Monitoring and ecology of coastal turf on the Waitakere coast, Auckland, New Zealand.

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A thesis submitted to

Auckland University of Technology

in partial fulfilment of the requirements for the degree of

Master of Science

2018

School of Science

Auckland University of Technology

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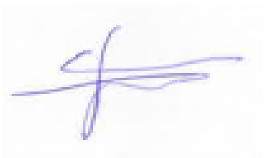

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Acknowledgements

I would like to thank my supervisors Dr Daniel Breen and Dr Craig Bishop for their guidance and advice. Further thanks to those that have provided advice and resources including Dr Hannah Buckley at AUT and Brenda Osborne at Auckland Council. Thank you also to my partner Casey Rothwell and family members, Carol George and James Crompton who helped with data collection in the field.

1. ABSTRACT

Biodiversity monitoring is important for both science and environmental management. In the Auckland region, there are established monitoring programmes for forest and freshwater-wetland ecosystems, but currently there is no systematic biodiversity monitoring programme for the terrestrial coastal area. The coastal area includes ecosystems that are often rare, unique and under high development pressures, but the coastal area has less protection than many inland ecosystems. A regional analysis identified nine coastal ecosystems in Auckland, four of which are critically endangered. The rarest of these ecosystems is coastal turf.

This thesis uses the coastal turf ecosystem as a case study to assess ecological integrity using measures such as indigenous dominance, species occupancy and environmental representation. Species diversity and abundance were measured at two separate times for three coastal turf locations along the Waitakere coast at Piha, Bryers, and Te Henga (Bethells Beach) using an almost continuous coverage of point intercepts on three subsites within each location.

Plants were identified on over 12,000 point intercepts within coastal turf patches ranging in size from $2.8m^2$ to $164m^2$. Nineteen native plant species, five exotic species and one exotic species group were identified with native species dominating at two locations, and an approximately equal coverage of native and exotic species found at the third site (Bethells). Repeated sampling of the same subsites was undertaken at time intervals ranging from a few hours to several months to assess short-term sampling error and temporal variation. Natives and exotics were generally found to increase in coverage between sampling events, suggesting a seasonal increase over summer.

Patterns in species abundance and composition were mapped in a geographic information system (GIS) and analysed in multivariate ordinations to assess differences in species composition. Changes in bare ground and native and exotic vegetation were graphed as indicators of indigenous dominance and changes related to environmental data on slope, aspect, soil depth and mammal pests were assessed.

The species composition of Waitakere coastal turf was similar to previous studies of coastal turf at Great Barrier Island, but different to other locations in New Zealand. Composition was most strongly related to vegetation coverage and to slope.

High density, point intercept estimates of cover provided a reliable method to assess status and trends in species abundance and composition at these locations. Although labour intensive, the method provided precise information for these relatively small, rare ecosystems. Recommendations for further research and management include examining long term changes in coastal turfs, their response to threatening processes and investigation of other locations and coastal ecosystem types.

2. INTRODUCTION

Coastal turf is one of 11 saline terrestrial ecosystems identified in New Zealand (Singers & Rogers, 2014). It is a naturally rare ecosystem that is geographically limited in extent (Allen, Bellingham, Holdaway, & Wiser, 2013) and has been rated as a critically endangered ecosystem under the International Union for Conservation of Nature (IUCN) system (Holdaway, Wiser, & Williams, 2012; Singers et al., 2017). It is one of nine ecosystems in the Auckland region that occur predominantly in the terrestrial coastal area (Singers et al., 2017). Coastal turf is composed of herbs that are generally less than 50mm in height, as well as grasses and sedges. Many of the plants are salt tolerant and short in stature to cope with the physical environments of coastal promontories affected by salt spray and exposure to strong winds.

There are a range of legislative drivers that require the Auckland Council to monitor indigenous biodiversity within the region, including the Resource Management Act (1991), the New Zealand Coastal Policy Statement (2010), the Auckland Plan (2009), the Environmental Reporting Act (2015) and others. The Waitakere coast also lies within the Waitakere Ranges Heritage Area, which has a specific requirement for the council to provide five-yearly biodiversity monitoring reports under the Waitakere Ranges Heritage Area Act (2008).

Auckland currently has systematic monitoring programmes for forest and wetland ecosystems (the terrestrial biodiversity monitoring programme and the wetland monitoring programme respectively). However, to date, any monitoring carried out in the terrestrial coastal area has been done in an incidental or *ad hoc* manner. In order to address the lack of information about the state of coastal ecosystems, a targeted 'coastal terrestrial biodiversity' monitoring programme for Auckland has been proposed (personal communication, Dr Craig Bishop, Auckland Council).

This study systematically analyses gaps in the protection and monitoring of coastal ecosystems near Auckland to prioritise ecosystems for future monitoring programmes. It then focuses on coastal turf. one of the rarest ecosystems in Auckland, as a case study of how to monitor the terrestrial coastal area of Auckland.

In order for any monitoring to be effective from a management perspective, appropriate indicators should be identified and the means of measurement addressed. (Lee & Allen, 2011; Lee, McGlone, & Wright, 2005). In this study, it was necessary to define the extent of the coastal environment, use a suitable ecosystem framework to define what ecosystems to include, map those ecosystems and then present the indicator data in formats suitable for a range of audiences.

The coast is an area of transition between land and sea, with environmental extremes in salinity, moisture and exposure. It is also an area that has significant anthropogenic pressure, with heavy historic land clearance and development occurring. In New Zealand, while we have a significant percentage of land area protected, much of this is inland at higher altitudes and much of the coast has already been cleared for agriculture, forestry and development (Leathwick, Overton, & McLeod, 2003).

Coastal turf is found in several regions of New Zealand, particularly Taranaki, Nelson, north Westland, Otago, Southland and Fiordland. Turf can also occur on off shore islands including the Chatham Islands (Rogers, 1999). Throughout this range, there is distinct regional variations in species composition (Rogers, 1999).

In the Auckland region, sites have been recorded on Great Barrier Island (Wright & Cameron, 1985) and on the Waitakere coast (Singers et al., 2017). Surveys of Auckland coastal turf sites show they are generally composed of several small patches of turf, some as small as a few square metres in area, surrounded by bare ground or other coastal ecosystems. Threats to coastal turf include habitat loss, land development, over grazing, stock damage, trampling and invasive weeds (Rogers & Wiser, 2010). Many sites are thought to occur on private land (Singers et al., 2017). Due to the small size of the plants and the turf patches, information on their extent and condition is currently limited. The coarse scale of regional and national monitoring means that specialized ecosystems with restricted distributions – such as coastal turf – are not adequately captured by random or systematic sampling at these larger scales.

The Auckland region is defined as the area under the governance of Auckland Council. This includes the islands of the Hauraki Gulf (Singers et al., 2017). In the existing forest and wetland monitoring programmes in Auckland, around 400 forest and 250 wetland sites are monitored every five-years. Data is collected on species composition and size, environmental variables, mammalian pest presence and bird presence. Data is used to monitor and report on the state and change in species composition and other indicators over time. This is for statutory purposes, to inform management and for public awareness. A coastal biodiversity monitoring programme would be undertaken for the same purposes, focussing on the terrestrial coastal area. This thesis prioritises coastal turf for biodiversity monitoring, identifies indicators and sampling methods, and interprets baseline and temporal data on species abundance and composition for coastal turfs along the Waitakere coast of Auckland.

Figure 1. A narrow patch of coastal turf at the ‘Bryers’ site, south of Piha.
Fourth of February 2017.

3. LITERATURE REVIEW

This chapter reviews the literature associated with the main areas of interest in this study. The first section reviews literature on coastal turf in New Zealand and overseas, discusses its distribution, species composition, ecology and methods for its monitoring. The second section discusses ecosystem classifications including definitions, descriptions, and the relevance, advantages and limitations of different methods of classification. The third section reviews literature on objectives, statutory requirements, methods and limitations associated with biodiversity monitoring in New Zealand and overseas. The final section critiques the selection and use of indicators for biodiversity monitoring and how to report them, with a particular focus on those relevant to rare coastal ecosystems.

3.1 Coastal Turf

Coastal turf is a geographically restricted but highly distinctive ecosystem (Singers, Osborne, Hill, & Sawyer, 2013). It is generally composed of tightly interlaced, prostrate herbs, that seldom grow over 50mm tall, and it can also include grasses and sedges. It is usually found on coastal promontories and consolidated sand and gravel where persistent wind and salt spray prevents less halophytic (salt tolerant) plants from growing (Johnson & Rogers, 2003; Rogers, 1999; Rogers & Wiser, 2010; Singers et al., 2013). Coastal turf is a floristically rich ecosystem (Mark, Grealish, Ward, & Wilson, 1988) which, in species composition, overlaps with both freshwater turf communities and estuarine salt marsh. While many species are found in both freshwater turf and coastal turf, the halophytic species have a higher presence in coastal turf. Coastal turf is differentiated from saltmarsh in relation to the nature of saline delivery. Coastal turf occurs in windswept exposed areas with areal deposition of salt, while saltmarshes tend to occur in sheltered areas which are regularly inundated with brackish or salt water, such as in estuarine environments (Johnson & Rogers, 2003). Because of the exposed nature of coastal turf environments, short or prostrate plants are selected for. While salt tolerance is probably the key factor in floral composition, it has been identified that effects of grazing are another key influence (Rogers & Monks, 2016). In the areas of New Zealand where coastal turf is most abundant, it is usually found abutting or near pastureland. European colonisation of New Zealand, with the resultant forest clearing and farming, is thought to have caused an expansion of coastal turf (Rogers & Wiser, 2010). There is often competition for light and resources between the exotic pasture species, (e.g. *Trifolium* spp. and *Lotus* spp.) and the native herbfield species (e.g. *Leptinella dioica*, *Selliera radicans* and *Plantago triandra*). Previous studies (Rogers, 1999; Rogers & Monks, 2016; Rogers & Wiser, 2010) have shown that moderate grazing by ungulates and lagomorphs (rabbits) favour the native turf species, with the generally taller exotic species being eaten by the herbivores. Indeed, where stock is excluded, exotic species have been found to suppress and/or exclude native herbs. While cattle (*Bos Taurus*) can cause damage and disruption to the soil, light grazing by sheep (*Ovis aries*) appear to limit soil damage while maintaining turf dominance.(Rogers, 1999)

International occurrence

Internationally, literature referring to the term coastal turf and the ecosystem type it describes is sparse. On Aldabra Atoll, near Madagascar, ‘tortoise browsed close cropped turf’ is recorded (Hnatiuk, 1979). On Ouessant, a small island in the English Channel, coastal turf was described with low plants (<5cm height) (Kerbiriou & Julliard, 2007). Sea machair is described in Southland, New Zealand. This is similar to coastal turf and is compared with the machair of Ireland and Scotland, particularly the

Outer Hebrides (Wilson, Watkins, Rapson, & Bannister, 1993). The common themes in these examples are coastal islands, high winds, salt spray and vertebrate browsing. Exactly why coastal turf is not specified more in the literature is unclear. This is possibly because its species composition is similar to saltmarsh and the two are not distinguished. It may also be because of the limited size and range of the ecosystem. Coastal turfs are regarded as fringes to other ecosystem types, and because their environmental requirements are so limiting, they do not occur in many places on the globe. Coastal cliffs, headlands and offshore islands are also often steep, remote and difficult to access. As a result, many coastal turfs may yet be undescribed.

Coastal turf in New Zealand

In New Zealand, coastal turf has been described as a kind of salt meadow or coastal moor affected by salt spray (Cockayne, 1958). On the east coast of Great Barrier Island, it was referred to as coastal turf (Wright & Cameron, 1985) but few other studies focussing on coastal turf are available. The first comprehensive study was published for the Department of Conservation (Rogers, 1999). This looked at coastal turf locations and species composition in mainland New Zealand in regions where they are most prevalent, namely in Taranaki, Nelson, north Westland, Otago, Southland and Fiordland. A later study (Rogers & Wiser, 2010) described regional differences in species composition and discussed ungulate herbivory for the same areas. Another study looked at alternative stable states of pasture and coastal turf communities in Otago (Brownstein, Lee, Pritchard, & Wilson, 2014) and conducted experiments to look at the effects of salinity, nitrogen levels and surrounding plant communities on ecosystem dominance. A study of surrogate grazing by mammals, to simulate extinct avian grazers (Rogers & Monks, 2016) linked grazing to coastal turf health. Coastal turf in the Auckland region is only described for Great Barrier Island with no published studies specifically on coastal turf for the rest of the Auckland region.

Other studies do discuss coastal turf as one of many ecosystem types. Coastal turf is identified as a historically rare ecosystem (Williams, Wiser, Clarkson, & Stanley, 2007). It is also identified as ‘Herbfield [coastal turf]’, one of 152 terrestrial ecosystems identified in New Zealand by Singers and Roger (2014), and one of eleven ecosystems found in saline environments. In a regional identification of ecosystems in the Auckland region (Singers et al., 2017), coastal turf was listed as one of 32 indigenous ecosystems occurring in the region. This report described coastal turf as occurring on offshore islands and along the west coast of Auckland. The publication listed several locations, but also stated that there was a need for further survey work to identify the full extent of coastal turf present in Auckland.

Species composition

Most of the native herbs found in coastal turf are prostrate succulents with fleshy leaves and waxed cuticles, well adapted to this environmental niche (Rogers & Wiser, 2010). In the primary coastal turf study (Rogers, 1999), 150 taxa (122 native, 28 exotic) were recorded over 94 plots. An average taxon richness of 13.2 ± 3.42 per plot was estimated. Several species have been found within coastal turfs of all the major regions of mainland New Zealand where they occur, however regional differences have been observed. *Leptinella dioica, Selliera radicans* and *Plantago triandra* have been noted as the most frequently occurring and dominant species in terms of cover. *Zoysia minima, Centella uniflora, Colobanthus muelleri, Hydrocotyle novae-zeelandiae* var. *montana, Isolepis cernua, Samolus repens, Agrostis stolonifera,* and *Trifolium dubium* were also frequently observed. On the seaward edge of turf sites, salt tolerant species such as *Sarcocornia quinqueflora, Disphyma australe, Samolus repens, Crassula moschata* and

Isolepis cernua were more common. Widespread exotic species in coastal turf include *Cerastium fontanum*, *Hypochoeris radicata*, *Plantago coronopus*, *Sagina procumbens*, *Agrostis stolonifera*, *Holcus lanatus* and several legumes, particularly *Trifolium* spp. and *Lotus* spp.

The successional pattern of turf is largely unknown. However, it has been suggested that newly formed or disturbance induced coastal turfs tend to have low species diversity and a dominance of *Selliera radicans*, *Leptinella dioica*, and *Zoysia minima* (Rogers, 1999). This suggests a need for ongoing monitoring of turfs to assess their successional patterns and determine whether communities are at their climax or in a constant transitional phase. It is possible that because of the dynamic and continually eroding nature of coastal environments, turfs may always be 'transient' ecosystems.

Distribution

The distribution of coastal turf in New Zealand is mainly in Taranaki, Nelson, north Westland, Otago, Southland, Fiordland and the Chatham Islands (Rogers, 1999; Rogers & Wiser, 2010) with scattered examples elsewhere, such as Great Barrier Island (Wright & Cameron, 1985) and the west coast of Auckland (Singers et al., 2013; Singers et al., 2017). The regional distinctiveness of turfs is quite high, mostly because of the presence or absence of threatened or uncommon plants in different regions. For example, *Poa astonii* and *Gentinella saxosa* are only found in Otago, Southland and Fiordland.

A multivariate analysis of species composition (TWINSPAN) identified 12 vegetation associations (Rogers & Wiser, 2010). Broadly, four main regional groups were found with distinct species composition and dominance. The analysis grouped coastal turfs within Taranaki–Wairarapa, northwest Nelson–north Westland, south Westland and Fiordland–Otago) (Singers et al., 2013). This regional variation is explained by geographic location, landform shape and substrate type (Rogers & Wiser, 2010). Coastal turfs in the Auckland region were not part of the analysis. Species found on the east coast of Great Barrier Island in the Auckland region include *Disphyma australe, Samolus repens, Senecio lautus, Dichondra repens, Sarcocornia quinqueflora, Anagallis arvensis* and *Lobella anceps* (Wright & Cameron, 1985). The regional distinctiveness highlights the need for monitoring at a regional scale and local management of this rare ecosystem.

Soil and topography

Coastal turf is found on a wide variety of soil types ranging from sand to clay to bedrock, with associated differences in drainage and cohesion (Rogers & Wiser, 2010). High soil salinity and aerial salt deposition appear to favour native turfs over exotic species. In their study of mainland coastal turfs, Rogers and Wiser (2010) found the most common soil is free draining loamy soil with an average depth of 370mm ± 150mm. Mean elevation associated with turf is 15 ± 13m above sea level, with some examples at 40-60m above sea level in Fiordland and Taranaki. They occur at a mean distance inland of 19 ± 15m and have a mean area of 0.17 ± 0.28 ha.

The bedrock under coastal turf is generally sedimentary strata, with erosion characteristics resulting in flat, cliffed headlands and bays. Coastal exposure to high winds causing physical buffeting and salt deposition are thought to favour turf species (Rogers, 1999).

Herbivory, salinity and nutrient loading

It has been suggested that, historically, coastal grazing birds and sea mammals had an impact on coastal turf, reducing the amount of taller vegetation and allowing coastal turf to encroach on other communities (Lee, Wood, & Rogers, 2010; Rogers & Monks, 2016). With the introduction of exotic mammals and hunting by humans, the presence of these native grazing animals on the mainland is now much reduced. The introduction of exotic plants, in particular exotic grasses and nitrogen fixing species such as *Lotus pedunculatus*, created competition with native turf and other native species and this relationship also appears to be affected by grazing animals. With the loss of the native birds it appears that light grazing by sheep, rabbits (*Oryctolagus cuniculus*) and possibly possums (*Trichosurus vulpecula*) has had a positive effect on the species composition and spatial coverage of coastal turfs. Presence of cattle appears to have had mixed effects. Whilst grazing may have kept the taller plants down, the pugging and soil disruption caused by these heavier animals is thought to have a negative impact (Rogers, 1999). Grazing, along with salt concentration and nitrogen concentration appear to be three main drivers of coastal turf presence. As salinity decreases inland, the presence of grazing and nitrogen levels become more important drivers for whether coastal turf or other ecosystems persist (Brownstein et al., 2014).

Threats

The main threats to coastal turf are habitat loss and weed encroachment (Dopson et al., 1999). Erosion and trampling by livestock, human foot traffic (e.g. tourists) and vehicle traffic, can also cause degradation of coastal turfs. Most coastal turfs occur on private land. As their conservation values are not well known, coastal turfs may not be managed as a rare ecosystem. Conversion to improved pastureland, either incrementally or intentionally is a potential issue and further land development for urban use may also have an effect.

Exotic plant species compete directly with native turf species, particularly as pasture species become more abundant as salinity levels drop inland. Nitrogen fixing species such as *Lotus pedunculatus*, and the use of fertiliser can change the soil chemistry to favour non-turf species. Exotic halophytic species such as *Plantago coronopus* can compete directly with native turf species in the saline environment, and the removal of grazers could also favour exotic, taller species.

Contrary to most native ecosystems, total removal of mammalian pests such as rabbits may have a detrimental effect on native turf species as they browse the taller exotic vegetation (Rogers, 1999; Singers et al., 2013).The effects of climate change could be complex and varied (Shaver et al., 2000), but changes in temperature and an increase in extreme weather events are likely to impact the distribution and species composition of coastal turf ecosystems.

Conservation status

In New Zealand, coastal turf is described as a naturally uncommon, or rare, ecosystem (Bellingham et al., 2016). It has been assessed as critically endangered along with 17 other naturally uncommon ecosystems using the IUCN system (Holdaway et al., 2012; Wiser et al., 2013). In Auckland, an assessment of the region's indigenous ecosystems assigned a regional IUCN threat status of critically endangered to coastal turf (Singers et al., 2017). The IUCN red list for ecosystems (Keith et al., 2013) arose from the IUCN red list for species which is regarded as an effective assessment protocol for species. The ecosystem rating model is a global assessment protocol to allow standardisation of risks at the level of ecosystems This rating has been applied nationally in New Zealand to naturally uncommon ecosystems (Holdaway et al., 2012; Wiser et al., 2013) and regionally to all ecosystems in Auckland (Singers et al., 2017).

Previous monitoring

In the two national studies of coastal turf (Rogers, 1999; Rogers & Wiser, 2010), sites were identified from areas previously reported to contain coastal turf. Aerial reconnaissance was also undertaken on areas thought likely to contain turf. Identified sites were then comprehensively surveyed using the RECCE method (Hurst & Allen, 2007), by assessing vegetation composition and structure and examining associated geographical factors. Turfs were differentiated as sectors, mainly by their geographical distinctiveness, for example by headland. Sectors of often discontinuous turf could cover up to 200m or more of coast. Plots were subjectively selected to provide a representative example of each sector. Ninety-four variable area plots were sampled in the first study (Rogers, 1999) and 116 variable area plots in the second study (Rogers & Wiser, 2010).

Plot area varied to accommodate the limits of vascular plant richness and ranged from $15m^2$ to $42m^2$. Floristic composition included vascular flora as well as aggregate categories for native liverworts, mosses and lichens. Environmental variables were collected including wind direction, soil type, landform type, vegetation cover, northern and eastern aspect, distance to sea, altitude and livestock access. Soil pH and salinity were also sampled subjectively in areas containing exotic species and native turfs. Plant species composition data were classified using TWINSPAN and broad scale relationships between species cover and environmental variables were examined using detrended correspondence analysis and detrended canonical correspondence analysis. Altitude, distance from the sea and substrate type were three of the main environmental variables thought to influence species composition.

Management and conservation

Rogers & Wiser (2010) state that coastal turf is one of the most restricted ecosystems in New Zealand. While its total area may have increased since pre-human times due to land clearance, turfs have received little protection, mainly because the majority of sites are on private land. Rogers & Wiser (2010) emphasise the regional distinctiveness of coastal turf and the large list of threatened and uncommon plants, many confined to only one or a few regions. They suggest that conservation priorities should be set within each region and light grazing be considered as a management practice where appropriate.

Setting of priorities within each region is justified by the varying size, species composition, land use and tenure of coastal turfs in different areas but these should be viewed within the overall context of coastal turf conservation. In Fiordland, coastal turf occurs largely on public and protected land, and has different issues than in Taranaki, where farming is predominant (Rogers & Wiser, 2010).

Coastal turf, while restricted in its environment, has probably increased in area nationally. This is an interesting contrast to most other native ecosystems that have declined in area over time. Light grazing is even considered as a potential tool for turf conservation by maintaining species diversity and turf dominance (Rogers, 1999; Rogers & Monks, 2016; Rogers & Wiser, 2010) but cattle presence can also be detrimental. It is recommended that they are conserved as both a unique ecosystem and as part of a more holistic approach to managing coastal ecosystem sequences in the context of surrounding and adjacent vegetation. (Rogers, 1999).

Currently there is no systematic management of data on the distribution and status of coastal turf. For most other ecosystems and species, comprehensive information systems exist for storing, referencing and providing public access to information. It is recommended that a comprehensive database is created and that the ecological value of sites be assessed using criteria from the Department of Conservation (Myers, Park, & Overmars, 1987) such as representativeness, diversity and naturalness.

3.2 Defining and mapping ecosystems

Defining appropriate units of measurement in biodiversity is important in order to quantify trends in ecological health (Park, 2000). Ecosystems may be defined as biological communities of interacting organisms and their physical environments. Climate, soil and organisms all play a role in terrestrial ecosystems (Tansley, 1935). The ecosystem concept is used in international agreements and in New Zealand legislation, monitoring and reporting. For example the New Zealand Biodiversity Strategy has a goal to 'maintain and restore a full range of remaining habitats and ecosystems ' (Department of Conservation, 2000).

Defining ecosystems in a practical manner for management, mapping and monitoring is not an easy task and a range of different systems have been developed and used within New Zealand (Singers & Rogers, 2014; Williams et al., 2007; Wiser et al., 2013; Wiser & Cáceres, 2013; Wiser, Hurst, Wright, & Allen, 2011). Defining an ecosystem is dependent on the scale you are working at, and the objectives and scope of the work undertaken. There is no universally optimum scale for ecosystem classification (Singers & Rogers, 2014). Ecosystem boundaries are open and dynamic. Any classification and mapping is an arbitrary and simplified version of the complex nature of ecology. Delineation can also be difficult as some ecosystem boundaries are diffuse, such as for lowland forests (Park, 2000; Singers & Rogers, 2014).

In New Zealand, a number of frameworks have been used to define and map vegetation cover and landscapes including the Vegetative Cover Map of New Zealand (Newsome, 1987), the Land Cover Database 4 (LCDB 4), and the Land Environments of New Zealand (LENZ) (Leathwick, 2002). The Vegetative Cover Map of New Zealand delineated vegetation community cover at a coarse scale with a minimum map unit area of 500 ha. The LCDB 4 digitally classified and mapped land cover and land use with a minimum unit size of 1 ha. It classified land cover into 33 classes using physical parameters for climate, landform and soil in numerical models.

An identification of historically rare ecosystems complements the LENZ to cover the specialised ecosystems missed in the LENZ modelling process (Williams et al., 2007). This was refined using IUCN status assessments to identify threatened naturally uncommon ecosystems (Holdaway et al., 2012; Wiser et al., 2013).

More recently, an ecosystem mapping system has been developed which aims to classify all of New Zealand's terrestrial ecosystems (Singers & Rogers, 2014). This classification focusses specifically on ecosystems as opposed to a broader environmental classification. It uses biotic and abiotic factors including temperature, moisture availability, soil gradients and landforms, vegetation classifications and expert opinion to qualitatively define ecosystem types.

The Singers and Rogers system classifies ecosystems into broad zonal and azonal categories. Zonal ecosystems are primarily driven by temperature and moisture availability, similar to the LENZ classification, and azonal ecosystems are primarily defined by variables producing edaphic extremes such as extreme soil chemistry, extreme temperature or frequent disturbance. Azonal ecosystems tend to align with the naturally uncommon ecosystems defined by Williams et al. (2007).

The Singers and Rogers system differs from the LCDB, LENZ and naturally uncommon ecosystem framework. It has many more categories than the LCDB, focusses on existing ecosystems as opposed to the environmentally predicted classes in the LENZ, and aims to cover all extant ecosystem types found in New Zealand, not just the naturally uncommon ones. The Singers and Rogers ecosystem classification has 152 ecosystems defined across New Zealand, of which 78 are zonal and 74 azonal. Each ecosystem has a name, description and code, which is readily comprehended by experts and laypersons. Successional ecosystems such as regenerating scrub are included, as well as intact vegetation. The system also allows for additions if necessary. The classification has tried to create mapped ecosystems at a scale useful for national and regional biodiversity prioritisation and management (Singers & Rogers, 2014).

The Singers and Rogers classification has been adopted by the Department of Conservation as well as several regional councils for biodiversity monitoring, ecosystem mapping and threat status. Auckland Council has adopted the system (Singers et al., 2017) to classify 36 terrestrial and wetland native ecosystems in the region, and provides a description, regional IUCN threat status and mapped extent of each natural ecosystem.

Naturally uncommon ecosystems

Naturally rare, or uncommon ecosystems are of interest and are a priority for monitoring as they have comparatively high biodiversity values for the area they cover. They are generally defined as ecosystems that were uncommon before humans colonized New Zealand. Using Williams (2007) definition of covering less than 0.5% of mainland New Zealand's total area (i.e. <134,000 ha), 72 ecosystem types were identified nationally. Eighteen were ranked as critically endangered, 17 as endangered, and ten as vulnerable ecosystems (Holdaway et al., 2012).

Naturally uncommon ecosystems contain 145 (85%) of mainland New Zealand's taxonomically distinct, nationally critical, endangered and uncommon plants (de Lange et al., 2009) of which 66 (46%) are endemic to naturally uncommon ecosystems (Wiser et al., 2013). They are at risk in several ways and due to their geographically limited scale, any external effect has a higher potential to disturb the ecosystem. They often support specialized species, which may be rare and endemic, and habitat destruction from land development, pollution, invasive flora and fauna can critically affect these ecosystems. They have been especially identified as areas for the protection of rare and threatened organisms on private land (Wiser et al., 2013).

Coastal ecosystems

Defining coastal ecosystems can be difficult, especially when defining their landward extent. The New Zealand Coastal Policy Statement 2010 (NZCPS) (Department of Conservation, 2010, 2013) recognises that the extent and characteristics of the coastal environment may vary from region to region and that these can be issue dependant. It also states that coastal vegetation should be considered as part of the coastal area. Myers et al. (1987) defines the zone of coastal influence as within one kilometre of the coast and less than 300m in altitude. While this may be applicable in certain areas, in Auckland this would cover a significant percentage of land area, and perhaps lose focus on specifically coastal ecosystems.

Eleven saline ecosystems are recognised in New Zealand under the Singers and Rogers classification. These are defined as having high concentrations of alkaline salts which select for halophytic plants, and are most predominant in New Zealand within the coastal environment. In the Auckland region, four of the 11 national saline ecosystems are identified (Singers et al., 2017). These are: mangrove forest and scrub; shore-bindweed, knobby clubrush-gravelfield/stonefield; herbfield (coastal turf); and iceplant, glasswort herbfield/loamfield. In addition to this, five other ecosystems in Auckland are described as coastally influenced, these include two dune, one cliff, one wetland and one forest ecosystem type. While other ecosystems may occur incidentally in the terrestrial coastal area, and monitoring should extend to these, it seems reasonable that any initial focus should be on those ecosystems integrally related to the coast as listed above.

Auckland Ecosystems

The growing population of the Auckland region places increasing pressures on biodiversity and the natural environment (Auckland Council, 2011). Auckland Council has a legislative obligation to monitor the biodiversity of the region. Understanding the regional diversity of ecosystems, their distribution, locations, ecological health, threat status and how they change over time is critical for effective biodiversity management. Prioritising effort, and understanding which management interventions are most effective is important for land use management and ecological restoration (Auckland Council, 2013, 2014, 2015).

3.3 Biodiversity monitoring

Biodiversity monitoring should be undertaken for both scientific and management purposes (Leathwick et al., 2003; Overton et al., 2015; Schmeller et al., 2015; Yoccoz, Nichols, & Boulinier, 2001). One approach to biodiversity monitoring adopted in New Zealand is to assess ecological integrity, which includes aspects of indigenous dominance, species occupancy and environmental representation (Lee et al., 2005). It is important that the high level goal of ecological integrity is used to guide the method selection, results, analysis and interpretation of biodiversity monitoring (Lee & Allen, 2011).

It is also important to use appropriate indicators that measure conservation outcomes rather than just the management effort put in, though the former may be harder to quantify. For example, the amount of possum bait laid in a pest eradication scheme is much easier to quantify than working out how many possums were killed, how many are left, or even more importantly, how indigenous biodiversity has responded to possum removal (Green & Clarkson, 2005; Lee & Allen, 2011). Recently a suite of 18 national indicators to monitor terrestrial biodiversity were developed for New Zealand to standardise the monitoring process (Bellingham et al., 2016). The framework was developed with input from specialists in biodiversity management throughout New Zealand and across organisations including Landcare Research, the Ministry for the Environment, regional councils and the New Zealand Department of Conservation (DOC).

These indicators facilitate the compilation and analysis of national datasets and priorities and allow data to be compared across regions. This is part of a wider drive to standardise data management in New Zealand and is exemplified by the National Environment Monitoring Standards (NEMS) (https://www.lawa.org.nz/learn/factsheets/(nems)-national-environmental-monitoring-standards/) project which seeks to standardise methods and units for environmental variables such as dissolved oxygen, temperature and salinity. An example of standardisation is using a standard naming convention such as the National Organisms Register (http://www.nzor.org.nz/), which can help deal with taxonomic name changes over time (Wiser & Cáceres, 2013).

There are 18 national biodiversity indicators identified, and work is ongoing to standardise appropriate measures and methods relating to them (Bellingham et al., 2016). Of specific interest to coastal turf, as a naturally rare ecosystem, is indicator ‘M5: Vulnerable ecosystems’ which discusses the special considerations for these unusual and/or rarer ecosystem types. Other indicators of relevance to coastal turf include ‘M2 Vegetation structure and function’; ‘M6: Number of new naturalisations’; ‘M7: Distribution and abundance of weeds and animal pests’; ‘M9: Habitat and vegetation loss’; and ‘M12: Change in protection of naturally uncommon ecosystems’.

Indicator M5 focusses on two key components, extent and condition. Extent relates to the area covered by each vulnerable ecosystem, and condition refers to their health and quality. Interestingly, in this document, coastal turf is listed as potentially occurring in eight regions of New Zealand and Auckland is not listed as one of those regions. This is different to the listings undertaken by Auckland Council (Singers et al., 2017) and is probably due to the higher relative abundance of coastal turf in other regions such as Otago and Taranaki, compared to the much sparser distribution of coastal turf in the Auckland region.

Measuring the extent of vulnerable ecosystems requires mapping at a regional scale, for example using a geographic information system (GIS), so that the total area can be calculated and other spatial analyses carried out. Investigating the condition of vulnerable ecosystems can be undertaken using plant ecology investigation methods such as: plant species surveys; estimates of percentage cover; evaluation of the composition, relative abundance, and distribution of plant associations, and vegetation mapping (Artiola, Pepper, & Brusseau, 2004). However, it is noted that "There is an outstanding research and development need for suitable sampling methods and intensities to measure changes in the condition of many of these [vulnerable] ecosystems" (Bellingham et al., 2016). Because of the diverse nature of the ecosystems, novel or specialised methods may be required to monitor them.

It was recommended that reporting on vulnerable ecosystems should occur every three years but that where specific management was being undertaken, monitoring may need to be more frequent.

Legislation

There are multiple agreements and legislation that require or encourage biodiversity monitoring at international, national and regional levels.

Key international treaties and policy documents include the Convention on Biological Diversity and the IUCN threatened species and threatened ecosystems red lists, each of which, along with other agreements, places New Zealand in an international framework of concepts and reporting (Lee et al., 2005).

Key national legislation and policy documents include:

- The Resource Management Act (1991), section 35, which requires councils to gather information, monitor, keep records and take appropriate action.
- The New Zealand Biodiversity Strategy (2000), which aims to maintain and restore natural habitats and ecosystems.
- The New Zealand Coastal Policy Statement (NZCPS) (2010), which aims to protect indigenous biological diversity in the coastal environment.
- The New Zealand Coastal Policy Statement Guidelines (Department of Conservation, 2013), which encourages effective information gathering on biodiversity.
- The Proposed National Policy Statement on Biodiversity (2011), which aims to maintain healthy functioning ecosystems

The NZCPS outlines the need to protect indigenous biological diversity and avoid significant adverse effects in the coastal area. It specifically refers to indigenous ecosystems and vegetation types that are threatened in the coastal environment, or are naturally rare. The need to identify the current state and changes in these ecosystems is self-evident if coastal ecosystems are to be protected and adverse effects avoided, mitigated or remedied. Furthermore, the guidance document for the NZCPS (Department of Conservation, 2013) states “the NZCPS encourages effective information gathering to identify amongst other things, areas or sites of significance or special value to … biodiversity (Policy 11), natural character (Policy 13), natural features and natural landscapes (Policy 15)" At the least, this signifies a need to identify the state of the ecosystems in the coastal area.

