Manaaki Whenua
Landcare Research

Coastal turfs of Otago: monitoring plan

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Coastal turfs of Otago: monitoring plan

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Project and client

- Otago Regional Council (ORC) contracted Manaaki Whenua – Landcare Research to prepare a monitoring plan for the coastal turf communities (a naturally uncommon ecosystem) in Otago.
- This report identifies representative sampling sites and monitoring methods for the timely detection of ecological changes in coastal turf communities.

Background

- Naturally uncommon ecosystems hold a disproportionately high number (85%) of New Zealand's threatened plant species.
- There are 71 naturally uncommon ecosystems in New Zealand, of which 45 (63%) are threatened. In the Otago region there are 18 critically endangered ecosystems, and one of the most threatened ecosystems is coastal turfs.
- Coastal turfs are a distinctive herbaceous community found in New Zealand coastal areas. They are heavily influenced by salt spray and wind, and in many places grazing favours the formation and maintenance of these communities.
- The coastal turf ecosystems are classified as threatened due to their declining distribution and restriction to few locations, with a continuing reduction in ecological function.
- Nationally, coastal turfs are threatened by agricultural and urban development, and conservation management is required. Robust monitoring that can detect changes in their extent and ecological integrity is required.
- Coastal turfs support a disproportionately high number of threatened species. Nationally, 25 'Threatened' and 'At Risk' plant species are recorded as present in coastal turfs, with 12 of those species found in Otago.
- This report identifies representative sampling sites and monitoring methods for the timely detection of ecological changes in coastal turf communities.

Proposed monitoring

- It is key to maintain, and therefore measure, ecological integrity and extent.
- The data required to monitor these components are estimates of area, measures of ecological function, and quantification of the severity of threats.
- Ecological function can be measured using ground-based sampling to track changes in composition, including (i) the distribution and abundance of indigenous species associated with the coastal turf ecosystem, (ii) the distribution and abundance of threatened indigenous species associated with the coastal turf ecosystem, and (iii) the distribution and abundance of exotic weedy species.
- Six sites are proposed for monitoring that represents the geographical distribution, habitat types, and types of coastal turf community present in Otago.
- The proposed monitoring programme at these sites includes establishing a set of permanent vegetation plots and photo-points.

- The vegetation plots will quantify changes in condition as follows: (i) any shift in community composition within the turf patches, and (ii) any reduction in the extent of turf due to invasion by non-native vegetation.
- Aerial imagery and ground-based photography will allow a visual record of the vegetation communities' extent through time.

Management recommendations

- If an increase of greater than 20% in exotic species cover or a decrease of greater than 20% in indigenous turf species is detected, management options should be discussed with landholders.
- For threatened plant species, trends outside the natural population fluctuations should initiate new management options (this will be species dependent).
- A decrease in the extent of turf beyond what is predicted to be the natural extent should also cause a review of management.
- Action to reduce exotic biomass should be either light grazing with sheep or mowing during the spring and summer growth period.

1 Project

Otago Regional Council (ORC) engaged Manaaki Whenua – Landcare Research to prepare a monitoring plan for the coastal turf communities (a naturally uncommon ecosystem) in Otago as part of the ORC's wider workstream to develop naturally uncommon ecosystem monitoring. This report identifies representative sampling sites and monitoring methods for the timely detection of ecological changes in coastal turf communities.

2 Background

2.1 Naturally uncommon ecosystems

New Zealand has a diverse range of unique ecosystems. Some ecosystems are naturally rare, others are uncommon internationally, and many are vulnerable to human impacts. Ecosystems that covered less than 0.5% of the country's land area in prehuman times are often referred to as naturally uncommon ecosystems[1] (Williams et al. 2007). These ecosystems can be small in area (e.g. less than a couple of hundred hectares) but geographically widespread, or large in area but geographically restricted (Wiser et al. 2013). They contain a disproportionately high number (85%) of New Zealand's nationally critical, nationally endangered, and nationally vulnerable plant species, with 46% of these species confined to naturally uncommon ecosystems (Holdaway et al. 2012). There are 71 naturally uncommon ecosystems in New Zealand, of which 45 (63%) are threatened (Holdaway et al. 2012).

The Otago region has a higher proportion (70%) of types of threatened ecosystems than the national average. One of the most threatened of these naturally uncommon ecosystems is the coastal turfs. They are one of the 18 critically endangered ecosystems (the highest level of threat) due to their small and declining current distribution and restriction to a few locations with a continuing reduction in ecological function (Holdaway et al. 2012). Coastal turfs are threatened by agricultural development and urban development, and conservation management is required. They are also inherently dynamic systems, being vulnerable to disturbance from extreme marine inundation or erosion events.

Critically, 86% of coastal turfs occur on land that is not formally protected (i.e. not on public conservation land, under a QEII covenant, or ngā whenua rāhui).[2] The Otago region contains one-fifth of all known coastal turf sites and the only locations on the east coast of the South Island. Only half of these sites have any formal protection (Table 1).

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[1] 'Naturally rare' was the initial term used for naturally uncommon ecosystems

[2] https://www.doc.govt.nz/our-work/monitoring-reporting/national-status-and-trend-reports-2020-2021/ecosystems-protected-2020-2021/.

The ORC is working to develop fit-for-purpose monitoring programmes for the naturally uncommon ecosystems, in line with requirements to report on the state and trend of biodiversity in the Otago region. The coastal turfs were ranked by regional council biodiversity scientists as being among the highest-priority naturally uncommon ecosystems in Otago to have a monitoring programme developed, due to their high threat level, the large proportion of known coastal turf sites in the region, and the region having the only known locations on the east coast of the South Island. Here we outline what is known about the coastal turf ecosystem and detail a monitoring plan to assist in managing these important ecosystems.

2.2 Coastal turfs

Coastal turfs are a distinctive herbaceous community, composed of short-stature halophytic herbs, sedges, and grasses that intertwine to form a dense ground cover (Brownstein et al. 2014; Partridge & Wilson 1988; Rogers & Wiser 2010). They occupy hard-rock landforms on exposed headlands subjected to persistent salt-laden onshore winds and occasional high water (Rogers & Wiser 2010). These communities are often found in small strips along headland margins between the sea and what was once coastal forest, but they are now more often adjacent to non-native pasture (Figure 1). Turfs are the dominant vegetation type at some of New Zealand's most iconic sites (e.g. Slope Point and Tunnel Beach).

Figure 1. A mosaic of coastal turf (the brown-green vegetation) and exotic pasture (strips of dark green vegetation) communities on Long Point. These mosaics are typical across the turf sites in Otago.

Coastal turfs occur in eight mainland regions, across both the North and South Islands (where their extent is probably less than 40 ha), and on offshore islands, including Stewart Island / Rakiura, the Chatham Islands, and subantarctic islands (Wiser et al. 2013). Individual patches of turf are very small (on average only 0.17 ha), and are confined to the coastline, often within 20 m of the sea (Rogers & Wiser 2010). The greatest extent and spatial area of coastal turfs occur along the south coast in the Southland region. In Otago, they are reported to occur on most Catlin coast promontories and are scattered on headlands and wave-exposed rock shelves on the coast north to Kakanui (Rogers & Wiser 2010).

Rogers and Wiser (2010) identified 22 patches of coastal turfs across 13 sites in Otago (Figure 2). Recent visits (August–September 2022) to some of the previously reported locations noted that the extent of the turfs was greatly reduced. At Shag Point the turfs had been invaded by exotic pasture species (mostly grasses), and while a few of the turf species were present (e.g. *Goodenia radicans* and *Leptinella dioica*), they were confined to within 2 m of the seaward edges. The extent of the turf communities at Kātiki Point, Māori Head, and Kakanui also appeared greatly reduced. At Kakanui the turf community extent was reduced to 2 m^2 (Figure 3). Invasion by non-native plant species (especially exotic pasture species) has been identified as one of the main threats to these ecosystems (Holdaway et al. 2012).

