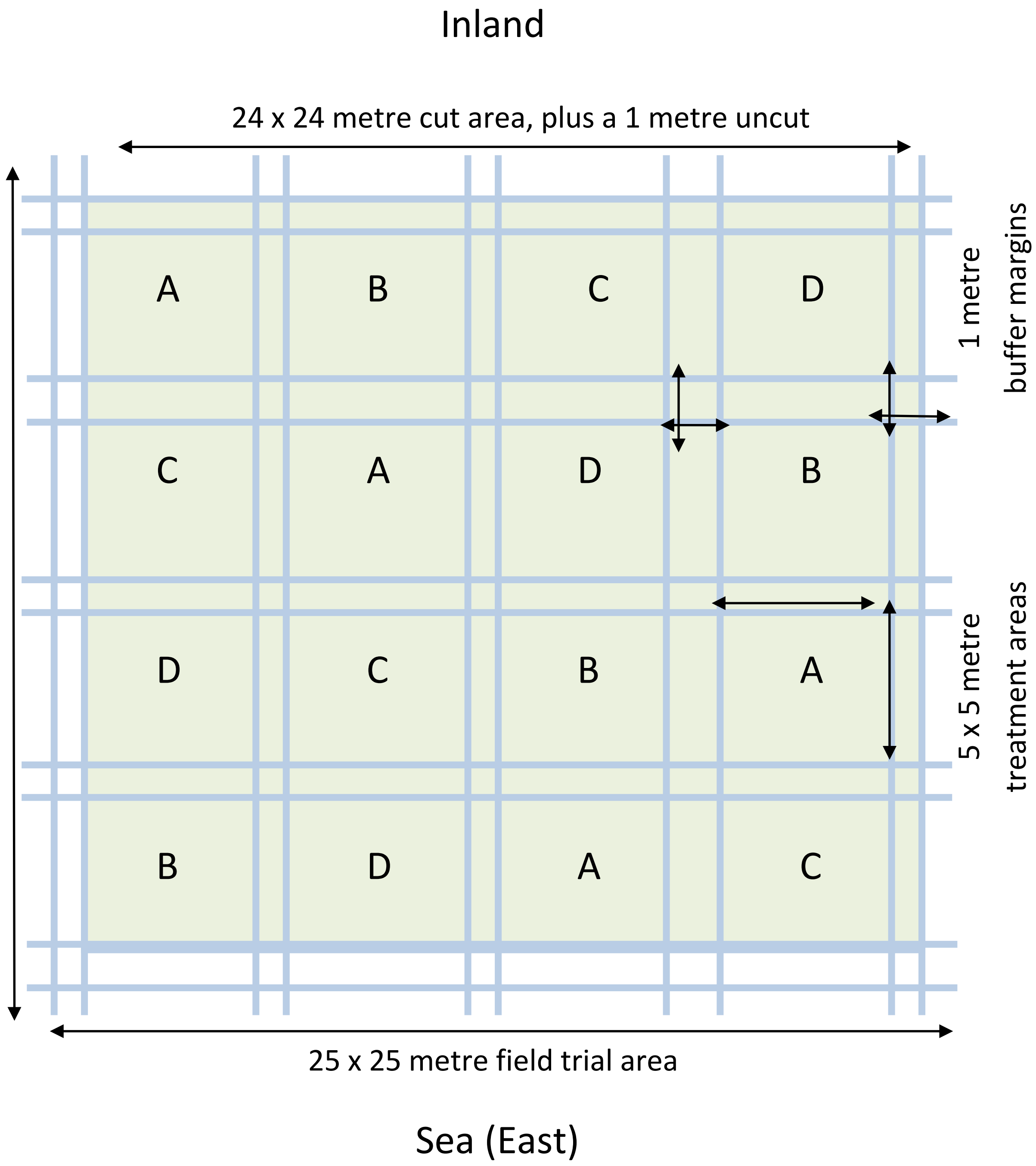


Figure 5.2 4x4 Latin Square Design at Princes Golf Club showing random allocation of treatments

Establishing trial sites and sampling methods

The treatment allocations were marked out using three measuring tapes, two ranging poles, and 40cm wooden pegs to mark-out the treatment blocks. Ropes were used to mark the perimeter of the management trial and the individual treatment unit areas.

The management trial areas (Plate 5.1) were mown during the initial stages of setting up the management trial, in order to make it practicable to mark out the management trial perimeters and individual units. This meant it was only necessary to implement two of the treatments at a later stage during the initial setups, which were the burning application and the sward removal.

Plate 5.1 Marked areas of the Latin square design at Princes Golf Club

Only the cut and remove treatment was repeated on an annual basis, after recording the NVC data. The cut and remove treatment was applied during the autumn months using a scythe. This particular treatment focuses upon the removal of vegetation. The cut sward was carefully removed to ensure that none of the seed from the vegetation was dispersed into other treatment areas.

A range of different equipment was trialled for the application of the sward removal treatment, with the intention of standardising the depth of cut. The use of a turf cutter was trialled at RSGGC, but the use of this machine proved to be impracticable due to the undulations of the ground, which either made the equipment inoperable or resulted in an uneven cut.

A mini digger proved to be more successful at sward removal, and was used for all of the management trials. Particular attention was paid to standardising the sward removal to depths of between 6 - 10 inches. The areas were then levelled to ensure that there were no undulations within the treatment area following use of the mini digger, as can be seen in Plate 5.2.

Plate 5.2 Sward removal treatment at Princes Golf Club

For each management trial the burning treatment was applied once during the period of the study. This was during the initial setup in February 2013.

Burning was carried out using a roofers' flame-lance to obtain a relatively fierce but localised heat, thus permitting a suitable replication of the burning technique under variable topographic conditions. To safeguard the surrounding vegetation, a firebreak, consisting of mown swards, ensured that areas surrounding the management trials were not at risk from accidental burning (Plate5.3).

The preferred time of year to burn grassland, as a management technique, varies widely, based upon the location. RSGGC, as part of their winter management of the golf course, timetabled burning regimes for February, since restrictions against harming ground-nesting birds are enforced from March to September. However, with such a narrow window, and the necessity for suitable weather conditions, this form of management had not been used by RSGGC for more than seven years prior to this study.

Plate 5.3 Burning treatment using a flame lance at RSGGC

After completion of these treatments (Plate 5.4), the wooden markers were left in place for the duration of the study, to ensure accurate delineation of the boundaries between different treatments, and were replaced where necessary.

Plate 5.4 Completed treatments within the Latin square design at Princes Golf Club

Statistical analysis

The vegetation, within each treatment unit of the management trials, was analysed using a 2 x 2m rope quadrat, to obtain a representative sample of species in each sample area, from which NVC scores were estimated (Rodwell, 2006). An Excel spreadsheet/program was developed in line with recommendations from Dargie (2009), and this transformed the NVC quadrat data into Ellenberg scores for different Ellenberg gradients, details of which were explained in Chapter 4. The transformed data were then used for the Latin square analysis, to compare the vegetation composition between rows, columns, treatments and sites, for different years. Data from the transformed quadrat data, representing Ellenberg F (moisture) and N (nutrients) gradients were used to create prediction ellipses that displayed species change within the treatments, i.e. the change in environmental conditions, due to the treatments, in relation to the Ellenberg F and N gradients, for each year.

Comparisons of similarities in vegetation structure were undertaken by converting the raw quadrat data to percentage cover for species within individual quadrats. The data were then ranked, based upon species present in each of the treatment areas, and a resemblance matrix was run, using the statistical package, Primer E (version 6.1.2) [PRIMER-E Ltd, Ivybridge, UK], to investigate similarities of vegetation types between treatment and between site, using Analysis of Similarities (ANOSIM). A Non-metric Multi-Dimensional Scaling (nMDS) plot was used to view similarities in treatments and sites.

5.3 Results and discussion

Management trial analysis

Analysis of the combined datasets, comprising the three Latin square designs, is shown in Table 5.1. The aim of the management trials was to compare vegetation re-colonisation using the control treatment (do nothing) versus the three experimental treatments. The null hypothesis being tested against was:

H_0: Land management techniques have no significant effect on vegetation colonisation patterns

Table 5.1 it can be seen that site (course location) had a significant effect on Ellenberg L (light), N (nutrients), F (moisture) and S (salinity) gradients for the analysis in 2013, but site only had a significant effect on Ellenberg N in 2014. Treatment had a significant effect on Ellenberg S gradient for both 2013 and 2014 observations.

These management trial sites are located at different distances away from the high tide mark, so the change in vegetation composition, particularly salt-tolerant grasses such as *Ammophila arenaria* (Ellenberg S reference value of 3), indicated that salinity levels were likely to be a determining factor in species variation.

Detailed analysis of the variables at the individual sites showed that the 2013 management trials had significant effects on Ellenberg values. RCPGC showed that Row had a significant effect on Ellenberg N ($P = 0.031$), and Treatment had a significant effect on Ellenberg R ($P = 0.029$). Princes Golf Club showed that Treatment had a significant effect on Ellenberg S ($P = 0.040$). For the 2014 analysis of individual sites, RCPGC showed that Row had a significant effect on Ellenberg N ($P = 0.018$) and Ellenberg R ($P = 0.039$). Analysis of Princes Golf Club showed that Row had a significant effect on Ellenberg F ($P = 0.022$).

Table 5.1 Tables showing ANOVA general linear model results for the combined 2013 and 2014 management trial data

2013 Analysis	Model (P Values)			
Response	Row	Column	Treatment	Site
Ellenberg L	0.166	0.776	0.337	0.006*
Ellenberg F	0.065	0.38	0.529	0.005*
Ellenberg R	0.237	0.353	0.141	0.117
Ellenberg N	0.545	0.294	0.453	0.003*
Ellenberg S	0.507	0.407	0.003*	0.000*

2014 Analysis	Model (P Values)			
Response	Row	Column	Treatment	Site
Ellenberg L	0.832	0.892	0.216	0.062
Ellenberg F	0.942	0.986	0.209	0.781
Ellenberg R	0.510	0.842	0.261	0.135
Ellenberg N	0.771	0.961	0.450	0.020*
Ellenberg S	0.131	0.212	0.040*	0.253

L = light; F = moisture; R = pH; N = nutrients; S = salinity.
(Significant values are indicated with *)

The analysis of the combined Latin square designs demonstrated that Site has an effect on Ellenberg L, F and S for 2013, and Ellenberg N for both 2013 and 2014, and Treatment has an effect on Ellenberg S for both 2013 and 2014. Ellenberg scores can be used directly for the estimation of suitability of vegetative species belonging to particular NVC classifications, and thus the null hypothesis - that land management techniques have no significant effect on vegetation colonisation patterns - could be rejected, in favour of the idea that the treatments affect salinity, which then affects the vegetation colonising that site. Figures 5.3 and 5.4 show the prediction ellipses for the NVC community compositions, based upon Ellenberg F and Ellenberg N, at each of the golf clubs recorded in 2013 and 2014.

The individual quadrat data, for percentage cover of individual species types, were assigned similarity values within a resemblance matrix, comparing each sample against each other, with the treatment for each sample specified as a factor. Analysis of similarities (ANOSIM), were also performed to test the null hypothesis:

H_0: Land management techniques have no significant effect on vegetation colonisation patterns

ANOSIM was performed for both the year 2013 data and the year 2014 data, to determine whether there was a significant difference between sample species compositions and treatment, and between site and sample species compositions. It was shown that there was a significant difference between treatments across all management trials (for 2013 $P = 0.001$, for 2014 $P = 0.002$), and a statistical difference between management trial locations (for 2013 $P = 0.001$, for 2014 $P = 0.001$).

Therefore, the null hypothesis can be rejected, as the ANOSIM analysis showed that there was a significant difference between management treatments and species composition, for both the years 2013 and 2014.

The management trial prediction ellipse NVC ordination data were combined for the 3 sites, for r x c contingency table Chi-square test (Table 5.2) to compare Ellenberg F and Ellenberg N gradients between the years 2013 and 2014, to test for independence between the years. The null hypothesis being tested was:

H_0: There is no association between year and Ellenberg gradients

Analysis showed that there was a significant difference in Ellenberg F gradient values between 2013 and 2014, which indicated a significant difference in species change between NVC classes. However, the Ellenberg N gradient did not show a significant difference between the years 2013 and 2014.

