Living on the edge:
Saltmarsh spiders and beetles

How does a saltmarsh environment influence the distribution of spiders and beetles?

by

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A thesis submitted in partial fulfilment of the requirements for an Honours Degree at the School of Land and Food, Discipline of Geography and Spatial Sciences, University of Tasmania (October, 2014).

Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma in any tertiary institution, and to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

Signed:

John G Aalders BSc.

Date:

Citation

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Abstract

Saltmarshes are an intriguing ecotone representing the transition between the marine and terrestrial environments. Much is understood in terms of zonation and vegetation communities in saltmarshes, however considerably less is understood about their edaphic factors. In Australian saltmarshes, terrestrial arthropod fauna and factors that determine invertebrate assemblages are largely unknown.

The aim of this study was to understand the factors that influence the presence of epigeal spiders and beetles in a coastal saltmarsh. The chosen site at Long Point, a saltmarsh on Tasmania's east coast, included adjacent woodland which enabled expansion of the study to incorporate a full environmental gradient. Moisture, salinity and pH gradients were analysed alongside vegetation community structure. During the 12 month study period 5 606 spiders (37 taxa) and 1 165 beetles (84 taxa) were caught in 141 pitfall traps. Indicator species (spider and beetle) were identified for each vegetation community within the saltmarsh zone and adjacent woodland zone. Spiders and beetles reacted in a similar fashion to edaphic factors and vegetation species. However, the sequential order of importance for spiders was moisture, salinity and vegetation, whereas, the response order for beetles was moisture, vegetation and salinity.

Further investigation into the interaction between saltmarsh vegetation species and spider and beetle species will assist in our endeavours to understand the loss or gain of arthropod species due to climate change and sea-level rise.

Key words

Saltmarsh, landscape features, edaphic factors, vegetation communities, invertebrate assemblages, spiders, beetles, Tasmania

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Glossary

ARS: code for saltmarsh vegetation community dominated by saline graminoids.

ASS(a): code for saltmarsh vegetation community dominated by *Sarcocornia quinqueflora*.

ASS(b): code for saltmarsh vegetation community dominated by *Tecticornia arbuscula*.

BOM: Bureau of Meteorology.

Braun-Blanquet: method of assessing vegetation presence and cover abundance that estimates the quantity of cover of each species in a community in one scale (Mueller-Dombois & Ellenberg 1974).

Dolerite ridge: extreme southern section of Long Point consisting of exposed dolerite outcrop and associate soils (see Figure 2.4).

DSE: dry (non-lactating) sheep equivalent.

EC: electrical conductivity. The electrical conductivity indicates the amount of soluble (salt) ions in soil, and can be used as a proxy for salinity (Hazelton & Murphy 2007).

Edaphic factors: soil-related variables, a component of research in this project. Variables include moisture, pH, EC, carbon and soil organic matter.

GPL (dr): code for woodland vegetation as on dolerite ridge.

GPL (sr): code for woodland vegetation as on sand ridge.

Group: a vegetation community detected by multivariate analysis – three in the saltmarsh zone, three in the woodland zone in this study.

GSL: code for woodland vegetation as on sand dune.

Halophilic: describes organisms capable of living in high concentrations of salt.

Halophyte: salt-tolerant plant.

Hypersaline: water with a high concentration of salt generally greater than that of sea (marine) water.

Indicator species: species whose status provides information on the overall makeup and condition of the ecosystem and of other species in that ecosystem (De Cáceres *et al.* 2010).

Intertidal: the zone/environment between the level of high and low tide.

Inundation: the condition of water occurring above the ground surface as a result of flooding by tidal waters or high precipitation.

Invertebrate assemblage: a collection of invertebrates characterised by a distinctive combination of species occupying a common environment and interacting with one another; a component of research interest in this project.

Landscape features: a component of research in this project. Features include elevation, hill shade and solar radiation.

Location: the setting of the research site, i.e. east coast of Tasmania.

LOI: loss on ignition. A method to estimate the organic matter content in soils.

pH: a scale that measures how acidic or basic a substance is. It ranges from 0 to 14; solutions with a pH of 7.0 are neutral, less than 7 are acidic, and greater than 7 are basic or alkaline.

Pitfall trap: a collection container sunk into the ground, the top flush with the ground surface. A killing/preserving agent is added at time of setting.

PSA: particle size analysis.

Ramsar Convention: *Convention on Wetlands of International Importance, especially as Waterfowl Habitat* is the official name of the Ramsar Convention – the abbreviated names "Convention on Wetlands (Ramsar, Iran 1971)" or "Ramsar Convention" are more commonly used.

Saltmarsh: tract of land tidally connected to the sea, covered with emergent, herbaceous, halophytic vegetation (Prahalad 2009).

Sand dune: in this study, the primary linear dune aligned north south composed of yellow/orange sand (see Figure 2.4).

Sand ridge: in this study, the secondary linear sandbank aligned east west composed of white/grey sand (see Figure 2.4).

Site: the general research location eg Long Point.

SOM: soil organic matter.

Spring tide/king tide: tide that is greater than the mean tidal range – occurs about every two weeks, when the moon is new or full.

Station: in this study, a point along each transect located as near as possible in the centre of each vegetation community that transect passes through.

Sub-tidal: permanently below the level of low tide, an underwater environment.

TASVEG: a comprehensive digital map of Tasmania's vegetation produced by the Tasmanian Vegetation Monitoring and Mapping Program (TVMMP). Each vegetation community is assigned a three-letter code that defines the dominant vegetation community present within each polygon. TASVEG 3.0 is the current version (Department of Primary Industries Parks Water and Environment 2014).

Transect: a line crossing environmental gradients, laid out in such a way to gather as much data as possible of landscape features, edaphic factors, vegetation communities and invertebrate assemblages that made up the research site.

Vegetation community: a collection of plant species that form a relatively uniform patch and is distinguishable from the adjacent community due to the different plant species contained therein; a component of research interest in this project.

Vegetation community code: alpha code based on TASVEG 3.0 vegetation codes.

Chapter 1: Introduction

1.1 Saltmarshes

Historically, saltmarshes are despised landscapes. Typically they are mainly flat, damp, boggy and cold, the source of many biting insects such as mosquitos and midges, and often feature in horror stories (Bridgewater *et al.* 1981). Commonly regarded as wastelands, coastal saltmarshes have over time, become the domain of playing fields, grazing and agriculture, coastal resorts and even sites for the disposal of refuse (Kirkpatrick & Glasby 1981; Finlayson & Rea 1999; Saintilan 2009a). Notwithstanding the historical negative connotations and sustained abuse, saltmarshes are a distinctive and intriguing ecosystem that bridges the land-sea boundary (Bridgewater *et al.* 1981). Yet these intertidal ecotones are one of the most restricted habitats in the world (Pétillon *et al.* 2008) covering less than 0.01% of the earth's surface (Desender & Maelfait 1999). Saltmarsh areas are increasingly reducing in area from a raft of pressures such as port extensions, soil pollution from adjacent agricultural lands (Pétillon *et al.* 2008), aquaculture, introduced species and sea-level rise (Adam 2002).

Although widespread and found on all continents, saltmarshes are generally located between the Tropic of Cancer and the Arctic Circle in the Northern Hemisphere, and between the Tropic of Capricorn and latitude 60^{o}S in the Southern Hemisphere (Chapman 1974). They only occur infrequently within the tropics, either being limited to areas not dominated by mangroves or interspersed with mangroves (Adam 2002).

Saltmarshes occupy sheltered coasts, particularly those in protected estuaries. They can be recognised by their distinctive vegetation communities ranging from saline succulents to saline graminoids, and are often located in areas inundated by tidal influences (Long & Mason 1983; Adam 1990). Many estuarine saltmarshes have distinguishing features such as conspicuous zonation, which is the delineation of the marsh into low, middle and upper zones defined by vegetation.

On a global scale it is difficult to estimate, let alone measure, the extent of saltmarshes. Estimation is made more difficult by the question of definition given that the US data includes brackish marshes, whereas Canada excludes these areas, and in Europe, though extensively studied, saltmarsh area data are not available (Adam 2002). Chapman (1974) estimates that the east and west coasts of the North American continent are home to the most extensive areas of saltmarshes followed by the north, western and Mediterranean coasts of Europe.

Australia, by global standards, has only a small proportion of its coastline as saltmarsh ecosystems which cover approximately 16 000 square kilometres (Saintilan & Adam 2009). Australian saltmarshes are generally limited to the south east of the continent, including Tasmania, with small areas in the southwest of Western Australia (Chapman 1974). Tasmania has approximately 10 000 hectares of saltmarsh (V Prahalad 2014, pers. comm. 31 July), principally located on its east coast and Flinders Island, north coast and the far north west.

The saltmarsh ecosystem has held a long standing interest for authors such as Ranwell (1972), Chapman (1974), Long and Mason (1983) and Adam (1990). However, attention has been limited to the distribution and patterns of vegetation variance (Adam 2002). In recent years, with an increasing focus on conservation and restoration, a renewed and expanding interest in saltmarshes has evolved especially in Europe (Desender *et al.* 1998; Desender & Maelfait 1999; Irmler *et al.* 2002; Finch *et al.* 2007; Pétillon *et al.* 2008). This has led to emerging studies into saltmarsh soils such as Álvarez-Rogel *et al.* (2000) and some invertebrate taxa for example Finch *et al.* (2007). A similar renewal in interest has been somewhat lacking in Australia. Fairweather (1990) noted that Australian saltmarshes had received the least attention of all marine habitats and their ecological values were being ignored. Furthermore, there has been little study of the terrestrial fauna of saltmarshes, leading to assumptions that Australian saltmarsh fauna is similar to those found in other locations around the world (Morrisey 2000). Nevertheless, during the last decade the growing appreciation of saltmarsh values and a realisation that predicted climate change related sea-level rise will impact saltmarshes, have led to increased research in this challenging environment (Saintilan & Adam 2009).

Recent studies of coastal invertebrates in the Northern Hemisphere have included the conservation of saltmarsh dwelling terrestrial arthropods (Desender & Maelfait 1999), invertebrate zonation and effects of sea-level rise (Irmler *et al.* 2002), and the influence of salinity on spiders (Pétillon *et al.* 2003; Pétillon *et al.* 2011). Research has also explored the use of spiders and beetles as indicator taxa in studies on sea-level rise and climate change (Finch *et al.* 2007; Pétillon *et al.* 2008). However, comparable information on saltmarsh fauna is lacking in Australia, as this fauna has been the least studied component of Australian saltmarsh ecology (Laegdsgaard 2006). Indeed, Boon (2011) maintained that

> *Australian saltmarshes suffer from massive knowledge gaps (for example, habitat and food for saltmarsh fauna, including invertebrates), and that until recently (2009), the most recent text with substantive sections on Australian coastal saltmarsh was 20 years old* (Boon 2011, p. 131).

Terrestrial invertebrates such as spiders and insects scarcely rate a mention in the "Conservation advice for Australian Subtropical and Temperate Coastal Saltmarsh", and although benthic invertebrates have been listed under common fauna in the document, spiders and beetles have been neglected (Department of the Environment 2013).

Nevertheless, in an important development, the Australian Federal Minister for the Environment amended the list of threatened ecological communities under Section s266B of the *Environment Protection and Biodiversity Act 1999* (EPBC Act) by including the Subtropical and Temperate Coastal Saltmarsh Community in the "vulnerable" category in August 2013 (Department of the Environment 2013). Previously, NSW was the only Australian jurisdiction to list coastal saltmarsh as endangered, others, including Tasmania do not list this ecological community (Department of the Environment 2013).

1.2 Tasmanian saltmarsh studies

Tasmania has a cool temperate climate that excludes the presence of mangroves, probably as a result of wintertime frosts (Kirkpatrick 1981). Coastal saltmarshes are found in the southeast, east coast, Flinders and King Islands, north coast and the far north west of the island. Pioneering Tasmanian saltmarsh research was conducted by Curtis and Somerville (1947) on the botanical and historical aspects of Boomer Bay on the Tasman Peninsula. Other early work focused on intertidal ecology, principally algae (Guiler 1949; 1952a; 1952b; 1952c), and the distribution, mapping and vegetation of saltmarshes (Glasby 1975; Kirkpatrick & Glasby 1981). Work on the benthic fauna, vegetation and soil factors continued in the 1980s and 1990s (Marsh 1982; Richardson *et al.* 1991; Wong *et al.* 1993; Richardson & Mulcahy 1996; Richardson *et al.* 1997; 1998). A thesis by Gouldthorpe (2000) researched the impacts of drainage and grazing on Derwent River marshes and recently an extensive project identified changes in the extent and community composition of southeast Tasmanian saltmarshes (Prahalad 2009). The real and projected impacts of climate change have also received attention (Mount *et al.* 2010; Prahalad *et al.* 2011). Finally, work by Prahalad, in the period 2010-2014, saw completion of coastal saltmarsh mapping in all three NRM regions of Tasmania. Nevertheless, no studies on Tasmanian saltmarshes have explored the interactions of saltmarsh soils, vegetation and terrestrial invertebrates.

1.3 Research project aims

Within the research question, a number of aims have been identified:

a) Undertake a baseline survey of the research site. This will serve as a reference point for future research at Long Point particularly in relation to sea-level rise and its effects;

b) Investigate the epigeal (ground dwelling) arthropods, principally spiders and beetles in a saltmarsh and their relationships with vegetation communities and edaphic (pertaining to soil) factors;

c) Define a saltmarsh reference state. By the use of indicator species analysis, be able to predict the incidence of spider and beetle taxa in certain saltmarsh vegetation communities; and

d) Prepare a reference document for use by local community groups interested in monitoring saltmarshes.

1.4 Structure of thesis

This thesis consists of six chapters. As the study encompassed four principal saltmarsh aspects (vegetation communities, landscape features, edaphic factors and terrestrial arthropods), the thesis has been structured in a way to allow each aspect to be fully addressed.

Chapter Two describes the characteristics, past history, vegetation, climate and intrinsic values of the research site. It gives the reader an understanding of the value of Long Point for this type of study.

Chapter Three discusses in separate detail, the methods used to study each individual aspect. It includes reviews of methods used to gather data in ecological research, particularly those that pertain to saltmarshes and makes clear why specific methods were chosen. The chapter also describes the statistical analyses applied to the data gathered for each aspect in the study.

Chapter Four provides the results of each individual aspect by the use of narrative descriptions, plots, tables and charts.

Chapter Five discusses the results of each aspect – vegetation communities, landscape features, edaphic factors and spiders and beetles – and relates this to other studies wherever possible. Following the discussion of each aspect separately, they are then collectively addressed in an attempt to understand the associations and interactions between each, and then all aspects.

Chapter Six summaries the findings of the study, outlines limitations apparent within the study and concludes with suggestions for further work to address continuing knowledge gaps.

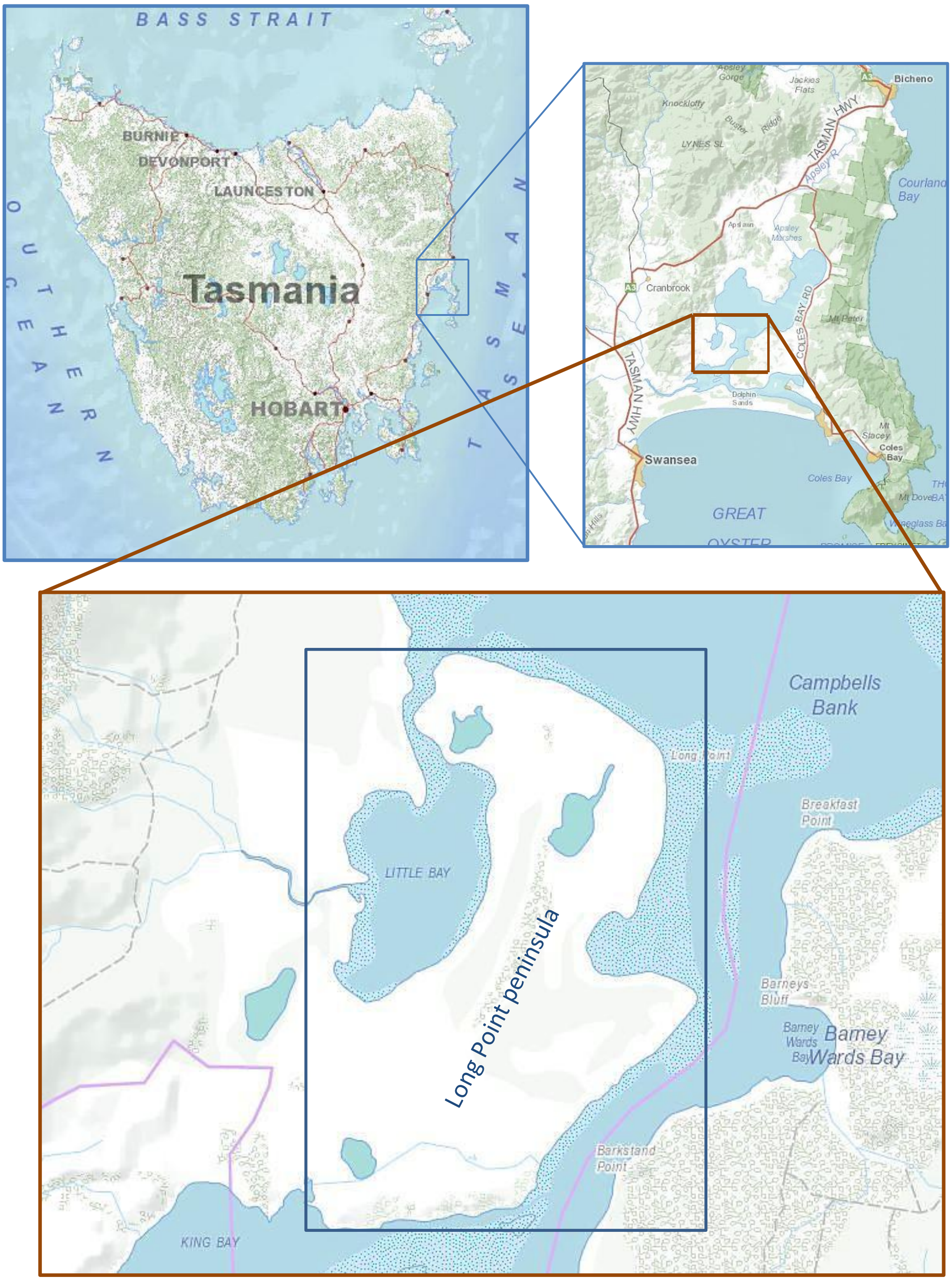
Chapter 2: Research Site

2.1 Description

Long Point, owned by the Tasmanian Land Conservancy (TLC), is a low spit of land, approximately 3.2 kilometres long by 1.3 kilometres wide. It is located on a NE/SW alignment in the south west corner of Moulting Lagoon on the East Coast of Tasmania. The mid-point lies at 42.0506°S 148.1512°E (Figures 2.1 – 2.3). It is a mixed saltmarsh/woodland/grassland environment; the saltmarsh component being recognised as the largest contiguous coastal saltmarsh in Tasmania (V Prahalad 2014, pers. comm., 20 July). An area of approximately 380 hectares is bisected by a central sand dune varying between five and 20 metres in height and running most of its length, splitting the saltmarsh into western and eastern sectors. A dolerite ridge dominates the extreme southern margin of the site. The orientation of the major dune does not appear to align with existing tidal water edges, suggesting that the dune pre-dates the current margins (Kiernan 2013). It has been proposed that fluvial processes have played a major role in the formation of Long Point's topographic framework with grey silts deposited during the Holocene Period (Kiernan 2013). Two distinct lunettes, Gum Tree Hole and Round Hole are located in the northern and eastern sections of the sand dune (Figure 2.4). These have been recognised as unique geomorphological features and have been nominated for inclusion in Tasmania's Geo-conservation Database (Kingdom 2008).

Long Point is encircled on three sides (north, east and south) by Moulting Lagoon, a waterway that forms the estuary to the Swan and Apsley Rivers, and Little Bay on the western side. The Lagoon has been described as a wave dominated estuary – a low energy central basin that is rimmed by intertidal environments and a coastal parallel barrier (Harris *et al.* 2002; Heap *et al.* 2004). It contains a 4 000 hectare game reserve that is managed by the Tasmanian Parks and Wildlife Service under a Game Reserve Management Plan (Parks and Wildlife Service 2007). The Lagoon itself has been identified as a wetland of national significance and is recognised as an internationally important wetland under the *Ramsar Convention on Wetlands (1971)*

(Parks and Wildlife Service 2007; Department of Sustainability 2008). Long Point has an 11 kilometre coastal border with Moulting Lagoon and Little Bay, and along with its extensive intertidal flats, plays a vital role in the ecological function of the Lagoon (Kingdom 2008).

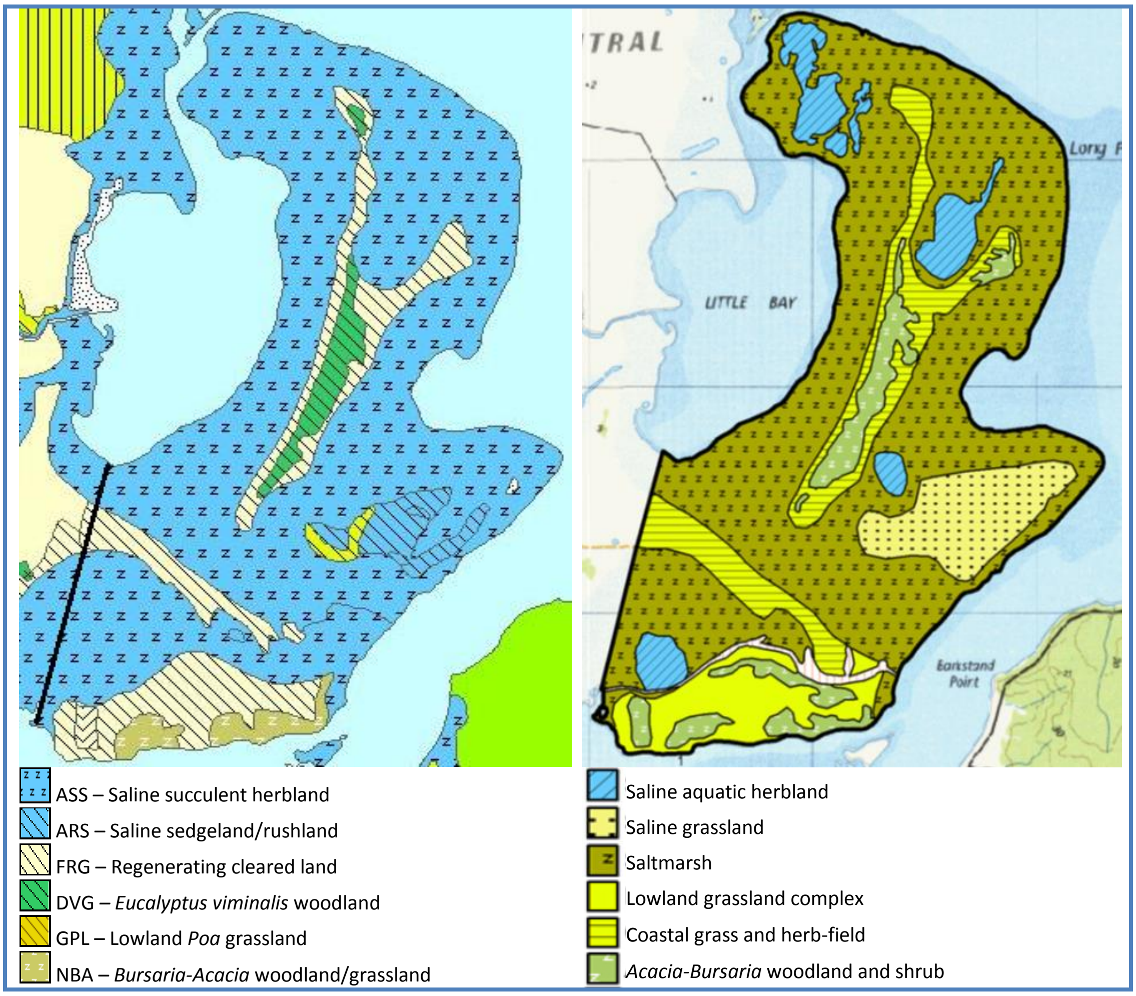


Figures 2.1 – 2.3: Top left – location in Tasmania; **Top right** – location on Tasmania's east coast; **Bottom** – Long Point peninsula. Source: DPIPWE (2014).

Figure 2.4: Long Point physical and geomorphological features. Source: Google Maps (2014).

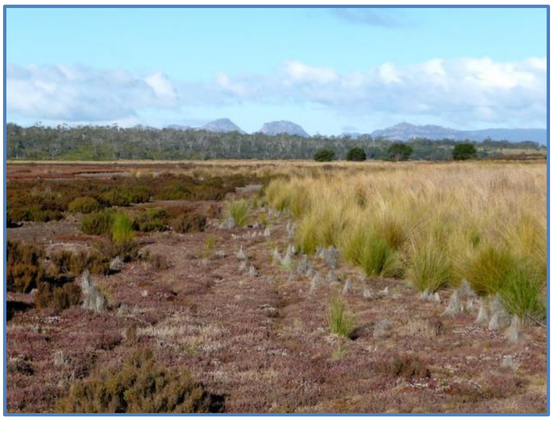
2.2 Vegetation

The vegetation at Long Point has been classified under TASVEG 3.0 (TASVEG) as ASS (Saline succulent herbland), ARS (Saline sedgeland/rushland), GPL (Lowland *Poa* grassland), NBA (*Bursaria-Acacia* woodland/grassland). The sand dune is classified as DVG (*Eucalyptus viminalis* woodland) and FRG (Regenerating cleared land) (Harris & Kitchener 2005; Department of Primary Industries Parks Water and Environment 2014) (Figure 2.5). In 2005 the TLC conducted a vegetation survey and identified six vegetation communities (Kingdom 2008) which have been described as: a) Saline aquatic herbland; b) Saline grassland; c) Saltmarsh; d) Lowland grassland complex; e) Coastal grassland and herb-field; and f) *Acacia* – *Bursaria* woodland and scrub (Kingdom 2008) (Figure 2.6).



Figures 2.5 and 2.6: Interpretation of vegetation types at Long Point. **Left** – TASVEG 3.0 applied to aerial photos. Source: DPIPWE (2014). **Right** – vegetation survey at time of acquisition by TLC. Source: Kingdom (2008).

Long Point is characterised by extensive, low-lying tidal marsh dominated by succulent herbs, primarily *Sarcocornia* spp. (glassworts). Other species found in the marshes are *Tecticornia arbuscula* (shrubby glasswort) and *Disphyma crassifolium* (pigface). The saline grasslands, though irregularly inundated, still present saline conditions harbouring *Gahnia* spp. (saw-sedges) and *Austrostipa* spp. (spear-grasses). The lowland grasslands and woodlands contain native and introduced graminoids, gorse and bracken with overstorey species such as *Acacia* in the woodland areas (Kingdom 2008). Vegetation communities on the site, particularly the saltmarsh section, are generally well defined (Figures 2.7 and 2.8).



Figures 2.7 and 2.8: Distinctive vegetation boundaries. **Left** – saline succulent herbland (ASS) of *Sarcocornia blackiana* and *Tecticornia arbuscula* (left side) and saline sedgeland/rushland (ARS) of *Austrostipa* spp. and *Juncus* spp. (right side). **Right** – saline succulent herbland (ASS) of *Tecticornia arbuscula* (left side) and *Sarcocornia quinqueflora* (right side) displaying vegetation boundary within a TASVEG vegetation class.

2.3 Invertebrates

No comprehensive, terrestrial faunal surveys have been conducted at Long Point, though casual observations have been made that include invertebrates (Kingdom 2008). Invertebrate surveys by authors Wong *et al.* (1993), Richardson *et al.* (1997; 1998) and Edgar *et al.* (1999), have been conducted on Tasmanian saltmarshes including Moulting Lagoon. However, research has so far only focused on benthic fauna, such as molluscs and amphipods.

2.4 Intrinsic values

In 2008, a team from National Resource Management South (NRM South) carried out a significant assessment of its coastline responsibilities. The assessment included Moulting Lagoon and Long Point but only from the shoreline to 100 metres inland from the shoreline (Temby & Crawford 2008). The assessment documented several important intrinsic values of Moulting Bay and Long Point as listed in Table 2.1.

Table 2.1: Intrinsic values of Moulting Bay/Long Point. Source: NRM South (2008).

Category	**Assessment**
Pressure from anthropogenic modification	Slight anthropogenic modification
Ecological disturbance and foreshore condition	Minimal ecological disturbance
Fauna significance within 100 metres of the coast	Endangered
Biological values of foreshores	Very high biological values
Vulnerability of foreshores to climate change	Most vulnerable to climate change
Condition of foreshores	Very good condition
Natural value of foreshores	Very high natural values
Pressure from pollution on foreshore	No pressure from pollution
Pressure on the foreshore	Slight pressure
Pressure from recreation and tourism use on foreshore	No pressure from recreation and tourism
Geomorphic value of foreshores	High geomorphic values
Introduced species and foreshore condition	WEST shoreline: condition not affected by introduced species EAST shoreline: condition slightly affected by introduced species
Introduced species and foreshore pressure	Slight pressure from introduced species
Native vegetation condition	Intact
Native vegetation viability	Viable and self-sustaining
Vegetation	ASS = succulent saline herbland
Vegetation significance within 100 metres of the coast	Non-threatened
Weeds	No weeds present
Potential fauna habitat within 100 metres of the coast	Yes, all of coastline

Saltmarshes in the area have also been described as:

> …*among the most sensitive coastal landforms in the Southern NRM Region and are associated with biological communities of high conservation values* (NRM South 2008, pp. 8, 9).

Past occupation by local Indigenous Peoples could have occurred in several suitable sites, however no records or evidence of such occupation have been discovered (Kingdom 2008; Kiernan 2013). The large numbers of black swans in waters adjacent to and within Long Point would have provided a valuable food source of eggs to the Aboriginal people (Department of Sustainability 2008). Nevertheless, no Aboriginal heritage artefacts or sites were found during an Indigenous Heritage Survey carried out in July 2007 (Kingdom 2008).

Since European occupation, extensive duck hunting has taken place, becoming an important feature of the Moulting Lagoon. Although this still occurs today, the activity is managed. Historical evidence of hunters on Long Point exists, however the purchase of Long Point by TLC in 2005 coincided with the exclusion of hunting on the site (Kingdom 2008).

Subsequent to the acquisition of Long Point, TLC has adopted the following objective:

> *To identify, conserve, assist people to appreciate and where necessary restore the Reserve's (Long Point) natural and cultural heritage values and to ensure these values are passed on to future generations in as good or better condition than at present* (Kingdom 2008, p. 17).

2.5 Climate

Tasmania's east coast has a temperate maritime climate with prevailing westerly winds. The site is equidistant between Swansea and Friendly Beaches, each the location of a weather station managed by the Bureau of Meteorology (BOM) (Figure 2.9). The Swansea station is a full weather recording facility (FWS) situated at an elevation of six metres, whereas Friendly Beaches is an automatic facility (AWS) recording temperature, rainfall and wind parameters and is located at an elevation of 55 metres (Bureau of Meteorology 2014c).

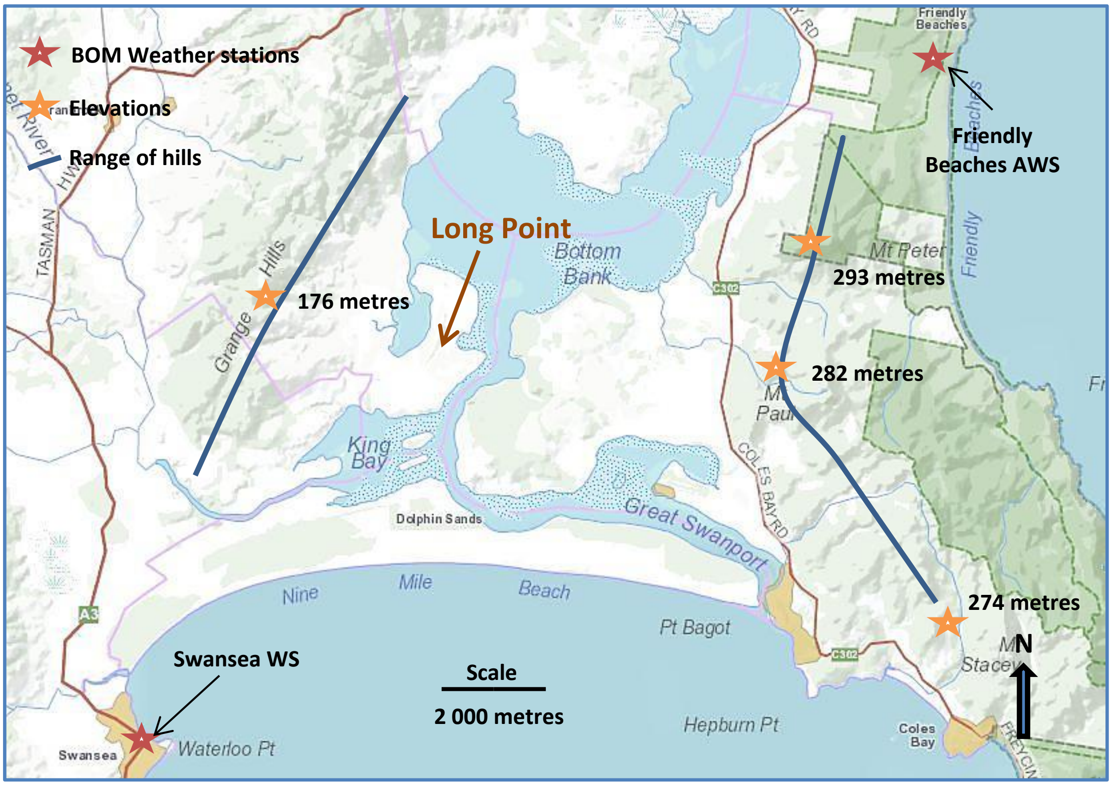


Figure 2.9: Long Point in relation to BOM weather stations and the range of hills on the west and the east that appear to create a rain shadow effect. Source: DPIPWE (2014).

Climate modelling shows that the central Tasmanian east coast will experience drier and warmer conditions in the future (McInnes *et al.* 2004). These conditions have already become apparent in the 30-year period mean climate statistics (Table 2.2).

Table 2.2: Change in 30-year period mean climate statistics at Swansea. Source: BOM (2014a). NB: At present, 2008 is the last year of statistical data available for Swansea.

Statistic/30-Year period	1891-1920	1921-1950	1951-1980	1981-2008
Rainfall (mm)	581.2	614.4	606.3	524.8
Maximum temperature (°C)			17.6	18.1
Minimum temperature (°C)			7.4	8.0

2.5.1 Precipitation

The general rainfall pattern for both BOM stations is variable throughout the year, though higher falls are experienced during the summer months. Friendly Beaches records higher rainfall for every month except December and January (Bureau of Meteorology 2014a; 2014b) (Figure 2.10). As Long Point appears to be in a rain shadow of both BOM sites, precipitation is expected to be lower.

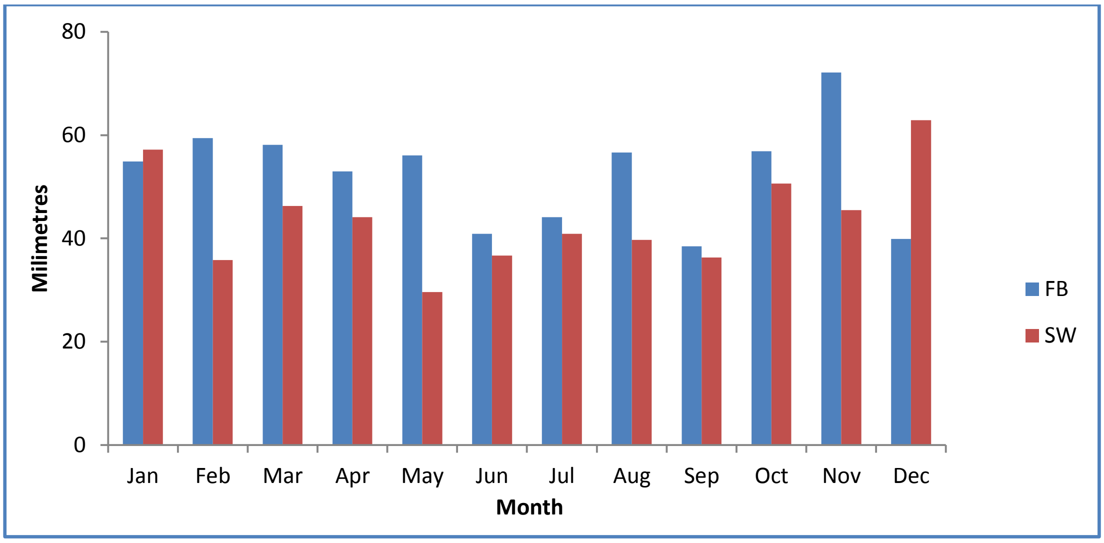


Figure2.10: Average precipitation per month for Friendly Beaches (FB) and Swansea (SW) – FB 1997-2014, SW 1981-2008. Source: BOM (2014a & b).

2.5.2 Temperature

Both weather stations show similar average monthly maximum and minimum temperatures (Figure 2.11). The warmest months are January and February with a mean daily maximum of 22.5°C and a mean minimum of 12.5°C. July is the coldest month with a mean daily maximum of 13.5°C and a mean minimum of 4.5°C (Bureau of Meteorology 2014a; 2014b).

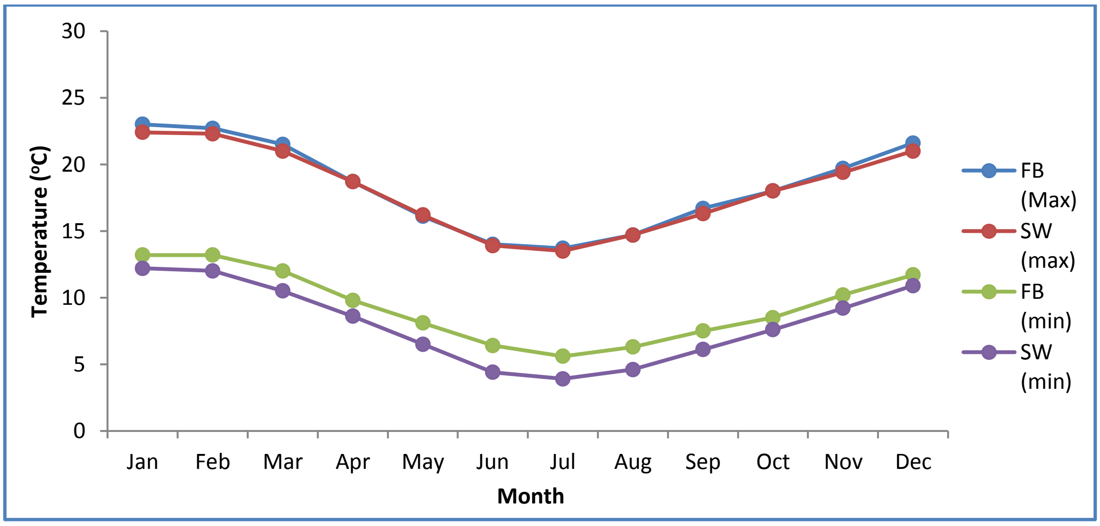


Figure 2.11: Average monthly maximum and minimum temperatures for Friendly Beaches (FB) and Swansea (SW) – FB 1997-2014, SW 1981-2008. Source: BOM (2014a & b).

2.5.3 Wind

At 9am, west to north-westerly winds are the most prevalent for both Friendly Beaches and Swansea, followed by north-easterlies at 3pm (Bureau of Meteorology 2014a; 2014b) (Figures 2.12 and 2.13). Wind strength at Friendly Beaches is greater, as the location is more exposed and elevated (Bureau of Meteorology 2014c). Wind strength at Long Point is more likely intermediate between Friendly Beaches and Swansea, however the shadow effect (see Figure 2.9) may alter the wind direction.

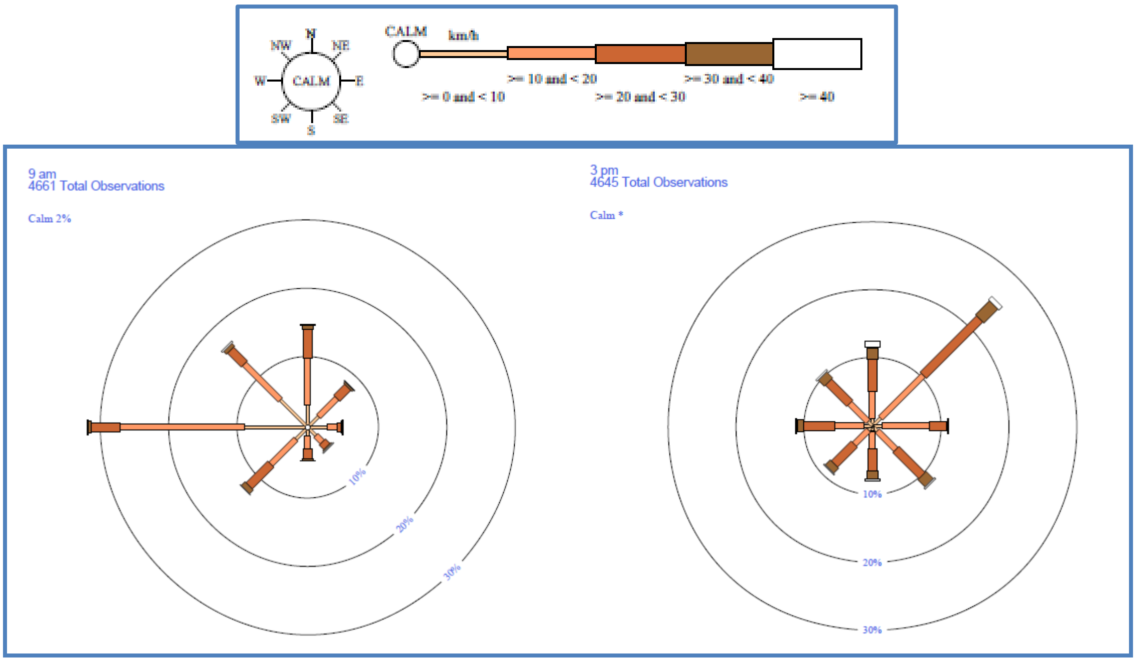


Figure 2.12: Wind-rose data (L = 9am, R = 3pm) for Friendly Beaches for the period Mar 1997 to Sep 2010. Source: BOM (2014b).

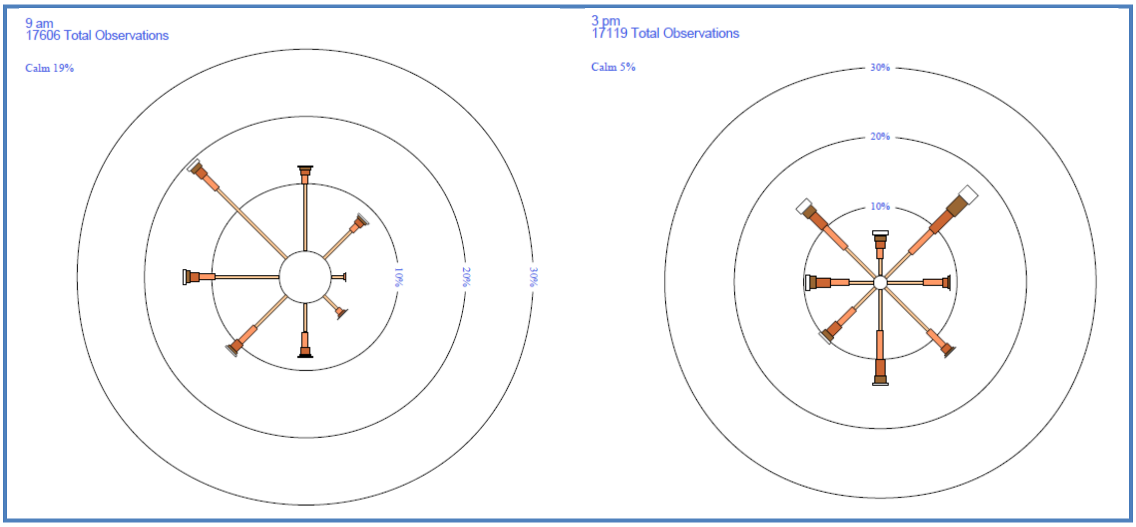


Figure 2.13: Wind-rose data (L = 9am, R = 3pm) for Swansea for the period Jan 1957 to Sep 2008. Source: BOM (2014a).

2.6 Site history

Long Point was originally part of "The Grange", a freehold property purchased in 1848 by the Cotton family. In the 1890s, "The Grange" was sold and in the early 1900s was repurchased by the Cottons and since then has remained in the family until Long Point was subdivided from "The Grange" in 2005 (J Cotton 2014, pers. comm., 24 August).

Following subdivision from "The Grange" in 2005, Long Point was purchased by the Tasmanian Land Conservancy, a registered environmental organisation established in 2001 "to protect areas of high conservation values for species which are not adequately protected" (Tasmanian Land Conservancy 2014).

On purchase of the site, TLC sought a perpetual conservation covenant in the form of a Private Sanctuary over Long Point to be registered under the *Tasmanian Nature Conservation Act 2002* (Kingdom 2008). However, declaration as a Private Sanctuary under the Act has not been attained as the Tasmanian Department of Primary Industry, Parks, Water and the Environment are currently reluctant to take on "any more official responsibilities" (D Kingdom 2014, pers. comm., 17 February).

2.6.1 Past land use

Traditionally, Long Point had been used for bush grazing sheep with a dry stocking rate of approximately 0.75 DSE (dry, (not lactating), sheep equivalent) per hectare (J Cotton 2014, pers. comm., 24 August). Cultivation of the area has been limited to sporadic attempts to establish exotic pasture which failed. From the late 1880s to the 1930s, black wattle was harvested to feed the Swansea bark mill; the processed material was exported for use tanning leather. Sometime in the early years of European ownership, several drains were dug across the marshland (Kingdom 2008). Though their purpose was not recorded, their location and direction appears to suggest that attempts were made to drain the marsh of flooding tides (Kingdom 2008). In the early 1990s, a channel was constructed on the northern side of the dolerite ridge from Moulting Lagoon to King Bay, in effect isolating the dolerite ridge from the saltmarsh (see Figure 2.4). Unsuccessful attempts at aquaculture ventures followed – one for Tasmanian whitebait the other for Pacific oysters (Kingdom 2008). The channel drain remains open with weak tidal waters generally flowing east to west. For some years, Long Point was used by duck hunters and two small, derelict shacks are still visible at the north-eastern end of the site. Bird hides were also built in the ephemeral ponds such as Gum Tree Hole and Opening Hole for duck hunters (Kingdom 2008).