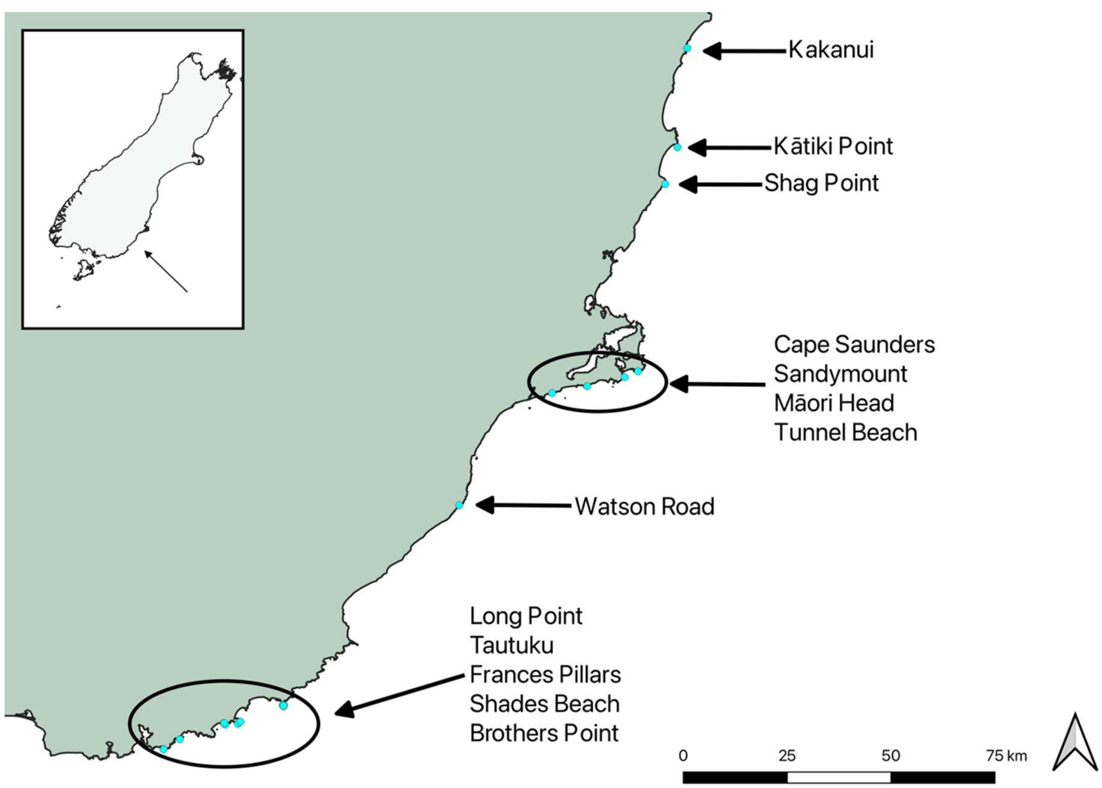

Figure 2. The 13 coastal turf sites (blue circles) identified in Otago by Rogers and Wiser (2010). Multiple patches of turf can be located within the sites (e.g. five at Long Point).

Figure 3. The current extent of coastal turf (circled in blue) at Kakanui (August 2022) surrounded by exotic grasses.

In terms of conservation values, 25 threatened plant species have been recorded in coastal turf plots, 12 of which are found in Otago turfs (Table A1, the threat status follows de Lange et al. 2018). They are also important habitat for native marine mammals (e.g. pinnepids), birds, and invertebrates. The exact composition of the plant community varies, but often includes a mix of species such as *Goodenia radicans, Leptinella dioica, Samolus repens, Apium prostratum, Isolepis cernua, Crassula moschata, Atriplex buchananii*, and *Poa astonii* (Figure 4). While coastal turfs share species with salt marsh and dune slack ecosystems, turfs differ in that salt is delivered via wind rather than tides, and turfs occupy hard, stable substrates rather than unstable sands (Rogers & Wiser 2010).

Figure 4. Typical coastal turf community at Long Point: *Leptinella dioica, Goodenia radicans, Isolepis cernua,* and the rare species *Ranunculus recens* (example circled in blue).

Salt-laden maritime winds and grazing interact to promote turf species and create these unique ecosystems. As maritime winds accelerate along exposed coastal headlands, the combination of mechanical damage, lower temperatures, and desiccation stress selects for the low-growing, thick-leaved turf species (Rogers & Wiser 2010). Evidence for the importance of this environmental driver can been seen in the wind shadows of taller turf species (e.g. *Poa astonii* or *P. cita*), where less salt tolerant, often weedy species are found (e.g. *Holcus lanatus* or *Cerastium fontanum*).

Grazing, either avian historically or mammalian (rabbits, domestic stock, wild ungulates) currently, favours the formation and maintenance of these communities by altering the competitive ability and/or removal of taller native and non-native species that out-compete the prostrate turfs (Brownstein et al. 2014; Lee et al. 2010). Also, removal of leaves and litter by grazers increases the exposure of lower strata to a higher salt level, which again favours the salt-tolerant turf species (Brownstein et al. 2014).

Rogers and Monks (2016) found that mammal grazing, largely by stock (sheep/cattle), on coastal turfs in Southland and Taranaki facilitated native turfs, especially within 10 m of the coast. Brownstein et al. (2014), using field and glasshouse experiments, showed that the dominance of either native turf or exotic species can be promoted by manipulating salt spray and mowing (their surrogate for grazing). Rogers (1999) suggests there are examples where heavy grazing of pasture has promoted turf expansion inland, beyond the extent expected by wind and salt-spray alone. Māori Head is one such example, where, in the absence of sheep or other grazers, swards of exotic pasture grasses have expanded towards the sea, and the once extensive turfs are now confined to the edges and highly exposed slopes.

However, grazing (or the lack of) has little impact on turf community presence and distribution where there is a strong abiotic influence of wind and salt spray, such as at the extremities of the headland at Long Point. Here, strong abiotic influences of wind and salt spray on the west- and southwest-facing slopes maintain the presence of turf communities. A 10-year exclosure experiment showed little difference between the grazed and un-grazed plots in terms of community composition on the most exposed slopes, except for two grazing-sensitive native species (*Poa astonii* and *Apium prostratum*), which increased in abundance when grazing was excluded (Brownstein & Lee 2021). These studies all point to coastal turfs probably representing an unstable successional vegetation state, requiring specific sets of conditions to reset or maintain this dynamic system (Figure 5) (Brownstein et al. 2014; Rogers & Monks 2016).

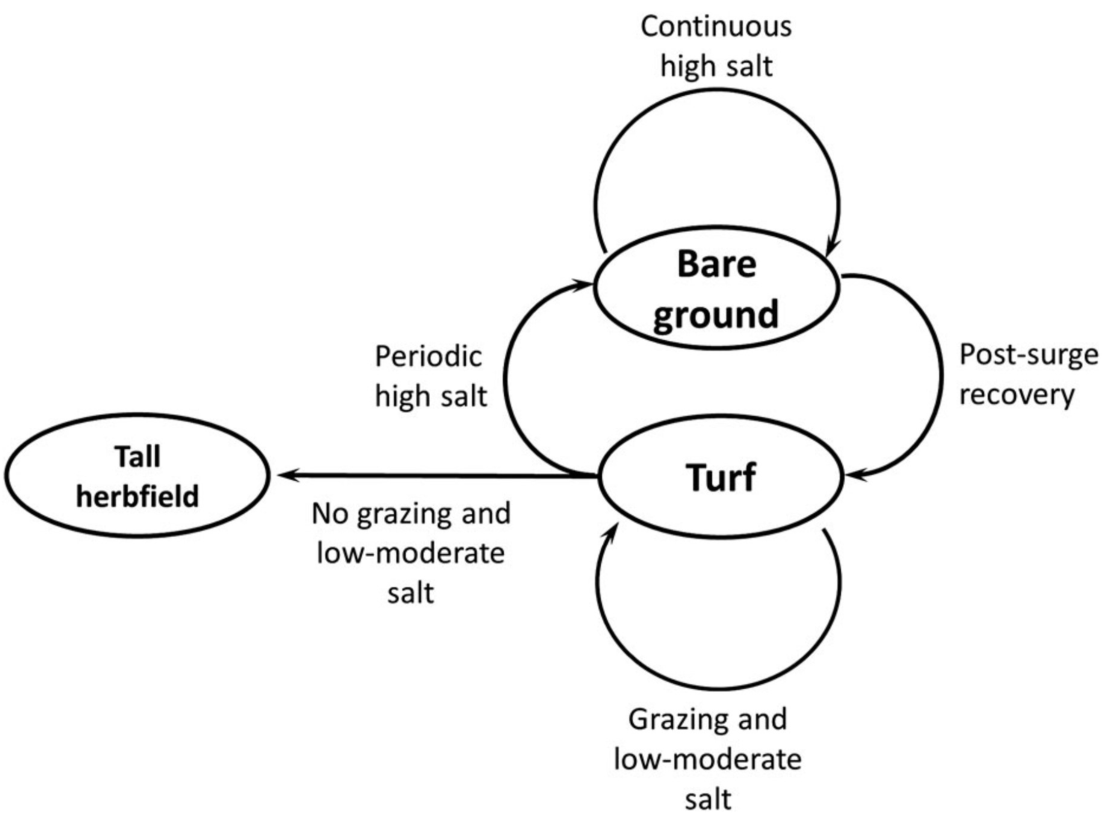

Figure 5. Vegetation dynamics under marine salt and grazing gradients in turf communities. Oval boxes indicate vegetation states. Arrows indicate transitions. Figure from Rogers & Monks 2016.