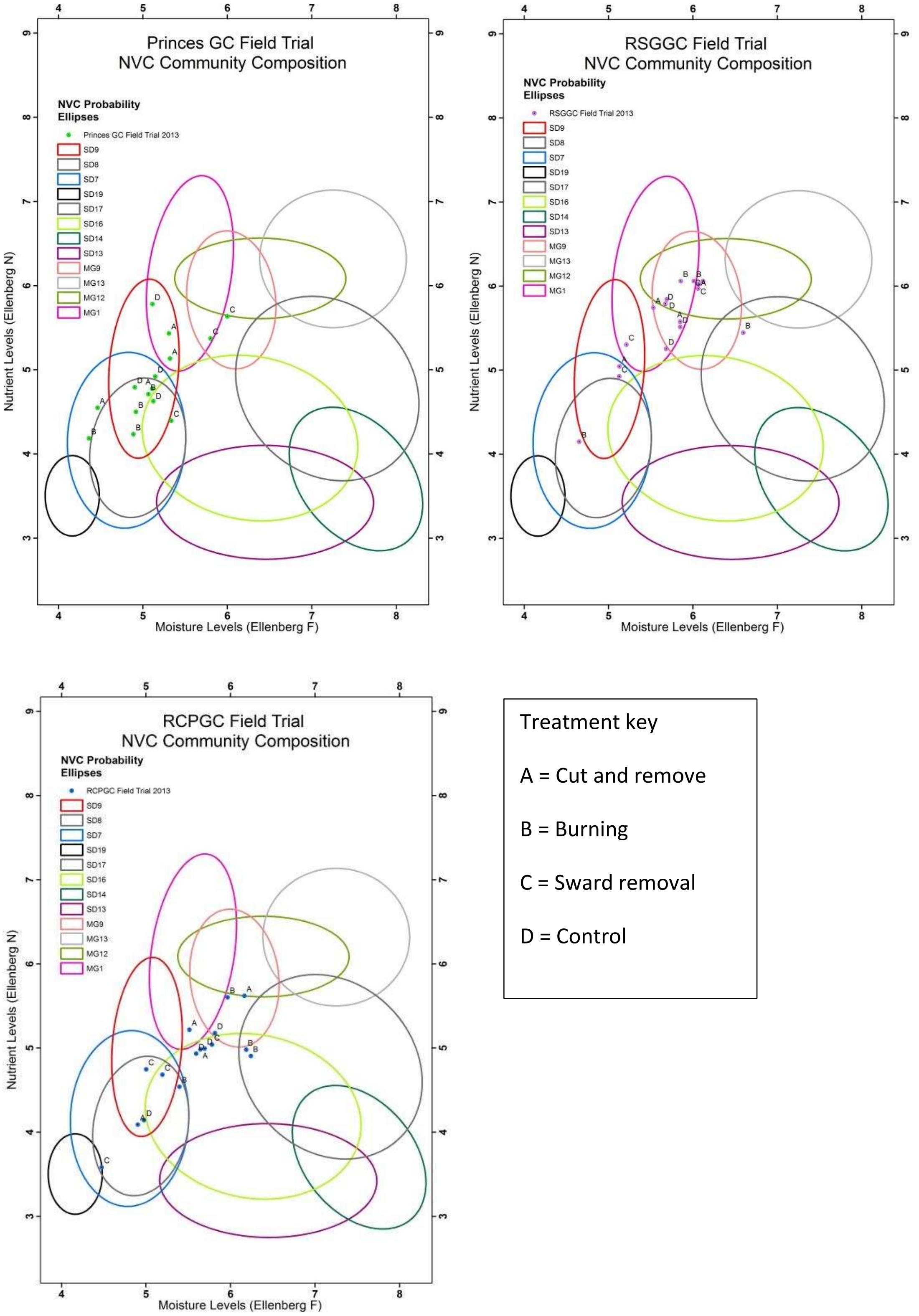
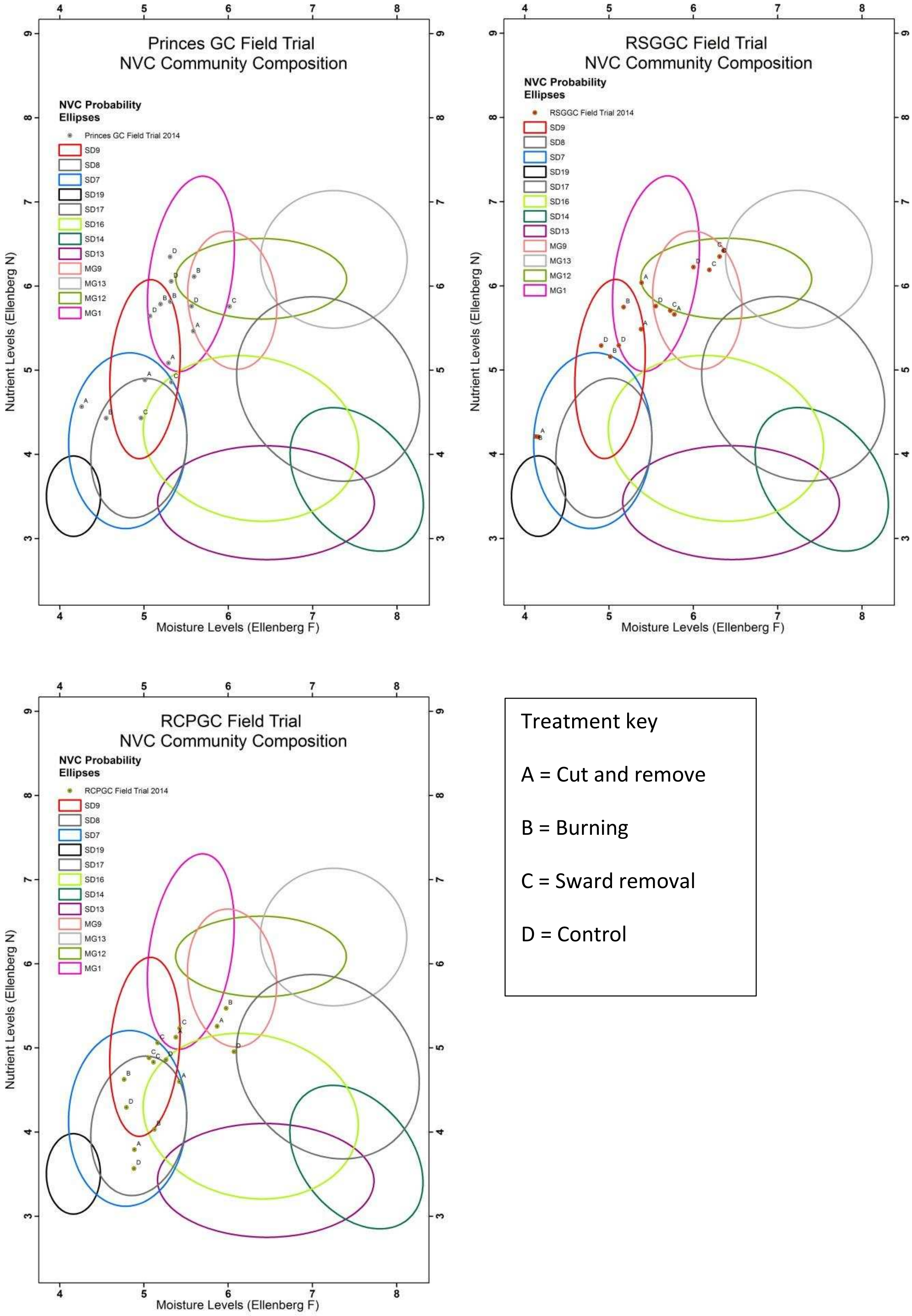


Figure 5.3 Maps showing prediction ellipses estimating the 2013 NVC data for the management trials at each golf course, with treatment labels



Treatment key

A = Cut and remove

B = Burning

C = Sward removal

D = Control

Figure 5.4 Maps showing prediction ellipses estimating the 2014 NVC data for the management trials at each golf course, with treatment labels

Table 5.2 r x c contingency table Chi-squared test on combined management trial quadrat ordinations between the years 2013 and 2014, and Ellenberg F and N gradients

Location	**Ellenberg**	**df**	**α level 0.05**	**χ2 value**
Combined Trials	F	1	3.841	32.755*
Combined Trials	N	1	3.841	1.467

If χ^2 < p-value then accept the null hypothesis
If χ^2 > p-value then reject the null hypothesis (significant chi-square values *)

When visually assessing the management trials, RSGGC appeared to be the most eutrophic location of all the management trials because of the abundance of *Festuca arundinacea* and the opportunistic *Cirsium arvense* and *Equisetum arvense:* pioneer species that recolonized those treatment units with bare ground. RSGGC had the least amount of bare ground out of all three management trial locations, particularly with regards to treatment C (sward removal), where there was a re-colonisation rate of 72.5% after the first year, compared with 18.75% at Princes golf club, and only 5.25% at RCPGC, with the same treatment.

The height of the vegetation was another indicator that the RSGGC management trial area had an excessive amount of moisture and nutrient input, because the vegetation swards were ≥ 40 cm, even in the locations where the sward was removed by mechanical means (treatment C). Table 5.3 shows the different species recorded for each treatment across all of the management trials. This table shows that there are a greater number of individual plant species recorded for treatment B (burning).

Table 5.3 Table of management trial observations; recorded species based upon treatment type (Table adapted from Jones *et al.*, 2009)

	Treatment A (cut & remove)	Treatment B (burn)	Treatment C (scrape)	Treatment D (control)
Bare Ground (Avg %)	6.83 (2013) : 4.33 (2014)	9.25 (2013) : 6.33 (2014)	67.83 (2013) : 60 (2014)	7.5 (2013) : 3.58 (2014)
No. spp.	51 (2013) : 49 (2014)	59 (2013) : 52 (2014)	38 (2013) : 43 (2014)	54 (2013) : 48 (2014)
Species	*Achillea millefolium*	*Achillea millefolium*	*Achillea millefolium*	*Achillea millefolium*
	Agrostis capillaris †	*Agrostis capillaris* †	*Agrostis capillaris* †	*Agrostis capillaris* †
	Agrostis stolonifera	*Agrostis stolonifera*	*Agrostis stolonifera* †	*Agrostis stolonifera*
	Allium vineale	*Allium vineale*	*Ammophila arenaria*	*Allium vineale*
	Ammophila arenaria	*Ammophila arenaria*	*Anthoxanthum odoratum* †	*Ammophila arenaria*
	Anacamptis pyramidalis	*Anacamptis pyramidalis*	*Arenaria serpyllifolia* †	*Anacamptis pyramidalis*
	Anthoxanthum odoratum	*Anthoxanthum odoratum*	*Arrhenatherum elatius*	*Anthoxanthum odoratum*
	Arenaria serpyllifolia †	*Arrhenatherum elatius*	*Artemisia vulgaris*	*Arrhenatherum elatius*
	Arrhenatherum elatius	*Bellis perennis* †	*Asparagus officinalis*	*Asparagus officinalis*
	Artemisia vulgaris	*Brassica oleracea*	*Bellis perennis* †	*Brassica oleracea*
	Asparagus officinalis	*Bromus hordeaceus* †	*Brassica oleracea*	*Carex arenaria*
	Bellis perennis †	*Carex arenaria*	*Campylium stellatum* †	*Carex elata*
	Carex arenaria	*Carex distans*	*Carex arenaria* †	*Carex flacca*
	Carex distans †	*Carex elata* †	*Carex elata*	*Carex hirta* †
	Carex elata †	*Carex flacca*	*Centaurium erythraea*	*Carex nigra* †
	Carex flacca	*Carex hirta* †	*Cerastium arvense*	*Cirsium arvense*
	Carex hirta †	*Carex nigra*	*Cirsium arvense*	*Crepis biennis* †
	Carex nigra †	*Cerastium diffusum* †	*Crepis capillaris* †	*Dactylis glomerata*
	Cladonia rangiformis †	*Cirsium arvense*	*Daucus carota* †	*Dactylorhiza praetermissa* †
	Cirsium arvense	*Cladonia rangiformis* †	*Elymus pycnanthus*	*Daucus carota* †
	Crepis biennis †	*Crepis capillaris*	*Epilobium hirsutum* †	*Elymus pycnanthus*
	Crepis capillaris	*Dactylis glomerata*	*Erodium cicutarium* †	*Equisetum arvense*
	Dactylis glomerata	*Dactylorhiza praetermissa*	*Euphrasia officinalis agg.* †	*Euphrasia officinalis agg.* †
	Elymus pycnanthus	*Daucus carota* †	*Equisetum arvense*	*Festuca arundinacea*
	Elymus repens	*Elymus pycnanthus*	*Festuca rubra*	*Festuca pratensis*
	Equisetum arvense	*Elymus repens*	*Helictotrichon pubescens*	*Festuca rubra*
	Festuca arundinacea	*Epilobium hirsutum*	*Holcus lanatus*	*Galium mollugo*
	Festuca pratensis	*Equisetum arvense*	*Hypochoeris radicata*	*Galium verum*
	Festuca rubra	*Festuca arundinacea*	*Juncus gerardii* †	*Geranium molle* †
	Galium verum	*Festuca pratensis*	*Lathyrus pratensis*	*Helictotrichon pubescens*
	Geranium molle †	*Festuca rubra*	*Leontodon autumnalis*	*Holcus lanatus*
	Helictotrichon pubescens	*Galium mollugo*	*Leontodon hispidus*	*Hypochaeris glabra*
	Holcus lanatus	*Galium verum*	*Leontodon taraxacoides*	*Hypochoeris radicata*
	Hypochaeris glabra †	*Geranium molle* †	*Lotus corniculatus*	*Juncus gerardii* †
	Hypochoeris radicata	*Helictotrichon pubescens*	*Moehringia trinervia* †	*Juncus maritimus*