Key regional legislation and policy documents include:

- The Waitakere Ranges Heritage Area Act 2008, which requires five yearly reporting on environmental indicators
- The Auckland Plan (2012), which aims to reduce the vulnerability of identified ecosystems and ensure indigenous biodiversity is protected and restored
- Auckland Council's Indigenous Biodiversity Strategy July 2012, which requires the management of a full range of ecosystems, and an improvement of knowledge and understanding of biodiversity in the region

Legislation provides important support and justification for the time and expense required for biodiversity monitoring.

Biodiversity monitoring in the Auckland region

The Environmental Monitoring Plan for the Auckland region (Auckland Council, 2014) acts on the legislation above and outlines programmes to monitor different areas of the environment. The Research Evaluation and Monitoring unit (RIMU) of Auckland Council is tasked with undertaking the systematic and representative environmental monitoring in the Auckland region. Environmental monitoring in Auckland includes the terrestrial biodiversity monitoring programme (TBMP) which was implemented in 2009 and was designed to quantify the state of indigenous terrestrial biodiversity and monitor changes and patterns through time. It was designed to focus on indigenous forests and shrublands, as well as wetlands and dune ecosystems across the Auckland region. Currently there are two main programmes in operation- forest and shrubland monitoring, and freshwater wetlands monitoring. The forest and shrubland programme has approximately 400 plots across Auckland, and the freshwater wetland programme has approximately 250 plots. They are designed to cover a variety of catchment areas as well as representative ecosystem types within their domain in the region. A dune ecosystem monitoring programme is currently being developed, but is awaiting national guidelines (C. Bishop, personal communication 10th February 2018). Saline wetlands monitoring is planned for, but has not yet been put into effect. Both saline wetlands and dune ecosystems could be covered in a coastal biodiversity monitoring programme, which would also include vulnerable ecosystems such as coastal turf., as well as other areas of interest such as mangrove (*Avicennia marina*) expansion. The existing forest/shrubland and freshwater ecosystem monitoring are undertaken in plot based sampling, with variations specific to forest and wetlands. Bird monitoring, pest monitoring using chew cards, and site data is collected, such as photography, GPS coordinate, slope, aspect, and soil depth (Auckland Council, 2014).

The indicators relevant to coastal turf as part of a coastal biodiversity monitoring framework for the Auckland region are covered by M5: Vulnerable ecosystems (Bellingham et al., 2016). Although the guidelines currently state the need for methods development, certain aspects can be considered and monitored. Those considered practical for this study include the measurement of extent and condition. Extent can be mapped at a regional level, ground truthed and refined as better information becomes available. Measures of condition include native dominance, which includes native vegetation cover and non-native plant and animal dominance. These can be measured by monitoring the change in area and species composition of an ecosystem such as coastal turf, and by measuring pest animal presence.

Change in the area of ecosystems at a regional scale should be considered for Indicator M9: Habitat and vegetation loss (Bellingham et al., 2016), however, current data constraints do not allow for this. This is reviewed in the discussion chapter.

Reporting

Appropriate reporting of data gathered as part of biodiversity monitoring is of critical importance. The *raison d'être* of monitoring is that it will inform future management or policy and in order to do this there must be effective and timely communication of monitoring results.

Understanding the variety of audiences and their needs is the key to deciding appropriate presentation methods for effective communication. At Auckland Council, a variety of options are utilized. Annual reports, state and trends reports, state of the environment reports and report cards are some examples. Annual reports and state and trends reports are undertaken at a technical level providing a comprehensive understanding of the field of study. Examples include the marine water quality annual report 2014 (Vaughan & Walker, 2015) and the State of the Environment River Water Quality State and Trends in Auckland 2005-2014 report (Council, 2016a). These contain an executive summary that can be of benefit to councillors and policy makers, and can also provide an exhaustive analysis of the data which can be of benefit to scientists and specialists.

State of the environment reporting, for example the Health of Auckland's Natural Environment 2015 (Auckland Council, 2015), summarises all aspects of the environment, and needs to cover broad areas succinctly. It is also important that the wider public and community at large have access to, and understanding of, the indicators and their significance in relation to changes in the 'state' of indigenous biodiversity. For this reason, report cards with simplified grading systems and key information are also produced (Council, 2016b).

In this thesis, I will look at the spatial distribution of coastal ecosystems in the Auckland region. I define coastal ecosystems according to the Singers and Rogers classification system and identify coastal ecosystems in order of priority for monitoring, based on their total area and IUCN threat status.

I then focus on coastal turf, the rarest coastal ecosystem, as a case study. A pilot monitoring programme is undertaken at three coastal turf sites along the Waitakere coast. Plant species diversity and abundance is measured and compared to environmental variables such as slope, aspect and soil depth. Fine scale mapping in a geographic information system and multivariate ordinations are used to make spatial and temporal comparisons in species composition and environments among and within sites and for coastal turfs in other regions of New Zealand. A comparison of same day repeat sampling at one of the coastal turf sites is used to estimate short term sampling error. The results of using chew cards to detect the presence of mammalian pest species presence, and the use of an unmanned aerial vehicle (UAV/drone) to map turf patch extent and species composition are also discussed.

Links to relevant national indicators for biodiversity monitoring are demonstrated and possible methods for data dissemination are shown in the form of graphs and report-card style tables with grading bands for ecosystem ‘health’. Finally, the effectiveness of the monitoring methods for coastal turf ecosystems, the state of coastal turf along the Waitakere coast and the requirements of a coastal terrestrial biodiversity monitoring programme are evaluated.

4. METHODS

Data collection and analysis was undertaken in two parts. Firstly, a regional assessment of coastal turf in the context of other ecosystems was undertaken. Secondly, field survey techniques were developed and applied to describe coastal turf abundance, species composition, condition and changes over time at three coastal turf locations on the west coast of Auckland.

4.1 Regional ecosystem data collection and analysis

An initial literature review and geographic information system (GIS) based analysis was undertaken to investigate the current known spatial distribution of coastal turf in the Auckland region and evaluate its priority for monitoring in the context of other ecosystems in the region. Total ecosystem area, rarity, endangered status and the existence of active monitoring programmes were assessed. GIS data on ecosystems was cross referenced with council reports and monitoring programmes using ArcGIS 10.3.1 (ESRI, 2014) and Excel 2016 (Microsoft, 2016).

Data sources

Data from three different sources were used for the regional ecosystem analysis:

1. Description and endangered status of the native ecosystems of the Auckland region, obtained from Singer et al. (2017). This included broad categorisation of each ecosystem into one of several classes - including forest, cliff, regenerating, wetland, saline and dune - and the regional IUCN threat status for each ecosystem type.
2. A GIS dataset of the current extent of terrestrial ecosystems in the Auckland region based on the ecosystem coding of Singers et al (2017) obtained from the Biodiversity Team at Auckland Council (data accessed 7th July 2016). These data

included the ecosystem type, digitized area of the ecosystem ‘patch’, location and source of origin of the data.

3. Current and proposed monitoring programmes for the different ecosystem types, obtained from the Research Evaluation and Monitoring unit (RIMU) at Auckland Council. This included information on the forest and shrubland biodiversity monitoring programme and the freshwater wetland biodiversity monitoring programme (personal communication, Dr Craig Bishop).

Data analysis

The ecosystem layer from Auckland Council was imported into ArcMap 10.3.1 and each ecosystem type coded in the attribute table according to the IUCN grading from Singer et al. (2017). I classified ecosystems as coastal according to the descriptions of each ecosystem type from Singer et al. (2017) and their locations relative to the mean high-water springs (MHWS) mark in the GIS map. Ecosystems described as coastal in the Singers and Rogers System were found to occur predominantly within 500m of MHWS. These were considered as coastal ecosystems for this study. Attributes such as areas and numbers of ecosystem occurrences in the Auckland region, were exported to Excel for analysis. Biodiversity monitoring programmes identified from RIMU were cross referenced with ecosystem class and endangered status and tabulated for analysis.

Total area, percentage of native vegetated area, number of ecosystem patches and average size were calculated for each ecosystem. This information was then cross referenced with monitoring programmes that could cover each ecosystem type. Based on these data, ecosystems were prioritised for monitoring according to where gaps in monitoring were evident and where future monitoring programmes would prove to be most beneficial.

4.2 Coastal turf abundance, composition and condition

Field data were collected at three coastal turf locations. At each location three turf patches, designated as subsites, were sampled. Species composition data was collected using a high density, systematic point intercept transect method at all patches.

4.2.1 Site information

Site Selection

Three coastal turf sites, located on the west coast of Auckland along the Waitakere coast, were selected for this study (Figure 2). Two sites were located on headlands south of Piha – ('Piha' and 'Bryers') and a third site was established on an outcrop at the southern end of Te Henga (Bethells Beach) – ('Bethells'). It was considered that three sites could be repeat monitored within the timeframes of this project and, as a pilot study, provide sufficient information for the creation of a long term coastal turf biodiversity monitoring programme. Logistical issues, site access and time constraints prevented sampling more sites. However, there are several other known locations for coastal turf along the Waitakere coast, including Anawhata, Cannibal Creek, Karekare and Muriwai. Other coastal turfs may also exist along this exposed coast of headlands, cliffs and beaches.

Sites were identified through a combination of the GIS maps provided by the Biodiversity Team at Auckland Council, expert advice (personal communication, Brenda Osborne. Auckland Council Senior Ecologist) and field reconnaissance.

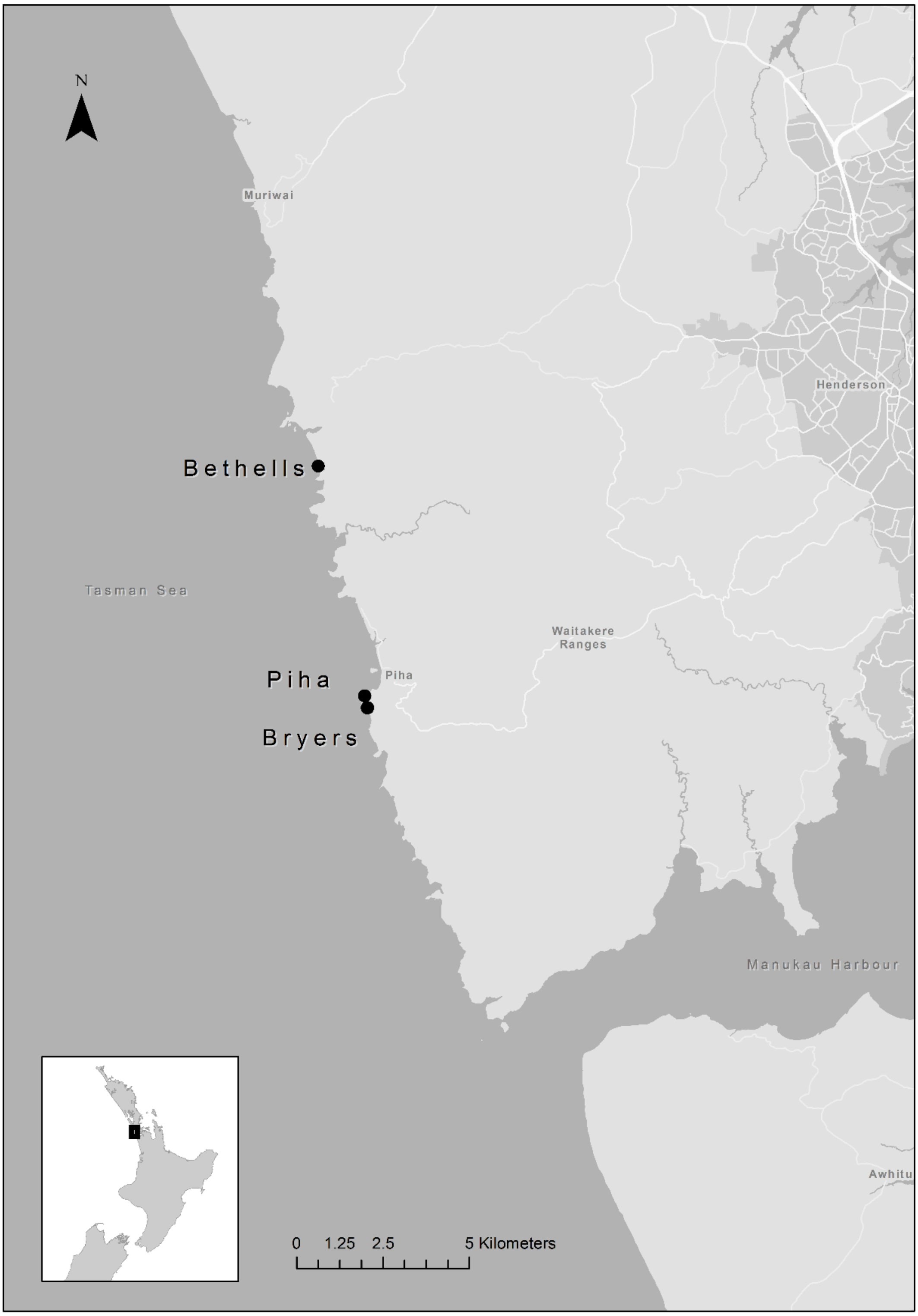

Figure 2. Map of Auckland region showing the three coastal turf sites sampled.

Piha

The Piha site is located off a coastal walkway south of Piha Beach. It is composed of five patches of coastal turf on an eroding hillside with clay and conglomerate rock as the substrate. It faces the north-west with a wide shelf of conglomerate rock leading down to the beach. Surrounding vegetation includes exotic grass, oioi (*Apodasmia similis)* - knobby clubrush (*Ficinia nodosa*) sedgeland and pohutakawa (*Metrosideros excelsa*) treeland/rockland. The Piha site ranges from 15m to 21m above sea level.

Bryers

The Bryers site lies approximately 300m south of the Piha site around a headland. It is composed of approximately seven patches of coastal turf on a rockshelf approximately 60m to 70m above sea level. Coastal turf lies in a mosaic of exotic grass, oioi - knobby clubrush sedgeland and pohutakawa treeland/rockland. The western edge of the site leads onto bare rock which falls away to the sea. Coastal turf occurs along much of the eroding edge of the site, and as large patches within the vegetation mosaic. Substrate ranges from sandy soil to clay to conglomerate bedrock.

Bethells

The Bethells site lies on a small hillock at the southern end of Bethells Beach (Te Henga). The hill is surrounded by sand and at king tides would be cut off from the mainland. It has a maximum elevation of 11m. There are four patches of coastal turf at this site. The substrate is conglomerate rock with clay and sandy soil occurring towards the inland side. The hill has exotic grass, pohutakawa treeland/rockland and patches of flaxland.

Subsite Selection

At each site, coastal turf occurred as several patches, or subsites. These were within or along the edge of a mosaic of other ecosystems and bare ground. At each site, three subsites were randomly selected for sampling. A subsite was generally readily differentiated from other areas of coastal turf. The locations of subsites within each site can be observed in Figure 3, Figure 4 and Figure 5.

Figure 3. Aerial photo showing the three subsite locations for Piha.
Aerial photo sourced from the Auckland Council Geomaps website
https://geomapspublic.aucklandcouncil.govt.nz 2010-2011.

Figure 4. Aerial photo showing the three subsite locations for Bryers. Aerial photo sourced from the Auckland Council Geomaps website https://geomapspublic.aucklandcouncil.govt.nz 2010-2011.

Figure 5. Aerial photo showing the three subsite locations for Bethells. Aerial photo sourced from the Auckland Council Geomaps website https://geomapspublic.aucklandcouncil.govt.nz 2010-2011.

4.2.2 Species composition and environmental data

Data collection

Three subsites within each site were sampled twice (initial T0 and repeat T1) to look for differences in vegetation composition over time. The time interval between the T0 and T1 samples varied among sites (Table 1). At the Bethells site a third sampling event (T2) was undertaken on the same day to assess short term sampling error. Sampling occurred between August 2016 and February 2017 providing a range of temporal variation for this pilot study. Sampling dates are shown in Table 1.

For each sampling event, a tape measure was laid along the longest axis of each subsite. A second tape measure was repeatedly laid perpendicular to the long-axis transect, to define numerous cross transects. The subsites varied in size and the distances between cross transects varied accordingly. Small subsites had only ten centimetres between each cross transect, while larger ones had 50 or 75 cm between each one. The exception to this is the first sampling event, Piha A T0, which had fewer cross transects (30cm distance) than its repeat sampling at the same site (i.e. Piha A T1 at 10cm distance). This was because it was the first subsite sampled and methods were being trialled. Depending on the length of the main transect, distance between cross transects was calculated so that approximately 30 cross transects would be sampled. The start-point for the first cross transect on the main transect was randomly selected within the first calculated distance (i.e. within the first 10cm, 30cm, 50cm or 75cm depending on subsite). From that point the distance between cross transects was always equal. The cross transects were of variable length; the length being determined by the width of the individual coastal turf subsites. Cross transects were long enough to include the entire width of the subsite as shown in Figure 6. The number of cross transects varied between subsites, and was based on their relative size (Table 1).

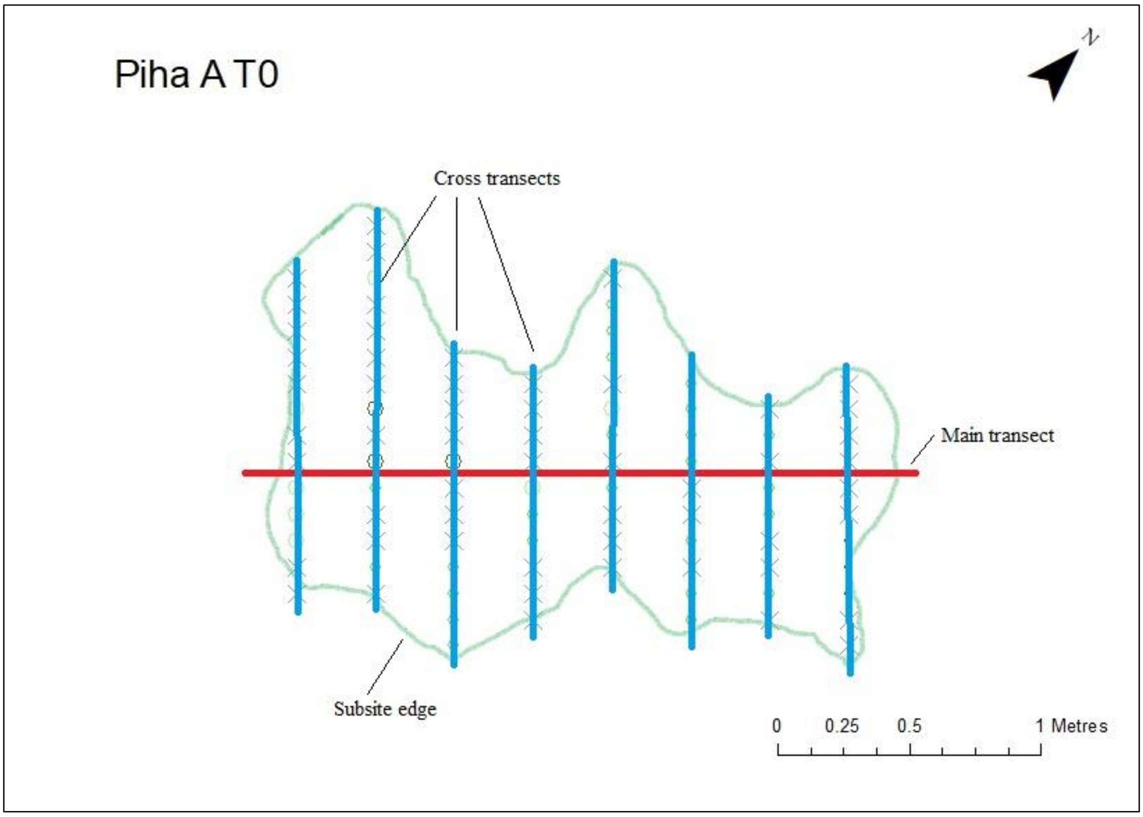

Figure 6. Map for Piha A subsite showing the sampling methodology for each subsite with main transect and cross transects.

An aluminium pin was positioned every ten centimetres along each cross transect and species touching the pin were identified and recorded. When multiple species touched the pin at the same point, all were recorded. The total area of each coastal turf sub-site was calculated by drawing a perimeter around the outer points of the cross transects to create a map in ArcGIS 10.3.1.

Permanent markers for the beginning and end of the main transect were not used. This was due to concerns of safety and amenity values as the sites were on publicly accessible land and markers could cause impalement (stakes) or impact visual amenity (paint).

Measuring changes in the size and shape of the coastal turf subsites through time required defining and accurately measuring the ‘edges’ of each individual subsite. The edges of the subsites were subjectively determined by the sampler using the following approach:

1. Edges of patches where the coastal turf was surrounded by bare ground were generally clearly demarcated by the abrupt transition from vegetated to bare ground.
2. Edges of patches where the coastal turf was surrounded by non-turf vegetation were delineated at the point where the biomass of non-turf species, such as *A. similis* and *P. tenax*, was estimated as greater than turf species.

Table 1. Magnetic bearing and length of the main transect, number of cross transects, distance between cross transects, total area, total number of sample points and points per meter squared shown for initial (T0) and repeat (T1, T2) sampling events at each subsite.

Subsite	Sample Event	Sampling Date	Main transect bearing	Main transect .	# Cross transects	Distance between .	Total area	Total # points	Points/m^2
			degrees	m		m	m^2	n	
Piha A	T0	15/08/2016	44	2.7	8	0.3	2.8	92	33
	T1	17/12/2016	44	2.7	27	0.1	2.9	285	100
Piha B	T0	15/08/2016	244	6.5	13	0.5	11.5	230	20
	T1	17/12/2016	244	6.5	13	0.5	12.9	258	20
Piha C	T0	15/08/2016	334	10.5	21	0.5	16.2	323	20
	T1	17/12/2016	334	10	20	0.5	18.9	377	20
Brye A	T0	5/09/2016	142	20.25	27	0.75	136.4	1819	13
	T1	26/01/2017	142	20.25	27	0.75	167.3	2231	13
Brye B	T0	5/09/2016	322	15.5	31	0.5	23.0	459	20
	T1	4/02/2017	322	15.5	31	0.5	26.1	521	20
Brye C	T0	8/10/2016	284	16.5	33	0.5	40.3	805	20
	T1	4/02/2017	284	16.5	33	0.5	41.1	821	20
Beth A	T0	30/10/2016	225	2.9	29	0.1	3.8	383	100
	T1	26/11/2016	202	2.9	29	0.1	4.2	417	100
	T2	26/11/2016	207	2.4	24	0.1	4.1	414	100
Beth B	T0	13/11/2016	270	2.9	29	0.1	4.4	440	100
	T1	26/11/2016	254	2.9	29	0.1	4.6	462	100
	T2	26/11/2016	254	2.9	29	0.1	4.6	464	100
Beth C	T0	13/11/2016	90	3.4	34	0.1	4.2	416	100
	T1	26/11/2016	116	3.5	35	0.1	4.5	450	100
	T2	26/11/2016	116	3.5	35	0.1	4.5	447	100

Where possible, plants were identified to species. Where species identification was unclear, samples were taken and identified using the New Zealand Plant Conservation Network website (http://www.nzpcn.org.nz). Identification data collected included common and scientific names, whether they were native or exotic, threat status and structural class as shown in Appendix A. Identification of native species was prioritised, but most exotic species were identified to species level. The exceptions to this were exotic grasses, which were grouped together as a single class because of difficulties in identifying them. In order for the data to be relevant for other regional and national studies, all species were identified and labelled using the New Zealand Organisms Register (http://www.nzor.org.nz).

Environmental variables

Environmental variables were measured at each subsite to determine any relationships between the environment and species composition. These included total area, percentage vegetation cover, altitude, distance to the sea, slope angle, exposure, aspect and soil depth. Metadata including global positioning system (GPS) coordinates, date sampled and the amount of time taken to sample were also recorded.

The environmental data were collected as follows:

- GPS coordinates for each subsite were recorded using a handheld GPS (Garmin GPSMAP 78). The coordinates were recorded for the centre of each subsite and the GPS error was also recorded.
- Total area for each subsite was calculated by drawing a perimeter around the outer points of the cross transects in a projected map in ArcGIS 10.3.1.
- Percentage vegetation cover was taken as the inverse of the percentage bare area. The bare area for each sampling event was calculated by dividing the

number of points where bare ground was recorded by the total number of points sampled at each subsite and time.

- Altitude and distance to the sea were calculated using the Auckland Council Geomaps website (http://geomapspublic.aucklandcouncil.govt.nz/). The 'Topo 2009' base map was used to determine the altitude of each subsite. To calculate the distance to the sea, aerial base maps were used and the distance from the GPS coordinates to the MHWS mark were measured.
- Slope angle was calculated using a clinometer (Suunto PM-5/360 PC Clinometer). The slope was assessed by having two poles of one metre height at the highest and lowest point of the subsite. The clinometer was balanced atop the up-site pole and the angle to the top of the lower pole was measured.
- Exposure was calculated from horizon angles by a method created by Dr Craig Bishop for the Auckland Council forest biodiversity monitoring programme. This method was used so that the data could be used and compared in any future regional studies. The vertical angle to the horizon from the centre of each subsite was calculated using the clinometer (Suunto PM-5/360 PC Clinometer) at eight points of the compass (N, NE, E, SE, S, SW, W, NW). The resultant angles were added together and added to 200. This created an 'index of exposure' with lower index values representing more exposed subsites and higher index values the converse. The realistic minimum value for the most exposed forest sites sampled in Auckland is -280 and the realistic maximum value (least exposed forest sites) is 480 (personal communication Craig Bishop).
- Aspect was calculated from a compass aligned with the steepest slope at each subsite. This was used as a proxy for weather effects as the predominant weather on the west coast of Auckland comes from the west.

- The method for soil depth was adapted from the Auckland Council and national forest biodiversity monitoring programmes (Payton, Newell, & Beets, 2004). Soil depth was measured at seven points around each subsite by pushing a 7mm wide aluminium rod into the soil. Five of the points were along the main transect. These were at the beginning, a quarter way, half way, three quarters along and at the end. The other two points were at the beginning and end of the middle cross transect. Measurements were taken to the nearest five centimetres. An average of all seven measurements was recorded. The method is quite subjective. It requires a constant 'pressure' to be applied by the observer across multiple readings both within and between sites. In order to minimise observer bias, all soil depth readings were made by a single observer.

Metadata were collected at each sampling event including the name of each site, subsite and sampling event, the date of collection, GPS error, main transect bearing, main transect length, number of cross transects, distance between cross transects, total number of sample points, total number of plant counts and the time taken to sample each event. Photos were taken at each sampling event along the main transect and middle cross transect. Photos were also taken of each species found.

Estimate of short term sampling error

In order to assess the sampling error of the point intercept transect method, repeat sampling was undertaken at each of the three Bethells subsites on the same day, the 26th November 2016. Bethells A, B and C were sampled in the morning (T1) and then sampled again in the afternoon (T2). The same person (the author) undertook the sampling for all events and all equipment was completely removed and replaced at each subsite. This sampling was undertaken approximately one month after the first sample event (T0). Differences in estimates of patch size, species composition and environmental variables between sampling events were assessed using maps, graphs and tables of summary statistics.

Geographic information systems (GIS) maps of abundance composition and distribution within turf patches

To visually assess spatial and temporal variation within and between sampling events at each subsite the results from each sampling event were mapped in ArcGIS 10.3.1. The presence or absence of species under each point intercept within each subsite and sampling event were tabulated in Microsoft Excel and imported into ArcGIS with data describing sampling event, date, distance along the main transect, distance along cross transects and environmental variables. For each sampling event, maps were created representing species composition and distribution within each patch at initial (T0) and repeat (T1, T2) sampling events.

Multivariate ordination of species, subsites, times and environmental variables

Multivariate ordinations were used to look at patterns and trends in species composition between patches, locations and times and to examine relationships with measured environmental variables. Data was analysed using the computer programme PC-ORD Version 6 (2011). Non-metric multidimensional scaling (NMS) of a Sorensen (Bray-Curtis) metric derived from species presence and absences was used to represent variation in species composition among subsites and sampling times in a reduced number of dimensions (Clarke, 1993; Cox & Cox, 2000; McCune, Grace, & Urban, 2002). Environmental data in a second matrix were used to examine correlations with species composition.

Percentage vegetation cover and relative abundance

Percentage cover was calculated for each species (and for bare ground) by dividing the number of points a species occurred by the total number of points sampled at each sample time, multiplied by 100.

$$\text{\% cover (species X)} = \frac{\text{number of points with species X}}{\text{total number of points}} \times 100$$

As multiple species often occurred at a single point, and vegetation cover was high at some subsites, the summed species abundance could exceed 100% cover (McCune et al., 2002). Changes between T0 and T1 for each subsite for natives, exotics and bare ground were calculated and graphed.

Relative abundance was calculated for each species (and for bare ground) by dividing the number of points a species occurred at by the total number of species (and bare ground points) occurrences recorded for each sample time, multiplied by 100.

$$\text{Relative abundance (species X)} = \frac{\text{number of points with species X}}{\text{sum (species 1, species 2, species 3 etc and bare ground occurrences)}} \times 100$$

Changes between T0 and T1 for each subsite for natives, exotics and bare ground were calculated and graphed.

Species richness

Species richness was calculated at each sample time and the changes between sample times graphed. Total species as well as total native species and total exotic species were estimated. As exotic grasses were not differentiated, the number of exotic species is a conservative estimate.

4.2.3 Indicators and data presentation

Results were converted to standard national biodiversity indicators (Bellingham et al., 2016) to assist in standardised assessments of the state and change of coastal turf between sites and in time.

The indicators assessed were:

- Change in total area and vegetated area.
- Change in native vegetation dominance, expressed as percentage cover and relative dominance.
- Change in exotic vegetation dominance, expressed as percentage cover and relative dominance.

Data dissemination in formats appropriate for a range of managers, scientists and stakeholder audiences is an important part of the monitoring process. A combination of graphs and tables were developed to present coastal turf and site-specific indicators in regional council site reports and state of the environment reporting.

The change in total area and in total vegetated area were calculated for each subsite to help assess ecosystem change over time. Combining this with native and exotic dominance can help provide an overall pattern of change at the subsite, site and ecosystem level.

Changes in 'total area' and 'total vegetated area' for initial and repeat sampling events were calculated and graphed as a percentage change from the initial subsite area. Grading bands were used to show relative increase and decrease in area.

Native vegetation cover was calculated by summing the percentage cover of all native species. Native relative abundance was calculated by summing the relative abundance of all native species. Change in percentage cover and relative abundance for native species were presented with grading bands to assess native dominance within subsites and change over time, and to also compare methods of data assessment.

Exotic vegetation cover was calculated by summing the percentage cover of all exotic species. Exotic relative abundance was calculated by summing the relative abundance of all exotic species. Change in percentage cover and relative abundance for exotic species were presented with grading bands.

Report card tables showing the change in area and change in native and exotic dominance, along with grades and colour bandings for each indicator were developed as tools for public engagement and general management use.

The reports trial alternative data views including summarising results at both the site and subsite level.

4.2.4 Animal pest data

Animal pest data were collected to link to the indicator for abundance of animal pests [M7] (Bellingham et al., 2016). Lagomorphs (rabbits and hares) are known to browse on coastal turfs (Rogers, 1999). Possum droppings have also been observed at the Piha and Bryers sites. Light browsing is suggested as a possible benefit to coastal turf as the taller plants are cropped, allowing the turf species to compete (Rogers & Monks, 2016). Identifying the presence of animal pests would assist in understanding their effect on the health of turf communities.

Chew cards were trialled at Piha and Bryers sites to assess animal pest presence. Chew cards are white rectangular pieces of corflute (like plastic corrugated cardboard) approximately 9cm x 18cm by 3mm width that are smeared with possum bait. Chew cards can be effective at detecting the presence of possums, rabbits, hares (*Lepus europaeus*), rats (*Rattus* spp.) and mice (*Mus musculus*) (Ruffell, Innes, & Didham, 2015). Chew cards were folded into an L shape and fixed onto aluminium rods. Each rod was pushed into the ground so that the chew card was 20cm to 30cm above ground, close to any tree or undergrowth if possible. Each card was labelled with both site and number. At both Piha and Bryers, ten chew cards were placed around the outer perimeter with five to ten metres between chew cards. This differs to standard deployment along a transect line and was done due to the small size of the turf sites and for health and safety considerations. Chew cards were placed on the 5th of September 2016 and collected after three nights on the 8th of September 2016. This process was trialled once at both Piha and Bryers sites to test the efficacy of the method at coastal turf sites.

Each chew card was analysed for the presence of bite-marks from invasive mammalian pests such as possums, rats, rabbits and mice as per standard practice (Sweetapple & Nugent, 2011). As the chew cards at each site were so close together, the results for all chew cards at a site were combined to show the presence or absence of invasive mammals at that site. Data was presented in a table of presence absence for each major invasive mammalian species grouping at each site sampled.

4.2.5 Unmanned aerial vehicle (UAV drone)

While aerial photography of areas that contain coastal turf occurs periodically in the Auckland region, the latest available photography for the sites sampled as part of this thesis was taken in 2011. The use of an unmanned aerial vehicle (UAV or drone) to acquire aerial photos of coastal turf provided an opportunity to view more recent imagery directly related to each sampling event, and capable of detecting specific temporal changes in area and potentially species composition.

Additionally, some coastal ecosystems, and coastal turf in particular, occur in locations that are unsafe or impossible to access, such as cliffs. If drone photography provided an effective monitoring approach, it could mitigate risks involved with safely sampling in some areas.

Drone photography was trialled at Bryers site at two altitudes. First a high-level flight to allow visual assessment of the site and look at changes in and around the area of the site. Second, a low-level flight to see if it would be possible to identify species composition through photographs.

At the Bryers site, a DJI Phantom 3 Professional quadcopter was used to record three hundred 11-megapixel photographs along grids at heights of 6 m and 40 m.

Pix 4d mapper version 3.1 (2016) was used to create an orthomosaic from the photos for each height. Subsites were identified and traced over the photos and visually compared with aerial photos from 2011 (Auckland Council GIS https://geomapspublic.aucklandcouncil.govt.nz/)

5. RESULTS

5.1 Regional ecosystem data collection and analysis

Regional maps

The Auckland region is home to around 40 different general ecosystem types, of which 32 are identified as native ecosystems (Singers et al., 2017). These ecosystems were broken into different categories: forest, cliff, regenerating, wetland, coastal saline, dune and other. This section reviews the distribution, status and management of these ecosystems and examines which should be prioritised for biodiversity monitoring.