2.6.2 Current land use

Long Point is now freehold land retained by the TLC (Figure 2.14). The site is somewhat remote with limited access. Activities are restricted to those outlined in the conservation covenant that is attached to the land title (Kingdom 2008). A visitor management policy has been implemented with its principal aims being reserve management, scientific research and donor and educational visits. In each case visitor numbers are limited to a maximum of 20 persons at any one time (Kingdom 2008). With respect to introduced species, gorse (*Ulex europaeus*) eradication is underway with the aim of eliminating gorse cover estimated at approximately 50 hectares (in 2005). Contract spot spraying, and cut and paint of gorse by conservation volunteers, have been used for this task with some success (Kingdom 2008).

Figure 2.14: Access gate to Long Point Reserve fitted with appropriate signage.

2.7 Relevant treaties, legislation and regulations

Current legislation and policies pertaining to the site are outlined in Table 2.3.

Table 2.3: Legislation and policies requirements for the management of Long Point. Source: Kingdom (2008).

Jurisdiction	Legislation and Policies
Federal	*Commonwealth Environment Protection and Biodiversity Conservation Act (1999)*
State	*Tasmanian Nature Conservation Act (2002)*
	Tasmanian Threatened Species Protection Act (1995)
	Tasmanian Aboriginal Relics Act (1975)
	Tasmanian Coastal Policy
Local	Glamorgan-Spring Bay Council Planning Scheme

Chapter 3: Research Methods

3.1 Introduction

Long Point was chosen as an appropriate study site for a number of reasons. Firstly, the land is privately owned and under consideration for protection as a private sanctuary, thereby facilitating future reassessment of environmental modifications resulting from climate related sea-level rise. Secondly, it contains a compact sequence of habits of varying vegetation communities and edaphic factors, ranging from the coastal to woodland and a full transitional range of marine to terrestrial communities. Thirdly, the adjacent woodland zone, although having incurred a low degree of anthropogenic impact in the past, provides a very important opportunity to study the full ecological range of terrestrial invertebrates now and in the future (Richardson & Mulcahy 1996).

Preliminary site visits revealed that several environmental aspects played an important role within the saltmarsh ecosystem therefore necessitating investigation in conjunction with a study of spiders and beetles. These aspects were vegetation communities, landscape features and edaphic factors, with tides and climate regarded as being secondary. The need to carefully document these aspects influenced the research methodology for this project given that:

1. Landscape features, for example, elevation and hill shade, determine various soil and vegetation characteristics;
2. The edaphic factors, such as, moisture, salinity and pH, determine what and where plant species live and survive; and
3. As terrestrial epigeal invertebrates live on vegetation and the ground surface, occupancy of particular habitats may be influenced by the make-up of vegetation communities and abiotic impacts.

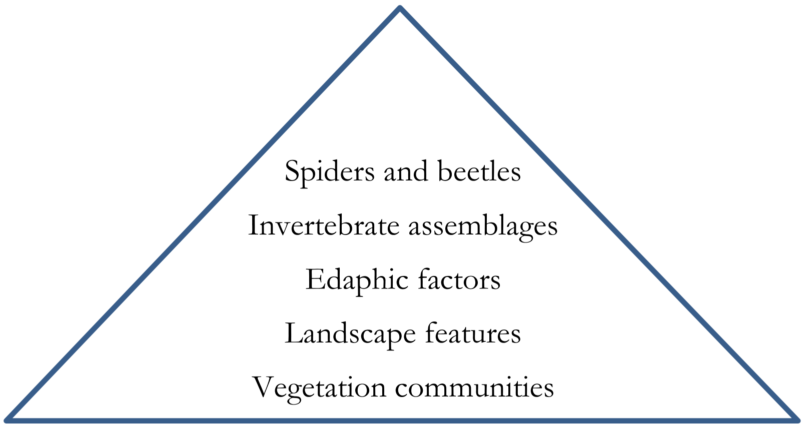
Assessment of these three aspects helped to formulate the primary research question:

- *To what extent does a saltmarsh environment influence the distribution of cursorial spiders and ground beetles?*

From this, two secondary questions arose:

- *What is the relationship between soils, vegetation communities and invertebrate assemblages?*
- *Are spider and beetle taxa faithful to their habitats as described by well-defined plant communities, or do they range between the saltmarsh and woodland environments?*

A hierarchical approach then defined the research processes as follows:



Outlined below in subsequent sub-sections are the methods used to answer the research question. A review of each component and its role within the saltmarsh environment is followed by a justification of the methods used in this study.

3.2 Transects, stations and identification

Three transects were established. Two were orientated west to east across the site and traversed the sand dune. The third tracked in a southerly direction incorporating the sand ridge and ended on the dolerite ridge (access to the shoreline here was hindered due to extensive gorse infestation). Transect locations and direction were determined by the profile of the landform and originally positioned to capture as much environmental range as possible across the elevation gradient (Figure 3.1).

Figure 3.1: RED, YELLOW and GREEN transects with identified stations at the research site, Long Point. Note: the GPS coordinates for all stations were uploaded to Google MAPS to generate the above image and saved as a .kmz file. Source: Google MAPS (2014).

Vegetation communities were the most visible and readily assessable factor and generally had well defined boundaries. They became the basis for allocating the positions of individual pitfall stations along each transect. For example, if a vegetation community dominated by *Sarcocornia* spp. was followed by another vegetation community dominated by *Tecticornia arbuscula*, a station would be positioned in the centre of each vegetation community positioned in a way that avoided the impact of edge effects. Although vegetation communities occurred more than once on transects, each time the community composition changed, a station was established.

Pitfall trapping was used to sample terrestrial invertebrates, particularly spiders and beetles that inhabit the saltmarsh surface. In order to confer replication, three pitfall traps were established at each station, one on the transect line, one to the north of the line and one to the south. Pitfall traps to the north and south of the transect line were at least four metres and no more than six metres from the centre trap. All three pitfall traps were placed in positions that represented the vegetation community of the station. Additionally, the GPS coordinate of each pitfall trap at each station ($n = 141$) was recorded.

It was very important that numbering and identification of transects, stations and pitfall traps were simple yet effective in order to facilitate site and laboratory work. To this end, a three character alphanumeric code was adopted, incorporating: a) R, Y, G (Red, Yellow, Green transect); b) stations numbered from west to east beginning 1 for each transect; and c) pitfall traps B (centre line trap), A and C (traps set north and south of centre line). For example, "Y4B" describes the pitfall trap position on Yellow transect in the 4th vegetation community along transect from western end, and it is the centre line pitfall trap.

Transect attributes, including length, number of stations and pitfall traps are listed in Table 3.1.

Table 3.1: Transect attributes at Long Point.

Transect	Description	Length (m)	Stations	Pitfall traps
RED	Northern transect through Gum Tree Hole; crosses the sand dune twice either side of the lunette; sand dune has a woodland dominated vegetation cover. Saltmarsh vegetation is extensive either side of the sand dune and around Gum Tree Hole.	995	14	42
YELLOW	Middle transect through Round Hole after crossing sand dune; vegetation either side of the dune dominated by grasses, some introduced. Saltmarsh vegetation is extensive either side of the sand dune and around Round Hole.	1 215	17	51
GREEN	Southern transect crosses the low east/west sand ridge dominated by bracken; traverses beside Opening Hole and ends on the dolerite ridge. This transect had two unavoidable bends due to impenetrable gorse cover present at the time of establishment.	1 320	16	48
	TOTALS	**3 530**	**47**	**141**

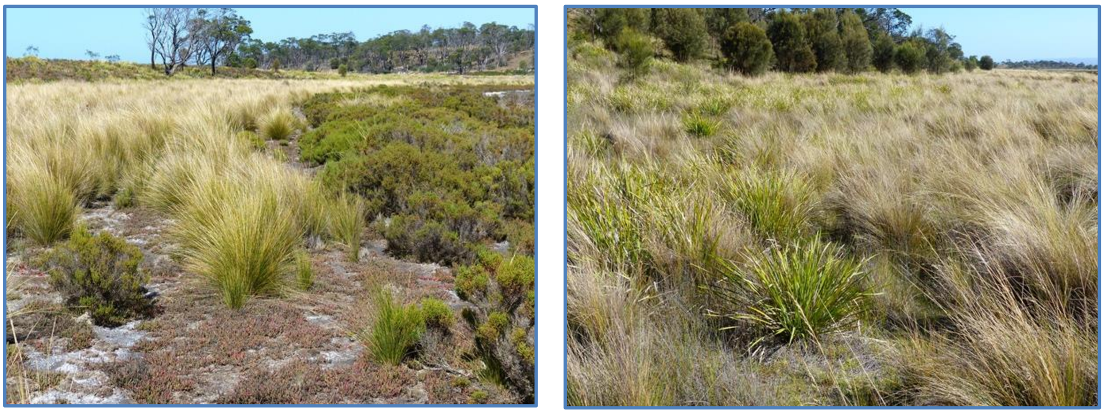
Although many stations were established in similar vegetation communities, all were retained in order to improve statistical robustness to the data being collected.

3.3 Vegetation communities

In order to survive harsh saltmarsh conditions, saltmarsh plants must be able to endure frequent inundation by salt water and live in soils that are often waterlogged (Long & Mason 1983; Saintilan 2009b). Furthermore, those plants that are further inland are prone to aerobatic salt, particularly on the windward side of the marsh. Soil types that vary across the saltmarsh are dependent on a number of factors, for example, frequency of saltwater incursion, salinity and elevation. Saltmarsh plants may adapt and survive in a wide range of soils, however their abundance and health will be markedly affected by the variable factors that make up soil types (Ranwell 1972).

A frequent claim made for saltmarsh vegetation is that it is species-poor. This impression is compounded by the dominance of a single species, or at times a few species, particularly in the lower marsh (Adam 1990; Saintilan 2009b). Here, halophytic (salt tolerant), succulent vascular plants dominate the marsh, these plants having adapted to the constant variations of salinity, moisture and at times anaerobic conditions to not only survive but also thrive (Long & Mason 1983). With increasing elevation, the number of species tends to increase, especially in the upper marsh zones, where mixtures of halophytic and non-halophytic species as well as saline and woodland grasses dominate alongside herbs (Long & Mason 1983; Adam 1990). This progressional change in vegetation is a universal feature of coastal marine marshes (Chapman 1974).

As a general rule, the tropics exhibit the greatest richness of plant species, with richness declining as latitude increases (Adam 2009). However, Australian saltmarshes show a very noticeable contrary pattern (Adam 1990; Saintilan 2009). Australia's four southern states – Tasmania, Victoria, New South Wales and South Australia, though home to less than 2.5% of the total saltmarsh/saltpan area of Australia, house over 90% of Australian saltmarsh species (Saintilan 2009), Tasmanian saltmarshes recording the highest number (Bridgewater & Cresswell 2003). Although there are taxonomic affinities at family and genus level with saltmarsh taxa from other continents, at species resolution, Australian saltmarshes plants display a high level of endemism (Adam 1990).



Figures 3.2 and 3.3: Distinct vegetation boundaries. **Left** – saline grassland containing *Austrostipa* spp. (left side), woody succulents – *Tecticornia arbuscula* (right side). **Right** – lowland woodland community comprising *Lomandra longifolia* (left side), saline grassland containing *Austrostipa* spp. and *Poa* spp. (right side).

Vegetation patterns are conspicuous within saltmarshes, leading to what has been described as zonation (Long & Mason 1983; Adam 1990; 2009; Saintilan 2009b). Zonation is recognised in three rudimentary classes – low, middle and upper marsh (Long & Mason 1983), with often distinct boundaries. In turn, this zoned arrangement of the saltmarsh reflects vegetation communities (Figures 3.2 and 3.3), and is dominated by tidal and elevational aspects.

3.3.1 Classification

Long and Mason (1983) suggested that the best manner to classify the saltmarsh is to consider the vertical range within the saltmarsh and split this range into three equal vertical zones, each supporting different vegetation communities. The low marsh would include three or four species, with one species dominant and there would be bare areas; the middle marsh containing more species, with the low marsh species present but with reduced abundance; the upper marsh comprising both salt and non-salt tolerant species (Long & Mason 1983).

Kirkpatrick and Glasby (1981) defined the structural forms of Tasmanian saltmarsh communities as: communities dominated by succulent herbs such as *Sarcocornia* spp.; communities dominated by grasses such as *Austrostipa stipoides*; communities dominated by sedges and grasses such as *Juncus krausii*, and communities dominated by herbs, such as *Samolus repens* (Kirkpatrick & Glasby 1981).

Similarly, Bridgewater and Cresswell (2003) identified diverse coastal saltmarsh vegetation communities on an Australian continental basis and recognised a specific Tasmanian subgroup within the main *Tecticornia arbuscula-Juncus kraussii* group (Bridgewater & Cresswell 2003). Work by Saintilan (2009a; 2009b) analysing Australia's coastal bioregions, revealed that with increasing latitude, vegetation richness of saltmarsh biogeographic provinces increased. Furthermore, Tasmania, as a whole, has 53% of Australia's saltmarsh flora with the island's South East bioregion containing 46% of the total flora (Saintilan 2009). Add any buffer or woodland fringe to the saltmarsh and species richness increases considerably.

3.3.2 Sampling

Many challenges are faced when sampling saltmarsh environments. Together with bare areas and saltpans, the complexity and diversity of vegetation in temperate saltmarsh habitats makes it difficult to define at a fine scale, the vegetation communities that are found (Kelleway *et al.* 2009). Long Point was no different. Canopy cover of some plants obscured smaller plants, hampering identification and estimates of abundance. Furthermore, the timing of sampling was important, as identification of some species from the same genus was far easier at different times of the year. For example, *Sarcocornia blackiana* was easier to identify from *S. quinqueflora* in autumn due to its colour contrast.

Floristic composition and species abundance was measured using two methods. The first was qualitative assessment to determine the position of pitfall stations along each transect. The second was a quantitative method to determine species composition and abundance and to identify any species that had not been recognised using the previous method.

Boundaries of vegetation communities at Long Point are very discernible (see Figures 2.7 and 2.8, 3.2 and 3.3) with generally two or three species being the most dominant within the community. As transects were established, stations were identified by using the qualitative approach based on the three dominant vegetation species (if possible) or by genus (if species not possible) within the particular community, and their respective percentage cover at the station. As would be expected, many stations at the site were identical in vegetation complexes. Some communities were replicated but were in a different landscape setting. For example, a *Sarcocornia* spp. community was very close to the marine environment (the edges of the saltmarsh) and a similar vegetation community was also duplicated within the site adjacent to large water holes. All stations were retained irrespective of their location or vegetation make-up.

A second survey was conducted using a modified Braun-Blanquet (BB) cover-abundance method that estimates the quantity of each species in a vegetation community in one scale – cover and abundance (Mueller-Dombois & Ellenberg 1974; Moore & Chapman 1986). This method ascribed a numerical value to crown cover percentage of individual species as follows:

1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75% and 6 = >75%

Due to the overlaying cover of most species, the total cover for each sample plot may exceed 100% (Moore & Chapman 1986) and was a common outcome at Long Point.

Each station on each transect *(n = 47)* was assessed in April 2013 and reassessed in January 2014 in order to capture any summer growing plants. An area approximately one metre on either side of the line through the three pitfall traps (A, B and C, therefore two metres wide) at each station was evaluated for individual species and ascribed a numerical value based on its percentage cover within the plot using the Braun-Blanquet scale above.

3.3.3 Analysis of data and presentation of results

The first vegetation assessment was used to establish transects and stations on the research site and following completion the information had no further use, but was retained.

3.3.3.1 Grouping to vegetation communities

Vegetation is the most visible and easily assessable factor of a saltmarsh. The principal species that make up the individual vegetation communities do not change season by season. Dominant species, such as *Sarcocornia* spp. and *Tecticornia arbuscula* are easily identifiable. Furthermore, saltmarsh vegetation communities are generally well defined and have distinct boundaries. Therefore, it was beneficial to use vegetation communities to cluster the stations at the research site.

Following the second vegetation survey, stations were grouped using a cluster analysis incorporating the Ward linkage method from the *vegan* package in R (Oksanen 2013). The analysis of BB cover values 1 to 6 (individual species cover from less than 1%) and cover values 2 to 6 (individual species cover from 1%) produced too much distortion, where in both cases, groups included too many stations that were visually different in the species present at individual stations. Furthermore, the Ward analysis of BB cover values 1 to 6 and 2 to 6, created groups that contained just one station, a situation that was not represented in the field. An analysis using BB cover values 3 to 6 (individual species cover of greater than 5%) improved the results by reducing the number of stations in particular groups.

However, groupings of seven and eight clusters still resulted in some groups containing a single station each.

The best grouping of stations was derived from a whole evidence approach that included a statistical analysis of cover data, a visual appraisal and knowledge of the site. To this end, using BB cover values of 3 to 6 in an analysis resulting in six clusters met the criteria. This was consistent with field inspection of the vegetation communities that made up each group, recognisable as lower/middle/upper marsh and fringe (woodland) areas. Furthermore, although two woodland groups had only two stations each, each of these groups represented an excellent fit based on field evidence.

For ease of use and understanding, the vegetation communities at the research site were matched with the recognised units used in the formal mapping of Tasmania's vegetation – TASVEG 3.0 (TASVEG). Currently saltmarsh vegetation units in TASVEG are identified by three codes, ASS, ARS and AUS (Department of Primary Industries Parks Water and Environment 2014) (Table 3.2).

Table 3.2: TASVEG saltmarsh codes and description. Source: Harris and Kitchener (2005).

Code	Description
ASS	**Succulent saline herbland** (**ASS**) is a low-growing community dominated by *Sarcocornia quinqueflora* and sometimes *Sclerostegia arbuscula* (now known as *Tecticornia arbuscula* – author note), the latter shrubs being up to 80 cm high. Often the community has a strong reddish tinge resulting from the visibility of leaf anthocyanin, which is an adaptation to highly saline and sunny environments.
ARS	**Saline sedgeland/rushland (ARS)** is a coastal community frequently dominated by *Juncus kraussii* or, sometimes, other species such as *Gahnia filum*. Some succulent species may be intermixed.
AUS	**Saltmarsh (undifferentiated) (AUS)** is a generic saltmarsh code, which has been used where remote-mapping of the specific saltmarsh ecological vegetation communities has not been possible.

While TASVEG codes were useful at a broad scale, they were limiting in identifying vegetation at a finer scale. The ASS unit (succulent saline herbland) did not discriminate between *Tecticornia arbuscula* dominated vegetation compared to *Sarcocornia* spp. dominated vegetation, nor, if the vegetation was coastal, or, in the case of Long Point, inland.

Based on the vegetation dendrogram (see Results – Section 4.1.1, Figure 4.1, page 60) of the three defined saltmarsh vegetation communities, two groups at Long Point fell into succulent saline herbland (ASS) code, one that was wholly dominated by *Sarcocornia quinqueflora* and/or *S. blackiana*, the other dominated by *Tecticornia arbuscula*, *S. quinqueflora* and/or *S. blackiana*, and *Disphyma crassifolium*. These two groups were assigned codes ASS(a) and ASS(b) respectively. The third group represented saline sedgeland/rushland dominated by *Juncus* spp. (rushes) and *Gahnia* spp. (sedges) and is consistent with the TASVEG description, therefore assigned the code ARS.

The research site also included buffer zones and woodland. TASVEG codes that have been used to describe these dry-land communities at Long Point were DVG and GPL (Department of Primary Industries Parks Water and Environment 2014) (Table 3.3).

Table 3.3: TASVEG dry-land codes and description. Source: Harris and Kitchener (2005).

Code	Description
DVG	***Eucalyptus viminalis*** **grassy forest and woodland (DVG)** is characteristically low to medium height (15-25m), open, grassy forest dominated by *E. viminalis*. The understorey is generally grassy, however rock can form a significant cover in some situations. Low shrubs may form a sparse layer. The specific make-up of the understorey depends largely on the fire and grazing regimes.
GPL	**Lowland grasslands (GPL)** are dominated by tussocks of *Poa labillardierei* that may be large and spreading or small and tufty, depending on the situation. The tussocks may form a closed sward or an open layer with smaller grasses and herbs between the tussocks.

The DVG code includes typical understorey tall shrubs as *Acacia mearnsii, Allocasuarina verticillata* and *Bursaria spinosa*. These three species were present on the sand dune, with *Acacia mearnsii* also occurring on the dolerite ridge. However, there was no evidence of living *Eucalyptus viminalis* at the site, this tree having succumbed to the ravages of grazing (sheep), browsing (possums), drought and old age (J Cotton 2014, pers. comm., 24 August). In this instance it was prudent to characterise this vegetation community as GSL – lowland grassy sedgeland (Table 3.4), as *Lomandra longifolia*, and to a lesser extent *Lepidosperma concavum,* were well established in several large areas of the sand dune. The GSL vegetation code also includes tall shrubs such as *Acacia mearnsii* and *Bursaria spinosa,* both evident in the vegetation community being classified.

Table 3.4: TASVEG GSL description. Source: Harris and Kitchener (2005).

Code	Description
GSL	**Lowland grassy sedgeland (GSL)** is dominated by sedges such as *Lomandra longifolia* and *Lepidosperma* species interspersed with grasses. *Acacia dealbata, A. mearnsii, A. melanoxylon* and *Bursaria spinosa* can form scattered small tree layer on slopes

Using the groups identified by Ward method on BB cover values 3 to 6, vegetation communities at Long Point were assigned vegetation codes based on TASVEG (see Results – Section 4.1.1, Table 4.1, page 61) and stations identified to those vegetation codes were grouped (see Results – Section 4.1.1, Table 4.2, page 64). A non-metric multidimensional plot was produced to demonstrate station relationships based on the groups selected above.

The saline community's descriptions for ASS(a), ASS(b) and ARS fit realistically with those described by Kirkpatrick and Glasby (1981) in their study of vegetation distribution and community composition of Tasmanian saltmarshes (Table 3.5).

Table 3.5: A comparison of vegetation descriptions between Kirkpatrick and Glasby (1981) and this study.

Kirkpatrick and Glasby	TASVEG Code	This study
Communities dominated by succulent shrubs: *Arthrocneum arbuscula* (now known as *Tecticornia arbuscula* – author note), *Sarcocornia quinqueflora, Sarcocornia blackiana, Disphyma blackii* (now known as *Disphyma crassifolium* – author note)	ASS(a)	Succulent saline herbland wholly dominated by *Sarcocornia quinqueflora* and/or *S. blackiana*
	ASS(b)	Succulent herbland dominated by *Tecticornia arbuscula*, *Sarcocornia quinqueflora* and/or *S. blackiana*, *Disphyma crassifolium* and bare areas
Communities dominated by sedges or rushes: *Juncus kraussii, Gahnia filum* and/or *Gahnia trifida*	ARS	Saline sedgeland/rushland dominated by *Juncus* spp., *Gahnia* spp., *Austrostipa stipoides,* and to a lesser extent, *Poa labillardierei* with bare areas

The groups – three saltmarsh ASS(a), ASS(b), ARS, and three woodland GSL, GPL (dr) and GPL (sr), formulated above and in Results (see Section 4.1.1), will now form the basis for the further analysis of landscape, soil and invertebrate data in this study.

3.3.3.2 Vegetation communities – indicator species

Species are chosen as indicators when they reflect the biotic state of the environment if their presence can predict the diversity of communities within an area (De Cáceres 2013). Indicator species emerge through an analysis of occurrence or abundance values from a set of sampled sites and the classification of the same sites into site groups, which may represent vegetation communities. For this study, one data element has been used to cluster the stations into group sites, and then to determine the indicator species within those groups. The site classification vector was determined by the use of BB values of 3 to 6; subsequently, the species indicator analysis used the BB values of 1 to 6 in order to fully characterise each vegetation community. The indicator species analysis was carried out in the R package *indicspecies* using the function "IndVal" (De Cáceres 2013).

3.4 Landscape features

The principal factor that differentiates the saltmarsh environment from the adjacent terrestrial environment is tidal inundation (Adam 1990), and the main feature that controls what is flooded and what is not is elevation. The elevational gradient from sea-level interacts with the tides to determine which sections are inundated daily, seasonally or infrequently, such as via storm events. This gradual altitudinal increase decreases tidal influences, which in turn limits soil salinity, moisture, waterlogging and pH. These factors all impact directly on the extent and nature of vegetation cover in saltmarshes (Ranwell 1972; Long & Mason 1983; Adam 1990; 2009).

The amount of light reaching the ground is another factor that is determined by the interplay of tides and elevation (Ranwell 1972). During times of tidal inundation, the amount of light available to submerged vegetation is reduced, and often fine silt will settle on plant leaves, impacting the rate of photosynthesis following tidal retreat (Ranwell 1972; Chapman 1974). Solar insolation, the amount of energy that reaches the earth's surface, plays a role in the make-up of vegetation communities. For example, shading by tall saline grasses limits types of ground cover vegetation, and evaporation can alter soil moisture thereby increasing salinity (Clarke & Hannon 1969; Adam 2009).

A minor factor, yet still important, is hill shade. Sand dunes that border or intersect saltmarshes can limit sunlight by shading depending on elevation and dune orientation, which can determine the impact on surrounding vegetation and soils. Hill shading could influence the fringe/hinterland to the saltmarsh and data from GPS coordinates was analysed to see if there was any evidence of impact.

3.4.1 Tides

Tides play several roles in the daily life of a saltmarsh. Of particular importance is the daily flooding of saline water that influences the plant and animal saltmarsh species of the lower marsh zone (Ranwell 1972; Adam 1990). The recurrent cycle of inundation and withdrawal exerts selective pressure on both plants and animals that have adapted to conditions of exposure and submersion in combination with hypersaline surroundings. A flooding tide recharges the lower marsh with saline waters, whereas an ebbing tide will leave substantial volumes of saline water within the soil and in saltmarsh pans (Long & Mason 1983). Evaporation draws off water leaving increased salt levels behind, thus changing the local environment to hypersaline conditions (Morrisey 2000).

Tidal patterns vary around the world and fall into three categories, a) semi–diurnal: two high tides per day of relatively equal height; b) mixed: two high tides per day, with varying heights; and c) diurnal: one high tide per day (Adam 1990). Furthermore, tidal heights vary over a 28 day period (the lunar cycle) and again at the time of equinoxes when the maximum amplitude occurs (Long & Mason 1983). As a consequence of tidal height fluctuations, different sections of the saltmarsh become inundated, some more often than others (Ranwell 1972; Long & Mason 1983; Adam 1990). Variable levels of marsh inundation lead to zonation, in turn leading to varying vegetation communities that adapt and survive in different levels of tidal flooding (Long & Mason 1983; Adam 1990) and salinity levels.

Zonation is very evident at Long Point with many vegetation communities having well defined boundaries (see Figures 2.7 and 2.8). During this research project, tidal flooding events were observed particularly in winter. No observations were recorded during these events except for some photographs (Figures 3.4 and 3.5).

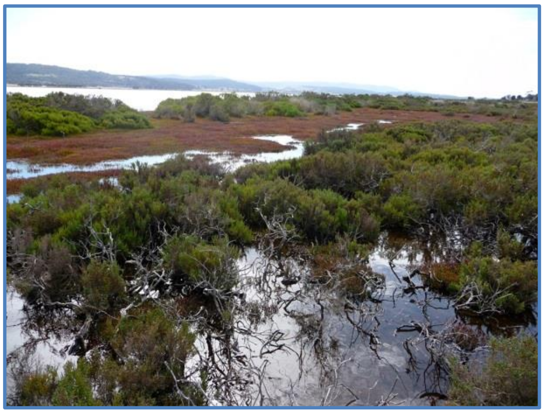



Figure 3.4 and 3.5: Flooding events. **Left** – RED transect station R13. **Right** – YELLOW transect station Y2.

A desktop study of tidal activity during the time of invertebrate collections, March 2013 to February 2014, was undertaken using tidal data from the Bureau of Meteorology Tidal Predictions portal, and is reported in Section 4.2.1 (see Results – Tides).

3.4.2 Climate

Climatic influences operate unvaryingly over the flat surface of marshland, and tend to be "unidirectional across marsh surfaces" (Ranwell 1972, p. 11). It is not clear what impact rainfall has on saltmarshes other than locally reducing salinity in soils, particularly after heavy rain, and also increasing soil moisture levels in upper marsh areas (Chapman 1974). High rainfall at times of extreme high tides will increase the marsh area flooded both spatially and temporally (personal observation). Although it appears not to have been studied in detail, temperature range and variation can play a role in the saltmarsh vegetation germination and survival (Ranwell 1972; Chapman 1974). High temperatures, which occur during periods of neap tides when tidal inundation is at its weakest, will escalate evaporation and as a consequence, increase salt efflorescence in soils (Chapman 1974). Young vegetation at this time is at serious risk. Low temperatures such as frost, particularly at times of low inundation levels, will seriously damage vegetation, such as *Sarcocornia quinqueflora,* often resulting in death of shoots and at times whole plants (personal observation – see Appendix A1b – Frosts, page 165).

Precipitation and temperature data were available from nearby BOM weather stations at Swansea and Friendly Beaches. However, as Long Point is probably in a rain shadow caused by the surrounding hills and ranges (see Figure 2.9), it was considered important that an attempt be made to record precipitation and temperature at the site and compare to that of the official weather stations to establish any variations.

3.4.2.1 Precipitation

Four standard 2 000ml Nylex rain gauges were set up at: a) the entry gate to Long Point (LPS); b) station R4; c) station Y12; and d) station G16 (Figure 3.6). Rainfall recordings were taken at every visit to the site and data tabulated with rainfall data for the same period from the BOM weather stations.

3.4.2.1 Temperature

Ten LogTag® (Model Trix-8) (http://www.microdaq.com) temperature data loggers were located at various stations on Red and Yellow transects to record temperature on marshland and the sand ridge, and one was placed at the end of Green transect on the dolerite ridge (Figure 3.6). Each logger, attached to a marker peg adjacent to the A pitfall trap, was covered with an upturned white plastic pail that had ventilation holes drilled into it in an attempt to mimic a Stevenson Screen, a standard used internationally to house temperature instruments (Bureau of Meteorology 2013) (Figures 3.7 and 3.8). The loggers were set to record the temperature every 66 minutes for 365 days, a total of nearly 8 000 measurements per logger.

Figure 3.7: Temperature logger.

Figure 3.8: Temperature logger cover.

Figure 3.6: Location of rain gauges and temperature loggers at Long Point. Source: Google MAPS (2014).

The LogTags® were positioned on 9 June 2013 and retrieved 12 June 2014 – recording concluded on 8 June 2014. Data from two LogTags® (stations R1 and Y17) were irretrievable. Data retrieval from the remaining LogTags® was successful.

Retrieved data were collated by station, sorted for maximum and minimum per month, and tabulated and plotted with the maximum and minimum temperatures from Swansea FWS and Friendly Beaches AWS. The maximum and minimum temperatures for June 2013 were taken from the period 9 to 30 June 2013 to match the date range from the data loggers.

3.4.3 Elevation, hill shade and solar radiation

A GPS survey using a Garmin GPS 72 handheld unit was completed as transects and stations were established. At that time the coordinate of each pitfall trap was recorded. Fortuitously, LiDAR (Light Detection and Ranging) data from a Tasmanian Government project on climate futures for Tasmania was available. This facilitated the analysis of the GPS data for elevation using Esri ArcMap 10™. However, the elevation results were found to be unreliable as LiDAR has more difficulty penetrating dense saltmarsh vegetation, such as *Sarcocornia* mats, than it does open woodland vegetation (Davidson 2010). This resulted in the estimates of elevation of closed vegetation communities of the lower and middle marsh areas to be higher than actual by up to 0.20m (Davidson 2010).

A real-time kinematic (RTK) survey was completed in June 2014 using geodetic grade GPS receivers. A base station was setup on ST114's Reference Mark (RM) 5 (ST114 is a 4th order Survey Control Point located on Grange Hill near Long Point) utilising a Leica® 1200 GPS and a radio transmitter (Figure 3.9). A Leica® 1200 rover GPS was used to measure each pitfall trap ($n = 140$) at 1 second epochs for 20 seconds (Figure 3.10). The anticipated accuracy of these points relative to the base station was ±20mm horizontally and ±50 mm vertically. Given real uncertainty of ST114 and associated RMs, detailed both in its Survey Report and the Geospatial Infrastructure Branch of DPIPWE (S Strong 2014, pers. comm., 11 June), a new and more accurate coordinate for ST114 RM5 was calculated using standard GPS surveying techniques. This involved undertaking an ~30 min static GPS survey between the nearby SPM10953, a 2nd order survey point situated on the Lake Leake Highway, and ST114, over an ~5km baseline. From the new updated coordinate of ST114 RM5, an easting, northing, and height correction factors were calculated in order to update the pitfall trap coordinates. The horizontal positions for each pitfall trap were correlated to MGA Grid, GRS80 Ellipsoid, GDA94 and Zone 55. The orthometric height, which approximates mean sea level (MSL), was computed using the AusGeoid09 model (for further information see: http://www.ga.gov.au/ausgeoid/ nvalcomp.jsp) (all coordinates are available in Appendix E). As an independent check on ST114 RM5's solution, base station data for ST114 RM5 was converted into RINEX format and this file was uploaded to AUSPOS (http://www.ga.gov.au/ earth-monitoring/geodesy/auspos-online-gps-processing-service.html) to determine another solution. As the AUSPOS solution is a 'modelled' solution, using a number of GPS base stations over great distances (up to ~2,300km), this was not as accurate as the Static GPS survey between SPM10953 and ST114 RM5.

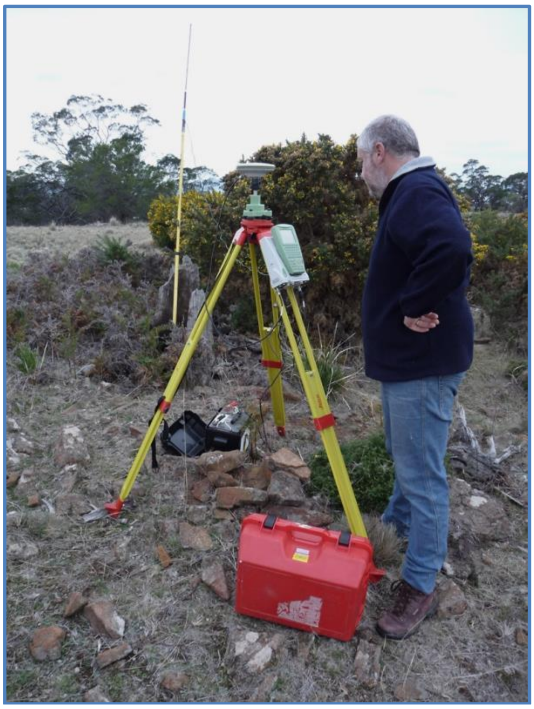



Figure 3.9 and 3.10: Left – GPS base station at ST114 RM5. **Right** – rover GPS recording coordinates (at Y12).

3.4.4 Analysis of data and presentation of results

It was imperative to identify the correct location of each pitfall trap for future work at Long Point. As the GPS data from the first survey was only accurate to within 10 metres in the horizontal plane (R Anders 2014, pers. comm., 6 June), it was not precise enough to enable relocation of existing pitfall traps in the future.

The height data from AusGeod09 were used to generate an elevational profile of each transect based on longitudinal distance. Additionally, the new GPS coordinate data were analysed by Esri ArcMap 10™ for solar radiation and hill shade and used to produce a digitised terrain map and maps of hill shade and solar radiation.

Height data from each station (the B pitfall trap which was the centreline of transect) were aligned to the six vegetation community groups formulated using the vegetation data – ASS(a), ASS(b), ARS, GSL, GPL (sr) and GPL (dr) (see Methods Section 3.3.3 and Results Section 4.1.1). Once associated to each group, the group height data were analysed using multivariate methods in the *vegan* package in R to:

1. Examine the attributes of each group by use of a boxplot summarising the quartiles;
2. Check for differences of groups means using analysis of variance (ANOVA). A post hoc test, Tukey's Honestly Significant Difference (HSD) test, was used to identify groups that differ significantly from each other.

3.5 Edaphic factors

Saltmarsh soils are made up of sediments transported by fluvial flows, which are deposited on low-lying marine zones when flows decrease in velocity (Phleger 1977). These deposits are generally fine silts and clays that allow vascular plants to become established (Long & Mason 1983), and as vegetation increases in abundance, more sediment is trapped and the surface rises in elevation (Phleger 1977; Long & Mason 1983). Decaying plant matter adds organics thereby increasing the nutrient supply to the established vegetation, stimulating further vegetation growth. Biological activity breaks down the decaying plant matter and bioturbation by invertebrate burrowers transport detritus deep into the sediment substrates (Ranwell 1972) further improving the soil. Soil characteristics vary across saltmarsh zones and are dependent on the regularity of saltwater incursion, topography, erosion and vegetation type, and also environmental features such as wind, precipitation and evapotranspiration (Phleger 1977; Long & Mason 1983).

Soil excavated from the three the pitfall traps at each station was removed from the corer, combined, boxed and labelled. Soil samples were taken to a depth of 10cm. The initial soil sampling was conducted in January 2013, with a further sampling taken in July 2013, from cores adjacent to the original cores. The later sampling was conducted to investigate any changes to moisture content, pH and EC due to winter time precipitation and evaporation at the site.

On return to laboratory, a representative sub sample from each sample was dried to determine as received moisture content (see 3.5.1 below). The remaining soil from each sample was air dried in a fume hood using only fan forced air in order to prevent mould growth or any changes to the characterisation of the soil. Once dried, the samples were sieved on a 2mm sieve with large pieces broken up using a mortar and pestle (if possible) prior to sieving. Care was taken to remove any obvious plant material from each sample. The <2mm fraction was packaged in seal-top plastic bags, labelled and stored (Figures 3.11 and 3.12).

Figures 3.11 and 3.12: Left – RED transect soil samples – numbered from top left R1, R13 and R14 at bottom. **Right** – soil samples for storage.

The analysis of soil moisture content (3.5.1), soil chemistry (3.5.2), soil organic matter, carbon and texture (3.5.3) of the <2mm fraction from each sample (from each station on all transects), was undertaken by the author. The methodology used in the analysis of the results is outlined in 3.5.4 (below).

3.5.1 Soil moisture content

Soils can hold substantial amounts of moisture, yet moisture content is often overlooked or ignored (Rayment & Lyons 2011). However, it is an important factor in saltmarshes and therefore has been used as one of the factors in the characterisation of soils in this study. The cyclical rise and fall of tides, floods and drains water from the soil and moisture retention is determined by the soil structure (Long & Mason 1983). Soils containing high levels of organic matter can retain over 10% of their oven dried weight as moisture, whereas those with low levels of organic matter such as siliceous sands retain less than 2% moisture (Rayment & Lyons 2011). Waterlogging in saltmarshes is a major factor in saltmarsh ecology (Adam 1990) and its basic effect is limiting the supply of oxygen and allowing the soil to become anaerobic (Long & Mason 1983). Variation in plant species capacity to tolerate anaerobic conditions and high levels of salinity caused by tidal flooding, determines patterns of plant species distribution within saltmarshes (Long & Mason 1983; Adam 1990). Furthermore, waterlogging impacts the reducing potential of saltmarsh soils which can lead to the production of organic compounds such as methane (Long & Mason 1983). Soil moisture tests used to determine moisture content are from Rayment and Lyons (2011) and described below:

As received moisture content: on receipt at the laboratory, a sub sample from each sample was removed, weighed, and air dried in a fan forced fume cupboard. Each sub-sample was reweighed to determine the field moisture weight and reported as: Field moisture content (%).

Air dry moisture content: a pre-weighed (10-50g) sub-sample of each air dried sample was oven dried at 105^{o}C in a fan forced oven to constant weight, generally 24 hours, then reweighed to determine the weight of moisture and reported as: Air dry moisture content (%).

Field to oven dry moisture content: total moisture content for each sample was calculated by summing the above field and air dry moisture contents and reported as: Total moisture content (%).

3.5.2 Soil chemistry (EC and pH)

The distribution of vegetation in a saltmarsh can be influenced by acidity (Wherry 1920), and the concentration of salt within the soil (Álvarez-Rogel *et al.* 1997; Álvarez-Rogel *et al.* 2000). With increasing elevation, flooding tides decrease, although this it is not necessarily synonymous with salinity (Adam 1990). Salinity levels can vary spatially and temporally throughout saltmarshes (Álvarez-Rogel *et al.* 1997). Precipitation between tidal flooding can reduce salinity, yet during periods of dry weather, salinity levels can increase due to evapotranspiration (Long & Mason 1983; Adam 1990) resulting in salinity levels greater than that of seawater (personal observation). The elevated terrestrial profile is also subject to high levels of aerosolic salt borne by strong onshore winds thus increasing soil salinity levels (Long & Mason 1983).

3.5.2.1 Electrical conductivity (EC)

Salinity levels in soils are usually assessed by measuring the electrical conductivity (EC) of a soil/water solution (Hazelton & Murphy 2007). The EC of a soil solution is directly related to the amount of total dissolved salts that are present in the soil, however the salinity level depends on the type of salt that is present in the soil (Hazelton & Murphy 2007). At present there is no internationally agreed technique for determining EC, the main option being a soil/water ratio of 1:5 which is widely used in Australia (Rayment & Lyons 2011). The common units for EC used in soil science are deciSiemens per metre (dS/m) (Hazelton & Murphy 2007), these units are used throughout this report. Soil chemistry tests used to determine EC content are from Rayment and Lyons (2011) described below.

$EC_{1:5}$ soil and water: three sub-samples from each summer and winter soil sample (*n = 282*) were prepared and tested by adding ten grams of air dried soil to 50ml of deionised water and placed in a centrifuge tube. The solution was mechanically shaken end over end for one hour so as to dissolve soluble salts. After standing for 20-30 minutes to allow the soil to settle, three electrical conductivity readings were taken using a temperature compensated pre-calibrated Mettler Toledo® (model Seven Multi) meter (Figures 3.13 and 3.14), thus nine readings were taken for each sample (3 readings from 3 sub-samples). An average was calculated from the nine readings, this became the $EC_{1:5}$ value of each sample, reported as: $EC_{1:5}$ (dS/m) at 25^{o}C on an air dry (40^{o}C) basis.

Figures 3.13 and 3.14: Left – Mettler Toledo® Seven Multi meter. **Above** – fitted with pH and EC probes.

As the dominant salt is expected to be composed of sodium chloride (from sea water), the conversion of EC to salinity is: 0.64 X $EC_{1:5}$ dS/m (Hazelton & Murphy 2007).

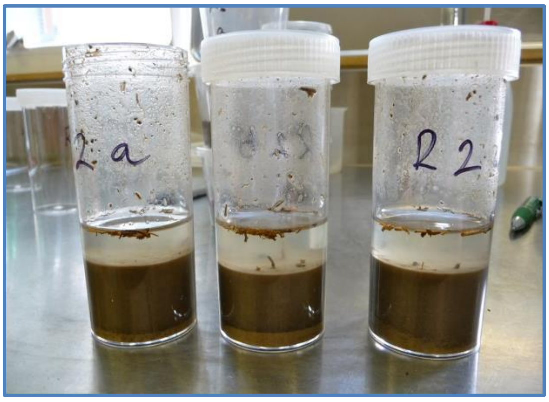
3.5.2.2 pH

The pH measure of soil is its value of the acidity or alkalinity, indicating the chemical activity of the hydrogen ion and/or the hydroxyl ion in a water solution (Hazelton & Murphy 2007; Rayment & Lyons 2011). This chemical activity is at its lowest when the pH value is 7.0. Soil pH plays an important role in the distribution of native plants (Wherry 1920). Saltmarsh soils that undergo regular inundation become anaerobic leading to the release of sulphates that in turn causes the lowering of pH (Adams 1963). Soil pH is generally measured in a water or 0.01M calcium chloride ($CaCl_2$) solution at a ratio of one part soil to five parts solution (Hazelton & Murphy 2007). The use of a $CaCl_2$ solution is recommended for soils that have been affected by salts such as sodium from sea water (Rayment & Lyons 2011).

pH of 1:5 soil/0.01M calcium chloride ($CaCl_2$): this method was used as the results are largely unaffected by the occurrence of soluble salts, whereas the use of deionised water instead of $CaCl_2$, impacts the results due to the occurrence of soluble salts. Three sub samples from each summer and winter soil sample (*n = 282*) were prepared and tested as follows: ten grams of air dried soil was added to 50.0g of 0.01M $CaCl_2$ and placed in a centrifuge tube. The solution was mechanically shaken end over end for one hour. After standing for 20-30 minutes to allow the soil to settle, three pH readings were taken using a temperature compensated pre-calibrated Mettler Toledo® (model Seven Multi) meter (Figure 3.13 and 3.14) fitted with an InLab®Expert Pro electrode that is recommended for use in soil measurements (Mettler Toledo 2007). Thus nine readings were taken for each sample (3 readings from 3 subsamples) (Figures 3.15 and 3.16).

Figures 3.15 and 3.16: Above – testing laboratory. **Right** – pH and EC probes in soil solution.

An average was calculated from the nine readings and nominated as the pH value for each sample, reported as pH (1:5 soil/0.01M $CaCl_2$) on an air dry basis. There was a noticeable difference in the composition of the measured solution in each sample (Figures 3.17 and 3.18).



Figures 3.17 and 3.18: Difference between samples. **Left** – station R2 little organic matter. **Right** – station R3 high organic matter.

<u>Note on calibration</u>: Prior to use each day, the meter was calibrated using pH buffers of 2.0, 4.0, 7.01 and 9.21, and EC buffers of 0.5, 1.413 and 12.88 dS/m.

The calibration was checked prior to measurement using pH buffers of 4.0 and 7.0 as this was the expected range of the soil measurements, and all three EC buffers. The meter was checked during measurements and recalibrated if necessary.

Note on measurements: Although pH measurements were reported using DI water, and EC using 0.01M $CaCl_2$, pH and EC measurements were taken for each test and the information retained. Only the applicable measurements have been included in this report.