	Juncus gerardii †	*Holcus lanatus*	*Oenothera stricta* †	*Koeleria macrantha*
	Juncus maritimus	*Hypochaeris glabra*	*Papaver dubium*	*Lathyrus pratensis*
	Koeleria macrantha	*Hypochoeris radicata*	*Pimpinella saxifraga*	*Leontodon autumnalis*
	Lathyrus pratensis	*Juncus acutiflorus*	*Plantago lanceolata*	*Leontodon hispidus* †
	Leontodon autumnalis	*Juncus gerardii* †	*Potentilla reptans*	*Leontodon taraxacoides*
	Leontodon hispidus †	*Juncus maritimus*	*Pulicaria dysenterica*	*Lotus corniculatus*
	Leontodon taraxacoides	*Koeleria macrantha*	*Ranunculus repens*	*Luzula campestris*
	Lotus corniculatus	*Lathyrus pratensis*	*Rhytidiadelphus squarrosus* †	*Ononis repens*
	Luzula campestris	*Leontodon autumnalis*	*Rumex acetosa*	*Phleum bertolonii*
	Phleum bertolonii	*Leontodon hispidus*	*Rumex acetosella* †	*Pimpinella saxifraga*
	Pimpinella saxifraga	*Leontodon taraxacoides*	*Rumex crispus*	*Plantago lanceolata*
	Plantago lanceolata	*Lotus corniculatus*	*Sedum acre*	*Poa pratensis*
	Poa pratensis	*Luzula campestris*	*Senecio jacobaea*	*Potentilla reptans*
	Potentilla reptans	*Ononis repens*	*Silene latifolia*	*Pseudoscleropodium purum*
	Pseudoscleropodium purum	*Phleum bertolonii*	*Silene noctiflora*	*Pulicaria dysenterica*
	Pulicaria dysenterica	*Pimpinella saxifraga*	*Solanum dulcamara*	*Ranunculus repens*
	Ranunculus repens	*Plantago lanceolata*	*Stellaria graminea*	*Rubus fruticosus agg.*
	Rubus fruticosus agg.	*Poa pratensis*	*Taraxacum sp.* †	*Rumex acetosa*
	Rumex acetosa	*Potentilla anserina*	*Torilis japonica*	*Rumex acetosella* †
	Rumex acetosella	*Potentilla reptans*	*Trifolium campestre*	*Rumex crispus*
	Rumex crispus	*Pseudoscleropodium purum*	*Vicia cracca*	*Senecio jacobaea*
	Senecio jacobaea	*Pulicaria dysenterica*	*Vicia sativa* †	*Silene latifolia*
	Silene noctiflora	*Ranunculus bulbosus* †		*Silene noctiflora*
	Sonchus arvensis	*Ranunculus repens*		*Sonchus arvensis*
	Stellaria graminea	*Rubus fruticosus agg.*		*Stellaria graminea*
	Torilis japonica	*Rumex acetosa*		*Torilis japonica*
	Tragopogon pratensis	*Rumex acetosella* †		*Tragopogon pratensis*
	Tortula ruralis ruraliformis †	*Rumex crispus*		*Trifolium campestre*
	Trifolium campestre	*Senecio jacobaea*		*Urtica dioica*
	Vicia cracca	*Silene latifolia*		*Vicia cracca*
	Vicia sativa †	*Silene noctiflora*		*Vicia sativa* †
	Vicia tetrasperma †	*Stellaria graminea* †		*Vicia tetrasperma* †
		Sonchus arvensis		
		Stellaria graminea		
		Tragopogon pratensis		
		Trifolium campestre		
		Veronica chamaedrys †		
		Vicia cracca		
		Vicia sativa †		
		Vicia tetrasperma †		

†—new species appearing since last monitoring period. Underlined species were not recorded in the control treatment.

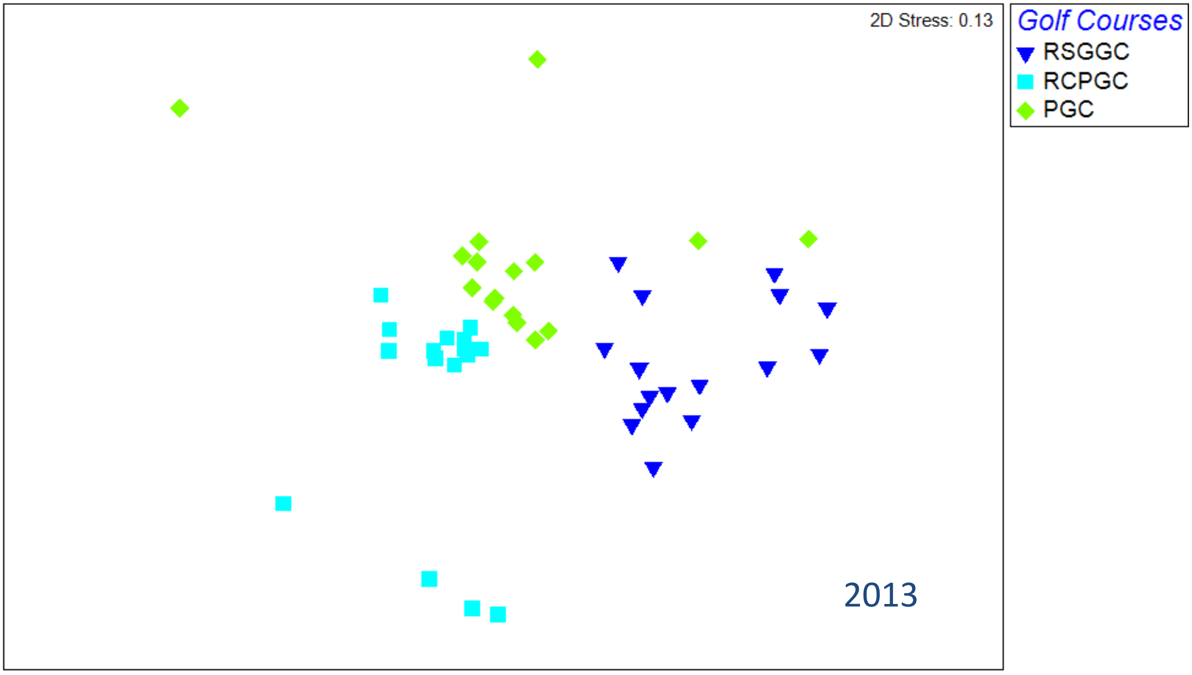
Two-dimensional quadrat ordinations were created using nMDS plots, which show similarities in data, based upon the Bray Curtis similarity index. In an nMDS plots, distances between points on graph are an approximation to their degree of similarity in terms of the distribution between quadrats (Kent, 2012). To aid interpretation, NVC classifications and treatment units were assigned as factors.

The stress levels indicated in the nMDS plots represent how well the multidimensional data fits the 2 dimensional plot (Buckley, 2001), for example, a stress level of 0.07 indicates a good ordination with no real prospect of a misleading interpretation, while a stress level of ≥0.30 indicates that the data were difficult to fit and has a level of inaccuracy in the data.

nMDS plots were also created to analyse species composition based upon site. Figure 5.5, indicates that the quadrat species data at Princes Golf Club and RCPGC, were similar species compositions based upon the data recorded at the management trials.

Analysis of the 2013 nMDS plot showing NVC and treatment allocation (Figure 5.7) indicates that treatments had an effect on species assemblages in the first year of the trial, with clear treatment-biased clustering, independent of NVC classification. The 2014 analysis showed that after initial disturbance during the application of the treatments, all treatments, apart from treatment C, varied in species composition. Site-specific analysis showed that RSGGC had the greatest variation in species composition in both of the recorded years.

Analysis, using nMDS and treatment-specific NVC classifications indicated that treatments A and B, promoted the greatest variation in species composition, based upon nMDS analysis. While site-specific analysis showed that treatment B, particularly for RSGGC, selected a greater range of species than any other treatment (Table 5.3), the level of relatedness between management treatments and NVC classifications, showed that treatments A and B selected for NVC classification SD8 (Figures 5.6 and 5.8).



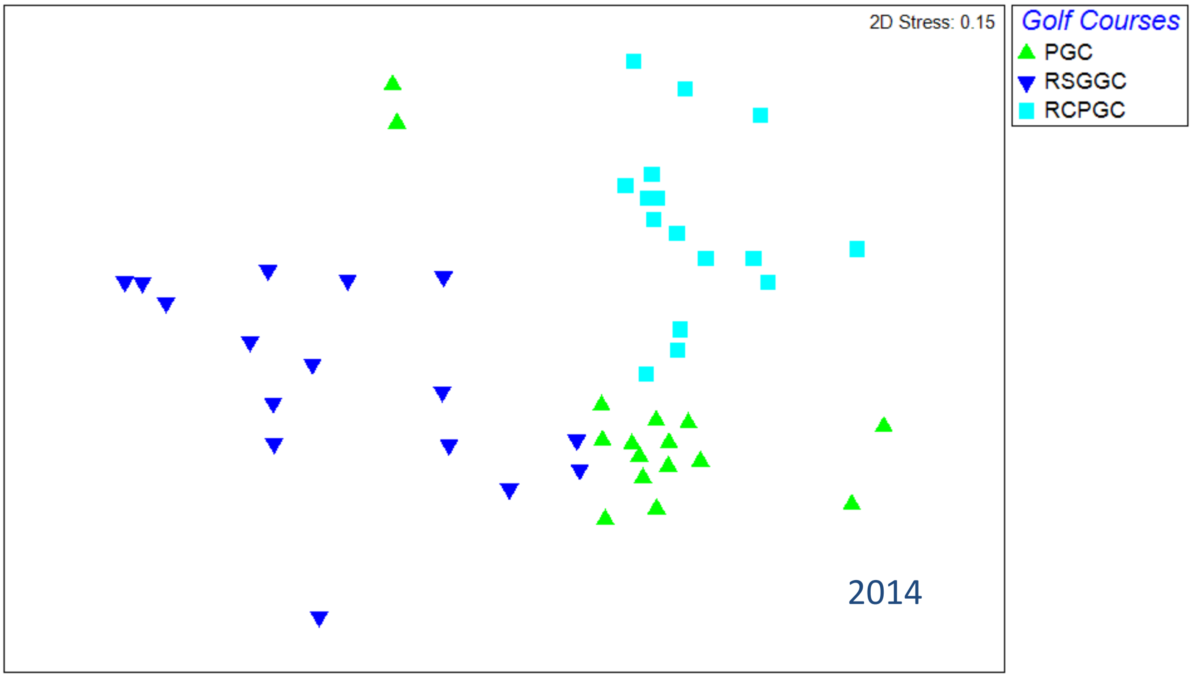


Figure 5.5 nMDS plot of vegetation similarities in the management trial treatments between golf courses at Sandwich Bay for (top) 2013 and (bottom) 2014

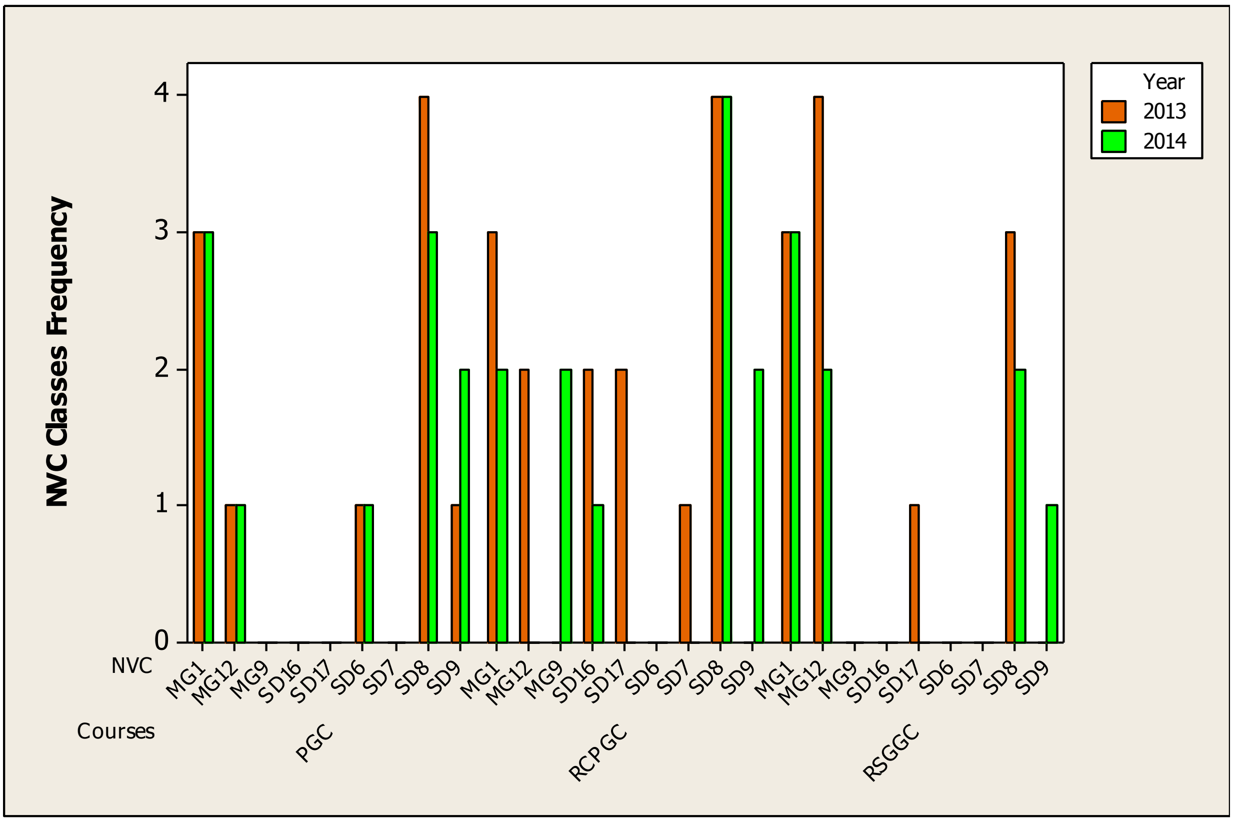


Figure 5.6 Graph showing the frequency of NVC communities in the management trials at different golf courses