Table 1. Turf sites found in Otago, ordered from north to south. The 1999 extent is from Rogers 1999. The current extent was estimated from aerial imagery by G. Brownstein for this report; * = extent from Brownstein et al. 2014, ? = unknown condition as the site hasn't been visited in the last 2 years, ** = information provided by J Barkla.

Site	Extent of turf		Dominant turf species	Tenure	Formal protection	Habitat	Current condition	Include in proposed monitoring
	1999	Current						
Kakanui	Not reported	2 m^2	*Leptinella dioica*	Private	No	Coastal platform	Invaded by exotics	No
Kātiki	Not reported	0.01 ha	*Salicornia quinqueflora, Poa pusilla*	Private	Yes	Headland	Invaded by exotics	Backup site
Shag Point	0.05 ha	0.01 ha	*Leptinella dioica, Goodenia radicans*	DoC	Yes	Coastal platform	Invaded by exotics, rare species still present	Yes
Cape Saunders	0.05 ha	0.01 ha	*Leptinella dioica, Goodenia radicans*	Private	No	Headland	Good, rare species still present**	No
Sandymount	0.05 ha	Unable to find in imagery	*Sarcocornia quinqueflora, Puccinellia walkeri*	DoC	Yes	Cliff	Not known	No
Māori Head	0.9 ha*	0.2 ha	*Leptinella dioica, Samolus repens*	Private	Yes	Headland	OK. Invaded by native and exotic species	Yes
Tunnel Beach	0.36 ha	0.25 ha	*Leptinella dioica*	DoC	Yes	Headland	OK	Yes
Watson Road	0.05 ha	0.02 ha	*Leptinella dioica, Goodenia radicans*	Private	No	Coastal platform	Good, rare species still present	Yes
Long Point	0.35 ha	1.5 ha	*Leptinella dioica, Goodenia radicans, Rumex neglectus*	DoC	Yes	Gully slopes / headlands	Good, rare species still present	Yes
Tautuku Peninsula	0.65 ha	0.7 ha	*Poa astonii, Leptinella dioica*	Private	No	Headland	?	Backup site
Frances Pillars	3.5 ha	1.0 ha	*Leptinella dioica, Goodenia radicans, Poa astonii*	Private	No	Coastal platform / headland	?	Yes
Shades Beach	0.01 ha	Unable to find in imagery	*Leptinella dioica*	Private	No	Headland	?	No
Brothers Point	0.81 ha	2.6 ha	*Leptinella dioica, Goodenia radicans*	Private	No	Headland	?	No

3 Proposed monitoring

An effective monitoring programme requires a suitable framework for evaluating progress towards clearly stated biodiversity goals (Lee et al. 2005). Also, given that other councils and organisations are monitoring similar ecosystems, cross-organisational coordination is key for consistency and to gain an understanding of nationwide trends (Bellingham et al. 2021).

For naturally uncommon ecosystems, two key components are ecological integrity and extent. Ecological integrity is defined in the New Zealand Environmental Reporting Act 2015 as 'the full potential of indigenous biotic and abiotic features and natural processes, functioning in sustainable communities, habitats, and landscapes'. The data required to monitor these components are estimates of area (current and historical), measures of ecological function in both pristine and degraded ecosystems, and quantification of the severity of threats (Holdaway et al. 2012).

For coastal turf communities, ecological function can be measured using ground-based sampling to track changes in composition (i.e. distribution and abundance of diagnostic turf species and weedy exotic species, and the presence of key rare/threatened species). In addition, high-resolution aerial or satellite imagery alongside targeted ground-truthing can be used to track extent through time. A set of permanent, ground-based photo-points will allow a visual record of the changes in vegetation communities through time.

The monitoring needs to be robust so that detrimental ecological changes are detected in a timely way. A moderately severe decline in ecosystem function is defined as >30% decline in native vegetation cover and >30% increase in non-native cover, and >30% decline in plant functional type (Holdaway et al. 2012; Lee et al. 2005). The sampling regime needs to be able to detect changes well below that level. We set the power to detect a 20% change, which we think allows time to apply corrective management actions if required (see Appendix C for results of the power analysis).

The key measures of ecological condition include the:

- distribution and abundance of indigenous species associated with the coastal turf ecosystem
- distribution and abundance of threatened indigenous species associated with the coastal turf ecosystem
- distribution and abundance of exotic species.

3.1 Representative sampling sites

Surveys from the early 2000s identified 22 patches of coastal turfs across 13 sites in Otago (Rogers 1999; Rogers & Wiser 2010; see Table 1). We recommend monitoring at five of these sites, which represent the geographical distribution, habitat types, and turf community types present in Otago (Figure 6, Table 1). These sites encompass turf communities with different threats and modifications, including tramping by humans, invasion by weedy exotics, and sheep grazing. Appendix B gives a brief introduction to each site, including site maps, land tenure, list of threatened species present, the key disturbances or risks, and potential management actions and key indicators of integrity to measure.

We also recommend investigating adding the Frances Pillars turfs in the Catlins as a sixth monitoring site. Due to the remoteness of these sites we were unable to survey them for this report, but they should be surveyed and potentially included in a monitoring programme. This site is potentially the only place in Otago where the turf to native forest vegetation sequence is still present without exotic pasture. Because these turf to native forest vegetation sequences are now rare, it is important to prioritise their protection (or re-establishment) (Rogers 1999).

For all proposed sites (except for Watson Road, where we were unable to contact the owner), landowners are happy to consider a monitoring programme led by the ORC (as of September 2022). We have also included two backup sites with landowners that are receptive to the idea of a monitoring programme (Table 1).

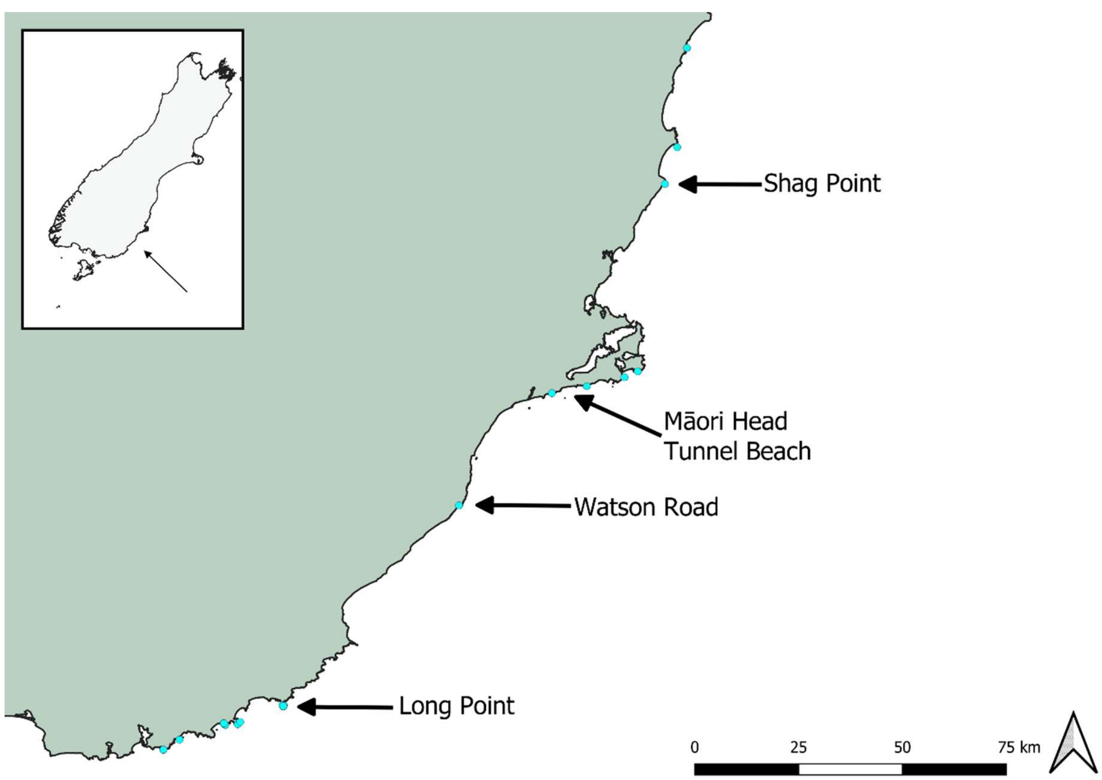

Figure 6. The five coastal turf sites proposed for monitoring in Otago.

