Manaaki Whenua
Landcare Research

Upper Taiari Scroll Plains wetland vegetation survey

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Upper Taiari Scroll Plains wetland vegetation survey

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Summary

Project and client

- The Otago Regional Council (ORC) engaged Manaaki Whenua – Landcare Research (MWLR) to carry out a wetland vegetation survey of the Upper Taiari[1] Scroll Plain to provide baseline data for ongoing monitoring of wetland condition.

Objectives

- Carry out a wetland vegetation survey in previously delineated wetland polygons to better understand the links between the vegetation and dominant environmental drivers, including effects of grazing.
- Provide wetland vegetation information to assist the Otago Regional Council (ORC) in designing effective management and monitoring plans for the Upper Taiari Scroll Plains.
- Establish and measure 150 wetland vegetation plots across the Upper Taiari Scroll Plains to provide a baseline for monitoring condition and trend changes.
- Propose a representative network of permanent sites for future monitoring.

Methods

- We carried out wetland condition monitoring as detailed in Clarkson et al (2004), including assessing vegetation composition, signs of grazing, and for a subset of plots, laboratory analyses of soil chemistry.
- For the wetland condition and pressures indices we assessed the scroll plains in three sections: (Styx/Paerau Basin Wetlands, Māniatoto Basin Wetlands, and Taieri Lake / Tunaheketaka[2]).
- To better understand how the vegetation patterns vary across the Upper Taiari Scroll Plains we surveyed 151 wetland vegetation plots, each measuring 5 × 5 m.
- All potential plot locations were restricted to within the previously delineated wetland polygons of the Upper Taiari Scroll Plains.
- The number of plots sampled was roughly proportional to area of mapped wetland in each: Paerau basin (1,067 ha of mapped wetland, 72 plots), Māniatoto basin (1,098 ha of mapped wetland, 74 plots), and Tunaheketaka (76 ha of mapped wetland, 5 plots).
- To examine effects of grazing within each of the Paerau and Māniatoto basins we further restricted the placement of 80 plots (40 per basin) with 40 plots per treatment (e.g. 20 grazed and 20 ungrazed plots at Paerau; 20 grazed and 20 ungrazed plots at Māniatoto).
- At the request of the ORC, 12 of the 151 plots (5 in Paerau and 7 in Māniatoto) were co-located with the ORC's continuous water monitoring stations and bore holes.

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[1] The correct spelling for the Tareri is Taiari. While this is not yet in the NZ Gazetteer, place names follow Kā Huru Manu: https://www.kahurumanu.co.nz (accessed 3 May 2023).
[2] Place names follow Kā Huru Manu: https://www.kahurumanu.co.nz (accessed 3 May 2023).

- In all plots, the percentage cover across all height tiers and cover classes in each height tier was recorded for all vascular plant species.
- Two soil cores (10 cm diameter x 7 cm deep) were collected from the south-west corner of each plot or from the lowest point in the plot. Seventy-five of the 151 soil cores were analysed for soil chemistry.
- Evidence of grazing in or around the plot was recorded (e.g. cropped or trampled vegetation, and/or faecal matter present). We also recorded the species inferred to be doing the grazing (cattle, sheep, or bird), where possible.
- Depth to the water table was measured (where required a hole was dug up to 60 cm deep). Where a water table was present or there was standing water on the plot, pH, temperature, and conductivity were measured using a TPS WP81 conductivity and pH meter.
- We assigned species wetland indicator status following the New Zealand Wetland Plant List 2021:
    - OBL: Obligate Wetland. Almost always is a hydrophyte, rarely in uplands (non-wetlands).
    - FACW: Facultative Wetland. Usually is a hydrophyte but occasionally found in uplands.
    - FAC: Facultative. Commonly occurs as either a hydrophyte or non-hydrophyte.
    - FACU: Facultative Upland. Occasionally is a hydrophyte but usually occurs in uplands.
    - UPL: Obligate Upland. Rarely is a hydrophyte, almost always in uplands
- To assess the degree of wetland-preferring species in each plot, we calculated the Dominance Test and Prevalence Index.
- We used a combination of linear models and multivariate analyses to examine questions related to vegetation patterns and environmental drivers.
- To investigate effects of grazing type, we grouped plots based on evidence of grazing and type of grazing (cattle, sheep, bird, or combination of), then used linear models to test whether grazing could be related to cover and number of native species.
- We tried using a grazing chronosequence (a series of sites differing in age since abandonment or disturbance but otherwise similar) from the Paerau basin to test the effect of time since grazing on cover and number of native wetland species.