3.5.3 Soil organic matter, carbon and texture

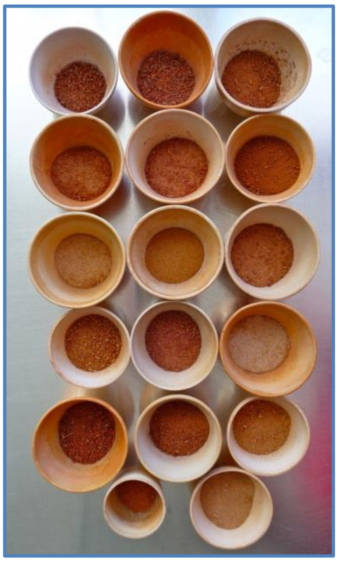
Sub-samples from each of the summer and winter soil collections from each station were combined and thoroughly mixed to create an averaged soil sample for each station. These samples were labelled to indicate that they were a representation of summer and winter, for example R10SW (Red transect, station 10, summer/winter). Sub samples were taken from this new representative sample for the following analysis of soil organic matter and texture.

3.5.3.1 Soil organic matter and carbon

Soil organic matter (SOM) in the saltmarsh environment is sourced from decaying vegetative matter that grows on the marsh in addition to roots and rhizomes that support the vegetative growth (Long & Mason 1983). SOM does not decompose quickly due to poor drainage which inhibits microorganisms' ability to break down plant residues (Rayment & Lyons 2011), leading to increased levels of plant material in saltmarsh soils. Carbon (C) is an important contributor to soil and plays an essential role in the biological, chemical and physical properties of soil (Rayment & Lyons 2011). Soil carbon can range from greater than 60% in peaty soils to practically nil in silica sands (Rayment & Lyons 2011). In estuarine systems, saltmarsh soils are the foremost reservoir of C. Until recently, the measurement of C has been either by loss on ignition (LOI) or dichromate oxidation (Craft *et al.* 1991), both with comparable results to that of carbon analysers (Soil and Plant Analysis Council 1999), a more recent, but expensive method.

LOI has been used for many years by soil scientists, geographers and geologists as a reliable technique in the measurement of C (Konen *et al.* 2002). It is a safe, quick and relatively cheap process (Craft *et al.* 1991; Navarro *et al.* 1993; Pribyl 2010) and requires simple laboratory equipment (Rayment & Lyons 2011). This method has been described as one of the more accurate methods of assessing C in soils (Navarro *et al.* 1993). Yet it does have some limitations with the accuracy of the result being dependent on a number of factors such as the dryness of the sample, the temperature of the furnace, the sample's composition (Pribyl 2010), the loss of structural water from carbonaceous materials (clays) and CO_2 from soil carbonates (Navarro *et al.* 1993). LOI is a technique that determines SOM content of a soil sample, and from this an estimation of soil organic carbon (SOC) can be made. Historically, this estimate has been based on an assumption that SOC to SOM conversion is 1.724 (SOM to SOC of 58%), called the "Bemmelen factor", however the original source of this conversion factor is generally unknown (Pribyl 2010). In Pribyl's (2010) critical appraisal of the SOC to SOM conversion, he assessed over 480 studies and concluded that the empirical factor should actually be 1.97, which concurred with that obtained from theoretical calculations of 1.95 (SOM to SOC conversion of 51%) (Pribyl 2010). This is supported in an earlier study by Navarro *et al.* (1993) on the relationship between organic matter and carbon of organic wastes where they reported a value for SOC to SOM conversion of 1.957 for plant residues (Navarro *et al.* 1993).

Figures 3.19 – 3.21: Above – muffle furnace. **Centre** – pre ashing in furnace. **Right** – post ashing (same samples).



The procedure for LOI adopted in this research is a combination of Rayment and Lyons (2011) and Soil and Plant Analysis Council (1999), slightly modified. Each of the samples *(n = 47)* was dried in an oven at 105°C for four hours, then following weighing in a crucible, was ashed at 550°C for two hours in a muffle furnace (SEM (SA) Pty Ltd, model CE MLM). The furnace was fitted with a digital temperature display, a thermostatic temperature control and a settable timer (Figure 3.19).

Following cooling in the furnace to between 250-280°C, approximately 6-8 hours, the samples (Figures 3.20 and 3.21) were reweighed still in their respective crucibles and once emptied, the crucible was also weighed. The organic matter component of the soil was calculated as follows:

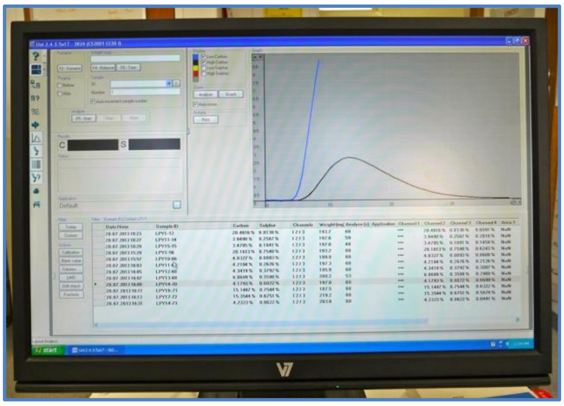
$$\%SOM = [(W_{105} – W_{550}) \times 100] / W_{105}$$

where W_{105} = oven dried sample less the weight of the crucible, W_{550} = muffle furnace sample weight less the crucible. The result is reported as soil organic matter by LOI (%SOM) on an oven dry basis.

A study by Heiri *et al.* (2001) considered whether the position within the furnace and the size of the sample affected LOI results. To see if this had a bearing on the SOM values and reproducibility/precision of the results of this research, several samples were repeated during the LOI process using different weights, in different size crucibles (surface area) and placed randomly in the furnace. Very little variation in results was observed.

The development of carbon analysers that operate on dry combustion (DC) of the soil sample has become the standard (Craft *et al.* 1991; Konen *et al.* 2002; Chatterjee *et al.* 2009). Studies have shown that there is a correlation of greater than 90% between this method and LOI (Pribyl 2010), with a study by Craft *et al.* (1991) on 250 samples of estuarine marsh soils showing a relationship between organic carbon and LOI of $R^2 = 0.990$. Although DC has a greater precision then LOI (Chatterjee *et al.* 2009), the unit cost of this method is not cheap (Konen *et al.* 2002) – $12 per sample following sample preparation (Chatterjee *et al.* 2009). In dry combustion, the soil sample, generally ground to less than 63µm and weighing 200mg, is mixed with a catalyst, heated to approximately 1 000°C in a stream of pure oxygen allowing all C to be oxidised to CO_2. The CO_2 released is measured by solid state infrared absorption and converted to total carbon (TC) (Pribyl 2010). TC though, includes organic and inorganic carbon, therefore any carbonates in the soil are included in the TC value, whereas, LOI at 550°C does not include carbonates as the LOI temperature needs to be over 800°C to incinerate any carbonates.

Fortuitously, an opportunity arose that gave rise to the access of a carbon analyser at the School of Earth Sciences (University of Tasmania). The analyser, an ELTRA® CS 2000 Carbon Sulphur Determinator, was fitted with a resistance furnace making it excellent for testing organic soils (Figure 3.22). The standard procedure for carbon analysis in the ELTRA, outlined in the operating manual, was followed. A ground subsample of each of the summer/winter soil combinations was weighed to three decimal places and added to the ELTRA along with accelerants (pure iron and pure tungsten) and a C value was obtainable within 60 seconds (Figure 3.23). The result was expressed as a percentage of C by weight of the sample. Due to the high per unit cost factor of this process, none of the samples were repeated to confirm repeatability/precision.



Figures 3.22 and 3.23: Left – ELTRA CS 2000 Carbon Sulphur Determinator. **Right** – screen display of Y14 soil sample.

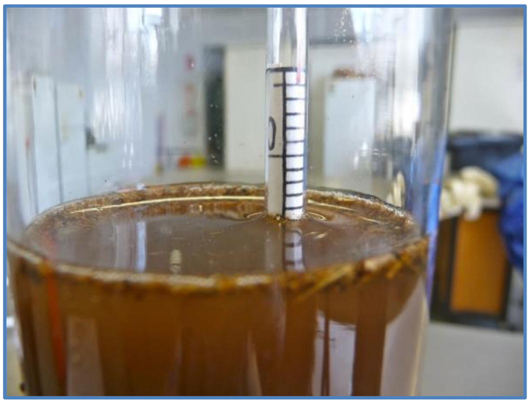
3.5.3.2 Texture

Texture is an important attribute of soil and one of its fundamental properties (Hunt & Gilkes 1992; White 1997). Texture controls soil temperature (White 1997), the movement of air, water and nutrients, this in turn affects plant growth (Bouyoucos 1927; Bohn & Gebhardt 1989; Hunt & Gilkes 1992). Soils are classified by their texture, for example loamy sand, sandy loam, silty loam etc. This classification is determined by the size of particles in the soil which are determined by the particle size analysis method (White 1997). The results are then plotted a triangular texture diagram (Hunt & Gilkes 1992; White 1997; Loveland & Whalley 2000).

A particle size analysis (PSA) was carried out on all collected soil samples *(n = 47)* to classify the soil texture for each station. The analysis was based on the density method and followed the most widely used procedure – the Bouyoucos hydrometer (Day 1965; Sur & Kukal 1992; Loveland & Whalley 2000). The density method relies on the change in density of the soil solution as soil particles settle, measured by the Bouyoucos hydrometer at specified points of time (Sur & Kukal 1992). This in turn determines the percentages of sand, slit and clay in the sample. The procedure is well documented (Bouyoucos 1927; 1962; Day 1965; Sur & Kukal 1992), and was used with the following protocol:
Each analysed sample was a mix of summer and winter soils (see 3.5.3 above) taken from each station. A sub-sample of approximately 25 grams, weighed to 3 decimal places, was shaken with dispersing solutions – 10ml of 5% Calgon (sodium hexametaphosphate), 5ml of 1N NaOH (sodium hydroxide) and 250ml of deionised (DI) water in a 500ml flask on a Chiltern Flash Shaker for 15 minutes (Figure 3.24).

Figure 3.24: Chiltern flask shaker.

The solution was transferred to a cylinder and topped up with DI water to the 500ml level (Figure 3.25). The mixture was well stirred with a metal plunger for at least 30 seconds and the Bouyoucous hydrometer introduced immediately the plunger was removed and a stopwatch started. Hydrometer readings were taken at 23 seconds, 40 seconds, 5 minutes and 2 hours along with temperature. Each hydrometer reading was taken at the top of the meniscus (Day 1965) (Figure 3.26).

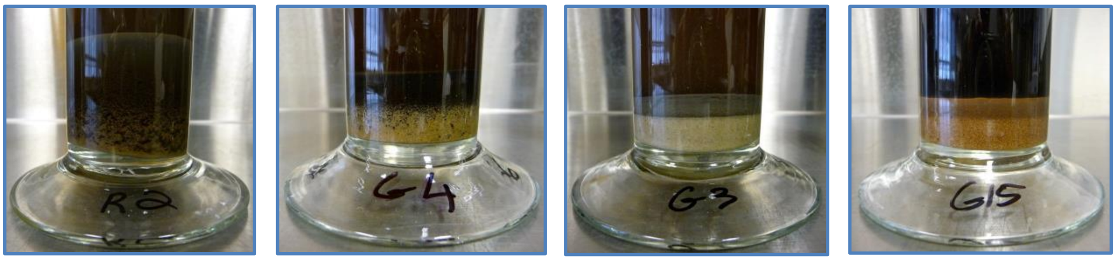



Figures 3.25 and 3.26: Left – soil solution in cylinders – left to right: R1, R2, R4, G3, G4, G7, G8, and G15. **Right** – hydrometer reading at meniscus – reading = 4.5g per 500ml.

As the hydrometer was calibrated to record in grams per litre, the reading had to be corrected (a 500ml volume was used not 1 000ml) and further corrections applied to compensate for temperature (for each degree above 20^{o}C add 0.3g or below subtract 0.3g – a change in temperature alters the viscosity of the solution altering the rate of fall of the particles in the solution (Baver *et al.* 1972)), and the dispersion agents (subtract 0.5g) (Hutton 1950).

There is considerable discussion in the literature relating to the question of the time of the hydrometer readings (Day 1965; Bohn & Gebhardt 1989; Sur & Kukal 1992; Ashworth *et al.* 2001), with suggested times being up to 24 hours (Bohn & Gebhardt 1989). It is generally accepted that the time taken to separate the sand fraction from the silt/clay fraction is between 30 and 60 seconds (Bohn & Gebhardt 1989), with 40 seconds being acceptable (Ashworth *et al.* 2001), yet contention centres on the time taken to separate the silt and clay fractions. Day (1965) had recommended that the time should be between eight and ten hours, however, though his method is sound and accurate, its time efficiency discourages its use on a routine basis (Sur & Kukal 1992). Subsequent work by Sur and Kukal (1992) modified Day's (1965) hydrometer method, reducing the analysis time from eight hours to just two hours, this later validated by Adiku *et al.* (2005). However, Ashworth *et al.* (2001) countered this suggestion claiming that too much bias still existed using the two hour reading and that the silt/clay fractionation should be six hours, which would still allow the same operator to make all readings in one working day (Ashworth *et al.* 2001). In light of the above arguments it was resolved to use the 40 sec and 2 hour readings due to time constraints with six samples tested over an eight hour period at a later date in an attempt to validate the 2 hour readings. A little variation was observed, however it was not sufficient to impact the results.

During the PSA process, a very serious flaw was observed. The hydrometer method is based on the principle that the heaviest grains fall the quickest followed by smaller and smaller grains (Adiku *et al.* 2005). Therefore, as sand is heavy, it falls fastest in the water column, followed by silt and finally clay. However, the results obtained had to be modified as many samples contained high to very high levels of organic matter (see Results – Section 4.3.2, page 91). Some researchers suggest that prior to using the hydrometer method, organic matter should be removed with the use of hydrogen peroxide (Day 1965), however this is expensive and time consuming (Hutton 1950), and difficult to remove (Clarke & Hannon 1967). In this research, the size and the volume of organic grains were so great, they settled at a similar rate to that of sand, therefore increasing the representative percentage of sand compared to actuality (Figures 3.27 to 3.30).



Figures 3.27 – 3.30: Results of particle size analysis. R2 and G4 – note the organic particles mixed within the sand portion; R2 – note the silt fraction above the organics topped by the clay fraction; G3 and G15 – expected outcomes, note the definitive graduations of sand, slit and clay.

To overcome this, the percent weight of SOM ascertained from previous assessments of each soil sample (see Soil organic matter and carbon analysis above) was deducted from the weight of sand, and the percentages for sand, silt and clay were recalculated based on the reduced amount of sand as per the following example:

Sample weight of soil added to cylinder = 100g;

SOM content of sample (previously determined) = 25%, therefore SOM = 25g;

Result of PSA based on Bouyoucous hydrometer: clay = 5% (5g), silt = 25% (25g), sand = 70% (70g).

As the SOM had mostly settled with the sand, the value of SOM was subtracted from the sand to ascertain the "true" weight of sand = 45g. The sand, silt and clay fractions were recalculated, clay = 7%, silt = 33% and sand = 60%. It is acknowledged that some of the SOM may have been included in the silt percentage (or even the clay portion) of the solution, however there was no method of accurately ascertaining whether this was so, or the amount. Therefore, the weight of SOM was subtracted from sand portion and for consistency was applied across all 47 samples analysed.

3.5.4 Analysis of soil data and presentation of results

Soil analysis data were plotted in a linear format based on the elevation profile of each transect. The results from the summer and winter analysis of pH, EC and moisture were plotted within the same chart to demonstrate the temporal differences between the two seasons. The outcome of SOM from Loss-on-Ignition and carbon from dry combustion were plotted together by percentage for each transect. The results from the PSA were presented in chart form, each variable – sand, silt and clay, plotted by percentage. All plots are underlain by the elevation profile for each respective transect.

Data from soil analysis of each station were aligned to the groups formulated using the vegetation data – ASS(a), ASS(b), ARS, GSL, GPL (sr) and GPL (dr) (see Methods Section 3.3.3 and Results Section 4.1.1). Once associated to each group, the group soil data were analysed using multivariate methods in the *vegan* package in R to:

1. Examine the attributes of each group by use of boxplots summarising the quartiles;
2. Check for differences of group means using analysis of variance (ANOVA). A post hoc test, Tukey's Honestly Significant Difference (HSD) test, was used to identify those groups that differ significantly from each other.

The relationship between edaphic factors was tested using the correlation (cor) function in R in order to identify predictor variables that would be useful tools in the laboratory and the field. Correlation was tested between all factors.

Soil texture analysis was carried out in the R package *soiltexture* (Moeys 2014). The results of PSA for each sample along with the average for each vegetation group were plotted on the USDA triangular texture diagram to determine the soil texture classification for each station and tabulated by vegetation group. The use of the USDA/FAO diagram was recommended by Minasny and McBratney (2001) for most countries, including Australia, following their evaluation based on scientific and educational grounds.

3.6 Invertebrate assemblages

Saltmarsh fauna can be divided into three groups: a) aquatic – such as mosquitoes; b) specialised saltmarsh – those derived from aquatic ancestors such as crustaceans and snails; and c) terrestrial – for example, spiders and beetles (Morrisey 2000). The terrestrial group can be separated into residents, those that live in the saltmarsh their entire lives or visitors, those that source food and leave (Adam 1990; Morrisey 2000). Terrestrial invertebrates face a daunting task living in saltmarshes, particularly in the lower marsh which is subject to regular tidal inundation (Adam 1990). Phytophagous invertebrates (plant feeders) can avoid this inconvenience by simply climbing their host plant, however epigeal invertebrates have had to adapt, in some cases by modifying their activity rhythms, or face the inevitable – death by drowning (Long & Mason 1983; Adam 1990; Morrisey 2000).

Cameron (1976), in his research on tides and insect communities, found that insects did not move up into the vegetation strata during inundation, but remained in place. It was also recognised through field observations that members of certain families of beetles were covered in air bubbles (Cameron 1976). Many epigeal spiders also trap air bubbles under epidermal hairs allowing respiration to continue while submerged (Adam 1990). Several species have adapted in different ways to counter mortality by adjusting to periods of inundation that occurs twice daily, alternating with some tides that do not reach their zone of habitation (Foster 1983). One such species is a carabid beetle (*Dicheirotrichus gustavi)* that lives underground but emerges to the surface to forage for food. This animal has developed a phase-relationship in sync with its activity rhythm so that it can avoid the adverse effects of submergence from critical tides that would inundate its habitat (Daiber 1982; Foster 1983; Long & Mason 1983; Morrisey 2000). Foster (1983) observed in two separate populations that *D. gustavi* have diel (24 hour) activity rhythms, which has a peak at just after dusk and is suppressed during total submergence with the beetle being able to live for up to a week underground. Another example of adaptation is the saltmarsh spider, *Arctosa fulvolineata*. This wolf spider is a non-migratory, terricolous (living on or in the soil) species and has the ability to overcome tidal submergence by falling into an hypoxic coma (Pétillon *et al.* 2009). The capacity to become comatose is considered a physiological adaptation to its saltmarsh environment, with females being able to endure submergence for approximately 16 hours and still remain reactive (Pétillon *et al.* 2009). Research has shown that periods of inundation do not change the number of species present, their representation in the vegetation communities, the taxonomic composition nor the tropic structure of the assemblage (Cameron 1976).

Other invertebrates escape submergence by retreating to the upper branches of saltmarsh vegetation to wait for tidal waters to retreat before returning to the saltmarsh surface to continue foraging (Morrisey 2000). However, this behaviour is dependent on their active state and temperature at the time of inundation (Davis & Gray 1966; Morrisey 2000). Predatory terrestrial invertebrates have also had to adapt to the high salinity levels encountered in saltmarshes, particularly herbivores, such as aphids and grasshoppers, which have become specialists feeding on certain parts of plants or plant species (Long & Mason 1983).

3.6.1 Classification

Similar to zonation in saltmarsh vegetation, zonation also occurs in saltmarsh invertebrates. This is controlled by the hydroperiod (Daiber 1982) and flooding regime (Irmler *et al.* 2002). Gradients of tidal reach, salinity and desiccation are all features which determine zonation, and though there may be distinct boundaries between the marshes and the adjacent mudflats, zonation is less distinct within the saltmarsh due to a mosaic of microhabitats (Long & Mason 1983). Saltmarsh vegetation communities play a pivotal role in the number of invertebrate species and abundance found in the saline environment, with communities of spiders and beetles being analogous to vegetation communities (Finch *et al.* 2007). Mid-marsh fauna is richer in species than the lower marsh and is generally of terrestrial origin (Adam 1990) with upper marsh species being true terrestrial species (Finch *et al.* 2007). However, the number of species that are dependent on the saltmarsh environment in the mid-marsh is less than that of the lower marsh. Marsh dependent invertebrates account for 75-80% species in the lower marsh, with 25-50% in the middle marsh and just 5-10% in the upper marsh (Adam 1990).

A large number of insect species are phytophagous, some are generalist, many are specialist, feeding not only on a particular plant, but often restricted to specific parts of those plants (Cameron 1972; Adam 1990). Vegetation communities that have plants with frequent branching and larger leaf cavities, such as *Sarcocornia* spp. or *Distichlis* spp., house more species than communities made up of *Juncus* spp., as the former provide additional places of refuge from tidal submergence and are more palatable (Daiber 1982). Habitat configuration along with physical influences such as tidal reach, are important elements that determine the make-up of spider communities (Dobel *et al.* 1990). Work by Larsen (1951) showed that the distribution of marsh beetles was strongly influenced by vegetation and soil type, this distribution changing as vegetation invaded bare areas of the marsh. Work by Cameron (1972) established that trophic diversity within saltmarshes has distinct seasonal patterning. Resident species, along with seasonal species, avoid competitive interactions in order to maximise the resource base. However, during spring resource expansion, the invertebrate assemblage undergoes a process of species packing, with additional species utilising the expanded resource (Cameron 1972).

3.6.2 Sampling

3.6.2.1 Pitfall traps

Saltmarsh terrestrial invertebrates were the target group in this study. Pitfall trapping is one of the most frequently used methods for invertebrate capture as it is cost effective and easy to use (Weeks & McIntyre 1997; Woodcock 2005). The most commonly sampled invertebrates captured by this method are guild specific, those that are active on the soil surface, epigeal invertebrates (Woodcock 2005). These invertebrates are represented by spiders such as Lycosidae and Linyphiidae, beetles, for example, Carabidae and Staphylinidae, and ants. Many are highly active, mostly predators and polyphagous (feed on a variety of matter) (Greenslade 1964; Thiele 1977) which can make these species difficult to capture (Woodcock 2005). There is no set design for a pitfall trap, and most researchers design their own with cost effectiveness and availability of materials in mind (Woodcock 2005).

A 65mm borer was used to remove the soil for the trap to a depth of 150mm; the top 100mm was retained for soil analysis in the laboratory. The excavated hole was lined with 150mm of 70mm PVC pipe and a plastic disposable 215ml cup inserted to act as the trap (Figure 3.31).

Figure 3.31: Pitfall trap components. A 65mm hole was dug into the soil, the 70mm long PVC sleeve (left) was used as a liner (in the hole) and support for the 215ml plastic cup (trap) containing approximately 40ml of ethylene glycol as the killing/preservative agent. Between collections, the cup was removed and plant material was placed in the hole to allow fauna, which had inadvertently fallen in to escape.

Identical cups were used throughout the site and for the time of the research. The traps were constructed at least two weeks before sampling commenced so that digging in effects would be minimised at the commencement of the first sampling (Woodcock 2005). At the time of each sampling set, approximately 40ml of preservative was added to each trap. Several killing agents/preservatives were considered for use in the research, for example, propylene glycol, ethanol, and saline solution. Ethylene glycol (antifreeze: Kmart) was chosen and although it is possibly attractive to some invertebrates (Woodcock 2005), its cost effectiveness and retention of preservative properties following dilution by rain or flooding were the decisive factors in its selection. Furthermore, ethylene glycol has higher conservation attributes and better sampling efficiencies for ground beetles and spiders than any other ethanol based products (Schmidt *et al.* 2006). The trap contents were retrieved after seven days and transferred to 70ml labelled vials topped up with 75% ethanol. Plastic cups were removed following each sampling.

Three traps were placed at each station, a total of 141 traps. The traps were placed wherever possible in the centre of each station away from vegetation boundaries in an effort to avoid edge effects (Figure 3.32). Within each station, traps were placed no further than six metres apart and always in a position that represented the overall vegetation community and structure, including bare areas, of the station. Traps were not covered, as uncovered traps are generally more successful (Spence & Niemelä 1994). Only those that were prone to attack by wombats were protected with a wire mesh guard (see Appendix A1e – Wombats, page 168). Several traps were secured by roofing nails to prevent removal by birds or to prevent lifting by a rising water table during periods of inundation (Figure 3.33). Extreme care had to be taken with protrusion of the trap rim as this could deter/prevent invertebrate captures. Saltmarsh soils are prone to desiccation (shrinkage) followed by expansion during inundation which can cause the cup to lift during the sampling period.


Figures 3.32 and 3.33: Left – station R2 pitfall traps. **Right** – pitfall trap secured by roofing nails – station R2.

3.6.2.2 Sampling duration and temporal patterns

Sampling duration using pitfall traps can range from a week to over three years depending on the study (Woodcock 2005), but sampling should be generally be undertaken for a minimum of four months (Niemelä 1990) or at least for the growing season (Uetz & Unzicker 1975). Sampling of up to a year is preferable as this will cover the activity period of the invertebrate community in question (Baars 1979). In temperate regions, the winter season is often ignored due to low activity (Woodcock 2005). There is some question in the use of quantitative data from pitfall trapping in that the differences in population size (abundance) of one species between sites should not be used to compare the relative numbers between each species (Baars 1979). However, Baars (1979) caveats this by stating that comparing population sizes between several species is a possibility if sampling continues over a year. Important information can be obtained through shorter temporal patterns of up to 28 days, but with increased sampling periods, similarity increased and variance decreased (Woodcock 2005). Another consideration of invertebrate sampling is the concept of activity-abundance.

The rate of invertebrate capture is proportional to their activity, therefore numbers caught are not directly representative of their true abundance (Woodcock 2005). In reality, the rate of capture is proportionate to the interaction of abundance and activity – the concept of activity-abundance (Thiele 1977). In other words, species which have high numbers but are largely sedentary, may yield low numbers in samples, and species, though few in number but highly active, may record high numbers. Similarly, seasonal aspects also come into play. Activity for some species can be very high in summer and very low, or perhaps not at all, in winter. Furthermore, behavioural peculiarities are likely to confound capture rates (Greenslade 1964; Woodcock 2005). One taxon such as amphipods is a source of food for spiders so that the rates of abundance in the target taxa are dependent on non-target taxa (personal observation). Additionally, Spence and Niemelä (1994) found low carabid beetle catch during summer months due to their low activity even though their numbers were high. In light of the inherent biases that are the result of individual species behaviour it is difficult to find the optimum pitfall trapping scenario, however a great majority of species will have their true abundance reflected over time (Woodcock 2005).

In an attempt to avoid some of the limitations outlined above, pitfall trapping was conducted over a 12 month period. This enabled sampling of each climatic season during which two collections were made for each season *(n = 8)*, as close to six weeks apart as practicable. In most cases traps were set on a Saturday and collected the following Saturday. Care had to be taken to avoid periods of high astronomical tides (predictable) and heavy rainfall (unpredictable) as low elevation areas were prone to inundation in which case traps could not be set, or would be flooded with the possibility of contents being lost (see Appendix A1a – Flood tides, page 167).

3.6.2.3 Sorting and identification

On return to the laboratory, collections were sorted by pitfall trap into spiders, beetles and miscellaneous, and stored in vials of 75% ethanol. Subsequently, specimens were identified to either family, genus or species level wherever possible with particular attention paid to spiders and beetles. Additionally, abundance of each family/genus/species was recorded.

Following identification, all sorted contents were rehoused in glass vials with fresh 75% ethanol, suitably labelled to identify station and collection date, and archived for future work – no invertebrates were discarded.

3.6.3 Analysis of data and presentation of results

The following analysis was carried out individually for spiders and beetles:

1. The five dominant spider and beetle taxa by abundance in each vegetation group were graphed in a stacked bar plot based on percentage. Information for each season was plotted to investigate changes that occurred over a 12 month period.
2. Vegetation communities were used to cluster stations into groups. Subsequently, an indicator analysis of spiders and beetles, independently of each other, was carried out in the R package *indicspecies* (De Cáceres 2013). This

analysis used the totals of spider and beetle taxa captured over the 12 month period and tabled based on site (vegetation) groups.

3. The data from each invertebrate taxon – spiders and beetles, was transformation by log(x+1), which down weighted the influence of the very abundant taxa in the data sets, thus making the data more tractable and the variance relatively constant. The transformed data was utilised as an input to ordination – non-metric multidimensional scaling (nMDS) using R. An ordination nMDS explores the relationship between samples/sites and produces a visual representation of the associations such as similarity or preference, between the spider and beetle taxa that are not directly evident in the raw data.

To better interpret nMDS, it is preferable to overlay environmental information onto the ordination plots. This can be used to clarify and also justify the ordination based on collected ecological data (Oksanen 2013). The nMDS plots based on the transformed log(x+1) spider and beetle data were independently fitted with soil and vegetation vectors using the *vegan* package in R by means of the "envfit" function (Oksanen 2013). The fitted vectors were arrows interpreted as follows:

a. The arrows point in the direction of most rapid change of the vector variable (the direction of the gradient); and
b. The length of the arrow is proportional to the correlation between the vector variable and the ordination (strength of the gradient) (Oksanen 2013).

The following analysis was carried out jointly for spiders and beetles:

1. The combined spider and beetle collections were plotted in a linear format based on the elevation profile of each transect. A representative sample of seven spider taxa and seven beetle taxa were used to demonstrate groups that are generalists (ranged over the whole site), specialist (confined to specific areas), those that co-exist or that exist in isolation.

Chapter 4: Results

Several events/issues were experienced during the course of the study that may have had a minor impact on some results, in particular the incidence and abundance of terrestrial invertebrates. These events are documented in Appendix A.

4.1 Vegetation communities

4.1.1 Grouping to vegetation communities

Data from the second vegetation survey (available in Appendix F) was used to cluster the 47 stations into six groups (Figure 4.1).

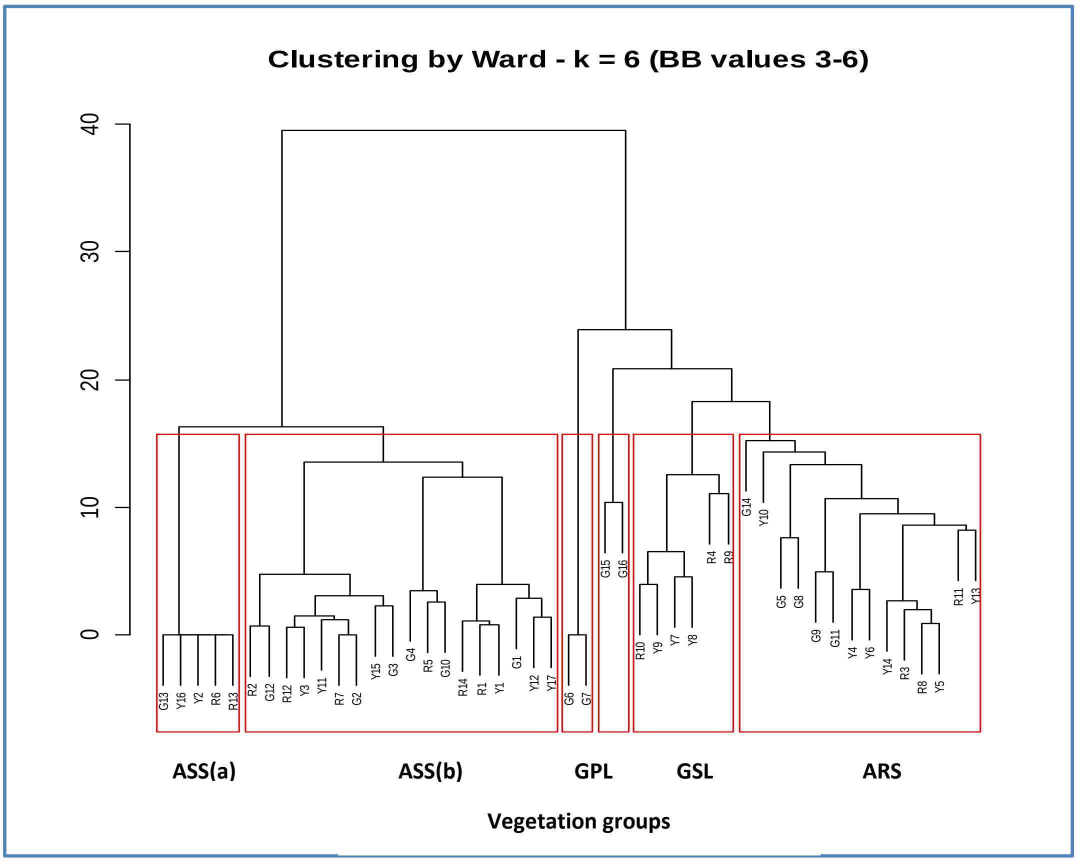


Figure 4.1: Dendrogram of 47 stations clustered by Ward linkage method into six groups based on vegetation communities cut to a level of 16% dissimilarity. Groups have been assigned TASVEG codes.

The six groups were assigned vegetation codes from the Tasmanian vegetation mapping system – TASVEG 3.0 (Table 4.1).

Table 4.1: Assigned vegetation community codes at Long Point.

No. stations	TASVEG Code	Assigned Code	Description
5	ASS	ASS(a)	Succulent saline herbland wholly dominated by *Sarcocornia quinqueflora* and/or *S. blackiana*.
18	ASS	ASS(b)	Succulent herbland dominated by bare areas, *Tecticornia arbuscula*, *Sarcocornia quinqueflora* and/or *S. blackiana*, and *Disphyma crassifolium.*
14	ARS	ARS	Saline sedgeland/rushland dominated by *Juncus* spp., *Gahnia* spp., *Austrostipa* spp., and to a lesser extent *Poa labillardierei.*
6	GSL	GSL	Dominated by *Lomandra longifolia* with *Acacia mearnsii* and *Bursaria spinosa* tall shrubs interspersed with lowland grasslands.
2	GPL	GPL (sr)	Lowland grassland dominated by *Pteridium esculentum* (bracken) and *Juncus* spp.
2	GPL	GPL (dr)	Dolerite soils lowland grassland dominated by *Poa labillardierei* and prostrate herbs.

4.1.1.1 Group descriptions

All plant species discussed below have been aligned for nomenclature, classification and current status (endemic, introduced etc) with the most recent version of "*The census of vascular plants of Tasmania*" by Baker and de Salas (2013). Groups ASS(a), ASS(b) and ARS are saltmarsh communities, groups GSL, GPL (sr) and GPL (dr) are grassy woodland communities. Examples of the six vegetation communities are shown in Figures 4.2 to 4.7

<u>ASS(a) (Figure 4.2)</u>

Affectionately known as *Sarcocornia* lawns, this group of prostrate, succulent plants occupied large areas at Long Point, especially on the landward side of the coastal levee and adjacent to the ephemeral pools. At most sites, just three succulent species were present: *Sarcocornia quinqueflora, S. blackiana* (glassworts) and *Disphyma crassifolium* (pigface). In two locations individual *Gahnia* spp. (a perennial tussock) plants and *Spergularia tasmanica* (a native sea spurry) were also evident. This group represented the low marsh, an area that was most often inundated by marine waters.

Figure 4.2: ASS(a) – succulent herbland (type a) – *Sarcocornia* spp. lawn mixed with *Disphyma crassifolium* often with bare ground.

Figure 4.3: ASS(b) – succulent herbland (type b) – dominated by *Tecticornia arbuscula* with *Sarcocornia* spp. and *Disphyma crassifolium* as ground covers and some bare ground.

ASS(b) (Figure 4.3)

Dominated by *Tecticornia arbuscula* (shrubby glasswort) shrubs with groundcover of *Sarcocornia quinqueflora, S. blackiana* and *Disphyma crassifolium,* this group occupied the coastal levee and large inland areas. The coastal vegetation was verdant and flourished with *T. arbuscula* reaching approximately two metres in height with a dense *Sarcocornia* spp. groundcover. The inland areas were less verdant, having an arid like appearance; *T. arbuscula* ranged in height from 0.5 to 1.5 metres, and many plants appeared to be stunted and under stress. *Sarcocornia* spp. were less abundant and there were many bare areas. *Hemichroa pentandra* (trailing salt star – a prostrate perennial herb) was present, along with *Gahnia* spp. *Chenopodium glaucum* (oak-leaved goosefoot), an introduced plant, was also evident, although had very low cover abundance. This vegetation group represented the middle marsh which was less regularly inundated than the low marsh, though when inundated, waters receded very slowly particularly from the inland areas (personal observation).

ARS (Figure 4.4)

Saline grassland covered a significant area in the east section of Long Point and was the zone that separated the saline succulent groups from the grassy woodlands in other areas. This group was made up of graminoids, the dominant species being rushes (*Juncus* spp.), sedges (*Gahnia* spp.) and saline grasses (for example *Austrostipa* spp.). These plants were often intermixed with succulents from the ASS(a) group. Other natives such as *Schoenus nitens* (shiny bog-rush), *Selliera radicans* (swamp weed), *Epilobium billardierianum* (willow herb) were evident in low numbers. Introduced species, for example, *Anthoxanthum odoratum* (sweet vernal grass), *Anagallis arvensis* (scarlet pimpernel), *Centaurium erythraea* (common centaury) existed with *Senecio jacobaea* (ragwort), a declared weed. The ARS group represented the upper marsh and from current observations it did not appear to be flooded by marine water. Following heavy rainfall, water did remain for some time before evaporating or draining away (personal observation).

Figure 4.4: ARS – saline grasslands – mixture of *Austrostipa* spp., *Poa* spp. and *Gahnia* spp. with *Disphyma crassifolium* as ground cover with some bare areas.

Figure 4.5: GSL – sand dune – mixture of *Lomandra longifolia* and *Poa* spp., small patches of *Pteridium esculentum* (bracken) and *Ehrharta stipoides* with *Oxalis perennans* as a ground cover with bare ground.

<u>GSL (Figure 4.5)</u>

This group encompassed the sand dune that runs north/south at Long Point. It had a woodland appearance with *Acacia* and *Bursaria* tall shrub/low trees, though neither species were recorded at stations along transects. The principal species in this group were *Ehrharta stipiodes* (weeping grass), *Oxalis perennans* (grassland sorrel), *Lomandra longifolia* (mat rush), and *Austrostipa* spp. This area, along with the saline grasslands, was used for sheep grazing prior to acquisition by the TLC, resulting in a number of introduced species being present. These include *Vellereophyton dealbatum* (white cudweed), *Hypochaeris* spp. (cat's ears), *Plantago coronopus* (buck's horn plantain) and *Ulex europaeus* (common gorse), a declared weed.

<u>GPL (sr) (Figure 4.6)</u>

Centred on the small sand ridge that runs W/E in the southern section of Long Point was group GPL (dr). The dominant species were *Hibbertia prostrata* (bundled guinea flower), *Ficinia nodosa* (knobby club-rush), *Poa* spp. and *Pteridium esculentum* (native bracken). Many bare areas were associated with this group. Though subjected to sheep grazing, the only introduced species found was *Ulex europaeus*.

Figure 4.6: GPL – sand ridge – mixture of *Poa* spp., *Pteridium esculentum* (bracken) and *Hibbertia prostrate* with *Ficinia nodosa* as a ground cover and bare ground.

Figure 4.7: GPL – dolerite ridge – mixture of *Poa* spp., *Lomandra longifolia, Baumea juncea, Aira caryophyllea* and *Austrodanthonia setacea* and some bare ground.

GPL (dr) (Figure 4.7)

The dolerite ridge was at the extreme southern end of Long Point. It was a large grassy knoll, covered in native species of grasses (*Poa* spp.), rushes (*Juncus* spp.), *Lomandra longifolia* (mat rush) and *Zoysia macrantha* (prickly couch). Similar to the sand ridge, this area would have been prone to sheep grazing, however only one introduced species was evident, *Aira caryophyllea* (silver hairgrass).

The stations assigned to each vegetation community code are shown in Table 4.2.

Table 4.2: Stations assigned to vegetation community codes.

Vegetation Code	Transect RED	Transect YELLOW	Transect GREEN
ASS(a)	R6, R13	Y2, Y16	G13
ASS(b)	R1, R2, R5, R7, R12, R14	Y1, Y3, Y11, Y12, Y15, Y17	G1, G2, G3, G4, G10, G12
ARS	R3, R8, R11	Y4, Y5, Y6, Y10, Y13, Y14	G5, G8, G9, G11, G14
GSL	R4, R9, R10	Y7, Y8, Y9	
GPL (sr)			G6, G7
GPL (dr)			G15, G16

Using non-metric multidimensional scaling, the relationship between stations and groups are presented in Figure 4.8.

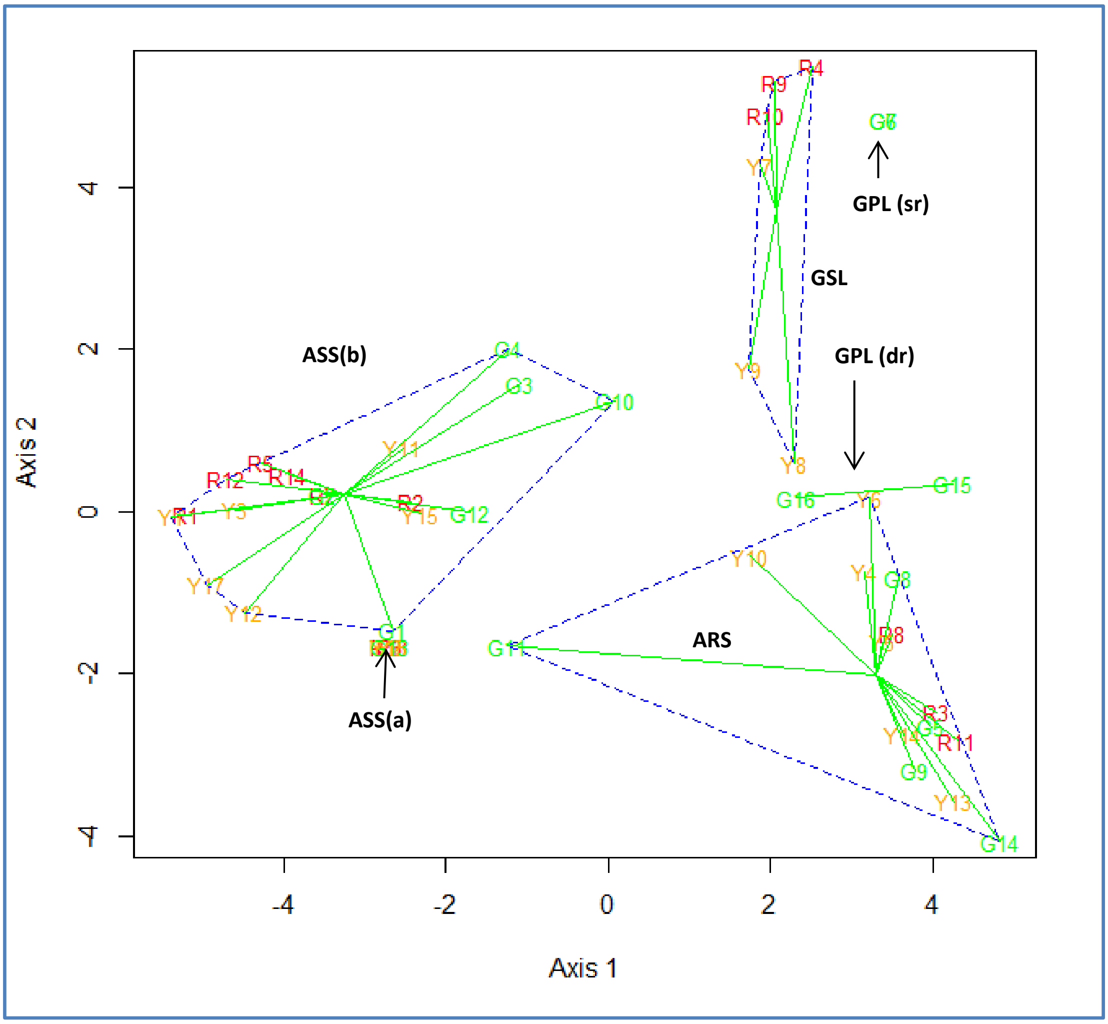


Figure 4.8: Ordination plot demonstrating relationships between groups and stations within groups. The green lines connect each station to the centroid of each group; the hashed blue line defines the ordination space taken up by each group.

The ordination summarises the relationship between vegetation groups and stations within groups. All five stations within group ASS(a) are superimposed on each other in the plot indicating the close relationship of these stations to each other.

4.1.2 Vegetation communities – indicator species

The results of the indicator species analysis are listed in Table 4.3 highlighting vegetation taxa for which $p < 0.05$.

Table 4.3: Indicator vegetation species for each vegetation community ($p < 0.05$).

Group	Vegetation species	stat	p.value	
ASS(a) (succulent herbland - a)	*Sarcocornia quinqueflora*	0.944	0.001	***
	Disphyma crassifolium	0.822	0.011	*

Group	Vegetation species	stat	p.value	
ASS(b) (succulent herbland - b)	Bare ground	0.961	0.002	**
	Sarcocornia quinqueflora	0.944	0.001	***
	Tecticornia arbuscula	0.904	0.001	***
	Disphyma crassifolium	0.822	0.011	*
ARS (saline grassland)	Bare ground	0.961	0.002	**
	Poa labillardierei	0.939	0.001	***
	Juncus spp.	0.869	0.002	**
	Gahnia spp.	0.854	0.001	***
	Disphyma crassifolium	0.822	0.011	*
	Austrostipa spp.	0.807	0.015	*
GSL (sand dune)	*Ehrharta stipoides*	1.000	0.001	***
	Bare ground	0.961	0.002	**
	Oxalis perennans	0.894	0.001	***
	Lomandra longifolia	0.877	0.005	**
	Austrostipa spp.	0.807	0.015	*
	Leontodon taraxacoides	0.764	0.017	*
	Poa rodwayi	0.707	0.011	*
GPL (sr)	*Hibbertia prostrata*	1.000	0.003	**
	Bare ground	0.961	0.002	**
	Poa labillardierei	0.939	0.001	***
	Ficinia nodosa	0.935	0.002	**
	Oxalis perennans	0.894	0.001	***
	Lomandra longifolia	0.877	0.005	**
	Pteridium esculentum	0.835	0.018	*
	Isolepis nodosa	0.800	0.027	*
GPL (dr)	*Aira caryophyllea*	1.000	0.005	**
	Austrodanthonia setacea	1.000	0.005	**
	Bare ground	0.961	0.002	**
	Poa labillardierei	0.939	0.001	***
	Juncus spp.	0.869	0.002	**
	Zoysia macrantha	0.910	0.002	**
	Oxalis perennans	0.894	0.001	***
	Lomandra longifolia	0.877	0.005	**
	Austrostipa spp.	0.807	0.015	*
	Baumea juncea	0.801	0.022	*
	Poa rodwayi	0.707	0.011	*

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

4.2 Landscape features

4.2.1 Tides

The closest port that had available tide prediction data was Spring Bay (Triabunna), approximately 59 kilometres SSW from Long Point. From observations at the research site, tide times varied from approximately one hour (eastern side – Moulting Lagoon) to approximately two hours (western side – Little Bay) from those predicted at Spring Bay. It was difficult to ascertain whether the tidal height predictions followed those of Spring Bay, however predicted days of extreme high and low tides were observed and followed predictions for Spring Bay.