3.2 Permanent plots

For the permanent plots, sampling at two scales is recommended: (1) smaller plots to detect change in turf and exotic species cover, and (2) larger belt transects to detect the presence of rare/threatened turf species. We expect native woody seedlings to be an important indicator of natural succession. The threatened species are naturally uncommon but indicate ecosystem intactness and condition. Using a belt transect spanning the main gradient improves the detection rate of sparse individuals.

Five 1 m-wide belt transects running perpendicular to the main environmental gradient (onshore wind) and no closer than 10 m to each other should be placed across the mapped turf community. In smaller sites this number will have to be adjusted for the size and shape of the area. Detailed transect and plot locations for each proposed site are given in Appendix B. Carrying out the proposed sampling would take two botanists 1 to 2 days per site.

A short waratah, c. 30 cm above the ground, should mark the start on the inland side, and the transect should run from the seaward edge to the inland edge of the turf (although this will have to be adjusted on a site-by-site basis). A short wooden or plastic peg could also be used as a marker; alternatively, fenceposts or similar features already in place could be used. Transects should be marked with a GPS to aid in relocation. Using a transect-based sampling method minimises the number of permanent plot markers required, because only one or two markers are needed to accurately lay out a tape (along which multiple plots are located), resulting in lower visual and ecological impacts on the sites. Non-transect-based methods (e.g. random placement within the area of interest) would require a permanent marker per plot.

All seedlings of woody species and individuals of threatened species will be counted in 1 m-wide by 2 m-long contiguous subplots along the length of the transect (Figure 7). Using 1 m × 2 m subplots will make the search area small enough to allow for a systematic and thorough search for woody seedlings and threatened species. Counts of the number of individual plants of each species will be recorded (for clonal species, where counting individuals is difficult, cover estimates in the 1 m × 2 m subplots could be used instead).

The 50 × 50 cm plots should be arranged along the belt transects to aid in relocation, ideally with five plots on each transect evenly spaced along the full gradient. A power analysis of the 50 × 50 cm plot data from Long Point indicated that between 9 and 25 plots (depending on the test used) would be sufficient to detect a 20% change in turf species; and between 9 and 13 plots would be required to detect a 20% change in exotic species cover (Appendix C). Given the size of some sites, 25 plots may not fit, but nine should be used as a minimum.

In each 50 × 50 cm plot, the estimated percentage cover (to the nearest 1%) of all vascular species, moss, lichen, litter (i.e. unattached vegetation and animal dung), and bare ground (including rock) present should be recorded. Using a plot divided into twenty-five 10 × 10 cm squares will assist in systematic searching and estimating percentage cover for each species in the plot. Species with less than 1% cover should be assigned a nominal 0.5% value. Due to the nature of vegetation cover (i.e. plants overtopping one another), total percentage cover can exceed 100%. Where vegetation or moss is dead but still identifiable, it is recorded as the species or moss (this allows for short-lived annuals to be counted, even if sampling occurs outside their growth period). Unidentifiable dead vegetation is recorded as 'dead vegetation'. Use the standard plant species nomenclature and coding system for recording (see Hurst et al. 2022 for further details and examples of using nomenclature and species codes).

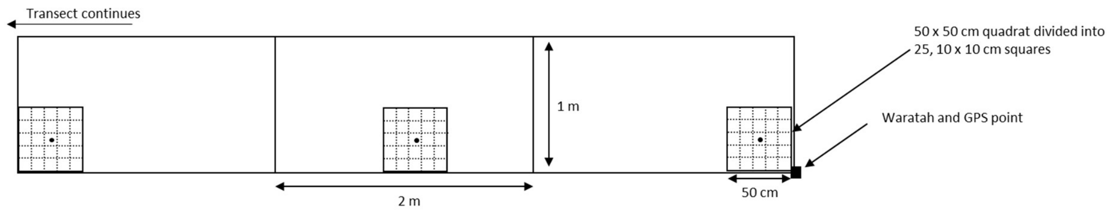

Figure 7. Diagram of a belt transect and plot set-up. The 50 × 50 cm plot is nested within the 1 m-wide belt transect. The marker (waratah) is the transect origin on the inland edge of the turf community.

3.3 Aerial imagery and photo-points

Aerial imagery and photo-points can be used to support and illustrate the quantitative data generated by the permanent ground-based plots (Bellingham et al. 2021). Aerial imagery can be used to delineate changes in the turf extent by mapping ecotone/boundary location through time. A drone/UAV could be used to gather the imagery at regular intervals (ideally collected at the same time as the plot data) from standard elevations or locations. Even with satellite imagery from Google Earth, change in the turf extent is evident (Figure 8).

Good knowledge of the sites and ground-truthing will be required. For instance, in the example shown here, turf is being invaded by native species (taller, tussock-forming grasses and woody shrubs), as well as exotics. In other cases, invasion by *Plantago coronopus* (and other exotic flat weeds) of the turf extent would not change as seen by satellite/UAV imagery. The purpose of aerial imagery is to help illustrate the quantitative data generated by ground-based plots.

Figure 8. The change in extent of the coastal turf at Māori Head at four time intervals between 2005 and 2022. The turf (light grey polygon) contracts over the 17-year time span.

A set of permanent photo-points should be taken each time the plot data are collected. Depending on the size of the site, a set of three to 10 oblique photos showing key features, including the pasture/turf ecotone, grazed turf areas, and threatened plant patches can be set up. Associating the photo-points with the permanent plots or at set distances along the belt transect will aid in relocation; recording a compass direction will also help in relocation. When taking the photos, record the date, time, and photo location on the datasheet. Using the original photo will assist with re-taking the image (i.e. allow key features such as rocks, hills, and skylines to be located). The images can be used to illustrate the species data gathered from the plots (Figure A3).

3.4 Data storage and analysis

Plot data should be digitised and stored in a database (e.g. the National Vegetation Survey databank, New Zealand's primary repository for data on the structure and composition of indigenous vegetation [Hurst et al. 2022], or the Manaaki Whenua Datastore). Photo-point images should be renamed with location label and year and stored in a database (e.g. Datastore). A metadata file with date of sampling, who measured and recorded the data, and any site notes should be kept for each sampling time point. Example datasheets are provided in Appendix D.

For assessing ecosystem extent, comparisons of calculated area of mapped (and ground-truthed) polygons of turf between time points can be made.

Changes in condition (i.e. species composition and cover) between surveys can be tested by using either linear mixed effects models or non-parametric randomisation tests. For the community-level analysis, the species can be grouped into 'turf' (native species found in turf, Rogers 1999) and 'exotic' (using the National Vegetation Survey BioStatus classification). See Appendix C for a discussion of modelling approaches and details on potential model structure.

Parameters to track at specific sites include:

- change at the species level for rare and diagnostic turf species (species present in more than 50% of plots), which should be tested within each site.
- change in the amount of bare ground (an indicator of high disturbance)
- establishment or expansion of native woody species (an indicator of natural succession)
- evidence of introduced mammal presence or grazing.

3.5 Sampling interval and timing

The sampling interval will vary depending on the current state of the site and the management actions (if any) initiated. Prior work shows that detectable change can occur after 14 months under intensive manipulation, or take up to 3 years under more general grazing (Brownstein & Lee 2021; Brownstein et al. 2014; Rogers & Monks 2016). Sampling on a 2-year interval is sufficient to capture long-term trends. Sampling too frequently will increase disturbance (e.g. trampling by workers) and should be avoided in these communities (Burrows et al. 2015).