Results

- From across the 151 plots, 151 vascular species were recorded, with a mean of 11 species recorded per plot. The most species-rich plot (n = 22) was in wet grassland in the Māniatoto section at the base of a terrace. The most species-poor plots were underwater or on recently exposed silts.
- Across all plots, 52 native species were recorded, 7 of which are classified as threatened or at-risk plant species. The threatened or at-risk plant species were recorded in both the Māniatoto and Paerau basins.
- The most common occurring species were: foxtail – *Alopecurus geniculatus* (FACW, exotic, occurred in 50% of the plots); white clover – *Trifolium repens* (FACU, exotic,

occurred in 40% of the plots); and autumn hawkbit – *Scorzoneroides autumnalis* (UPL, exotic, occurred in 46% of the plots).

- Of the 151 plots, 30% of them contained exclusively exotic species, which were mainly exotic grasses.
- Of the 151 plots, 32% had 50% or more cover of exotic non-wetland species (i.e. FACU and UPL species). This means these plots are not likely to be in wetlands.
- The only woody species recorded were two species of willow (both invasive exotics), *Salix cinerea* and *Salix* x *fragilis*.
- Three plots contained solely native species; all these plots all had standing water present at time of measure (during a drought).
- Of the 151 plots, only 7% of the plots had greater than 50% cover of native species (5 plots in the Māniatoto basin and 5 in the Paerau basin).
- The cluster analysis of the 149 plots suitable for analysis produced four groups (plant communities). The groups reflect both gradients of soil moisture and location through the scroll plain.
- Recent grazing was evident in all vegetation types of the scroll plain wetlands. Current grazing or evidence of recent grazing (e.g. cropped or trampled vegetation, and/or faecal matter present) was noted in more than half (n = 81) the 151 plots. This included 40% of the 'non-grazed' treatment plots. This meant that despite our stratification, we could not draw robust conclusions about influence of grazing.
- When we assessed the presence of actual grazing, we found it was not correlated with species richness, percentage cover of obligate wetland species, or percentage cover of native species. However, the unbalanced sampling design means further investigation will be required to answer this question robustly.
- We were unable to draw robust conclusions from the attempted grazing chronosequence as several key assumptions for chronosequences were not met.
- The soil chemistry varied with scroll plain location, and to some degree with grazing. Both soil pH and conductivity (EC) increased with distance down catchment.
- Soils in the Paerau basin tended to have higher percentages of nitrogen, potassium, and phosphorus than soils in the Māniatoto basin and Tunaheketaka.
- Sixty percent of the plots surveyed meet the wetland delineation vegetation requirements and qualify as wetlands, while 40% of the plots surveyed do not qualify as wetlands or require further investigation. We were unable to assess the extent of wetlands that were not mapped as wetlands, as only areas delineated as wetland were included in our sampling universe.
- The wetland condition scores (current state indicators and a pressure index) show the Taiari Scroll Plain is a highly modified system, with significant ongoing pressures.

Conclusions

- Hydrological drivers are important for creating and maintaining the vegetation patterns observed.
- The vegetation groups appear to be linked with the various landforms found in the floodplain of the Upper Taiari Scroll Plain.

- The plant communities surveyed ranged from drier rough pasture communities growing on the higher berms between oxbows to wet sparsely vegetated mud turf communities growing in the more continuously inundated pond areas.
- Most areas in the wetlands within the scroll plain can probably be classified as marsh due to the presence of mineral soils, but some could be classified as swamp.
- The drier areas of the scroll plain are currently primarily pastoral grassland.
- Although modified, the scroll plain retains representatives of New Zealand's indigenous wetland flora, including several threatened species.
- We were unable to detect a significant effect of grazing on the vegetation composition. The whole of the scroll plain has been grazed at some point and to some extent. Further studies are needed.

Recommendations

- Manage the Upper Taiari Scroll Plain to maintain and enhance native plant species, especially those with restricted habitat types, e.g. mud turf, by maintaining natural hydrological processes, controlling invasive weeds and restoring native shrubland on drier, elevated sites.
- Remeasure wetland extent and condition at 6-year intervals.
- Investigate conducting a Before-After-Control-Impact (BACI) type experiment to better understand the long-term influence of stock grazing in the different parts of the scroll plain.