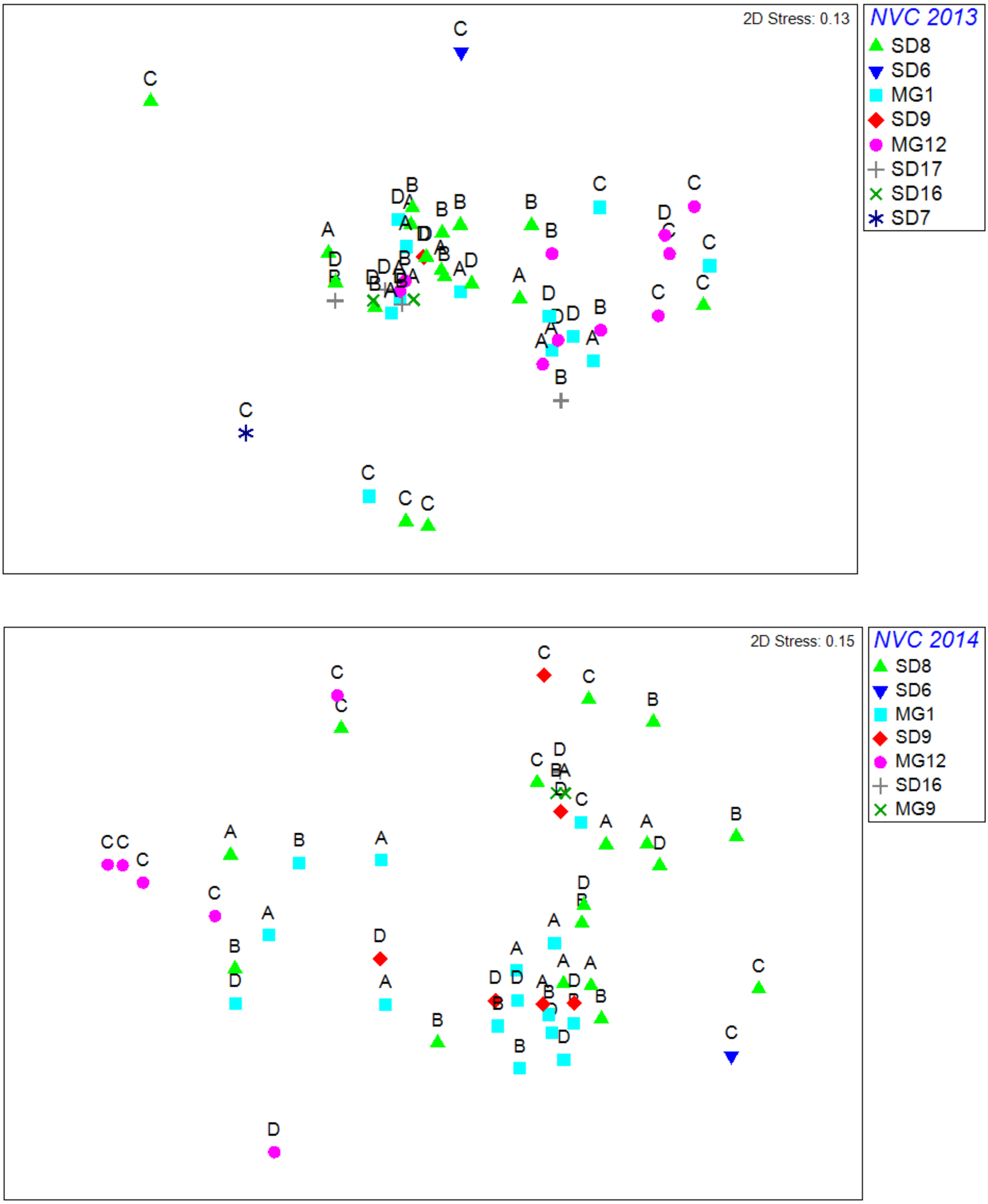


Figure 5.7 Non-metric multi-dimensional scaling similarity plot of all management trial treatments at Sandwich Bay, showing NVC classifications treatments for 2013 (top) and 2014 (bottom)

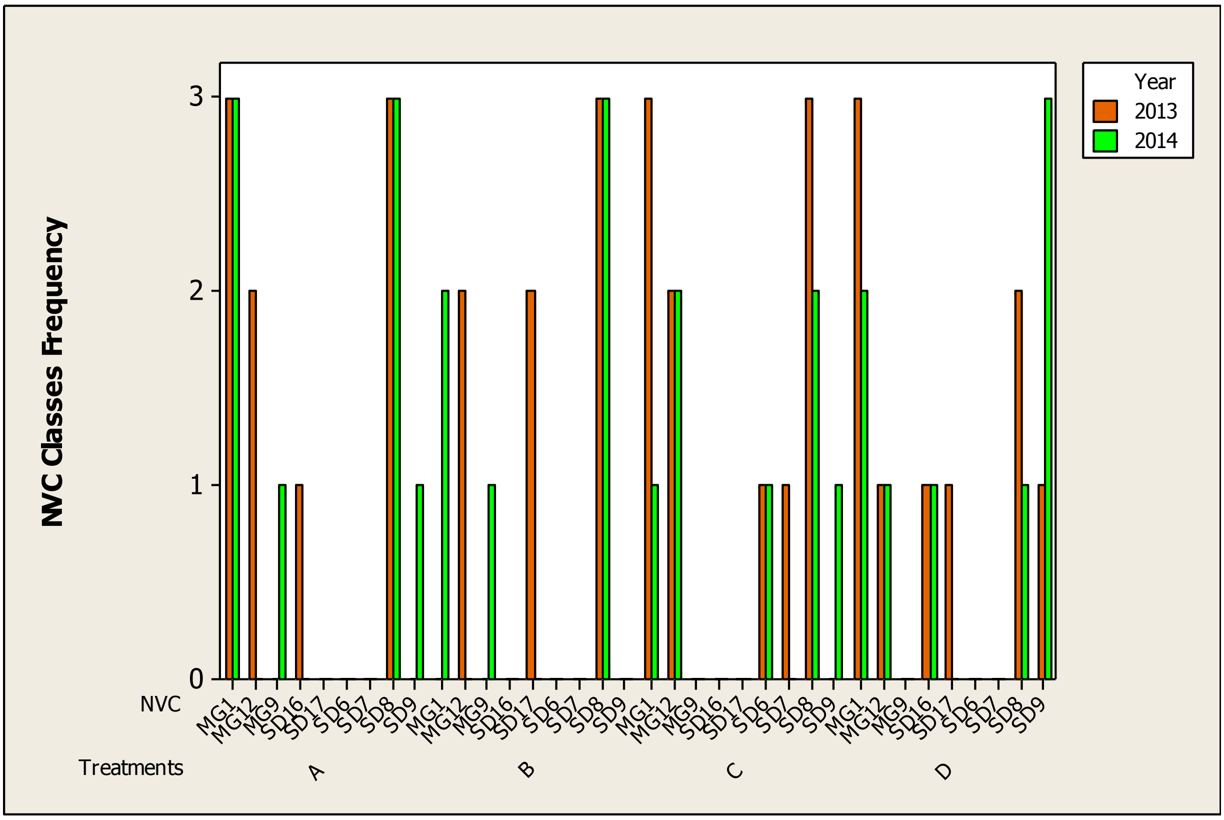


Figure 5.8 Graph showing the frequency of NVC communities within different treatments across all management trial treatments at Sandwich Bay

5.4 Conclusion

Management trial analysis

After reviewing the pseudo-quadrat data, the observed vegetation composition change in distribution was noted to be similar to that discerned when analysing the overall vegetation change across Sandwich Bay, whereby an increase in nutrients and moisture levels was an influencing factor in vegetation composition change.

Table 5.3, shows the recorded species for the combined management trials for each of the treatments. The analysis of the species composition for each treatment shows that burning provided the most desirable habitat for re-colonisation by SD8 species assemblages (.

Although disturbance has been shown to promote vegetation re-colonisation (Jones *et al*., 2009), it is important to note that an established nearby seed bank is an important factor for vegetation re-colonisation. When analysing treatment C (scraping), particularly for RSGGC already established seed bank nearby containing MG12 specific species: such as, *A. elatius* and *F.* arundinacea. However at other management trial locations, treatment C selected for species typically found in SD8, such as *F. rubra, G. verum, Pimpinella saxifraga, and A. arenaria.*

Relief is also a contributing factor to species colonisation. For example, the management trial at RSGGC was located in a large dune slack, which was sheltered by other dune formations. The other management trial locations situated at Princes Golf Club and RCPGC were in areas that were exposed to quite strong inshore winds, particularly that at RCPGC, where wind desiccation was noted, from ground-observations in the field, to be a limiting factor when comparing the size and cover of similar species across the different management trial locations. *Holcus lanatus*, for example, is a broader-leafed grass, and although it was present throughout all of the management trial locations, it was particularly stunted in areas where wind disturbance was apparent.

This implies that wind desiccation could have been an unaccounted-for variable affecting vegetation re-colonisation within the management trials (Jones *et al*., 2009).

nMDS ordinations showed that, of the treatments observed, burning proved to be the most consistent management treatment application, in promoting the growth of SD8 vegetation across all of the sites. Although it is noted that burning does recycle nutrients, the process of burning also reduces the thatch, allowing for existing seed banks, with a more diverse sward, to re-establish, on what is essentially bare ground after the burning treatment is applied. While the cut and remove treatment produced similar results across two of the golf courses, burning proved to be the most successful treatment for eutrophic areas, such as those found in the management trial at RSGGC.

Treatment application limitations

The aim of the burning treatment was to have a deep penetrating burn down to ground layer but, due to wet weather, the fact that the grass swards were cut late in the season (to mark out the plots), and because of relatively lush vegetation due to a mild winter, it proved difficult to obtain a deep burn and in some cases only localised charring was achieved. Ideally the preferred conditions to burn swards as a treatment in a sensitive and managed environment, such as Sandwich Bay, would include a full year's growth of sward that has died back, with a prevailing westerly offshore wind, to disperse smoke from the treatment away from the shore, and either dry ground or a heavy ground frost.

The standardisation of the sward removal treatment involved sward removal to depths ranging from 6 inches to 10 inches below ground level. Unfortunately, inconsistent depth of sward removal and related mechanical compaction to some of the surrounding management trial plots was unavoidable, which may have affected vegetation re-colonisation and existing vegetation growth.

In areas where possible compactions were noted, the vegetation growth of these areas was considered and relative vegetation height was compared to surrounding areas that had not been compacted. Visual analysis, water infiltration and vegetation height, indicated that compaction as a factor affecting vegetation re-colonisation could be ruled out.

Methodological problems

The treatments undertaken were based upon available equipment and expertise. For example, the scraping treatment was undertaken at a later date due to the availability of equipment and trained operators. However, to maintain a consistent timeframe, all operations relating to the management trials were undertaken within a month, to ensure that the potential re-colonisation and vegetation growth timeframes were standardised where possible.

Analyses were performed to investigate the dynamics between vegetation composition and various factors that could affect species development in the landscape such as elevation, water table height, hydro-chemical parameters, and management trial treatments. However it was acknowledged that there were other possible contributing factors that affected re-colonisation of particular species, rather than the management treatments, such as the amount of organic material available at each management trial site, the capillary rise in the soil, and the age of the dune systems.

The following chapter will briefly analyse the work that was undertaken and relate the findings to the original questions put forward at the start of this study.

Chapter Six

Conclusion and Future progression

6.1 Overview of the research

There are three distinct areas of investigation in this study. The first examined both the historic data and the newly acquired data, focusing upon the vegetation composition and how the species structure has varied in the intervening years. The second concentrated on a hydro-chemical analysis of the groundwater and how this related to vegetation communities within 1 m distance of each sample/dipwell position. The third looked at a range of different management techniques in a small-scale area, and consisted of a ground-level analysis of management treatments that could conceivably promote a range of different species assemblages. This was done with the intention of implementing effective management techniques into the management regimes of the golf courses, focusing particularly upon those areas identified as having unfavourable conditions according to the Annex 1 Habitats Directive based loss of grey dunes priority feature (Dargie, 2002; Williams, 2012).

6.2 Main conclusions of chapters

Chapter 1 - Literature review

Over a third (35.4%) of sand dunes in the UK (Taylor, 2012), are managed as golf courses (Saito, 2010; R&A, 2013). Therefore golf course management could be a crucial influence on the overall health of this endangered habitat. Most studies of dune systems are undertaken on sand dunes which not managed for amenity purposes (Jones, 2014; *pers. comm.).*

Current studies focus mainly upon dune slacks within sand dune systems (Jones *et al.,* 2006), and not dry fixed dunes, such as the grey dunes at Sandwich Bay. Research undertaken within sand dunes as indicated that there is a trend in the loss of plant diversity, and a number of different management techniques have been researched and implemented to encourage diversity of swards.

Past studies of Sandwich Bay, indicate that the observed trends in the decline of sensitive sand dune plant communities found other sand dune systems is also apparent even though the dune systems at Sandwich Bay reside within the particularly dry locality. Reasons for this decline and the rate and speed of this decline were not fully understood. Speculated reasons included increased nutrient input and increased retention of moisture in the dune system, possibly driven by sea level rise (Dargie, 2009).

Chapter 2 - Historic NVC datasets

Two main datasets exist for past conditions in Sandwich bay for the years 1989 and 2001. Analysis of these two datasets indicated that the majority of change in vegetation composition was from diverse SD8 type community structures to more generalist MG1 grass communities. There were also a number of communities that were SD8 in both time periods, and a small number of communities that reverted from MG1 to SD8 between 1989 and 2001.