Tides for the east coast of Tasmania have a semi-diurnal pattern (Figure 4.9).

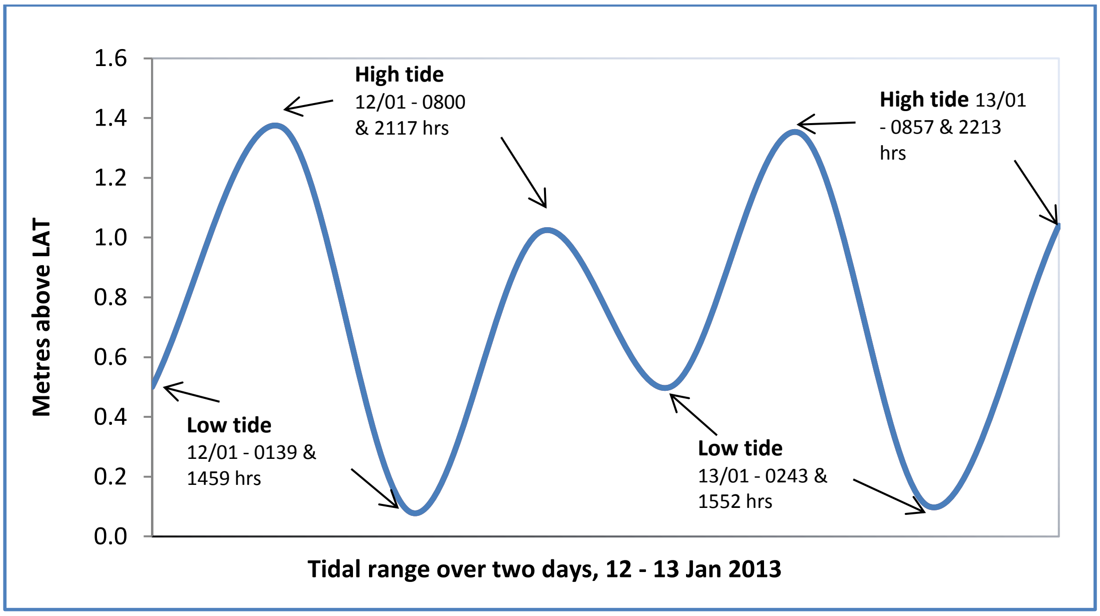


Figure 4.9: Semi-diurnal tide pattern, Spring Bay, Tasmania for 12 and 13 January 2013. Source: BOM (2013).

The monthly tidal amplitude varied according to the alignment of sun, moon and earth, this known as spring tides (Figure 4.10).

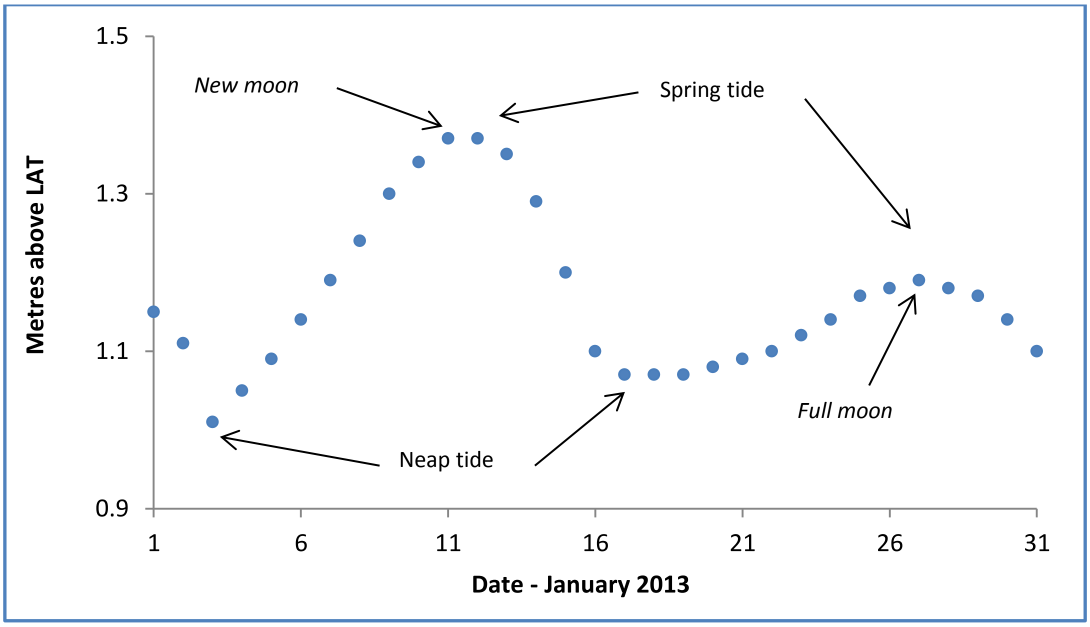


Figure 4.10: The amplitude of high tides for the month of January 2013, Spring Bay, Tasmania. Source: BOM (2013).

Furthermore, the annual tidal amplitude varied according to solstices and equinoxes (Figure 4.11).

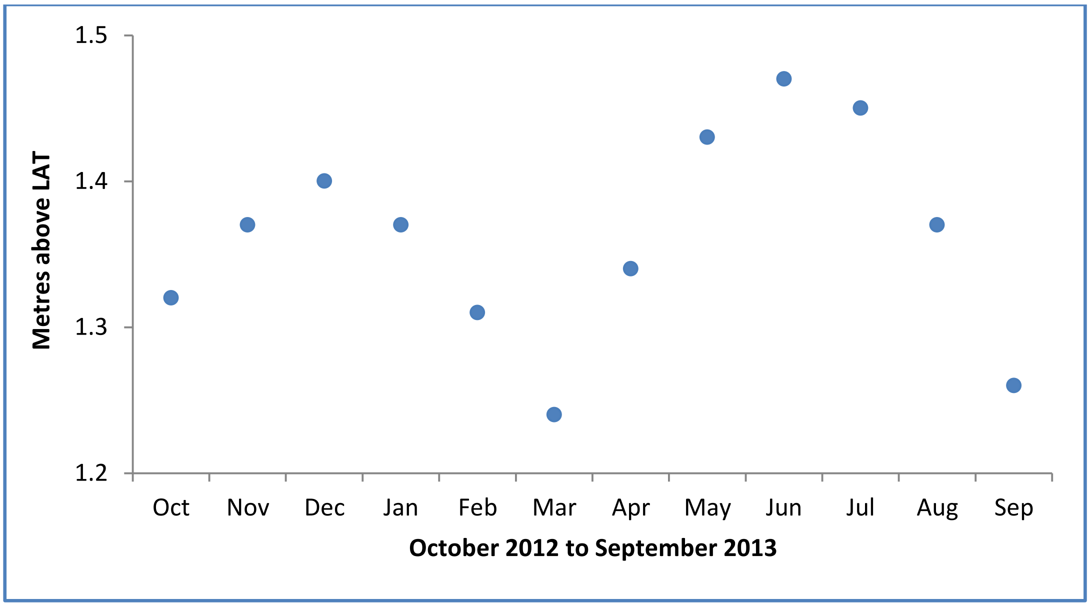


Figure 4.11: The amplitude of spring high tides for the year October 2012 to September 2013, Spring Bay, Tasmania. LAT = lowest astronomical tide. Source: BOM (2013).

Extreme flooding along the western and eastern sides of Long Point was observed during June and July 2013, the period of the highest spring tides for the year. At times this occurred up to 150-200 metres inland. Flooding was restricted to *Sarcocornia* spp. and *Tecticornia arbuscula* dominated vegetation, and around Gum Tree and Round Holes. There was little evidence of marine water intrusion into saline grassland vegetation.

4.2.2 Climate

4.2.2.1 Precipitation

All four recording rain gauges at Long Point recorded less rain than Swansea FWS and Friendly Beaches AWS over the period of invertebrate survey – 23 February 2013 to 23 February 2014. Total precipitation for the 12 month period at Long Point varied from 514mm at Y12 (Round Hole) to 524mm at G16 (dolerite ridge) (Figure 4.12).

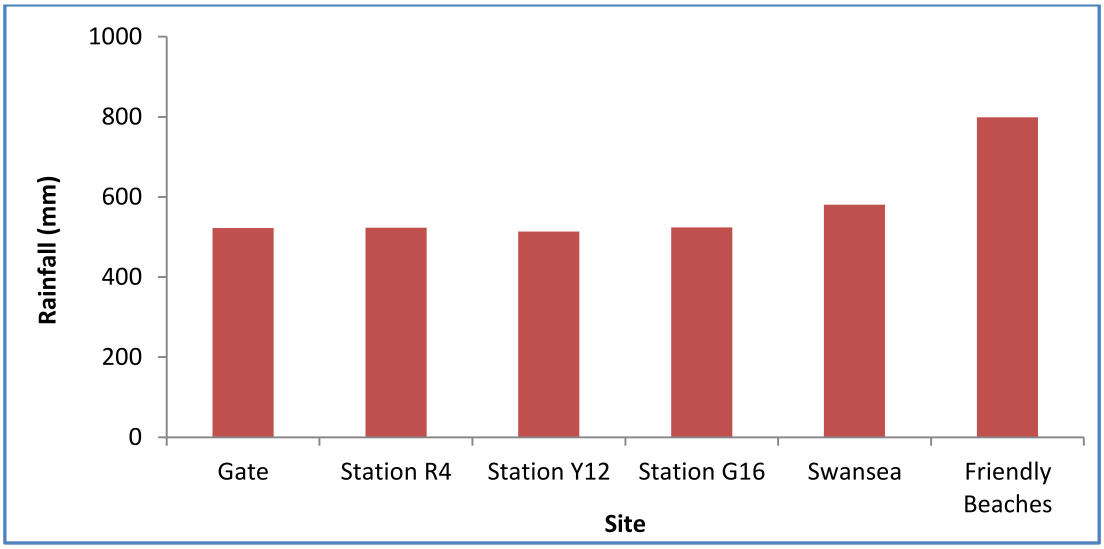


Figure 4.12: Precipitation at four sites at Long Point compared to Swansea and Friendly Beaches. Source of data for Swansea and Friendly Beaches: BOM (2014).

Generally, precipitation was on average 10% lower than Swansea and 35% lower than Friendly Beaches (Table 4.4). It is acknowledged that the rain gauges were subject to evaporation, particularly during the six week periods between visits in the summer months. This could impact on results, probably bringing precipitation at Long Point more in line with that of Swansea.

Table 4.4: Total precipitation for period 23 Feb 2013 to 23 Feb 2014 and variation to Swansea and Friendly Beaches. Source of data for Swansea and Friendly Beaches: BOM (2014).

Site	Total (mm)	Variation to Swansea	Variation to Friendly Beaches
Gate	522.0	-10.11%	-34.67%
Station R4	523.5	-9.85%	-34.48%
Station Y12	513.5	-11.57%	-35.73%
Station G16	524.0	-9.76%	-34.42%
Swansea	580.7	0.00%	-27.32%
Friendly Beaches	799.0	37.59%	0.00%

4.2.2.2 Temperature

Monthly maximum and minimum temperatures from Swansea FWS, Friendly Beaches AWS, and LogTags® at stations Y1, Y8, R14 and G16 are presented in Table 4.5 and Figure 4.13. A full set of maximum and minimum temperatures for stations fitted with LogTags® is available in Appendix G.

Table 4.5: Monthly maximum and minimum temperatures for Swansea (SW), Friendly Beaches (FB), Little Bay (LB = station Y1), sand dune crest (SD = station Y8), Moulting Lagoon (ML = station R14) and dolerite ridge (DR = station G16). Source of data for Swansea and Friendly Beaches: BOM (2014).

	Maximum (°C)						Minimum (°C)					
Month	**SW**	**FB**	**LB**	**SD**	**ML**	**DR**	**SW**	**FB**	**LB**	**SD**	**ML**	**DR**
Jun ‘13	16.4	17.2	15.4	19.0	17.7	20.8	0.1	2.6	-1.2	-0.4	-1.0	-2.4
Jul	19.5	18.6	17.7	19.5	18.7	21.7	-2.1	1.1	-1.8	-1.2	-1.2	-4.0
Aug	19.4	19.4	19.6	23.8	22.5	22.8	-1.1	0.2	-0.6	-0.2	-0.5	-2.6
Sep	23.2	23.8	24.6	24.2	24.8	25.4	-2.1	-1.0	1.1	-1.6	-1.1	-3.6
Oct	28.8	30.7	27.6	36.9	32.4	32.8	1.9	3.7	2.8	3.8	4.2	1.5
Nov	27.8	25.0	28.7	35.7	30.0	33.5	2.3	5.2	4.2	3.2	5.1	1.2
Dec	29.2	31.1	31.4	36.8	33.4	33.2	5.9	7.6	7.1	5.5	7.1	3.6
Jan ‘14	38.0	35.8	34.3	42.3	37.0	41.0	7.2	8.4	6.7	7.9	8.3	5.5
Feb	38.6	37.3	34.5	43.9	37.3	43.0	6.0	8.1	7.2	6.9	6.9	4.7
Mar	33.2	28.6	30.4	34.0	30.7	34.4	6.6	9.0	6.0	7.1	6.9	5.3
Apr	31.0	30.4	28.3	32.4	30.9	32.7	2.4	3.5	3.2	3.3	3.5	1.7
May	22.0	22.0	21.0	23.0	21.6	24.7	-0.1	2.3	-0.2	0.5	0.7	-1.6

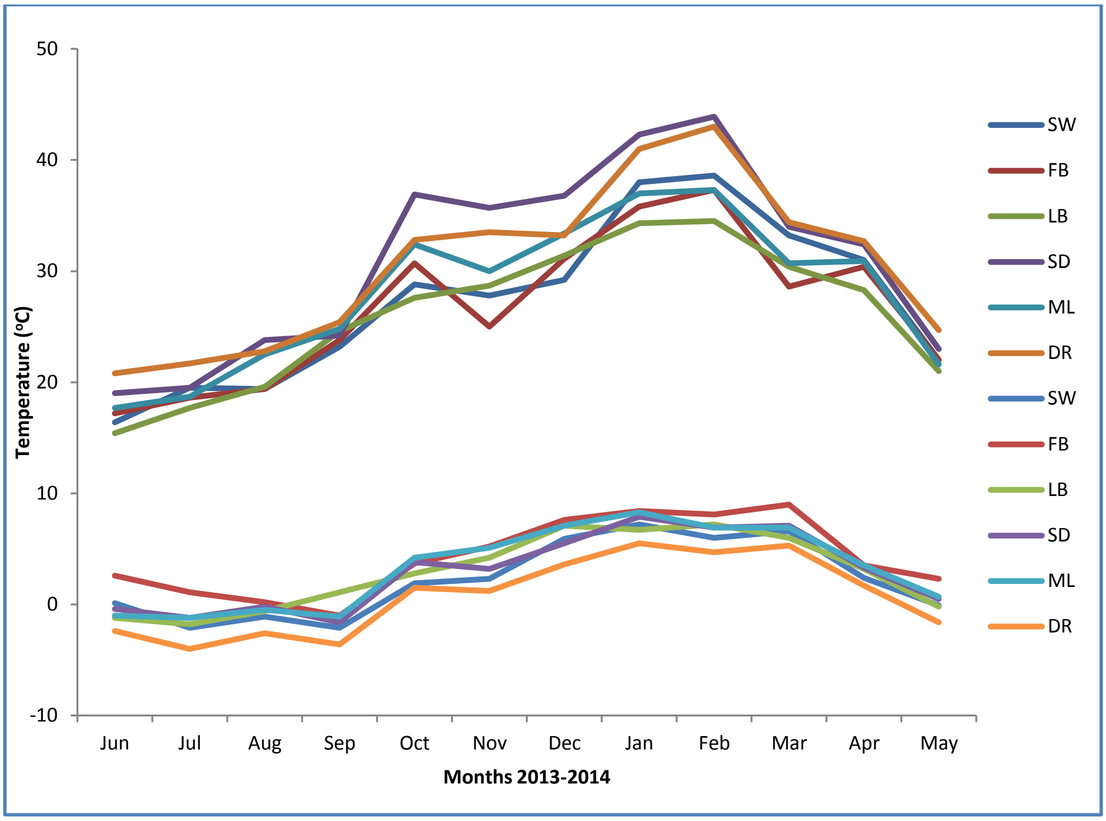


Figure 4.13: Monthly maximum (top) and minimum (bottom) temperatures for period June 2013 to May 2014. Swansea (SW), Friendly Beaches (FB), Little Bay (LB = station Y1), sand dune crest (SD = station Y8), Moulting Lagoon (ML = station R14) and dolerite ridge (DR = station G16). Source of data for Swansea and Friendly Beaches: BOM (2014). Note: the lower portion of the legend (from SW) relates to the minimum data.

There was little monthly minimum temperature variation between the BOM weather stations and stations at the site. However, variations in monthly maximum temperature between the October and March were evident with increased spread of data. This correlated well with the increased number of invertebrate taxa and abundance at the site.

4.2.3 Elevation, hill shade and solar radiation

Station elevation data, hill shade and solar radiation analysed by ArcMap 10™ from the second GPS survey are presented in Appendix B and as transect profiles in Figures 4.14 to 4.16.

The detailed elevation study of the saltmarsh zone confirmed how uniform and flat this area was. There was a similarity in elevation profile between the sand dune and the sand ridge, however the dolerite ridge was very dissimilar.

Figure 4.14: RED transect – elevation profile, hill shade and solar radiation.

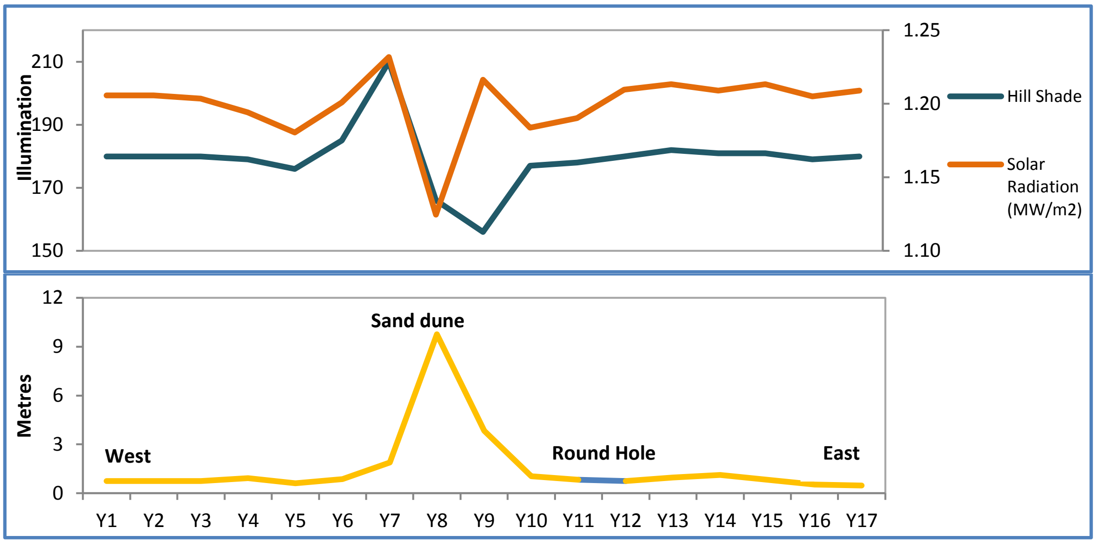


Figure 4.15: YELLOW transect – elevation profile, hill shade and solar radiation.

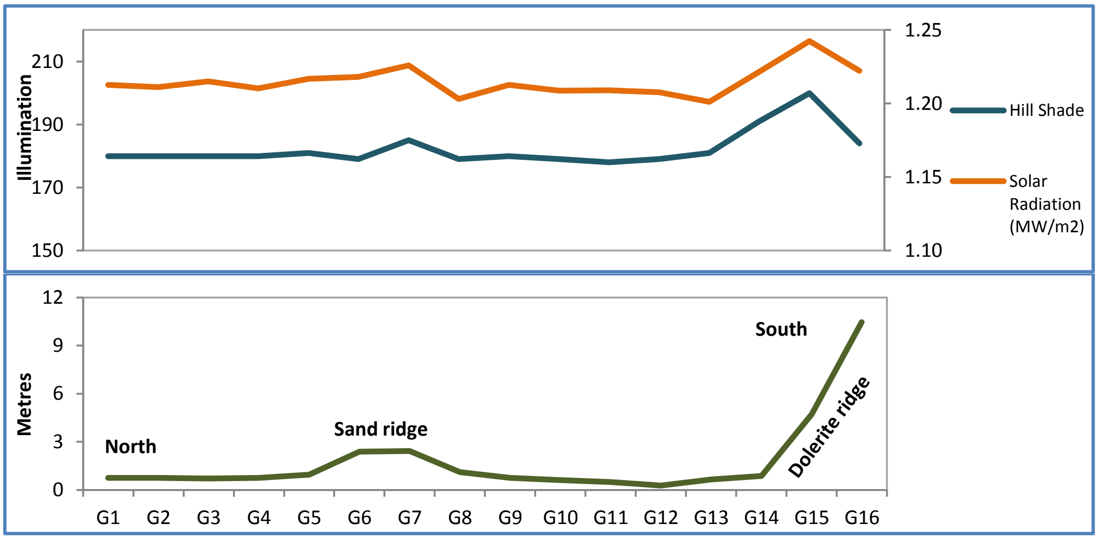


Figure 4.16: GREEN transect – elevation profile, hill shade and solar radiation.

Note: the horizontal axes in each figure are equally spaced; they are not scaled for distance.

Hill shade and solar radiation were inverse to elevation on each transect profile particularly those transects aligned W to E – Red and Yellow transects (Figures 4.14 and 4.15). In the case of Green transect, aligned north-south, hill shade and solar radiation are generally parallel except at G16 which is located just to the south of the dolerite ridge crest, hence both variables tending to decrease (Figure 4.16).

The height variation between the first two and the last two stations on each transect, for example, R1 (0.304m) and R2 (0.169m), Y16 (0.225m) and Y17 (0.247m) and G1 (0.273m) and G2 (0.227m), illustrate the existence of a levee on the saltmarsh fringe bordering Little Bay and Moulting Lagoon.

Saltmarsh hill shade values approximate 180 with solar radiation value ~ 1.21 x 10^6 $MW/m^2/year$. The west facing slope of the sand dune (stations R9, Y7) has increased hill shade and solar radiation values, whereas the east facing slope (stations R10, Y9) has the opposite. This demonstrates that the west facing slopes experience longer periods of sunlight than those facing east. The highest hill shade/solar radiation were at station G15, this having an aspect of NNW. There was a positive correlation between hill shade and solar radiation.

A boxplot of the elevation data is presented in Figure 4.17.

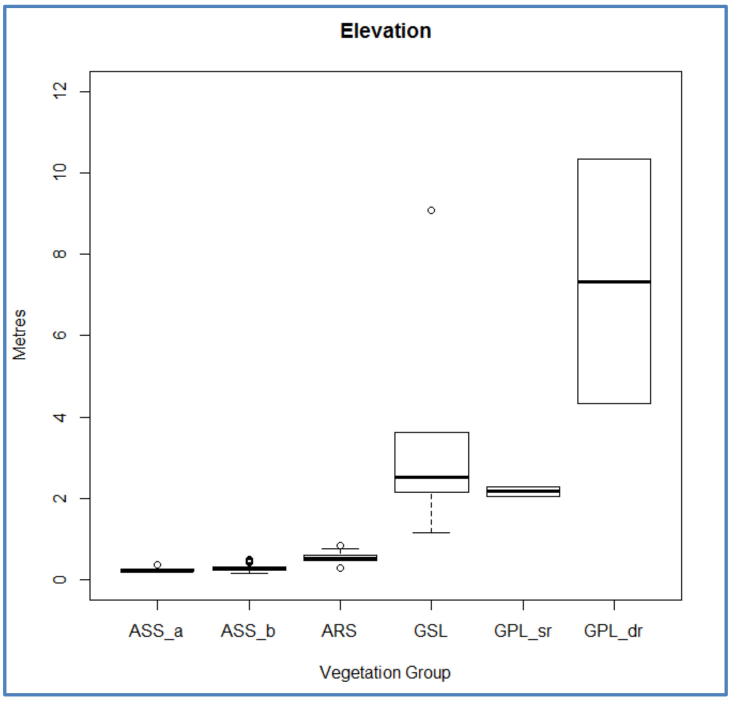


Figure 4.17: Boxplot of elevation.

The group medians of elevation for vegetation communities ASS(a), ASS(b) and ARS were not significantly different, nor the means for GSL and GPL (sr). The only vegetation community that was dissimilar in elevation was GPL (dr).

The ANOVA table for elevation analysis is presented in Table 4.6.

Table 4.6: ANOVA table of elevation (Df = degrees of freedom).

Environmental feature	Df	F value	p-value
Elevation	5,41	18.65	1.26e – 09 (P < 0.001)

The very low p-value indicates that there was at least one vegetation community that is highly significantly different to all other vegetation communities.

Tukey's Honestly Significant Difference (HSD) test results are presented in Table 4.7.

Table 4.7: Group means, standard deviation, range and Tukey groups for elevation. Tukey group values followed by the same letter are not different at p < 0.05.

Feature	Group	*n*	Mean ± Std Error (m)	Min	Max	Tukey groups
Elevation	ASS(a)	5	0.256 ± 0.028	0.214	0.363	a
	ASS(b)	18	0.300 ± 0.023	0.169	0.516	a
	ARS	14	0.562 ± 0.036	0.290	0.837	a
	GSL	6	3.511 ± 1.161	1.153	9.069	b
	GPL (sr)	2	2.180 ± 0.119	2.061	2.298	a, b
	GPL (dr)	2	7.331 ± 2.991	4.338	10.323	c

The Tukey groups demonstrate that the saltmarsh vegetation groups – ASS(a), ASS(b) and ARS – are similar. GPL (sr) is similar to GSL and also the saltmarsh vegetation groups, however GPL (dr) is dissimilar to all other vegetation groups.

Hill shade and solar radiation are presented as graphic displays in digitised maps along with a digitised elevation map (Figures 4.18 to 4.20) produced by ArcMap 10™.

Figure 4.18: Digitised terrain map of Long Point.

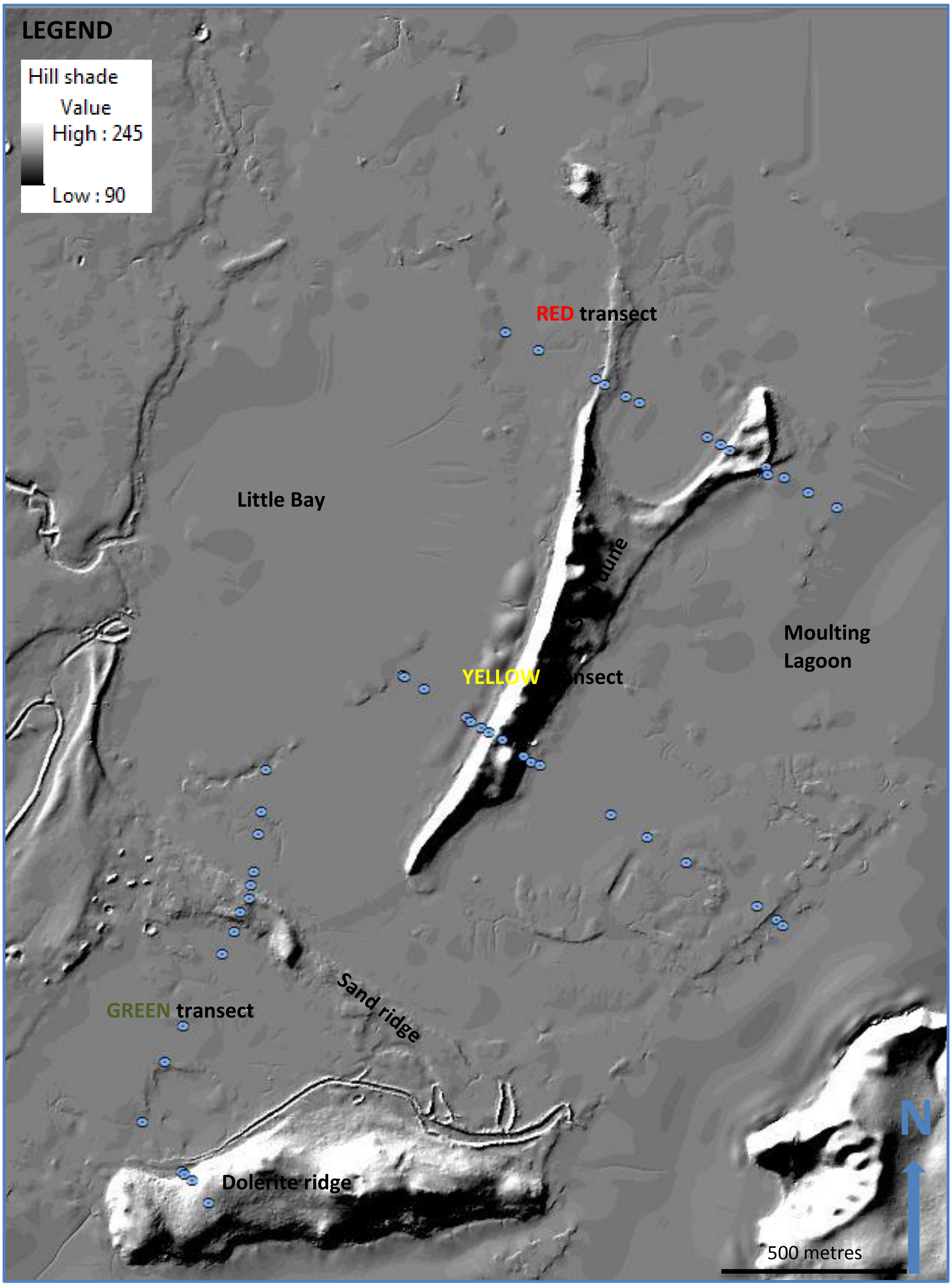


Figure 4.19: Hill shade at Long Point – the lighter the colour, the more exposed. The saltmarsh zones display a standard grey colour, indicating flat ground.

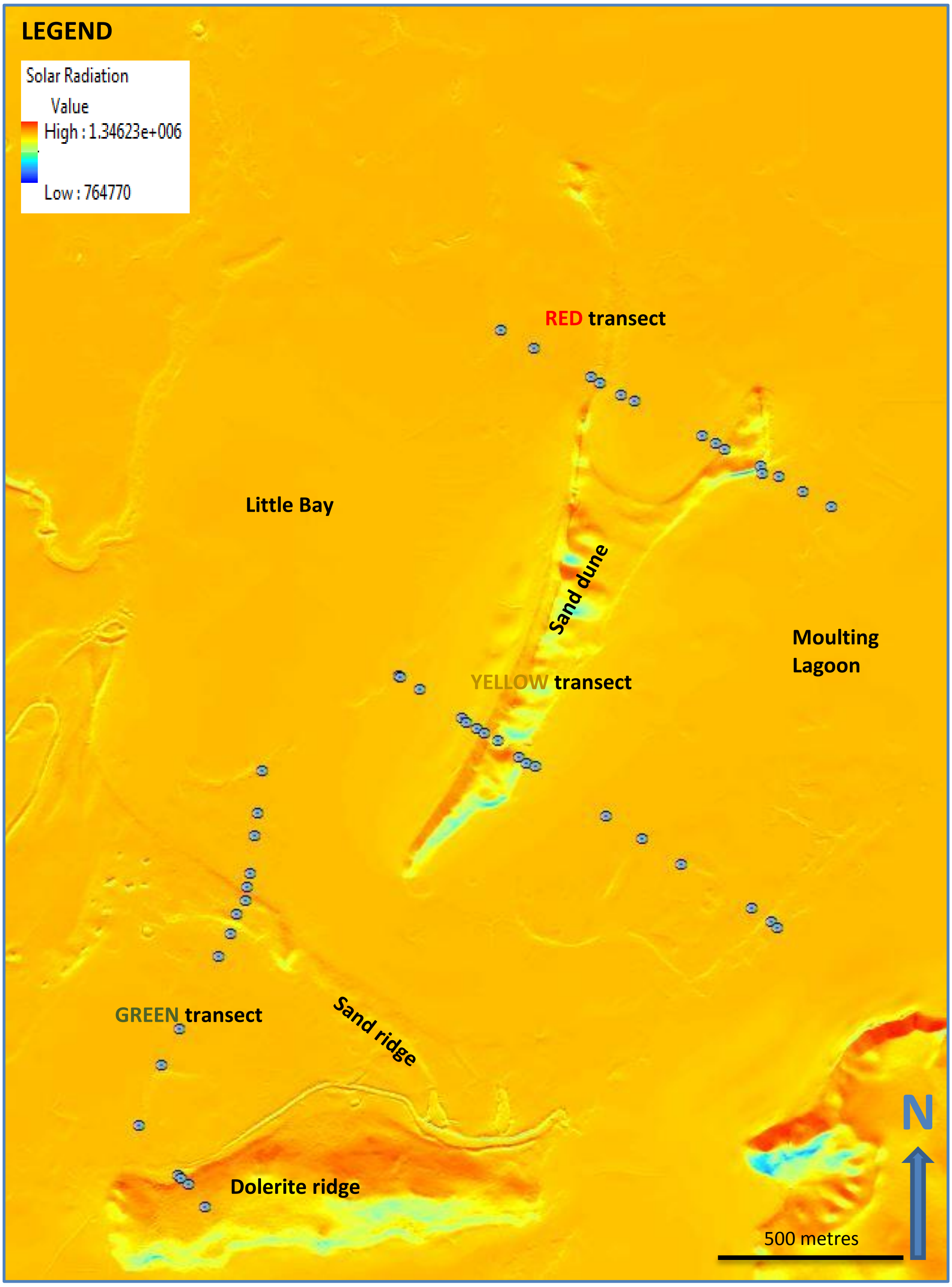


Figure 4.20: Solar radiation of Long Point – deep yellow to orange = higher the value; west/northwest facing slopes have very high values, south/southeast facing slopes have low values.

4.3 Edaphic factors

4.3.1 Soil analysis

Soil analysis data for each transect is presented in Appendices C (attached) and H (on CD) and graphically in Figures 4.21 to 4.23.

The relationship of elevation to sand, silt and clay.
Sand content is positively aligned to elevation:
RED Transect (Figure 4.21) – increased levels at R4, R9 and R10 (> 80%) are in response to the sand dune. The decreased level at R5/6 reflects the position of the northern lunette (Gum Tree Hole).
YELLOW Transect (Figure 4.22) – high levels of sand content at Y9 and Y10 (>80%) are in response to the sand dune, similar to Red transect. The high sand level (>60%), though in decline, is maintained to the east, possibly resulting from aeolian activity of westerly winds prior to the sand dune becoming fully vegetated.
GREEN Transect (Figure 4.23) – increased levels at G6 and G7 (>80%) are a result from the influence of the sand ridge. The increasing level at G15 and G16 (~80%) are in response to the dolerite ridge.
In contrast, silt and clay content are negatively aligned to elevation and sand content.

The relationship of elevation to edaphic factors:
Summer moisture and EC, winter moisture and EC, carbon and SOM are all strongly negatively aligned to elevation. Small changes in elevation have a marked impact on moisture and EC, for example R4, Y4 and Y14 and G6 and G7. Similarly, although to a less extent, summer and winter pH are negatively aligned to elevation. The response of pH may be aligned more to a combination of elevation and vegetation community structure.

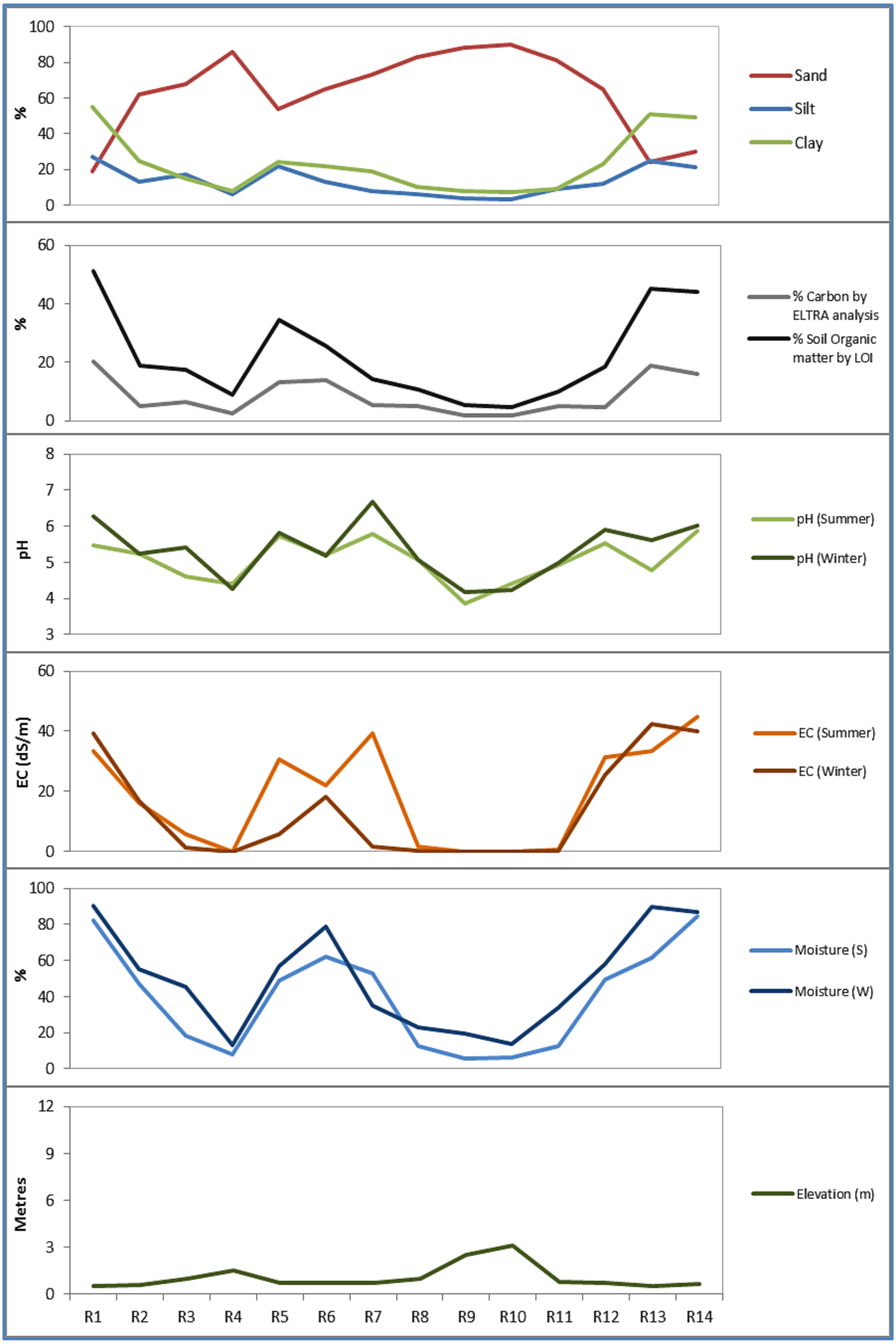


Figure 4.21: Results of soil analysis of RED transect plotted over elevation profile; note that all factors except for sand (top plot) are aligned inversely to elevation. R1 = Little Bay; R14 = Moulting Lagoon; R4 and R10 – summit of sand dune; between R6 and R7 – Gum Tree Hole (lunette). Legend note: Carbon by ELTRA = dry combustion method, LOI = loss on ignition, EC = electrical conductivity.

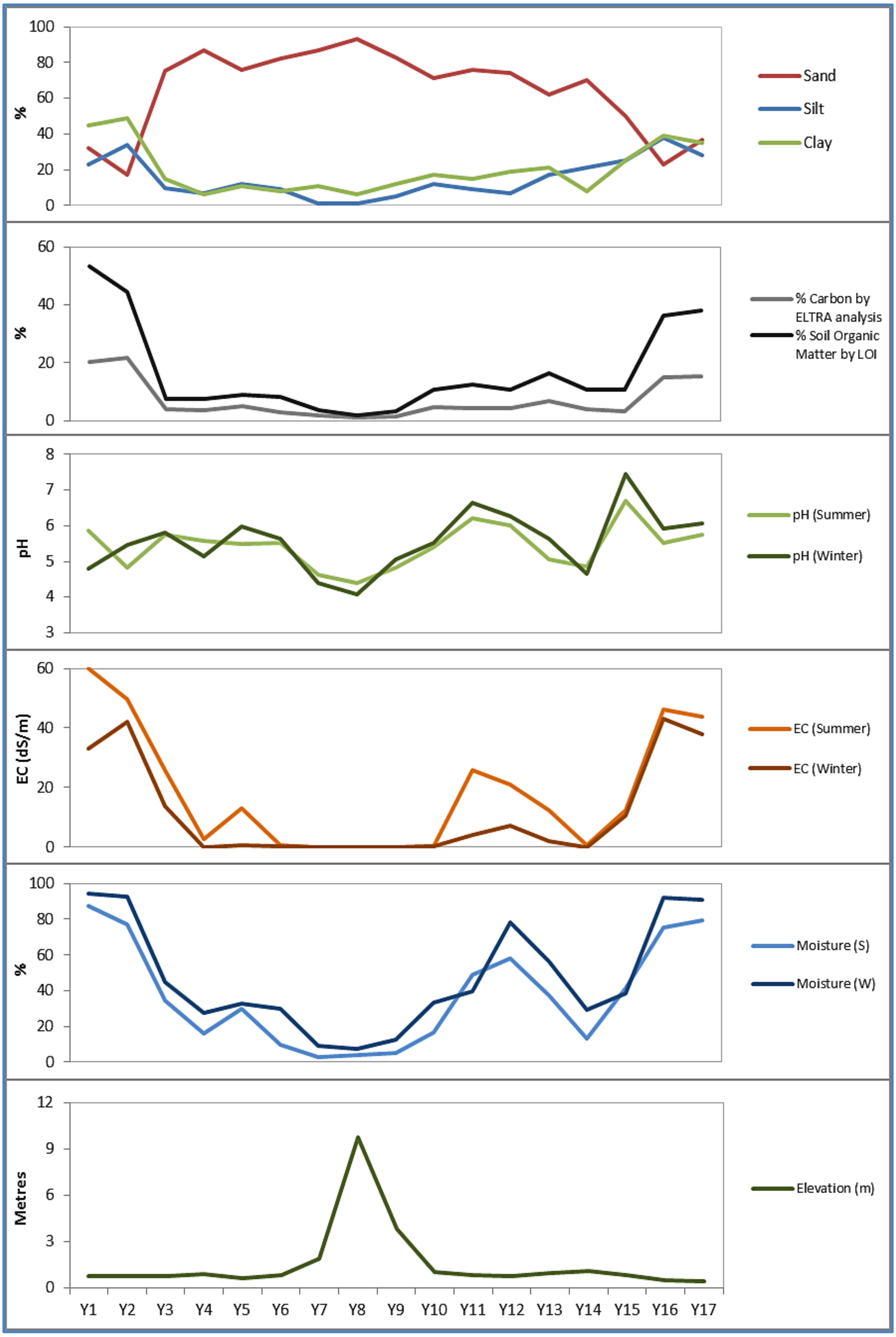


Figure 4.22: Results of soil analysis of YELLOW transect plotted over elevation profile; similar to RED transect, note that all factors except for sand (top plot) are aligned inversely to elevation. Y1 = Little Bay; Y17 = Moulting Lagoon; Y8 – summit of sand dune; between Y12 and Y13 – Round Hole (lunette); Y4 and Y14 are slightly higher in elevation than surrounding marsh land, note the change in moisture, EC and pH. Legend note: Carbon by ELTRA = dry combustion method, LOI = loss on ignition, EC = electrical conductivity.