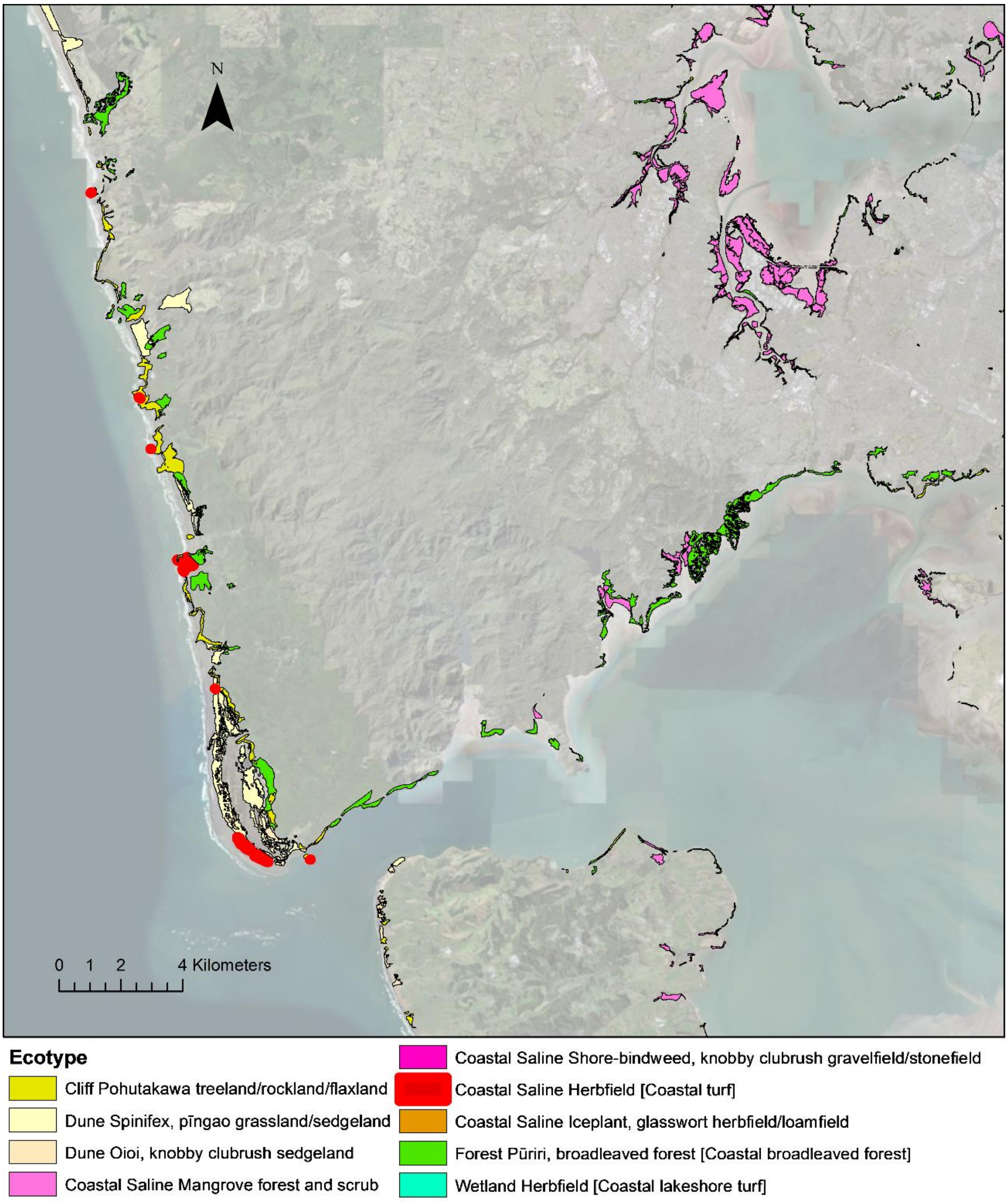

Figure 7. Map of the Waitakere area showing coastal ecosystems identified and mapped by Auckland Council as at 7th July 2016.
Coastal turf sites are highlighted in red. Data from Auckland Council.

A variety of coastal ecosystem types are evident along the west coast of the Waitakere Ranges (Figure 7). Within the harbours, mangroves and coastal broadleaved forest dominate the coastal areas. Along the exposed coast, dune, cliff and forest coastal ecosystems can be observed. Coastal turf sites are found along the exposed western coast and are highlighted in red. The actual size of the coastal turf sites is smaller than shown here, as they are highlighted to make their locations more apparent.

Ecosystem status

This section provides an understanding of the native ecosystems in the Auckland region and where they sit in relation to their rarity, endangered status and monitoring. The nine ecosystems identified for consideration in a coastal biodiversity monitoring programme in the Auckland region are outlined in Table 2. Full details of all Auckland regions ecosystems are shown in Appendix B.

Table 2. List of terrestrial ecosystems in the Auckland region that are associated with the coastal area.

Ecosystem Type	Code	Total Area (Hectares)	Total number of sites	Average Size (Hectares)	IUCN Status	Monitoring Programme
Forest	Coastal broadleaved forest	4624	1079	4.29	Endangered	Forest/Coastal
Cliff	Cliff pohutakawa	2621	939	2.79	Vulnerable	Cliff/Coastal
Wetland	Coastal lakeshore turf	20	28	0.72	Critically Endangered	Wetland/Coastal
Coastal Saline	Mangrove forest	10548	6337	1.66	Least Concern	Coastal
	Shore bindweed	55	20	2.74	Endangered	Coastal
	Coastal turf	16	30	0.55	Critically Endangered	Coastal
	Iceplant herbfield	81	7	11.56	Critically Endangered	Coastal
Dune	Dune grassland	3359	236	14.24	Endangered	Dune/Coastal
	Dune sedgeland	281	116	2.42	Critically Endangered	Dune/Coastal

Four of the nine ecosystems have total areas of less than 100 hectares remaining in the Auckland region. Four of the ecosystems are listed as critically endangered, highlighting the need for monitoring and management of their biodiversity values.

Coastal turf is shown to cover around 16 hectares across 30 sites in the Auckland region. This is the ecosystem with the smallest mapped area within the coastal bioclimatic zone. Some of the data in the GIS mapping requires ground truthing. At least one area of coastal turf of around four hectares shown on the map was found to be incorrect on a site visit to Piha. This brings the total mapped area of coastal turf down to about 12 hectares in the Auckland region and makes coastal turf one of the rarest ecosystems in the Auckland region.

For monitoring purposes, the nine ecosystems identified (Table 2) have had highly variable amounts of past 'sampling effort' devoted to them:

1. the forest ecosystems are partially covered by the existing forest and scrub monitoring programme. However, this provides only incidental coverage, as currently this programme does not specifically identify coastal forest ecosystem types, and therefore sampling is patchy in these ecosystems.
2. Monitoring of the two dune ecosystems is proposed as part of a regional dune monitoring programme, due to commence in 2019. Duneland monitoring could be included as part of a more extensive monitoring programme that encompassed the full range of coastal ecosystems.
3. The single wetland ecosystem in Table 2 is not covered under the existing wetland programme, as that focusses on non-saline influenced wetlands.
4. The remaining five ecosystems are not known to be part of a systematic and representative biodiversity monitoring programme, although some *ad-hoc* monitoring of specific locations has recently commenced (C. Bishop, personal communication 20th November 2017).

Combining IUCN threatened status and total area for each ecosystem, an initial priority ranking for biodiversity monitoring is shown (Table 3), which clearly shows coastal turf as one of the rarest and most vulnerable ecosystems in the region.

Table 3. Priority ranking of coastal ecosystems for monitoring based on IUCN threat status and total area.

Code	Total Area (Hectares)	Total number	Average Size (Hectares)	IUCN Status
Coastal turf	16 (12)	30	0.55	Critically Endangered
Coastal lakeshore turf	20	28	0.72	Critically Endangered
Iceplant herbfield	81	7	11.56	Critically Endangered
Dune sedgeland	281	116	2.42	Critically Endangered
Shore bindweed	55	20	2.74	Endangered
Dune grassland	3359	236	14.24	Endangered
Coastal broadleaved forest	4624	1079	4.29	Endangered
Cliff pohutakawa	2621	939	2.79	Vulnerable
Mangrove forest	10548	6337	1.66	Least Concern

The table also demonstrates the limited total area of several of the ecosystems and their endangered status, particularly coastal turf, coastal lakeshore turf, iceplant herbfield, dune sedgeland and shore bindweed. This provides a system for prioritisation for monitoring given their limited distribution and endangered status.

5.2 Coastal Turf

5.2.1 Site information

Figure 8, Figure 9 and Figure 10 show the subsites sampled, with a measuring tape laid on a transect along the primary axis of each subsite. A variety of physiography can be observed. Piha A, is a small *Samolus repens-Disphyma australe* herbfield, surrounded by bare soil and rock. It is sparsely vegetated, lying on a moderate slope with potential tourist foot traffic as a disturbance.

Piha B and Piha C are ‘*Selliera radicans-Sarcocornia quinqueflora* herbfields. These subsites are generally long and narrow and bordered with bare rock on one side, and other ecosystem types including exotic grass, oioi - knobby clubrush sedgeland and pohutakawa treeland/rockland on the other. Both subsites have an erosion ridge along the main transect length, with coastal turf species straddling the ridgeline (Figure 8).

Bryers A is a *Selliera radicans* herbfield, and is the largest subsite sampled with its longest axis measuring 20.25m. It occurs on a level area and is surrounded by other ecosystems with taller vegetation, including exotic grass, oioi - knobby clubrush sedgeland and pohutakawa treeland/rockland.

Bryers B and Bryers C both occur along the coastal fringe of other ecosystems, leading to bare rock on the exposed coastal side of a cliff stack. Bryers B is a *Selliera radicans-Sarcocornia quinqueflora* herbfield and Bryers C is a *Selliera radicans* herbfield. They are generally long and narrow, with possible foot traffic disturbance. An erosion ridge is observed along each subsite, (Figure 9) with coastal turf straddling this area, similar to Piha B and Piha C.

Bethells A and Bethells B are small *Lotus pedunculatus-Samolus repens-Disphyma australe* herbfields, surrounded by mixed substrata of dirt and rock. They occur on a gentle slope in an area sheltered by a headland and small patches of flax (*Phormium tenax*). They are surrounded by bare ground and low density sporadic occurrence of *Samolus repens* and *Selliera radicans*.

Bethells C is a ‘*Leontodon taraxacoides-Apium prostratum-Senecio lautus* herbfield, surrounded by bare rock, on a steep area of hard substrate. It is more exposed than the other Bethells subsites.

Piha A. *Samolus repens-Disphyma Australe* herbfield. Tape length shown 2.76m.

Piha B. *Selliera radicans-Sarcocornia quinqueflora* herbfield. Tape length shown 10m.

Piha C. *Sarcocornia quinqueflora- Selliera radicans* herbfield. Tape length shown 15m.

Figure 8. Photographs of Piha subsites A, B and C.
Photos taken 15th August 2016

Bryers A. *Selliera radicans* herbfield. Tape length shown approximately 9m. Total main transect length is 20.25m.

Bryers B. *Selliera radicans-Sarcocornia quinqueflora* herbfield. Tape length shown 15.5m.

Bryers C. *Selliera radicans* herbfield. Tape length shown 16.5m

Figure 9. Photographs of Bryers subsites A, B and C.
Photos taken 26th January 2017, 5th September 2016 and 8th October 2016 respectively.

Bethells A. *Lotus pedunculatus-Samolus repens-Disphyma australe* herbfield. Tape length shown 2.9m

Bethells B. *Lotus pedunculatus-Samolus repens-Disphyma australe* herbfield. Tape length shown 2.9m

Bethells C. *Leontodon taraxacoides-Apium prostratum-Senecio lautus* herbfield. Tape length shown 3.5m.

Figure 10. Photographs of Bethells subsites A, B and C. Photos taken 26th November 2016.

5.2.2 Species composition and environmental data

Twenty-four species and one species group were identified across all sites (Table 4). Native plants identified included 11 herb species, three grasses, one rush, one sedge, one liana and one shrub (Appendix A-1). Of the 19 native species recorded, only one (*Leptinella rotundata*) is listed as nationally threatened (de Lange et al., 2013). Five exotic herb species were identified along with one exotic species grouping of all exotic grasses. Further species information is available in Appendix A:.

Table 4. Species and species group(s) identified across all sites

	Natives	
Apium prostratum	*Muehlenbeckia complexa*	*Senecio lautus*
Apodasmia similis	*Ozothamnus leptophyllus*	*Spergularia tasmanica*
Austroderia fulvida	*Phormium tenax*	*Tetragonia implexicoma*
Dichondra repens	*Samolus repens*	*Triglochin striata*
Disphyma australe	*Sarcocornia quinqueflora*	*Zoysia minima*
Ficinia nodosa	*Selliera radicans*	*Zoysia pauciflora*
Leptinella rotundata		
	Exotics	
Anagallis arvensis	*Leontodon taraxacoides*	*Myosotis arvensis*
Exotic grass	*Lotus pedunculatus*	*Sonchus oleraceus*

Percentage cover shows the percentage of points for each species, species group and bare ground for each sample time (Table 5). The relative abundance of each taxon is also shown (Table 6). Environmental data is displayed in Table 7, showing changes in environmental variables between initial (T0) and repeat (T1) sample times at each subsite.

GIS maps of point intercepts showing species distribution and composition for each turf subsite are displayed in Figure 11 to Figure 22. Native plants are shown as circles or diamonds in the yellow-green-blue colour range. Exotic plants are squares in the purple-red-orange colour range. The exceptions are Figure 16 and Figure 17 where the view was simplified to presence/absence of all natives and all exotic. In all figures, grey x's symbolize bare ground where no plants occurred. All sites are shown to scale with any gaps between the cross transects proportional to the actual distance between each cross transect.

The average relative abundance across all sampling events was 20% bare ground, 55% native species and 25% exotic species (Table 6). Bare ground ranged from around one percent at subsite Bryers A, up to nearly 60% at Piha A, with an average of just under 20% (Table 6). The most dominant native species observed were *Selliera radicans, Sarcocornia quinqueflora, Samolus repens,* and *Disphyma australe* in order of decreasing percentage cover across all sites (Table 5). For the exotics *Lotus pedunculatus*, the exotic grass group and *Leontodon taraxacoides* had the highest total percentage cover, in that order. *S. radicans* had the highest cumulative cover, followed by *L. pedunculatus. Z. minima* had the lowest percentage cover across the sites; this species occupied less than 0.5% cover of all the sites it was found in. The species and environmental data are described in conjunction with the GIS subsite maps below.

Piha A was initially sampled in August 2016, and repeat sampled in December 2016, with four months between sample times. It is a small subsite (2.8 m^2 to 2.9 m^2) with the lowest vegetation cover and species diversity observed at any of the subsites sampled. Soil depth is relatively shallow (6cm to 9cm) and it occurs at a moderate horizontal distance (78m) to the mean high water spring tide (MHWS) compared with other subsites. At the initial sampling time (T0) there was only 41% vegetation cover. It was dominated by native species, mainly *Samolus repens* and *D. australe*, with minimal presence of *Selliera radicans*. It was initially sampled in winter (T0) and repeat sampled (T1) in summer, over that period of time vegetation cover increased, mainly due to the increased presence of *Samolus repens.* At the initial sampling time there were no exotic species recorded, but at the repeat sampling event a small amount (2% cover) of *L. pedunculatus* was recorded towards the middle of the longitudinal axis. *Disphyma australis* occurred predominantly towards the southern end of the site (Figure 11), in most cases surrounded by bare ground, but at a few points overlapping with *Samolus repens*. The initial sampling event utilised fewer cross sections at 30cm intervals along the main transect and repeat sampling was undertaken every 10cm along the main transect, potentially confounding results.

Piha B was initially sampled in August 2016, and repeat sampled in December 2016, with four months between sample times. It is an elongated subsite, varying markedly in width (1m to 3.5m). It has relatively low vegetation cover (60% in winter (T0) and 74% cover in summer (T1)) and relatively deep soil (27cm depth in winter (T0) and 17cm depth in summer (T1)). Two species are dominant at the site, *Sarcocornia quinqueflora* and *Selliera radicans.* Exotic species presence increased at the repeat sampling event (T1). The main increase was in *L. pedunculatus,* which was not present at initial sampling but was recorded at 9% cover at T1 (Table 5) and occurred in patches across the subsite. The subsite is sparsely vegetated, with bare ground occurring in many places throughout its area (Figure 12). *Senecio lautus* only occurs at the northern end of the subsite, concentrated along one cross transect. *Apodasmia similis* is recorded at the outer fringe of the site, surrounded by bare ground.

Piha C was initially sampled in August 2016, and repeat sampled in December 2016, with four months between sample times. It is an elongated, relatively narrow subsite with moderate to high vegetation cover (78% at T0 and 90% cover at T1) with a soil depth (13cm) equal to the average among all subsites. Piha C has high percentage cover of *Sarcocornia quinqueflora* and *Selliera radicans,* similar to Piha B, but also has *A. similis* and *T. implexicoma* present in greater amounts. There is a large change between T0 and T1 in percentage cover of the exotic *L. pedunculatus* (changing from 4% (T1) to

23% (T2). This can be clearly observed in Figure 13, where this species increases in presence across the western side of the site between sample times. At this subsite, native vegetation cover increased (from 87% to 98%, Table 5), but native relative abundance decreased (from 76% to 70%, Table 6).

Bryers A was initially sampled in September 2016, and repeat sampled in January 2017, with four months between sample times. It is the largest subsite sampled (136.4m^2 at T0 and 167.3m^2 at T1). Much of the difference in area observed at this site between sampling events was probably due to the subjective placement of the main transect line. Soil depth changed markedly between winter (26cm depth, T0) and summer (9cm depth, T1). This subsite maintained high vegetation cover (98%) at each sample time. It was recorded as one of the flattest subsites (6^o to 7^o slope) and was at the highest altitude (68m) of any subsite sampled (Table 7). It was dominated by *Selliera radicans,* occurring across 82% (T0) to 92% (T1) of points sampled (Table 5).

Bryers A was the only site in this study to record *Z. minima* and *Z. pauciflora* (greater than 0.5% cover). Exotic grass and the exotic herbs *Leontodon taraxacoides* and *Lotus pedunculatus* covered much of the site (Table 5), with exotic grass covering 32% of the site at initial sampling. Figure 14 (T0 sample time) and Figure 15 (T1 sample time) show high vegetation cover and a complex overlapping of species. *Selliera radicans* can be seen to be present through most of the subsite. *Zoysia pauciflora* occurs mainly at the northern end of the subsite, often only overlapping with *S. radicans. Ozothamnus leptophyllus* occurred only along the edges towards the west of the subsite. Relative abundance of natives decreases slightly between sample times from 69% to 67% (Table 6).

Exotic species occur across most of the subsite. At initial sampling (T0) exotic presence is minor in the northern area of the subsite, but at repeat sampling (T1), exotics have spread to this area. This can be better seen in Figure 16 and Figure 17, where species have been amalgamated into groups of natives and exotics. At the initial (T0) sampling time Figure 16) the low concentrations of exotics can be seen in the northern area, but are present in much of the rest of the subsite, with high percentage cover in the west. At repeat sampling (T1) (Figure 17), exotics are present in most of the subsite, but the western area now has a patch relatively free of exotics. Bare ground can also be observed in this area previously covered by exotics. The shape of the site has changed between sample times. At T0 a wedge of non-turf in the top middle of the subsite can be seen, this appears to have changed to coastal turf between sampling events, and the repeat sampling (T1) has a less variable perimeter.

Initial sampling at Bryers B was undertaken in September 2016, and repeat sampled in February 2017, with five months between sample times. It is a long narrow subsite (Figure 18) with moderate (65% at T0 to 78% at T1) vegetation cover. Several native species are present in moderate to low abundances including *Selliera radicans, Sarcocornia quinqueflora, Disphyma australe, Dichondra repens, A. similis* and *T. implexicoma.* Percentage cover of *S. radicans* increases markedly (9% at T0 to 21% at T1) between sampling events (Table 5). The exotic *L. pedunculatus* increased in a similar way (11% at T0 to 26% at T1). Figure 18 shows the change in *S. repens* occurring in the centre of the site and the change in *L. pedunculatus* occurring mainly towards the western end of the subsite between T0 and T1. In the repeat sample, some of the cross transects are longer, and some shorter compared to the initial sample time, suggesting a minor change in shape of the subsite.

Bryers C initial sampling was undertaken in October 2016, and repeat sampling undertaken in February 2017, with four months between sample times. It is another long subsite, and is the second largest in area (40.3m^2 at T0 and 41.1m^2 at T1). It also has the second lowest vegetation cover (54% at T0 to 58% at T1) and is the closest subsite to MHWS in horizontal distance (36m). The main species present is *S. radicans*, with low percentage presence of *Dichondra repens, A. similis* and *Disphyma australe* (Table 5). Low amounts of *Lotus pedunculatus,* exotic grass and *Leontodon taraxacoides* are also present. Figure 19 shows the spatial variation in species throughout the subsite. The western edge (which leads to bare rock and faces the ocean) is sparsely vegetated with *S. radicans.* Along the eastern edge (which fringes other ecosystems) vegetation cover and species diversity increases. Exotics occur along this edge mainly in the northern part of the subsite. A small area of *O. leptophyllus* can be observed at the very north of the subsite. Presence of *S. radicans* at the southern edge of the site declines between sampling events.

Bethells A sampling was undertaken between October 2016 and November 2016 with 27 days between initial and repeat sample times. It is a small ($3.8m^2$ to $4.2m^2$) subsite with low elevation (6m above MHWS) and shallow soil (7cm to 10cm depth). It has high vegetation cover (93% to 95% cover) and *Samolus repens, Disphyma australe, Selliera radicans* and *Senecio lautus* are the main native species present. It is dominated by exotic species, mainly *L. pedunculatus* and exotic grass (Table 5). Figure 20 shows the shape as roughly ovoid. The high occurrence of *L. pedunculatus* is shown in this figure. *Samolus repens* is present along much of the edges of this subsite.

Bethells B sampling was undertaken in November 2016, with 13 days between sample times. It is similar in size ($4.4m^2$ to $4.6m^2$) and shape (ovoid) to Bethells A. The subsite also sits at 6m above MHWS and has a similar species composition. The subsites are located only a few metres apart from each other. A similar pattern in species presence can also be seen (Figure 21) with *L. pedunculatus* present over much of the subsite and *S. repens* along the edges. *Lotus pedunculatus* appears to increase in presence towards the east and decrease in presence towards the west between sampling events. There were 13 days between initial (T0) and repeat (T1) sample times and sampling was undertaken in November.

Bethells C is also a small subsite ($4.2m^2$ to $4.5m^2$) but has a variable perimeter. There were 13 days between initial (T0) and repeat (T1) sample times and sampling was undertaken in November 2016. This subsite is the only one to have considerable percentage cover of *A. prostratum* (19% at T0 and 20% at T1) and has the highest percentage cover of *S. lautus* (13%% atT0 and 10% at T1, Table 5). It is dominated by the exotic species *L. taraxacoides* (40% at T0 and 36% at T1). Figure 22 shows *L. taraxacoides* present through most of the subsite. Bare ground can be observed through much of the middle of the subsite and the native *M. complexa* is present at the south-eastern edge. The shape of the subsite along the western side of the subsite changes between sampling events, increasing in variation.

These results show the variety in species composition, environmental variables and spatial patterns between subsites of coastal turf and temporal changes that can occur within subsites over time periods of weeks to months.

Table 5. Percentage cover of each species grouping at each subsite for initial (T0) and repeat (T1) sample times.
As there was overlapping by different species, total cover can be >100%. Percentages rounded to nearest whole number. Total cover for native and exotic groups are also shown.

	Piha						Bryers						Bethells					
Subsite	Piha A		Piha B		Piha C		Bryers A		Bryers B		Bryers C		Beth A		Beth B		Beth C	
Sample Time	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1
Bare ground	59	37	40	21	19	7	1	1	27	18	40	35	5	7	5	4	13	16
Native																		
A. prostratum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19	20
A. similis	0	0	0	6	8	9	14	6	9	11	4	9	0	0	0	0	0	0
A. fulvida	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0
D. repens	0	0	3	5	2	3	0	1	11	4	7	9	3	4	3	4	8	8
D. australe	8	14	0	1	3	2	0	0	16	11	4	5	15	21	6	5	6	4
F. nodosa	0	0	0	0	0	0	2	3	0	0	0	1	0	0	0	1	0	0
L. rotundata	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
M. complexa	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	6	7
O. leptophyllus	0	0	0	2	0	0	0	1	4	4	1	3	0	0	0	0	0	0
P. tenax	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
S. repens	26	45	0	0	0	0	0	7	0	0	4	4	13	15	17	28	0	0
S. quinqueflora	0	0	26	36	36	46	0	0	17	11	0	0	0	0	0	0	9	11
S. radicans	3	2	27	28	22	21	82	92	9	21	34	32	18	10	22	14	0	2
S. lautus	0	0	0	5	1	4	0	1	1	1	1	0	7	6	7	10	13	10
S. tasmanica	4	3	0	0	1	0	0	0	1	0	0	0	0	0	0	0	3	0
T. implexicoma	0	0	1	2	13	11	0	0	9	3	0	0	0	0	0	0	0	0
T. striata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Z. minima	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Z. pauciflora	0	0	0	0	0	0	10	7	0	0	0	0	0	0	0	0	0	0
Total Native	41	64	59	84	87	98	116	119	78	70	57	64	56	56	54	61	64	66
Exotic																		
A. arvensis	0	0	0	1	0	1	0	0	0	0	0	0	3	5	0	1	1	0
Exotic grass	0	0	1	2	2	7	32	20	7	7	6	5	26	26	5	6	6	4
L. taraxacoides	0	0	0	0	0	0	6	22	0	1	1	4	2	3	4	3	40	36
L. pedunculatus	0	2	0	9	4	23	11	16	11	26	6	5	54	48	62	56	9	10
M. arvensis	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	2
S. oleraceus	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0
Total Exotic	0	2	1	13	5	31	49	58	18	34	13	14	85	84	71	65	59	53
Total Cover	101	105	100	124	114	139	167	179	131	127	116	119	149	151	132	133	141	141

Table 6. Relative abundance of each species (and bare ground) at each subsite for initial (T0) and repeat (T1) sample times.
Percentage calculated from total count of all plants and bare ground at each sample event. Percentages rounded to nearest whole number. Relative abundance for native and exotic groups are also shown.

	Piha						Bryers						Bethells					
Subsite	A		B		C		A		B		C		A		B		C	
Sample Time	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1
Bare ground	59	37	40	21	19	7	1	1	27	18	40	35	5	7	5	4	13	16
Native																		
A. prostratum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	14
A. similis	0	0	0	5	7	6	8	3	7	9	4	7	0	0	0	0	0	0
A. fulvida	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
D. repens	0	0	3	4	2	2	0	0	8	3	6	7	2	2	2	3	6	6
D. australe	8	13	0	1	3	2	0	0	12	9	4	4	10	14	4	4	4	3
F. nodosa	0	0	0	0	0	0	1	2	0	0	0	1	0	0	0	0	0	0
L. rotundata	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
M. complexa	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	4	5
O. leptophyllus	0	0	0	2	0	0	0	0	3	3	1	3	0	0	0	0	0	0
P. tenax	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
S. repens	26	43	0	0	0	0	0	4	0	0	4	4	9	10	13	21	0	0
S. quinqueflora	0	0	26	29	32	33	0	0	13	9	0	0	0	0	0	0	6	8
S. radicans	3	2	27	22	19	15	49	52	7	16	30	27	12	7	17	11	0	1
S. lautus	0	0	0	4	1	3	0	1	1	1	1	0	5	4	5	8	9	7
S. tasmanica	4	3	0	0	1	0	0	0	1	0	0	0	0	0	0	0	2	0
T. implexicoma	0	0	1	1	11	8	0	0	7	2	0	0	0	0	0	0	0	0
T. striata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Z. minima	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z. pauciflora	0	0	0	0	0	0	6	4	0	0	0	0	0	0	0	0	0	0
Total Native	41	61	59	68	76	70	69	67	60	55	49	54	38	37	41	46	46	47
Exotic																		
A. arvensis	0	0	0	1	0	1	0	0	0	0	0	0	2	3	0	0	1	0
Exotic grass	0	0	1	2	1	5	19	11	6	6	5	4	18	17	4	4	4	3
L. taraxacoides	0	0	0	0	0	0	4	12	0	1	1	3	1	2	3	2	28	25
L. pedunculatus	0	2	0	8	3	16	7	9	8	20	5	4	36	32	47	42	6	7
M. arvensis	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	1
S. oleraceus	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Total Exotic	0	2	1	11	5	22	29	32	14	27	11	11	57	56	54	49	42	37
Total Cover	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 7. Environmental variables measured at each sampling event.
Total area is the area sampled. Vegetation cover is the percentage of area sampled covered by plants. Altitude and distance to sea calculated from Auckland Council Geomaps. Slope angle measures the sample site angle from the horizontal plane, Exposure is the measure of possible sunlight available; northern and eastern aspect are the direction of the slope, relative to the northern and eastern cardinal points respectively; and soil depth is the average of seven soil depths taken at site.

Subsite	Sample Event	Total area	Veg Cover	Altitude	Dist. to sea	Slope Angle	Exposure	N_Aspect	E_Aspect	Soil depth	Sampling Date
		m^2	%	m	m	degrees	degrees	degrees	degrees	cm	
Piha A	T0	2.8	40	21	78	28	351	130	140	9	15/08/2016
	T1	2.9	61	21	78	28	351	130	140	6	17/12/2016
Piha B	T0	11.5	60	19	83	29	200	45	135	27	15/08/2016
	T1	12.9	74	19	83	29	303	45	135	17	17/12/2016
Piha C	T0	16.2	78	15	85	29	308	45	135	13	15/08/2016
	T1	18.9	90	15	85	29	308	45	135	13	17/12/2016
Brye A	T0	136.4	98	68	58	7	273	162	108	26	5/09/2016
	T1	167.3	98	68	58	6	273	162	108	9	26/01/2017
Brye B	T0	23.0	65	62	38	22	272	125	145	10	5/09/2016
	T1	26.1	78	62	38	35	272	125	145	11	4/02/2017
Brye C	T0	40.3	54	58	36	18	305	180	90	28	8/10/2016
	T1	41.1	58	58	36	22	272	180	90	12	4/02/2017
Beth A	T0	3.8	92	6	86	14	315	90	0	6	30/10/2016
	T1	4.2	89	6	86	14	294	90	0	13	26/11/2016
Beth B	T0	4.4	94	6	88	5	282	45	45	5	13/11/2016
	T1	4.6	94	6	88	12	276	67	23	10	26/11/2016
Beth C	T0	4.2	82	8	69	28	319	180	90	7	13/11/2016
	T1	4.5	78	8	69	29	323	180	90	12	26/11/2016
Average		29	77	29	69	21	294	113	97	13	
Standard error		11.0	4.0	8.3	6.6	2.2	8.2	12.8	11.6	1.7	

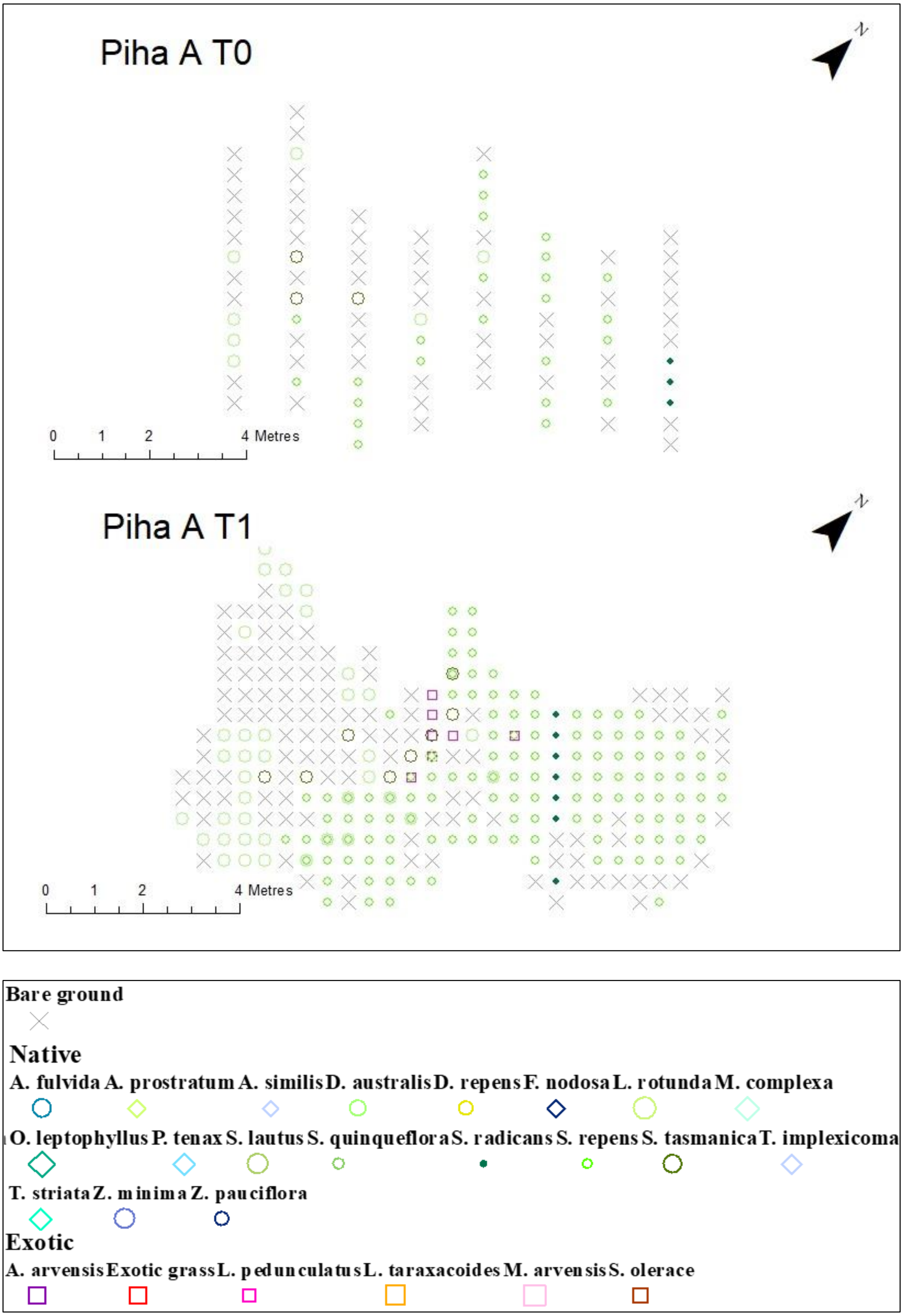

Figure 11. Plot showing species identified at each sample point for subsite Piha A at initial (T0) and repeat sampling event (T1).
Multiple icons at a point show multiple species recorded at that point. Note for Piha A T0 transects were 30cm apart so show fewer sample points than Piha A T1 which had transects 10cm apart.