1 Introduction

The upcoming revision of the Otago Land and Water Regional Plan (LWRP) will detail how National Policy Statements and regulations for wetland resource management are implemented in Otago. The following national regulations/guidelines must be actioned:

- National Policy Statement for Freshwater Management (NPS-FM; 2020)
- Resource Management Regulations (Stock Exclusion; 2020)
- Resource Management Regulations (National Standards for Freshwater; NES-F 2020)

These guidelines and regulations set the standards for natural wetland management and monitoring. Every regional council must:

> (a) develop and undertake a monitoring plan that: (i) monitors the condition of its natural inland wetlands (including, if the council chooses, wetlands referred to in subclause (2)); and (ii) contains sufficient information to enable the council to assess whether its policies, rules, and methods are ensuring no loss of extent or values of those wetlands; and (b) have methods to respond if loss of extent or values is detected. (NPS-FM; 2020)

The NPS-FM identifies ecosystem health as a compulsory value to monitor, and specifically lists ecological processes as one of five components of ecosystem health (the other four are water quality, water quantity, habitat, and aquatic life). For discrete and isolated, and relatively homogenous wetlands, these new national requirements to monitor extent and condition can be implemented in an intuitive and pragmatic manner. However, in expansive wetland ecosystem complexes in diverse agricultural landscapes, such as the Upper Taiari[3] Scroll Plains, designing a monitoring scheme is particularly challenging. The complex ecology of the plains is overlain by legacy effects from a post-settlement history of fire, stock grazing, water extraction and drainage, and a range of different adjoining other land uses.

The recent wetland maps of the Upper Taiari Scroll Plain (produced following NPS-FM directions; (Pyatt & Konlechner 2022)) illustrate the complex patterns and processes influencing these wetlands. To protect and enhance these nationally significant wetlands effectively we need a clear understanding of how the entire complex functions in relation to water regimes, nutrient flows, sedimentation patterns, plant communities, and seasonal grazing impacts.

This report gives a brief overview of the current understanding of the vegetation of the Upper Taiari Scroll Plain and presents results of a new vegetation survey (2022–2023). We discuss how these data can be used as a baseline for ongoing monitoring of wetland condition and trend changes to fulfil requirements under the NPS-FM and associated regulations.

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[3] The correct spelling for the Tareri is Taiari. While this is not yet in the NZ Gazetteer, place names follow Kā Huru Manu: https://www.kahurumanu.co.nz (accessed 3 May 2023).

2 Background

The Taiari River, in eastern Otago, has its upper headwaters in the Lammerlaw and Lammermoor Ranges and flows northeast through the Māniatoto basin before wrapping around Pātearoa (Rock and Pillar Range) to flow south out to the Otago coast. This report focuses on the Upper Taiari Wetlands Complex which is composed of three sub-sections: the Styx/Paerau Basin Wetlands, the Māniatoto Basin Wetlands, and Taieri Lake /Tunaheketaka (Figure 1). For convenience, study sites in these areas will generally be referred to as the Paerau basin, Māniototo basin, and Tunaheketaka in the rest of this report. The Upper Taiari Wetland Complex is one of the largest freshwater wetlands in the country, covering over 3,000 hectares (Barkla et al. 2003). The Paerau and Māniatoto wetlands are outstanding examples of large valley-floor, alluvial scroll plain landforms, composed of meanders, oxbows, cut-offs, old braids, and back-waters which continue to change over time as the river flows (and floods) through these low gradient valleys. Tunaheketaka was once a large lake at the end of the scroll plains but has been infilled with sediment from gold mining and drained, leaving areas of wet marsh and ponds (Allen 1985).

The whole of the Taiari, and especially Tunaheketaka, was once important for kāinga mahinga tuna and kāinga nohoanga[4] and continues to be a regionally significant waterfowl hunting and fishing area. The area is recognised as internationally important waterfowl habitat, one of the three most valuable freshwater wildlife habitats in Otago and one of the ten most valuable freshwater wildlife habitats in the country (Grove 1994). The scroll plains are now surrounded by agricultural development, mainly dairy, sheep, and beef farming.

[4] Traditional food gathering places and settlements. https://www.kahurumanu.co.nz (accessed 3 May 2023).