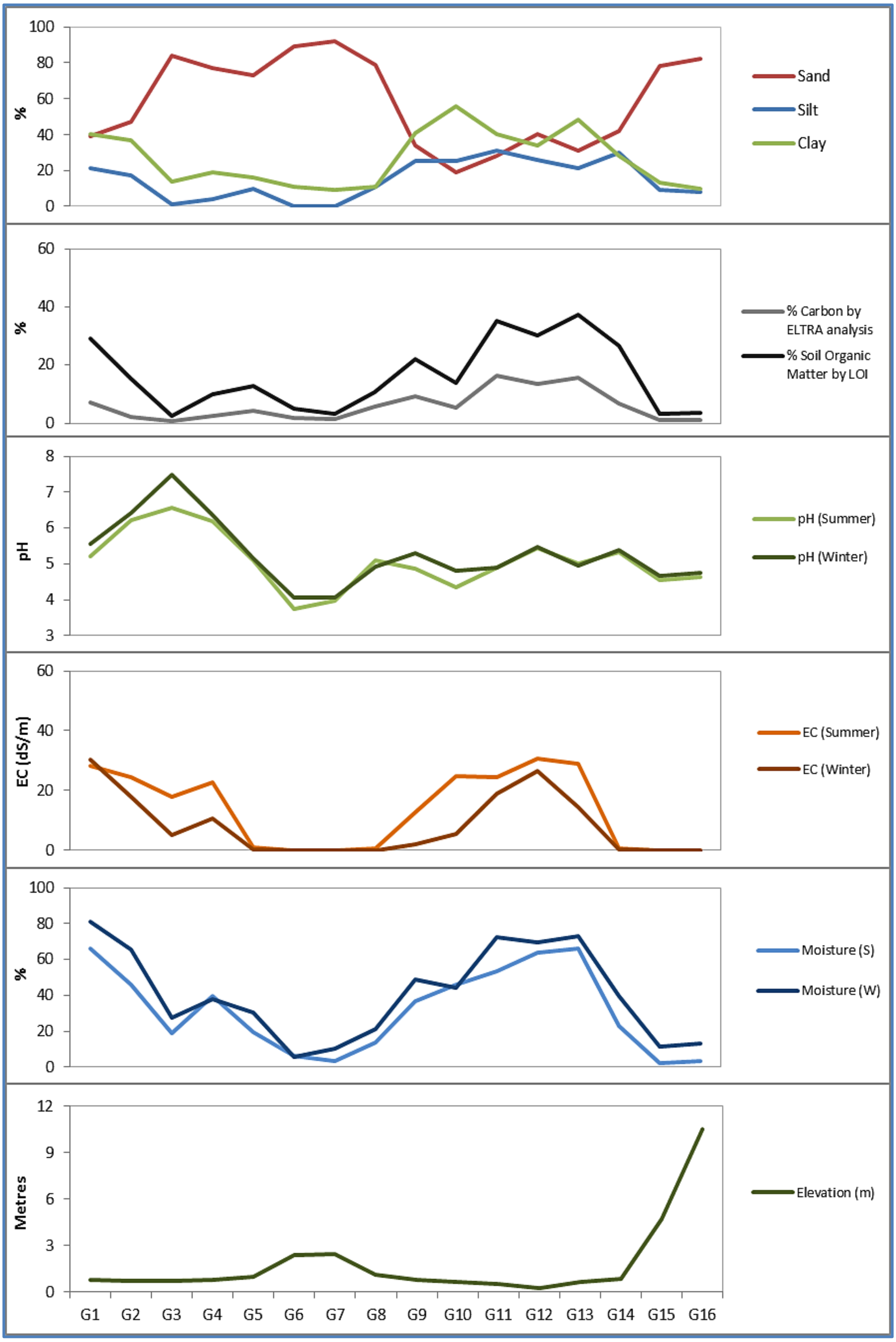


Figure 4.23: Results of soil analysis of GREEN transect plotted over elevation profile; similar to RED and YELLOW transects, note that all factors except for sand (top plot) are aligned inversely to elevation. G1 = Little Bay; G16 = summit of dolerite ridge; G6 and G7 – summit of sand ridge; between G12 – Opening Hole. Legend note: Carbon by ELTRA = dry combustion method, LOI = loss on ignition, EC = electrical conductivity.

4.3.2 Grouping to vegetation communities

The 47 stations were aligned to the vegetation groups ASS(a), ASS(b), ARS, GSL, GPL (sr) and GPL (dr) (Table 4.8).

Table 4.8: Station groups with edaphic factors (Moist = moisture, (S) = summer, (W) = winter, EC = electrical conductivity, SOM = soil organic matter). Values for moisture, SOM and carbon are in %, EC in dS/m.

GROUPS	Station	Moist S	Moist W	pH S	pH W	EC S	EC W	SOM	Carbon
ASS(a)	R6	62.10	78.56	5.207	5.178	22.18	18.32	25.66	13.85
	R13	61.59	89.60	4.788	5.619	33.38	42.58	45.05	18.74
	Y2	77.12	92.45	4.821	5.463	49.64	42.19	44.43	21.70
	Y16	75.39	92.19	5.532	5.926	46.27	43.00	36.42	15.14
	G13	65.83	72.89	5.012	4.950	29.12	14.30	37.26	15.64
ASS(b)	R1	82.31	90.17	5.459	6.285	33.59	39.13	51.20	20.48
	R2	47.35	55.29	5.240	5.238	16.17	16.75	18.94	4.90
	R5	49.00	57.08	5.739	5.817	30.82	5.97	34.68	13.34
	R7	52.66	35.18	5.776	6.665	39.43	1.84	14.43	5.48
	R12	49.15	58.27	5.522	5.908	31.51	25.33	18.59	4.82
	R14	84.45	86.70	5.873	6.008	44.98	39.86	44.26	16.22
	Y1	87.31	94.25	5.859	4.787	60.13	32.98	53.16	20.16
	Y3	34.17	44.52	5.760	5.819	25.86	13.67	7.61	3.95
	Y11	48.92	39.42	6.207	6.639	25.87	3.94	12.41	4.21
	Y12	57.92	78.24	6.022	6.267	20.90	7.29	10.79	4.34
	Y15	41.41	38.49	6.701	7.463	12.51	10.76	10.92	3.47
	Y17	79.15	90.89	5.742	6.055	43.74	38.00	38.23	15.35
	G1	65.92	81.09	5.209	5.569	28.40	30.23	29.33	7.21
	G2	45.72	65.72	6.232	6.432	24.50	17.78	15.23	2.28
	G3	18.98	27.79	6.574	7.475	17.74	5.16	2.52	0.78
	G4	39.83	37.78	6.184	6.350	22.84	10.58	10.12	2.48
	G10	46.16	44.26	4.341	4.814	24.84	5.46	14.10	5.27
	G12	63.56	69.40	5.428	5.456	30.77	26.46	30.09	13.67
ARS	R3	18.46	45.53	4.609	5.404	5.95	1.31	17.60	6.37
	R8	12.85	22.85	5.064	5.068	1.61	0.24	10.86	5.18
	R11	12.75	34.02	4.925	4.986	0.54	0.15	9.98	5.21
	Y4	16.22	27.46	5.583	5.151	2.59	0.10	7.69	3.79
	Y5	29.62	32.87	5.492	5.970	13.00	0.61	9.00	4.96
	Y6	10.00	30.02	5.524	5.636	0.75	0.14	8.42	2.90
	Y10	16.65	33.02	5.391	5.527	0.20	0.19	10.77	4.83

GROUPS	Station	Moist S	Moist W	pH S	pH W	EC S	EC W	SOM	Carbon
ARS	Y13	37.40	56.39	5.063	5.628	12.38	1.96	16.33	6.86
(cont'd)	Y14	13.24	29.23	4.861	4.646	0.73	0.08	10.62	4.18
	G5	19.74	30.49	5.099	5.159	1.05	0.26	12.71	4.50
	G8	13.73	21.20	5.094	4.934	0.59	0.11	10.75	5.89
	G9	36.84	48.96	4.875	5.304	12.58	1.93	22.27	9.25
	G11	53.33	72.41	4.887	4.893	24.48	19.03	35.36	16.38
	G14	23.06	39.90	5.331	5.376	0.79	0.42	26.55	6.70
GSL	R4	7.87	13.35	4.408	4.253	0.06	0.10	8.86	2.52
	R9	5.56	19.26	3.871	4.178	0.04	0.05	5.57	1.98
	R10	6.48	13.52	4.394	4.240	0.03	0.04	4.70	1.74
	Y7	2.59	8.94	4.630	4.392	0.06	0.06	3.66	1.73
	Y8	4.11	7.44	4.410	4.083	0.03	0.02	1.84	1.04
	Y9	5.05	12.32	4.838	5.052	0.04	0.03	3.46	1.48
GPL (sr)	G6	6.01	5.46	3.740	4.070	0.08	0.07	4.94	1.97
	G7	3.29	10.40	3.969	4.074	0.05	0.02	3.37	1.38
GPL (dr)	G15	2.38	11.46	4.539	4.674	0.06	0.02	3.30	1.21
	G16	3.53	13.33	4.631	4.757	0.03	0.02	3.57	1.34

Figure 4.24: Example of soil based on vegetation grouping – **Top left**: ASS(a) from G13. **Top right**: ASS(b) from R2. **Centre left**: ARS from R8. **Centre right**: GSL from Y7. **Bottom left**: GPL (sr) from G7. **Bottom right**: GPL (dr) from G15. All soils had been sieved to 2mm.

Soil examples from each group based on the six vegetation communities are presented in Figures 4.24.

<u>ASS(a) top left:</u>

Dark brown colour, high in organic matter, a sandy clay loam.

<u>ASS(b) top right:</u>

Light brown to grey, sandy clay material containing lower levels of organic matter.

<u>ARS centre left:</u>

Dark brown sandy loam containing high levels of fibrous plant material.

<u>GSL centre right:</u>

Yellow loamy sand material with some plant matter.

<u>GPL (sr) bottom left:</u>

Grey loamy sand material with some plant matter.

<u>GPL (dr) bottom right:</u>

Mid brown sandy loam with a little plant material.

Following the alignment of stations to vegetation groups, results for each edaphic factor were summarised in boxplots by vegetation group (Figures 4.25 to 4.32).

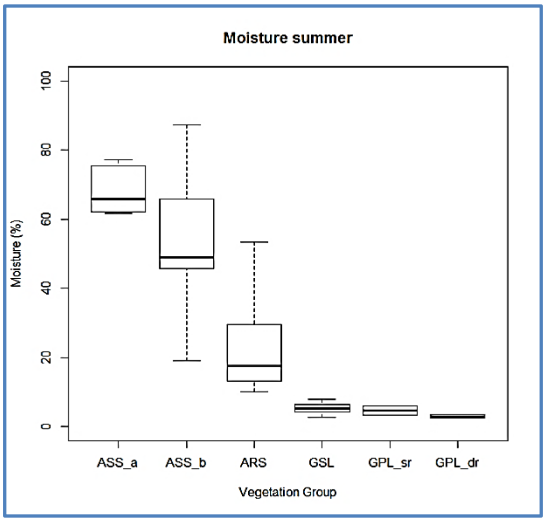


Figure 4.25: Summer moisture by group

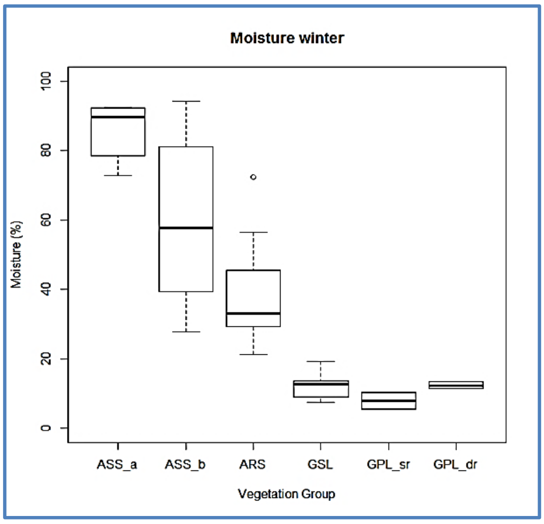


Figure 4.26: Winter moisture by group

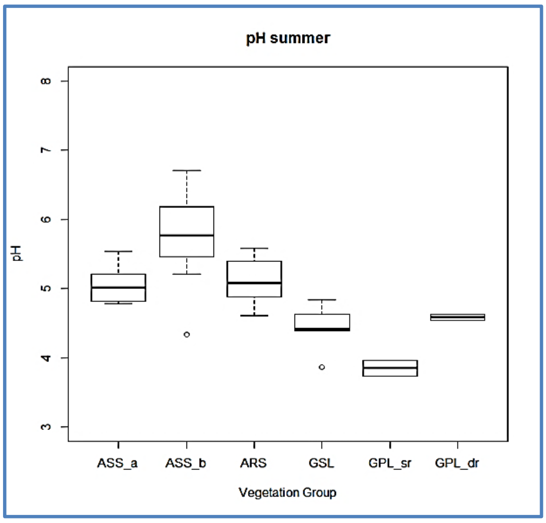


Figure 4.27: Summer pH by group

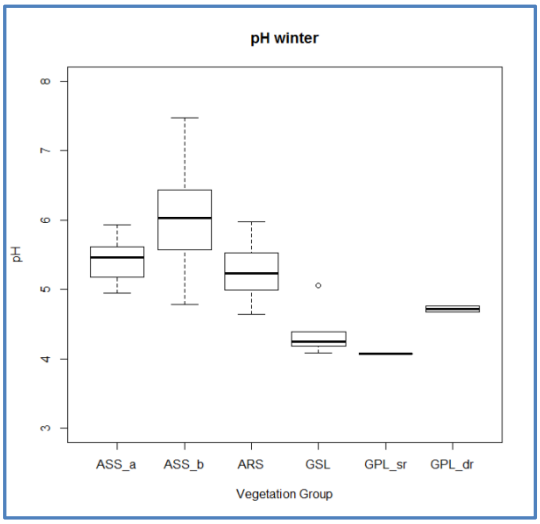


Figure 4.28: Winter pH by group

<u>Moisture:</u>

The group medians for moisture (Figures 4.25 and 4.26) are highly dissimilar for the saline groups (ASS(a), ASS(b) and ARS), yet highly similar for non-saline soils (GSL, GPL (sr) and GPL (dr)).

<u>pH:</u>

In Figures 4.27 and 4.28 group medians in ASS(a) and ARS display similarity for both summer and winter. GSL and GPL (dr) display similarity in summer, yet dissimilarity in winter. Between saltmarsh groups, ASS(a) is dissimilar to the other two groups.

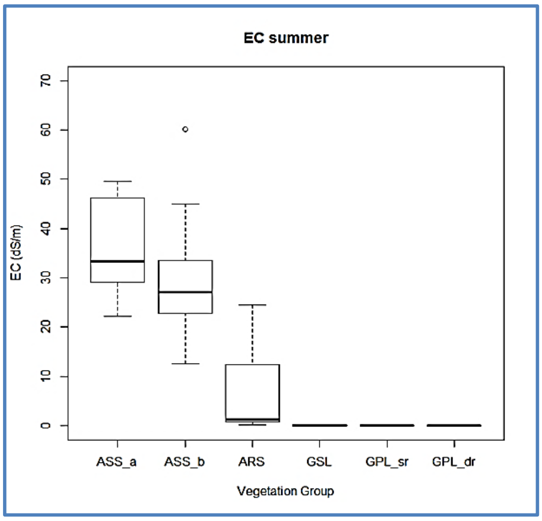


Figure 4.29: Summer EC by group

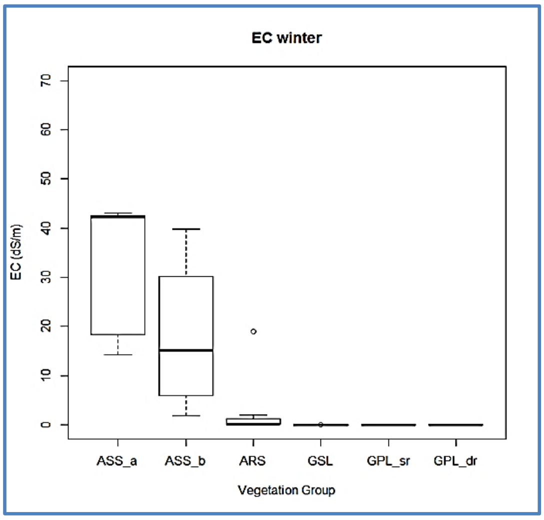


Figure 4.30: Winter EC by group

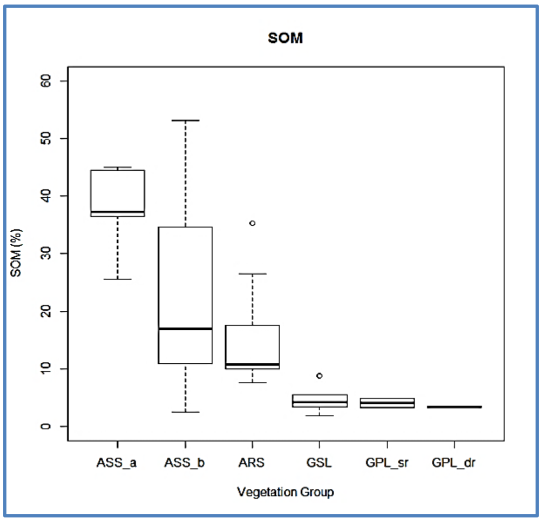


Figure 4.31: SOM (soil organic matter) by group.

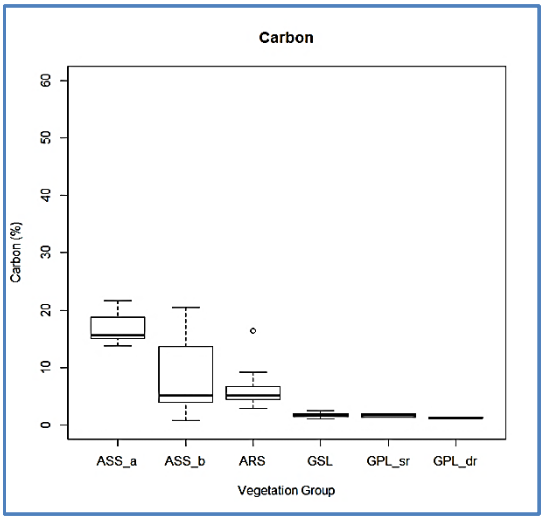


Figure 4.32: Carbon by group.

EC:

In Figures 4.29 and 4.30, group medians for saltmarsh soils display a level of dissimilarity for both summer and winter, reflecting varying degrees of marine water inundation. There is a high degree of similarity in the non-saline soils for both seasons, a reflection of the non-inundation by marine water.

SOM and carbon:

Group medians for SOM (Figure 4.31) are dissimilar for saline soils with overlap between ASS(b) and ARS, with similarity for the woodland soils. In carbon (Figure 4.32), all groups except for ASS(a) display similarity.

ANOVA outputs of all factors are presented in Table 4.9.

Table 4.9: ANOVA output of all edaphic factors (Df = degrees of freedom).

Soil variable	Df	F value	p-value	
Moisture summer	5,41	24.31	2.75e – 11	(P < 0.001)
Moisture winter	5,41	17.97	2.09e – 09	(P < 0.001)
pH summer	5,41	16.08	9.24e – 09	(P < 0.001)
pH winter	5,41	12.50	2.13e – 07	(P < 0.001)
EC summer	5,41	21.90	1.29e – 10	(P < 0.001)
EC winter	5,41	11.01	9.21e – 07	(P < 0.001)
SOM	5,41	6.97	8.61e – 05	(P < 0.001)
Carbon	5,41	7.65	3.73e – 05	(P < 0.001)

All edaphic factors have a significant difference between the groups. The very low p-value for each edaphic factor indicates that there is at least one vegetation group within that factor that is significantly different to all other vegetation groups.

Tukey's Honestly Significant Difference test results are presented in Table 4.10.

Table 4.10: Group means, standard error, range and Tukey groups for each edaphic factor. Within each edaphic factor, the values followed by the same letter are not different at p < 0.05.

Variable	Group	*n*	Mean ± Std Error	Min	Max	Tukey Groups
Moist S (%)	ASS(a)	5	68.406 ± 3.298	61.590	77.120	a
	ASS(b)	18	55.221 ± 4.399	18.980	87.310	a
	ARS	14	22.421 ± 3.343	10.000	53.330	b
	GSL	6	5.277 ± 0.750	2.590	7.870	b
	GPL (sr)	2	4.650 ± 1.360	3.290	6.010	b
	GPL (dr)	2	2.955 ± 0.575	2.380	3.530	b
Moist W (%)	ASS(a)	5	85.138 ± 3.977	72.890	92.450	a
	ASS(b)	18	60.808 ± 5.174	27.790	94.250	a
	ARS	14	37.454 ± 3.769	21.200	72.410	b
	GSL	6	12.472 ± 1.691	7.440	19.260	c
	GPL (sr)	2	7.930 ± 2.470	5.460	10.400	c
	GPL (dr)	2	12.395 ± 0.935	11.460	13.330	c
pH S	ASS(a)	5	5.072 ± 0.137	4.788	5.532	bc
	ASS(b)	18	5.770 ± 0.129	4.341	6.701	a
	ARS	14	5.128 ± 0.078	4.609	5.583	b
	GSL	6	4.425± 0.132	3.871	4.484	cd
	GPL (sr)	2	3.855 ± 0.115	3.740	3.969	d
	GPL (dr)	2	4.585 ± 0.046	4.539	4.631	b c d

Variable	Group	*n*	Mean ± Std Error	Min	Max	Tukey Groups
pH W	ASS(a)	5	5.427 ± 0.170	4.950	5.926	a b
	ASS(b)	18	6.058 ± 0.177	4.787	7.475	a
	ARS	14	5.263 ± 0.095	4.646	5.970	b
	GSL	6	4.366 ± 0.143	4.083	5.052	c
	GPL (sr)	2	4.072 ± 0.002	4.070	4.074	c
	GPL (dr)	2	4.716 ± 0.042	4.674	4.757	b c
EC S (dS/m)	ASS(a)	5	36.118 ± 5.180	22.178	49.644	a
	ASS(b)	18	29.700 ± 2.742	12.508	60.133	a
	ARS	14	5.518 ± 1.964	0.200	24.478	b
	GSL	6	0.042 ± 0.006	0.027	0.061	b
	GPL (sr)	2	0.062 ± 0.014	0.048	0.075	b
	GPL (dr)	2	0.044 ± 0.013	0.031	0.056	b
EC W (dS/m)	ASS(a)	5	32.077 ± 6.469	14.034	43.000	a
	ASS(b)	18	18.399 ± 3.125	1.839	39.856	a
	ARS	14	1.895 ± 1.330	0.083	19.031	b
	GSL	6	0.048 ± 0.011	0.015	0.095	b
	GPL (sr)	2	0.043 ± 0.025	0.018	0.068	b
	GPL (dr)	2	0.023 ± 0.001	0.022	0.023	b
SOM (%)	ASS(a)	5	37.764 ± 3.508	25.660	45.050	a
	ASS(b)	18	23.145 ± 3.658	2.520	53.160	a b
	ARS	14	14.922 ± 2.154	7.690	35.360	b c
	GSL	6	4.682 ± 0.981	1.840	8.860	c
	GPL (sr)	2	4.155 ± 0.785	3.370	4.940	c
	GPL (dr)	2	3.435 ± 0.135	3.300	3.570	c
Carbon (%)	ASS(a)	5	17.014 ± 1.420	13.850	21.700	a
	ASS(b)	18	8.245 ± 1.511	0.780	20.480	b
	ARS	14	6.214 ± 0.886	2.900	16.380	b
	GSL	6	1.748 ± 0.202	1.040	2.520	b
	GPL (sr)	2	1.675 ± 0.295	1.380	1.970	b
	GPL (dr)	2	1.275 ± 0.065	1.210	1.340	b

4.3.3 Relationship of edaphic factors for all groups

The relationship between edaphic factors was tested using the correlation function in R. A pairwise scatterplot demonstrated variables that have an association. An investigation into the strength of the correlation between each variable showed that SOM and winter moisture have the best fit of correlation to the remaining edaphic factors (Table 4.11).

Table 4.11: The correlation between each edaphic factor; 0 to 0.3 (nil symbol) = the weakest correlation, 0.95 to 1 (B symbol) = the strongest correlation (EC = electrical conductivity, S = summer, W = winter).

Variable	SOM	Carbon	pH S	pH W	EC S	EC W	Moist S	Moist W
SOM	**1**	**B**			+	+	+	+
Carbon	**B**	**1**			,	+	+	+
pH S			**1**	**+**	.		.	
pH W			**+**	**1**	.	.	.	.
EC S	**+**	**,**	**.**	**.**	**1**	+	*	+
EC W	**+**	**+**		**.**	**+**	**1**	+	+
Moist S	**+**	**+**	**.**	**.**	*****	**+**	**1**	B
Moist W	**+**	**+**		**.**	**+**	**+**	**B**	**1**

[1] 0 ‘ ’ 0.3 ‘.’ 0.6 ‘,’ 0.8 ‘+’ 0.9 ‘*’ 0.95 ‘B’ 1

This demonstrates that both SOM and winter moisture data can be used as predictors for the remaining edaphic factors and that it may be unnecessary to measure the remaining factors.

Exploring the data reveals the strength of the correlation between SOM and winter moisture with the remaining factors (Figure 4.12).

Table 4.12: The correlation between SOM and winter moisture with each edaphic factor; 0 = no correlation, 1 = the highest level of correlation (EC = electrical conductivity, S = summer, W = winter).

Variable	SOM	Carbon	pH S	pH W	EC S	EC W	Moist S	Moist W
SOM	**1.000**	0.965	0.225	0.211	0.804	0.847	0.873	**0.894**
Carbon	**0.965**	1.000	0.154	0.150	0.768	0.810	0.830	**0.858**
pH S	**0.225**	0.154	1.000	0.891	0.478	0.294	0.483	**0.413**
pH W	**0.211**	0.150	0.891	1.000	0.471	0.319	0.480	**0.415**
EC S	**0.804**	0.768	0.478	0.471	1.000	0.846	0.940	**0.861**
EC W	**0.847**	0.810	0.294	0.319	0.846	1.000	0.867	**0.880**
Moist S	**0.873**	0.830	0.483	0.480	0.940	0.867	1.000	**0.950**
Moist W	**0.894**	0.858	0.413	0.415	0.861	0.880	0.950	**1.000**

SOM shows very little correlation with pH in summer and winter, but strong correlation with the remaining factors. Winter moisture displays moderate correlation to summer and winter pH, with strong correlation for the remaining factors. Variables, SOM and winter moisture, independently of each other, could be used as a predictor for saltmarsh and woodland soils.

4.3.4 Soil texture

The results from the particle size analysis were plotted on the USDA/FAO soil texture triangle using R (Figure 4.33). The plot demonstrates the decrease in clay content and increase in sand content from the lower marsh to the upper marsh, with further increases of sand content into the woodland indicating the impact of the sand dune and ridge.

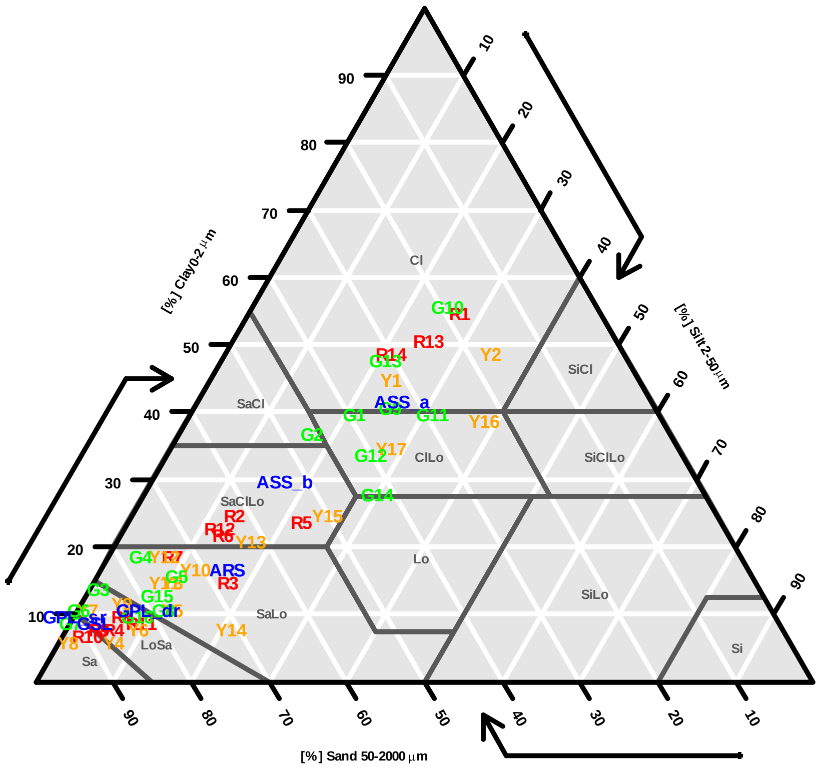


Figure 4.33: USDA/FAO soil texture triangle with data for clay, silt and sand plotted by station/group. Red sites = RED transect, orange sites = YELLOW transect, green sites = GREEN transect, blue sites = vegetation groups.

Soil classifications are tabled in Table 4.13 along with the PSA results.

Table 4.13: Station particle size analysis data – clay, silt and sand in %, classification to USDA/FAO classes; value of 1 = wholly within polygon, value of 2 = on side of two polygons, value of 3 = on corner of three polygons.

Group/ Station	CLAY	SILT	SAND	Clay	Sandy clay	Clay loam	Sandy clay loam	Sandy loam	Loamy sand	Sand
ASS(a)	42	26	32	1						
R6	22	13	65				1			
R13	51	25	24	1						
Y2	49	34	17	1						
Y16	39	38	23			1				
G13	48	21	31	1						

Group/ Station	CLAY	SILT	SAND	Clay	Sandy clay	Clay loam	Sandy clay loam	Sandy loam	Loamy sand	Sand
ASS(b)	30	17	53				**1**			
R1	55	27	18	**1**						
R2	25	13	62				**1**			
R5	24	22	54				**1**			
R7	19	8	73					**1**		
R12	23	12	65				**1**			
R14	49	21	30	**1**						
Y1	45	23	32	**1**						
Y3	15	10	75					**1**		
Y11	15	9	76					**1**		
Y12	19	7	74					**1**		
Y15	25	25	50				**1**			
Y17	35	28	37			**1**				
G1	40	21	39	**2**		**2**				
G2	37	17	46		**1**					
G3	14	1	85						**1**	
G4	19	4	77					**1**		
G10	56	25	19	**1**						
G12	34	26	40			**1**				
ARS	17	16	67					**1**		
R3	15	17	68					**1**		
R8	10	6	84						**1**	
R11	9	9	82						**1**	
Y4	6	7	87						**1**	
Y5	11	12	77					**1**		
Y6	8	9	83						**1**	
Y10	17	12	71					**1**		
Y13	21	17	62				**1**			
Y14	8	21	71					**1**		
G5	16	10	74					**1**		
G8	11	11	78					**1**		
G9	41	25	34	**1**						
G11	40	31	29	**2**		**2**				
G14	28	30	42			**1**				
GSL	9	3	88						**1**	
R4	8	6	86						**1**	
R9	8	4	88						**1**	
R10	7	3	90							**1**
Y7	11	1	88						**1**	
Y8	6	1	93							**1**
Y9	12	5	83						**1**	

Group/ Station	CLAY	SILT	SAND	Clay	Sandy clay	Clay loam	Sandy clay loam	Sandy loam	Loamy sand	Sand
GPL (sr)	10	0	90						**3**	**3**
G6	11	0	89						**2**	
G7	9	0	91							**2**
GPL (dr)	11	9	80					**1**		
G15	13	9	78					**1**		
G16	10	8	82						**1**	

Each vegetation group has been classified as follows:

ASS(a) – clay; 5 stations – clay (4) to clay loam (1).
ASS(b) – sandy clay loam; 18 stations – across the spectrum of clay to sandy loam.
ARS – sandy loam; 14 stations – clay to clay loam (3), remainder sandy loam/loamy sand.
GSL – loamy sand; 6 stations – loamy sand (4) to sand (2).
GPL (sr) – loamy sand; 2 stations – loamy sand to sand.
GPL (dr) – sandy loam; 2 stations – sandy loam to loamy sand.

4.4 Invertebrate assemblages

The results of all pitfall collections are presented in Table 4.14.

Table 4.14: Pitfall trap collections over the 12 month period by season and total.

	Spring	Summer	Autumn	Winter	TOTAL
Transects	3	3	3	3	3
Pitfall stations	47	47	47	40	47
Pitfall traps	141	141	141	118	141
Pitfall trap – set and collect	2	2	2	2	8
Total traps collected	282	282	282	236	1 082
Total catch	10 984	20 073	4 667	2 106	37 830
No. Orders	15	14	16	14	22
SPIDERS					
Spider Families	10	13	11	6	23
Spider Taxa	15	18	15	10	37
Spiders	1 726	2 597	639	644	5 606
% spiders of total catch	15.71%	12.94%	13.69%	30.58%	14.82%

BEETLES	Spring	Summer	Autumn	Winter	TOTAL
Beetle Families	10	12	12	8	22
Beetle Taxa	29	38	27	13	84
Beetles	351	486	241	87	1 165
% beetles of total catch	3.20%	2.42%	5.16%	4.13%	3.08%

A full data set of all pitfall trap collections by station is available in Appendix I.

4.4.1 Spiders

Five dominant spider families by abundance in each vegetation group and by season are presented in Figures 4.34 to 4.37.

Three spider families were ubiquitous in all seasons: Lycosidae (wolf spiders), Linyphiidae (sheet weaver spiders) and Zoridae (wandering ghost spiders), with a clear dominance by Lycosidae (Figures 4.34 to 4.37). A seasonal signal was evident with a decline in the Lycosidae, increasingly replaced by Linyphiidae from summer to winter, reverting to Lycosidae in spring. Zoridae, though having a lower representation across the site, are more dominant in the woodland groups, for example, GPL (sr) in autumn.

Of the remaining dominant families, Miturgidae (large sac spiders) was evident during the colder seasons of winter and spring; Gnaphosidae (ground spiders) was present spring to autumn, generally restricted to the drier woodland vegetation communities such as the sand dune; Nicodamidae (red and black spiders) occurred during the warmer seasons spreading across the site during autumn.

Autumn was the most variable season for spider activity across all vegetation groups and winter the least variable season.

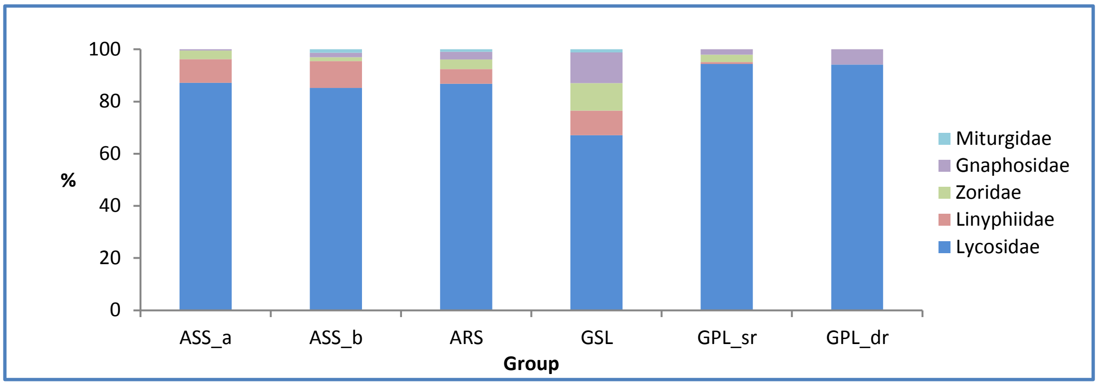


Figure 4.34: Top five dominant spider families by vegetation group – spring.

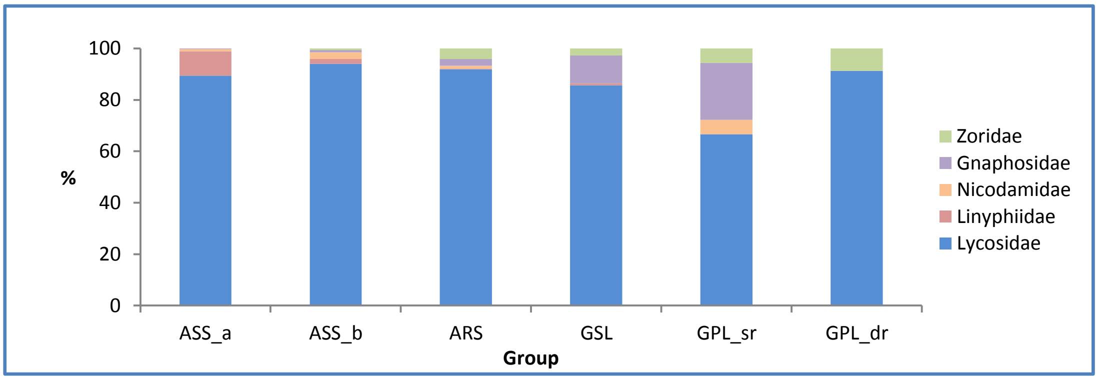


Figure 4.35: Top five dominant spider families by vegetation group – summer.

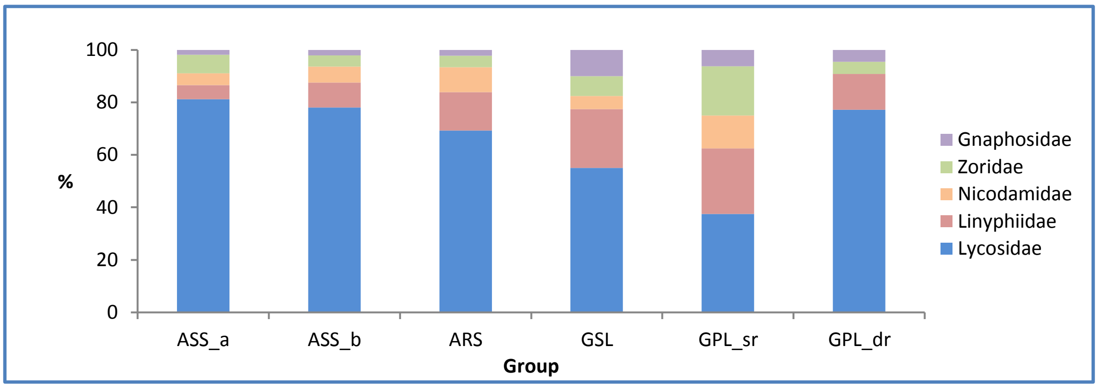


Figure 4.36: Top five dominant spider families by vegetation group – autumn.

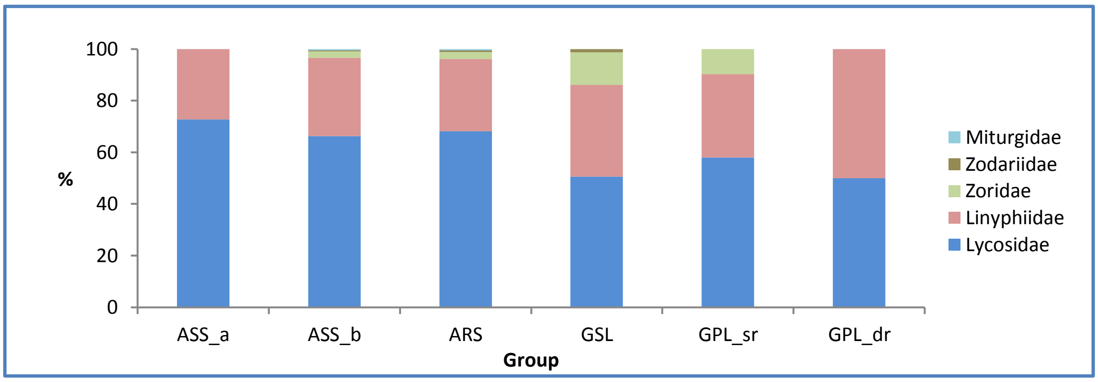


Figure 4.37: Top five dominant spider families by vegetation group – winter.

The results of spider indicator species analysis for each vegetation group are presented in Table 4.15 along with vegetation indicator species of each vegetation group.

Table 4.15: Vegetation groups and significant vegetation species (indicator species) of p-value < 0.05 with significant spider taxa (indicator species) of p-value < 0.05 over 12 months of invertebrate collection at Long Point.

Vegetation group/ Dominant vegetation taxa	stat	p-value		Dominant spider taxa	stat	p-value	
ASS(a)							
Sarcocornia quinqueflora	0.944	0.001	***	*Venatrix* (s)	0.984	0.002	**
Disphyma crassifolium	0.822	0.008	**	Zodariidae	0.838	0.044	*
				Zoridae	0.814	0.016	*
ASS(b)							
Bare ground	0.961	0.001	***	*Venatrix* (s)	0.984	0.002	**
Sarcocornia quinqueflora	0.944	0.001	***				
Tecticornia arbuscula	0.904	0.001	***				
Disphyma crassifolium	0.822	0.008	**				
ARS (saline grassland)							
Bare ground	0.961	0.001	***	*Venatrix* (s)	0.984	0.002	**
Poa labillardierei	0.939	0.001	***	Gnaphosidae (A)	0.894	0.003	**
Juncus spp.	0.869	0.001	***	Zodariidae	0.838	0.044	*
Gahnia spp.	0.854	0.001	***	Zoridae	0.814	0.016	*
Disphyma crassifolium	0.822	0.005	**				
Austrostipa spp.	0.807	0.005	**				
GSL (sand dune)							
Ehrharta stipoides	1.000	0.001	***	*Venatrix* (s)	0.984	0.002	**
Bare ground	0.961	0.001	***	Gnaphosidae (A)	0.894	0.003	**
Oxalis perennans	0.894	0.001	***	Salticidae	0.857	0.006	**
Lomandra longifolia	0.877	0.003	**	Zodariidae	0.838	0.044	*
Austrostipa spp.	0.807	0.005	**	Zoridae	0.814	0.016	*
Leontodon taraxacoides	0.764	0.026	*				
Poa rodwayi	0.707	0.014	*				
GPL (sr)							
Hibbertia prostrata	1.000	0.002	**	Gnaphosidae (A)	0.894	0.003	**
Bare ground	0.961	0.001	***	Salticidae	0.857	0.006	**
Poa labillardierei	0.939	0.001	***	Zodariidae	0.838	0.044	*
Ficinia nodosa	0.935	0.001	***	Zoridae	0.814	0.016	*
Oxalis perennans	0.894	0.001	***				
Lomandra longifolia	0.877	0.003	**				
Pteridium esculentum	0.835	0.019	*				
Isolepis nodosa	0.800	0.021	*				

Vegetation group/ Dominant vegetation taxa	stat	p-value		Dominant spider taxa	stat	p-value	
GPL (dr)							
Aira caryophyllea	1.000	0.002	**	Salticidae	0.857	0.006	**
Austrodanthonia setacea	1.000	0.002	**	Theridiidae	0.845	0.009	**
Bare ground	0.961	0.001	***	Zodariidae	0.838	0.044	*
Poa labillardierei	0.939	0.001	***	Zoridae	0.814	0.016	*
Zoysia macrantha	0.910	0.004	**				
Oxalis perennans	0.894	0.001	***				
Juncus spp.	0.869	0.001	***				
Lomandra longifolia	0.877	0.003	**				
Austrostipa spp.	0.807	0.005	**				
Baumea juncea	0.801	0.019	*				
Poa rodwayi	0.707	0.014	*				

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. P values based on 999 permutations.
(s) = striped; (A) = genus A

The most significant ($p < 0.05$) spider group across the site was the genus *Venatrix* evident in the saline zones and the woodland area of the sand dune (Table 4.15). The Gnaphosidae (A) taxon inhabited the dry saline grasslands and the sand dune and ridge woodlands with the Salticidae restricted to the dry woodland areas. Two families – Zodariidae and Zoridae were generalists being significant in all vegetation communities except for ASS(b).

The spider taxa nMDS plot fitted with the edaphic factors is presented in Figure 4.38.

Edaphic factors were strongly aligned in a negative direction on axis 1 with a small divergence of the pH variables from the other factors (Figure 4.38). The direction of the arrows indicated decreasing conditions, for example, increasing moisture, decreasing pH. In this case axis 1 can be regarded as an edaphic factor gradient.

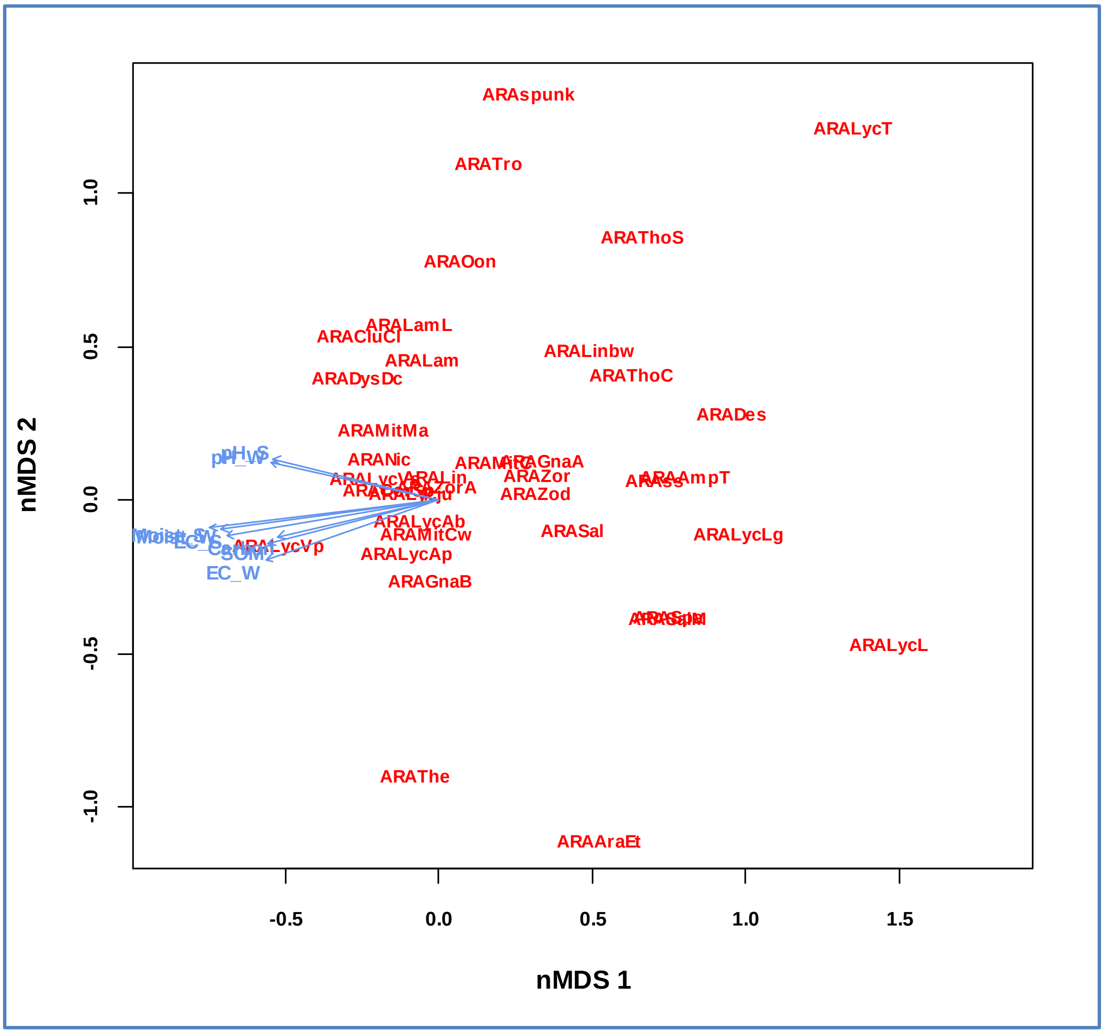


Figure 4.38: Edaphic (vector) factors (shown in light blue) fitted to non-metric multidimensional scaling plot of spider taxa data (shown in red) transformed by log(x+1). Spider codes are deciphered in Appendix J.