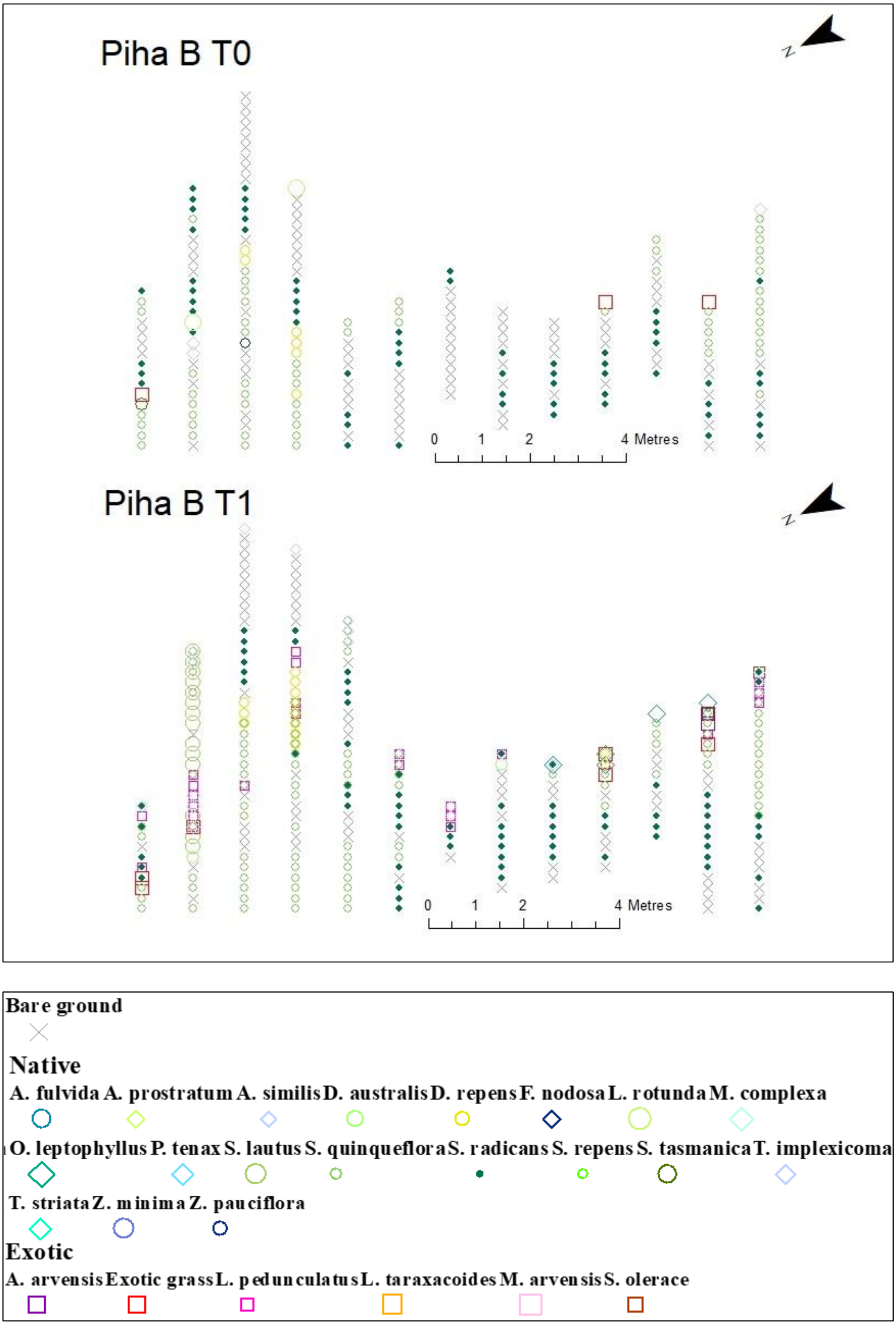

Figure 12. Plot showing species identified at each sample point for subsite Piha B at initial (T0) and repeat sampling event (T1).
Multiple icons at a point show multiple species recorded at that point.

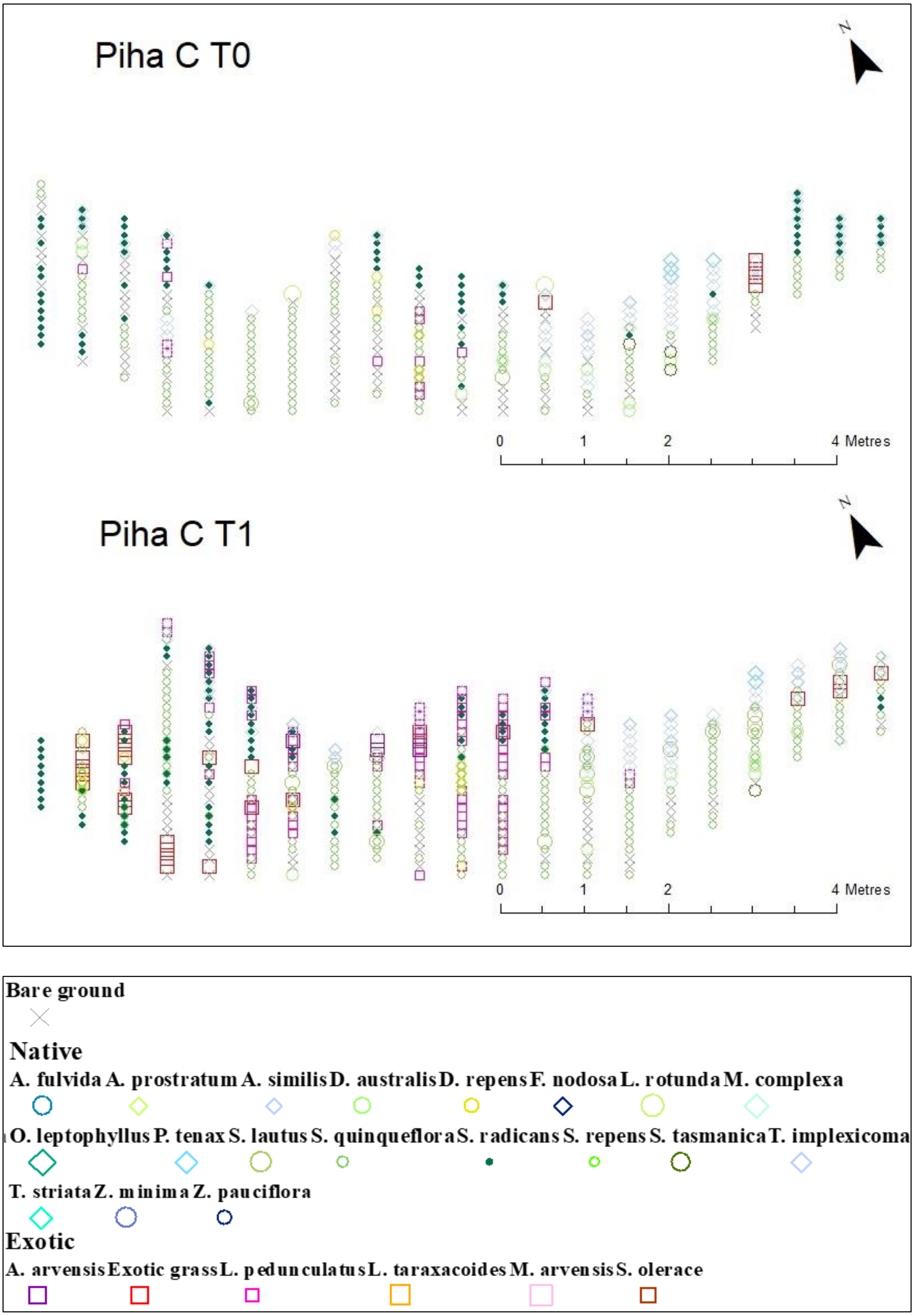

Figure 13. Plot showing species identified at each sample point for subsite Piha C at initial (T0) and repeat sampling event (T1).
Multiple icons at a point show multiple species recorded at that point.

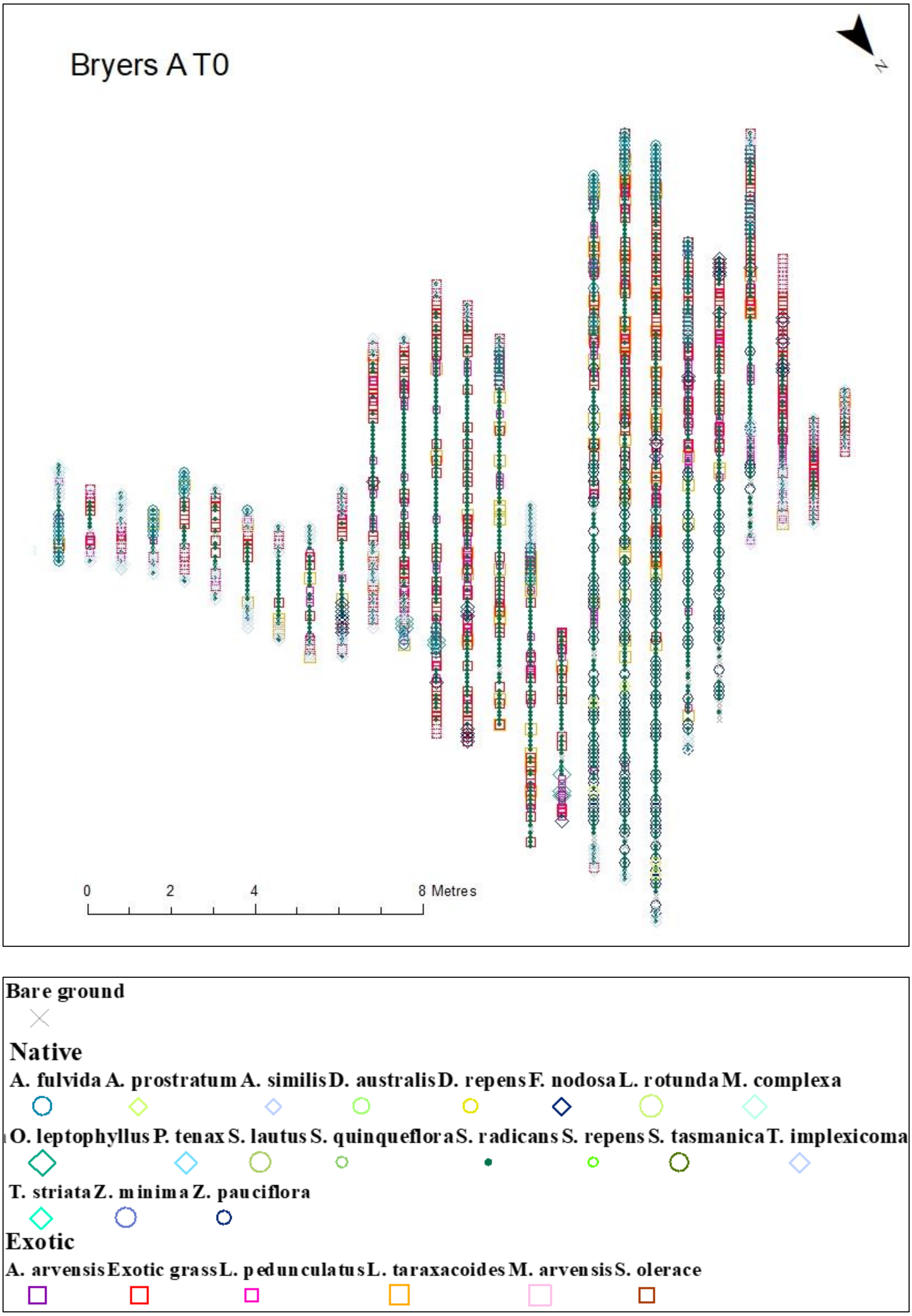

Figure 14. Plot showing species identified at each sample point for subsite Bryers A at initial sampling event. (T0)
Multiple icons at a point show multiple species recorded at that point.

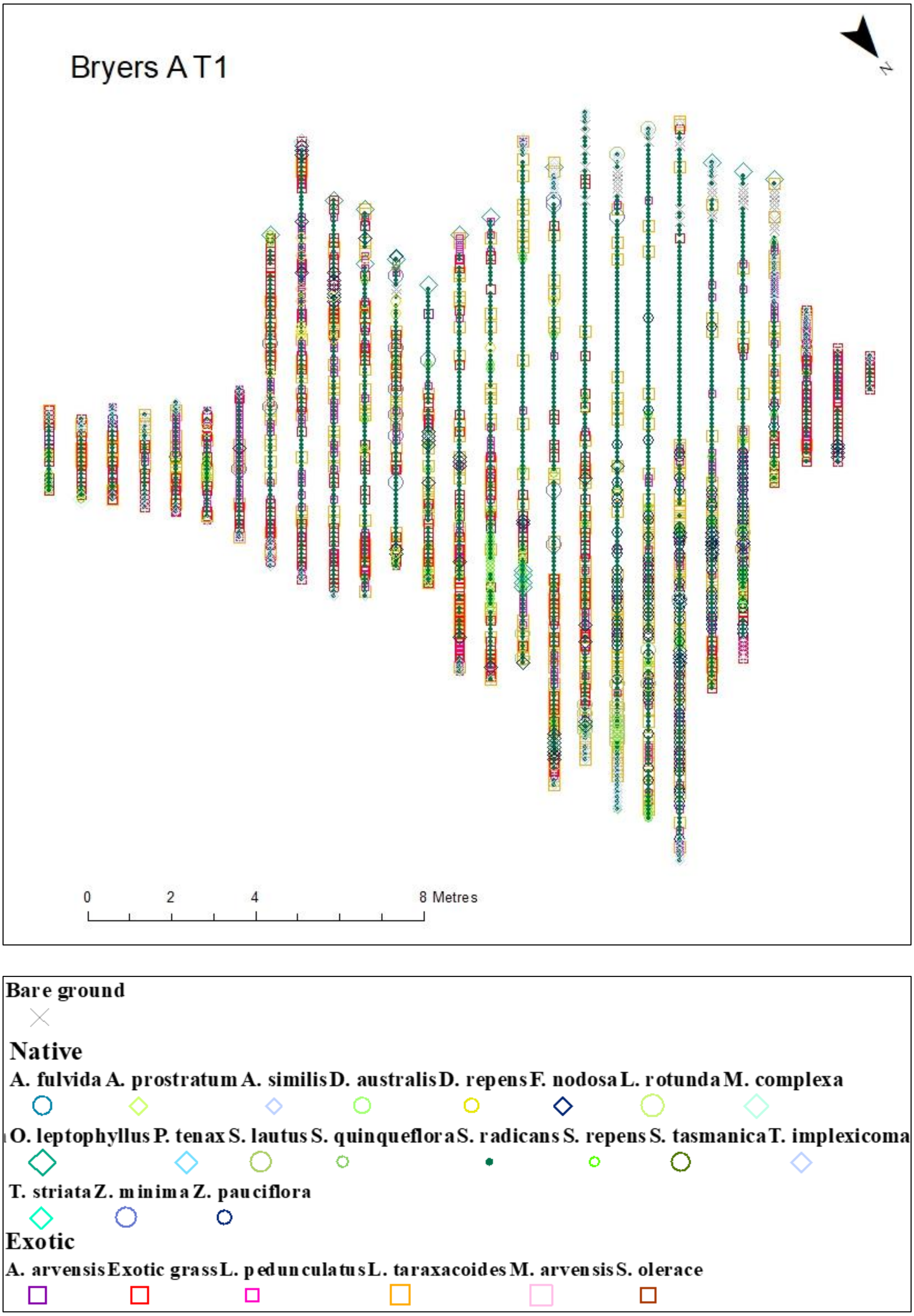

Figure 15. Plot showing species identified at each sample point for subsite Bryers A at the repeat sampling event (T1.)
Multiple icons at a point show multiple species recorded at that point.

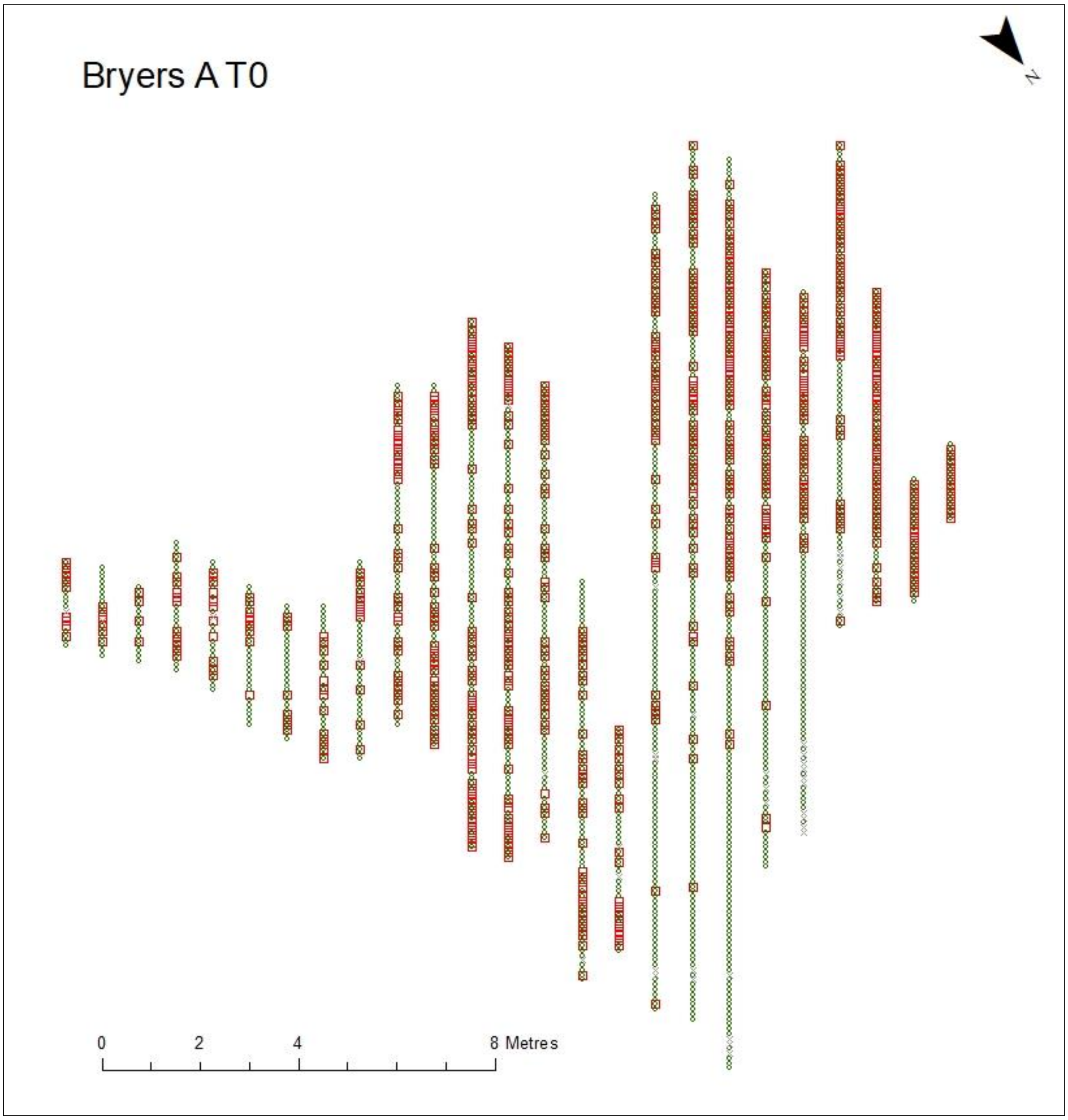

Figure 16. Plot showing presence of native, exotic or no vegetation (bare ground) identified at each sample point for subsite Bryers A at initial sampling event. (T0)

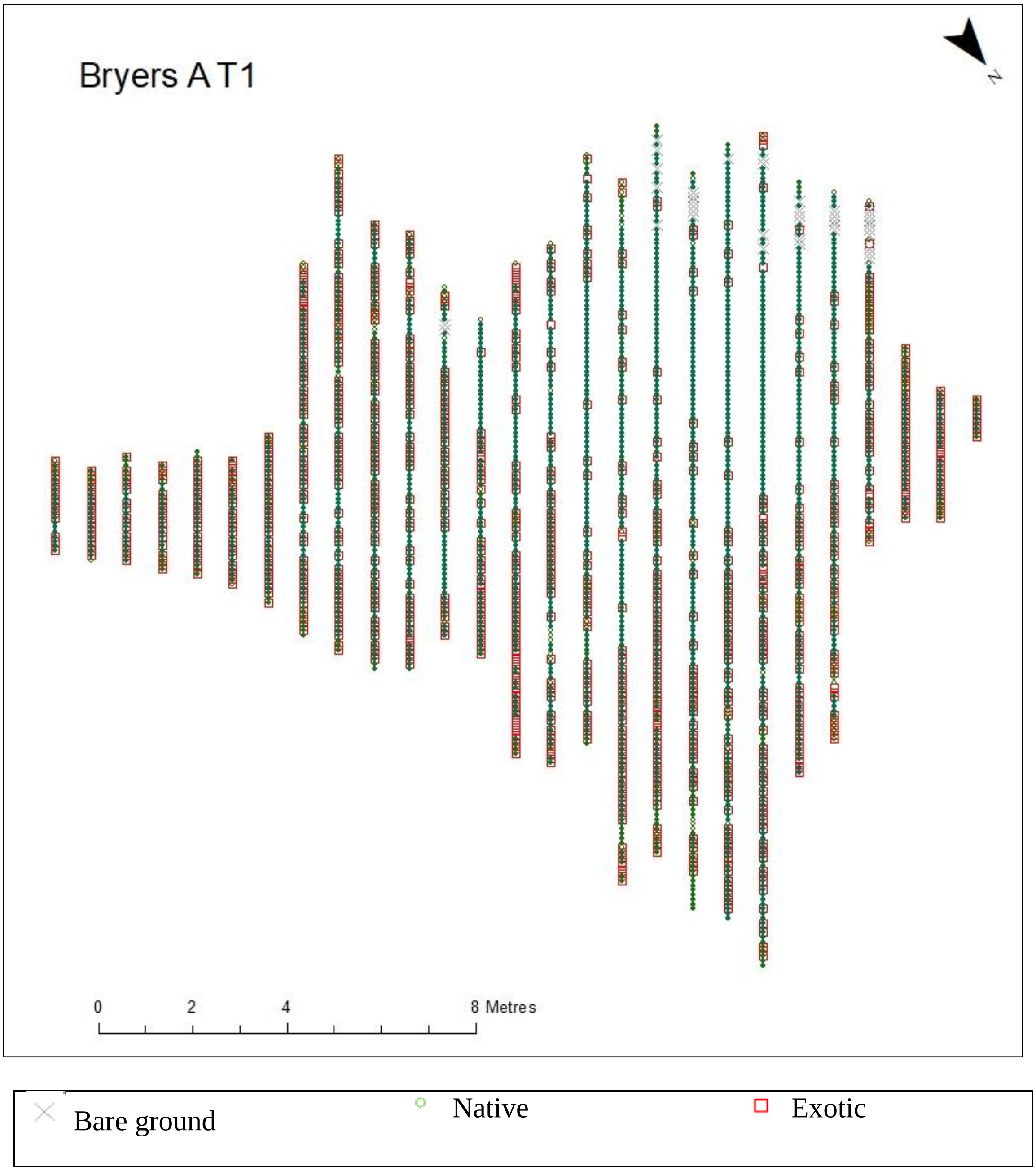

Figure 17. Plot showing presence of native, exotic or no vegetation (bare ground) identified at each sample point for subsite Bryers A at repeat sampling event. (T1).

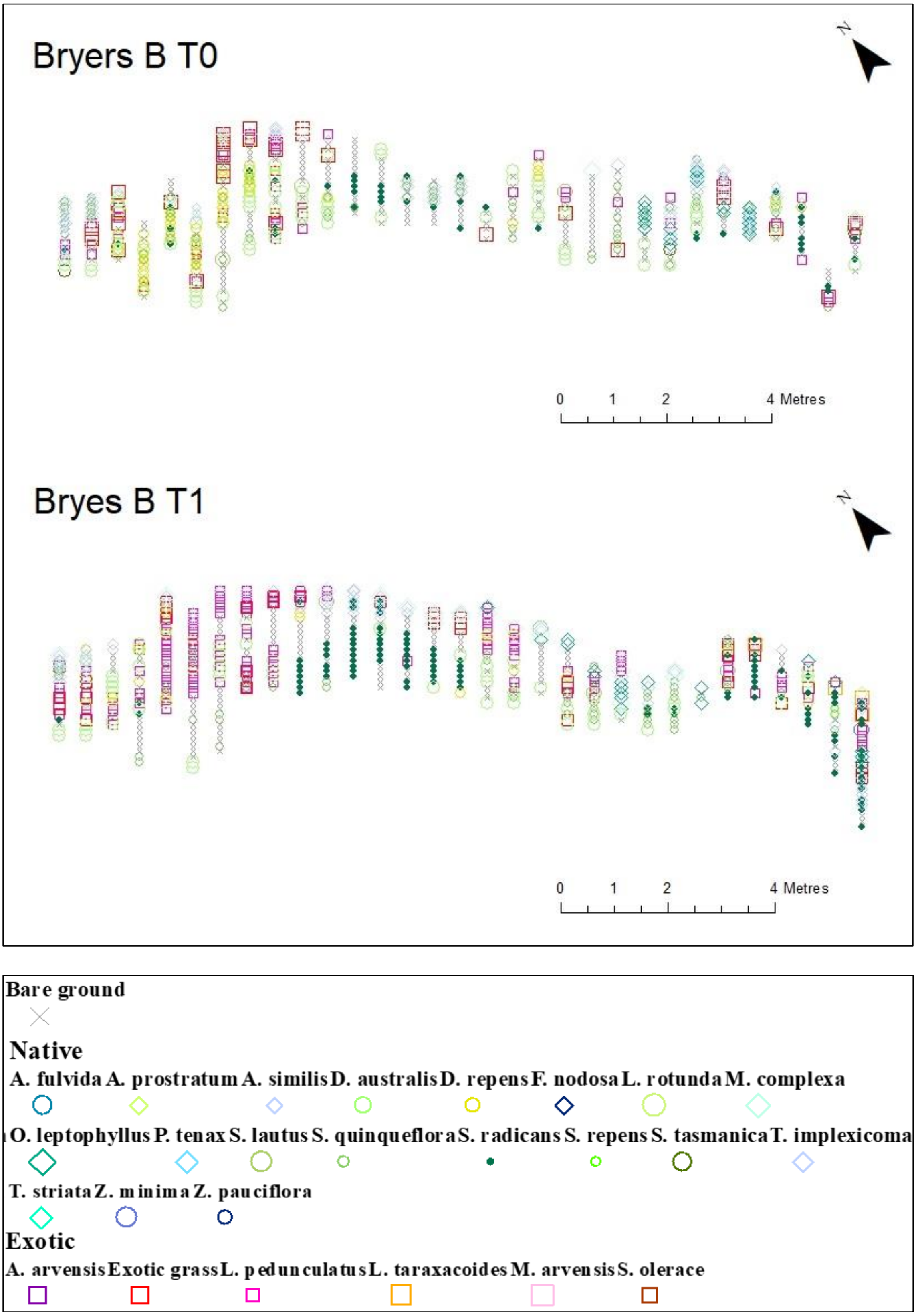

Figure 18. Plot showing species identified at each sample point for subsite Bryers B at initial (T0) and repeat sampling event (T1).
Multiple icons at a point show multiple species recorded at that point.

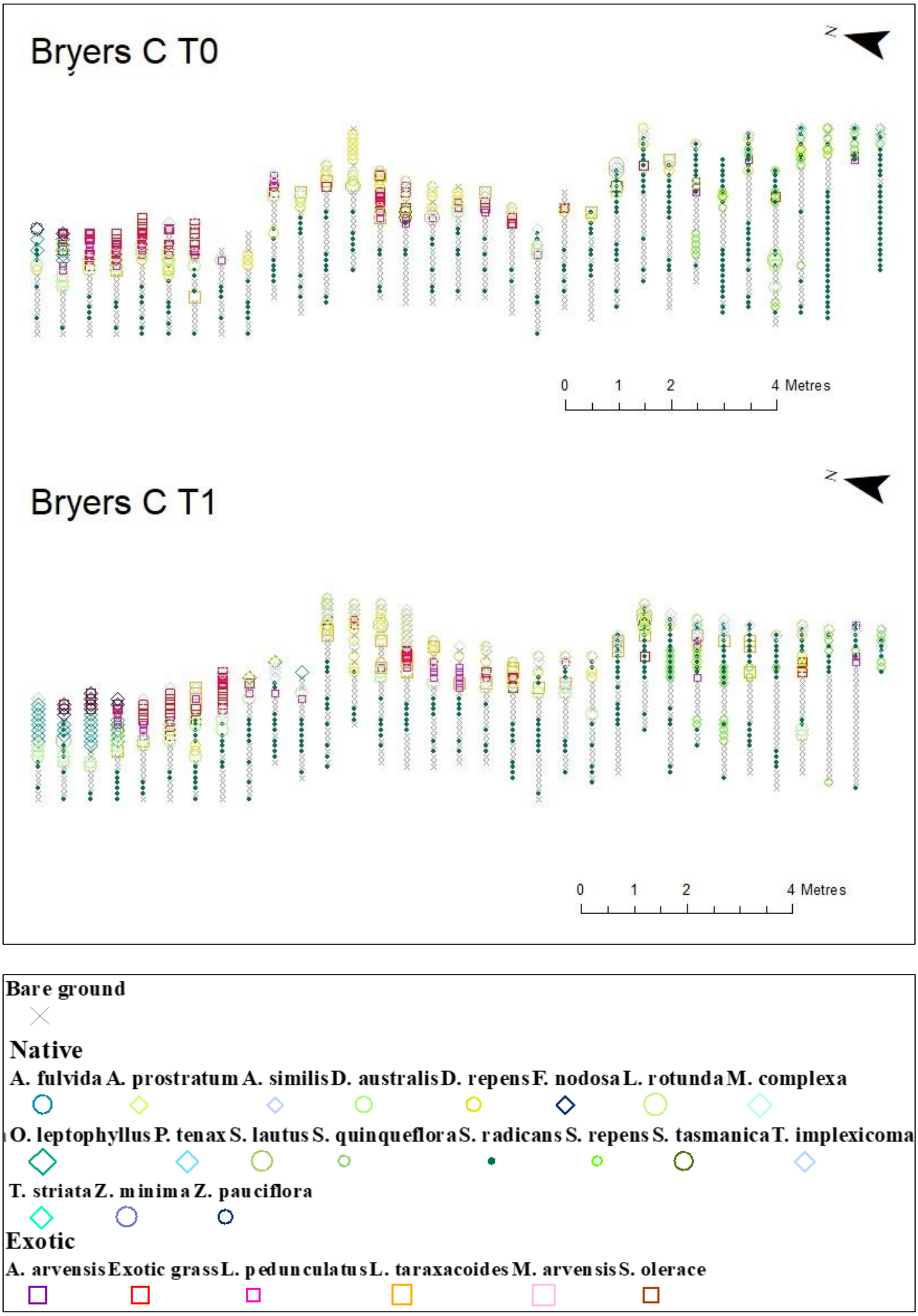

Figure 19. Plot showing species identified at each sample point for subsite Bryers C at initial (T0) and repeat sampling event (T1).
Multiple icons at a point show multiple species recorded at that point.

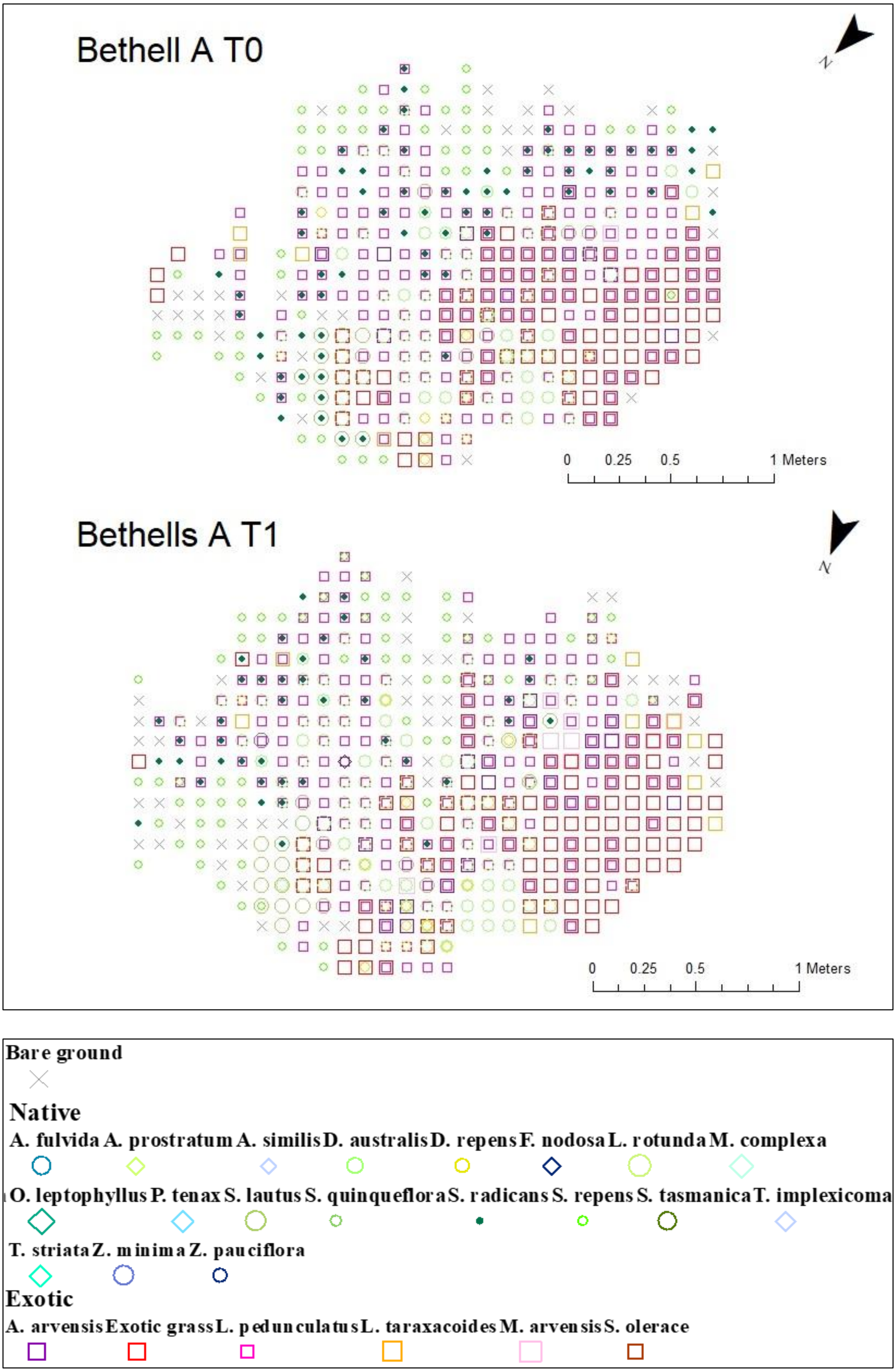

Figure 20. Plot showing species identified at each sample point for subsite Bethells A at initial (T0) and repeat sampling event (T1).
Multiple icons at a point show multiple species recorded at that point.