Chapter 3 - Dipwell installation

A feasibility study for an extensive network of ground water monitoring locations, using narrow bore holes (dipwells) on a sand dune system was carried out. The initial investigation used a desk based analysis of historic NVC datasets and an independent site based elevation survey, the combination of both of these factors informed judgement-quota sampling. Siting boreholes based on site elevation and historic NVC data proved to be a successful strategy, and would be recommended for future establishment of a similar study area.

Chapter 4 – Geographical and hydrological analysis

LiDAR

The Lidar data showed that elevation was a significant factor in predicting NVC category. NVC categories that were more desirable from a conservation point of view (such as SD8) were consistently found at higher elevations.

Meteorological

Observation of historic meteorological data indicated that there was an ongoing trend of increasing precipitation at the study site. This trend could encourage the establishment of more generalist and flood tolerant communities, such as MG12 and MG13.

NVC Pseudo-quadrats

The pseudo-quadrats showed a change is species composition between 2012 and 2013. Change from SD communities to MG communities happened most often at sites of lower elevation. Analysis over the period showed a significant change of communities towards moisture tolerant communities such as MG12 and MG13. Change of communities to more nutrient adapted communities was significant at a local level, but not across the entire study area. This could be due to differences of management approach across the different golf courses.

Hydro-chemical analysis

This analysis indicated that there was no significant association between species composition and any of the physico-chemical variables that were measured, with the exception of water table height. This was probably due to the lack of contact between the overlying vegetation communities and underlying groundwater.

IDW analysis

Overall the IDW maps showed that NaCl and KCl concentrations both significantly negatively correlated with dune elevation, while TON concentrations were significantly positively correlated with dune elevation. In addition, IDW mapping picked up unusual impacts such a tidal surges and land use change. Therefore IDW maps are of use for picking up both general patterns and anecdotal changes that could affect the validity or accuracy of management decisions based on routine monitoring.

Chapter 5 - Management trials

Ellenberg ANOVA analysis

ANOVA analysis of Ellenberg scores showed a significant post treatment shift towards halophytic communities for swards that were subjected to scraping (sward removal). The scraping treatment also encouraged the establishment of more generalist plant communities in eutrophic areas (such as the RSGGC trial site). This same scraping treatment produced a sparse herb rich sward in more dystrophic conditions (such as the RCPGC and Princes trial sites). Two treatments that increased the general diversity of the sward, compared to the control swards, were burning and cut-and-remove treatments.

Management trial NVC pseudo-quadrats

Pseudo-quadrat analysis of the treatments specific to the three trial areas indicated that there was a directional movement for Cut-and-remove and Burning treated swards towards SD8 community composition. Chi-squared analysis indicated that of the factors in the pseudo-quadrat data moisture was the significant factor.

6.3 Research questions and null hypotheses

Based upon the literature review in Chapter 1, a number of questions were posed, and a number of null hypotheses were generated to test possible answers to these questions. The research questions involved data which were both numerical and categorical (NVC classifications). The questions asked are listed below, and answered based upon investigation of this study.

Are there any relationships between nutrient levels and vegetation communities at Sandwich Bay?

Analysis of the hydro-chemical data showed that there was no significant effect of varying concentrations of nutrients upon vegetation communities. The literature suggests that dune slack species (e.g. SD16 *Salix repens–Holcus lanatus* dune-slack community) are more influenced by water chemistry and fluctuations in groundwater (Jones *et al.,* 2006), than the SD8 *Festuca rubra–Galium verum* (fixed dune grassland) species which prefer drier conditions (Jones, 2014; *pers. comm*.). There was variation in the nutrient levels across Sandwich Bay;

however analysis indicated that chemical parameters are not a significant factor affecting vegetation colonisation in this dune system.

Does the variability in water table height affect vegetation composition?

The 2009 report at Sandwich Bay (Dargie, 2009), recommended an investigation into possible increases in the water table promoting vegetation change from diverse swards (SD8) to neutral grassland (MG1/MG12). In addition to this, the use of remote sensing was suggested. To investigate these elements from the 2009 report, two null hypotheses were created; 1. '*there is no correlation between ground elevation and vegetation community cover'* and 2. '*there is no significant relationship between vegetation colonisation and water availability*'.

Analysis of LiDAR indicated that there was indeed a statistically significant correlation between ground elevation and NVC type, when analysing adjusted dataset ≥ 3 replications of NVC classifications. Therefore the first null hypothesis was rejected.

The investigation into the second hypothesis was not so clear cut. For 'dry' NVC types, such as SD8 and MG1, the species composition showed evidence that it was not influenced by the groundwater and vegetation was more influenced by precipitation. However, for 'wet' NVC communities, such as SD13 and MG13 communities there was a significant influence of water table height on community type, with SD 'wet' communities occurring closer to the water table than MG 'wet' communities. Therefore the second null hypotheses was rejected for 'wet' type communities, but accepted for 'dry' NVC communities.

Is the use of remote sensing data practical for NVC surveys?

LiDAR data were the only remote sensing data used in this study. DTM data were predominantly used throughout and allowed for analysis of specific elevations of individual NVC classifications at fixed points. The benefits of LiDAR in assessing different vegetation structures by subtracting DTM and DSM datasets from each other have been well-documented (Hopkinson *et al.*, 2003; Horning *et al.,* 2010; Petchey *et al.*, 2011). However, investigations undertaken by this research were not concerned with the height of individual species or related assemblages, but the elevation of NVC vegetation types.

LIDAR analysis of the Sandwich bay area showed that the different NVC types occurred at significantly different elevations.

Can land management techniques elicit vegetation change at Sandwich Bay?

The null hypothesis created to help answer this question was; '*Land management techniques have no significant effect on vegetation colonisation patterns*'. Trials of four different management techniques demonstrated that both cut-and-remove and burning techniques promoted species composition change towards a more desirable SD8 type NVC community structure. The scraping technique appeared to work well in low nutrient and moisture conditions, but was less effective in more eutrophic and wetter conditions. Therefore the null hypothesis can be rejected for cut-and-remove and burning, and in some but not all cases for scraping.

6.4 Research issues

Comparisons of other sand dune systems

Although sand dune systems may be similar in appearance, and even in the vegetation assemblages present, there are fundamental differences that make each sand dune system unique in its own right. There are a number of contributing factors that are driving-forces for the formation of dune systems; in order of importance:

1. Positioning in relation to coastal processes, (i.e. Kenfig dunes);
2. Variation in precipitation levels
3. Energy in the system to shape and mobilise sediments;
4. Accreting or eroding coastline;
5. Shape and topography of the underlying landmass
6. Infrastructure;
7. Agricultural activities;
8. Underlying bedrock.

The issue of having a baseline was addressed by categorising the dipwells bounded within amenity management as one category, and the dipwells outside amenity management were situated in areas where agricultural management was in place such as grazing, silage and hay production, and a few areas which were classed as set-aside/wildlife areas within the golf courses. Direct comparison of this study would have to be undertaken and dune systems that have are similar amenity pressures, similar accreting or eroding coastline and energy in the system.

Vegetation analysis

Only categorical data were available from previous surveys, and continuous data such as water table height and hydro-chemical variables were not available. This meant that there was no baseline prior to the present investigation against which to compare vegetation change against varying chemical constituents and water table fluctuations at Sandwich Bay. Statistical analysis had to be able to interpret the relationships or correlations of continuous data (water table fluctuations) with categorical data (vegetation classes) which have no mathematical reference. An example of this was the difficulty of correlating discrete data, such as vegetation classification types based upon NVC surveys, with continuous data, such as the height of the terrain derived from LiDAR data sets. The implications of this meant that Ellenberg gradients scores were used to interpret categorical data, particularly when analysing the effects of the management trials. However Ellenberg gradients such as nutrients and salinity do not necessarily represent physico-chemical parameters such as total oxidised nitrogen and sodium chloride concentrations.

Hydro-chemical relationships of vegetation compositions

Hydro-chemical analysis at Sandwich Bay had never been undertaken previously, except for infrequent sampling by the Environment Agency of the single ditch next to RSGGC club-house, and the end of the River Stour as it flowed out into the sea.

The golf courses do not necessarily check the chemical constituents of the water extracted for irrigation purposes, except for infrequent checks of the electrical conductivity of the hectare-sized reservoir located at Princes Golf Club. This meant that the hydro-chemical conditions at Sandwich Bay were relatively unknown. The closest hydro-chemical values obtainable were from a research study investigating invasive species along the River Stour (Buckley, 2006). The chemical values from this study confirmed that there was an element of saline incursion along the River Stour beyond the water extraction point for irrigation at Princes Golf Club and Royal St Georges Golf Club.

Research undertaken by Curreli *et al*., (2013), indicated that, for vegetation assemblages to be affected by the groundwater, the water table needed to be close to the ground surface. Jones (2014) suggested that, in dry dune systems where the water table location is >2 m below surface level, vegetation compositions have an element of dissociation from the chemical conditions of the groundwater, and are more likely to be affected by precipitation and, in a managed landscape such as a golf course irrigation. It is to be noted that the climatic conditions during the study were not indicative of normal seasonal variability, the climatic conditions noted winter/spring broke records in southern UK for the amount of precipitation, and this would have had an impact on the vegetation composition and hydro-chemical constituents of the groundwater. However due to time constraints of the thesis, these potential climatic implications were not investigated.

Management trial implementation and translation

The limitations of the management trials were the geographical positioning and the suitability of available locations. For direct comparisons between management trials, each of the trial locations would ideally have had similar elevation, distance from the high tide mark, and similar soil conditions. As it was, the management trials extended from a coastal sea wall outwards, in an east to west direction, towards the rear of the dune systems, opposite fertile farmland.

The definitive purpose of the management trials was to remove available nutrients and reduce the accumulation of organic matter in the system. However, the treatments are not necessarily creating a new long-term habitat, but instead are maintaining, and potentially restoring, plant communities to a sparsely-vegetated sward layer. This was assessed by allocating a numerical value to each of the treatments, based upon Ellenberg values for different gradients (Ellenberg L, F, N, R and S), relating to recorded species composition, and to rank related treatments based upon the diversity.

Time limitations with respect to the management trials undertaken at Sandwich Bay, meant that definitive conclusions from this analysis of these site-specific management regimes can only have relative accuracy if the management trials continue for a greater extended period than study has allowed, therefore to draw accurate representation of all management techniques they need to be continued for an extended period of 10 years with annual analysis of the species compositions.

6.5 What are the implications of this thesis for the management of sand dunes?

The study found that the key implications to management of sand dunes are to do with the hydrological dynamics of the dune systems, particularly the amount of moisture that was retained within the dunes. The comparisons between historic and current vegetation data for a target dune system leads to research informed management, for example LiDAR analysis indicated that elevation had a significant effect on the species compositions that are found within SD8 NVC types, therefore an active management for a dry dune system such as Sandwich bay would benefit from dune nourishment, where sand could be redistributed in a dune system to artificially increase the height of the dunes.

For Sand dune systems that have a paucity of dune slacks, the physico-chemical state of the underlying groundwater, is not a significant management concern. However, this conclusion come with the following *caveat*: within an actively managed area, the application of nutrients to intensively managed areas in play was an unknown and further investigation was needed to understand the effects of low and high nutrient inputs to adjacent sensitive natural areas.

LiDAR and tidal amplitude observations specified that the transmissivity of the dune aquifer was consistent across the 1km transect. Even daily fluctuations in the height of the sea and the nearby Stour estuary affected the height of the water table. Therefore sea level rise is likely to have a significant impact on the dune system. Active management of the dune system in the medium term could involve a seasonal and tidally dictated variation in the irrigation, to account for tidal fluctuations, such as spring tides.

Management trials indicated that burning and, cut-and-remove were efficient management treatments, while scraping depends on pre-treatment assessment. Two years observation is not long enough and needs to be extended, and management techniques that reduce water retention in the sward layer are more likely to have beneficial effects.

6.6 Study Impact

The study involved working closely with the course management staff of all three golf courses located at Sandwich Bay. The frequency of ground-based observations required for this type of study permitted a large amount of knowledge dissemination, as the results gained were reported back to the golf courses as the study progressed.

This led to the enthusiastic adoption of an environmentally-conscious outlook on the management regimes incorporated in the golf courses, and major adjustments in what had been classed as tried and tested historic practices have been incorporated into the management regimes of all of the golf courses. These included the application of extensive cut-and-remove practices on the roughs in winter, burning of the roughs during early winter, and a review of the irrigation rates applied to the dune system.

One example of the impact that this study has had upon golf course management regimes can be highlighted in respect of the way that golf courses are irrigated using water table height measurements.

In 2013, RSGGC club reduced the water regime by roughly half of their allowed extraction quota, using approximately 12000 cubic metres of water throughout the entirety of the year, out of a possible 21000 cubic metres of water that is permitted by the extraction licence. This was the lowest amount of water extracted to irrigate the course on record at RSGGC irrespective of the weather conditions and the amount of precipitation within that year, as a direct result of the change in management KCl concentrations were reduced across RSGGC between spring 2013 – autumn 2013.

The reasoning behind this was based upon the head green keeper, Paul Larsen's, decision to intervene to reduce generalist swards (i.e. *Poa annua* - annual meadow grass), that out-compete the fescue grasses on the golf course. A maintained moisture content of greater than >35% will allow *P. annua* to persist, while reducing the relative moisture in the greens to 20% favours the finer swards such as *Fescue spp* (Carrow *et al*., 2001).