The grouping of the spider taxa near the centroid of the ordination indicated that many preferred neutral soil conditions. However, some taxa have particular preferences such as *Trochosa* preferred dry, low saline conditions, whereas the spotted *Venatrix* was content in wetter, more saline conditions.

The vector values of the fitted edaphic factors (displayed in Figure 4.38) are tabled in Table 4.16.

Table 4.16: Vector values of fitted edaphic factors to nMDS plot of spider taxa data transformed using log(x+1). The table is sorted by Pr(>), then nMDS1.

Variables	nMDS 1	nMDS 2	r^2	Pr(>r)	
Moisture summer	-0.99281	-0.11973	0.6389	0.001	***
Moisture winter	-0.99157	-0.12958	0.5790	0.001	***
EC summer	-0.98619	-0.16561	0.5543	0.001	***
EC winter	-0.94488	-0.32741	0.4019	0.001	***
SOM	-0.96976	-0.24407	0.3725	0.001	***
pH winter	-0.97559	0.21961	0.3546	0.001	***
pH summer	-0.96939	0.24551	0.3483	0.001	***
Carbon	-0.97561	-0.21953	0.3252	0.001	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. P values based on 999 permutations.

The very low vector values of nMDS for each of the edaphic factors confirmed the effectiveness of Axis 1 in the nMDS plot (Figure 4.38), reinforcing the notion of this axis being regarded as the edaphic factor gradient. The more neutral values of axis 2 demonstrated the little importance this axis has on the edaphic factors. Two factors, summer and winter moisture, had the highest r^2 value indicating that they were the dominant soil factors that influenced the spider community.

The spider taxa nMDS plot fitted with the vegetation taxa is presented in Figure 4.39.

Vegetation taxa were less uniformly aligned then the edaphic factors. In this case (Figure 4.39) many vegetation taxa were aligned with axis 1, for example *Sarcocornia quinqueflora* and *Oxalis perennans* were respectively strongly negatively and positively aligned with this axis. Several taxa, such as, *Dichelachne crinita* and *Austrodanthonia setacea* were negatively aligned with axis 2.

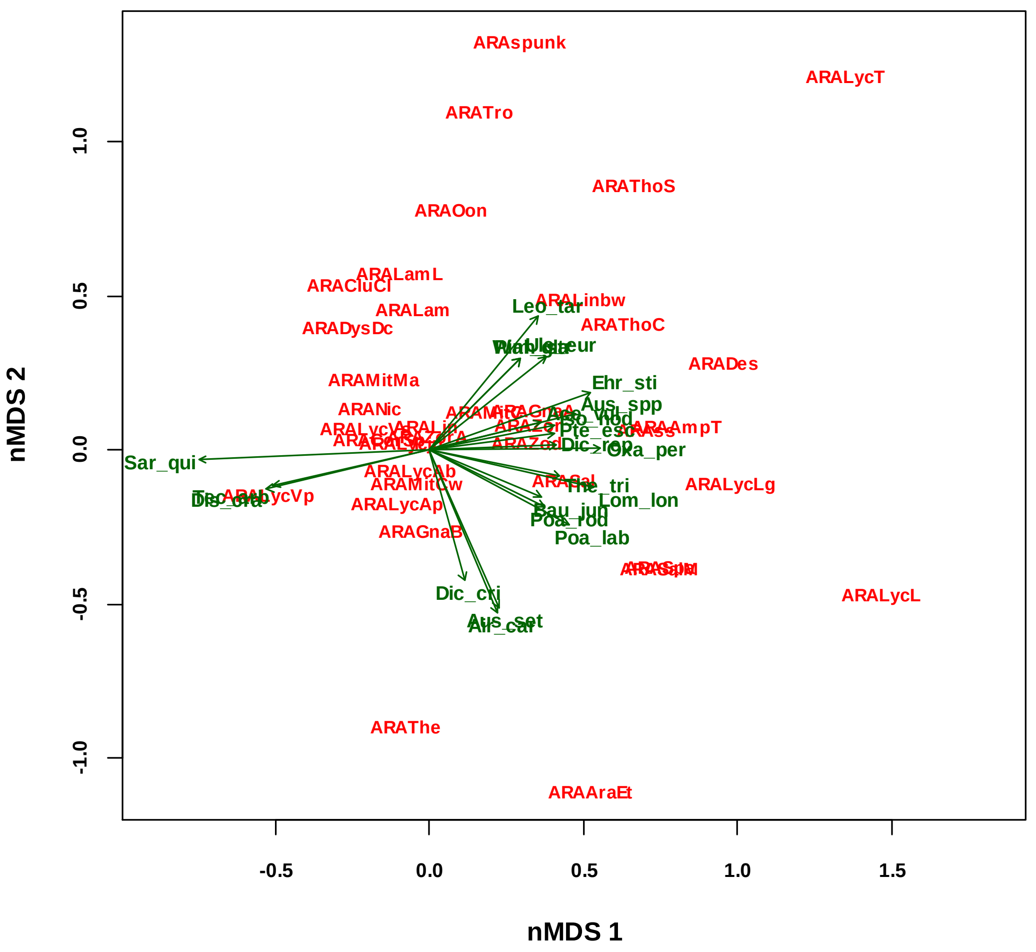


Figure 4.39: Vegetation (vector) taxa (shown in green) with maximum p-value < 0.05 fitted to non-metric multidimensional scaling plot of spider taxa data (shown in red) transformed by log(x+1). Spider codes are deciphered in Appendix J.

The grouping of the spider taxa near the centroid indicated that many preferred a range of vegetation taxa. However, some spider taxa have particular preferences, for example, the spotted *Venatrix* was found in *Sarcocornia quinqueflora/Tecticornia arbuscula/Disphyma crassifolium* vegetation communities – ASS(a)/ASS(b), whereas the black and white Linyphiidae was found associated with *Leontodon taraxacoides, Pimelea glauca* and *Wahlenbergia stricta* vegetation communities (ARS and GSL).

The vector values of the fitted vegetation taxa (displayed in Figure 4.39) are tabled in Table 4.17.

Table 4.17: Vector values of fitted vegetation taxa of p-value < 0.05 to nMDS plot of spider data transformed by log(x+1). The table is sorted by Pr(>r), then nMDS1.

Vegetation taxa	nMDS 1	nMDS 2	r^2	Pr(>r)	
Sarcocornia quinqueflora	-0.99920	-0.03993	0.5420	0.001	***
Aira caryophyllea	0.38519	-0.92284	0.3162	0.001	***
Leontodon taraxacoides	0.62925	0.77721	0.3040	0.001	***
Oxalis perennans	0.99992	0.01301	0.3028	0.001	***
Austrodanthonia setacea	0.40443	-0.91457	0.3027	0.001	***
Lomandra longifolia	0.97486	-0.22283	0.2907	0.001	***
Tecticornia arbuscula	-0.97564	-0.21937	0.2629	0.001	***
Ehrharta stipoides	0.94184	0.33605	0.3016	0.002	**
Disphyma crassifolium	-0.97273	-0.23195	0.2856	0.002	**
Poa labillardierei	0.88402	-0.46744	0.2556	0.003	**
Ulex europaeus	0.77984	0.62597	0.2298	0.004	**
Autrostipa spp.	0.97022	0.24221	0.2352	0.006	**
Themeda triandra	0.98107	-0.19365	0.1817	0.014	*
Isolepis nodosa	0.98072	0.19544	0.1676	0.017	*
Pteridium esculentum	0.99170	0.12856	0.1651	0.019	*
Dichelachne crinita	0.26286	-0.96483	0.1851	0.020	*
Poa rodwayii	0.89839	-0.43920	0.1676	0.021	*
Ehrharta stipoides	0.99910	0.04241	0.1657	0.023	*
Baumea juncea	0.92570	- 0.37825	0.1502	0.024	*
Pimelea glauca	0.70366	0.71053	0.1722	0.038	*
Wahlenbergia stricta	0.70366	0.71053	0.1722	0.038	*
Acetosella vulgaris	0.96927	0.24600	0.1373	0.040	*

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. P values based on 999 permutations.

The impact of both axis 1 and axis 2 was equal in the nMDS plot (Table 4.17). Some vegetation taxa, for example *Sarcocornia quinqueflora*, were strongly negatively aligned to axis 1, with *Aira caryophyllea* strongly negatively aligned to axis 2. *Leontodon taraxacoides* was an example of a species that was positively aligned midway between axis 1 and axis 2.

The vegetation species with the greatest r^2 value was *Sarcocornia quinqueflora* indicating that this taxon was the dominant vegetation species followed by *Aira caryophyllea*.

4.4.2 Beetles

Five dominant beetle families by abundance in each vegetation group by season are presented in Figures 4.40 to 4.43.

Interesting and clear patterns of beetles were evident throughout the site (Figures 4.40 to 4.43). Analogous to spiders, three beetle families were ubiquitous in all seasons: Carabidae (ground beetles), Staphylinidae (rove beetles) and Curculionidae (weevils). Carabidae were the dominant taxa in the saltmarsh vegetation communities with decreasing abundance towards dryer, less saline conditions; numbers were highest in winter/spring and lowest in autumn. Staphylinidae presence was mixed throughout the year – autumn, winter and spring saw this family evident in the wet and dryer vegetation communities, yet in summer Staphylinidae appeared increasingly in the wetter communities. The Curculionidae family was restricted to dryer and less saline conditions in winter and spring, however it became a generalist during summer and autumn favouring most conditions. Two beetle families were active over three seasons, Scarabaeidae (scarab beetles) spring to autumn, and Elateridae (click beetles) winter to summer. Scarabaeidae dominated the dry vegetation communities during spring and summer and were evident across all vegetation communities except for ASS(a) during autumn. Elateridae preferred the dry sand dune during winter, however became a generalist during spring and summer. Two other families, Byrrhidae (pill beetles) and Cantharidae (soldier beetles), made a brief appearance in the top five dominant species, autumn and winter respectively. Byrrhidae was evident on the sand dune (GSL) and the saline grasslands (ARS), while Cantharidae was dominant on the dolerite ridge (GPL (dr)) with a lower appearance in ARS and ASS(b).

Summer and autumn were the most variable seasons for beetle activity across all vegetation groups, followed by winter, with spring being the least variable.

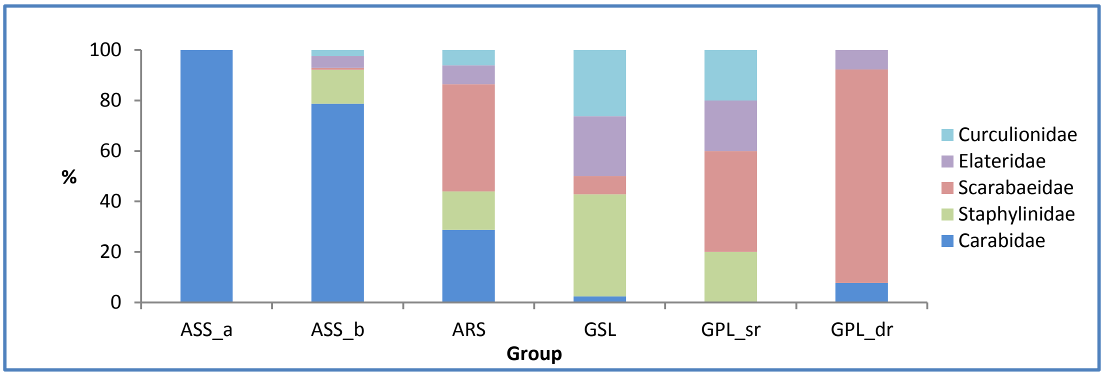


Figure 4.40: Top five dominant beetle families by vegetation group – spring.

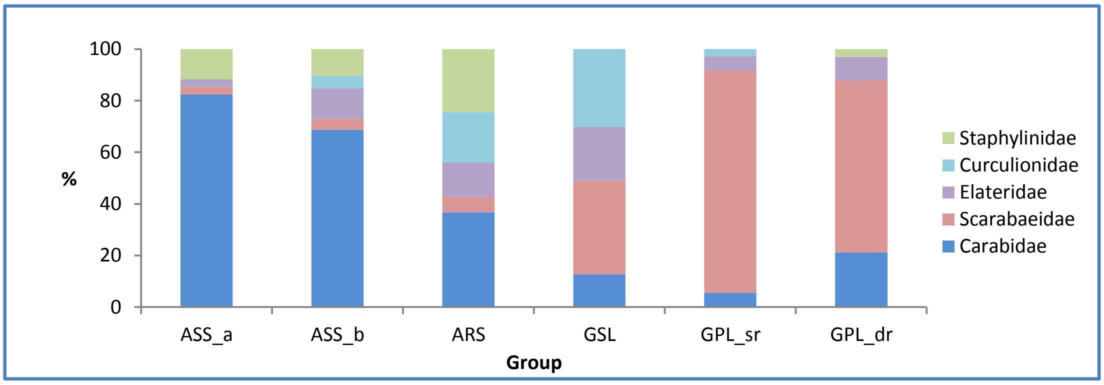


Figure 4.41: Top five dominant beetle families by vegetation group – summer.

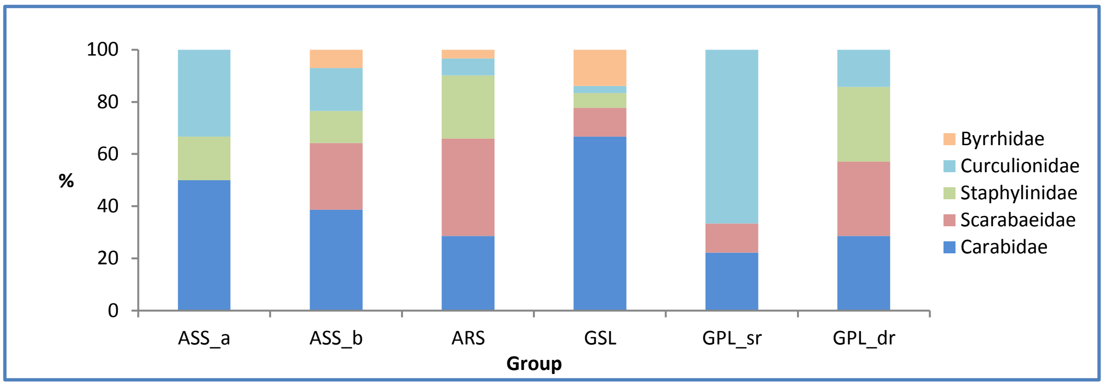


Figure 4.42: Top five dominant beetle families by vegetation group – autumn.

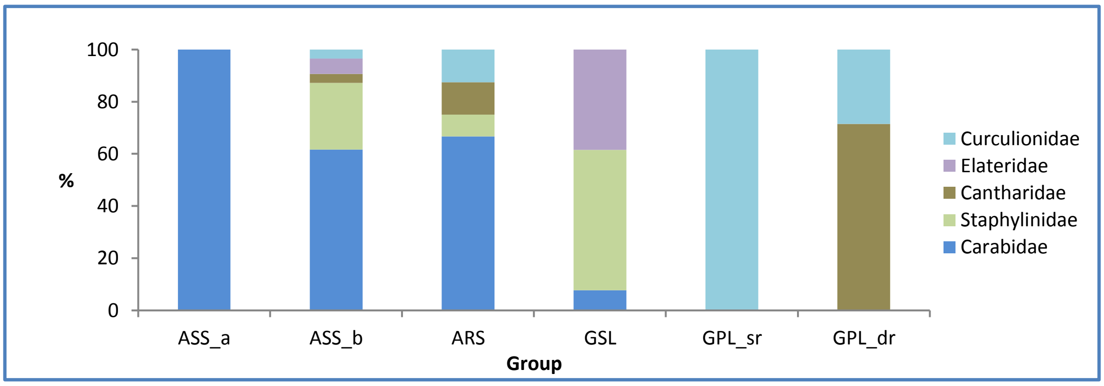


Figure 4.43: Top five dominant beetle families by vegetation group – winter.

The results of beetle indicator species analysis for each vegetation group are presented in Table 4.18 along with the indicator vegetation species of each group.

Table 4.18: Vegetation groups and significant vegetation species (indicator species) of p-value < 0.05 aligned with significant beetle taxa (indicator species) of p-value < 0.05 over 12 months of invertebrate collection at Long Point.

Vegetation group/ Dominant vegetation taxa	stat	p-value		Dominant beetle taxa	stat	p-value	
ASS(a)							
Sarcocornia quinqueflora	0.944	0.001	***	*Bembidion*	0.949	0.001	***
Disphyma crassifolium	0.822	0.008	**				
ASS(b)							
Bare ground	0.961	0.001	***	*Bembidion*	0.949	0.001	***
Sarcocornia quinqueflora	0.944	0.001	***				
Tecticornia arbuscula	0.904	0.001	***				
Disphyma crassifolium	0.822	0.008	**				
ARS (saline grassland)							
Bare ground	0.961	0.001	***				
Poa labillardierei	0.939	0.001	***				
Juncus spp.	0.869	0.001	***				
Gahnia spp.	0.854	0.001	***				
Disphyma crassifolium	0.822	0.005	**				
Austrostipa spp.	0.807	0.005	**				
GSL (sand dune)							
Ehrharta stipoides	1.000	0.001	***	*Lepispilus sulcipennis*	0.876	0.009	*
Bare ground	0.961	0.001	***	*Mandalotus*	0.874	0.010	**
Oxalis perennans	0.894	0.001	***	*Saragus*	0.866	0.014	*
Lomandra longifolia	0.877	0.003	**	*Acrossidius tasmaniae*	0.844	0.019	*
Austrostipa spp.	0.807	0.005	**	*Conoderus* (large)	0.830	0.014	**
Leontodon taraxacoides	0.764	0.026	*	*Microchaetes*	0.777	0.022	*
Poa rodwayi	0.707	0.014	*	*Simodontus*	0.775	0.025	*
GPL (sr)							
Hibbertia prostrata	1.000	0.002	**	*Onthophagus posticus*	0.951	0.001	***
Bare ground	0.961	0.001	***	Coccinellidae	0.894	0.008	**
Poa labillardierei	0.939	0.001	***	*Saragus*	0.866	0.014	*
Ficinia nodosa	0.935	0.001	***	*Acrossidius tasmaniae*	0.844	0.019	*
Oxalis perennans	0.894	0.001	***	*Conoderus* (large)	0.830	0.014	*
Lomandra longifolia	0.877	0.003	**	*Simodontus*	0.775	0.025	*
Pteridium esculentum	0.835	0.019	*				
Isolepis nodosa	0.800	0.021	*				

Vegetation group/ Dominant vegetation taxa	stat	p-value		Dominant beetle taxa	stat	p-value	
GPL (dr)							
Aira caryophyllea	1.000	0.002	**	*Metriorrhynchus* (larva)	1.000	0.002	**
Austrodanthonia setacea	1.000	0.002	**	*Onthophagus posticus*	0.951	0.001	***
Bare ground	0.961	0.001	***	*Onthophagus australis*	0.950	0.002	**
Poa labillardierei	0.939	0.001	***	*Conoderus* (large)	0.830	0.014	*
Zoysia macrantha	0.910	0.004	**	*Simodontus*	0.775	0.022	*
Oxalis perennans	0.894	0.001	***	*Microchaetes*	0.777	0.025	*
Juncus spp.	0.869	0.001	***				
Lomandra longifolia	0.877	0.003	**				
Austrostipa spp.	0.807	0.005	**				
Baumea juncea	0.801	0.019	*				
Poa rodwayi	0.707	0.014	*				

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1. P values based on 999 permutations.

No beetle group was significant ($p < 0.05$) across the whole site (Table 4.18). The genus *Bembidion* was restricted to the saline conditions of ASS(a) and ASS(b). The genera *Conoderus* and *Simodontus* were significant in the dryer woodland areas of the sand dune, and the sand and dolerite ridges. There were some interesting anomalies: the genus *Saragus* and species *Acrossidius tasmaniae* were significant in the sandy woodlands of GSL and GPL (sr), however, not significant on the dolerite ridge; in a similar manner, the small dung beetle, *Onthophagus posticus,* was significant on the sand ridge and the dolerite ridge, but not on the sand dune.

The beetle taxa nMDS plot fitted with the edaphic factors is presented in Figure 4.44.

Edaphic factors were strongly aligned in a negative direction with a small divergence of the pH from the other factors (Figure 4.44). The direction of the arrows indicated decreasing conditions, for example increasing moisture. Again, similar to spiders, axis 1 can be interpreted as the edaphic factor gradient.

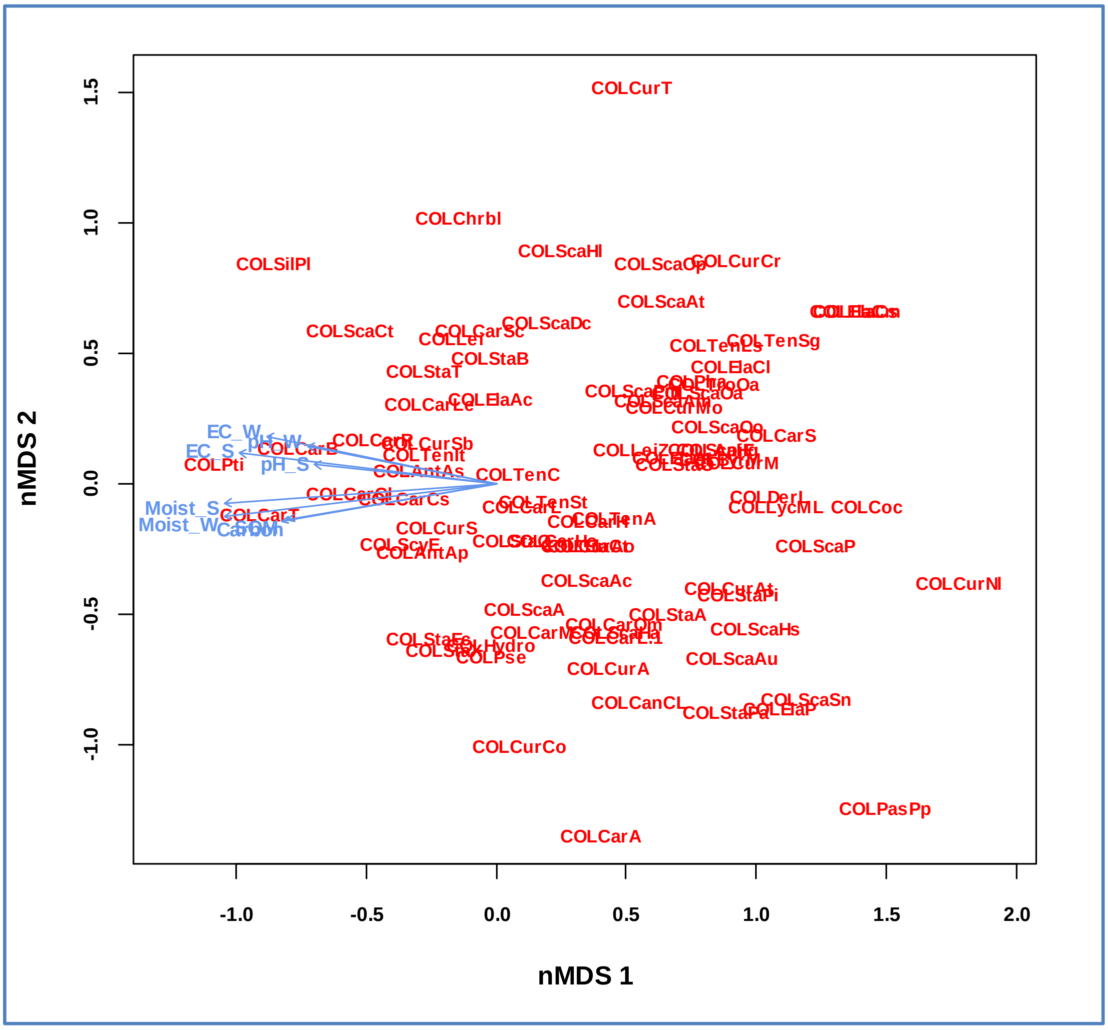


Figure 4.44: Edaphic (vector) factors (shown in light blue) fitted to non-metric multidimensional scaling plot of beetles data (shown in red) transformed by log(x+1). Beetle codes are deciphered in Appendix J.

The grouping of the majority of beetle taxa on the positive (right) side of axis 1 suggests that beetles favour improving soil conditions, for example, decreasing moisture, lower salinity and more alkaline soils. The genus *Phyllotocus* and species *Naupactus leucoloma* are two examples. Yet, some taxa did favour less favourable soil conditions, for example increasing acidity, higher moisture and salinity. The genera *Bembidion* and *Clivina* (large) are two examples.

The vector values of the fitted edaphic factors (displayed in Figure 4.44) are tabled in Table 4.19.

Table 4.19: Vector values of fitted edaphic factors to nMDS plot of beetles data transformed using log(x+1). The table is sorted by Pr(>r), then nMDS1.

Variable	nMDS 1	nMDS 2	r^2	Pr(>r)	
Moisture summer	-0.999820	-0.018938	0.7567	0.001	***
Moisture winter	-0.994410	0.105609	0.7564	0.001	***
EC summer	-0.988000	-0.154485	0.7004	0.001	***
EC winter	-0.979140	-0.203181	0.5831	0.001	***
SOM	-0.999950	-0.010474	0.4741	0.001	***
Carbon	-0.999480	0.032240	0.4452	0.001	***
pH winter	-0.964490	0.264125	0.3959	0.001	***
pH summer	-0.982660	0.185402	0.3478	0.001	***

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. P values based on 999 permutations.

The very low vector values of nMDS for each of the edaphic factors confirmed the effectiveness of axis 1 in the nMDS plot as the edaphic factor gradient (Figure 4.44). The more neutral values of axis 2 demonstrated the little emphasis this axis has on the edaphic factors.

Two factors, summer and winter moisture, had the highest r^2 value indicating that they were the dominant edaphic factors followed by summer and winter EC respectively. Summer and winter pH had the lowest r^2 values suggesting the least dominant factors.

The beetle taxa nMDS plot fitted with the vegetation taxa is presented in Figure 4.45.

Vegetation taxa were a lot less aligned than the edaphic factors. In this case (Figure 4.45), some vegetation taxa were aligned with axis 1, for example *Sarcocornia quinqueflora* and *Ulex europaeus* were respectively strongly negatively and positively aligned. The tall sedge, *Gahnia* spp., was strongly negatively aligned with axis 2. The majority of vegetation taxa was neutral, either positive/positive or positive/negative aligned with axis 1 and 2 respectively.

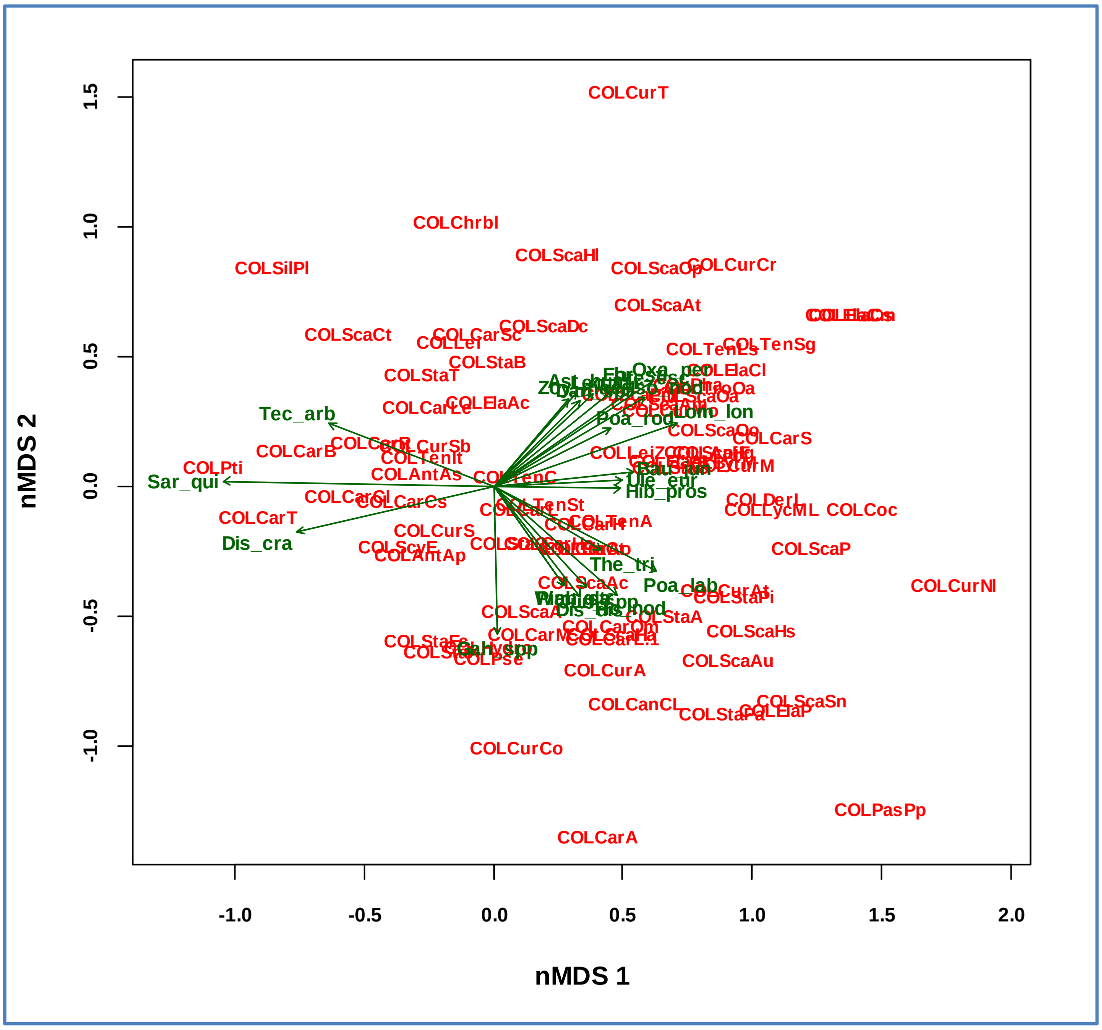


Figure 4.45: Vegetation (vector) taxa (shown in green) with maximum p-value < 0.05 fitted to non-metric multidimensional scaling plot of beetles data (shown in red) transformed by log(x+1). Beetle codes are deciphered in Appendix J.

The grouping of the majority of beetle taxa on the positive (right) side of axis 1 suggests that beetles favour dry-land vegetation communities containing *Oxalis perennans* and *Isolepis nodosa*, with the scarabs, *Automolius* and *Antitrogus tasmanicus,* being two examples. Yet, some taxa, such as *Bembidion* and *Anthicus* (striped) did favour more saline plants such as *Tecticornia arbuscula*.

The vector values of the fitted vegetation taxa (displayed in Figure 4.45) are tabled in Table 4.20.

Table 4.20: Vector values of fitted vegetation taxa of p-value < 0.05 to nMDS plot of beetles data transformed by log(x+1). The table is sorted by Pr(>r), then nMDS1.

Vegetation	nMDS 1	nMDS 2	r^2	Pr(>r)	
Sarcocornia quinqueflora	-0.99980	0.01992	0.7056	0.001	***
Lomandra longifolia	0.94519	0.32651	0.3652	0.001	***
Oxalis perennans	0.83199	0.55480	0.3523	0.001	***
Poa labillardierei	0.88698	-0.46181	0.3284	0.001	***
Isolepis nodosa	0.86359	0.50420	0.2994	0.001	***
Tecticornia arbuscula	-0.93445	0.35609	0.2987	0.001	***
Ficinia nodosa	0.75158	-0.65964	0.2607	0.001	***
Disphyma crassifolium	-0.97452	-0.22430	0.3932	0.002	**
Pteridium esculentum	0.82181	0.56977	0.2824	0.002	**
Ehrharta stipoides	0.77905	0.62696	0.2548	0.002	**
Distichlis distichophylla	0.62142	-0.78348	0.1911	0.006	**
Gahnia spp.	0.02889	-0.99958	0.2128	0.007	**
Baumea juncea	0.99447	0.10506	0.1914	0.008	**
Leontodon taraxacoides	0.73407	0.67907	0.1789	0.012	*
Hibbertia prostrata	0.99988	-0.01565	0.1560	0.012	*
Ulex europaeus	0.99902	0.04436	0.1618	0.014	*
Themeda triandra	0.86062	-0.50925	0.1518	0.016	*
Juncus spp.	0.67853	-0.73457	0.1814	0.017	*
Poa rodwayi	0.89634	0.44338	0.1641	0.019	*
Astroloma humifusum	0.66572	0.74620	0.1544	0.023	*
Pimelea glauca	0.58444	-0.81144	0.1424	0.024	*
Wahlenbergia stricta	0.58444	-0.81144	0.1424	0.024	*
Danthonia spicata	0.71466	0.69947	0.1428	0.027	*
Zoysia macrantha	0.65431	0.75623	0.1296	0.050	*

Significance codes: 0 '***' 0.001 '**' 0.01 '*'0.05 '.' 0.1 ' ' 1. P values based on 999 permutations.

The impact of both axes was somewhat uniform in the nMDS plot (Table 4.24). A large group of vegetation taxa were equally aligned to both axes such as *Poa labillardierei* and *Astroloma humifusum*. Similar to spiders and vegetation, *Sarcocornia quinqueflora* was strongly negatively aligned with axis 1. Taxa aligned positively to axis 1 included *Hibbertia prostrata, Ulex europaeus* and *Baumea juncea.* The succulent glasswort*, Sarcocornia quinqueflora* recorded the greatest r^2 value, followed by *Disphyma crassifolium* and *Lomandra longifolia*.

4.4.3 Spiders and beetles

A representative sample of seven spider taxa and seven beetle taxa was used to demonstrate the distribution of each taxon across each transect in a linear format based on the elevation profile (Figures 4.46 to 4.48). The figures highlight occurrence in vegetation communities across each transect gradient during the course of the year and are based on presence only (not abundance). The presence of two or more taxa in the same vegetation group does not necessarily indicate that those taxa co-exist as some taxa are not present in all seasons.

Examples of spiders and beetles and a description of their habitats are presented in Figures 4.49 to 4.54 (spiders) and Figures 4.55 to 4.60 (beetles).

Of the spider taxa, the genera, *Venatrix* (striped) and *Artoria* (plain), were the most widely distributed across all vegetation communities followed by the family Gnaphosidae and genus *Nicodamus*, both avoiding the wetter, more saline communities. The families Zoridae, Zodariidae and Salticidae preferred the dryer, saline grasses and woodland areas.

The beetle genera *Bembidon* and *Anthicus* (plain) were the most widely distributed across all gradients, though they appeared to mostly shun the saline grasses and woodland areas. The rove beetle, *Bledius,* was generally evident in most vegetation communities, but avoided the *Sarcocornia* spp. – the ASS(a) group. Conversely, the weevil, *Mandalotus,* was restricted to woodland areas – GSL, GPL (sr) and GPL (dr), with some limited presence in saline grasses but did not venture into the moist, saline communities.

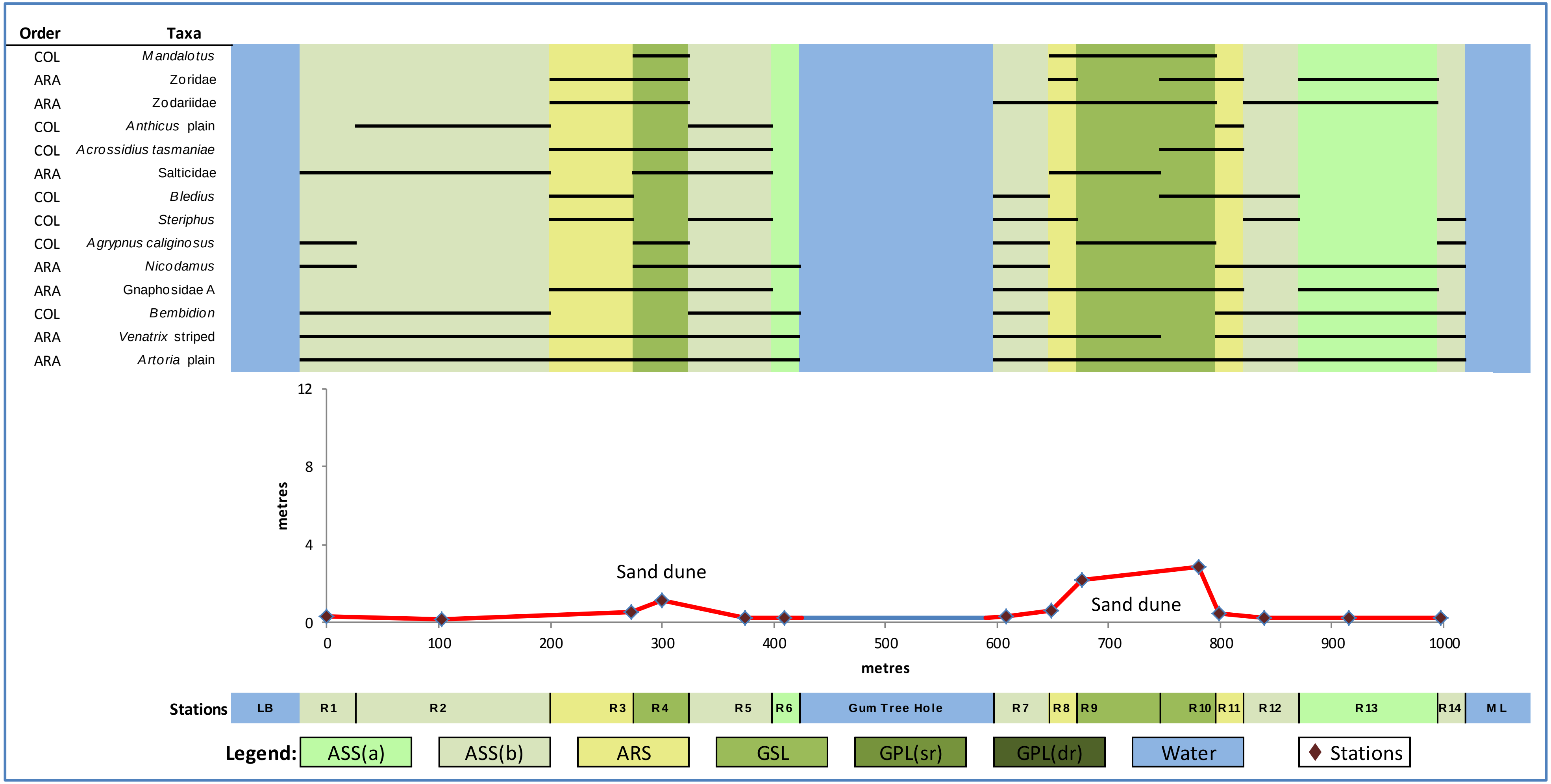


Figure 4.46: RED transect – representative taxa along transect over 12 months, stations aligned to vegetation groups. COL = Coleoptera, ARA = Araneae, LB = Little Bay, ML = Moulting Lagoon. Vertical exaggeration = 16.5.

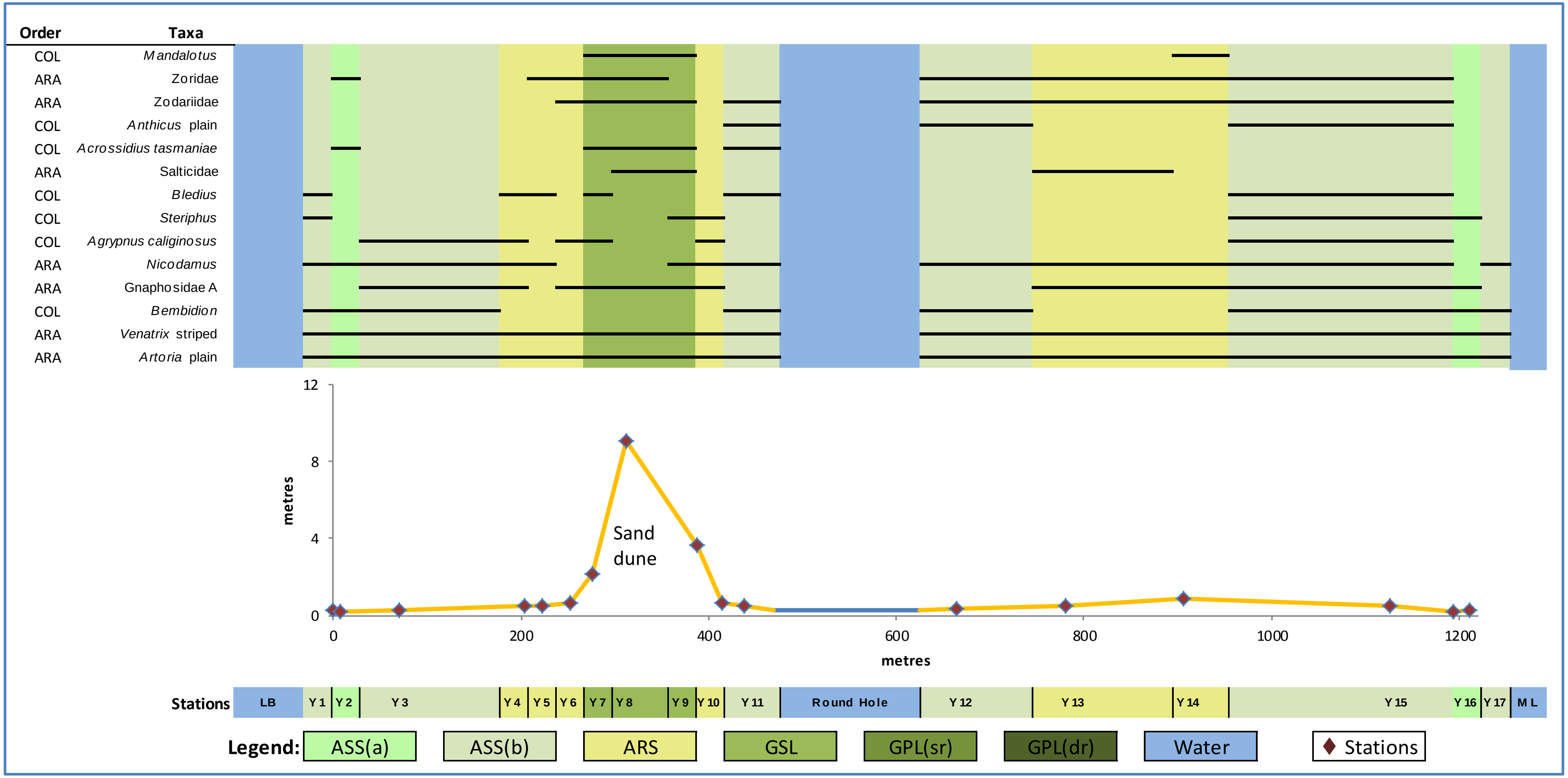


Figure 4.47: YELLOW transect – representative taxa along transect over 12 months, stations aligned to vegetation groups. COL = Coleoptera, ARA = Araneae, LB = Little Bay, ML = Moulting Lagoon. Vertical exaggeration = 16.5.

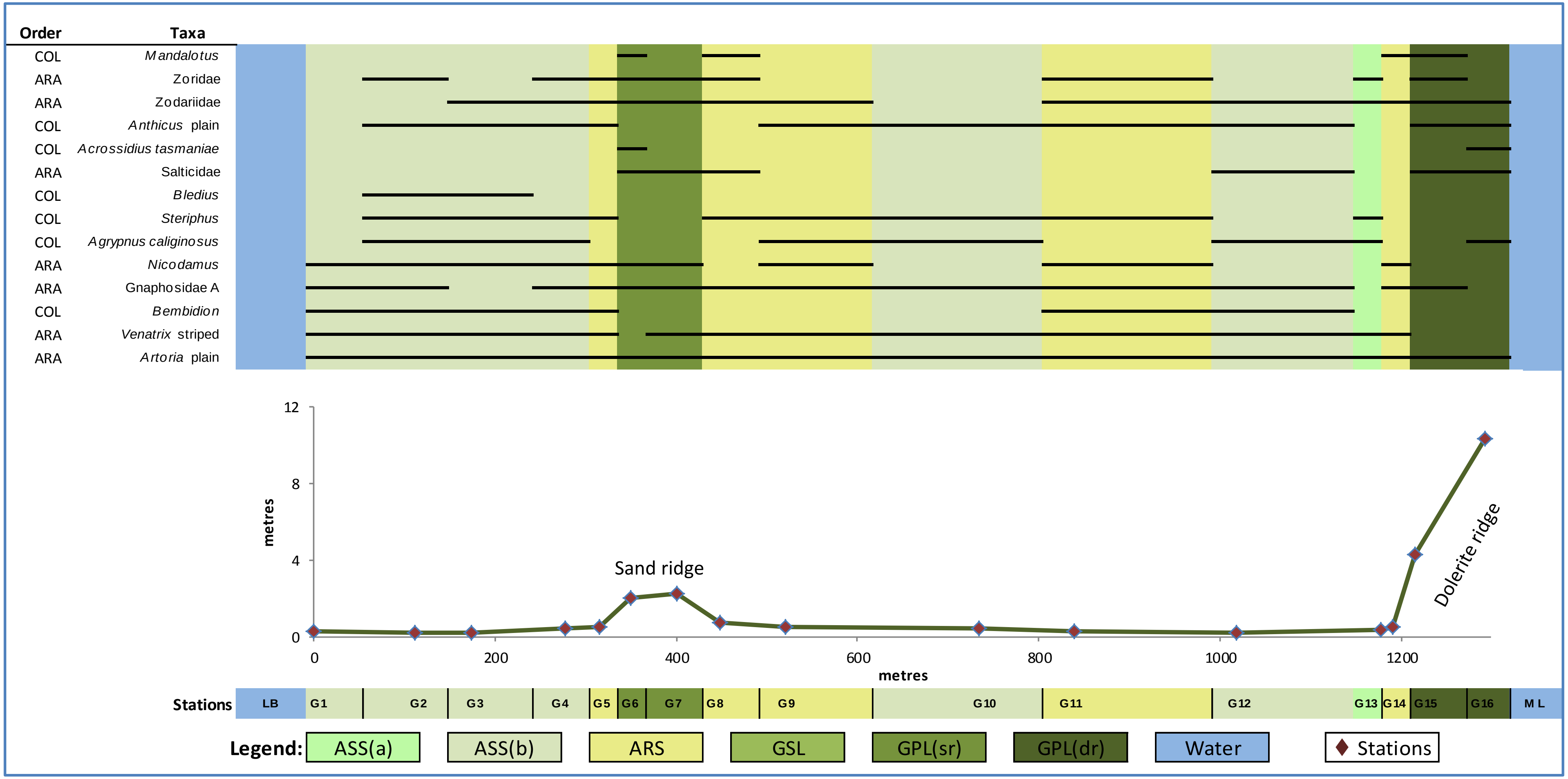


Figure 4.48: GREEN transect – representative taxa along transect over 12 months, stations aligned to vegetation groups. COL = Coleoptera, ARA = Araneae, LB = Little Bay, ML = Moulting Lagoon. Vertical exaggeration = 16.5.