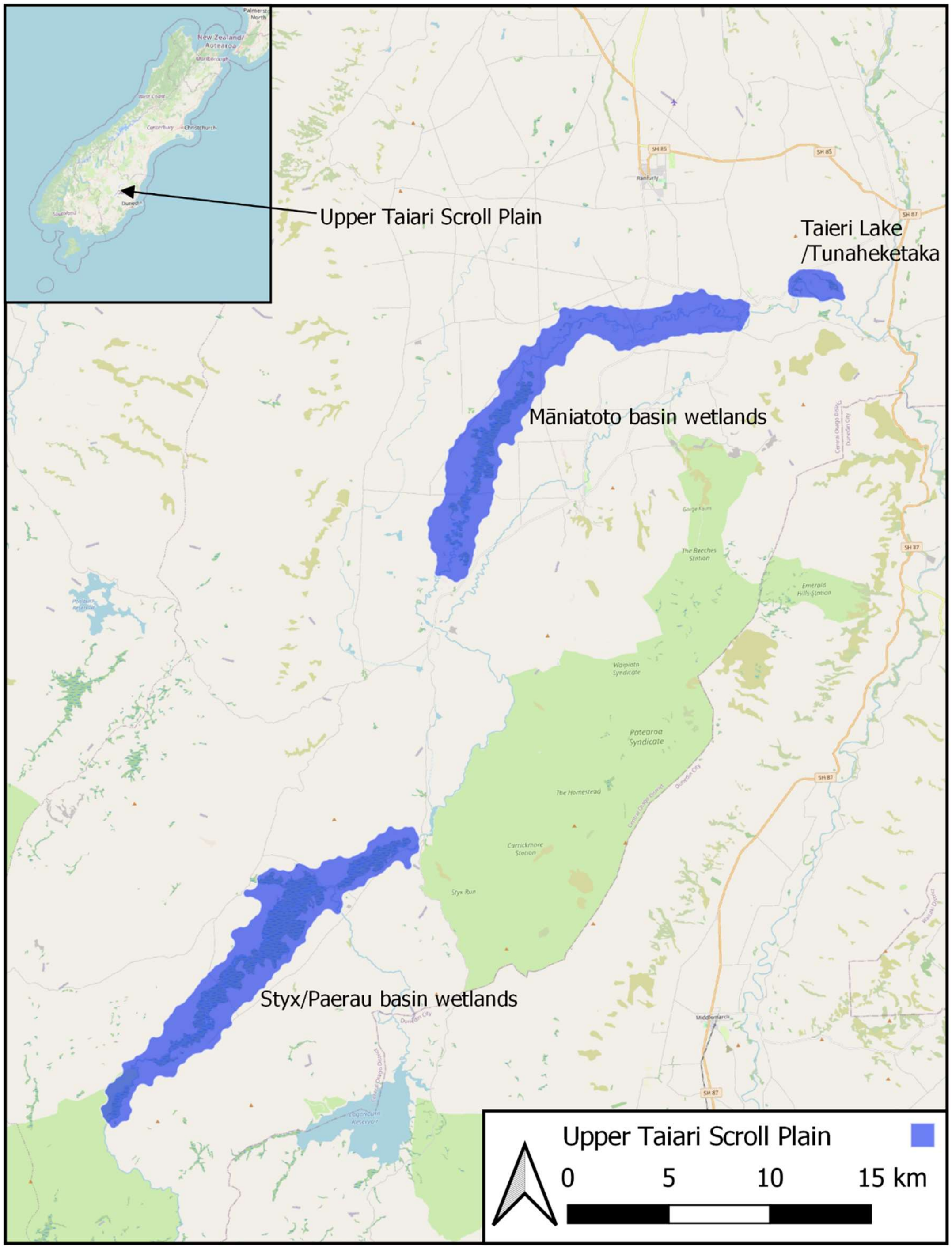

Figure 1. Map of the Upper Taiari Scroll Plain showing general locations for the three main sections (royal blue): Styx/Paerau basin wetlands, Māniatoto basin wetlands, and Taieri Lake /Tunaheketaka. Inset shows scroll plain location within the South Island. Upper Taiari Scroll Plain polygons supplied by ORC, overlaid on Open Street Map.