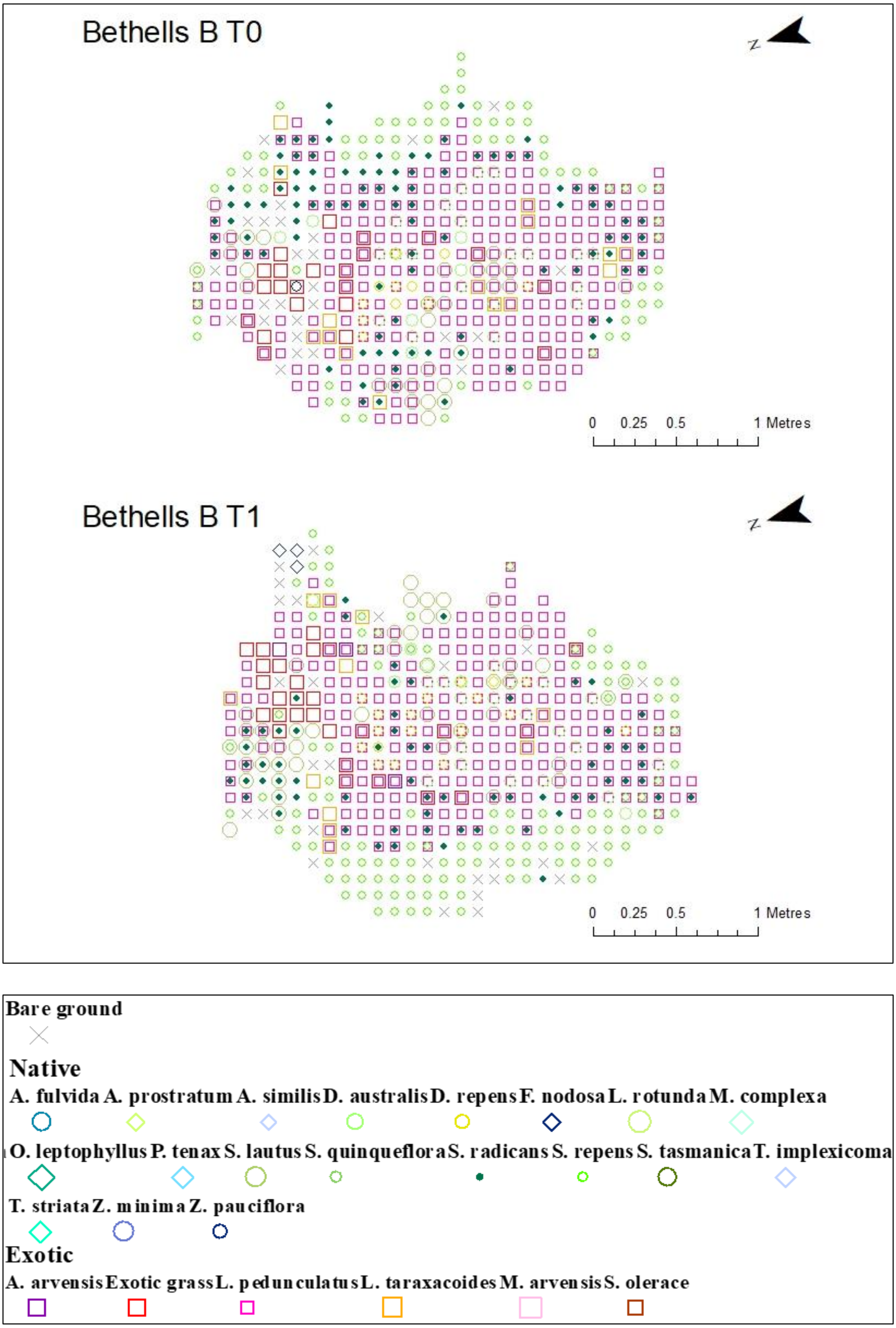

Figure 21. Plot showing species identified at each sample point for subsite Bethells B at initial (T0) and repeat sampling event (T1).
Multiple icons at a point show multiple species recorded at that point.

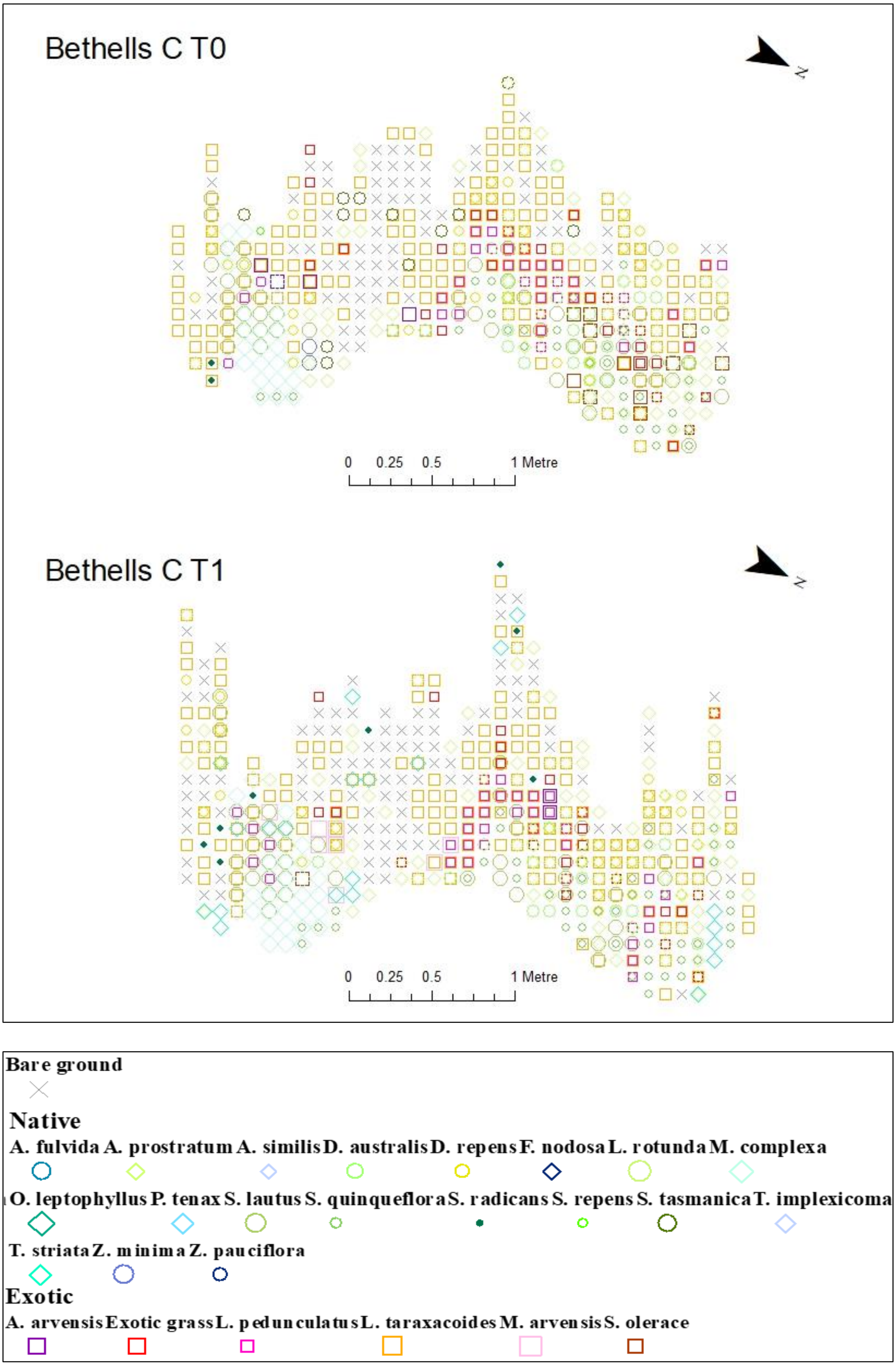

Figure 22. Plot showing species identified at each sample point for subsite Bethells C at initial (T0) and repeat sampling event (T1).
Multiple icons at a point show multiple species recorded at that point.

Change in area

Subsites at Piha ranged in size from 2.76m^2 to 18.85m^2 (Figure 23). All subsites increased in total area between initial (T0) and repeat (T1) sample times. Piha A, the smallest subsite only increased slightly by four percent; Piha B by 12%; and Piha C by 17%. Each subsite also increased in vegetation cover, Piha A increased in vegetation cover by 21%; Piha B by 14%; and Piha C by 12%. Piha A showed the largest relative increase in vegetation at the site.

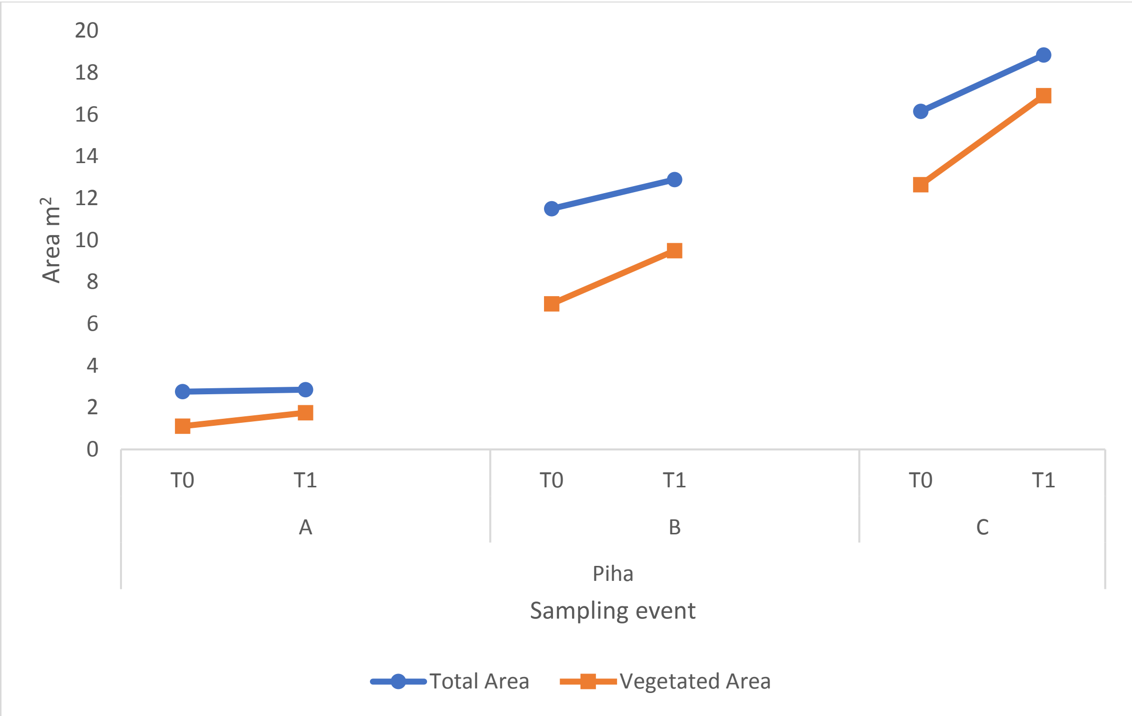

Figure 23. Change in measured total area and area covered by vegetation for Piha subsites at initial (T0) and repeat (T1) sample times.

Bryers subsites ranged in size from 22.95m^2 to 167.33m^2 (Figure 24). Bryers A was the largest subsite and increased area by 23% between sampling events; Bryers B increased by 13%; and Bryers C by only two percent. Bryers A did not increase in percentage vegetation cover, but as the area of the site increased, vegetation cover increased with it (i.e. vegetation cover remained at 98% of total area). Bryers B increased in vegetation cover by 13% and Bryers C by four percent.

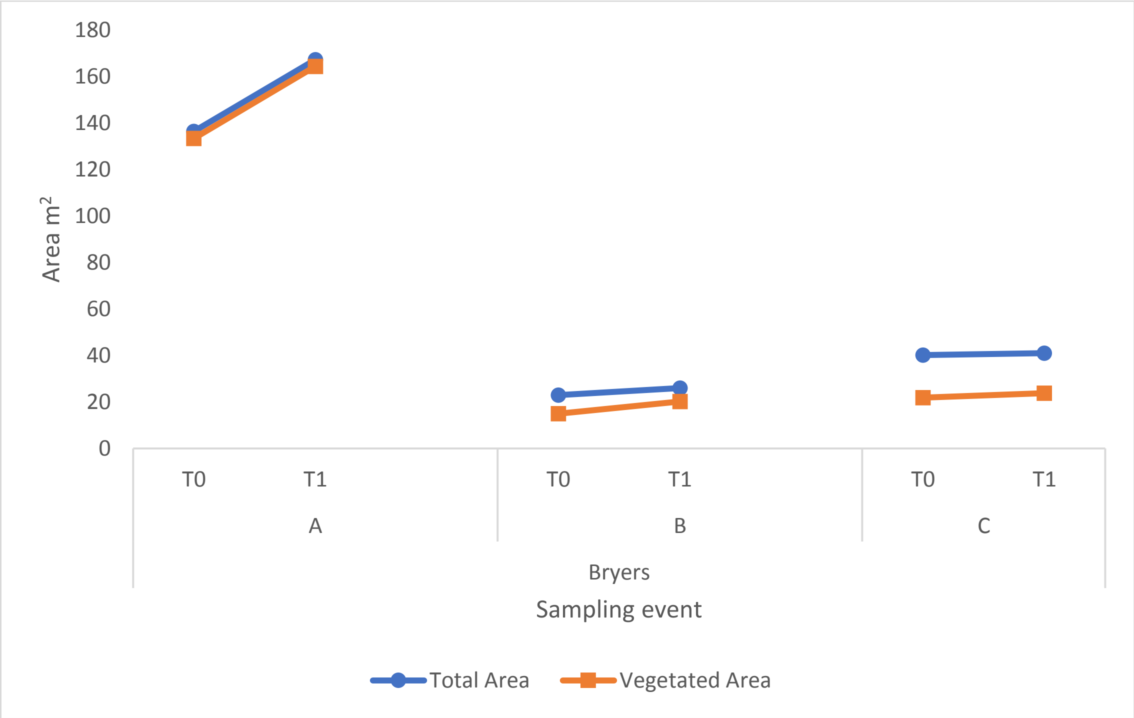

Figure 24. Change in measured total area and area covered by vegetation for Bryers subsites at initial (T0) and repeat (T1) sample times.

Bethells subsites ranged in size from 3.8 m^2 to 4.5 m^2 (Figure 25). All subsites increased slightly in size and vegetation cover between sampling events. Bethells A increased in area by 11% between sampling events; Bethells B increased by five percent; and Bethells C by seven percent. Bethells A decreased in vegetation cover by three percent; there was no change in percentage cover at Bethells B, and Bethells C decreased in vegetation cover by four percent. The decrease in vegetation cover differs to results at Piha and Bryers sites which had longer time intervals between sample times.

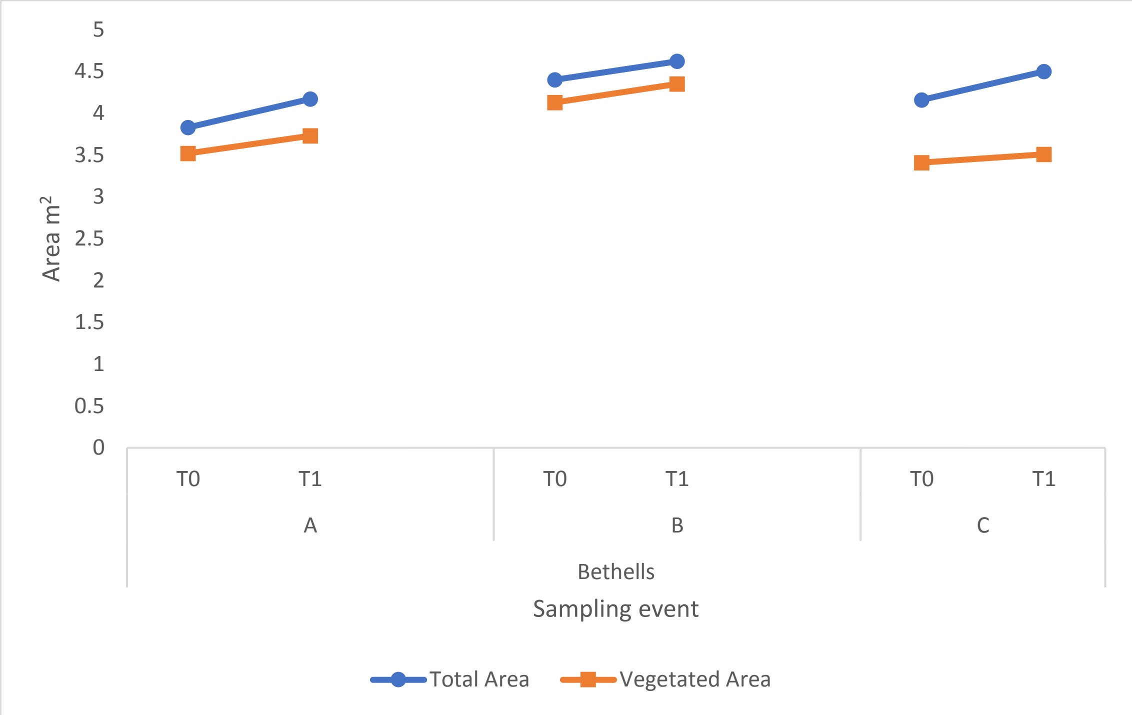

Figure 25. Change in measured total area and area covered by vegetation for subsites at initial (T0) and repeat (T1) sample times.

These results show that at all three sites, subsites held constant or increased in area and that vegetated area generally tracked with the increase in total area. Increase in vegetation cover was generally greater at sites which had initial sample time in the winter and repeat sampling in the summer.

Percentage vegetation cover and relative abundance

Percentage cover for natives, exotics and bare ground (Figure 26) show a higher percentage cover of natives at the Piha and Bryers sites than exotics. This also occurred at Bethells subsite C, but at Bethells A and Bethells B, exotics have a higher percentage cover. Piha A increases in native cover (from 41% at T0 to 64% at T1) with a reciprocal decrease in bare ground. Piha B has the greatest increase in native vegetation cover (from 59% at T0 to 84% at T1). Piha C has the largest increase in exotic cover (from 5% at T0 to 31% at T1). Bryers A has the highest recorded native cover (from 116% at

T0 to 119% at T1) showing that a lot of native species overlapped at the same points. Bryers B is the only subsite that showed a decrease in native vegetation cover (from 78% at T0 to 70% at T1) and also showed an increase of exotic cover (from 18% at T0 to 34% at T1) between sample times. Bethells A had the highest cover of exotics (from 85% at T0 to 84% at T1). Bethells B had more exotics than natives at both sample times, but exotics decreased from 71% to 65% and natives increased from 54% to 61% at T1. Bethells C had similar cover for natives and exotics and bare ground increased slightly between sample times (from 18% at T0 to 22% at T1).

Trends in relative abundance of natives and exotics (Figure 27) differ from percentage cover (Figure 26) at some subsites, but are similar at others. For native percentage cover, all subsites except Bryers B show an increase. For native relative abundance Piha C, Bryers A, Bryers B and Bethells A all show a decrease (between 1% to 7%).

As many of the species overlapped, percentage cover for both natives and exotics was higher at most subsites compared to relative abundance. For example, Piha C T1 natives (98% cover, 70% relative abundance), Bryers A T1 natives (119% cover, 67% relative abundance) and Bethells A T0 exotics (85% cover, 57% relative abundance). At subsites where only small variation between sample times was observed, for example, at Bethells C native percent cover (64% at T0, 66% at T1) and relative abundance (46% at T0 and 47% at T1) changed by only one or two percent, between sample times, although there was a large difference between the two measures (18% to 19%).

At Piha A, where exotic occurrence was minimal, percentage cover and relative abundance was similar (e.g. Piha A T1 natives 64% cover and 61% relative abundance).

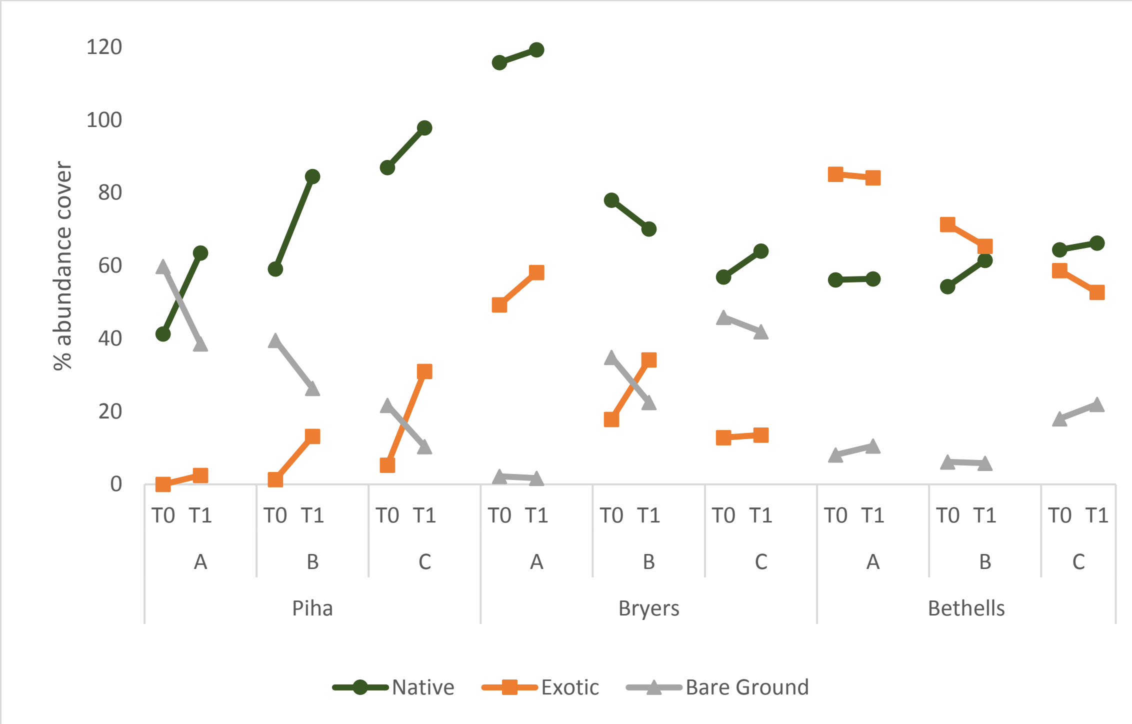

Figure 26. Change in percentage cover of bare ground, native species and exotic species between T0 and T1.
Percent cover was calculated for each species and added together. As species can overlap it is possible to get greater than 100% abundance.

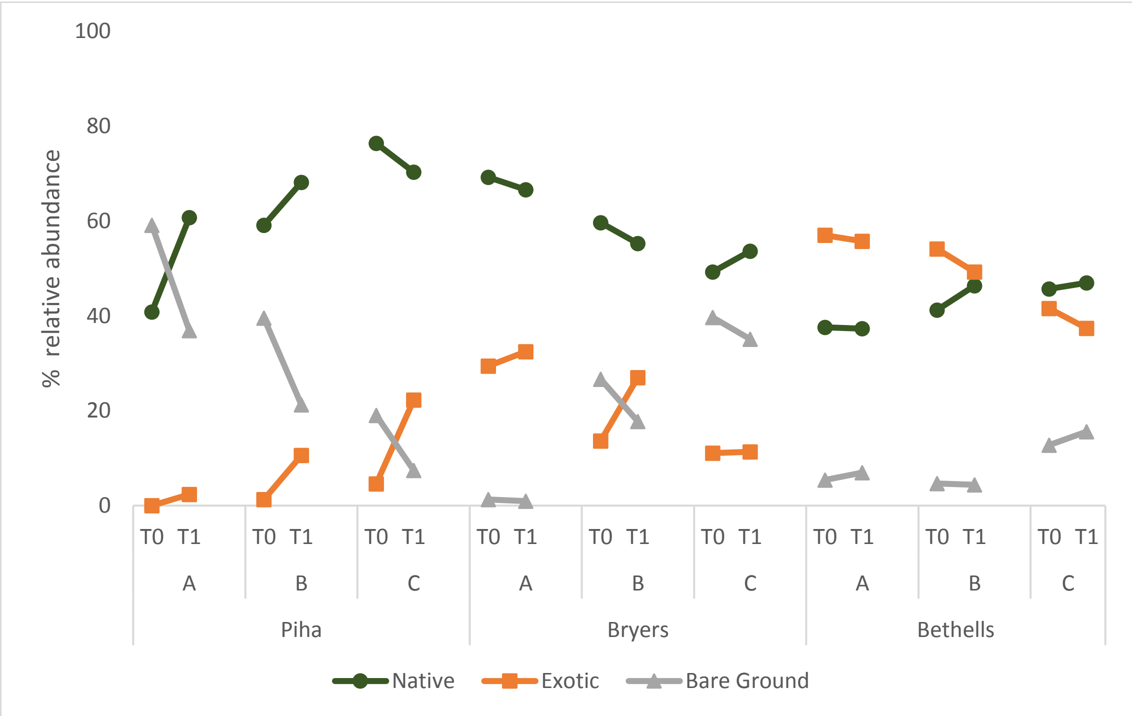

Figure 27. Change in relative abundance of bare ground, native species and exotic species between T0 and T1.

Species Richness

Total species richness ranged from four (Piha A T0) to 16 species (Bryers A T1 and Bryers B T1) (Figure 28). For three subsites, total species richness did not change between sample times (Piha C, 12 species; Bryers C, 12 species; and Bethells B, 10 species). At two subsites, species richness increased by four species (Piha B, from eight to 12 species and Bryers A from 12 to 16 species). Piha B had one extra native and three extra exotic species identified at T1, for Bryers three extra natives and one extra exotic were identified. Only at one subsite (Bethells C) was a decrease in species richness observed (two native species fewer, but with an increase of one exotic).

Across all sample events an average of 8.2 native species, 3.3 exotic species and 11.1 total species per subsite were observed. More native species than exotics were present across all sites, although exotic species composition estimate is conservative as all exotic grasses were classed into one species group.

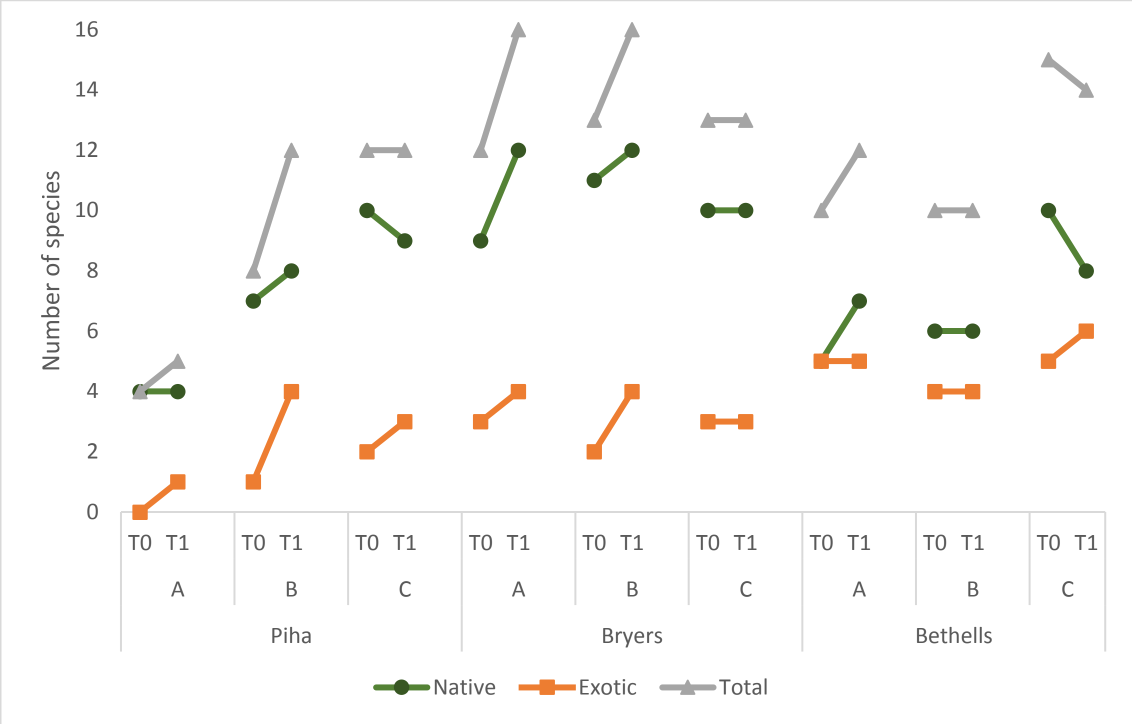

Figure 28. Species richness for total, native and exotic species, showing change in richness from T0 to T1.
Note exotic grasses are all categorised as one species.

Nonmetric multidimensional scaling ordination

Nonmetric multidimensional scaling (NMS) ordinations of species presence and absence at different subsites and times are shown in Figure 29 and Figure 30. Same day sampling was undertaken at Bethells sites (Bethells T1 and T2) to help assess sampling error and the results are included in this analysis. The NMS ordination had a final stress of 6.86 for a three-dimensional solution.

Most exotic species (*A. arvensis*, exotic grass, *Leontodon taraxacoides*, *Lotus. pedunculatus* and *M. arvensis)* occur closely grouped along axis one (Figure 29). Three exotic species (*A. arvensis*, *L. pedunculatus* and *M. arvensis*) group tightly on axis one and axis two. The native species *A. fulvida* and *Z. pauciflora* group tightly together in the top right corner of the ordination, close to the subsite Bryers A, the only subsite where these species were found in any significant quantity. The No_Veg point, representing bare ground, occurs towards the left of axis one, reflecting the low vegetation cover observed at subsite towards the left of axis one. The species *A. prostratum, M. complexa, S. oleraceus* and *T. striata* all group in the upper middle of the ordination, close to subsite Bethells C where they were predominantly found.

The positions of species in the ordination space relative to different subsites indicate which species are most responsible for differences among subsites. More common species which occurred across the subsites had a central position in the ordination. *Selliera radicans* was observed at every subsite, but has high concentrations at Bryers A (82% cover at T0 and 92% cover at T1), placing this species closer towards that subsite in the ordination. *Dichondra repens* occurred at all sites except Piha A, and *Disphyma australe* occurred at all sites except Bryers A and these species are placed centrally along axis one of the ordination.

On axis 1 and axis 2 of the NMS ordination (Figure 29), repeated surveys of the same subsite at Piha A, Bryers A. Bryers C and all Bethells subsites are grouped tightly between sampling events. Piha B, Piha C and Bryers B showed looser grouping between sampling events. Bryers B (T0) is closer to Piha B (T0) than its repeat sample (Bryers B T1). Bryers A and Bryers C repeat samples group closely together and have a similar time period between sampling events as Bryers B (four to five months), which has the loosest grouping between sample events. Sampling at Bethells subsites between initial (T0) and repeat (T1) sampling was between 13 and 27 days apart. Repeat sampling undertaken on the same day (T1 and T2) grouped closer together than with initial sampling time (T0). The close correspondence in species composition shown in the ordination between subsites sampled on the same day suggests that the methods provide consistent results, over at least short time periods. This suggests the recorded change between T0 and T1 at the Bethells subsites is real and not solely due to sampling error.

Subsites Piha B and Piha C loosely group together, but subsite Piha A does not group with these and is located at the bottom left of the ordination. Piha A was more sparsely vegetated and was surrounded by bare ground while Piha B and Piha C fringe non-turf vegetation. Bryers B and Bryers C loosely group together, but Bryers A does not and is located at the top right of the ordination. Bryers B and C fringe other non-turf vegetation and have bare rock on their outer edges, whereas Bryers A is a large flat subsite surrounded completely by non-turf vegetation. Bethells B and Bethells C group closely together and Bethells C occurs closer to other subsites (Bryers B and Piha C) in the ordination. This shows variation between subsites can be greater than variation between sites, possibly relating to subsite environmental variables.

Along axis one of the ordination, vegetation coverage explains differences in species composition, with high vegetation cover sites (Bryers A, Bethells A and Bethells B) situated towards the right of the graph; and sites with low vegetation cover (Piha A and Bryers C) situated towards the left of the graph. Where change in vegetation cover occurred such as Piha B (changed from 60% (T0) to 74% (T1) vegetation cover), and Bryers B (changed from 65% (T0) to 78% (T1) vegetation cover), movement along axis one towards the right is observed. Subsites with a shallow slope angle were also towards the right of the axis one (Bryers A (6^o to 7^o), Bethells A (14^o) and Bethells B (5^o to 12^o)).

Environmental variables relating to position along axis two are eastern aspect, soil depth, altitude and area. For area the smaller subsites sit (Piha A, Bethells A and Bethells B) near the bottom of axis 2 and the largest (Bryers A) towards the top. For altitude some subsites of similar altitude group together (Piha B and Piha C, Bethells A and Bethells B), whilst others do not group strongly. Piha B and C are at similar altitude and are at a similar point along axis 2, as are Bethells A and B. However, Piha A and Bethells C occur far away along axis two from the other subsites within their respective sites, which occur at a similar altitude. The environmental variables that relate strongest with subsite position are vegetation cover and slope for axis one, and eastern aspect and area for axis two.

Figure 30 shows axis 1 and axis 3 of the NMS ordination. Results along axis 1 are the same as that shown in Figure 29, but there are some differences along axis 3 as compared with axis 2. Notably Bethells C sampling events are placed at the top of axis 3, compared to the more central grouping showed in the previous figure. Piha A and Bryers A are also centralised along axis 3 compared to the bottom and top of axis 2.

The main environmental variable that relates with axis 3 is northern aspect. Bethells C (northern aspect 180^{o}) lies at the top of axis 3 and Piha C (northern aspect 45^{o}) at the bottom.