Figure 4.49: Family: Miturgidae, species: *Miturga agelenina,* length: 20mm, habitat: dry saline grassland and woodland – ARS and GPL (G Anderson at http://www.arachne.org.au/ 01_cms/ details.asp?ID=2570).

Figure 4.50: Family: Lycosidae, Genus: *Atoria* (banded), length: 10mm, habitat: generalist – saltmarsh to woodland – ASS(a and b), ARS, GSL and GPL (J Douglas at http://www.tasmanianspiders. info/ A074.htm).

Figure 4.51: Family: Nicodamidae, Genus: *Nicodamus*, length: 8mm, habitat: generalist – saltmarsh to woodland – ASS(a and b), ARS, GSL and GPL (R Whyte at http://www. arachne.org.au/ 01_cms/details.asp?ID=2528).

Figure 4.52: Family Lycosidae, Genus: *Venatrix,* length: 10mm, habitat: generalist – saltmarsh to woodland – ASS(a and b), ARS, GSL and GPL (R Whyte at http://www.arachne.org.au/01_cms/ details.asp?ID=1163).

Figure 4.53: Family: Linyphiidae, length: 2mm, habitat: generalist – saltmarsh to woodland – ASS(a and b), ARS, GSL and GPL. Note: very small, difficult to ID (J Douglas at http://www.tasmanianspiders.info/276.htm).

Figure 4.54: Family: Thomisidae, Genus: *Cymbacha*, length: 6mm, habitat: woodland – GSL (R Whyte at http://ednieuw. home.xs4all.nl/australian/thomisidae/crabspiders.html).

Figure 4.55: Family: Tenebrionidae, Genus: *Saragus*, length: 15mm, habitat: woodland – GSL and GPL (T Daley at https://sites.google.com/site/insectsoftasmaniacoleoptera/suborder-polyphaga/tenebrionidae-darkling-beetles).

Figure 4.56: Family: Staphylinidae, Genus: *Bledius*, length: 15mm, habitat: saltmarsh to saline grasslands – ASS(b) and ARS (T Daley at https://sites.google.com/site/insectsoftasmaniacoleoptera/suborder-polyphaga/ staphylinidae-rove-beetles/genus-bledius).

Figure 4.57: Family: Scarabaeidae, Genus: *Onthophagus*, length: 8mm, habitat: woodland – GSL and GPL (T Daley at https://sites.google.com/site/insectsoftasmaniacoleoptera/suborder-polyphaga/scarabaeidae-scarab-beetles/genus-onthophagus).

Figure 4.58: Family: Carabidae, Genus: *Bembidion,* length: 7mm, habitat: saltmarsh with some intrusion into saline grasslands – ASS(a and b) and ARS (D Maddison at http://bembidion.org*).*

Figure 4.59: Family: Elateridae, Genus: *Agrypnus*, length: 12mm, habitat: generalist, though more evident in saltmarsh – ASS(a and b), ARS and GSL (from: http://commons.wikimedia.org/wiki/File:Agrypnus.murinus. 1.jpg).

Figure 4.60: Family: Scarabaeidae, Genus: *Aphodius*, length: 8mm, habitat: saline grassland and woodland – ARS, GSL and GPL (P Skelly at http://museum.unl.edu/research/entomology/Guide/Scarabaeoidea/Scarabaeidae/Aphodiinae/AphodiinaeTribes/ Aphodiini/Aphodius/Aphodius.html).

Chapter 5: Discussion

Long Point presents a rich ensemble of saltmarsh plant community groups near sea-level which interface with adjoining more elevated communities featuring coastal grassland and woodland. These in turn support diverse communities of ground dwelling insects and arachnids not previously documented in Tasmania.

This discussion addresses the vegetation communities, landscape features and spider and beetle assemblages in turn, before attempting to summarise their integrative aspects.

5.1 Vegetation communities

Three discrete vegetation communities were apparent in both saltmarsh and adjacent woodland zones at Long Point. Each community was closely identified with a particular vegetation structure and can be readily recognised in the field based on a specific indicator species or some combination of them.

Saltmarsh zonation was very marked at the study site, both in terms of species incidence by group, and in the visual demarcation of each group. Woodland zonation however, was less conspicuous with the intermixing of several species between groups often apparent, yet it was discernible on analysis, as principal species in each group were obvious.

5.1.1 Saltmarsh zone

Saltmarshes are characterised by dominant vegetation species and communities that are adapted to the harsh saltmarsh environment (Kirkpatrick & Glasby 1981; Bridgewater & Cresswell 2003; Saintilan 2009b). The spatial distribution of plants within the saltmarsh is not random; it is organised into distinctive communities arranged in a sequence or zonation (Long & Mason 1983; Adam 1990; 2002; Silvestri *et al.* 2005). Many authors, for example, Kirkpatrick and Glasby (1981), Bridgewater and Cresswell (1999), Bridgewater and Cresswell (2003), and Saintilan (2009), have described the succession of dominants, from saline succulents in the low-marsh zone through to saline graminoids including grasses, rushes and sedges, in the upper zone. Similarly, species diversity increases from just a few taxa at the low marsh end to higher numbers in the upper marsh (Adam 1990; Saintilan 2009).

Bridgewater and Cresswell (2003) formulated five saltmarsh phytogeographic groups, further divisible into 12 subgroups, based on the Australian Virtual Herbarium (AVH) and the Interim Biogeographical Regionalisation of Australia (IBRA). The southern Australian coastline including Tasmania was placed in group I – *Sclerostegia* (now *Tecticornia*) *arbuscula* – *Juncus kraussii* group. This group is further subdivided into four sub-groups, in which sub-group I.2: *Stipa* (now *Austrostipa*) *stipoides* – *Agrostis billardieri* (now *Lachnagrostis billardierei*) (Baker & de Salas 2013) defines eastern Tasmania and south-eastern Australia. This group has no further subdivisions. Adam (1990) on the other hand, describes three vegetation categories based on dominant growth form: a) herb communities; b) graminoids; and c) dwarf shrubs. Kirkpatrick and Glasby (1981) used a slightly different approach in classifying Tasmanian saltmarsh vegetation, based on the life-form of the dominant species that had the highest cover in the tallest layer. This led to four defined communities: a) succulent herbs; b) grasses; c) sedges and rushes; and d) herbs. These were further subdivided in terms of height and cover of the dominant species into a total of 15 sub-communities (Kirkpatrick & Glasby 1981). However, dominants could comprise a number of species, in particular various *Gahnia*, *Juncus* and *Austrostipa* spp. making such a variable combination difficult to assign a particular classification.

At Long Point, the saltmarsh zone is organised into three groups based on vegetation structure and composition and its position in the landscape. This broadly reflects the findings of Richardson *et al.* (1997; 1998) who recognised three broad vegetation groups within Tasmanian saltmarsh zones. The groundcover succulents (the low marsh) were typified by *Sarcocornia quinqueflora* and *S. blackiana* (and others), the saltbush group (mid marsh) described by *Arthrocnemum* (*Tecticornia*) *arbuscula*, and the grass-sedgelands (upper marsh) by *Austrostipa*, *Juncus* and *Gahnia* spp. and others. An earlier study of three separate saltmarshes in the Derwent region of southeast Tasmania by Marsh (1982) identified a similar arrangement of zones with a corresponding vegetation community structure.

Saltmarsh vegetation classification is sensitive to scale with a broad brush approach of Bridgewater and Cresswell (2003) grouping Tasmania's east coast with south-eastern Australia, whereas Kirkpatrick and Glasby (1981) have developed classifications at a much finer scale. In general terms, the classification of *Sarcocornia* and *Tecticornia* into separate zones, as has been promoted in this thesis, would probably not be appropriate. Both plants are succulents, were mostly found together and could easily fall into the succulent herbs category of Kirkpatrick and Glasby (1981). However, it was important to divide this category into two as there was marked distinction between these genera in terms of height, well defined mappable boundaries and position in the landscape. This allowed each genus to be allocated low and middle marsh respectively. The two vegetation types may also represent definitive invertebrate habitats, a key focus of this study. Visually distinguishing the zone containing grasses, sedges and rushes was more difficult, yet the clustering analysis clearly classified this as a single group – designated here as upper marsh.

Evidence from Long Point demonstrated that classification grouping can be either floristic or non-floristic based. Floristic classification is relatively straightforward if only one or two species is dominant in the community. However, when a community displays multiple dominant species or where no dominant species is apparent, classification reverts to non-floristic terms (Adam 1990). In saltmarshes species diversity increases with elevation (Adam 1990), therefore floristic classification is often used for low to middle marsh zones, whereas the upper marsh zone accommodates a greater number of species and is often classified using a non-floristic term.

The low marsh is dominated at times by a single species, *Sarcocornia quinqueflora*, or by a combination of *S. quinqueflora*, *S. blackiana* and *Disphyma crassifolium* and therefore became the *Sarcocornia* zone. Similarly, the middle marsh, dominated by *Tecticornia arbuscula* often with low marsh species as groundcover, was referred to as the *Tecticornia* zone. However, due to the difficulty in defining grasses, sedges and rushes into individual groups, and in order to retain the grouping suggested by the clustering method, the upper marsh was referred to as saline grasslands. In a similar fashion, Richardson and Mulcahy (1996), in their study of talitrid amphipods (Crustacea) at Lutregala Marsh on Bruny Island, classified their saltmarsh study sites based on the dominant plant species that made up each vegetation community.

Coastal saltmarshes occur worldwide and although local features are often exhibited, most have similarities that are immediately recognised (Adam 2002; 2009). The appearance and the make-up of Australian saltmarsh vegetation communities are broadly comparable to saltmarshes elsewhere (Chapman 1974; Adam 2009). As a result Chapman (1974) proposed a global saltmarsh classification based on floristic and vegetation criteria. He delineated nine biogeographical saltmarsh groupings with Australia and New Zealand united as the Australasian group. In both appearance and vegetation, there is a relationship, at least to genus level, between Australian saltmarshes, particularly those in SE Australia (including Tasmania) and those in the Northern Hemisphere (Adam 1990). For example, *Juncus kraussii* appears to be ecologically equivalent to *Juncus maritimus* in Europe. Various salt tolerant genera of Cyperaceae, Restionaceae, Poaceae and Chenopodiaceae are shared between Europe, North and South America, and South Africa. *Isolepis*, *Leptocarpus*, *Distichlis*, *Sarcocornia* and *Suaeda* are widespread in those regions (Long & Mason 1983; Vince & Snow 1984; Adam 1990; Álvarez-Rogel *et al.* 2000; Adam 2009; Lovell & Davis 2012). These extensive genera occupy similar saltmarsh zones as in Australia, for example *Distichlis*, occupies the upper zone (saline grasslands), while *Sarcocornia* is typical of the lower/middle zones.

5.1.2 Woodland zone

At Long Point, native woodland abuts the saltmarsh zones and provided a valuable opportunity to study the distribution of a full range of ground dwelling invertebrates, particularly cursorial spiders and ground beetles, in relation to woodland vegetation. The local topography determined that the woodland zone was made up of three different vegetation types, as recognised by the clustering analysis. Apart for a limited number of studies, for example Richardson and Mulcahy (1996) and Clarke and Hannon (1967), consideration of the saltmarsh to woodland zone continuum has not been common.

There were several shared plant species between the three woodland groups such as *Oxalis perennans* and *Lomandra longifolia*. Common species were identified between two of the three groups such as *Poa rodwayi* and in two cases, the saline grassland genus, *Austrostipa* was found in the woodland zone. However, each group could be identified by the significant occurrence of indicative species: *Ehrharta stipoides* on the sand dune, *Hibbertia prostrata* on the sand ridge and A*ira caryophyllea* and *Austrodanthonia setacea* on the dolerite ridge. A notable indicative species was *Pteridium esculentum* which delineated the sand ridge from the sand dune as the bracken zone.

5.2 Landscape features

As hill shade and solar radiation were uniform across the saltmarsh zone, the main area of study, these factors will not be further discussed. Although elevation shows minor variation in the saltmarsh zone, it does play an important role in the saltmarsh environment through its interaction with tidal flows, and therefore demands further discussion.

5.2.1 Saltmarsh zone

Typically, the saltmarsh zone will gently rise from the seaward fringe and tidal flats to its landward limit or the terrestrial zone (Long & Mason 1983). This elevational gradient determines the temporal pattern of inundation by tidal flooding (Sánchez *et al.* 1996) that results in decreasing tidal influence as elevation increases (Long & Mason 1983). This pattern was apparent in elevation data at Long Point. The elevation range of the three saltmarsh groups was 0.306m. It ranged from 0.256m in ASS(a), through to 0.300m in ASS(b) and 0.562m in ARS. These mirror a study in northwest Spain where Sánchez *et al.* (1996) found the levels separating the low marsh from the mid marsh to the high marsh were 0.260m, 0.350m to 0.400m respectively. In both cases, elevation was based on mean sea level. It is important in any ecological study of elevational aspects in saltmarshes, deliberation be given to the more meaningful use of relative tide height as opposed to actual altitude. Communities that are found at high tide mark at varying locations for example will have more similarity than those that are one or two metres above mean sea level irrespective of the tidal range at a particular site (Long & Mason 1983). This is due to the influence of the frequency and duration of inundation on intertidal communities (Adam 1990).

The lower marsh, which can be inundated once to twice per day, is able to be flooded up to 700 times per year. Yet, the upper marsh, which may only be inundated once per month, will only be impacted by marine waters 12 times per year (Long & Mason 1983). However, Bockelmann *et al.* (2002) found that elevation (shore height) only had a weak correlation with inundation frequency, which may reflect the influence of local winds and the dynamics of the site such as the drainage system (Bockelmann *et al.* 2002). Furthermore, storm tide events and onshore/offshore winds can impact the inundation area irrespective of the elevation of the zones at normal inundation times (Long & Mason 1983). The speed of tidal retreat is also controlled by elevation which in turn determines zonation. Creek systems for example, permit the rapid retreat of flooding waters once the tide begins to fall, allowing adjacent areas to be clear of inundation faster than those areas further away, even if there is no change in elevation (Bockelmann *et al.* 2002).

5.2.2 Saltmarsh zone – elevation and vegetation

The zonation discussed above is linked to tidal inundation which is determined by elevation (Sánchez *et al.* 1996; Huckle *et al.* 2000). Plant distribution is therefore not a direct reflection of altitude within the saltmarsh, rather it is more a consequence of inundation controlled by elevation (Long & Mason 1983). Some plant species are limited to precise elevational classes. However many appear in two zones and some appear in all three (Sánchez *et al.* 1996). In an Alaskan saltmarsh, Vince and Snow (1984) found that vegetation communities changed markedly with increasing elevation. In several cases this occurred over an elevation difference of less than eight centimetres with some individual species ranging over a number of zones (Vince & Snow 1984). Inundation frequency therefore has a greater explanatory value for forecasting the occurrence of dominant species than will altitude (Davis & Gray 1966; Bockelmann *et al.* 2002). Minor changes in elevation, particularly closer to sea level, leads to greater variations in inundation, which in turn results in greater variation in vegetation. Some plant species can still be found over a wide range of inundation frequencies (Bockelmann *et al.* 2002).

At Long Point, *Disphyma crassifolium* was significant in all three saltmarsh groups ($p < 0.05$). Similarly, *Sarcocornia quinqueflora* was highly significant in groups ASS(a) and ASS(b) ($p < 0.001$), but was also evident in ARS as a groundcover species, though in reduced extent. Similarly, *Austrostipa* spp. was found on the sand dune (GSL) and dolerite ridge (GPL dr) as well as the saline grasslands (ARS) ($p < 0.015$). During the study period, the saline grasslands at Long Point were only inundated once in conjunction with an equinoctial tide and very high recent rainfall. There is no simple explanation as to why some species occupy two or more zones, except that some individual plant species may be more adaptable to, or tolerant of, a wide range of saltmarsh conditions.

5.2.3 Woodland zone

Contrary to the saltmarsh groups, the elevation within woodland communities varied as a result of the undulating landscape. Mean elevations ranged from 2.18m for the sand ridge (GPL sr), 3.51m for the sand dune (GSL) to 7.33m on the dolerite ridge (GPL dr). As the mean of the lowest group was over 2m it was well out of the reach of even the highest tide and therefore not subjected to inundation. However, regardless of elevation, the woodland zone is subject to varying inputs of aerosolic salt from onshore winds which can affect the make-up of coastal vegetation communities (Adam 1990).

5.2.4 Woodland zone – elevation and vegetation

The altitudinal range of the woodland zone at Long Point was small (1.15m to 10.32m) therefore the coastal vegetation species diversity of the site was not expected to be high. Irrespective of elevation and woodland grouping, some species were found in all three woodland groups, for example *Lomandra longifolia*, ($p < 0.005$) with *Poa rodwayii* ($p < 0.011$), was found on the sand dune (GSL) and dolerite ridge (GPL dr). However, there were species identified to particular groups such as

Ehrharta stipoides ($p < 0.001$) which were restricted to the sand dune, *Hibbertia prostrata* ($p < 0.003$) to the sand ridge and *Aira caryophyllea* ($p < 0.011$) found on the dolerite ridge. There were other species that were identified to a particular group such as *Pteridium esculentum* on the sand ridge, which became the distinguishing species at this location as it was absent from the dolerite ridge and was minimal on the sand dune. Therefore, other factors including biotic, local habitat and competition were possibly more crucial to the presence of species than elevation alone (Bockelmann *et al.* 2002).

5.3 Edaphic factors

Soil data were aligned with the vegetation grouping previously established (see above). Five factors were analysed by group, with three of the factors – moisture, pH and EC, assessed for summer and winter. In every case there was a significant difference between groups. This was generally the case between the saltmarsh and woodland groups, but differences also existed between the saltmarsh groups. The only variable that was significantly different between the woodland groups was pH. Further analysis of the data showed that predictor factors were winter moisture and SOM with winter moisture being the better of the two in indicating other factors. As a predictor factor, SOM is more difficult to measure as it requires laboratory testing with highly accurate weighing equipment and a 550^{o}C muffle furnace. Winter moisture can be measured in the field with an inexpensive handheld meter.

Edaphic factors generally show gradients from the low marsh to the high marsh that correspond with elevation and tidal impacts (Pennings & Callaway 1992). Throughout the study site interesting patterns of positive and negative correlations in the soils were evident. Moisture and EC (summer and winter) along with SOM and carbon, all showed a distinctive negative correlation to elevation. The pH (summer and winter) though less distinctive, was still negatively correlated to elevation. Among soil texture variables, sand was positively correlated to elevation as all elevated areas at Long Point were composed of sand, yet silt and clay were negatively correlated to elevation.

5.3.1 Saltmarsh zone

There are difficulties in comparing data from this study with others of a similar nature. Edaphic factors have correlations in the same study site and when a factor is taken out of context it is problematic trying to relate this to the same factor from another study site. For example soil sand/silt/clay components vary between saltmarshes and within saltmarshes, resulting in variations to moisture retention, organic matter and possibly pH. However, it is expected that overall findings between studies would have a degree of similarity.

The following section will discuss each factor independently, in combination, and then in combination with vegetation and elevation.

<u>Moisture</u>:

Tidal inundation and retreat on the saltmarsh zone results in the cyclical increase and decrease of the water table (Long & Mason 1983). The tidal retreat is slow, due in part to the flat topography, and also to the low hydraulic conductivity of saltmarsh soils (Clarke & Hannon 1967; 1969). The soil is waterlogged, oxygen is limited and the soil becomes anaerobic (Long & Mason 1983; Adam 1990).

Moisture content varies considerably over the saltmarsh. Areas that are prone to frequent inundation have high levels of moisture, whereas areas of reduced inundation frequency record lower levels of moisture content (Long & Mason 1983). This pattern was replicated at Long Point. The coastal stations and those adjacent to the ephemeral ponds recorded levels of moisture exceeding 61% in summer and 72% in winter, with group ASS(a) recording means of 68% and 85% respectively. Decreasing moisture content was strongly evident progressing through the middle marsh to the upper marsh with means of 55% and 22% respectively for summer and 60% and 37% for winter. Similarly, Richardson and Mulcahy (1996) on Bruny Island, reported high levels of moisture throughout the saltmarsh zone with levels decreasing on approach to the woodland zone. Analysis of the data from a study by Gouldthorpe (2000) on the effects of drainage and grazing on Derwent Estuary saltmarshes revealed that a site very high in *Sarcocornia quinqueflora* cover – equivalent to the ASS(a) group in this study – had a moisture content of 40%. Furthermore, two sites very high in *Tecticornia arbuscula* cover – equivalent to ASS(b) – had a mean moisture content of 51% (Gouldthorpe 2000). The frequency of inundation and distance to a waterbody of Gouldthorpe's (2000) Derwent marsh sites is unclear. Nevertheless, his results do demonstrate high moisture content in saltmarsh soils. On the other hand the conclusions of Marsh (1982) were contrary to this and other Tasmanian studies, in that she reported the low and high marsh both had a very low moisture content (~ 3%), whereas the mid marsh had 15%. These seem unusually low.

<u>EC (salinity)</u>:

Decreasing tidal inundation as a result of increasing elevation of the saltmarsh zone most often results in a decrease in soil salinity (Adam 1990; Silvestri *et al.* 2005). Low marsh salinity levels are generally constant throughout the year as tidal inundation recharges the water table and the soils (Adam 1990). However, the middle and upper marsh zones are subject to temporal variations in salt levels due to evapotranspiration, which can lead to increased salinity sometimes exceeding that of seawater, and also decreasing salinity following heavy rainfall (Long & Mason 1983; Adam 1990; Álvarez-Rogel *et al.* 1997). This demonstrates that salinity has neither a positive or negative relationship, but a combination of effects with elevation (Adam 1990).

As salinity and EC have a close relationship (Hazelton & Murphy 2007), EC was used as a proxy for salinity in this study.

At Long Point, there was a clear decreasing EC gradient across the saltmarsh zone. Soil EC decreased from summer to winter. EC for the ASS(a and b) groups were similar ($p < 0.05$), however the ARS group was significantly lower for both summer and winter. The three groups each recorded lower winter EC readings compared to that of summer following heavy rainfall in July 2013. Work by Richardson and Mulcahy (1996) supported the results from Long Point. Although they only reported sodium (Na) levels, there is a clear decline in levels progressively from the seaward side towards the woodland zone. A study by Adams (1963) of North

Carolina saltmarshes somewhat supported the finding of decreasing EC values in this study, though not conclusively. Aligning the vegetation species in North Carolina to saltmarsh zones does indicate a declining EC value of approximately 40dS/m at the low marsh to approximately 27dS/m at the high marsh (Adams 1963). This is supported by this study where the low marsh recorded a mean of 36dS/m falling to a mean of 5dS/m in the upper marsh. In Gouldthorpe's (2000) study, the ASS(a) equivalent site recorded 35dS/m and the mean of the ASS(b) equivalent sites was 57dS/m, again not a conclusive comparison. A similar study by Clarke and Hannon (1967), also documented decreasing salinity across the saltmarsh, where EC (m-mhos used in report, 1 m-mhos = 1 dS/m) values decreased from the *Arthrocnemum* zone to the *Juncus* zone from ~ 35dS/m to ~11dS/m (Clarke & Hannon 1969).

Following further investigation into the relationship between EC and salinity, subsequent studies have shown that this relationship is not always satisfied (Álvarez-Rogel *et al.* 1997). The relationship is not completely linear especially in soils with a high content of soluble salts (Simón *et al.* 1994), typical of saltmarsh soils. To better evaluate saltmarsh soil salinity, further research and work needs to be conducted to understand salinity levels and the relationship to EC, if EC is to be used as a measure of salinity.

Furthermore, some studies report that salinity increases with elevation with increased salinities being recorded in the high marsh zone (Long & Mason 1983; Adam 1990; Pennings & Callaway 1992). This is contrary to results from Long Point where salinity (in this case EC) was found to decline with increasing elevation. Additional study on a number of sites is required to clarify this point.

<u>pH</u>:

Work by Wherry (1920) in the New Jersey saltmarshes showed a relationship between plant distribution and soil chemistry. Further study by Clarke and Hannon (1967) of saltmarshes and mangroves near Sydney determined that soils increased in acidity towards the woodland zone.

Clear patterns were difficult to determine in pH values at Long Point. The means for ASS(a) and ARS were more closely aligned for both summer and winter with values of pH 5.1 each in summer, increasing slightly to pH 5.4 and 5.3 respectively during winter. In the ASS(b) group, the means for both summer and winter were lower (summer) and higher (winter) than the other saltmarsh groups, pH 4.3 and 6.1 respectively. This didn't fit expectations, however there was a significant change ($p < 0.05$) from the saline grasslands to the adjacent woodland zone.

It is difficult to compare data from this study to that of Clarke and Hannon (1967). Their saltmarsh zones were identified as *Arthrocnemum* (now *Tecticornia*) which could equate to ASS(b) in this study, and *Juncus* which may relate to ARS. Furthermore, there is no indication as to which season or time of year the soil samples were collected. Still, it was important to compare results as there appears to be a lack of saltmarsh soil pH data especially in Australia. The *Arthrocnemum* zone pH ranged from 5.4 to 7.5 compared to the ASS(b) zone (in this study) which ranged from 4.3 to 6.7 in summer and 4.8 to 7.5 in winter. The *Juncus* zone (Sydney) range was 5.2 to 7.0, compared to the ARS zone (in this study) range of 4.6 to 5.5 in summer and 4.6 to 6.0 in winter. It is possible that Clarke and Hannon (1967) samples were collected over more than one season as they comment: "there does not appear to be any marked change associated with season…" (Clarke & Hannon 1967, p. 766). Similarly, the results from the Derwent Estuary study were far from comparable. The ASS(a) equivalent site recorded 9.5, and the mean of the ASS(b) equivalent sites was 8.9 (Gouldthorpe 2000). In this case, a colour test kit was used as absolute soil pH was not required (Gouldthorpe 2000).

<u>SOM and carbon</u>:

The primary contribution of organic matter in a saltmarsh is from *in situ* plant material (Adam 1990), with much originating from roots and rhizomes (Long & Mason 1983). Recorded levels of organic matter in saltmarshes are variable (Long & Mason 1983; Adam 1990), with studies reporting levels of 8% in the lower marsh, 13% in the mid marsh to 25% in the upper marsh (Long & Mason 1983). Adam (1990) doesn't report values in different saltmarsh zones, however he comments that levels of up to 50% have been recorded in some North American marshes.

There was a defined pattern of SOM at Long Point. The highest levels were recorded in ASS(a) – 37.7% ± 3.5, followed by decreasing levels in ASS(b) – 23.1% ± 3.7, to ARS – 14.9% ± 2.2. The transition from saltmarsh to the woodland zone showed a dramatic fall in SOM to 4.7% ± 1.0 (see below). These results are in contrast to the study by Clarke and Hannon (1967) in which the *Arthrocnemum* zone was 8.5% ± 3.7 and the *Juncus* zone recorded 20.9% ± 17.5, yet Clarke and Hannon values are comparable to those reported by Long and Mason (1983). A study at Westernport Bay (Victoria, Australia) on a site of *Sclerostegia* (now *Tecticornia*) *arbuscula* and *Sarcocornia quinqueflora*, similar to ASS(a and b) in this study, estimated 50-60% soil organic matter (Van Der Valk & Attiwill 1983). This value is higher than recorded at Long Point, however it does support the notion that the low/middle marsh has a high level of organic matter, which is possibly dependant on the vegetation make-up of the individual zones.

The relationship of organic matter levels to elevation is uncertain. Long and Mason (1983) and Adam (1990) both state that organic matter levels often increase with elevation. This assertion is supported by Clarke and Hannon (1967) and by Richardson and Mulcahy (1996). However, this study reports a contrary view, a well-defined decrease in organic matter levels with increasing elevation, even into the woodland zone. Organic content in three saltmarshes of the Derwent region also do not support the view that organic matter increases with increasing elevation, the low and upper marsh recorded 5.5% and the middle marsh 16.5% (Marsh 1982) and corresponds with the moisture values from the same study. In her study, Marsh only reported a combined mean for the three sites, so there was a difficulty in matching her results with other studies. In the case of Gouldthorpe's (2000) study, the ASS(a) equivalent site was 26.5% in organic matter, with the ASS(b) equivalent sites mean being 38.8%. This too correlated positively with moisture (Gouldthorpe 2000). All studies used a similar method in determining SOM by LOI and showed that there was a positive correlation between moisture and organic matter. Further study is required to support this view and perhaps should be undertaken at a number of diverse sites rather than at one site.

Texture:

The physical make-up of saltmarsh soils is largely a manifestation of sediment type, riverine or marine, or a combination of both (Adam 1990). Estuarine saltmarshes source the majority of their sediment from the adjacent land resulting in marked variations of inputs of sand, silt and clay (Long & Mason 1983). During and following periods of heavy rain and flooding, sediment discharges can be high and often contain higher levels of sand than during quieter times. Marshes that are adjacent to sand dunes can also have higher levels of sand due to aeolian affects (Adam 1990). The mineral composition of saltmarsh soils varies considerably. Studies in NW Europe have shown variations of sand content from 5% in East England to 75% in East Ireland (Long & Mason 1983).

Clarke and Hannon (1967) found that the sand component ranged from 78.5% in the *Arthrocnemum* zone to 69.4% in the *Juncus* zone decreasing landward. However, data from Long Point showed the contrary – 32% in ASS(a) to 67% in ARS. Reversal of that found at Woolooware Bay may not have any meaning at all as large variations of the sand component can be apparent (see above). Additionally, the saltmarsh flats at Long Point are intersected by a large sand dune which may have contributed to an increase in the sand component in the upper marsh due to strong winds prior to the dune being vegetated. Furthermore, as outlined in the methods in soil analysis, the sand component was impacted by the high level of organic matter and the factor applied to adjust this abnormality may not be entirely correct. Additional study into effective methods to determine texture of saltmarsh soils high in organic matter are warranted, and should not be restricted to samples from a single study site.

5.3.2 Saltmarsh zone – edaphic factors, elevation and vegetation

Growth and survival of saltmarsh vegetation species is influenced by various edaphic factors including soil texture and elevation. Zonation in response to elevation has long been appreciated in saltmarshes (Ranwell 1972; Chapman 1974; Sánchez *et al.* 1996). Yet increasingly, recent studies have begun to focus on edaphic factors such as salinity and moisture as key drivers (Snow & Vince 1984; Vince & Snow

1984; Álvarez-Rogel *et al.* 2000; Huckle *et al.* 2000; Silvestri *et al.* 2005). However, elevation is the key component in the saltmarsh environment – it determines areas that are inundated frequently, intermittently and spasmodically. This study has demonstrated that as a response to inundation (which is a response to elevation), moisture and salinity are either constant or high in the low marsh, through to declining moisture and salinity in the middle marsh, to low levels of moisture and salinity in the upper marsh, where very rare incidents of inundation occur (Pennings & Callaway 1992).

Vegetation response to moisture and salinity via a change in elevation has also been demonstrated. The composition of vegetation communities changes with an increase in elevation. The low marsh for example, is a low diversity community made up of one to three succulent species, whilst the middle marsh community is made up of three or more species, often a mix of succulents from the lower marsh with grasses from the upper marsh, and the upper marsh community is made up of a larger number of species principally saline graminoids. However, strict species restriction to certain zones is not evident. Many species can tolerate a range of moisture and salinity and at times some species, for example *Sarcocornia* spp. and *Disphyma crassifolium* have colonised areas in three zones. Many saltmarsh species have broadly overlapping salinity tolerance ranges as is evident from the field (Clarke & Hannon 1970; Kirkpatrick & Glasby 1981; Silvestri *et al.* 2005) and in the laboratory (Snow & Vince 1984). Yet, saltmarsh zonation, particularly at Long Point is well defined, so much so that in many cases species range appears to be pre-determined and there is no encroachment beyond the demarcation line. Perhaps complementary roles of tolerance to physical conditions such as moisture and salinity at one end of the gradient, and between-species competition where more species survive at the other end could be the key (Snow & Vince 1984; Pennings & Callaway 1992). Studies focusing on the biotic and abiotic impacts of saltmarsh species edaphic variability in conjunction with competition would be beneficial in determining the maintenance of saltmarsh vegetation zonation. Any results of this research may assist in determining the possible extent of landward encroachment of saltmarsh vegetation in response to sea-level rise.

5.3.3 Woodland zone

Soil factors in the woodland zone displayed far less disparity between groups compared to that of the saltmarsh zone groups. It was difficult to compare results from this study to any of a similar study where the woodland zone was assessed alongside the saltmarsh zone. Many factors respond to different attributes of the soil composition, for example, soils with high organic matter retain higher levels of moisture. The following edaphic factors are discussed in a similar sequence to that of the saltmarsh zone.

Moisture:

Moisture for both summer and winter were similar between groups ranging from 2.4% to 7.9% and 5.5% to 19.3% respectively. The increase in moisture content for winter was due to rainfall events prior to soil collection and reduced evaporation rates.

Clarke and Hannon (1967) report in their findings at Woolooware Bay, the *Casuarina* woodland zone, which could possibly equate to the woodland zone in this study, recorded moisture content of 13.6% to 37.0%. The explanation for the high reading was that the organic surface soil (LOI of ~ 30%) had a high moisture-holding capacity. Each group in the woodland zone at Long Point had very low organic material, hence the likelihood of low moisture retaining capabilities.

EC (salinity):

EC values in all woodland groups were very low ranging from 0.027 to 0.075dS/m in summer to 0.015 to 0.095dS/m in winter. The influence of tidal inundation was highly apparent in the contrast in soil conductivity between woodland groups, (overall mean 0.04dS/m) compared to the saltmarsh groups (overall mean 22dS/m), 550 times lower.

The *Casuarina* zone referred to by Clarke and Hannon (1969) recorded EC values from 4.2 to 49.6dS/m over a two year period. This was far less than that recorded in the *Arthrocnemum* zone, but similar to the *Juncus* zone (same study). At Long Point, the ARS group, though considered part of the saltmarsh zone, was comparable to the woodland zone, which had conductivity similar to the *Juncus* and *Casuarina* zones of Woolooware Bay.

<u>pH:</u>

The woodland zone soil at Long Point was typically acidic. Values for pH ranged from 3.9 to 4.6 and 4.1 to 4.7, respectively for summer and winter, and there was no difference between vegetation groups ($p < 0.05$). This reflected data from Woolooware Bay, where the *Casuarina* woodland zone recorded pH between 4.1 and 6.9 (Clarke & Hannon 1967). The woodland zone was more acidic than the saltmarsh zone.

<u>SOM and carbon</u>:

The SOM averaged 4.1% across the woodland groups, with no difference between groups ($p < 0.05$). The *Casuarina* woodland zone (Clarke & Hannon 1967) was not comparable, as it recorded a level of 29.7%.

<u>Texture</u>:

The texture analyses of the woodland soils place all the groups in the sandy loam/loamy sand categories. As the study site was a coastal environment, it was expected that the sand dune and the sand ridge would have high levels of sand. The dolerite ridge varied slightly having a higher silt/clay component than the sand dune/ridge, probably due to the weathering and erosion of the dolerite outcrops.

5.3.4 Woodland zone – edaphic factors, elevation and vegetation

Although there were strong edaphic and elevational similarities between the three woodland groups, the make-up of vegetation communities was far from similar, suggesting that it was not just edaphic factors and/or elevation that were responsible for the structure of the present day vegetation communities.

Each group had certain species that were highly significant to that individual group ($p < 0.005$). These species were not evident in the remaining groups at $p < 0.05$, suggesting that each species was the dominant in its respective group. Some species were represented across the three groups, some across two of the groups, some only in one group, at a higher p-value, though still under 0.05.

In the absence of other information, it was not clear what the controlling factor in each group was that determined the presence of particular dominant species, nor the make-up of the vegetation community. Key measured components such as elevation, edaphic factors, precipitation and temperature, all yielded similar results among the three groups. However, a number of other factors might be influential, the principal one being anthropogenic impacts. For a number of decades, Long Point was used as a dry grazing area for sheep (J Cotton 2014, pers. comm., 24 August). With sheep moving on and off the site, plant species that were not originally present may have been introduced from the adjoining lands. Other species that were initially present may have been preferentially grazed by sheep, decimated and not recovered due to competition. Other impacts include the attempted introduction of exotic pasture species and harvesting of Black wattle (*Acacia mearnsii*) (Kingdom 2008), which may have altered subsequent plant succession. Another factor that may have had an impact on vegetation community structure is drought. The mean rainfall at Swansea for the period 1884 to 2008 is 593mm (Bureau of Meteorology 2014a). Since 1979, there have been seven years when annual rainfall has fallen to approximately 50-55% of the average, and 1994 was particularly low at 45% (Bureau of Meteorology 2014a). As noted previously, all *Eucalyptus viminalis* trees that were present on Long Point some years ago have subsequently died.

A useful insight from this study is that soil sampling should be restricted to summer, as one collection will suffice to capture most of the variation present. All important edaphic factors can be determined from this single sample collection. Similarly, vegetation assessment is best conducted during summer.

This study confirms that individual saltmarshes differ subtly in their attributes, despite being similar in vegetation communities, elevation, inundation frequency, edaphic factors or invertebrate assemblages. In particular, data describing edaphic factors are very difficult to associate with other studies, even when similar methods are used. It is important to compare results from other studies to better understand the complexities of each environment. However, it is difficult to come to generalisable conclusions when there is so much disparity between similar environments.

5.4 Spiders and Beetles

Increasingly, study has also focused on a range of benthic saltmarsh invertebrates, worldwide, for example, Cammen (1976), Long and Mason (1983), Odum (1988), Adam (1990), and Australia (Wells 1983; Peterson 1991; Boon 2011) including Tasmania (Marsh 1982; Richardson *et al.* 1991; Wong *et al.* 1993; Richardson & Mulcahy 1996; Richardson *et al.* 1997; 1998). However, with the exception of the saltmarsh mosquito (Laegdsgaard 2006), there has been less study in Australia (Finch *et al.* 2007) of invertebrates in habitats which adjoin saltmarshes such as coastal woodland (Laegdsgaard 2006; Boon 2011). However, few studies, for example Marsh (1982) and Gouldthorpe (2000), have superficially included spiders and beetles as a component to a wider study of benthic invertebrates.

Explaining the patterns of invertebrate incidence in these environments presents many challenges. The apparent absence of any spider or beetle taxon in a particular season should not necessarily be construed as a true absence from the saltmarsh or woodland (McCoy & Rey 1981). There are well understood limitations in the sampling method used. Generally, pitfall trapping over a long period of time is more successful, however there is always a chance of missing species (false absences), particularly rare ones. Some species are not prone to pitfall sampling even though they are epigeal in behaviour. Individual habits such as levels of activity do play a role in species detection, however this can often be overcome with a longer trapping period (Woodcock 2005).

The influence of gradients of elevation, tidal inundation and edaphic factors witnessed in saltmarshes, was not apparent on the zonation of spiders and ground beetles by family as it was on the zonation of saltmarsh vegetation (Long & Mason 1983). Seasonal variations in surface activity do occur, particularly in winter when invertebrates are in the less active larval stage or respond by temporally leaving the site due to a decrease in food resources (Laegdsgaard 2006).

5.4.1 Spiders – seasonal variation

Most spiders did not appear to be confined to a particular vegetation group, or any season, although spider assemblage structures were different between them. Three spider families were dominant throughout Long Point over the year. The most dominant family by both incidence and abundance were wolf spiders (Lycosidae), similar to that of the Derwent estuary saltmarshes (Marsh 1982). Almost exclusively, the genera *Artoria* and *Venatrix* made up this family at Long Point. Wolf spiders are epigaeic, hunting in and on the ground surface and the base of plants and living in burrows in the soil (Hickman 1967; Whyte & Anderson 2014). *Artoria* are fast runners and live amongst plant litter, the larger *Venatrix*, live in open areas adjacent to water (Whyte & Anderson 2014). Lycosidae were present across the gradient, but were found in higher numbers in the saltmarsh zone. The incidence of wolf spiders did decline in autumn, particularly on the sand dune and sand ridge, with a further considerable decline in all groups during winter. This decline may have been in response to the inability of Lycosidae to adapt and survive to a decrease in temperature or the temporal increase of tidal inundation along with increased rainfall events particularly in the saltmarsh zone. As temperatures during late autumn and winter did fall below freezing on a number of occasions across the site, this factor may have been the principal cause in reduction of numbers and in some cases absence of any activity.

The next most dominant family was Linyphiidae, sheet weaver spiders. These are very small spiders (2-4mm long), and therefore difficult to identify to genus level let alone species level. They are not well studied in Australia (Whyte & Anderson 2014), and many species may be European introductions. Again, they were present in all vegetation communities, though their dominance was restricted to autumn and winter. This may have been in response to the natural decline in Lycosidae during the two seasons and also to the fact that Linyphiidae can live and survive within the plant structure using their ability to spin silken sheet webs close to the ground to catch prey (Hickman 1967). This survival technique leaves Linyphiidae less prone to the impact of inundation common during winter. It was unclear if the incidence or abundance of sheet weaver spiders were regulated by temperature. However, it appears that the possible decline response of one taxon (Lycosidae) to a seasonal climatic variable (temperature) has led to an increase response by another taxon (Linyphiidae) to fill the niche.

The third dominant spider family were Zoridae, the wandering ghost spiders. They are typically plant dwellers, using a web to build a silken retreat (Whyte & Anderson 2014). Again, they were present in both saltmarsh and woodland groups, but showed a preference for the woodland zone. The incidence of ghost spiders was low in summer, restricted to the woodland zone and to the dryer saline grasslands. However by autumn, it had increased in presence to all vegetation groups, with an increasing abundance in the woodland zone. By winter the ghost spiders had retreated to the woodland and saline grasslands, with a similar occupancy in spring. Similar to Linyphiidae, Zoridae appeared in response to the decline in Lycosidae presence during autumn and winter, with its presence in spring favouring the woodland as conditions became dryer and temperatures increased.

Less dominant families at Long Point included Gnaphosidae, Nicodamidae, Miturgidae and Zodariidae. Though these families were represented (by presence) in many groups on the site, their abundance in many cases was low, often recorded as singletons or doubletons in some vegetation groups.

Gnaphosidae, the ground spiders, are hunters, mostly active at night (Platnick 2000; Whyte & Anderson 2014). They were absent during winter, but present in the remaining seasons. Spring witnessed an emergence in presence and numbers, limited to the woodland and dry ARS group. Presence and abundance increased in summer, though Gnaphosidae were still restricted to the woodland zone where observations had increased, and were still evident in the dry saline grasslands. By autumn, this family had spread across all vegetation groups but its incidence and abundance were still highest in the woodland zone.

The family Nicodamidae, the red and black spiders, are only found in Australia and New Zealand (Harvey 1995; Nieuwenhuys 2013; Whyte & Anderson 2014). Nicodamidae are ground dwellers, and can be found among fallen bark, leaves and other debris. Females construct a tangled sheet web in hollow areas and between stones (Nieuwenhuys 2013). The genus *Nicodamus* were evident at Long Point, however its activity was restricted to summer and autumn. In summer, its range was limited to the woodland and dryer saltmarsh groups, however by autumn, its range had increased across all saltmarsh and woodland groups. At this time, temperatures were still high (30^{o}C plus) and the site was dry, even in the lower marshes, which indicated that *Nicodamus* preferred dryer habitats.

Miturgidae, the prowling spiders, are extremely widespread in Australia. There numbers were low and presence was confined to saline grasslands and some woodland areas. The dominant species found at Long Point from this family was *Mituga agelenina*, a large spider up to 20mm, confined to woodland areas.

Zodariidae are ground dwelling ant spiders, diurnal hunters often living in the vicinity of ants and mimicking their behaviour (Whyte & Anderson 2014). Similar to Miturgidae, they preferred the woodland and saline grass areas, however as their abundance was low it was difficult to more accurately define their habitat.

It was unclear what led to the seasonal cycle in the diversity of spiders which increased as seasons progressed from spring to autumn, before declining in winter. A number of explanations are plausible. Maximum daily temperatures increased from spring (25 to 35^{o}C) with the warmest month being February (35-40^{o}C plus), and remaining high (30^{o}C plus) through March and April, and were still 20^{o}C plus in May. Minimum daily temperatures were the highest December to March (6 to 9^{o}C), but fell sharply in May to below freezing on several occasions. Rainfall was relatively consistent through the year. However November was unusually wet with over 230mm recorded. High rainfall in November, in conjunction with increasing temperatures, led to greater vegetation growth during spring and summer. This provided sustenance for herbivorous insects, which in turn sustained predatory spiders. Catch rates during spring and summer of all terrestrial invertebrates (this excludes amphipods) increased sharply – spring yielded 3.5 times more individuals than winter, summer 5.9 times greater than winter. Furthermore, the number of taxa increased, increasing species diversity across the site. Increased presence and abundance of invertebrates would have led to a more abundant and diverse food supply for spiders.

5.4.2 Spiders and vegetation

Arachnid family preference for various vegetation community structures was somewhat confusing at Long Point. *Venatrix* (Lycosidae) were dominant ($p < 0.002$) in all three saltmarsh groups and on the sand dune. Yet vegetation groups incorporated varying plant species ranging from *Sarcocornia* spp. in ASS(a), to *Tecticornia arbuscula* in ASS(b), to saline grasses (ARS) to *Ehrharta stipoides* and *Lomandra longifolia* (GSL). One factor that was common to the groups except ASS(a) was bare ground ($p < 0.001$). This strongly suggests that *Venatrix* was a generalist throughout the saltmarsh zone as well as being content on the sand dune. As *Venatrix* are a ground dweller, plant structure was not an important factor, however open spaces among and under vegetation is important for hunting (Dobel *et al.* 1990). This may explain the link between bare ground and the incidence of *Venatrix*. Similarly, prostrate vegetation cover on the sand and dolerite ridges exclude *Venatrix* where for example, sufficient ground foraging space is less available under shrubs. On the one hand, this species could be classified as stenotopic (tolerant of a narrow range of environmental conditions), but on the other hand, it could be classed as eurytopic (tolerant of a wide range of environmental conditions). It is possible that spiders mainly present in the lower/middle marsh can be present in the upper marsh, but in low abundance, still contributing to species richness (Finch *et al.* 2007).