The reason why this was a radical development in course management is due to the fact that it is expected that golf courses should have 'definition', which is clear distinction between the playing surface and the rough. An element of definition on golf course is also a recommendation (Taylor, 2012) from the Royal and Ancient Golf Club (R&A), whom they are governing authorities of the game, and particularly applies to those courses involved in the British Open.

Orchid counts are undertaken by Kent Wildlife Trust at Sandwich Bay every year, focusing predominantly at RSGGC (Swandale, 2013). Species of interest are mainly *H. hircinum,* which is classed as nationally rare, and is only able to grow under suitable conditions, which in turn favour SD8 plant communities. It was noted that in 2013 there was a substantial increase in *H. hircinum*, counts at Royal St. George's Golf Club (Swandale, 2013; Swandale, 2014), with 1915 observations in the year 2012, 3099 observations in the year 2013 and 2080 observations in the year 2014 (Swandale, 2014).

It is unclear what set of conditions favoured such an increase in *H. hircinum* during the year 2013. However it is noted that the irrigation regime in 2014 had reverted to an irrigation regime similar to that which had been applied in 2012, due to pressure to increase definition on the golf course. It would, however, be premature to draw any conclusions about effects of the change in irrigation regime, as meteorological conditions, viability of the existing seed bank and the amount of disturbance that is needed to promote of growth of *H. hircinum* are unknowns. However the meteorological data (Figures 4.10 and 4.12), indicates that the observed water table measurements and the amount of precipitation during the summer of 2013, in addition to a change in management, would have had a beneficial effect on the growth of *H. hircinum*. Further investigation into the effects of irrigation, would provide additional insight into vegetation dynamics in managed landscapes.

6.7 Future progression

Continuation of the undertaken research

The research undertaken as part of this thesis has resulted in Sandwich Bay currently being classed as the most extensively monitored sand dune system in the United Kingdom. The importance of maintaining a continuation of the hydrological analysis has been agreed between Princes Golf Club, Royal St George’s Golf Club, Canterbury Christ Church University, Natural England and the Centre for Ecology and Hydrology.

The hydrological analysis is to be continued across a small number of dipwells along the transect shown in Figure 4.5 located at Princes Golf Club, with a further transect to be allocated across Royal St. Georges Golf Club. Additionally, upon agreement with the golf courses, the management trials were set up in locations where they will be allowed to persist for a minimum of 3 years (the duration of the study), with the possibility of extending this to 10 years, providing the opportunity for annual assessment of species dynamics and re-colonisation rates at the management trials.

Effects of irrigation

The research did not analyse the effects of irrigation, although the theoretical implications of plant species populations being directly affected by irrigation were considered. The rationale focused upon the groundwater, as it was theorised that this would have a greater effect on vegetation composition and structure than that of localised irrigation. It is conceivable that the effects of irrigation could promote an island biogeographical effect upon populations of specific plant assemblages (Jones, 2014; *pers. comm*.).

Future analysis of this site would need to investigate the spatial effects of irrigation and vegetation composition structure in areas out-of-play. The water chemistry from the River

Stour extraction points and from available reservoirs on the courses needs to be investigated chemically on a seasonal basis to ascertain if there is an influx of nutrients entering the dune systems inadvertently, due to the extraction processes used to aid irrigation.

The effects of irrigation could be measured by monitoring infiltration rates and taking soil profiles to observe the capillary rise in the strata. In addition to this, the dipwells could provide a baseline of groundwater chemistry compared to that of irrigation water chemistry.

Dune remobilisation management trials

The research undertaken at Sandwich Bay considered the remobilisation of the dunes as a pseudo-management treatment by adopting nourishment adaptation to dune remobilisation (Pye & Blott, 2012). This nourishment adaptation of dune remobilisation, involves strategic placing of sand which can then be redistributed within the Dune system to encourage establishment of pioneer species further inland, increasing isolated areas of diversity, which is of particular benefit within a fixed dune system. AA pilot trial of remobilisation was undertaken in October 2013, by positioning excavated sand at the northern end of Sandwich Bay on Princes Golf Club.

Modifications to the 7th Himalayas hole at Princes Golf Club, allowed for an excess of available excavated sand, which was positioned in an exposed area where management of the dune systems is restricted and where conditions are suitable for sand particle movement due to inshore winds. The rationale behind this *impromptu* management technique was not only to observe small-scale remobilisation, but also to investigate whether elevation is a limiting factor with regards to sward development, as was indicated by the LiDAR analysis.

Unfortunately the opportunity to undertake this type of management trial occurred towards the latter end of the study time period and to carry the investigation further would have exceeded the time limits of the current academic research, in particular because significantly more energy is needed for mobilisation as against stabilisation (Pye & Blott, 2012). Consequently the treatment was attempted purely as an observational exercise in addition to the management trials. Species re-colonisation rates will be recorded on an annual basis similar to that of the management trials, and recording has been allowed to continue with agreement from Princes Golf Club.

Extension of the study to encompass further study sites

In order to draw more general conclusions about the findings of this thesis it is necessary to investigate the same issues and parameters at other sites. This will give a more balanced view of conclusions and reveal which findings are generally true, and which findings are subject to local influence.

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Glossary

Aerial photography - a vertical picture often taken from aeroplanes which can give informed decisions of ecological dynamics and other features in the landscape.

Areal extent - the magnitude of an area. This term is often used in cartography.

Compact Airborne Spectrographic Imager (CASI) - high-resolution multispectral scanner imagery that is similar to the Landsat data but is flowing rather than satellite captured.

Coordination of Information on the Environment (CORINE) - CORINE programme is a broad European classification system that focuses inventory of land cover in 44 classes, and presented as a cartographic product, at a scale of 1:100 000. The CORINE programme uses landscape characteristics to highlight key areas of interest.

Countryside Vegetation System (CVS) - CVS considers the vegetation of Great Britain as whole, while other systems construct classifications for regions or habitats. CVS is used predominately in designations of land types and incorporated in the UKBAP broad habitat classification.

Digital Elevation Model (DEM) - is a data file that is created from a transformation of elevation data such as LiDAR, and can been used in a Geographical Information System program.

Digital Surface Model (DSM) - is a data file derived from the LiDAR data which takes into account the elevation of the canopy layer and any other structures on the landscape.

Digital Terrain Model (DTM) - is a data file derived from the LiDAR data which only records the elevation of the terrain and excludes the canopy layer height and where possible other structures on the landscape.

ESRI ArcGIS - geographical information system cartographic package, which comprises of various sub-packages including ArcMap and ArcScene.

ESRI ArcScene – additional software program as a part of the ArcGIS package that allows for three-dimensional map creation and video capture.

Geographic Information Systems (GIS) - is a cartographic/mapmaking program that specialises in geospatial analysis. The mainstream GIS programs are ESRI ArcGIS and Pitney Bowers MapInfo.

Ground truthing - field-based surveys which referred to the ecological maps and evaluate the accuracy in real time.

Interpolation – is a geographical procedure used to predict cell values for locations that lack sample points. Surface interpolation functions make predictions from sample measurements for all locations in a raster dataset, whether or not a measurement has been taken at the location.

Inverse Density Weighted (IDW) - spatial analysis tool within ArcMap, that uses a vector-based algorithm to produces a raster image of estimated displayed values within a vector across a larger area.

Joint Nature Conservation Committee (JNCC) - JNCC is the public body that advises the UK Government and devolved administrations on UK-wide and international nature conservation.

Landsat data - high-resolution multispectral scanner imagery that looks at different electromagnetic spectrums, and represents them as a visible colour banding which can be used to informed ecological management. Landsat data is captured via the Landsat satellites controlled by NASA.

Light Detecting and Ranging (LiDAR) - is a form of remote sensing that collects elevation data, using a gyroscopic mounted laser that builds up a three-dimensional elevation image of the landscape by measuring distance and time lag between laser pulses which are then reflected back into receptor. This method is often flown by the environment agency in the UK as part of their coastal monitoring and is an active method of data collection.

Modular Analysis of Vegetation Information System (MAVIS) - is a vegetation description analysis program, which uses a number of vegetation classification systems and floristic data to interpret raw quadrat data into the plant classifications.

Multi-Spectral Scanner Imagery (MSS) - is a data file that contains reflected electromagnetic information in the form of colour banding that can been used in ecological mapping. MSS is a passive method of data collection recording the reflective values of light.

National Vegetation Classification (NVC) of the UK - is one of the key common standards developed for the country nature conservation agencies. NVC is a comprehensive classification and description of the plant communities of Britain, each systematically named and arranged and with standardised descriptions for each. The general approach adopted was phytosociological and, therefore, concentrated on the rigorous recording of floristic data.

Newlyn OS datum – Mean high water height used for LiDAR elevation, derived from zero height above sea level (ASL), at Newlyn in Cornwall.

Non-metric Multi Dimensional Scaling (nMDS) – is a numerical technique that iteratively seeks a solution and stops computation when an acceptable solution has been found, or it stops after some prespecified number of attempts. The data is expressed as an ordination which displays similarity (biotic data) and dissimilarity (chemical).

Progradation - an accreting shoreline extending seaward.

Raster - is an image file that is used within a cartographic program and often contains digitised polygons and vector diagrams, as well as containing information on the image that has been represented.

Regression map - Map regression involves comparing maps drawn up at different dates, to understand changes over time. Modern and old Ordnance Survey, tithe, in-closure and estate maps can all be used for this purpose.

Remote sensing – is a term used when describing different data capturing methods, such as MSS and LiDAR data, that do not necessarily require a physical a presence to make informed decisions of a particular site.

Site of Special Scientific Interest (SSSI) – is a conservation designation denoting a protected area in the United Kingdom. SSSIs are classed as the country's very best wildlife and geological sites, and are the basic building block of site-based nature conservation in Great Britain

Triangulated Irregular Network (TIN) - is a digital data structure used in a GIS program for the representation of a surface. TIN is a vector-based representation of the physical land surface made up of irregularly distributed nodes and lines with three-dimensional coordinates, arranged in a network of non-overlapping triangles, derived from the elevation data of a rasterized digital elevation model (DEM).

UK BAP (Biodiversity Action Plan) - is the UK Government's response to the Convention on Biological Diversity. It describes the UK's biological resources (species and habitats) and commits to a detailed plan for the protection of these resources.

Vernal - vegetation which predominantly developed during spring

Appendices

Appendix One – NVC community types recorded at Sandwich Bay

List of shingle, strandline and sand-dune communities:

SD4 - *Elymus farctus* ssp. (foredune community)

SD6 - *Ammophila arenaria* (mobile dune community)

SD7 - *Ammophila arenaria–Festuca rubra* (semi-fixed dune community)

SD8 - *Festuca rubra–Galium verum* (fixed dune grassland)

SD9 - *Ammophila arenaria–Arrhenatherum elatius* (dune grassland)

SD10 - *Carex arenaria* (dune community)

SD11 - *Carex arenaria–Cornicularia aculeata* (dune community)

SD12 - *Carex arenaria–Festuca ovina–Agrostis capillaris* (dune grassland)

SD13 - *Sagina nodosa–Bryum pseudotriquetrum* (dune-slack community)

SD14 - *Salix repens–Campylium stellatum* (dune-slack community)

SD15 - *Salix repens–Calliergon cuspidatum* (dune-slack community)

SD16 - *Salix repens–Holcus lanatus* (dune-slack community)

SD17 - *Potentilla anserina–Carex nigra* (dune-slack community)

SD18 - *Hippophae rhamnoides* (dune scrub)

SD19 - *Phleum arenarium–Arenaria serpyllifolia* (dune annual community)

List of mesotrophic grassland communities:

MG1 - *Arrhenatherum elatius* (dry neutral grassland)

MG2 - *Filipendula ulmaria–Arrhenatherum elatius* (tall-herb grassland)

MG3 - *Anthoxanthum odoratum–Geranium sylvaticum* (grassland)

MG4 - *Alopecurus pratensis–Sanguisorba officinalis* (grassland)

MG5 - *Cynosurus cristatus–Centaurea nigra* (unimproved grassland)

MG6 - *Lolium perenne–Cynosurus cristatus* (semi-improved grassland)

MG7 - *Lolium perenne* (leys and related grasslands)

MG8 - *Cynosurus cristatus–Caltha palustris* (grassland)

MG9 - *Holcus lanatus–Deschampsia cespitosa* (grassland)

MG10 - *Holcus lanatus–Juncus effuses* (rush-pasture)

MG11 - *Festuca rubra–Agrostis stolonifera–Potentilla anserina* (wet grassland)

MG12 - *Festuca arundinacea* (wet neutral grassland)

MG13 - *Agrostis stolonifera–Alopecurus geniculatus* (wet neutral grassland)

Appendix Two – Procedure for converting raw quadrat data to probability ellipse data points

1. Input raw data into Excel spreadsheet, ensuring all field data is recorded and that all plant species are down column 1;
2. Create new tab and hyperlink raw data tab using this Excel equation '=IF('RAW DATA TAB NAME'!CELL VALUE = 0, 0, 0.25*EXP(LN(' RAW DATA TAB NAME '!CELL VALUE)*2.6))' The equation converts domin scores to a percentage;
3. When recording vegetation composition using the NVC protocols, percentage cover can equal more than 100%, so to adjust for this create another tab and hyperlink the domin transformed data using this Excel equation ='CALCULATION OF DOMIN SCORE TAB NAME'! CELL VALUE /'CALCULATION OF DOMIN SCORE TAB NAME'! CELL VALUE$TOTAL QUADRAT PERCENTAGE VEGETATION COVER this standardises the data to equal 100%;
4. Create another tab in Excel for each individual species identified, and input Ellenberg book values for Nutrients (N) and Moisture (F). Note that the Latin names must match those that are in the spreadsheet and cell location for the data;
5. Create a final tab for the results, import values such as percentage cover, bare ground, etc. Import the transformed data that is to be used as your non-spatial geographical data using this Excel equation =SUMPRODUCT('STANDARDISED DATA BY SITE COVER TAB NAME'!CELL RANGE,'ELLENBERG SCORES TAB NAME'!$CELL COLUMN$CELL ROW$CELL COLUMN$)

Appendix Three

Authorities of species identified at Sandwich Bay

Common Name	Scientific Name	Scientific Name Change (Stace, 2010)	Authority
Yarrow (common)	*Achillea millefolium*		L.
Ground Elder	*Aegopodium podagraria*		L.
Agrimony	*Agrimonia eupatoria*		L.
Common Bent	*Agrostis capillaris*		L.
Creeping Bentgrass	*Agrostis stolonifera*		L.
Yellow hairgrass	*Aira praecox*		L.
Water-plantain	*Alisma plantago-aquatica*		L.
Crow Garlic	*Allium vineale*		L.
Marsh foxtail	*Alopecurus geniculatus*		L.
Marram grass	*Ammophila arenaria*		L.
Green-winged Orchid	*Anacamptis morio*		L.
Pyramidal Orchid	*Anacamptis pyramidalis*		L.
Bog Pimpernel	*Anagallis tenella*		L.
Sweet Vernal Grass	*Anthoxanthum odoratum*		L.
Thyme-leaved Sandwort	*Arenaria serpyllifolia*		L.
False Oat-grass	*Arrhenatherum elatius*		(L.) P. Beauv. ex J. & C. Presl.
Mugwort	*Artemisia vulgaris*		L.
Asparagus	*Asparagus officinalis*		L.
Goldilocks Aster	*Aster linosyris*		(L.) Bernh.
Sea Aster	*Aster tripolium*		L.
Grass Leaved Orache	*Atriplex littoralis*		L.
Sea Purslane	*Atriplex portulacoides*		L.