At Long Point, after sheep grazing was reduced, an initial sampling followed by sampling every 2 years for up to 10 years was recommended (Brownstein & Lee 2021). Results from grazing experiments in turf communities suggest that at sites like Shag Point or Māori Head, where grazing or mowing might be reintroduced, an initial sampling followed by sampling once a year for 3 years would provide information on the outcomes of management actions.

It is important to sample the permanent plots in late spring / early summer (November/December) before the communities dry off and species become hard to identify as summer progresses. Late spring is when most turf species will be flowering, which increases their rate of detectability.

The monitoring programme and methods should be reassessed at 10 years, or after the fifth sample point.

4 Management options

The greatest conservation gains can be made by managing the key threats to the stated biodiversity objectives (Holdaway et al. 2012). The major conservation values are the extent of native coastal turf, the presence/dominance of turf indicator species, and the presence of rare and threatened species. The greatest threat to achieving these objectives is invasion by non-native plants, especially sward-forming pasture grasses (Brownstein et al. 2014; Rogers & Monks 2016). These grasses are tall and therefore easily able to shade the short-statured turf species. Nationally, habitat displacement by invasive plants is considered the biggest threat for most New Zealand native plant species (de Lange et al. 2018).

Moderately severe decline in ecosystem function is defined as a >30% decline in key indicators (Holdaway et al. 2012; Lee et al. 2005). The sampling regime needs to be able to detect changes well below that level. To allow time to apply corrective management actions, we recommend setting the following change thresholds to initiate a review of management options:

- a 20% change in population size for threatened plant species
- a decrease of 20% in cover of turf species
- an increase of exotic species cover by 20% in inside current turf extent.

Excessive exotic pasture species cover is easily managed in these communities through mowing or light seasonal grazing by sheep during the spring and early summer (the main growing season for grasses) to reduce the biomass and alter competition to favour native turf species. Short-statured native coastal turf species are largely unaffected by light grazing because they are too low growing to be easily harvested by grazing animals. Taller-statured native species may be reduced a little but are unlikely to be as palatable as pasture species. Care needs to be taken in soft soils not to use heavy-hooved animals such as cattle (Rogers & Monks 2016). Removing exotic vegetation through either digging or scraping is not recommended, as cleared areas are often reinvaded by exotics (Brownstein et al. 2014; Rogers 1999).

5 Acknowledgements

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Appendix A – Species lists

Table A1. List of native species recorded in sample plots in turf communities in the Otago region, with their current threat status (de Lange et al 2018), including data from Rogers 1999, Rogers & Wiser 2010, and Brownstein & Lee 2021

Species name	Family	Threat status
Disphyma australe	Aizoaceae	
Atriplex buchananii	Amaranthaceae	Threatened – Nationally Vulnerable
Chenopodium allanii	Amaranthaceae	At Risk – Naturally Uncommon
Salicornia quinqueflora subsp. quinqueflora	Amaranthaceae	
Suaeda novae-zelandiae	Amaranthaceae	
Hydrocotyle novae-zeelandiae var. montana	Araliaceae	
Myosotis pygmaea	Boraginaceae	At Risk – Declining
Myosotis rakiura	Boraginaceae	At Risk – Naturally Uncommon
Colobanthus apetalus	Caryophyllaceae	
Colobanthus muelleri	Caryophyllaceae	
Cotula coronopifolia	Compositae	
Leptinella dioica	Compositae	
Leptinella traillii	Compositae	At Risk – Naturally Uncommon
Pseudognaphalium luteoalbum 'coast'	Compositae	
Senecio carnosulus	Compositae	At Risk – Declining
Senecio lautus	Compositae	
Crassula moschata	Crassulaceae	
Cardamine dolichostyla	Cruciferae	
Lepidium tenuicaule	Cruciferae	At Risk – Declining
Carex flaviformis	Cyperaceae	
Isolepis cernua	Cyperaceae	
Gentianella saxosa	Gentianaceae	At Risk – Naturally Uncommon
Goodenia radicans	Goodeniaceae	
Agrostis muscosa	Gramineae	
Poa astonii	Gramineae	
Poa cita	Gramineae	
Poa pusilla	Gramineae	
Puccinellia walkeri	Gramineae	At Risk – Naturally Uncommon
Epilobium komarovianum	Onagraceae	
Plantago raoulii	Plantaginaceae	
Plantago triandra	Plantaginaceae	
Muehlenbeckia complexa	Polygonaceae	
Rumex neglectus	Polygonaceae	

Species name	Family	Threat status
Montia fontana	Portulacaceae	
Samolus repens	Primulaceae	
Ranunculus acaulis	Ranunculaceae	
Ranunculus foliosus	Ranunculaceae	
Ranunculus multiscapus	Ranunculaceae	
Ranunculus recens	Ranunculaceae	Threatened – Nationally Vulnerable
Acaena novae-zelandiae	Rosaceae	
Azolla rubra	Salviniaceae	
Anisotome lyallii	Umbelliferae	At Risk – Relict
Apium prostratum	Umbelliferae	
Eryngium vesiculosum	Umbelliferae	Threatened – Nationally Vulnerable

Table A2. List of exotic species recorded in sample plots in turf communities in the Otago region, including data from Rogers 1999, Rogers & Wiser 2010, and Brownstein & Lee 2021

Species name	Family
Cerastium fontanum	Caryophyllaceae
Sagina procumbens	Caryophyllaceae
Achillea millefolium	Compositae
Cirsium arvense	Compositae
Cirsium vulgare	Compositae
Hypochaeris radicata	Compositae
Sonchus oleraceus	Compositae
Taraxacum officinale	Compositae
Agrostis stolonifera	Gramineae
Aira caryophyllea	Gramineae
Bromus hordeaceus	Gramineae
Dactylis glomerata	Gramineae
Holcus lanatus	Gramineae
Lolium perenne	Gramineae
Poa pratensis	Gramineae
Trifolium pratense	Leguminosae
Trifolium repens	Leguminosae
Plantago coronopus	Plantaginaceae
Plantago major	Plantaginaceae

Appendix B – Site descriptions for locations proposed for monitoring

Shag Point / Matakaea

Land tenure: Public Conservation Estate, Moeraki Area, Otago

General Description: The turfs at Shag Point are part of a Department of Conservation (DOC) reserve on the north coast of Otago. In 1999 Rogers described the site as 0.05 ha of *Lepidium tenuicaule – Leptinella diocia* herbfield on a flat coastal platform 5 m above sea level. Rogers recorded 10 species, with exotic grass *Agrostis stolonifera* as the dominant species. Recent survey work found the main platform dominated by the exotic grasses *Dactylis glomerata* and *Agrostis stolonifera*, with some *Leptinella diocia* and *Samolus repens* confined to the southern edge. The 'At Risk' species *Lepidium tenuicaule* is still present (there is a thriving population in the car park, J Barkla, pers. comm., 2022*)*. The current area containing turf species is roughly 0.01 ha. The native woody species, *Muehlenbeckia complexa* and *Veronica elliptica,* were also present around the platform edges (Figure A1). Shag Point is also an established New Zealand fur seal and seabird-nesting area, so there is potentially some gradation between coastal turf and marine mammal haul-outs.

Disturbance: Walking tracks around the platform edge were well developed.

Management actions: Controlling the exotic pasture grasses (through mowing), especially on the exposed southern seaward edge, to maintain or increase its potential habitat should promote the spread of turf species.

Key measures of condition:

- a significant increase in turf species cover.

Sampling design: The current extent of turf at Shag Point is only 2–5 m wide and forms an L shape along the south and east edge of the point, so we suggest a single belt transect running the length of the community (130 m long) with ten 50 × 50cm plots (Figure A2). Photo-points should be taken at the start and end of the transect.

Figure A1. The invaded turf communities along the south edge of Shag Point. Exotic grasses are dominant, with some *Leptinella diocca* and *Samolus repens* present along the seaward edges and under the *Veronica elliptica* shrubs.

Figure A2. Example sampling layout for Shag Point. Yellow dots are 50 × 50 cm plots, black lines are 1 m-wide belt transects. The grey polygon is the approximate extent of the coastal turf community (2004–2011 imagery).