The family Gnaphosidae are mostly elongate spiders dependent on vegetation that allows them to construct tunnel-like nests (Dobel *et al.* 1990). In this study their suitable habitat was the saline grassland, the sand dune and the sand ridge ($p < 0.003$) and they were absent in areas of dense ground cover vegetation such as *Sarcocornia* spp. – ASS(a), and *Poa labillardierei* and *Zoysia macrantha* – GPL (dr). Across the study, spider body size was also important to habitat preference. Large robust taxa such as Miturgidae, cannot move effectively or forage in dense vegetation so prefer open structured habitat (Dobel *et al.* 1990) such as saline grasses and open woodlands.

A study by Dobel *et al.* (1990) has shown that population densities, particularly for ground foraging, hunting spiders tended to increase in relation to elevation increases, which suggested that inundation may limit the range of spiders to the upper-mid and upper marsh groups (Dobel *et al.* 1990; Desender & Maelfait 1999; Irmler *et al.* 2002; Finch *et al.* 2007). This result was not evident at Long Point. In contrast, ground foraging hunters such as *Artoria* and *Venatrix* tended to show a reverse trend with decreasing numbers up the elevation gradient. Even though *Artoria* were present in all vegetation groups across the site, their numbers were twice as great in the lower marsh region then elsewhere. This suggests that some species have been predominately selected for greater survival fitness by the regularity of inundation (Finch *et al.* 2007). Species abundant in the lower marsh can be expected to be more resistant to frequent and longer flooding events (Irmler *et al.* 2002). Additionally, many dominant species are 'r-selected', meaning they have the capability for speedy and abundant re-colonisation of the low marsh following flooding (Desender 1989; Finch *et al.* 2007). In the case of *Artoria* and *Venatrix*, this was highly probable due to greater abundance in the low marsh zone. Similarly, very high numbers of juvenile Lycosidae were observed in the low and middle marsh zones particularly in autumn and prior to the period of increased inundation frequency of the low/middle zone that occurred in winter.

Few spider species are exclusive to the low saltmarsh zone. Most have a range that includes the mid to high marsh (and beyond), and correlation to tidal inundation is non-existent (Irmler *et al.* 2002). Additionally, spider species richness (a count of species in an ecological community) is positively correlated with elevation (Desender & Maelfait 1999; Finch *et al.* 2007) and with sites bordering woodland zones, which further increases richness (Finch *et al.* 2007). In this study a number of families demonstrated this fact such as Zodariidae, which existed both in the middle and upper marshes and also the woodland zone. It was unclear whether progression was from saltmarsh to woodland or from woodland to saltmarsh. However, the upper marsh (ARS) and the adjoining buffer zone of the woodland zone did have some grass species, for example, *Austrostipa* and *Poa* spp., in common which may explain Zodariidae occurrence.

5.4.3 Spiders and edaphic factors

Contrary to the varying relationship of spider families to vegetation species, the relationship of spider families to edaphic factors was better defined. Wolf spiders, *Artoria* and *Venatrix,* were strongly aligned to decreasing soil conditions particularly increasing SOM, moisture and EC. Most taxa were content in neutral conditions, for example *Nicodamus*, Zodariidae and Zoridae. Some, such as *Sidymella* and *Trochosa* spp., were strongly aligned to dry conditions with low EC, whereas *Lycosa* were observed in conditions that were dry and high in pH (neutral to alkaline soils). However, as these taxa recorded very low numbers, it cannot be construed that the relationships described were entirely clear.

Variations in species richness have been described by others as a response to the salinity gradient (Long & Mason 1983) and also that few species adapt to the physiological conditions of high salinity (Desender & Maelfait 1999; Irmler *et al.* 2002). Of the 37 spider taxa observed at Long Point, only eight were confirmed to be resident in areas of high salinity and most of these were not restricted to saline conditions. This corresponds to the gradient of increasing species richness of vegetation along the salinity gradient (Desender & Maelfait 1999; Pétillon *et al.* 2008) suggesting a link between spider species richness and that of vegetation species. A study by Irmler *et al.* (2002) considered varying aspects of soil factors such as conductivity, moisture, pH and sand content. However, all but conductivity were omitted in data analysis due to the low variations in the elevation gradient (Irmler *et al.* 2002). This suggested that many edaphic factors were not controlling characteristics in the saltmarsh environment. This is contrary to the findings of Pétillon *et al.* (2008) in a study of edaphic factors on saltmarsh arthropods where spider species were negatively correlated with salinity and elevation (distance from the seawall) and only seven of the 57 species caught determined to be halophilic (thrives in a salt environment) (Pétillon *et al.* 2008). The findings of this study reflect those of Pétillon *et al.* (2008) where eight of the 37 taxa were halophilic. The factors that significantly affected the abundance of spider species for Pétillon *et al.* (2008), were in order of relevance, soil moisture, salinity and bare ground. These conclusions were also supported in this study, whereby, soil moisture and salinity were significantly negatively correlated to elevation, which was in turn negatively correlated to spider abundance. Additionally, SOM was identified as an important abiotic factor at Long Point, not considered by either Irmler *et al.* (2002) or Pétillon *et al.* (2008).

5.4.4 Beetles – seasonal variation

Similar to spiders, most beetles were not confined to a particular vegetation group, and were more limited by seasonal life cycles between spring and autumn with most spending winter in the larval stage (Davis & Gray 1966). In contrast to spiders however, beetles displayed a greater diversity within most vegetation groups, but not greater abundance. Although total beetle numbers were less than 25% of spider numbers, total beetle diversity was more than double that of spiders. While some literature is dated, high levels of beetle diversity in saltmarshes has also been found elsewhere, for example, Davis and Gray (1966), McCoy and Rey (1981), Desender and Maelfait (1999), and is particularly apparent for carabid species (Irmler *et al.* 2002; Desender *et al.* 2007; Finch *et al.* 2007), the most studied saltmarsh beetle family. Beetles were found in greater diversity (compared to spiders) in all seasons except for winter when the number of taxa was similar.

Three families were dominant by presence throughout the site over the 12 months of sampling appearing in all seasons. The principal family was <u>Carabidae</u>, the ground beetles. This family is one of the largest in the Coleoptera, with 295 genera and approximately 2 600 described species in Australia, some living up to two years in the wild (Hangay & Zborowski 2010). Carabids are found in all terrestrial environments and have been well studied (Thiele 1977) particularly in saltmarshes, for example, Irmler *et al.* (2002), Finch *et al.* (2007), Desender *et al.* (2007) and Pétillon *et al.* (2008). In addition to being the most dominant in terms of presence (15 taxa), Carabidae also rated the highest in terms of abundance, perhaps due in part to being wingless and therefore relatively easier to catch in pitfall traps. The main taxa in this family were *Bembidion*, followed by *Simodontus*, those from the Harpalini tribe and *Clivina*. Seasonally, carabids were dominant in the saltmarsh vegetation groups during winter and spring, their dominance decreasing in summer and further in autumn. Although autumn displayed the highest beetle taxa diversity, the presence and abundance of Carabidae was still the greatest.

The next dominant family by presence was Staphylinidae, the rove beetles. Staphylinids occupy most terrestrial habitats including marshes and tidal pools (Hangay & Zborowski 2010). At Long Point, the main taxa in order of abundance were *Bledius*, *Quedius* and *Oxytelus*. Except for the wetter and colder seasons, Staphylinidae were active across the site, principally during autumn. During the winter and spring they were restricted to the dryer, woodland vegetation groups with some incursion into ARS and ASS(b) groups. Unlike carabids, most species in this family are winged and therefore do not just live on the ground surface but also in the plant structure, hence a reduced chance of capture by pitfall trapping.

The third dominant beetle family by presence was Curculionidae, the true weevils or snout beetles. They form the largest animal family in the world with over 40 000 described species and possibly just as many undescribed (Hangay & Zborowski 2010). Eleven taxa were identified at Long Point, *Steriphus* the most abundant. The overall abundance of Curculionidae in samples at Long Point was low (fourth out of top five) which could be attributed to the fact that many species in the adult stage live on plants (Hangay & Zborowski 2010) rather than on the ground. Seasonally, they were restricted to the drier woodland groups in spring, increasing their range as temperatures increased and the other vegetation groups become drier. By autumn weevils were active across the site, with a high dominance on the sand ridge – GPL (sr). Winter witnessed retreat from the saline areas with increasing concentration in the woodland and complete dominance on the sand ridge.

The least observed by season of top five Coleoptera families at Long Point, were Scarabaeidae and Elateridae, both restricted to three differing seasons each. Scarabaeidae, the scarab beetles, which include the dung beetle (subfamily

Scarabaeinae), are a large family with over 2 200 species in over 270 genera found in Australia (Hangay & Zborowski 2010). Seventeen scarab taxa were captured over the 12 months making this the most diverse family captured and second largest by abundance. Their dominance of the woodland zone was evident during spring and increased in summer, particularly on the sand and dolerite ridges. During summer, scarab beetles were found in the saltmarsh zone though in very low numbers and by winter, they lost their membership of the top five Coleoptera families present on the site. The most evident species was *Acrossidius tasmaniae*, a pest in cultivated pastures (Hangay & Zborowski 2010). The dung beetle, *Onthophagus pronus*, was associated with wombat dung and active in all seasons except in winter.

Elateridae are click beetles, living on foliage, flowers or under the bark of trees (Hangay & Zborowski 2010). Their presence on the site was generally registered over winter, spring and summer, but their numbers were low (fifth out of the top five) with several of the seven taxa found recorded as singletons.

5.4.5 Beetles and vegetation

Beetles did not mirror the poor associations of spiders to vegetation groups. Most common saltmarsh Coleoptera are restricted to one type of marsh zone (Davis & Gray 1966). The carabid genus *Bembidion,* includes many halophilic species (Desender & Maelfait 1999) and was the most abundant beetle genus at Long Point found in the ASS(a and b) vegetation groups ($p < 0.001$). It was the only Coleoptera taxon to have any significance ($p < 0.05$) in saltmarsh vegetation – ASS(a and b). However, its association with the saline grasslands was virtually non-existent. This pattern reflects studies in Europe where the range of *Bembidion normannum* was solely restricted to the low marsh on the East Frisian Islands (Finch *et al.* 2007) and the North and Baltic Seas (Irmler *et al.* 2002). Additionally, three *Bembidion* spp. were found to occupy tidal marshes on the River Schelde in saline and brackish environments (Desender & Maelfait 1999). On the other hand, the carabid beetle *Simodontus*, is a true terrestrial beetle, restricted to woodland vegetation particularly the sand dune and dolerite ridge ($p < 0.025$). The tribe Harpalini was intermediate, dominating the saline grasslands with some incursion into the adjacent *Sarcocornia* vegetation. Of the burrowing carabids, the genus *Clivina* ranged across the site, occupying all vegetation types. Although there was no link with similar genera at Long Point, a study by McCoy and Rey (1981) into the association of Coleoptera to saltmarsh vegetation, found that different carabid species were restricted to certain vegetation communities. Locally, Carabidae were reported by Gouldthorpe (2000) in his study of the Derwent Estuary saltmarshes, however the taxa were not identified to genus level and abundance was very low, probably due to limited sampling.

The burrowing staphylinid genus *Bledius,* were found in saline grasslands with the occasional singleton found in *Sarcocornia* vegetation. *Quedius* ranged from *Tecticornia* dominated habitat to the woodland zone but its abundance was low, with singletons and doubletons observed at most stations. Rove beetles were also found in the Northwest Florida marshland fringe known as saline grassland in this study, however neither of the above genera were observed there (McCoy & Rey 1981). Staphylinids were reported in the Derwent marshes by Gouldthorpe (2000) but numbers were again very low.

The weevil genus *Steriphus* was restricted to *Tecticornia* – ASS(b) and the saline grasslands – ARS, whereas *Mandalotus* were a more terrestrial taxon, found in the woodland vegetation with some spread into the saline grasslands particularly if adjacent to woodland. Most other weevils were recorded as singletons or doubletons making it difficult to confidently align them with a particular vegetation group or groups. Curculionidae was also recorded in the Derwent marshes (Gouldthorpe 2000), again not defined to a particular vegetation group.

Scarab beetles were all found in the woodland zone with the exception of singletons at several saline grassland stations. The most diverse genus was *Onthophagus* (dung beetles), with three native species, *O. australis, O. posticus* and *O. pronus*, mainly restricted to woodland vegetation groups. The dominant marsupial at the site was the Tasmanian wombat, *Vombatus ursinus tasmaniensis*, generally present to the woodland zone, however scats and signs of browsing and disturbance were found in the saline grasslands adjacent to woodland areas especially during summer and autumn. Following expectations, *Onthophagus* spp.were evident wherever there were signs of wombat presence. *O. posticus* were strongly aligned ($p < 0.001$) with the sand and dolerite ridges, and *O. australis* with the dolerite ridge ($p < 0.002$), suggesting some influence of soil type. Similarly, *Acrossidius tasmaniae*, were also restricted to the woodland zone ($p < 0.019$), with some incursion into the ARS group. Two scarab beetles were also recorded in one Derwent marsh (Gouldthorpe 2000), however it is unclear how close the location was to a woodland zone.

The click beetle genus *Agrypnus* (Elateridae) was widespread across the site, in both saltmarsh and woodland zones. Its greatest abundance was found in the woodland and saline grasslands, however it was also evident in the halophilic areas of the saltmarsh in reduced numbers. Although classified as a foliage dweller by Hangay and Zborowski (2010), *Agrypnus* appears to be a generalist and its normal activity rhythms may have been repressed in saltmarsh vegetation. Its larvae are thought to be unspecialised feeders on plant roots.

5.4.6 Beetles and edaphic factors

The relationship of Coleoptera to edaphic factors was well defined. Most beetle taxa prefer neutral to improving soil conditions. Three taxa were aligned to poorer conditions, two, the tribe Trechini and the family Ptiliidae were only recorded as singletons, therefore should be discounted. The remainder, *Bembidion*, is a saltmarsh specialist (Desender & Maelfait 1999; Irmler *et al.* 2002; Desender *et al.* 2007), hence a confirmed resident of the halophytic zone.

Species richness respond to the salinity gradient (Long & Mason 1983), and that few species have adapted to decreasing edaphic conditions is evident when investigating the presence and abundance of Coleoptera. Of 84 taxa recorded at Long Point only two were truly halophilic, up to ten tolerate saline conditions, and most of the remainder tend to avoid the saltmarsh zone, although singletons and doubletons were occasionally identified in the ARS community. This somewhat reflects the situation in NW France where 11 species from 34 beetle species were considered halophilic (Pétillon *et al.* 2008). It was observed at Long Point that particular taxa will migrate seasonally to more saline conditions, perhaps in response to improving conditions in the saltmarsh zone such as increased food resources, increased temperature, dryer conditions, or in special cases wetter conditions as the saline conditions were ameliorated by increased precipitation. Beetles may respond to increasing vegetative richness along the elevational gradient (Desender *et al.* 2007; Pétillon *et al.* 2008). In a study by Irmler *et al.* (2002), most soil factors were omitted in the analysis as edaphic variation along their elevation gradient was minimal. In contrast, beetle species were negatively correlated with salinity, percentage cover of *Puccinellia maritima* (a seaside grass), soil moisture and salinity in the study by Pétillon *et al.* (2008). At Long Point, soil moisture and salinity are negatively correlated to elevation, whereas beetle abundance is positively correlated to elevation, the opposite trend seen in spiders.

5.4.7 Spiders and Beetles

At Long Point, the percentage of halophilic spiders was greater than that of halophilic beetles – 21% to 13%, which suggests that spiders and beetles are affected differently by vegetation communities, elevation and edaphic factors. However, if predatory ground beetles (carabids) alone were considered against spiders, the percentage would be somewhat closer – 21% to 20% respectively, suggesting that epigeal spiders and beetles are affected in a similar manner in the saltmarsh environment. Species richness appeared to be determined by several factors such as vegetation type and community and edaphic factors (Finch *et al.* 2007).

Factors in order of decreasing importance for spiders by taxa, on the basis of abundance (log(x+1)), were summer moisture, winter moisture, EC summer, *Sarcocornia quinqueflora*, EC winter, pH winter, pH summer, *Aira caryophyllea, Leontodon taraxacoides* and *Oxalis perennans*. For beetles by species on the basis of abundance (log(x+1)), the factors in decreasing order were summer moisture, winter moisture, *S. quinqueflora,* EC summer, EC winter, pH winter, *Disphyma crassifolium, Lomandra longifolium, Oxalis perennans and* pH summer. This suggests that the incidence and abundance of each order are initially controlled by similar factors – moisture, *S. quinqueflora*, EC, pH and then a mix of plant species peculiar to each order. However, although the determining factors are similar, spider species and abundance may be dissimilar to beetle species and abundance as the data analysis focused on the full range of taxa for both orders, irrespective of epigeous or phytophagous status. In this instance, most spiders are ground dwellers or being phytophagous, they mostly need to return to the ground to get to the next plant. Therefore, the chance of capture by pitfall trapping is high, but is dependant on activity. Except for ground beetles (carabids), most are winged and do not use the ground to move around, therefore capture by pitfall trapping decreases. Identifying the halophilic spider and beetle taxa to species level may refine the result. However, the analysis did demonstrate that moisture followed by the incidence of *S. quinqueflora* are the principal variables in determining spider and beetle presence.

Summer and autumn were the most variable seasons for spider and beetle activity across all vegetation groups as measured by both species richness and species abundance. This suggests that this period is an opportune time of the year to conduct surveys for saltmarsh invertebrates. However, not every taxon was evident during the summer/autumn period. Several taxa were only sampled during winter. If the opportunity exists, it would be prudent to conduct two invertebrate surveys – one in winter and the other summer/autumn in order to maximise species representation.

Chapter 6: Conclusion

6.1 Research findings

The primary motivation for this study was to identify the influences of the saltmarsh environment on the distribution of spiders and beetles at Long Point. Fortuitously, the study site facilitated the investigation to include a true terrestrial (woodland) zone adjacent to the saltmarsh that allowed a landscape style research approach that incorporated a comprehensive environmental gradient. The ability to position three transects at Long Point improved the robustness of the data collected as each transect became a replicate. Additionally, invertebrate data collection was further improved by the replication of pitfall traps within vegetation groups along each transect.

The demarcation of vegetation communities along each transect, the description of summer and winter soil conditions and landscape features such as elevation, has enabled the full documentation of the progressional change in habitat. Habitat variation could also be determined in the transition from a full coastal environment across a tidal saltmarsh, to the woodland zone, including the fringe/buffer between the saltmarsh and the adjacent woodland.

The most conspicuous characteristic of the saltmarsh area was the distinctive assemblage of plants within each vegetation community and in particular the clear delineation between each community. This facilitated the classification of the saltmarsh into three zones – lower, middle and upper. The key feature that drove zonation was the elevational gradient across the saltmarsh flat, which governed the frequency and duration of marine inundation. Soil moisture content, salinity and pH responded to the frequency and duration of inundation, which in turn determined vegetation species distribution. Each saltmarsh zone had a different vegetation structure. Vegetation representation in the low marsh was limited to three or four species with one generally being dominant; the middle zone had more species, which included some from the low marsh, while the upper marsh had the greatest species diversity, and generally none were shared with the lower marsh. Seasonally, variations can occur in edaphic factors such as increasing soil moisture in the low marsh. However there were no seasonal changes in the make-up of vegetation community species.

Spider and beetle taxa were generally not faithful to individual zones within the saltmarsh, or to particular vegetation communities. However, some individual taxa overlapped just two saltmarsh zones, while some others were restricted in their range to the saltmarsh environment and others to the woodland environment. A minority did range across both environments.

This study found that the incidence of halophilic beetles was far higher than that of spider taxa and moisture was the key factor determining the spider and beetle taxa distribution. However, dependence on vegetation type was the next determining factor for beetles followed by salinity. In contrast, salinity was more important for spiders, followed by vegetation type. The result suggested that although the determining factors differed, similarities did occur. In response to the similarities, both orders displayed evidence of vegetation and abiotic factor variability that determined their distribution on an environmental gradient. This information will be very useful in the management of saltmarshes, and monitoring environmental and climatic change over time.

6.2 Study aims

At the onset, three aims were identified for the study and are addressed below.

6.2.1 Baseline study

Long Point is an important ecological reference site. It is privately owned by the Tasmanian Land Conservancy, with the adjacent woodland buffer zone incorporated within the land tenure. Most importantly, the site is governed by a perpetual conservation covenant which ensures that land-use changes at the site, except for the management of noxious weeds (for example, gorse), will be keep to a minimum.

Establishing three transects across the full environmental gradient allowed a comprehensive assessment to be been undertaken of the vegetation, soils, and invertebrates. The location of each pitfall trap was identified by a real-time GPS kinematic survey to a high level of accuracy. This precision will enable a future study to be conducted using the same pitfall trap locations to document any change over time, for example in response to climate change and sea-level rise.

Furthermore, all invertebrate collections have been fully labelled, curated and archived, which will permit further identification to species level of unidentified taxa, and voucher specimens can be retained for comparisons in future studies at Long Point.

6.2.2 Defining a reference state

It is important to acknowledge that spiders and beetles range over the site in search of food and resources and that prevailing temperature can play a role in the seasonal activity of epigeal invertebrates. In many cases individual taxa are not restricted to specific vegetation species or communities. Indicator (spider and beetle) species for each saltmarsh vegetation community have been identified. It is clear from this study that some taxa are generalists ranging across the full spectrum of the environmental gradient. Others are specialists, being restricted to either the saltmarsh zone or the woodland zone. Principally, edaphic factors determine spider and beetle incidence in a saltmarsh environment, therefore two adjacent vegetation communities may have a similar range of indicator species.

6.2.3 Saltmarsh monitoring

To aid community groups in future, a reference list has been developed that will assist in the monitoring of local saltmarsh environments. Indicator vegetation species can be utilised to define the saltmarsh zone, indicator spider and beetle taxa will not. However, identifying the vegetation type will assist in determining spider and beetle taxa that would be expected within that particular vegetation community (see Appendix F). In other words, vegetation communities are a good indicator of spider and beetle incidence.

6.3 Limitations of the study

The study has been limited in resolution to a degree of confidence in the identification of spiders and beetles to species level. All taxa have been identified to family, nearly all to genus and some to species. Full identification to species may further clarify the results, but this is considered unlikely to alter the main conclusions.

Pitfall trapping, an acceptable method of invertebrate sampling especially if undertaken over a long period of time, is restricted to more active species, and those that generally reside on the ground. Litter collection along with beating and/or sweeping vegetation will add to the completeness of data and improve the knowledge of saltmarsh species diversity.

6.4 Future directions

Further study of saltmarsh soils may lead to a better understanding of the varying habitats of saltmarsh vegetation and spiders and beetles. Analysis of carbon, nitrogen and sulphur would yield C:N:S ratios and may assist in the research on stress levels witnessed on saltmarsh vegetation, in particular *Tecticornia arbuscula*. Improved analysis of soil texture that involved the efficient and cost effective removal of organic matter prior to particle size analysis would be beneficial in the precision of determining the levels of sand, silt and clay.

The use of EC as a proxy for salinity in highly saline soils needs to be properly evaluated. If possible the use of EC should be retained as it is an easy and straightforward measure. Studies on a number of sites are required to clarify the results from this study that salinity has a negative correlation to elevation.

Similarly, clarification of the correlation between SOM and elevation is needed. This can be completed simultaneously with the study into salinity.

Studies focusing on identifying individual spider and beetle species association in monospecific (single species) vegetation would be beneficial in determining the latitudinal range of invertebrate species (or genus) based on the vegetation species. This would assist in the understanding of future increasing (or decreasing) range of species resulting from vegetation gain or loss due to climate change and sea-level rise.

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Appendices

The following appendices are attached:

Appendix A: Abnormal events

Appendix B: Elevation, hill shade and solar radiation

Appendix C: Edaphic data by transect by station

Appendix D: Coastal saltmarsh community reference state

The following appendices are available on the enclosed CD:

Appendix E: Pitfall station coordinates (includes all pitfall traps)
File name: E – Coordinates.xlsx

Appendix F: Vegetation data (Braun-Blanquet values by species by station)
File name: F – Vegetation.xlsx

Appendix G: Temperature data (maximum and minimum values per month for each data logger)
File name: G – Temperature.xlsx

Appendix H: Edaphic data by transect by station
File name: H – Soil.xlsx

Appendix I: Invertebrate data (full list of all taxa per station, 12 months)
File name: I – Invertebrates.xlsx

Appendix J: Spider and beetle codes
File name: J – SpiderBeetleCodes.xlsx

Appendix A – Abnormal events

1a Flood tides

Tidal amplitude varies throughout the year and along with meteorological conditions, tides can be higher or lower than predicted (Long & Mason 1983). In the presence of a low atmospheric pressure system, high tides can be significantly higher than anticipated and increased flooding on the saltmarsh will occur particularly in the presence of a full moon (spring tide). Such an event occurred during the week commencing 18 July 2013 with expected tide heights up to 1.45 metres and low barometric pressures (Table A.1) coinciding with a full moon on 23 July.

Table A.1: Predicted tide height for Spring Bay and 9am barometric pressure for Friendly Beaches and Swansea week commencing 18 July 2013. Data source: BOM (2013; 2014a and b).

		Barometric Pressure (hPa)	
Date	**Predicted height (m)**	**Friendly Beaches**	**Swansea**
18 July 2013	1.29	1017.0	1016.0
19	1.35	998.0	996.3
20	1.40	1001.5	1000.9
21	1.44	999.5	999.2
22	1.45	1004.9	1004.1
23 (full moon)	1.44	1018.8	1018.2
24	1.39	1026.3	1025.6

Subsequently, large areas of the lower sections of Long Point were flooded, including the *Sarcocornia* flats and majority of *Tecticornia* areas; marine waters also flooded the ephemeral waterholes. Pitfall traps were planned to be set on 26 July 2013 with collection scheduled for 2 August 2013. Trap setting went ahead, however approximately 15% could not be set (Table A.2 and Figures A.1 and A.2).

Table A.2: Pitfall traps not set for collection period 26 July to 2 August 2013 due to flooding.

Transect RED	Transect YELLOW	Transect GREEN
R12a, b and c	Y2a, b and c	G1a, b and c
R13a, b and c	Y3a, b and c	G2a, b and c
	Y16a, b and c	G3a, and b

As a result there was a loss of data from the respective traps for this collection.

However, as it was a winter collection when terrestrial invertebrate species and numbers greatly reduced, it is expected that there was only a marginal impact on the results.

Figures A.1 and A.2: Left – flooded pitfall station Y16 (8 June 2013). **Right** – flooded pitfall trap.

1b Frosts

Frosts were recorded at Swansea FWS and at Long Point on several occasions during the research project (Table A.3).

Table A.3: Minimum temperatures (°C) recorded at Swansea (SW), Y1 (Little Bay), Y12 east side of Round Hole and R14 (Moulting Lagoon) during July, August and September 2013. Data source for Swansea and Friendly Beaches: BOM (2014a and b).

Date	SW	Y1	Y12	R14	Date	SW	Y1	Y12	R14	Date	SW	Y1	Y12	R14
6/07	6.8	5.0	2.8	5.0	7/08	7.1	1.1	-1.5	0.8	11/09	5.4	5.4	2.4	4.1
7/07	0.3	-0.6	-3.4	-0.2	8/08	-0.8	1.9	-1.0	2.4	12/09	-0.3	2.4	0.1	2.4
8/07	2.4	1.0	-2.5	0.9	9/08	3.1	3.8	2.7	5.1	13/09	-2.1	1.1	-3.8	-1.1
9/07	-2.1	-1.0	-4.2	-1.3	10/08	0.7	4.1	2.8	5.5	14/09	0.4	4.6	3.1	4.1
10/07	-1.5	-1.8	-5.1	-1.2	11/08	2.8	3.1	1.6	4.2	15/09	0.2	5.4	2.3	2.2
11/07	1.7	0.5	-1.8	1.6	12/08	0.9	6.5	5.4	5.6	16/09	4.4	7.4	7.3	9.0
12/07	2.9	-0.2	-3.5	0.7	13/08	5.4	1.6	0.0	2.0	17/09	9.9	11.1	11.3	11.6

Minima as low as minus 5.2°C were recorded at R4 (west side of Gum Tree Hole) during June to September 2013, and minus 4°C at G16 (crest dolerite ridge) during the same period. Similarly, Friendly Beaches AWS also recorded low temperatures, though not as low as Swansea and Long Point. Except for data from the temperature loggers, no frosts were documented at Long Point as no visits were made at the time frosts occurred at the site.

The most noticeable impact on vegetation following the frosts was the dieback or death of very large swathes of *Sarcocornia quinqueflora*, in particular the large areas of succulent lawns adjacent to water bodies (Figures A.3 – A.4). *S. quinqueflora* beneath a canopy cover of *Tecticornia arbuscula* or *Austrostipa* spp. survived the frost, similarly, any *S. quinqueflora* that had been immersed in water at the time of the frost also survived (Figure A.5). In contrast *Sarcocornia blackiana* was unaffected by the frost (Figure A.6).

Figures A.3 – A.4: station G13 *Sarcocornia quinqueflora* lawn. **Left** – January 2013. **Right** – September 2013 (frost damaged).

Figures A.5 – A.6: Left – frosted damaged *Sarcocornia quinqueflora* lawn with surviving edge that was submerged at time of frost (photo – January 2014). **Right** – *Sarcocornia blackiana* (left side – undamaged by frost), new growth of *S. quinqueflora* amongst frost damaged plants.

Pitfall traps that were located in the affected areas were retained. Although some of the terrestrial invertebrate data could be compromised as the invertebrate assemblages may have been altered following the change to the vegetation community, it was considered important to collect the data and record any change in invertebrate numbers and/or species. Additionally, it would be valuable to record if any new detritivore species present in the dead and decaying plant material.

1c Reduced collecting time

All invertebrate collections were planned to span seven days – traps set on a Saturday, collected the following Saturday, on eight occasions. It was reasoned that this was an adequate procedure that would capture as much data on terrestrial invertebrates over the 12 month period.

The first summer collection pitfall traps were set on 2 November 2013, due for collection on 9 November 2013. The average temperature for the seven day period was in line with the monthly average recorded at Swansea and Friendly Beaches (Table A.4). However, heavy rain fell beginning early AM on the 8th to AM on the 9th, virtually for the 24 hour period. Rainfall was recorded at the site as follows: R4 – 45ml; Y12 – 41ml; and G16 – 46ml.

Table A.4: Maximum temperatures and rainfall recorded at Swansea and Friendly Beaches 2-9 November 2013. Data source for Swansea and Friendly Beaches: BOM (2014a and b).

	Swansea		Friendly Beaches	
Date	**Temp (^{o}C)**	**Rainfall (mm)**	**Temp (^{o}C)**	**Rainfall (mm)**
2-Nov	18.5	0.0	20.4	0.0
3-Nov	16.5	0.8	17.2	0.0
4-Nov	17.6	0.4	19.3	0.8
5-Nov	17.6	0.0	19.4	0.0
6-Nov	27.8	0.0	25.0	0.0
7-Nov	15.7	0.0	16.3	0.0
8-Nov	10.9	10.0	10.7	9.4
9-Nov	14.1	38.8	15.3	37.8
Average for the period	17.3		18.0	
Average for the month	16.9		17.9	

Fresh water flooding caused several traps to lift from the pitfall trap liner and tip, though fortunately, not spill. All still retained the catch as ethylene glycol is denser than water, and captured invertebrates sink to the bottom of the cup.

Although it was possible that the pitfall traps may have lost some of their catch, and the catch period had been reduced by one day due to the rain, the sampling data was retained as heavy rainfall events are an integral component of the ecological process.

1d Ground swelling and contraction

Moisture content in saltmarsh soils can be very high, thus desiccation promotes soil contraction followed by swelling when moisture returns. This became apparent when setting pitfall traps in dry conditions, a large gap around the perimeter of the cup was evident, as the soil had contracted from the pitfall trap liner (Figures A.7 and A.8). Many targeted invertebrates would be unable to span the gap so care had to be taken to fill the cavity with similar material in order to assist invertebrates to enter the trap. This issue occurred on a number of occasions and at times while there was no gap on setting the trap, following a week of dry weather, a gap would be apparent on return to collect the takings. It is possible that some invertebrates may have been under sampled due to soil contraction; however, every effort was made to reduce the gaps.

Figures A.7 and A.8: pitfall trap liner and contracted soil; **Left** – among *Sarcocornia quinqueflora* (station R6). **Right** – in bare ground (station G10).

1e Environmental engineers – wombats

As woodland areas were an important part of the vegetation sequence at Long Point, pitfall traps were established there. However, a number of wombats (*Vombatus ursinus tasmaniensis*) resided in these areas. These animals are very inquisitive and protective of their habitat. They were reluctant to allow any transgression within their range and traps and trap liners were initially upended and the pitfall trap hole filled in (Figure A.9). To counter this insurgency, trap protectors were made from coarse galvanised mesh and fixed to the ground over the set pitfall trap with metal pegs. This achieved the objective, though the wombats still insisted on letting the researcher know that a violation had taken place by leaving droppings on the trap protector (Figure A.10). Fortunately, damage by wombats was encountered before pitfall trapping commenced and no protected traps were subsequently damaged.

Figures A.9 and A.10: Left – damage by wombats. **Right** – solution, "but it's still my patch".

Appendix B – Elevation, hill shade and solar radiation

Table B.1: Station elevation, hill shade and solar radiation. Elevation is based on the AusGeoid09. MSL = mean sea level; hill shade units (illumination) range from 0 to 255 – zero (no illumination, or complete shadow) to 255 (full illumination, or full sunlight) (Esri mapping centre 2011); solar radiation value = MW per square metre per year. Elevation data has a SD of 0.0155m averaged across all stations.

Station	Elevation (m) above MSL	Hill Shade (illumination)	Solar Radiation (MW/m2)
R1	0.304	179	1,211,974.25
R2	0.169	180	1,212,498.25
R3	0.509	181	1,213,181.63
R4	1.153	177	1,204,584.00
R5	0.243	180	1,209,345.75
R6	0.214	180	1,207,849.88
R7	0.293	180	1,203,368.88
R8	0.611	181	1,202,972.38
R9	2.157	194	1,217,994.13
R10	2.873	155	1,171,393.38
R11	0.472	174	1,181,738.38
R12	0.238	179	1,207,100.00
R13	0.257	180	1,208,996.75
R14	0.227	180	1,211,839.00
Y1	0.270	180	1,205,666.88
Y2	0.221	180	1,205,734.13
Y3	0.233	180	1,203,501.38
Y4	0.527	179	1,194,302.38
Y5	0.491	176	1,180,591.38
Y6	0.608	185	1,200,928.50
Y7	2.180	210	1,231,764.13
Y8	9.069	166	1,124,523.13
Y9	3.633	156	1,216,284.63
Y10	0.660	177	1,183,755.75
Y11	0.467	178	1,190,296.88
Y12	0.310	180	1,209,544.75
Y13	0.479	182	1,213,362.63
Y14	0.837	181	1,209,052.75
Y15	0.516	181	1,213,433.25
Y16	0.225	179	1,205,187.50
Y17	0.247	180	1,208,981.38

Station	Elevation (m) above MSL	Hill Shade (illumination)	Solar Radiation (MW/m2)
G1	0.273	180	1,212,585.75
G2	0.227	180	1,211,169.25
G3	0.234	180	1,214,993.63
G4	0.427	180	1,210,239.38
G5	0.529	181	1,216,770.00
G6	2.061	179	1,218,100.00
G7	2.298	185	1,226,034.63
G8	0.778	179	1,203,131.50
G9	0.540	180	1,212,774.50
G10	0.460	179	1,208,870.38
G11	0.290	178	1,208,911.88
G12	0.264	179	1,207,767.13
G13	0.363	181	1,201,217.88
G14	0.532	191	1,221,537.63
G15	4.338	200	1,242,559.63
G16	10.323	184	1,222,176.75

Appendix C – Edaphic data

1a Red transect

Table C.1: Results of soil analysis of Red transect (SOM = soil organic matter, EC = electrical conductivity, dS/m = deciSiemens per metre).

			Summer (January)			Winter (July)					
Station ID	% SOM	% Carbon	pH	EC (dS/m)	% Moist	pH	EC (dS/m)	% Moist	Sand (%)	Silt (%)	Clay (%)
R1	51.20	20.48	5.459	33.589	82.31	6.285	39.133	90.17	19	27	55
R2	18.94	4.90	5.240	16.174	47.35	5.238	16.747	55.29	62	13	25
R3	17.60	6.37	4.609	5.952	18.46	5.404	1.307	45.53	68	17	15
R4	8.86	2.52	4.408	0.061	7.87	4.253	0.095	13.35	86	6	8
R5	34.68	13.34	5.739	30.822	49.00	5.817	5.970	57.08	54	22	24
R6	25.66	13.85	5.207	22.178	62.10	5.178	18.316	78.56	65	13	22
R7	14.43	5.48	5.776	39.433	52.66	6.665	1.839	35.18	73	8	19
R8	10.86	5.18	5.064	1.612	12.85	5.068	0.241	22.85	83	6	10
R9	5.57	1.98	3.871	0.038	5.56	4.178	0.051	19.26	88	4	8
R10	4.70	1.74	4.394	0.027	6.48	4.240	0.037	13.52	90	3	7
R11	9.98	5.21	4.925	0.539	12.75	4.986	0.150	34.02	81	9	9
R12	18.59	4.82	5.522	31.511	49.15	5.908	25.333	58.27	65	12	23
R13	45.05	18.74	4.788	33.378	61.59	5.619	42.578	89.60	24	25	51
R14	44.26	16.22	5.873	44.978	84.45	6.008	39.856	86.70	30	21	49

1b Yellow transect

Table C.2: Results of soil analysis of Yellow transect (SOM = soil organic matter, EC = electrical conductivity, dS/m = deciSiemens per metre).

			Summer (January)			Winter (July)					
Station ID	% SOM	% Carbon	pH	EC (dS/m)	% Moist	pH	EC (dS/m)	% Moist	Sand (%)	Silt (%)	Clay (%)
Y1	53.16	20.16	5.859	60.133	87.31	4.787	32.978	94.25	32	23	45
Y2	44.43	21.70	4.821	49.644	77.12	5.463	42.189	92.45	17	34	49
Y3	7.61	3.95	5.760	25.856	34.17	5.819	13.667	44.52	75	10	15
Y4	7.69	3.79	5.583	2.594	16.22	5.151	0.102	27.46	87	7	6
Y5	9.00	4.96	5.492	13.001	29.62	5.970	0.612	32.87	76	12	11
Y6	8.42	2.90	5.524	0.746	10.00	5.636	0.143	30.02	82	9	8
Y7	3.66	1.73	4.630	0.056	2.59	4.392	0.056	8.94	87	1	11
Y8	1.84	1.04	4.410	0.034	4.11	4.083	0.015	7.44	93	1	6
Y9	3.46	1.48	4.838	0.035	5.05	5.052	0.034	12.32	83	5	12
Y10	10.77	4.83	5.391	0.200	16.65	5.527	0.190	33.02	71	12	17
Y11	12.41	4.21	6.207	25.867	48.92	6.639	3.944	39.42	76	9	15
Y12	10.79	4.34	6.022	20.896	57.92	6.267	7.286	78.24	74	7	19
Y13	16.33	6.86	5.063	12.384	37.40	5.628	1.959	56.39	62	17	21
Y14	10.62	4.18	4.861	0.732	13.24	4.646	0.083	29.23	70	21	8
Y15	10.92	3.47	6.701	12.508	41.41	7.463	10.763	38.49	50	25	25
Y16	36.42	15.14	5.532	46.267	75.39	5.926	43.000	92.19	23	38	39
Y17	38.23	15.35	5.742	43.744	79.15	6.055	38.000	90.89	37	28	35

1b Green transect

Table C.3: Results of soil analysis of Green transect (SOM = soil organic matter, EC = electrical conductivity, dS/m = deciSiemens per metre).

			Summer (January)			Winter (July)					
Station ID	% SOM	% Carbon	pH	EC (dS/m)	% Moist	pH	EC (dS/m)	% Moist	Sand (%)	Silt (%)	Clay (%)
G1	29.33	7.21	5.209	28.400	65.92	5.569	30.233	81.09	39	21	40
G2	15.23	2.28	6.232	24.500	45.72	6.432	17.781	65.72	47	17	37
G3	2.52	0.78	6.574	17.738	18.98	7.475	5.160	27.79	84	1	14
G4	10.12	2.48	6.184	22.844	39.83	6.350	10.583	37.78	77	4	19
G5	12.71	4.50	5.099	1.052	19.74	5.159	0.255	30.49	73	10	16
G6	4.94	1.97	3.740	0.075	6.01	4.070	0.068	5.46	89	0	11
G7	3.37	1.38	3.969	0.048	3.29	4.074	0.018	10.40	92	0	9
G8	10.75	5.89	5.094	0.594	13.73	4.934	0.112	21.20	79	11	11
G9	22.27	9.25	4.875	12.579	36.84	5.304	1.932	48.96	34	25	41
G10	14.10	5.27	4.341	24.844	46.16	4.814	5.460	44.26	19	25	56
G11	35.36	16.38	4.887	24.478	53.33	4.893	19.031	72.41	28	31	40
G12	30.09	13.67	5.428	30.767	63.56	5.456	26.456	69.40	40	26	34
G13	37.26	15.64	5.012	29.122	65.83	4.950	14.304	72.89	31	21	48
G14	26.55	6.70	5.331	0.790	23.06	5.376	0.418	39.90	42	30	28
G15	3.30	1.21	4.539	0.056	2.38	4.674	0.023	11.46	78	9	13
G16	3.57	1.34	4.631	0.031	3.53	4.757	0.022	13.33	82	8	10

Appendix D – Coastal saltmarsh community reference state

Feature	Zone	Description
Vegetation	**Low**	Prostrate saline succulent herbs – *Sarcocornia quinqueflora* and or *S blackiana,* often present as dense mats or “lawns”, bright green (spring) to deep red in colour (autumn).
	Middle	Shrub form succulents with prostrate succulent understory, occasional intrusion of saline grasses – *Tecticornia arbuscula, S quinqueflora, S blackiana, Disphyma crassifolium*, bare areas. Often present on the extreme coastal fringe (for example levee banks), *Tecticornia* can be up to 1.5m in height, very verdant; inshore of the low marsh, degraded areas, up to 1.0m in height, where *Tecticornia* appears to be under stress (not verdant), sometimes dead, bare areas can be significant.
	Upper	Saline grasslands – *Juncus* spp., *Gahnia* spp., *Austrostipa* spp. and some *Poa* spp., bare areas. Clusters of individual species are not uncommon, however generally mixed. Ground cover by *S quinqueflora, S blackiana, D crassifolium* and bare areas can occur.
Elevation		This depends entirely on the tidal range at the site. On coasts with an approximate range of <1.0m, the following is an estimate:
	Low	Range: 0.20 – 0.35 metres above Australian Height Datum (AHD)
	Middle	Range: 0.30 – 0.50 metres above AHD
	Upper	Above 0.50 metres above AHD
Inundation	**Low**	Frequently inundated by high tides, particularly from late autumn to early spring, water is often slow to recede.
	Middle	Seldom inundated, though subject to high astronomical tides and high rainfall flooding events, water can be slow to retreat.

Feature	Zone	Description
	Upper	No tidal inundation, subject to high rainfall flooding events, water is slow to recede.
Edaphic factors		**Summer**. The values are indicative only and very dependent on each site. There is a correlation between the factors, eg high organic matter = high moisture.
	Low	Moisture: High – range 60-80% EC (as a proxy for salinity): range 22-50dS/m pH: range 4.8-5.5 Soil organic matter: range 25-45% Soil texture: Clay
	Middle	Moisture: Medium – range 20-70% EC (as a proxy for salinity): range 10-50dS/m pH: range 4.3-6.7 Soil organic matter: range 5-50% Soil texture: Sandy clay loam
	Upper	Moisture: Low – range 10-40% EC (as a proxy for salinity): range 0.2-25dS/m pH: range 4.6-5.5 Soil organic matter: range 8-30% Soil texture: Sandy loam
Spiders (information from: www.arachne.org.au)	**Low**	Lycosidae (wolf spider) – *Venatrix,* agile hunters, ground dwellers, in litter or burrows, presence all year Zodariidae (ant spider)*, abundant, ground dwellers, day time hunters, often living among and mimicking ants, presence all year Zoridae (wandering ghost spider)*, superficially resemble wolf spiders, however build webs with a silken retreat, presence all year
	Middle	Lycosidae – *Venatrix,* presence all year Nicodamidae (red-black spider)*, distinctive by their colouring, small to medium, often in sheet webs, presence spring to autumn Miturgidae (prowling spider)* – *Miturga agelenina*, large, females up to 20mm, males 18mm, presence winter to summer

Feature	Zone	Description
	Upper	Lycosidae – *Venatrix,* presence all year Gnaphosidae (ground spider), night hunters, run down prey on surface, spend day in silken retreat, presence spring Zodariidae*, presence intermittent Zoridae*, presence spring to autumn Nicodamidae*, presence spring to autumn
Beetles (information from: *A Guide to Beetles of Australia* by Hangay and Zborowski)	**Low**	Carabidae (carabid beetle) – *Bembidion,* presence spring and summer Staphylinidae (rove beetle)* – *Quedius*, presence summer Carabidae – *Clivina**, presence spring through autumn Elateridae (click beetle)* – *Agrypnus* , presence summer Curculionidae (weevils)* – *Steriphus*, presence winter
	Middle	Carabidae – *Bembidion,* presence spring , summer, autumn* and winter* Carabidae – *Clivina*, presence all year* Anthicidae (ant-like flower beetle)* – *Anthicus,* mimic ants, scavenger(?), presence spring to autumn
	Upper	Pselaphidae (water-penny beetle), presence intermittent Scarabaeidae (scarab beetle) – *Heteronyx aphodioides**, presence all year Staphylinidae – *Bledius**, presence spring to autumn Carabidae – *Mecyclothorax**, presence summer to winter
		* = not significant ($p < 0.05$)