Spear Leaved Orache	*Atriplex prostrata*		Boucher ex DC.
Common Daisy	*Bellis perennis*		L.
Sea Beet	*Beta vulgaris ssp maritima*		(L.) Arcang.
Yellow-wort	*Blackstonia perfoliata*		L.
Sea Club-rush	*Bolboschoenus maritimus*		(L.) Palla.
Whitish Feather-moss	*Brachythecium albicans*		
Rough-stalked Feather-moss	*Brachythecium rutabulum*		
Wild Cabbage	*Brassica oleracea*		L.
Quaking-grass	*Briza media*		L.
Soft Brome	*Bromus hordeaceus*		L.
Tufted Thread-moss	*Bryum caespiticium*		
Marsh Bryum	*Bryum pseudotriquetrum*		
Sea rocket	*Cakile maritima*		Scop.
Pointed Spear-moss	*Calliergon cuspidatum*		
Larger bindweed	*Calystegia sepium*		(L.) R. Br.
Sea/Shore bindweed	*Calystegia soldanella*		(L.) R. Br.
Yellow Starry Feather-moss	*Campylium stellatum*		
Lesser Pond Sedge	*Carex acutiformis*		Ehrh.
Sand Sedge	*Carex arenaria*		L.
Distant Sedge	*Carex distans*		L.
Tufted Sedge	*Carex elata*		All.
Glaucous sedge	*Carex flacca*		Schreb.
Hairy sedge	*Carex hirta*		L.
Black Sedge	*Carex nigra*		(L.) Reichard.
Sea-fern Grass	*Catapodium marinum*		(L.) C.E. Hubb.
Fern Grass	*Catapodium rigidum*		(L.) C.E. Hubb.
Common Knapweed	*Centaurea nigra*		L.
Common Century	*Centaurium erythraea*		Rafn

Red Valerian	*Centranthus ruber*		(L.) DC.
Field Mouse-Ear Chickweed	*Cerastium arvense*		L.
Sea Mouse-ear	*Cerastium diffusum*		Pers.
Little Mouse-Ear Chickweed	*Cerastium semidecandrum*		L.
Redshank moss	*Ceratodon purpureus*		
Fat-hen	*Chenopodium album*		L.
Creeping Thistle	*Cirsium arvense*		(L.) Scop.
Marsh thistle	*Cirsium palustre*		(L.) Scop.
Spear Thistle	*Cirsium vulgare*		(Savi) Ten.
Lichen (grey-green chalice)	*Cladonia fimbriata*		
Lichen (gray leaf like)	*Cladonia foliacea*		
Lichen (branched and sphere)	*Cladonia furcata*		
Lichen (looks like rocket)	*Cladonia impexa*		
Lichen (pixie-cup lichen)	*Cladonia pyxidata*		
Lichen (branched spiky tufts)	*Cladonia rangiformis*		
Lichen (free standing spikes)	*Cladonia squamules/sp*		
Field Bindweed	*Convolvulus arvensis*		L.
Lichen (DB branched & spiked)	*Cornicularia aculeata*		
Sea Kale	*Crambe maritima*		L.
Hawthorn	*Crataegus monogyna*		Jacq.
Rough Hawksbeard	*Crepis biennis*		L.
Smooth Hawksbeard	*Crepis capillaris*		L.
Rock Samphire	*Crithmum maritimum*		L.
Crested Dog’s-tail (Grass)	*Cynosurus cristatus*		L.
Cock's-foot (Grass)	*Dactylis glomerata*		L.
Southern Marsh Orchid	*Dactylorhiza praetermissa*		(Druce) Verm.
Wild Carrot	*Daucus carota*		L.
Broom Fork-moss	*Dicranum scoparium*		

Viper's Bugloss	*Echium vulgare*		L.
Sea Couch	*Elymus pycnanthus*	Elytrigia atherica	Kerguélen
Sand Couch	*Elymus farctus*	Elytrigia juncea	(L.) Nevski
Couch Grass	*Elymus repens*	Elytrigia repens	(L.) Desv. ex Nevski
Great willowherb	*Epilobium hirsutum*		L.
Marsh Helleborine	*Epipactis palustris*		(L.) Crantz
Common Horsetail	*Equisetum arvense*		L.
Marsh horsetail	*Equisetum palustre*		L.
Blue Fleabane	*Erigeron acer*	Erigeron acris	L.
Stork's Bill	*Erodium cicutarium*		(L.) L'Hér
Sea Holly	*Eryngium maritimum*		L.
Hemp Agrimony	*Eupatorium cannabinum*		L.
Sea Spurge	*Euphorbia paralias*		L.
Eyebright	*Euphrasia officinalis agg.*		L.
Fern like' neat feather moss	*Eurynchium praelongum*		
Tall Fescue	*Festuca arundinacea*	Schedonorus arundinaceus	(Schreb.) Dumort.
Sheep's Fescue	*Festuca ovina*		L.
Meadow fescue	*Festuca pratensis*	Schedonorus pratensis	(Huds.) P. Beauv.
Red Fescue	*Festuca rubra*		L.
Fennel	*Foeniculum vulgare*		Mill.
Hybrid Fescue	*Festulolium loliaceum*	X Schedolium loliaceum	(Huds.) Holub
Cleavers	*Galium aparine*		L.
Hedge Bedstraw	*Galium mollugo*	Galium album	Mill.
Lady's Bedstraw	*Galium verum*		L.
Autumn Gentian	*Gentianella amarella*		(L.) Börner
Dovefoot Cranes-bill	*Geranium molle*		L.
Yellow Horned Poppy	*Glaucium flavum*		Crantz
Sea-milkwort	*Glaux maritima*		L.

Plicate Sweet-grass	*Glyceria plicata*	Glyceria notata	Chevall.
Meadow Oat-grass	*Helictotrichon pratense*	Avenula pratensis	(L.) Dumort.
Downy Oat-grass	*Helictotrichon pubescens*	Avenula pubescens	(Huds.) Dumort.
Hogweed	*Heracleum sphondylium*		L.
Lizard Orchid	*Himantoglossum hircinum*		(L.) Spreng.
Sea Buckthorn	*Hippophae rhamnoides*		L.
Yorkshire Fog	*Holcus lanatus*		L.
Yellow Feather-moss	*Homalothecium lutescens*		
Sea Sandwort	*Honckenya peploides*		(L.) Ehrh.
Sea Barley	*Hordeum marinum*		Huds.
Wall Barley	*Hordeum murinum*		L.
Marsh Pennywort	*Hydrocotyle vulgaris*		L.
Slender St John's-wort	*Hypericum pulchrum*		L.
Cypress-leaved Plait-moss	*Hypnum cupressiforme*		
Smooth cat's ear	*Hypochaeris glabra*		L.
Cats Ear	*Hypochoeris radicata*		L.
Lichen (flat to convex leafs)	*Hypogymnia physodes*		
Yellow Iris	*Iris pseudacorus*		L.
Sharp-flowered Rush	*Juncus acutiflorus*		Ehrh. ex Hoffm.
Jointleaf Rush	*Juncus articulatus*		L.
Compact Rush	*Juncus conglomeratus*		L.
Saltmarsh Rush	*Juncus gerardii*		Loisel.
Hard Rush	*Juncus inflexus*		L.
Sea Rush	*Juncus maritimus*		Lam.
Crested Hair-grass	*Koeleria macrantha*		(Ledeb.) Schult.
White Dead-nettle	*Lamium album*		L.
Nipplewort	*Lapsana communis*		L.
Meadow Vetchling	*Lathyrus pratensis*		L.

Tree Mallow	*Lavatera arborea*	Malva arborea	(L.) Webb & Berthel.
Autumn Hawkbit	*Leontodon autumnalis*	Scorzoneroides autumnalis	(L.) Moench
Rough Hawkbit	*Leontodon hispidus*		L.
Lesser Hawkbit	*Leontodon taraxacoides*	Leontodon saxatilis	Lam.
Broad-leaved Pepperwort	*Lepidium latifolium*		L.
Rock Sea Lavender	*Limonium binervosum*		(G.E. Sm.) C.E. Salmon
Common Sea-lavender	*Limonium vulgare*		Mill.
Perennial Ryegrass	*Lolium perenne*		L.
Bifid Crestwort Liverwort	*Lophocolea bidentata*		
Bird's-foot Trefoil	*Lotus corniculatus*		L.
Greater Bird's-foot Trefoil	*Lotus pedunculatus*		Cav. (L. uliginosus Schkuhr)
Tree Lupin	*Lupinus arboreus*		Sims
Field Wood Rush	*Luzula campestris*		(L.) DC.
Ragged Robin	*Lychnis flos-cuculi*	Silene flos-cuculi	(L.) Clairv.
Bur medick	*Medicago minima*		(L.) Bartal.
Honey clover	*Melilotus alba*		Medik.
Tall Melilot	*Melilotus altissima*	Melilotus altissimus	Thuill.
Water Mint	*Mentha aquatica*		L.
Three-nerved Sandwort	*Moehringia trinervia*		(L.) Clairv.
Red Bartsia	*Odontites verna*	Odontites vernus	(Bellardi) Dumort.
Parsley Water-dropwort	*Oenanthe lachenalii*		C.C. Gmel.
Evening Primrose	*Oenothera stricta*		Ledeb. ex Link
Restharrow	*Ononis repens*		L.
Adders Tongue (Fern)	*Ophioglossum vulgatum*		L.
Amethyst Broomrape	*Orobanche amethystea*		Thuill.
Bedstraw Broomrape	*Orobanche caryophyllacea*		Sm.
Common Broomrape	*Orobanche minor*		Sm.
Long Headed Poppy	*Papaver dubium*		L.

Hard Grass	*Parapholis strigosa*		(Dumort.) C.E. Hubb.
Sand Cat's-tail	*Phleum arenarium*		L.
Smaller Cat's-tail (Timothy)	*Phleum bertolonii*		DC.
Common Reed	*Phragmites australis*		(Cav.) Trin. ex Steud.
Bristly Ox-Tongue	*Picris echioides*	Helminthotheca echioides	(L.) Holub
Mouse-Ear Hawkweed	*Pilosella officinarum*		F.W. Schultz & Sch. Bip.
Burnet Saxifrage	*Pimpinella saxifraga*		L.
Many-fruited Thyme-moss	*Plagiomnium affine*		
Buck's horn Plantain	*Plantago coronopus*		L.
Ribwort Plantain	*Plantago lanceolata*		L.
Greater Plantain	*Plantago major*		L.
Sea Plantain	*Plantago maritima*		L.
Annual Meadow-grass	*Poa annua*		L.
Meadow-grass	*Poa pratensis*		L.
Rough-stalked meadow-grass	*Poa trivialis*		L.
Silverweed	*Potentilla anserina*		L.
Creeping Cinquefoil	*Potentilla reptans*		L.
Selfheal	*Prunella vulgaris*		L.
Neat Feather-moss	*Pseudoscleropodium purum*		
Common Saltmarsh-grass	*Puccinellia maritima*		(Huds.) Parl.
Common Fleabane	*Pulicaria dysenterica*		(L.) Bernh.
Bulbous Buttercup	*Ranunculus bulbosus*		L.
Creeping Buttercup	*Ranunculus repens*		L.
Yellow Rattle	*Rhinanthus minor*		L.
Springy Turf-moss	*Rhytidiadelphus squarrosus*		
Dewberry	*Rubus caesius*	Rubus sect. 4 Caesii	Lej. & Courtois (sect. Glaucobatus Dumort.)
Bramble (blackberry)	*Rubus fruticosus agg.*	Rubus sect. 2 Glandulosus	Wimm. & Grab. (subsect. Hiemales E.H.L. Krause)
Common Sorrel	*Rumex acetosa*		L.