2.1 Current understanding of the vegetation

The majority of wetlands in New Zealand have been modified by fire, stock grazing, invasive mammals, weeds, and drainage (Ausseil et al. 2008). The eastern South Island's wetlands were deforested through deliberate use of fire by early Māori (McGlone 2009). Though the landscape in the Upper Taiari has been highly modified in places, links between landform, hydrology, and vegetation patterns are still obvious in aerial imagery of the major scroll plain areas (Figure 2, Figure 3). In addition to forest communities, Raeside et al. (1966) suggested that pre-human indigenous plant communities for the plains area included:

- matagouri (*Discaria toumatou*) / fescue tussock (*Festuca novae-zelandiae*) on stony riverbeds
- fescue tussock / blue tussock (*Poa colensoi*) on shallow soils
- silver tussock (*Poa cita*) on deeper silt loams and moist soils
- salt-tolerant vegetation in areas with concentrations of soluble salts e.g. saltgrass (*Puccinellia raroflorens*)
- swamp vegetation on waterlogged soils (e.g. slender wine sedge, *Carex tenuiculmis*).

Figure 2. Example of the scroll plain landforms in the Paerau basin. The main river, oxbows, old braids, backwaters, cut-offs, and semi-permanent and temporary marshy areas and ponds are all evident. (LINZ aerial imagery https://data.linz.govt.nz/layer/106403-otago-03m-rural-aerial-photos-2019-2021)

The wetter areas (Raeside 1996's 'swamp vegetation') can be further classified based on length of inundation. Due to the low gradients in the Paerau and Māniatoto basins, high river flows result in frequent and prolonged inundation of the adjacent floodplains, leaving standing water for periods of weeks and even months. Grove (1994) gives three categories for these wetlands based on inundation time.

- Permanent river and lagoons (oxbows, old braids, backwaters, cut-offs etc). These experience seasonal variations.
- Semi-permanent shallow marshy areas, ponds etc created by flooding. They exist for months or longer and are sometimes present throughout the year.
- Temporarily inundated areas, existing for two months or less in an average year.

Each of these categories has one or more associated plant communities. The size and distribution of these wetland types varies greatly. They can occur in groups or individually, such that there is a mosaic of wetland types along with drier rough pasture across the flood plain (Grove 1994).