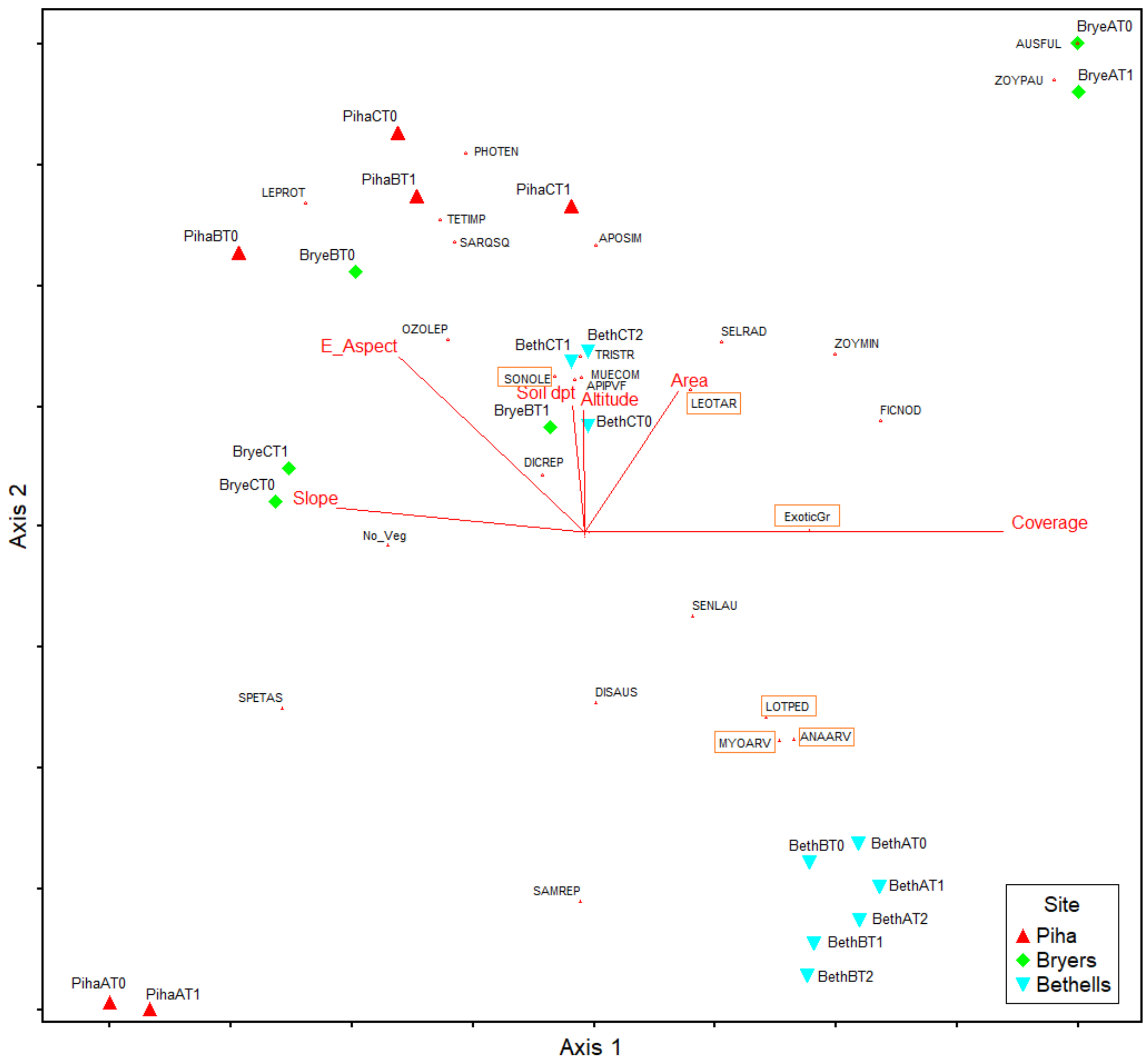

Figure 29. NMS Ordination of data collected showing axis 1 and axis 2.
Sampling events for each subsite along with the NVS species code for species found are shown, refer to Appendix 1 for species information. Exotic species outlined in orange. Also shown are measured environmental variables with the highest correlation to axis 1 and 2.

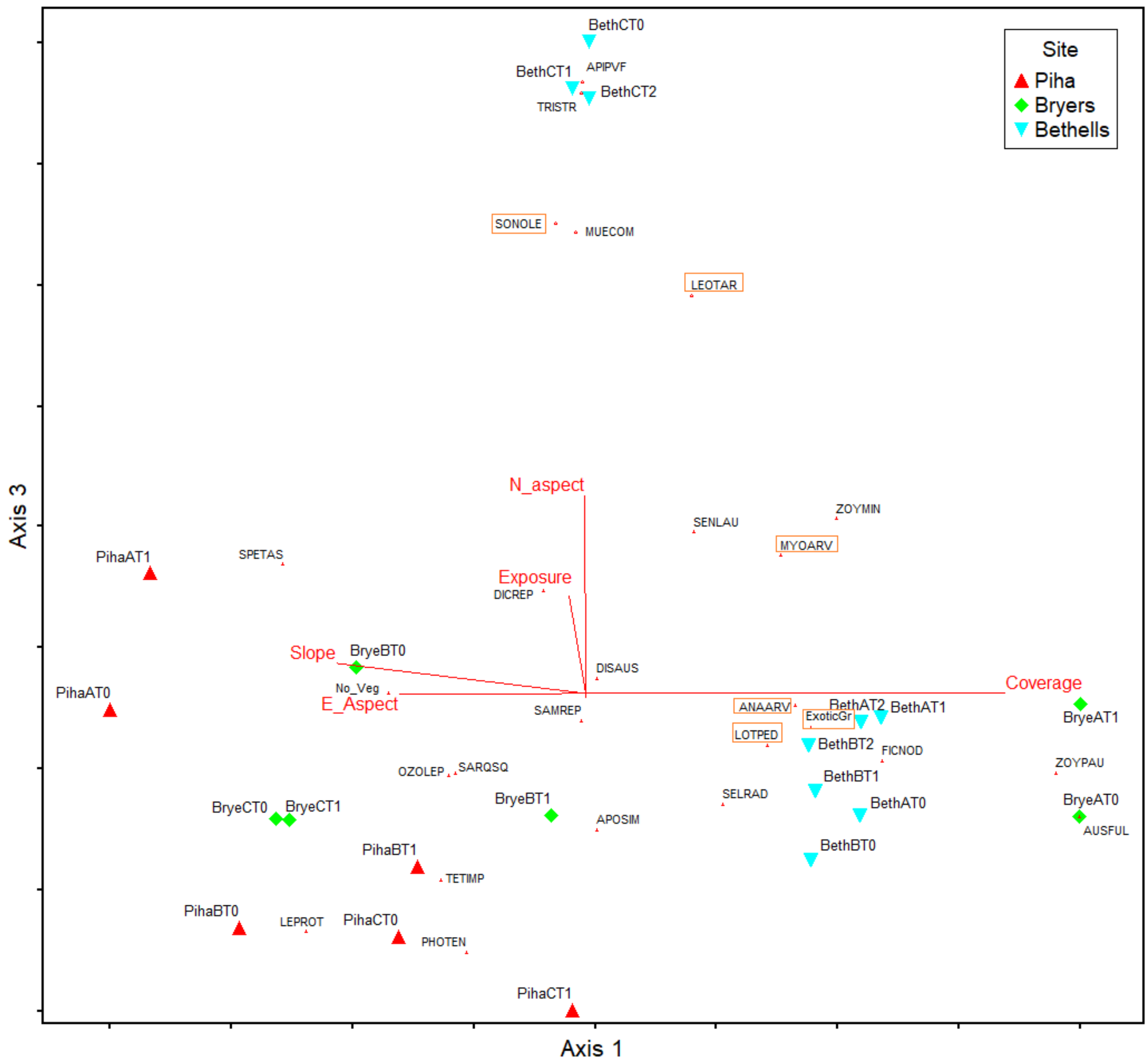

Figure 30.NMS Ordination of data collected showing axis 1 and axis 3.
Sampling events for each subsite are shown along with the NVS species code for species found, refer to Appendix 1 for species information. Exotic species are outlined in orange. Also shown are measured environmental variables with highest correlation to axis 1 and 3.

5.2.3 Indicators and data presentation

The proposed ecosystem condition grades for change in native and exotic cover (Table 8) provide a means for comparing subsites and sites with each other and over time. The grades were also applied to change in area and vegetated area (Table 9).

Table 8. Proposed ecosystem condition scale for native vegetation cover and non-native dominance.
Adapted from Bellingham, et al. (2016)

	Ecosystem condition (at any specific location)			
Indicator	Very poor	Poor	Moderate	Good
Native vegetation cover	≥80% decline in native vegetation cover	≥50% decline in native vegetation cover	≥30% decline in native vegetation cover	≤30% decline in native vegetation cover
Non-native plant and animal dominance	Non-native plants considered a threat account for ≥80% of total vegetation cover	Non-native plants considered a threat account for ≥50% of total vegetation cover	Non-native plants considered a threat account for ≥30% of total vegetation cover	Non-native plants considered a threat account for ≤30% of total vegetation cover

Table 9. Proposed ecosystem condition scale for change in area and change in vegetated area for subsites and sites.

	Ecosystem condition (at any specific location)					
Indicator	Very poor	Poor	Moderate	Good	Very good	Excellent
Change in area	≥50% decline in total area	20-50% decline in total area	1-20% decline in total area	0-20% increase in total area	20-50% increase in total area	≥50% increase in total area
Change in vegetated area	≥50% decline in vegetated area	20-50% decline in vegetated area	1-20% decline in vegetated area	0-20% increase in vegetated area	20-50% increase in vegetated area	≥50% increase in vegetated area

Change in total area of each subsite (Figure 31) shows an increase at all subsites between initial (T10) and repeat (T1) sample times. All except one subsite (Bryers A) increase within one grading band. Vegetation cover increases between sampling events for Piha and Bryers sites, where initial sampling was undertaken in winter or early spring, and repeat sampling was undertaken in the summer, except for subsite Bryers A. At Bryers A, vegetation cover was already high (98% cover) and did not change appreciably between sampling events. The largest change in vegetation cover occurred at Piha A (an increase of 21% vegetation cover), which was the subsite that was most sparsely vegetated. At the Bethells subsites vegetation cover either decreased (Bethells A and Bethells C) or stayed constant (Bethells B). Bethells subsites had much less time between sample events. The proposed grading bands provide broad categories for any changes observed.

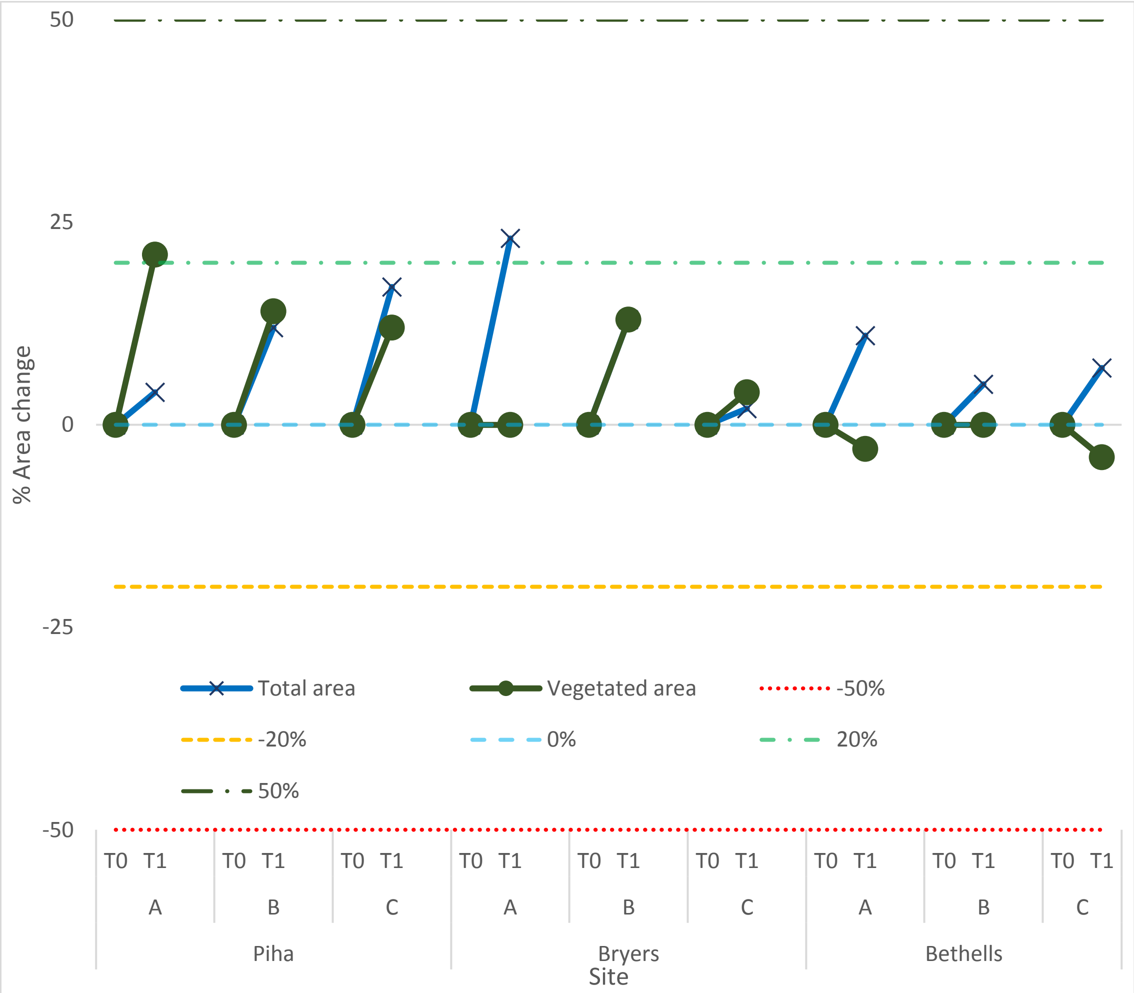

Figure 31. Percentage change in total area and vegetated area between initial (T0) and repeat (T1) sampling events at each subsite.
Colour grading bands for change in ecosystem area are shown.

Percentage native cover (Figure 32), with grading bands applied, compares native dominance between sample times and also provides a relative comparison of native dominance between subsites. Subsites Piha A and Piha B increased in native cover between sample times and also changed bands. Other subsites changed in native vegetation cover, but stayed within their grades. Piha C, Bryers A and Bryers B were all in the highest band for native vegetation cover; Bryers C and all three Bethells subsites were in the next band down.

Comparing this with relative abundance of natives (Figure 33), grading for most subsites is lower than that for percentage cover. For example, Bryers A, Bryers B, and all three Bethells subsites are all a grade lower. Piha A has a similar trend between percent cover and relative abundance, but had very low incidence of exotic occurrence. Piha B changed bands in percentage cover, but did not in relative abundance. Generally native cover is shown in a higher grade with percentage cover than with relative abundance.

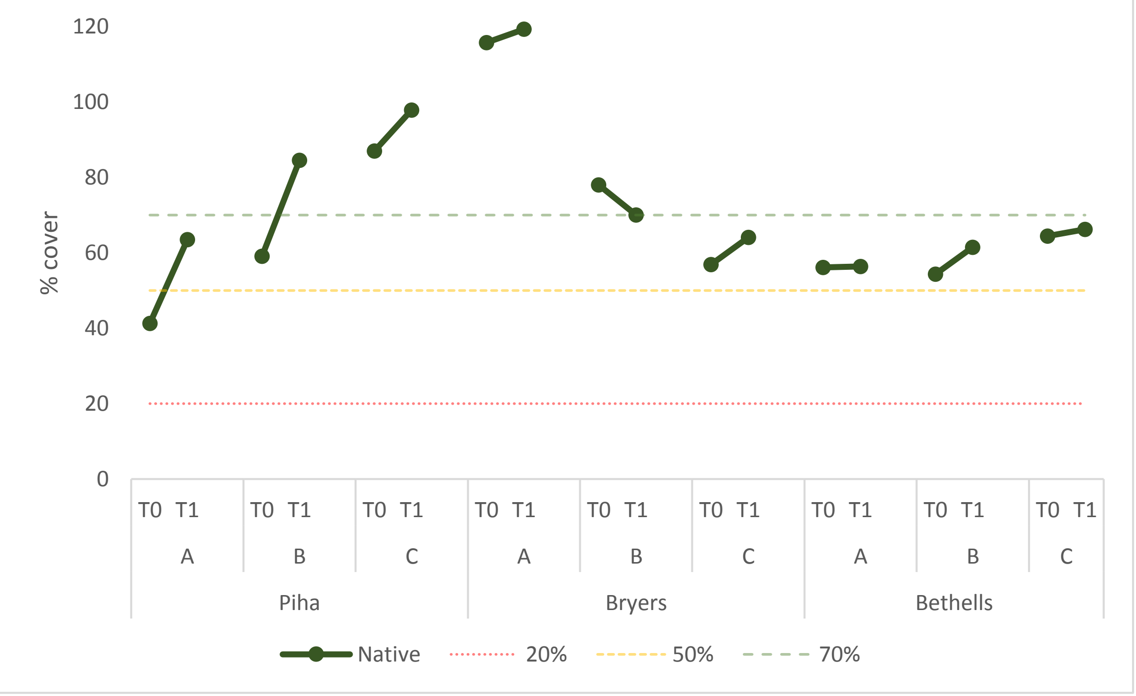

Figure 32. Percentage cover of natives for each subsite at initial (T0) and repeat (T1) sample times.
Colour grading bands for ecosystem condition are shown.

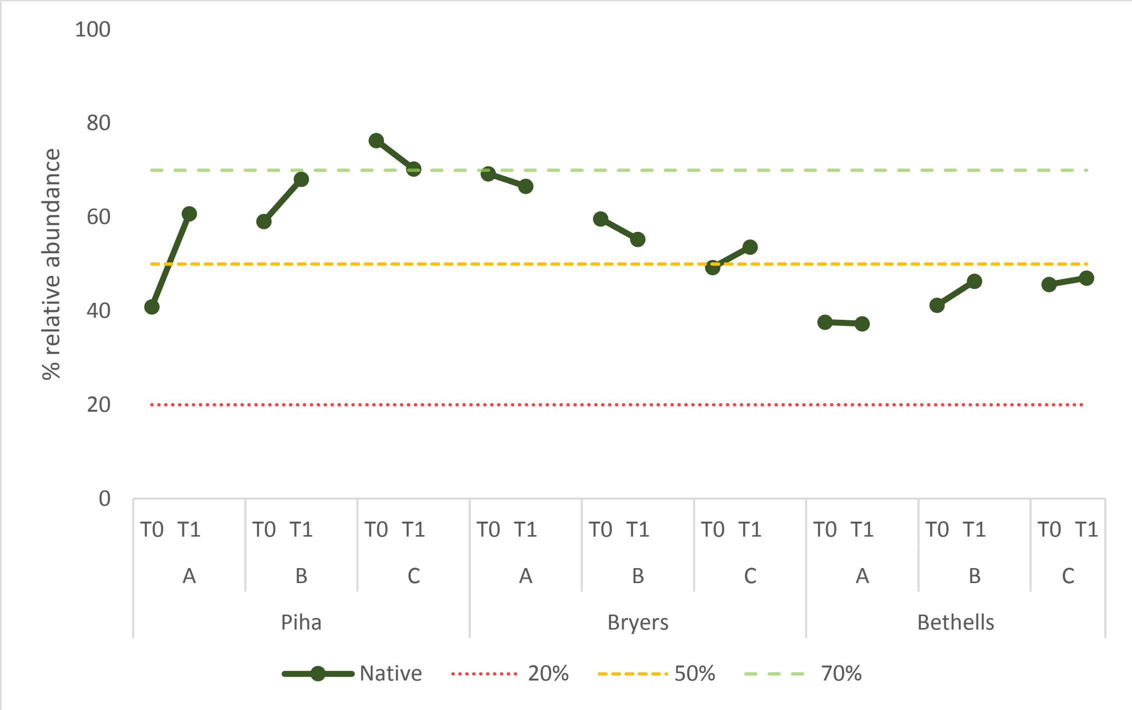

Figure 33. Percentage relative abundance of natives for each subsite at initial (T0) and repeat (T1) sampling events
Colour grading bands for ecosystem condition are shown.

Exotic dominance was presented for percentage cover of each subsite with proposed bandings (Figure 34). For exotic dominance, low exotic cover is considered ‘good’ and high cover ‘very poor’. Total exotic vegetation cover increased at all Piha and Bryers sites between T0 and T1. These sites had longer time periods between sampling than Bethells sites. Piha C and Bryers B had relatively large increases of exotic vegetation cover between sample times (both had a 19% increase) but stayed within the lowest grade. Bryers A increased the same amount (19%) but changed grades to the second lowest. Exotic cover at the Bethells site decreased between sample times (between 5%(Bethells A and Bethells C, and 7% (Bethells B) decrease in exotic cover).

Comparing exotic cover for the total area (Figure 34) with exotic relative abundance (Figure 35), all three Piha sites changed by similar percentage (within 1%). Bryers A had a 19% increase in percentage cover, but only a 2% increase in relative abundance.

Bryers B and C stayed within the best grade for both relative cover and percent cover. Bethells A and Bethells C stayed within the same grading bands. Bethells B had higher exotic percent cover (64% at T0 and 57% at T1) with a 7% change, compared to relative abundance (54% at T0 and 49% at T1) but improved a grade in relative abundance.

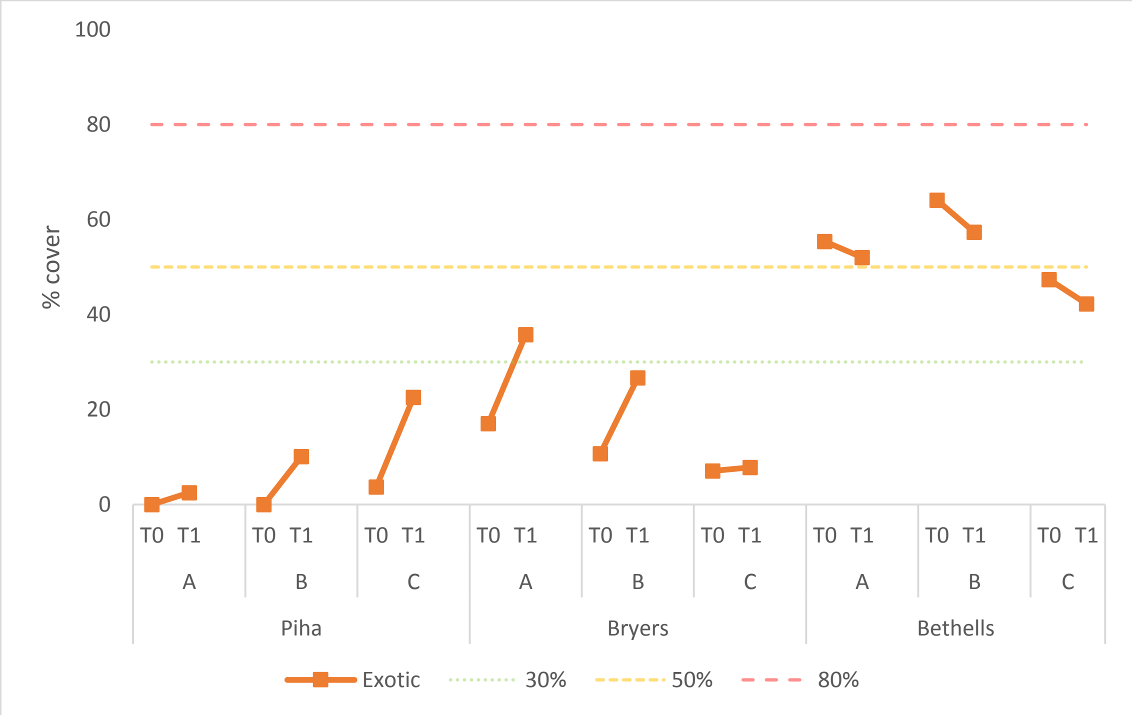

Figure 34. Percentage cover of exotics for each subsite at initial (T0) and repeat (T1) sample times
Colour grading bands for ecosystem condition are shown. Cover calculated including bare ground.

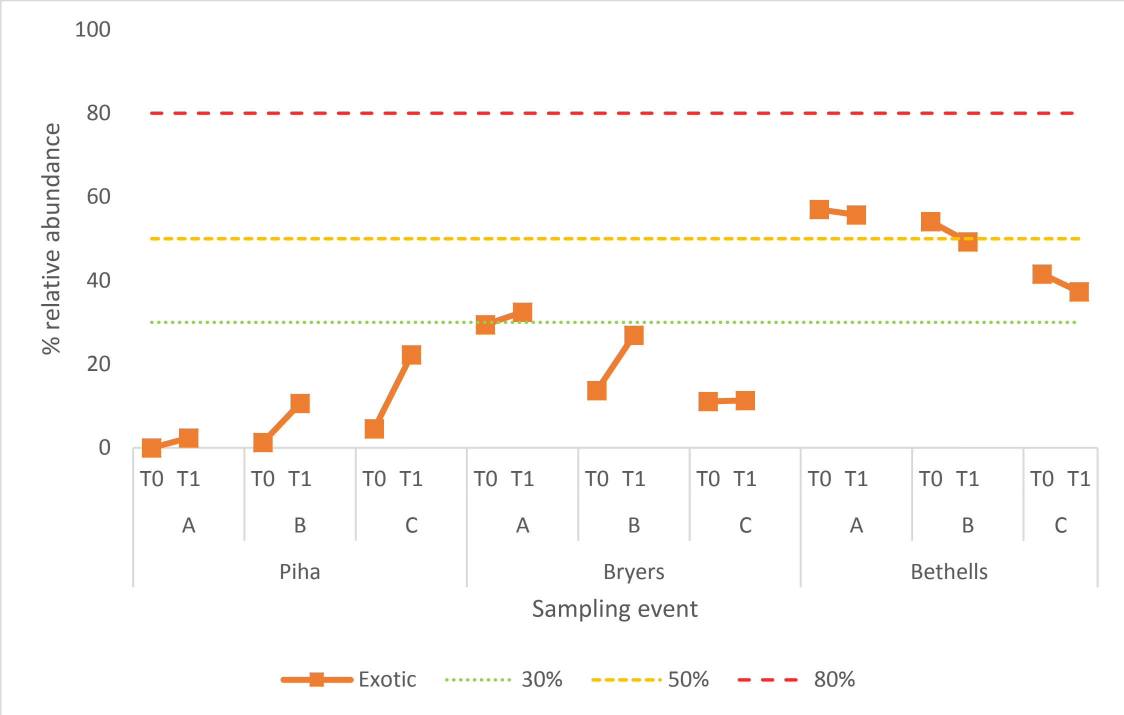

Figure 35. Percentage relative abundance of exotics for each subsite at initial (T0) and repeat (T1) sample times.
Colour grading bands for ecosystem condition are shown. Cover calculated including bare ground.

Report cards

Report cards at site and subsite level for change in total and vegetated area, change in percentage native cover, and change in relative abundance of exotics are displayed (Table 10 to Table 15) as examples of how monitoring results may be presented to the general public. These report cards represent the graphical data (in Figure 31, Figure 33 and Figure 35) in table format with coloured grades presented as a suitable format for rapid assessment of many sites or subsites.

All three sites can be seen graded as ‘good’ for their spatial area change (Table 10). All sites had ‘moderate’ native vegetation cover (

Table **12**) and Piha and Bryers had ‘good’ (<30%) exotic cover (Table 14). The Bethells site can be clearly identified as being heavily impacted by exotic plants and a change in grading between sample times (rated ‘poor’ at T0 and ‘moderate’ at T1) (Table 14). Comparing this to the subsite report card for exotics (Table 15) it can be seen that two of the subsites (Bethells A and Bethells B) are more heavily impacted (>50%) than Bethells C.

Table 10. Percentage change in total area and vegetated area between initial (T0) and repeat (T1) sampling events at each site.
Colour grading for change in ecosystem area is shown.

Site	Percentage change in area from initial sampling event				Grading for change in area	
					Very poor	≤ -50%
					Poor	-20 to -50%
	Total area	S.E.	Vegetated area	S.E.	Moderate	-20 to 0%
Piha	+11	4	+16	3	Good	0 to +20%
Bryers	+13	6	+6	4	Very good	+20% to +50%
Bethells	+8	2	-2	1	Excellent	> +50%

Table 11. Percentage change in total area and vegetated area between initial (T0) and repeat (T1) sampling events at each subsite.
Colour grading for change in ecosystem area is shown.

Site	Percentage change in area from initial sampling event		Grading for change in area	
	Total area	Vegetated area		
Piha A	+4	+21		
Piha B	+2	+14		
Piha C	+7	+12		
Bryers A	+23	0	Very poor	≤ -50%
Bryers B	+13	+13	Poor	-20 to -50%
Bryers C	+2	+4	Moderate	-20 to 0%
Bethells A	+11	-3	Good	0 to +20%
Bethells B	+5	0	Very good	+20% to +50%
Bethells C	+7	-4	Excellent	> +50%

Table 12. Average percentage cover of natives for each site at initial (T0) and repeat (T1) sampling events.
Colour grading for ecosystem condition and standard error are shown. Cover calculated including bare ground.

Site	% Native Cover per Sampling Event				Key	
	T0	S.E.	T1	S.E.	Very poor	≤20% native cover
Piha	62	13	82	10	Poor	21-50% native cover
Bryers	84	17	84	17	Moderate	51-70% native cover
Bethells	58	3	61	3	Good	>70% native cover

Table 13. Percentage cover of natives for each subsite at initial (T0) and repeat (T1) sampling events.
Colour grading for ecosystem condition is shown. Cover calculated including bare ground.

Site	% Native biomass cover per sampling event	
	T0	T1
Piha A	41	64
Piha B	59	84
Piha C	87	98
Bryers A	116	119
Bryers B	78	70
Bryers C	57	64
Bethells A	56	56
Bethells B	54	61
Bethells C	64	66

Key	
Very poor	≤20% native cover
Poor	21-50% native cover
Moderate	51-70% native cover
Good	>70% native cover

Table 14. Average percentage of relative abundance of exotics for each site at initial (T0) and repeat (T1) sampling events.
Colour grading for ecosystem condition and standard error are shown. Cover calculated including bare ground.

Site	% Exotic Cover per Sampling Event			
	T0	S.E.	T1	S.E.
Piha	2	2	12	6
Bryers	18	6	23	6
Bethells	51	5	47	6

Key	
Very poor	>80% exotic cover
Poor	51-80% exotic cover
Moderate	31-50% exotic cover
Good	≤30% exotic cover

Table 15. Percentage relative abundance of exotics for each subsite at initial (T0) and repeat (T1) sampling events.
Colour grading for ecosystem condition is shown. Cover calculated including bare ground.

Site	% Exotic Cover per Sampling Event	
	T0	T1
Piha A	0	2
Piha B	1	11
Piha C	5	22
Bryers A	29	32
Bryers B	14	27
Bryers C	11	11
Bethells A	57	56
Bethells B	54	49
Bethells C	42	37

Key	
Very poor	>80% exotic cover
Poor	51-80% exotic cover
Moderate	31-50% exotic cover
Good	≤30% exotic cover

5.2.4 Estimate of short term sampling error

To assess the short-term sampling error of the point-intercept transect method, repeat sampling was undertaken at each of the three Bethells subsites on the same day. Bethells A, B and C were sampled in the morning (T1) and then sampled again in the afternoon (T2).

Assessment of the sampling error has been undertaken in two ways. Visual assessment of variation using GIS plotting (Figure 36, Figure 37 and Figure 38), and variation in environmental variables and species composition indicators between the sampling events (Table 16 and Table 17).

At subsite Bethells A the mapped repeat sampling events T1 and T2 have different appearances (Figure 36). A slight difference in the bearing of the main transect (202^o (T1) compared with 207^o (T2)) resulted in graphical representations that appear skewed in orientation. Taking this into account, T1 and T2 still look similar if the T2 figure is rotated slightly counter-clockwise. Heavy concentrations of exotic species occur throughout the subsite with a concentration along the western edge.

Bethells subsite B was repeat sampled along the same transect bearing for T1 and T2. The repeat sampling at T2 shows a similar shape and species representation as T1 (Figure 37). *Lotus pedunculatus* dominates the centre and *S. repens* the western edge, and *F. nodosa* is present on the eastern tip.

The repeat T1 and T2 sampling events at Bethells C show a recognisably similar shape (Figure 38). The exact length of each cross transect varies as can be seen at the southern end. Patches of exotics remain in the same areas. There are some other relatively minor differences; one example is Bethells C T2 which shows less M. *complexa* at the south-eastern tip than was recorded in the T1 measure.

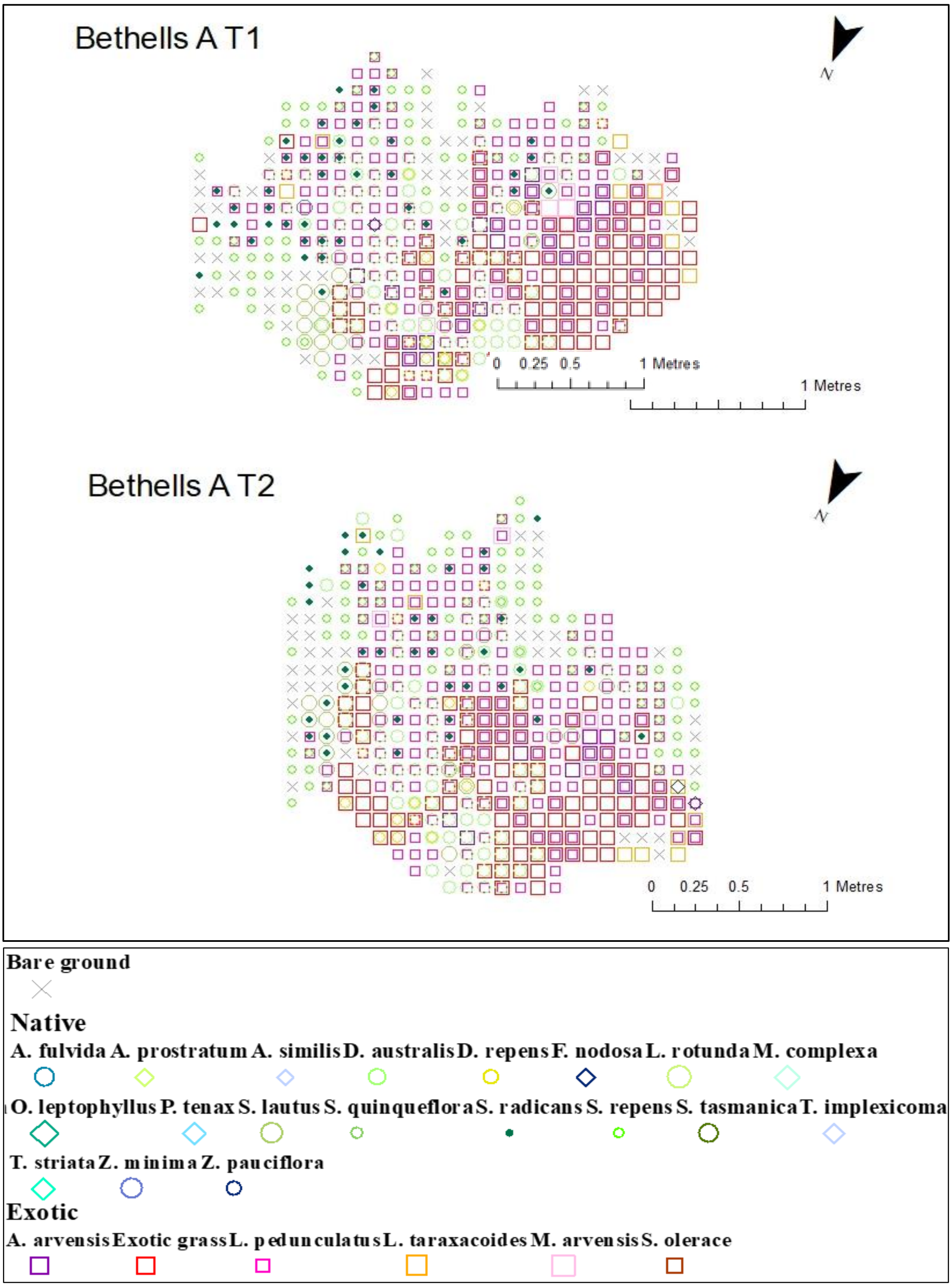

Figure 36. Plot showing species identified at each sample point for subsite Bethells A at repeat sampling events undertaken on the same day (T1 and T2).
Multiple icons at one point show multiple species recorded at that point. Natives are shown as circles or diamonds and are in the blue-green-yellow spectrum. Exotics are shown as squares in the red-purple spectrum. If no vegetation present then an X marks bare ground.