Māori Head

Land tenure: Private, protected under a QEII covenant.

General description: The turf communities on Māori Head are part of a QEII covenant on the Otago Peninsula. The turf extends along a southwest face at the crest of an exposed headland, 40 m above sea level. In 2010 Rogers and Wiser described the site as a gently sloping and well-drained turf of *Leptinella dioica* and *Samolus repens* (they don't give an extent of turf). Brownstein et al. (2014) write that in 2008 most of the headland was covered in a mosaic of turf and pasture, with turf patches ranging in size from 1 m^2 to 300 m^2. Recent visits in 2021 and 2022 found that the cover of woody plants (e.g. *Muehlenbeckia complexa*, *Veronica elliptica*, and *Coprosma repens*) has noticeably increased on the headland, with *Poa cita* and *P. astonii* becoming more dominant. The current of extent of the turf is roughly 0.5 ha, though in the past it was nearly double that (it was maintained by mammalian grazing until 2007).

Disturbance: Nothing was especially noticeable, though some lagomorph sign is present. This site was grazed by sheep and cows until 2007.

Management actions: Given that there are no rare or threatened turf species present, one management option is to allow the natural extent of the coastal turfs (i.e. the zone maintained by high salt spray alone) to re-establish. Since the removal of grazers, the site appears to be stepping towards the re-establishment of a coastal turf to coastal forest sequence that was once prevalent on the Peninsula. This type of vegetation sequence is uncommon in Otago. Monitoring these changes will allow documentation of the transition phase between pasture grazing and regenerated coastal turf/forest sequence.

Key measures of condition:

- a significant reduction in cover of exotic pasture species
- an increase in cover of woody species and native tussock species.

Sampling design: Because the turfs are along a southwest face along the crest of an exposed headland, we suggest that four belt transects (between 10 m and 70 m long) running east–west, with twenty-three 50 × 50 cm plots, is the most efficient way to capture the gradients present. These transects extend outside the current extent of turf to allow documentation of the transition phase between pasture grazing and regenerated coastal turf/forest sequence (Figure A3). Photo-points should be taken at the start and end of each transect, looking long the tapes.

Figure A3. The mosaic of coastal turf and exotic pasture in 2008 (left), which by 2021 (right) is dominated by exotic pasture (grazing was removed in 2007).

Figure A4. Since grazing was removed in 2007, the native tussocks *Poa cita* and *P. astonii* have become more widespread across the headland. A mixture of turf and exotic pasture species occupy the inter-tussock spaces. Photos taken September 2022.

Figure A5. Example sampling layout for Māori Head. Yellow dots are 50 × 50 cm plots, and black horizontal lines are 1 m-wide belt transects. The grey polygon is the approximate extent of the coastal turf community in 2016 (2013 imagery).

Tunnel Beach

Land tenure: Public Conservation Estate, Dunedin Area, Otago.

General description: Tunnel Beach turfs are on a small sandstone headland, c. 15 m above sea level, which is part of a DOC Recreation Reserve. The *Leptinella dioica, Goodenia radicans,* and *Samolus repens* turf covers most of the headland (c. 0.25 ha in extent), with some exotic grasses among *Poa astonii* tussocks at the seaward end. Where the headland connects to the mainland, the turfs grade into exotic pasture within a couple of metres. The Threatened – Nationally Vulnerable species *Atriplex buchananii* has been recorded on the headland (J Barkla, pers. comm., 2022).

Disturbance: This site is heavily affected by people walking off the marked track (Figure A6). There is a noticeable increase in the amount of bare ground on the headland over the last 5 years.

Management actions: Access the headland needs to be restricted or better controlled to stop trampling and allow turf to recolonise the bare areas. Starting in 2021, DOC is redeveloping the track and site to restrict access.

Key measures of condition:

- maintained or increased turf species cover

• a significant reduction in the amount of bare ground over time.

Sampling design: Due to the long, narrow shape and orientation of the headland, we suggest that six belt transects (between 16 and 50 m long) running north–south, with twenty-two 50 x 50 cm plots is the most efficient way to capture the gradients across the turf community (Figure A7). Depending on the visual impacts of markers, the number of transects may need to be reduced. Three transects could also be oriented along the length of the headland, which would require fewer markers. Photo-points should be taken at the start and end of each transect looking along the tapes.

Figure A6. The coastal turf on the headland at Tunnel Beach. Note the tracks and erosion. Photos taken September 2022.

Figure A7. Example sampling layout for Tunnel Beach. Red dots are 50 × 50 cm plots, black vertical lines are 1 m-wide belt transects. The grey polygon is the approximate extent of the coastal turf community (2013 imagery).

Watson Road

Land tenure: Unowned/unspecified part of the beach but access is through private land (using paper roads).

General description: The turfs at Watson Road are on a coastal platform, at c. 2 m asl, 15 km south of Taieri Mouth. Small patches (c. 2 m square) of turf are common on the rocky platforms along this section of coastline between Taieri Mouth and Toko Mouth. The *Leptinella diocia* turf at Watson Road is c. 0.02 ha in extent. Rogers (1999) recorded three threatened species present at the site (*Ranunculus recens*, *Lepidium tenuicaule*, and *Myosotis pygmaea*). *Lepidium tenuicaule* was re-found on a Botanical Society of Otago field trip in 2021 (Figure A8). The site was unable to be surveyed for this report because access is through private land, though the site itself is on the beach and unowned.

Disturbance: Grazing by sheep and lagomorphs.

Management actions: None required at this time, other than monitoring as an example of turf on a coastal platform.

Key measures of condition:

- <20% increase in cover of exotic species
- <20% decrease in cover of turf species
- <20% decrease in presence/abundance of threatened species.

Sampling design: Four 40 m-long belt transects running north–south with seventeen 50 × 50 cm plots will fit within the turf community (Figure A9). Photo-points should be taken at the start and end of each transect looking along the tapes.

Figure A8. *Lepidium tenuicaule* with *Leptinella dioica* at Watson Road (photo credit: R. Bridges, 2021).

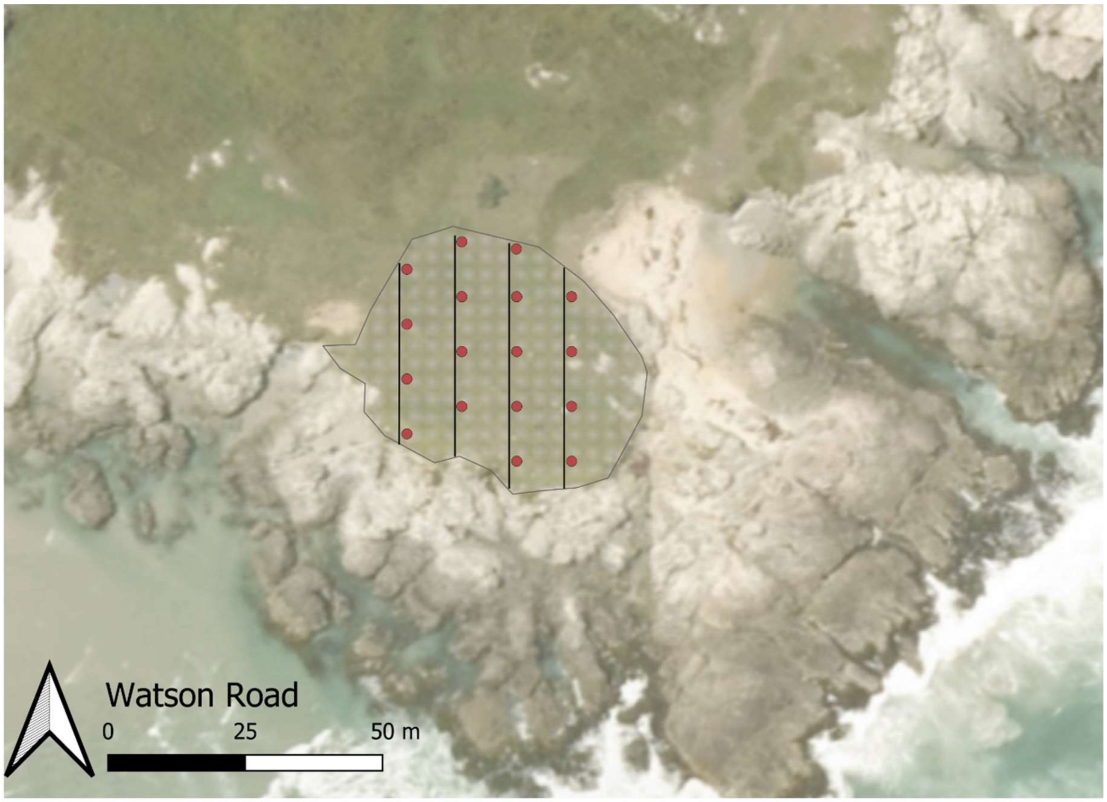

Figure A9. Example sampling layout for Watson Road turf. Red dots are 50 × 50 cm plots, black vertical lines are 1 m-wide belt transects. The grey polygon is the approximate extent of the coastal turf community (2013/14 imagery).