Sheep's Sorrel	*Rumex acetosella*		L.
Curled Dock	*Rumex crispus*		L.
Knotted Pealwort	*Sagina nodosa*		(L.) Fenzl
Glasswort	*Salicornia europaea agg.*		L.
Creeping Willow	*Salix repens*		L.
Club Rush	*Schoenoplectus lacustris*		(L.) Palla
Biting Stonecrop	*Sedum acre*		L.
White Stone	*Sedum album*		L.
English Stonecrop	*Sedum anglicum*		Huds.
Ragwort	*Senecio jacobaea*		L. (Jacobaea vulgaris P. Gaertn.)
Sand Catchfly	*Silene conica*		L.
Red Campion	*Silene dioica*		(L.) Clairv.
White Campion	*Silene latifolia*		Poir.
Sea Campion	*Silene maritima*	Silene uniflora	Roth
Night-flowering Catchfly	*Silene noctiflora*		L.
Catchfly sp.	*Silene sp.*		L.
Alexanders	*Smyrnium olusatrum*		L.
Bittersweet/Woody Nightshade	*Solanum dulcamara*		L.
Perennial Sow-thistle	*Sonchus arvensis*		L.
Branched Bur-reed	*Sparganium erectum*		L.
Common Cordgrass	*Spartina anglica*		C.E. Hubb.
Lesser Sea -spurry	*Spergularia marina*		(L.) Besser
Greater Sea-spurry	*Spergularia media*		(L.) C. Presl
Lesser Stitchwort	*Stellaria graminea*		L.
Shrubby Seablite	*Sueda vera*		Forssk. ex J.F. Gmel.
Tamarix	*Tamarix gallica*		L.
Dandelion	*Taraxacum sp.*		F.H. Wigg
Shepherd's Cress	*Teesdalia nudicaulis*		(L.) W.T. Aiton

Upright Hedge-parsley	*Torilis japonica*		(Houtt.) DC.
Twisted Star Moss	*Tortula ruralis ruraliformis*		
Goat's-beard	*Tragopogon pratensis*		L.
Hare's Foot Trefoil	*Trifolium arvense*		L.
Hop Trefoil	*Trifolium campestre*		Schreb.
Lesser Hop Trefoil	*Trifolium dubium*		Sibth.
Strawberry Clover	*Trifolium fragiferum*		L.
Red Clover	*Trifolium pratense*		L.
White Clover	*Trifolium repens*		L.
Sea Clover	*Trifolium squamosum*		L.
Sea Arrowgrass	*Triglochin maritima*		L.
Yellow Oat Grass	*Trisetum flavescens*		(L.) P. Beauv.
Common Bulrush	*Typha latifolia*		L.
Gorse	*Ulex europaeus*		L.
Common Stinging Nettle	*Urtica dioica*		L.
Germander Speedwell	*Veronica chamaedrys*		L.
Speedwell	*Veronica sp.*		L. (Hebe Comm. ex Juss.)
Tufted Vetch	*Vicia cracca*		L.
Common Vetch	*Vicia sativa*		L.
Seeded Vetch	*Vicia seedling/sp*		
Smooth Tare	*Vicia tetrasperma*		(L.) Schreb.
Hairy Violet	*Viola hirta*		L.
Brome Fescue	*Vulpia bromoides*		(L.) Gray

Appendix Four 2012 Dipwell installation geographical locations

Dipwell	E	N	Dipwell	E	N	Dipwell	E	N	Dipwell	E	N
1	635058	161476	**26**	635103	159550	**51**	635396	158202	**76**	636857	155968
2	635202	161382	**27**	635081	159454	**52**	635527	158161	**77**	636914	155910
3	634891	161293	**28**	635232	159356	**53**	635859	158154	**78**	636765	155849
4	635003	161166	**29**	635455	159375	**54**	635641	158029	**79**	636966	155777
5	634970	160966	**30**	635429	159250	**55**	635041	158052	**80**	636771	155643
6	635207	160988	**31**	635390	159156	**56**	635790	157932	**81**	636935	155612
7	635094	160836	**32**	635081	159151	**57**	635933	157925	**82**	637114	155495
8	634922	160730	**33**	635708	159127	**58**	636098	157931	**83**	636854	155472
9	635119	160708	**34**	635619	159179	**59**	635642	157874	**84**	637002	155431
10	634841	160602	**35**	635451	159034	**60**	635348	157824	**85**	637200	155349
11	635338	160639	**36**	635120	158905	**61**	636050	157821	**86**	637180	155239
12	635367	160484	**37**	635401	158907	**62**	635857	157732	**87**	636964	155209
13	635159	160423	**38**	635762	158894	**63**	636107	157730	**88**	637181	155073
14	634872	160335	**39**	635126	158703	**64**	635683	157644	**89**	637297	155076
15	635002	160281	**40**	635601	158683	**65**	635970	157616	**90**	637245	154977
16	635401	160280	**41**	635300	158652	**66**	636530	156909	**91**	637004	154945
17	635286	160261	**42**	634898	158620	**67**	636661	156797	**92**	637173	154909
18	635232	160084	**43**	635365	158515	**68**	636468	156685	**93**	637395	154753
19	635377	160059	**44**	635083	158490	**69**	636605	156491	**94**	637185	154699
20	635069	159992	**45**	635687	158500	**70**	636382	156437	**95**	637289	154640
21	635330	159857	**46**	635823	158457	**71**	636789	156406	**96**	637341	154498
22	635157	159714	**47**	635432	158351	**72**	636606	156223	**97**	637441	154491
23	635424	159707	**48**	635220	158337	**73**	636800	156180	**98**	637381	154362
24	635519	159694	**49**	635803	158295	**74**	636817	156116	**99**	637451	154326
25	635471	159570	**50**	635618	158244	**75**	636641	155974			

Appendix Five Original 1989 and 2001 addition NVC quadrat grid reference locations

Quadrat	E	N	Quadrat	E	N	Quadrat	E	N	Quadrat	E	N
Q01	636830.22	155816.45	**Q26**	635044.74	161144.92	**Q52**	635380.42	160583.89	**Q88**	635413.00	158986.00
Q02_2a	636601.31	156065.16	**Q27**	635166.47	161248.11	**Q53**	634780.21	160974.01	**Q89**	634934.00	158600.00
Q03	636533.23	156166.72	**Q28**	634975.39	160612.90	**Q54**	634787.07	161227.68	**Q90**	635012.00	158583.00
Q04	637007.13	155948.09	**Q29**	637279.83	154612.27	**Q55_55a**	634853.76	161599.86	**Q91**	635117.00	158883.00
Q05	636913.87	156086.92	**Q30**	637150.02	154669.02	**Q56**	634850.33	161922.11			
Q06	636828.41	156321.79	**Q31_31a**	635195.78	158868.32	**Q57_57a**	634758.68	162175.85			
Q07_7a	636735.64	156371.12	**Q32**	635659.85	159100.03	**Q58**	635060.62	161889.23			
Q08_8a	635157.06	158332.17	**Q33**	635635.18	159042.19	**Q59**	635205.76	161690.21			
Q09	635296.60	158529.97	**Q34**	635481.09	158970.24	**Q71**	635053.00	161931.00			
Q10	635648.96	158547.12	**Q35**	635516.90	159018.76	**Q72**	634944.00	162149.00			
Q11	635602.39	158433.32	**Q36**	635068.08	158705.96	**Q73**	634916.00	162554.00			
Q12	636273.36	157181.82	**Q37**	635555.97	159647.65	**Q74**	634801.00	162504.00			
Q13_13a	636251.64	157092.28	**Q38**	635510.70	159658.21	**Q75**	634680.00	162248.00			
Q14	636307.91	157291.87	**Q39**	635172.20	159140.26	**Q76**	636050.00	157799.00			
Q15	636338.57	157268.59	**Q40**	635168.35	159288.05	**Q77**	635610.00	158232.00			
Q16	636391.71	156677.52	**Q41**	635096.46	159520.93	**Q78**	635236.00	160540.00			
Q17	636416.14	156607.61	**Q42**	635093.08	159583.22	**Q79**	635281.00	158263.00			
Q18	634713.77	158707.47	**Q43**	636960.24	155722.40	**Q80**	635584.00	158355.00			
Q19	635877.54	158531.50	**Q44**	637066.06	155654.45	**Q81**	635780.00	158754.00			
Q20	635931.49	158646.24	**Q45**	637228.18	155268.61	**Q82**	635643.00	159056.00			
Q21	635024.36	160781.69	**Q46**	636124.75	158148.54	**Q83**	635535.00	159105.00			
Q22	635256.50	161485.36	**Q47**	636093.44	158121.47	**Q84**	635448.00	158942.00			
Q23	635238.81	161461.33	**Q48**	636114.78	158109.37	**Q85**	635446.00	158948.00			
Q24	635206.36	161447.64	**Q49**	635891.00	158093.30	**Q86**	635426.00	158967.00			
Q25	635168.33	161429.33	**Q51**	635228.20	160305.27	**Q87**	635426.00	158977.00			

Appendix Six 2012 – 2013 Survey NVC classifcations near dipwells

Quadrat	2012 NVC	2013 NVC	Quadrat	2012 NVC	2013 NVC	Quadrat	2012 NVC	2013 NVC	Quadrat	2012 NVC	2013 NVC
1	MG12a	MG1/MG12	**26**	SD8a	SD8c	**51**	MG11c	MG12a	**76**	SD8	SD8a
2	SD8a	SD8	**27**	MG1	MG1a	**52**	MG11	MG12a	**77**	SD8a	SD8a
3	MG12	MG1a	**28**	MG1a	MG1a	**53**	SD8a	SD8a	**78**	SD8	MG1a
4	MG1/MG11	MG1/MG12	**29**	SD8a	MG1a	**54**	MG1a	MG12a	**79**	SD7a	SD8a
5	MG11/MG12	MG11/MG12	**30**	MG1	SD9b	**55**	MG7	SD8a	**80**	MG1	MG1a
6	SD8a	SD8a	**31**	SD13	SD9a	**56**	SD14	SD16	**81**	MG1a	SD8a
7	MG11	MG12a	**32**	MG1/MG12	MG1	**57**	MG1a	MG1a	**82**	SD8a	MG1
8	MG12	MG12	**33**	SD8a	SD8a	**58**	SD8	SD8a	**83**	MG1	MG1
9	MG1	SD8a	**34**	SD8a	SD8a	**59**	MG12	MG13	**84**	MG1	MG1a
10	MG1a	MG1a	**35**	MG11c	MG11	**60**	MG1	SD8	**85**	SD17	SD8a
11	SD8c	SD8a	**36**	SD8a	SD8a	**61**	SD8a	SD8a	**86**	MG11	MG1
12	SD8a	SD8a	**37**	SD8a	SD8a	**62**	SD8a	SD8a	**87**	SD10	SD8a
13	SD8a	SD8a	**38**	SD8a	SD8a	**63**	SD8a	SD8a	**88**	SD8a	SD8a
14	MG13	MG13	**39**	SD8a	SD8a	**64**	SD8/MG1	SD9	**89**	MG1a	MG12
15	MG1a	SD8a	**40**	SD8a	SD8a	**65**	MG1/MG11	MG12	**90**	MG1	MG1
16	SD8a	SD8a	**41**	SD8a	SD8a	**66**	SD8b	SD9a	**91**	MG1	SD8a
17	MG12	MG12	**42**	MG1a	MG1a	**67**	SD7a	SD8a	**92**	MG11c	MG1
18	MG12	MG12	**43**	MG1d	SD8	**68**	SD8a	MG1	**93**	SD8a	MG12
19	MG1a	MG12	**44**	MG1a	MG1a	**69**	SD8a	SD8a	**94**	SD8a	MG1a
20	SD8a	SD8a	**45**	SD7d	SD9a	**70**	SD8a	SD8	**95**	MG11	MG12
21	MG12a	MG1a	**46**	SD8a	MG1a	**71**	SD9a	SD8	**96**	MG11	MG12
22	MG11	MG1a	**47**	SD8a	SD9a	**72**	MG1a	MG12	**97**	SD19	SD17
23	SD8a	SD8a	**48**	MG1a	MG1a	**73**	SD11a	MG12	**98**	SD19	SD9a
24	SD8a	SD8a	**49**	SD8a	SD8a	**74**	SD8c	SD9a	**99**	SD19	SD10
25	MG12	MG12	**50**	SD16	SD8	**75**	MG1a	MG1			

Appendix Seven

Field Trial Orientations

A = Cut and Remove standing sward
B = Burn
C = Removed Sward
D = Control

NVC 2X2 metre quadrat is to be measured within the centre of each of the field trial treatments.

Princes GC

Inland (West)

A	B	C	D
C	A	D	B
D	C	B	A
B	D	A	C

Sea (East)

Spread Sheet Orientation

Inland (West)

R1 C1	R1 C2	R1 C3	R1 C4
R2 C1	R2 C2	R2 C3	R2 C4
R3 C1	R3 C2	R3 C3	R3 C4
R4 C1	R4 C2	R4 C3	R4 C4

Sea (East)

RCPGC

Inland (West)

A	D	B	C
B	C	A	D
C	B	D	A
D	A	C	B

Sea (East)

RSGGC

Inland (West)

A	B	C	D
B	A	D	C
C	D	B	A
D	C	A	B

Sea (East)