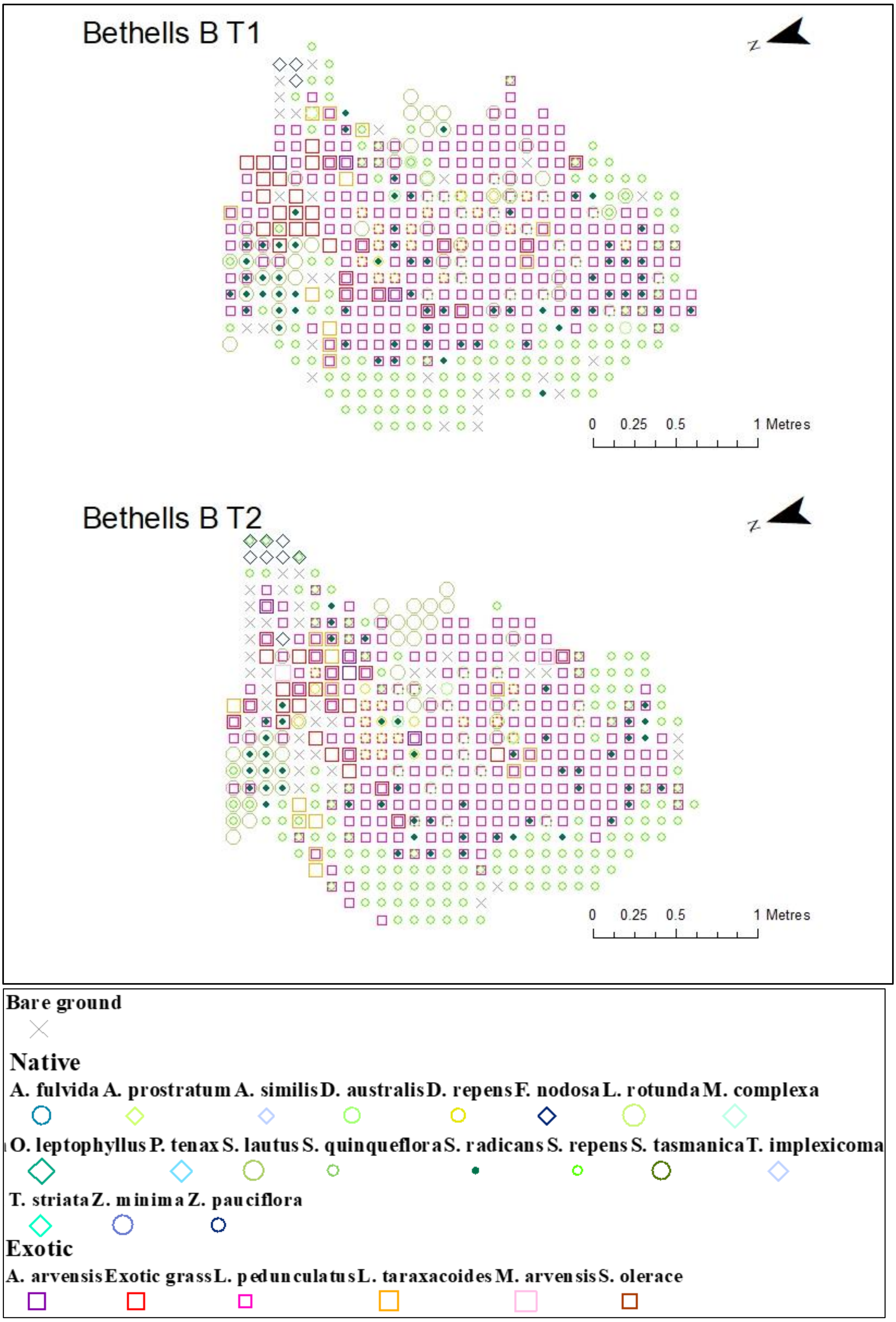

Figure 37. Plot showing species identified at each sample point for subsite Bethells B at repeat sampling events undertaken on the same day (T1 and T2).
Multiple icons at one point show multiple species recorded at that point. Natives are shown as circles or diamonds and are in the blue-green-yellow spectrum. Exotics are shown as squares in the red-purple spectrum. If no vegetation present then an X marks bare ground.

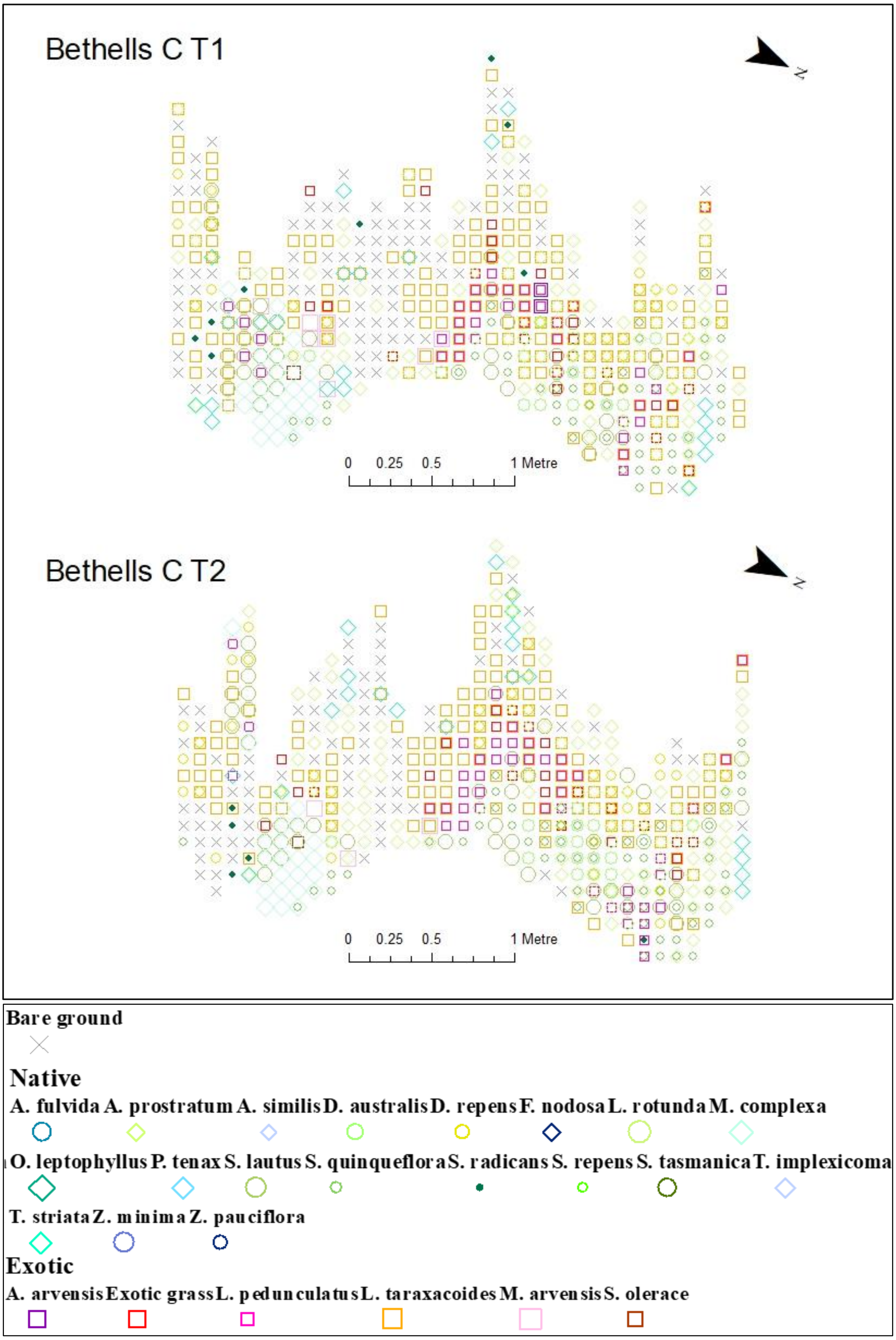

Figure 38. Plot showing species identified at each sample point for subsite Bethells C at repeat sampling events undertaken on the same day (T1 and T2).
Multiple icons at one point show multiple species recorded at that point. Natives are shown as circles or diamonds and are in the blue-green-yellow spectrum. Exotics are shown as squares in the red-purple spectrum. If no vegetation present then an X marks bare ground.

For the tabulated species results, an average of 0.72% variation was observed across all species (Table 16). Bethells A and Bethells B showed sample error of between 1.5% and 3% for native and exotic groupings. Bethells C had a larger sampling error of around 7% for both natives and exotics. Average difference between sampling events (T1 and T2) for bare ground was -1.10% ± S.E. 1.82%; native species 0.12% ± 0.14%; and exotic species -0.69% ±- 0.24%. Only exotics showed any significant difference between same day sampling events for the site

Bethells C has sparser vegetation cover and more variable shape, this led to higher subjectivity when defining the subsite area, which caused higher variability in estimates of the percentage cover of individual species, particularly the exotic *L. taraxacoides*.

The change in bearing at Bethells A (Table 17) resulted in a marked decrease in the length of the main transect (from 2.9m down to 2.4m). However, this resulted in a total area decrease of less than one percent, and the total species count difference is comparable with the other two subsites.

Slope angle was markedly different at Bethells A (14^o at T1 and 20^o at T2), possibly due to the small size of the site and the methods used. However, slope remained constant for same day repeat sampling at both Bethells B (12^o) and Bethells C (29^o). Exposure, calculated from the horizon angles at the eight main points of the compass, showed variability of up to five percent due to the subjectivity of the methods. Soil depth also varied markedly.

Table 16. Percentage cover change between same day measurements of all three subsites at Bethells

Species	BethA T1	BethA T2	% diff	BethB T1	BethB T2	% diff	BethC T1	BethC T2	%Diff C
Bare ground	10.6	9.2	-1.4	5.8	8.0	2.2	22.0	17.9	-4.1
Native									
A. prostratum	0.0	0.0	0	0.0	0.0	0	19.6	22.1	2.5
Ap. similis	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
A. fulvida	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
D. repens	3.6	3.4	-0.2	3.9	4.1	0.2	8.4	10.1	1.7
D. australe	20.9	18.6	-2.3	5.2	4.3	-0.9	3.8	4.7	0.9
F. nodosa	0.2	0.5	0.3	0.6	1.7	1.1	0.0	0.0	0
L. rotundata	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
M. complexa	0.0	0.0	0	0.0	0.0	0	6.9	5.6	-1.3
O. leptophyllus	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
P. tenax	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
S. repens	15.1	19.6	4.5	27.7	30.0	2.3	0.0	0.0	0
S. quinqueflora	0.0	0.0	0	0.0	0.0	0	10.7	13.9	3.2
S. radicans	9.8	9.2	-0.6	14.1	11.0	-3.1	1.8	1.1	-0.7
S. lautus	6.5	6.5	0	10.0	8.8	-1.2	10.4	11.0	0.6
S. tasmanica	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
T. implexicoma	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
T. striata	0.0	0.0	0	0.0	0.0	0	4.7	4.7	0
Z. minima	0.2	0.0	-0.2	0.0	0.0	0	0.0	0.0	0
Z. pauciflora	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0
Native Total	56.3	57.8	1.5	61.5	59.9	-1.6	66.3	73.2	6.9
Exotic									
A. arvensis	4.8	1.9	-2.9	0.6	0.9	0.3	0.4	0.0	-0.4
Exotic grass	26.1	25.4	-0.7	5.8	5.2	-0.6	4.4	4.9	0.5
L. taraxacoides	3.1	2.9	-0.2	2.6	2.8	0.2	35.6	28.6	-7
L. pedunculatus	47.7	49.5	1.8	56.3	53.0	-3.3	10.0	11.2	1.2
M. arvensis	2.4	1.9	-0.5	0.0	0.4	0.4	1.8	0.7	-1.1
S. oleraceus	0.0	0.0	0	0.0	0.0	0	0.4	0.2	-0.2
Exotic Total	84.1	81.6	2.5	65.3	62.3	-3	52.6	45.6	-7

Table 17. Comparison between environmental variables measured at Bethells on the same day (sampling events T1 and T2) showing percentage difference between events.

Subsite	BethA			BethB			BethC		
Sample time	T1	T2	% diff	T1	T2	% diff	T1	T2	% diff
Transect Bearing^0	202	207	2.5	254	254	0	116	116	0
Transect length m	2.9	2.4	17.2	2.9	2.9	0	3.5	3.5	0
# Cross transects	29	24	17.2	29	29	0	35	35	0
Area m^2	4.17	4.14	0.7	4.62	4.64	0.4	4.5	4.47	0.7
Total points	417	414	0.7	462	464	0.4	450	447	0.7
Total species count	630	615	2.4	613	604	1.5	634	611	3.6
Slope Angle ^{0}	14	20	42.9	12	12	0	29	29	0
Exposure	294	308	4.8	276	280	1.4	323	332	2.8
Soil depth cm	12.9	8.9	31.1	9.6	8.1	14.9	11.9	11.7	1.2

5.2.5 Animal pest data

Three pest species (mice, rats and possums) were recorded at Piha (Table 18). Only rats and possums were recorded at Bryers. Other pest species identifiable by chew cards, such as rabbit, hare, stoat (*Mustela erminea*) and cat (*Felis catus*) were not detected. That does not mean they were not present as chew cards have a much lower probability of detecting these pest species. Example chew cards are shown (Figure 39) with clear differences in chew patterns between species.

Table 18. Presence of mammal pest species at Piha and Bryers sites from chew cards. Chew cards were left for three nights from 5th September 2016. Only species identified are listed in the table.

Site	Mice	Rat	Possum
Piha	Yes	Yes	Yes
Bryers	Yes	No	Yes

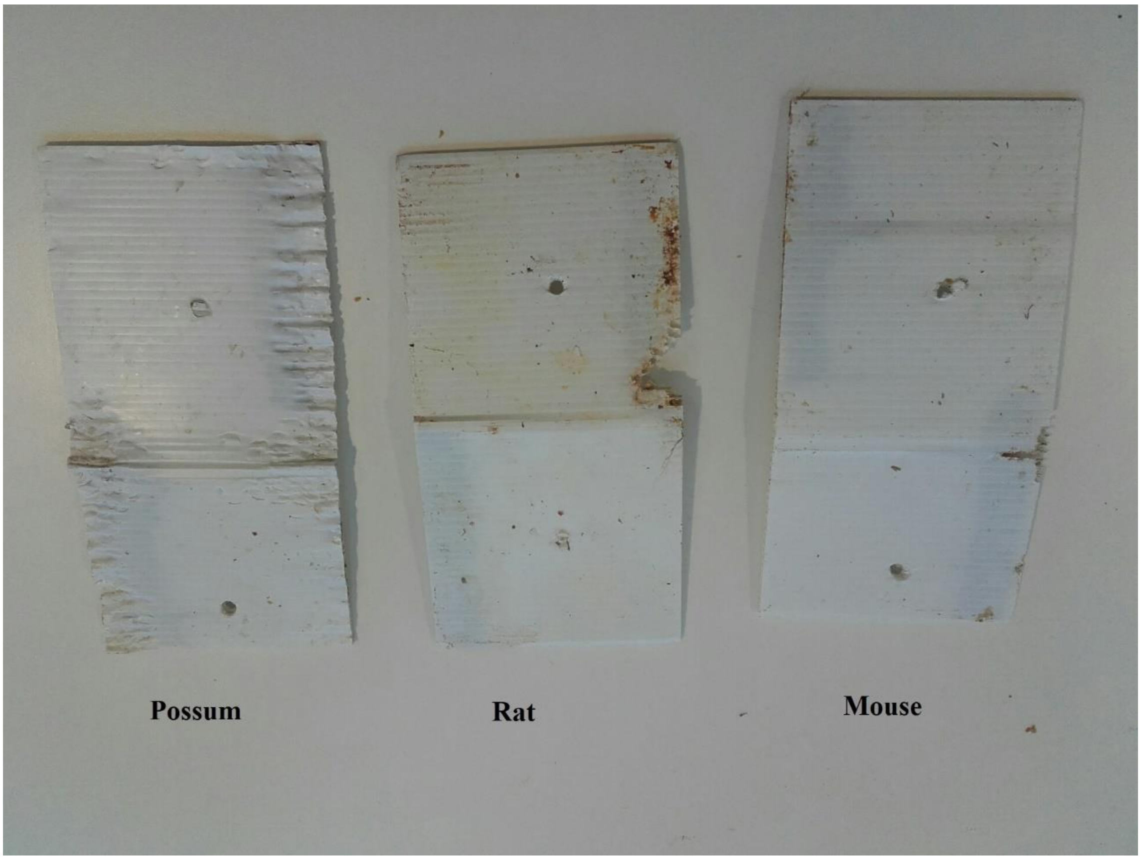

Figure 39. Example chew cards from Piha showing possum, rat and mouse chew marks

5.2.6 Unmanned aerial vehicle (UAV drone)

Examples of aerial photos captured in September 2016 by drone from a height of 40m (Figure 40 and Figure 41) and from 6m at the Bryers site (Figure 42) are displayed below. Subsites are outlined in colour on the 40m photos. Comparing the 2016 drone flight with the latest aerial maps of the area available taken in 2010/2011 (Figure 4), a change in vegetation type can be observed, with a reduction in light coloured grasses and turfs, and an increase in larger, darker vegetation

The six metre flight at Bryers A subsite produced 126 photos. The example photo (Figure 42) was taken near the edge of the subsite. Most of this photo shows an *S. repens*-exotic grass composition. *Ozothamnus leptophyllus* can be observed in the top left corner and *F. nodosa* is in the top and bottom corners to the right. The resolution is insufficient to allow for accurate species identification.

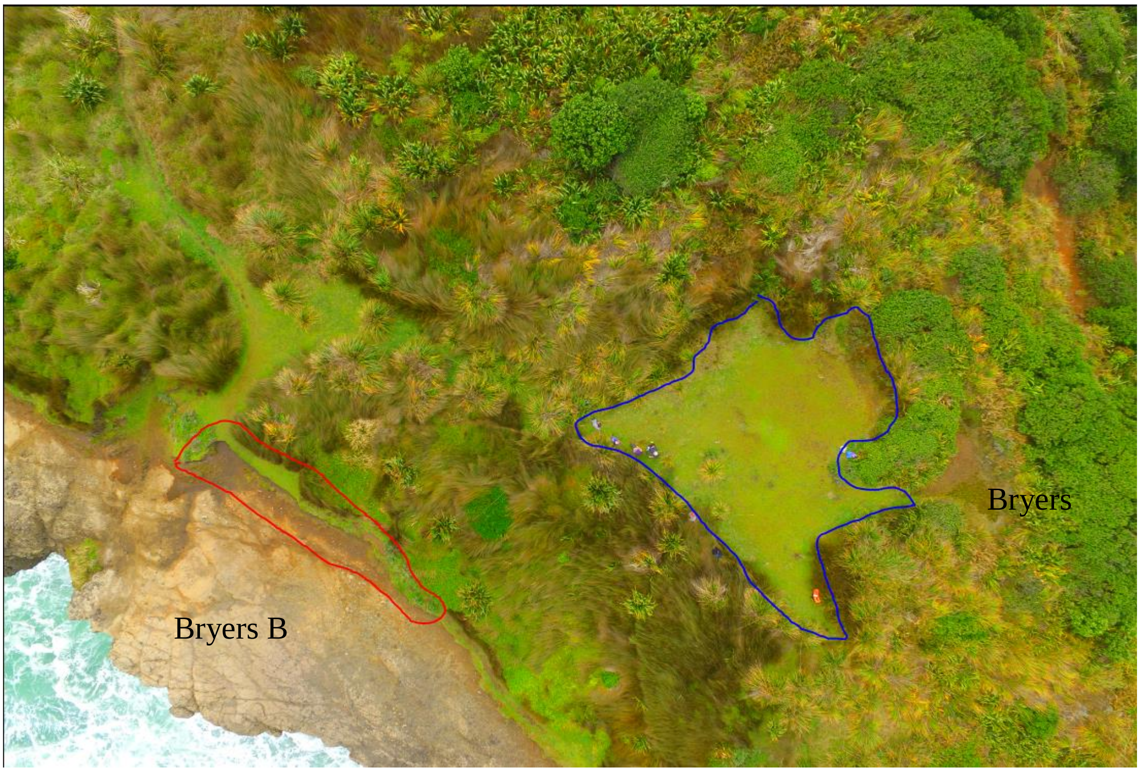

Figure 40. Drone photography of Bryers site taken at 40m altitude showing subsite A and B. Photography D. Breen, 22/09/2016.

Figure 41. Drone photography of Bryers site taken at 40m altitude showing subsite B and C. Photography D. Breen, 22/09/2016.

Figure 42. Example of drone photography of Bryers site taken at 6m altitude at subsite A. Photography D. Breen, 22/09/2016.

6. DISCUSSION

This chapter discusses the prioritisation and development of a terrestrial coastal monitoring programme in the Auckland region and the establishment of a monitoring programme for coastal turf ecosystems on the Waitakere coast.

6.1 Ecological interpretation of results

6.1.1 Regional ecosystem assessment

There are limits to the availability of resources for monitoring (Lee et al., 2005) and there is therefore a need to identify and prioritise monitoring. An assessment of coastal ecosystems was undertaken at a regional level in order to identify their relative size, frequency and conservation status. Auckland Council mapped the ecosystems of Auckland using the categories from Singers, et al. (2017) identifying 32 native ecosystems and ranking them according to IUCN guidelines. I used the data provided to identify which ecosystems are particular to the terrestrial coastal area by examining the descriptions and locations of the ecosystems.

Eleven ecosystems were identified that would be appropriate to monitor in a coastal terrestrial biodiversity monitoring programme. Of these, one was forest, two cliff, one wetland, four coastal saline and one a dune type ecosystem. There was a large variety in the total area of each ecosystem which ranged in size from 16 hectares for coastal turf, up to 10,548 hectares for mangrove forest. Based on the results for total area and endangered status of the coastal ecosystems in the Auckland Region, I recommend monitoring the following coastal ecosystems in order of priority: coastal turf, coastal lakeshore turf, Iceplant herbfield, dune sedgeland and shore bindweed.

Identifying and ground truthing ecosystems is an important factor for biodiversity monitoring, especially with many ecosystems being located on private land (Singers et al., 2017). The importance of ground truthing was highlighted when a 4ha coastal turf site mapped in the Auckland Council regional ecosystem layer was ground truthed and was instead found to be regenerating scrub. This site comprised 25% of the total coastal turf mapped for the whole Auckland region. This suggests the urgent need for further exploration, mapping and ground truthing of rare and endangered ecosystems, including coastal turfs.

One of the sites used in this study (Bethells) was not recorded in the Auckland Council regional ecosystem layer and was found by exploration of an environment typical of coastal turf locales. This highlights the difficulty in effective data collection and collation. Further exploration and mapping is recommended to form the basis of site selection for a representative coastal biodiversity monitoring programme.

Determining how to classify ecosystems is an important factor when approaching how and what to monitor. The Singers and Rogers (2014) system appears to be an appropriate ecosystem definition tool for effective delineation at a regional level. While the LCDB system may prove effective at a national level for broad-scale approaches, the broad coverage of each landcover class within LCDB does not allow for biodiversity monitoring of many specialized ecosystem types, and they are not delineated to the same level of detail as the Singers and Rogers system.

While the addition of historically rare ecosystems (Williams et al., 2007) does cover much of the detail not available in the LCDB system, it does not delineate the more common ecosystem types. For example, Kauri-podocarp forest, Kahikatea swamp forest and Pūriri-Taraire warm forest would all be classified as ‘indigenous forest’ in the LCDB + historically rare framework, despite their widely varied species composition, ecological role and threat status.

In addition, the intuitive nature and descriptive titles of the Singers and Rogers system allow for comparatively easy interpretation and provide a unified system. Although the detail in the Singers and Rogers classification system may require significant resources to create, ground-truth and maintain, from a conservation managers perspective, the classification is an essential tool for effective monitoring, management and understanding of the regions coastal biodiversity.

The use of IUCN red list categories for ecosystems in New Zealand applies international agreements and best practice standards to rating ecosystem vulnerability, and hence priorities for monitoring and management. The small area and vulnerability of coastal turf identifies it as a high priority ecosystem for monitoring.

6.1.2 Coastal turf

The overarching observation across almost all subsites was the relatively high variation in the size, species composition and condition of individual subsites of coastal turf, both within and between sites. Twenty-six plant species were identified across the three coastal turf sites. Species richness ranged from four to 16 species at each subsite. Subsites ranged in total vegetated cover from 41% to 99%, in native cover of between 41%-70% and exotic cover between 0%-57%. In some instances, differences among subsites were greater than differences between sites, suggesting that microclimate variations could be more important than inter-site variations.

In general, there was approximately twice as much coverage of native species as exotics. The native herbs *Selliera radicans, Sarcocornia quinqueflora* and *Samolus repens* were the most dominant native species. *Lotus pedunculatus* was the most dominant exotic species, and was observed in higher abundances in the summer compared to the winter.

Coastal turf in New Zealand is found mainly in Taranaki, Nelson, north Westland, Otago, Southland, Fiordland and the Chatham Islands (Rogers, 1999; Rogers & Wiser, 2010). There is possibly less than a total of 40 ha of this ecosystem in mainland New Zealand (Rogers & Wiser, 2010). In these areas, sites average 0.17ha ± 0.28ha in size. In Auckland the average size of each site as taken from the Auckland Council GIS layer is 0.55ha. However, the sites observed in the Waitakere ranges were much smaller than that and suggest that the GIS layer shows areas of possible turf habitat, or locations where turf has been noted in the past but not accurately mapped, as opposed to actual ground truthed areas of coastal turf.

The three sites monitored in this study, Piha, Bryers and Bethells, are estimated to have total areas of coastal turf of 0.02, 0.15 and 0.01ha respectively. This is lower than the average national size but within the expected range for turfs. Coastal turfs sampled along the Waitakere coast were generally small and fragmented, with several patches of turf making up a site interspersed with other ecosystem types or bare ground. Often the coastal turf patches were narrow and occurred along the edge of bare ground, exposed to wind and aerial sea-spray and as a fringe bordering other ecosystems, such as oioi-knobby clubrush sedgeland. As the sites sampled were all on the west coast of Auckland, there is a possibility that they are different to other sites in the Auckland Region, for example those on the east coast or Great Barrier Island. Further study would be required to assess this.

Species composition

I made detailed surveys of species abundance and diversity for nine examples of coastal turf patches at three sites along the Waitakere coast. The largest subsite (Bryers A) had the highest species richness and densest ground cover. The high percentage of recorded vegetation cover may be due to the subsites location, as it was the most protected subsite, surrounded by other taller vegetation. The smallest subsite (Piha A) had the least species richness. It was also sparsely vegetated and surrounded by bare, eroding clay and sedimentary rock. The sparse vegetation may be due to erosion, low moisture retention due to lack of surrounding vegetation or other environmental factors. The low species richness and small size suggest this subsite is a transient community. The amount of bare ground and the slopes of subsites were correlated with the major NMS ordination axis explaining the largest differences in species composition among subsites.

Nationally, taxon richness per coastal turf site has been recorded as 13.2 ± 3.42, with an average native taxon richness of 8.8 ± 2.59 including grouped mosses, liverworts and lichens (Rogers & Wiser, 2010). The Waitakere sites had an average taxon richness of 11.1 ± S.D. 3.0 and a native taxon richness of 8.2 ± S.D. 2.5 without mosses, liverworts or lichens, or differentiating exotic grasses. This is slightly lower than the national averages, but within the standard error. However, the species richness recorded for the Waitakere sites is conservative compared to the national study as exotic grasses were not differentiated and mosses, liverworts and lichens were not recorded.

Bethells and grazing

All the Bethells subsites have a comparatively high ratio of exotic species present. The Bethells site is on a small hillock shaped 'island', surrounded by sand, that is separated from mainland vegetation. At spring-tides the hillock is likely to be surrounded by seawater. Due to this, it is possible that grazing by mammals such as rabbits, rats and possums is limited. These species are present at the other two sites (Table 18) and light grazing is considered to be beneficial for the maintenance of coastal turf when competing with exotic species (Rogers & Monks, 2016). This may contribute to the high abundance of exotic species. Mammalian pest monitoring would need to be undertaken at this site to assess this hypothesis.

Another factor could be the comparatively low salinity levels and aerial salt deposition. The Bethells site is at the southern end of Bethells Beach (Te Henga) and is partially protected by the southern headland. Salinity testing of the soil could help assess this hypothesis.

Temporal variation

Subsites were repeat sampled in order to assess temporal variation. Initial sampling events occurred between August and November 2016. Repeat sampling events occurred between November 2016 and February 2017. During this time there was a general increase in total area and vegetation coverage. The Piha and Bryers sites had longer time periods between sampling events than at Bethells, and were sampled in winter/spring and in summer. Piha and Bryers sites showed a greater increase in vegetation cover, both in native and exotic species in that time, suggesting that coastal turf increases in biomass over the spring/summer period. Future sampling over autumn and winter may show a decrease in vegetation cover and total area.

Sample timing

Species identification was found to be easier in the summer months as many of the species were in flower at that time. While having different timings between initial and repeat sampling is not ideal in a systematic biodiversity monitoring programme, in this study it did allow an analysis of temporal variability. As a pilot study, this project helped identify seasonal variation and favourable sampling times. For long-term monitoring it is recommended that sampling be undertaken at the same time of year at all sites over as short a period as possible to limit seasonal variation. December was observed to be an ideal sampling month for species identification due to many of the species observed flowering at that time. Long term monitoring of coastal turfs would help assess their successional patterns to determine whether communities are at their climax or in a constant state of flux.

Sampling error

Short term sampling error assessed at the Bethells site by sampling twice on the same day as relatively small. Average percentage error for species abundance was 0.72% ± S.E. 0.14% with a maximum of 6.9%. Average differences for exotics sampled was -0.69% ± 0.24%. The main reason for the difference in exotic cover between times was the spatial heterogeneity at Bethells C which had very patchy vegetation cover and variable perimeter. This suggests that the point transect method works better in well-defined areas with higher vegetation cover. Provision of guidelines around site delineation could help reduce this error. Apart from this issue, the results suggest that the point intersect transect sampling method is an objective and reliable method for sampling coastal turf sites.

Measurement of certain environmental variables, particularly slope angle and exposure proved difficult as the subsites were small and often had topographical changes, such as a ridge, running throughout the subsite. These data may be useful for site description, but for any further monitoring, a review of these methods should be considered.

Regional variation

Variation in coastal turf species composition has been described (Rogers & Wiser, 2010) for four main regional groups in Taranaki–Wairarapa, northwest Nelson–north Westland, south Westland and Fiordland–Otago (Singers et al., 2013). The three species that occurred most frequently in these regions were *Leptinella dioica, Selliera radicans* and *Plantago triandra.* Of these, only *Selliera radicans* was observed in the Waitakere sites.

Other common species recorded in the other regions were *Zoysia minima, Centella uniflora, Colobanthus muelleri, Hydrocotyle novae-zeelandiae var. montana, Isolepis cernua, Samolus repens, Agrostis stolonifera,* and *Trifolium dubium, Sarcocornia quinqueflora, Disphyma australe, Samolus repens, Crassula moschata and Isolepis cernua*. Of these, only *Sarcocornia quinqueflora, Disphyma australe, Samolus repens* and a limited amount of *Zoysia minima* were observed at the Waitakere sites.

Species composition for coastal turf on Great Barrier Island has been described by (Wright & Cameron, 1985). Species composition here was different to that described in other regions. Common species included *Disphyma australe, Samolus repens, Senecio lautus, Dichondra repens, Sarcocornia quinqueflora, Anagallis arvensis* and *Lobella anceps.* All of these species except the last were also found on the Waitakere coast in this study, indicating similarities between these areas within the Auckland region. Although Great Barrier Island and the Waitakeres are on different coasts, they are at similar latitude and are subject to comparable wave exposure.

While the list of species found at the Great Barrier Island sites may not have been exhaustive, the large overlap with species found at the Waitakere sites suggests that a distinct regional variant of coastal turf exists in the Auckland region, or perhaps northern New Zealand, that is different to coastal turfs elsewhere in the country. Further sampling on Great Barrier Island and at other sites in Auckland would assist in confirming this.

The regional variation observed highlights the potential uniqueness of coastal turf in Auckland and provides support for further monitoring, and for more active management and conservation efforts.

GIS Mapping

The point intercept transect method was used to create an almost continuous coverage of each patch. The floristic composition for each sampling event was mapped using ArcGIS to assess spatial and temporal variability within and between sites. This proved to be a labour intensive method of data manipulation and presentation, but enabled a visual analysis of spatial pattern in species composition within each subsite, comparisons of patch edges and centres, changes in patch shape, and patterns of species co-occurrence.

For the smaller subsites with cross transects every 10cm, the mapping provided a comprehensive picture of species composition and variation. However, for the larger subsites, interpretation was more difficult due to the large amount of information being displayed. For the largest subsite, Bryers A, a simplified map displaying only three categories (native, exotic and bare ground) was produced, but its complexity still made it difficult to visually assess species patterns at the A4 scale. Producing this map at A3 page size or a viewing at range of scales within a GIS would permit more detailed visual comparisons to be made.