Long Point

Land tenure: Public Conservation Estate, managed in partnership with the Yellow-eyed Penguin Trust.

General description: The *Leptinella dio*ica – *Goodenia radicans* turfs at Irahuka Long Point are along the west- and southwest-facing slopes of the seaward end of the point (c. 35 m asl), with the three main patches covering approximately 1.5 ha of land. Also, there is a *Rumex neglectus*-dominated turf area (c. 0.01 ha) in a gully, which is a unique turf type in Otago (Figure A11). Six threatened species were recorded by Rogers (1999) in areas associated with these turfs: *Atriplex buchananii, Gentianella saxosa, Myosotis pygmaea, M. rakiura, Ranunculus recens,* and *Senecio carnosulus*. A survey in 2021 confirmed that at least three species were present: *A. buchananii, M. rakiura,* and *R. recens*. Originally, the headland and surrounding area were covered in broadleaf/podocarp forest. Only remnant patches remain now, especially inland. Non-native pasture is the current dominant vegetation type across the headland, which is grazed, mostly by sheep. The headland supports many marine animals, including fur seals, sea lions, and numerous seabird species (including hoiho and tītī).

Long Point is managed by the Yellow-eyed Penguin Trust, whose long-term goal is restoring coastal forest ecosystems to enhance habitat for seabirds, including hoiho. As part of this project, the Yellow-eyed Penguin Trust is collaborating with DOC to carry out large-scale fencing and removal of livestock from part of Long Point, which has a history of pastoral farming. In 2021 the new fence removed grazing from the largest area of coastal turf, along the western edge of the peninsula. The removal of stock grazing from the headland was predicted to have both positive and negative impacts on the coastal turf ecosystem (Brownstein & Lee 2021), with the main positive impacts being an increase in the abundance of grazing-sensitive native turf species, and the natural extent of the coastal turfs (i.e. the zone maintained by high salt spray alone) would be re-established. A monitoring programme was started to help inform the need for potential management to preserve coastal turfs during the transition from exotic pasture to native forest species.

We recommend including the monitoring at Irahuka Long Point with the monitoring of turfs in the wider Otago region because it has some of the most extensive turfs in Otago (that are easily accessible) and there are several threatened species present. The *Rumex neglectus* turf should be added to the monitoring programme led by the ORC.

Disturbance: Lagomorphs are present across the headland. Sheep have recently (2021) been excluded from the largest area of turf on the western edge.

Management actions: Continue the 2-yearly monitoring started by DOC in 2021, as outlined in Brownstein and Lee (2021).

Key measures of condition:

- <20% increase in cover of exotic species
- <20% decrease in cover of turf species
- <20% decrease in presence of threatened species.

Sampling design: Continue with the DOC monitoring. To make the data for rare and woody species comparable, add four 40 m-long belt transects running north–south, starting at existing plots (Figure A12). Also, place one 60 m-long belt transect with nine 50 × 50 cm plots in the *Rumex neglectus* turf (Figure A12). No additional photo-points are required beyond what is in the current DOC monitoring.

Figure A10. Looking north from the seaward end of Long Point back towards the mainland. In the foreground is *Leptinella dioica Goodenia radicans,* and *Samolus repens* (flowering) turf, with short *Poa astonii* plants.

Figure A11. *Rumex neglectus*-dominated turf area at Long Point.

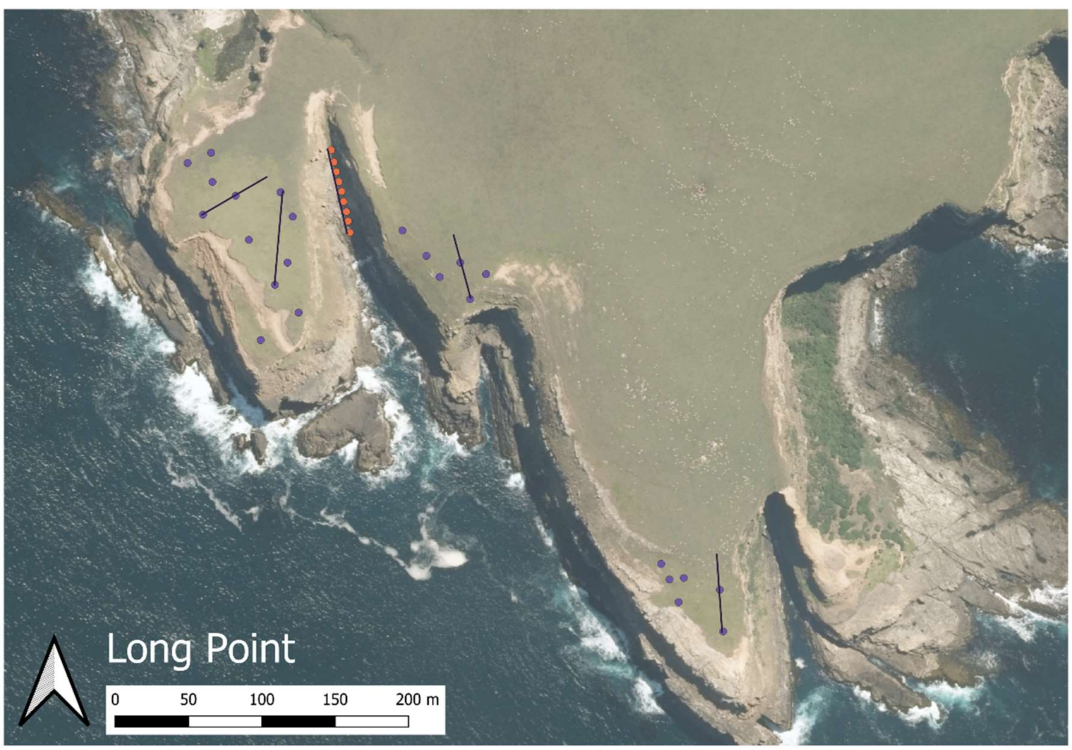

Figure A12. Location of the stratified grazing excluded plots and control plots (purple dots) that are being monitored 2-yearly by DOC; orange dots show additional plots in the *Rumex neglectus*-dominated turf, black lines show additional belt transects to link with rest of the proposed monitoring (2013/14 imagery).

Appendix C – Power analysis results

Power analyses were run using a dataset from 4 years of monitoring coastal turf communities at Long Point. These data are from an exclosure experiment established on the headland turf communities in 2010 at the request of the Yellow-Eyed Penguin Trust to investigate whether grazing pressure from stock is controlling species composition and the extent of coastal turf communities. These plots were remeasured in 2011, 2012, 2013, and 2020. For more information see Brownstein and Lee (2021).

Five sets of paired 75 × 75 cm plots were marked in each of the four areas across the headland (20 pairs, 40 plots in total). The grazing control plots were located across slope on the north side of the treatment (caged/grazing excluded) plots with a 15-cm buffer between them.

To assess change, species cover was calculated using 100-point quadrats for each exclosure and its control. The 100 points were evenly spaced over the centre 50 × 50 cm of each plot to reduce edge effects. All vascular species the point intersected were recorded, as well as the presence of litter, bare ground, and moss.

For the power analysis we only used the first four time-points, as 2020 had too many missing plots. Also, we used only the 20 grazed/control plots, as our question here is how the community changes under natural conditions.

Methods

Both non-parametric and parametric approaches were used for the power analysis. The non-parametric approach is useful in that it minimises the number of assumptions around the distribution and shape of the data (allows greater flexibility to adapt significance tests and simulation methods to suit the sampling design), while the parametric approach is more sensitive (fewer plots are required to detect change).

We started with the non-parametric approach, because the probability density distributions were highly variable and depend on the sampling dates being compared within a single site (Long Point, Figure A13). We think monitoring data at other sites will also follow variable probability density distributions. We used a non-parametric power analysis to determine sample sizes required to detect a 20% increase in pasture species abundance, or a 20% decrease in turf species abundance, with power 0.8 and alpha = 0.05.

The non-parametric approach simulated abundance change values using kernel density estimators. Kernel density estimators make no assumptions about the probability density distribution data follow, except for the degree of uncertainty for each observation (defined by the bandwidth). The bandwidth chosen was the Sheather-Jones direct plug-in with a Gaussian kernel within the density function of the stats package in R (R Core Team 2022; Sheather & Jones 1991). The significance test compared the observed mean differences against those expected under a null model, where the signs of differences were randomised. *P* values were estimated at 2× the proportion of randomisations, yielding a result as extreme or more extreme than the expected value (to provide a two-tailed test).

Separate power analyses were performed for all possible pairs of sampling date in the Long Point monitoring data to give an indication of potential variation in required sample size.

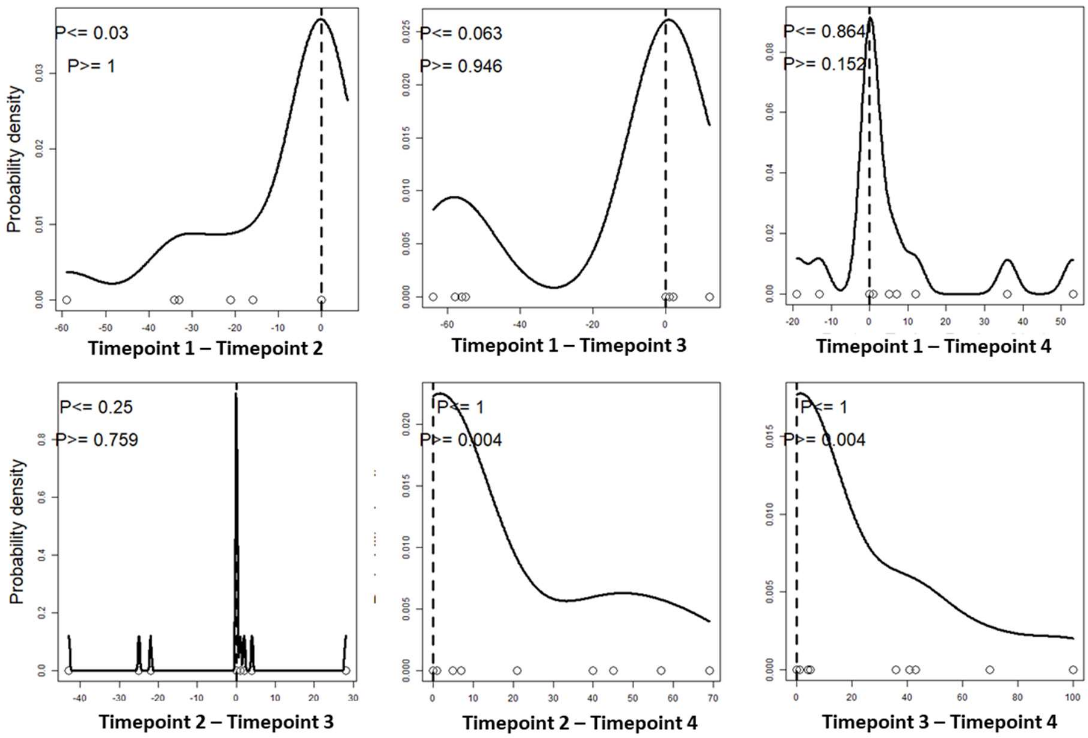

Figure A13. The probability density distributions for pasture species between each pair of sampling dates at Long Point.

For the parametric approach we wanted to detect invasion by pasture over time. There is a gradient from pure turf to pure pasture species driven by distance from coast / salt spray and modified by grazing; and plots tend to have none, some, or lots of pasture depending on where they are along the gradient. We used the plots that had >0 pasture species cover (because we are interested in changes in cover, rather than occupancy). We fitted a binomial generalised linear mixed effects model, with timepoint as the fixed effect and individual plots as a random effect (Bates et al 2015). Because we want to detect a trend through time (e.g. a year-on-year increase in exotics), we set the effect size to 10%, 20%, and 30% change between timepoints 1 to 2, 1 to 3, and 1 to 4, respectively. We then simulated the parameters from our model 2,000 times using sim from package 'arm' (Gelman & Su 2022). This simulates from the posterior distributions of the parameters. We simulated a new response using the simulated parameters and original data, then refitted the model to the simulated data and calculated how many times there was a significant effect for a given sample size.

Results

Using the non-parametric tests, the required sample size to detect a 20% increase in pasture species abundance varied from 10 to 19 across the Long Point sampling date comparisons, with a mean of 13 plots. The required sample size to detect a 20% decrease in turf species abundance varied from 11 to 30 across the Long Point sampling date comparisons, with a mean of 25 plots (Table A3).

Table A3. The number of plots required to detect a 20% change in turf or pasture species between each of the sampling times at Long Point using the non-parametric approach.

Timepoints	Sample size	
	Turf	Pasture
1 and 2	11	11
1 and 3	30	19
1 and 4	30	10
2 and 3	20	10
2 and 4	25	10
3 and 4	30	18

For the parametric approach, using the binomial generalised linear mixed effects model, a minimum sample size of nine plots was required to detect a year-on-year change of 10% in turf or exotic pasture cover over 3 years.

Given the results of both analyses, sampling at least 25 plots will result in good power to detect changes in exotic and turf cover. For the very small sites, where there is insufficient space for 25 plots, using 10 plots will still provide enough power to detect changes in exotic cover.

Discussion

Here we show that both parametric and non-parametric approaches can be used for analysing these types of data, though both have their strength and drawbacks.

Linear mixed effects models require the least amount of plots to achieve the desired power. These models can be used to test for changes in occupancy and cover between surveys for each site (allowing for nested random effects for transect and subplot). The default option in using mixed effects models to model repeated measures data is to include a plot-level random intercept term. In the context of turf communities this, in theory, accounts for differences between plots in key factors such as distance from the shore, which are likely to affect the abundance of turf or pasture species. Where there is reason to believe differences between plots might cause differences in the rate of change, random intercepts might also be fitted for each plot. However, it is unlikely there will be enough data to fit random plot-level slopes until multiple repeated surveys have been conducted.

Application of parametric approaches such as linear mixed effects models depends on the ability to summarise the probability density distribution of observed data using a parametric distribution (e.g. normal, log-normal, Poisson or negative binomial). Data from repeated surveys at Long Point reveal that the shape of the probability density distribution for plot-level changes in turf and pasture group abundances varies markedly depending on the survey years being compared. If this is the case, then a non-parametric approach could be used. Non-parametric approaches make no assumptions about the type of distribution data follow, and thus offer a more robust approach when data cannot be modelled by a parametric distribution or where the most appropriate distribution will vary through time. A simple randomisation test of pairwise differences similar to the one use for the power analysis could be used. An R source file is also available on request that implements the randomisation tests (and a power analysis) on the non-exclosure plot data from Long Point.

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Appendix D – Example datasheets

Below is an example datasheet for a 50 × 50 cm plot.

Location:	**Transect:**
Date:	**Measurers:**

GROUND COVER % by SPECIES												
Plot (Tape m)												
Substrate												
Bare												
Litter												
Bryos												
Species												

Below is an example datasheet for 1 m × 2 m rare and threatened plant belt transects.

Coastal Turf Monitoring - Rare plants	
1x2 m Subplots	**Rare Species-- Tally by Spp.**
Transect Number:	**Location:**
Date:	**Measurers:**

	Subplot									
Species	**0-2m**	**2-4m**	**4-6m**	**6-8m**	**8-10m**	**10-12m**	**12-14m**	**14-16m**	**16-18m**	**18-20m**

	Subplot									
Species	**20-22m**	**22-24m**	**24-26m**	**26-28m**	**28-30m**	**30-32m**	**32-34m**	**34-36m**	**36-38m**	**38-40m**