The general shape of subsites can be discerned from the GIS maps and an estimation of area can be calculated from them. Some changes in species abundance patterns were easily discerned. An example is the change in exotic growth at subsite Bethells B where exotics expanded to the east and declined to the west of the subsite between sampling events. This suggests that vegetation composition within turfs is quite dynamic as exotic growth and decline occurred rapidly between sampling events that were only one month apart. If these locations were repeat sampled, it is likely that a clear pictographic representation of what was occurring at the sites could be built up over time, and change in size, shape and species composition could be tracked within each subsite. This would assist in understanding changes over time and whether coastal turf is a transient ecosystem that changes through time.

If subsites were sampled regularly throughout a year, seasonal changes could be better understood. If sampling was undertaken over longer time periods, such as annually, or five yearly (as in the forest and wetland monitoring programmes), longer term changes could be monitored. If the main transect had permanent start and end points then spatial movement of the turfs could also be tracked, helping to understand if the boundaries of these ecosystems 'creep' due to environmental variables such as erosion and surrounding vegetation composition.

Environmental variables

Soil depth at the Waitakere sites had an average depth of 130mm ± 17mm. Sub-sites had a mean elevation of 29m ± 8m above sea level and a mean distance inland from the high-water mark of 69m ± 7m. This compares with national average values for soil depth, mean elevation and mean distance inland in coastal turfs of 370mm ± 150mm, 15m ± 13m and 19m ± 15m respectively (Rogers & Wiser, 2010). On this basis, Waitakere coastal turf appears to occur in more compacted soils, at a higher than average elevation and occurs significantly further inland than the national average. The higher average elevation is due to two of the sites (Piha and Bryers) being on or near cliffs.

Animal pest data

Chew cards were trialled at two sites (Piha and Bryers) to check for mammalian pests. They were laid out around the perimeter of each site and left for three nights. Mice, rats and possums were recorded. Chew cards are a relatively inexpensive and effective way of detecting invasive mammalian pests (Burge, Kelly, & Wilmshurst, 2017) (Sweetapple & Nugent, 2011). While standard practice is to lay chew cards out on a transect up to 200m long, the small size of coastal turf patches meant that if this was done then data would not relate to the turf sites themselves.

The chew cards were used in this study as an example to show what could be done in a coastal monitoring programme and that pest mammals could be found at two of the sites.

UAV/drone data

A drone was used to photograph the entire site and attempt species identification at the Bryers site. Using the drone to photograph the entire site proved effective as this allowed up-to-date aerial photographs to be created. The advantages of this, compared with publicly available aerial photographs (the latest for that area was 2011), is an increase in the spatial resolution of the aerial imagery, a much lower cost compared to conventional aircraft, and the ability to make temporal comparisons at any time scale of interest. If drone photography was undertaken at each sampling event, then visual and quantitative differences through time could be assessed, changes in area and shape estimated and changes in the surrounding environment observed.

However, using the drone for species identification did not prove effective. This was partly due to camera resolution and partly due to the overlapping distributions of many of the species observed, which photography did not adequately capture. Drone photography at the heights trialled is therefore not recommended for coastal turf species identification or monitoring changes in species composition, except at a very coarse scale.

Data analysis

In the non-metric multidimensional scaling (NMS) ordination, repeated monitoring times for subsites tended to group closer together than to other subsites. This suggested that temporal variation, at least over the timescale used here (i.e. hours to months), is less than spatial variation between subsites. Associations between some species were observed. The exotics *Lotus pedunculatus, Myosotis arvensis* and *Anagallis arvensis* occurred together at subsites including Bethells A and Bethells C and this may be due to the similar high vegetation coverage and the gentle slope at these sub-sites, or perhaps, other unmeasured environmental variables such as low salinity or less grazing.

The greatest differences between subsites were best explained by the amount of bare ground and vegetation cover and by slope and aspect. These environmental variables were most correlated with the greatest differences among subsites. High vegetation cover positively correlated with exotic species presence suggesting that exotics do not survive as well as some natives where the environment is harsh or has been more recently disturbed. However, fully understanding these correlations and the processes determining species composition may require an experimental approach.

Natives that appear to inhabit sparser areas include *Spergularia tasmanica* and *Ozothamnus leptophyllus.* Ubiquitous species such as *Selliera radicans* and *Samolus repens* were also present in areas with low vegetation cover. But as these species were found everywhere, the ordination did not highlight their presence in low vegetation cover sites.

The environmental variables most strongly correlated with changes in coastal turf species composition in this study, vegetation cover, slope and aspect, differ from a previous national study (Rogers & Wiser, 2010) where altitude, distance from the sea and substrate type were the most important environmental variables. That study included several measured environmental variables different to those measured in this study. While some of the measures differed, the most strongly correlated ones were measured in both studies and found to have different levels of correlation.

An explanation for the differences in importance of environmental variables between the two studies is their differences in scale. Rogers and Wiser (2010) examined coastal turf across a wide latitudinal range from Taranaki (approximately 39^{o} South) to Southland (approximately 47^{o} South). At this scale the effects of altitude, distance from the sea and substrate are more varied and may have greater impact on coastal turf community structure and species composition. The scale of this study sampled similar types of coastal turfs, on the same parent rock, and within a very limited latitudinal range (36.89^{o} to 36.95^{o} South). While it is regrettable that different methods and variables were used, this provides an example of why it can be helpful to develop and utilise national standards for biodiversity monitoring.

Percentage vegetation cover and relative abundance data for native and exotic species were presented. The percentage cover showed absolute changes between sample times for each species as well as for the native and exotic groups. Native species often occurred at the same sampling points, which resulted in greater than 100% native coverage at Bethells A (Figure 26). Measuring vegetation cover with species overlapping allows an understanding of how species, or species groups, are surviving independent of other species. Measuring relative abundance (Figure 27) compares species and species groups relative to each other. Both percentage cover and relative abundance can be useful, as discussed in the next section.

6.2 From analysis to indicators

Indicators of native and exotic cover

Choosing which method of data analysis and presentation to use is important when applying an ecosystem condition scale. Bellingham et al. (2016) use indicator bandings to ‘grade’ different locations. I applied the Bellingham et al. (2016) banding to both native percentage cover and native relative dominance (Figure 32 and Figure 33) to assess which measure would be more appropriate as a native dominance indicator.

The indicator for native dominance is to test for a decline in native vegetation cover, either from a ‘natural state’, or from some other baseline (Table 8). I interpreted this as the change in cover of native plants assuming a 100% original coverage. This may need to be reassessed once further data is obtained as coastal turf is likely to be patchy due to the environment it occurs in.

Native dominance at this scale should consider change in area and vegetated area (Figure 31), and also change in density, hence the measurement of percentage cover allowing for the overlap of species at a point. Percentage cover for natives was higher at all subsites than relative abundance, placing the sample times in the same or higher grades. The indicator for native vegetation refers specifically to change in cover and so using vegetation cover and applying the grade system to it appears the best measure for this indicator.

Exotic plant cover was also presented for vegetation cover and relative dominance (Figure 34 and Figure 35). Coverage of exotics as percentage cover allows a direct comparison with percentage cover of natives. However, the indicator for non-native plants (Table 8) refers to the relative amount of exotic vegetation compared to total vegetation cover. Therefore relative abundance, or dominance, is a more appropriate measure for this indicator.

While most subsites did not change banding between sampling events, there were some exceptions. Subsites Bethells C, Bryers A and Bryers B changed grade when measuring percent cover, but did not change grades when measured by relative abundance. There is a risk with setting arbitrary bandings (e.g. 80%, 50%) where minor changes can cause a change in banding, such as at Bryers A for relative abundance (3% change), whereas much larger changes, such as at Piha C (17% change) can occur but not change bands.

Applying grades can over-simplify indicator results, and looking at the actual results can be more meaningful. However. there are still valid reasons to apply them. When displaying data, the type of audience should be taken into account (Lee et al., 2005). A change in number has meaning when you understand what the numbers relate to, and where they sit relative to an established benchmark. But the application of a scientific understanding of the results and application of a grading system by a specialist allows dissemination to non-specialist audiences.

Both methods, percentage cover and relative abundance, are useful measures. Percentage cover measure allows an easy comparison with native cover and bare ground, while measuring relative abundance is more applicable for the indicator which specifically looks at changes in relative dominance. I think that the relative abundance measure is the better approach for measuring exotic dominance, as what is being assessed in this indicator is the degree to which exotics are dominating natives and competing with them for resources.

Indicators of change in area

The indicators for change in area and vegetated area were adapted from the indicators for native and exotic dominance, and complements them to help assess ecosystem condition. I chose broad categories of change (Table 8 and Table 9) in keeping with those from the native and exotic dominance, but added some extra positive categories to allow increases in the area of individual coastal turfs beyond their baseline extent. All subsites with the exception of Bethels (Figure 31) showed some increase in total area (0.1 m^2 to 30.9m^2) and most sites showed an increase in vegetated area as well. This was probably due to a seasonal increase in growth over the spring and summer, which occurred between the T0 and T1 sampling events.

The maintenance or decrease in vegetated area for Bethells subsites is probably due to the later sampling time in summer at this site, which meant there was a much shorter period between sampling events (13 to 27 days at Bethells compared to 117 to 152 days for Piha and Bryers).

The biggest change in area at a subsite (an increase of 30.9m^2 at Bryers A) occurred mainly because of a sampling artefact, as the beginning and end points of the main transect were not fixed, and were subjectively chosen by the sampler. This affected the measurement of total and vegetated area, where the longest axis through the centre of each patch of turf was located, and where the coastal turf patch began and ended.

It was initially thought that non-permanent starting points could be useful as turf patches could increase in size over time and fixed points would not capture that. The resulting bias from this approach is however, highlighted in this study. It is recommended that permanent points for the start and end of each main transect be used in future. It may be possible to fix permanent markers so that they do not protrude and do not present a safety risk or impact on visual amenity.

Report cards for State of Environment reporting and public engagement

It is important to not just gather and analyse data but to present it in an informative way, that is appropriate for a wide range of audiences, and directly informs management and policy (Lee et al., 2005). Report cards were developed as a means of presenting data on native and exotic dominance in a simplified manner. These may be useful for State of the Environment reporting and information dissemination to the public.

I presented data for native vegetation cover and exotic relative abundance at site and subsite level in report card form. Providing clear banding and colour with simple grades allows for a rapid assessment of the general ecological 'health' of each location. When large amounts of data need to be presented simply and quickly, a report card can convey this information.

Changing from reporting at subsite level to site level loses resolution but simplifies results. However, it is likely that representative, comprehensive monitoring of coastal turfs in Auckland, or any other region in New Zealand, would involve a relatively large number of subsites. Including other types of coastal ecosystems would increase the number of locations even further. In these situations, report cards summarized by location or sub-region are the only practical way of providing a rapid overview of sites over time. Given the rarity and small size of these ecosystems, data at the subsite level, and even raw data, could also be disseminated in a technical report for a more limited audience.

Limitations and mitigations

The point intercept transect method was used to census an almost continuous coverage of each coastal turf patch. Various methodologies to describe the sites were reviewed including the Recce method (Hurst & Allen, 2007), quadrat sampling and the point intersect transect method (Hill, 2005). The Recce method was designed as a rapid assessment tool and was not considered appropriate for this study as it does not provide sufficiently objective or quantitative data. Rogers and Wiser (2010) inferred that using this method may result in some species not being recorded. Quadrat sampling was not used as the sites are small and have a noticeable edge effect where they lead into other ecosystems. Randomly placed quadrats may end up sampling other ecosystem types if on the edge, or not capture potential edge change if sampled in the middle of a patch.

The point intercept transect method was selected as it is held to be an objective method (Hill, 2005), that reduces observer bias and is easy to apply to low growing vegetation (McCune et al., 2002). Using cross transects all along each patch allows for a mapping of the site showing the general area, shape and outline, and accounts for any differences in species composition throughout the turf. The point intercept method was labour intensive, especially for large patches of turf. It did however, provide objective quantitative data that could be mapped and analysed.

The sparser the vegetation cover was, the higher the sampling error observed (Table 16). This suggests that sites with higher vegetation cover, more uniform shape and clearly defined edges would have less sampling error. Possible mitigations for this include having fixed points for the main transect and clear guidelines for edge delineation, for example where vegetation cover drops below 20% cover when leading to bare ground, or where non- turf species dominate when leading to other ecosystem types. Photographs of examples of these situations would assist in applying consistent definitions.

One challenge for research and monitoring of coastal turfs is determining the full extent of turfs throughout its potential environment along the entire Waitakere coast and other less studied coasts. These cliff and headland habitats are often remote and difficult to access and survey. Ground truthing of one listed coastal turf in this study showed previous information to be inaccurate (near the Piha site). By searching at likely locations, this study also described a previously unknown site (Bethells). This study describes monitoring at only three sites along this extensive and complex coast. Given the rarity and vulnerability of this ecosystem, an understanding of the extent and condition of other coastal turf sites in the region is a priority. In less accessible areas, UAV drone surveys may be useful in identifying and monitoring coastal turfs.

6.3 A coastal monitoring programme for Auckland

Legislation and international treaties such as the New Zealand Biodiversity Strategy, Resource Management Act (1991), and the New Zealand Coastal Policy Statement require Auckland Council to manage and monitor biodiversity in the Auckland region terrestrial coastal area, in particular those ecosystems that are threatened or naturally rare. Coastal turf, along with a range of other coastal ecosystems, are both threatened and rare. Currently there is no systematic monitoring of the terrestrial coastal area in Auckland, though there are some ecosystems, such as dunes, for which pilot study monitoring has commenced. Current programmes in the region do not adequately cover the coastal area with its unique environments and rich biodiversity.

If a coastal terrestrial biodiversity monitoring programme is to be undertaken in the Auckland region, the work carried out in this study highlights the need to address the following points, given here relative to coastal turf:

1. The goals of the monitoring and the reasoning and legal justification for monitoring need to be well defined. For example: to measure ecological integrity using the ecological indicators relevant to rare or endangered ecosystems under the Resource Management Act (1991), the New Zealand Coastal Policy Statement (2010), the Auckland Plan (2009) and the Environmental Reporting Act (2015).
2. A thorough survey of coastal turf and other rare or endangered coastal ecosystem locations is required, including ground truthing of those areas already mapped. Potential locations for coastal ecosystems can be identified using expert opinion, surveying environments typical of particular coastal ecosystems such as coastal turf and using drone photography.
3. Decisions as to how many sites to sample and from which areas need to be made. For coastal turf, the Waitakere coast and Great Barrier Island are two areas that should be considered.
4. Indicators to assess ecological integrity need to be defined and measured. These include change in area, change in native dominance, change in exotic dominance and animal pest presence.
5. Appropriate methods for data collection, analysis and presentation must be applied. Choice of methods for sampling should be carefully considered. The point intersect sampling method provided an objective means of understanding spatial and temporal change in coastal turf, but was labour intensive. The benefits of this method should be compared with other methods, such as the

Recce method (Hurst & Allen, 2007), which may not supply such objective quantitative data, but may allow more sites to be monitored.

6. An initial monitoring programme undertaken regularly at a selection of sites throughout the year (for example every two months) would provide baseline data on seasonal variation.
7. Further annual monitoring should be undertaken to assess changes for at least three years. As coastal turf may be transient in nature, annual sampling would increase understanding of the consequences of spatial and temporal changes.
8. Long term monitoring and reporting would require sampling at least every three years as recommended by Bellingham et al. (2016) to assess change and improve knowledge of coastal turf and other vulnerable ecosystems.

Reporting should be undertaken with methods appropriate to relevant audiences including in-depth technical reports as well as clear, simplified reporting for management purposes, State of the Environment reporting and dissemination to the public.

7. CONCLUSION

The purpose of this study was to assess the requirements of biodiversity monitoring in the terrestrial coastal area of the Auckland region and prioritise ecosystems for biodiversity monitoring. Coastal turf was used as a case study to assess which biodiversity indicators to assess, which methods and analyses to use, and to demonstrate how the data could be reported.

The Singers and Rogers (2014) ecosystem classification system was used to define and describe ecosystems (Singers et al., 2017) and these were assessed using GIS maps supplied by Auckland Council to define those that predominantly occur in the terrestrial coastal area. Prioritisation of ecosystems for monitoring was determined from their total area and IUCN threat status, while also considering what systematic biodiversity monitoring was currently undertaken for these ecosystems.

Nine ecosystems were identified in the coastal area, four of which are rated as critically endangered. When considering total area and endangered status, high priority coastal ecosystems for monitoring are, in order of priority, coastal turf, coastal lakeshore turf, iceplant herbfield, dune sedgeland and shore bindweed.

This study shows that the application of a comprehensive ecosystem categorisation system (Singers & Rogers, 2014), combined with comprehensive mapping of these ecosystems and the use of IUCN threat guidelines for ecosystems can assist in prioritising ecosystems for monitoring and management. The combination of total area along with threat status provides a clear guideline to identify where monitoring effort should be undertaken.

The provision of comprehensive maps assists in planning for monitoring or management, but the need for accuracy through ground truthing is highlighted in this study. In some instances, areas that were designated as coastal turf in the regional mapping process were, on closer investigation, found to be other ecosystems. This highlights the need for accuracy in ecosystem identification and mapping, especially for rare or critically endangered ecosystems. Further surveying to identify and ground truth these ecosystems is recommended.

Coastal turf was monitored at three sites along the Waitakere coast. At each site, three subsites were repeat sampled using the point intersect transect method. Time between sampling events varied from hours to months. Subsites repeat sampled on the same day showed only small variation between sample times, which suggests this method is a reliable and repeatable way to sample this ecosystem type. Subsites sampled months apart (from winter to summer) showed a general increase in total area and vegetation cover over that time, suggesting seasonal variation in this ecosystem. Exotic plant species, in particular *L. pedunculatus*, increased in growth at many of the subsites in that time. Further sampling throughout the year would confirm whether this was seasonal variation or not. For long term monitoring, sampling at the same time of year is recommended to minimise seasonal variation. December is recommended as an ideal sampling time, when many of the species were observed to be in flower, making species identification easier.

The dominant native species observed across all sites were *Selliera radicans, Sarcocornia quinqueflora, Samolus repens*, and *D. australe.* The exotic plants with the highest percentage cover across all sites were *Lotus pedunculatus*, exotic grass and *Leontodon taraxacoides*. Regional variation has previously been recorded for coastal turf species composition (Rogers & Wiser, 2010) in other areas of New Zealand.

Species composition in Waitakere coastal turfs was most similar to that found on Great Barrier Island (Wright & Cameron, 1985). My data and the Great Barrier Island species descriptions suggest that species composition for Auckland coastal turf is distinctly different to other regions of New Zealand. This regional distinctiveness increases the intrinsic value of the coastal turfs of Auckland and further monitoring and management is therefore recommended.

Species composition at each subsite was mapped using ArcGIS for each sample time. This showed the shape of each subsite and spatial differences within subsites of species composition. Changes between sample times for each subsite could be observed with this form of data presentation. Repeat sampling and mapping within subsites improves understanding of how these ecosystems change both in area, vegetation cover and species composition. If fixed points for the main transect area are used, these could also show changes due to other variables, such as erosion and competition by non-turf species.

Methods for data capture and analysis need to be developed to implement the New Zealand national standardised terrestrial biodiversity indicators (Bellingham et al., 2016) for many vulnerable ecosystems. This study assessed different ways of measuring native dominance and exotic dominance. The strengths and weaknesses of the different methods in this study are outlined and can help inform decisions about the most appropriate methods for data capture, analysis and presentation.

The indicators assessed in this study focussed on vulnerable ecosystems, particularly their extent and condition. Change in area, change in vegetation cover, change in native cover and change in exotic cover were the variables used to measure extent and condition. Between initial and repeat sampling times, total area, vegetation cover, native cover and exotic cover generally increased at each site, probably in response to seasonal variation.

Native and exotic vegetation cover was presented for three-dimensional area (to account for the overlapping of several species at the same point) and two-dimensional area (to account for how much ground area natives or exotics covered). Native and exotic vegetation cover and bare ground within each subsite were presented to compare methods and understand change and the dominance of each species group. In comparing the two methods (3d and 2d), similar trends were shown, but due to the overlapping nature of species at many points, 3d cover provided a more accurate picture of native species presence. Two-dimensional exotic dominance of the vegetated area was the most appropriate measure for non-native dominance as the area of vegetation where exotics are present is where they are competing with native species.

Grading bands were used as a means of assessing the change in native dominance, exotic dominance and change in area. These provided a means of scoring the ecological 'health' of each subsite, allowing comparisons between subsites and changes through time. Utilising this grading simplifies the data and could be useful for reporting to the public such as State of the Environment reporting. The use of report cards for sites can also provide a snapshot of the general state of an ecosystem and how it is changing over time. This is in keeping with other programmes the Auckland Council reports on and is recommended for quick analysis.

Animal pest monitoring was undertaken at two sites (Piha and Bethells) using chew cards. This proved effective at identifying rats, mice and possums. Chew cards are used in other biodiversity monitoring programmes such as the forest and wetland programmes undertaken by Auckland Council and help to measure distribution of animal pests (Ruffell et al., 2015). Use of chew cards for pest monitoring is recommended for use in any further monitoring.

Unmanned aerial vehicle photography was tested at one site (Bethells) for mapping purposes and species identification. It proved effective for site mapping, allowed up to date photography at a site and could be useful in assessing changes in surrounding vegetation as well as changes within subsite area. It was not found to be useful for species identification due to image resolution, the small size of the plants and the overlapping of different species. Drone mapping could be useful to identify areas of coastal turf, especially where access is difficult due to the rugged nature of the terrain.

A coastal terrestrial biodiversity monitoring programme should be undertaken in the Auckland Region. It should consider the appropriate legislation, goals and indicators relevant to this complex environment. An accurate, ground truthed regional inventory of the location, extent and condition of coastal ecosystems should be undertaken. Appropriate methods of data collection and analysis which are objective, repeatable and linked to biodiversity indicators need to be trialled and established. Appropriate ways to communicate information to intended audiences should be considered for data dissemination. Finally, coastal turf, as one of the rarest critically endangered ecosystems of Auckland, and New Zealand, should be monitored, and management initiatives should be undertaken to preserve this rare and neglected ecosystem.

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APPENDICES

Appendix A: Species Information

Appendix A-1. Latin and common name of species identified at sites.
Current conservation status lists latest values which were 2012. All details identified via the New Zealand Plant Conservation Network website www. nzpcn.org.nz

Latin name	Common name	Current conservation status	Structural class
Natives			
Apium prostratum	New Zealand celery	Not Threatened	Dicotyledonous Herbs other than Composites
Apodasmia similis	Jointed wire rush, Oioi	Not Threatened	Rushes and Allied Plants
Austroderia fulvida	Toetoe	Not Threatened	Grasses
Dichondra repens	Mercury Bay weed, Dichondra	Not Threatened	Dicotyledonous Herbs other than Composites
Disphyma australe	Horokaka, native ice plant, New Zealand ice plant	Not Threatened	Dicotyledonous Herbs other than Composites
Ficinia nodosa	Wiwi, knobby club rush, ethel sedge	Not Threatened	Sedges
Leptinella rotundata	Leptinella	Nationally Vulnerable	Dicotyledonous Herbs - Composites
Muehlenbeckia complexa	Small-leaved pohuehue, scrub pohuehue, wire vine	Not Threatened	Dicotyledonous Lianas and Related Trailing Plants
Ozothamnus leptophyllus	Tauhinu	Not Threatened	Dicotyledonous Trees & Shrubs
Phormium tenax	Flax, harakeke, korari	Not Threatened	Monocotyledonous Herbs
Samolus repens	Sea primrose, shore pimpernel, water pimpernel	Not Threatened	Dicotyledonous Herbs other than Composites
Sarcocornia quinqueflora	Glasswort	Not Threatened	Dicotyledonous Herbs other than Composites
Selliera radicans	Selliera, remuremu, bonking grass	Not Threatened	Dicotyledonous Herbs other than Composites
Senecio lautus	Shore groundsel, variable groundsel	Not Threatened	Dicotyledonous Herbs - Composites

Spergularia tasmanica	New Zealand sea spurrey, native sea spurrey	Not Threatened	Dicotyledonous Herbs other than Composites
Tetragonia implexicoma	Native spinach	Not Threatened	Dicotyledonous Lianas and Related Trailing Plants
Triglochin striata	Triglochin	Not Threatened	Monocotyledonous Herbs
Zoysia minima	Prickly couch, zoysia	Not Threatened	Grasses
Zoysia pauciflora	Zoysia	Not Threatened	Grasses
Exotics			
Anagallis arvensis	Pimpernel	N/A	Dicotyledonous Herbs other than Composites
Grass introduced (various grasses unidentified to species level)	Exotic grass	N/A	Grasses
Leontodon taraxacoides	Hawkbit	N/A	Dicotyledonous Herbs - Composites
Lotus pedunculatus	Lotus	N/A	Dicotyledonous Herbs other than Composites
Myosotis arvensis	Field forget-me-not	N/A	Dicotyledonous Herbs other than Composites
Sonchus oleraceus	Sow thistle, sowthistle	N/A	Dicotyledonous Herbs - Composites

Appendix A-2. Taxon identification for each species identified during sampling. Identification utilised the New Zealand Organisms Register website www.nzor.org.nz

Latin name	Species code	Taxon identification
Natives		http://www.nzor.org.nz/names/3b22750d-cf1e-42af-8fe2-8a2e69a5ffc9
Apium prostratum	APIPVF	http://www.nzor.org.nz/names/cbdf40f8-63e6-4486-b6e6-ee2bf085e690
Apodasmia similis	APOSIM	http://www.nzor.org.nz/names/28cd4435-f258-4dd2-954d-4819f91f8c5e
Austroderia fulvida	AUSFUL	http://www.nzor.org.nz/names/ed9ee03e-723d-4b04-a980-9d3fc3610a8a
Dichondra repens	DICREP	http://www.nzor.org.nz/names/26370a1c-f640-43f0-8626-7d244c4bdc12
Disphyma australe	DISAUS	http://www.nzor.org.nz/names/f5cf6ec1-44e0-45a2-9a74-fcab7e140ce0
Ficinia nodosa	FICNOD	http://www.nzor.org.nz/names/9f8e5e00-1108-4d83-a036-ed16f35dd294
Leptinella rotundata	LEPROT	http://www.nzor.org.nz/names/284d8845-94fb-4641-bbaa-481347627a83
Muehlenbeckia complexa	MUECOM	http://www.nzor.org.nz/names/71e9bb47-2e84-452c-ada6-74361bd30df3
Ozothamnus leptophyllus	OZOLEP	http://www.nzor.org.nz/names/d3758b4a-9638-4e48-9b76-a12b13f5779e
Phormium tenax	PHOTEN	http://www.nzor.org.nz/names/06ced754-c19b-49cb-83f5-d685bd6074bb
Samolus repens	SAMREP	http://www.nzor.org.nz/names/d69138c2-d3ba-43d7-a00e-92b2c9821b11
Sarcocornia quinqueflora	SARQSQ	http://www.nzor.org.nz/names/4ca32f9d-2b45-4269-bd1e-88b230d5f19e
Selliera radicans	SELRAD	http://www.nzor.org.nz/names/03cb2542-b53d-4f19-ac98-fc2a52e68d49
Senecio lautus	SENLAU	http://www.nzor.org.nz/names/bb1375b5-6ae7-4d6b-a6eb-4ca6d95d90f0
Spergularia tasmanica	SPETAS	http://www.nzor.org.nz/names/76be2259-4709-4605-a06a-071b2c55b7f8
Tetragonia implexicoma	TETIMP	http://www.nzor.org.nz/names/ad12124d-77e1-4103-8d93-74ad9cb628e5
Triglochin striata	TRISTR	http://www.nzor.org.nz/names/886f5e03-9e5f-4158-9953-984fb280a3f9
Zoysia minima	ZOYMIN	http://www.nzor.org.nz/names/aa455602-77c5-41c6-a8e9-ba00dbecb506
Zoysia pauciflora	ZOYPAU	http://www.nzor.org.nz/names/3b22750d-cf1e-42af-8fe2-8a2e69a5ffc9
Exotics		
Anagallis arvensis	ANAARV	http://www.nzor.org.nz/names/0dddd3d5-ec3e-45fb-b737-34f8a8ac0eca
Grass introduced	ExoticGr	N/A

Leontodon taraxacoides	LEOTAR	http://www.nzor.org.nz/names/fd9346c9-2dc6-47aa-a766-d79171f61465
Lotus pedunculatus	LOTPED	http://www.nzor.org.nz/names/1dc3694b-aaa2-4435-bcf6-a3be26a075aa
Myosotis arvensis	MYOARV	http://www.nzor.org.nz/names/4d3d3766-0066-4238-8936-885841fc3b99
Sonchus oleraceus	SONOLE	http://www.nzor.org.nz/names/6ffa7cbf-2a41-4d51-838e-821f67a8b934

Appendix B: Auckland Native Ecosystem Information

Appendix B-1. Terrestrial and wetland ecosystem types found in the Auckland region showing type, code and name.
Adapted from an Auckland Council publication (Singers et al., 2017)

Ecosystem Type	Code	Ecosystem Name
Forest	WF4	Pūriri, broadleaved forest [Coastal broadleaved forest]
	WF5	Tōtara, kānuka, broadleaved forest [Dune forest]
	WF7	Pūriri forest
	WF8	Kahikatea, pukatea forest
	WF9	Taraire, tawa, podocarp forest
	WF10	Kauri forest
	WF11	Kauri, podocarp, broadleaved forest
	WF12	Kauri, podocarp, broadleaved, beech forest
	WF13	Tawa, kohekohe, rewarewa, hīnau, podocarp forest
	MF4	Kahikatea forest
	MF24	Rimu, tōwai forest
	MF25	Kauri, tōwai, rātā, montane podocarp forest
Cliff	CL1	Pōhutukawa treeland/flaxland/rockland
	CL6	Hebe, wharariki flaxland/rockland
Regenerating	VS1	Pōhutukawa scrub/forest
	VS2	Kānuka scrub/forest
	VS3	Mānuka, kānuka scrub
	VS5	Broadleaved species scrub/forest
Wetland	WL1	Mānuka, gumland grass tree–Machaerina scrub/sedgeland [Gumland]
	WL2	Mānuka, greater wire rush, restiad rushland
	WL10	Oioi, restiad rushland/reedland
	WL11	Machaerina sedgeland
	WL12	Mānuka, tangle fern scrub/fernland [Mānuka fen]
	WL15	Herbfield [Lakeshore turf]
	WL18	Flaxland
	WL19	Raupō reedland
Coastal Saline	SA1	Mangrove forest and scrub
	SA4	Shore-bindweed, knobby clubrush gravelfield/stonefield
	SA5	Herbfield [Coastal turf]
	SA7	Iceplant, glasswort herbfield/loamfield
Dune	DN2	Spinifex, pīngao grassland/sedgeland
	DN5	Oioi, knobby clubrush sedgeland

Appendix B-2. Native ecosystems of the Auckland region showing type, total combined area of each type, total number of ecosystems and average size of each type.
Data calculated from shape files using ArcGIS based on information provided by Auckland Council in July 2016. Not all data has been ground truthed.

Ecosystem Type	Code	Total Area (Hectares)	% Total native area	Number of Ecosystems	Average Size (Hectares)
Forest	WF4	4624	1.28	1079	4.29
	WF5	3116	0.87	578	5.39
	WF7	259	0.07	126	2.05
	WF8	413	0.11	217	1.90
	WF9	8119	2.26	734	11.06
	WF10	1285	0.36	109	11.79
	WF11	34759	9.66	1403	24.77
	WF12	6268	1.74	182	34.44
	WF13	12006	3.34	205	58.57
	MF4	705	0.20	241	2.92
	MF24	80	0.02	3	26.51
	MF25	158	0.04	7	22.57
Cliff	CL1	2621	0.73	939	2.79
	CL6	636	0.18	47	13.53
Regenerating	VS1	2334	0.65	11	212.22
	VS2	249293	69.27	3106	80.26
	VS3	10662	2.96	1123	9.49
	VS5	5405	1.50	760	7.11
Wetland	WL1	93	0.03	28	3.32
	WL2	12	0.00	6	2.04
	WL10	326	0.09	125	2.61
	WL11	368	0.10	346	1.06
	WL12	689	0.19	136	5.07
	WL15	20	0.01	28	0.72
	WL18	54	0.02	69	0.78
	WL19	1233	0.34	713	1.73
Coastal Saline	SA1	10548	2.93	6337	1.66
	SA4	55	0.02	20	2.74
	SA5	16	0.00	30	0.55
	SA7	81	0.02	7	11.56
Dune	DN2	3359	0.93	236	14.24
	DN5	281	0.08	116	2.42
Total Forest		71792	19.95	4884	17.2
Total Cliff		3257	0.91	986	8.2
Total Regenerating		267694	74.38	5000	77.3
Total Wetland		2795	0.78	1451	2.2
Total Coastal Saline		10700	2.97	6394	4.1
Total Dune		3640	1.01	352	8.3
Total		359878	100.00	19067	20.7

Appendix B-3. Native Ecosystem types found in the Auckland region showing type, code, IUCN endangered status and monitoring programme.
IUCN endangered status based on an Auckland Council publication (Singers et al., 2017). ‘Monitoring programme’ states which Auckland Council programme could cover each ecosystem type. Forest and wetland programmes are already in effect, Dune is under development, coastal is under proposal in this thesis and cliff is not yet developed.

Ecosystem Type	Code	IUCN Status	Monitoring Programme
Forest	WF4	Endangered	Forest/Coastal
	WF5	Critically Endangered	Forest
	WF7	Critically Endangered	Forest
	WF8	Critically Endangered	Forest
	WF9	Endangered	Forest
	WF10	Endangered	Forest
	WF11	Endangered	Forest
	WF12	Endangered	Forest
	WF13	Vulnerable	Forest
	MF4	Critically Endangered	Forest
	MF24	Critically Endangered	Forest
	MF25	Endangered	Forest
Cliff	CL1	Vulnerable	Cliff/Coastal
	CL6	Least Concern	Cliff
Regenerating	VS1	Endangered	Forest
	VS2	Least Concern	Forest
	VS3	Least Concern	Forest
	VS5	Least Concern	Forest
Wetland	WL1	Critically Endangered	Wetland
	WL2	Critically Endangered	Wetland
	WL10	Endangered	Wetland
	WL11	Critically Endangered	Wetland
	WL12	Critically Endangered	Wetland
	WL15	Critically Endangered	Wetland/Coastal
	WL18	Critically Endangered	Wetland
	WL19	Endangered	Wetland
Coastal Saline	SA1	Least Concern	Coastal
	SA4	Endangered	Coastal
	SA5	Critically Endangered	Coastal
	SA7	Critically Endangered	Coastal
Dune	DN2	Endangered	Dune/Coastal
	DN5	Critically Endangered	Dune/Coastal