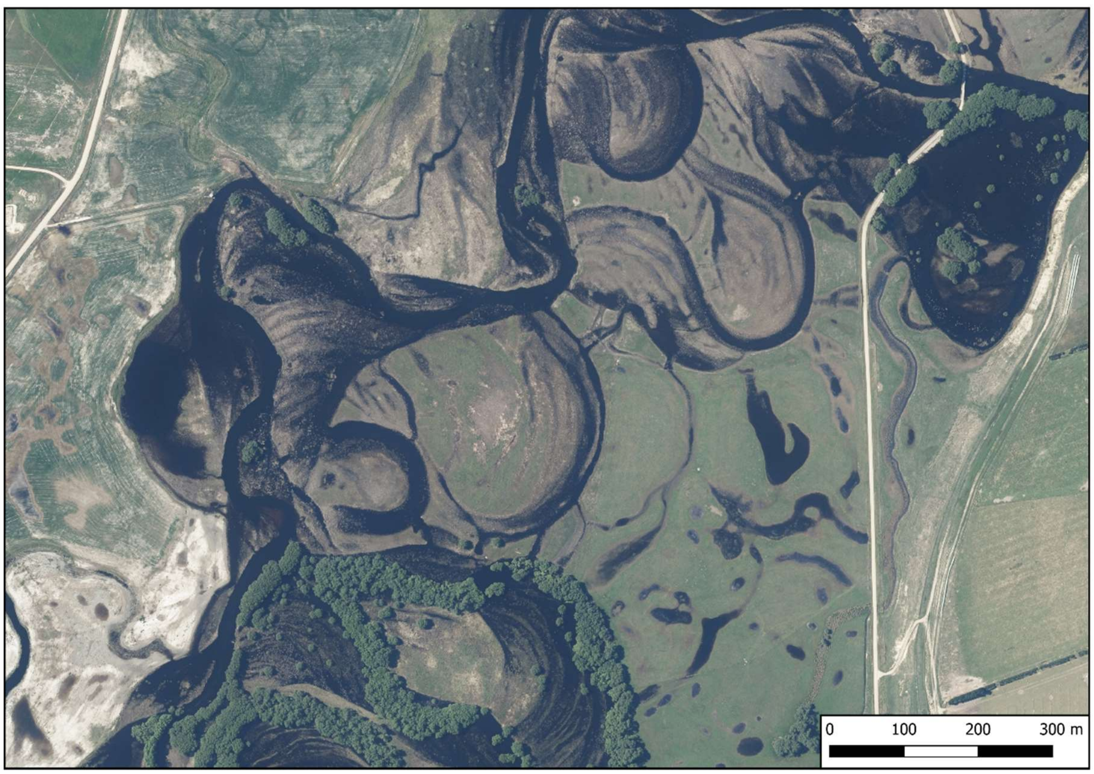

Figure 3. Vegetation patterns highlight the underlying hydrology: willows outline some of the oxbows in the damper areas, while pasture species occupy the higher, dryer ground between the oxbows (brown patches). The main Taiari River flows from bottom left to top right of the image. A small flooding event is evident in the top right of the image at the base of the terrace. (LINZ aerial imagery https://data.linz.govt.nz/layer/106403-otago-03m-rural-aerial-photos-2019-2021)

Over the past 100 years the Upper Taiari Scroll Plains have been highly modified through agricultural intensification both around the margins (i.e. the sides of the floodplain) and onto the scroll plains. While most of the habitat types are still present, their extent is greatly reduced and the composition comprises native and exotic species tolerant of past disturbances and current environmental conditions. Like most wetlands in New Zealand, the Taiari Scroll Plain wetlands face many threats, including river modification, drainage, expansion of crack willow, intensification of agricultural use, and invasion by exotic grasses, sedges, rushes and herbs (Grove 1994; Barkla et al. 2003). The Paerau section of the scroll plains has retained more native vegetation, while in the lower Māniatoto and Tunaheketaka areas the vegetation tends to be more highly modified (Allen 1985; Grove 1994). In the Paerau section, nearly half the recorded flora was native, and native species were dominant in some of the wetter areas, including patches of red tussock (*Chionochloa rubra*), nationally important populations of tufted hair-grass (*Deschampsia cespitosa*) and slender wine sedge (*Carex tenuiculmis*) (BD Rance, DOC, pers. comm., 1 June 2023). Further downriver, in Māniatoto and Tunaheketaka, the swamp vegetation has been reduced in extent and invaded by exotics, including crack willow (Grove 1994). A 1985 report on Tunaheketaka lists exotics as the dominant species, and the main vegetation community as rough pasture (Allen 1985).

Based on this information, we designed and carried out a survey of wetland vegetation of the Upper Taiari Scroll Plain vegetation to gain a fuller picture of the types and distribution of plant communities currently present. The survey aimed to inform the future management of these nationally significant wetlands.

3 Objectives

- Carry out a wetland vegetation survey in previously delineated wetland polygons to better understand the links between the vegetation and dominant environmental drivers, including effects of grazing.
- Provide wetland vegetation information to assist the Otago Regional Council (ORC) in designing effective management and monitoring plans for the Upper Taiari Scroll Plains.
- Establish and measure 150 wetland vegetation plots across the Upper Taiari Scroll Plains to provide a baseline for monitoring condition and trend changes.
- Propose a representative network of permanent sites for future monitoring.

4 Methods

We carried out wetland condition monitoring as described in Clarkson et al. (2004). These methods have been used in wetlands elsewhere as part of monitoring under the NPS-FM (2020). For the wetland condition and pressures indices we assessed the scroll plains in three sections: (Styx/Paerau basin wetlands, Māniatoto basin wetlands, and Taieri Lake / Tunaheketaka). To better understand how the vegetation patterns vary across the Upper Taiari scroll plains we surveyed 151 wetland vegetation plots (each 5m ×5m) following

Clarkson et al. (2004). Clarkson et al.'s (2004) methods link vegetation and soil indicators to assess wetland condition. This wetland sampling method is currently being used by other regional councils (e.g. Clarkson and Bartlam (2017) and Clarkson et al. (2014)). Using a common method will facilitate comparisons at a national level, enabling standardised reporting.

4.1 Plot locations

All potential plot locations were restricted to within the mapped wetland polygons of the Upper Taiari Scroll Plain. These polygons had previously been delineated using high resolution imagery and LiDAR, and were based on ground wetness, land curvature and the likelihood of land to be wet in an event of annual and seasonal high-water levels (Pyatt & Konlechner 2022). Anything not in the polygons (including wetlands not captured by the polygon mapping) was outside our sampling universe and not assessed.

Plot positions were assigned using stratified random sampling to ensure coverage across the three main study areas (Paerau basin, Māniatoto basin, and Tunaheketaka; see Figure 4, Figure 5, and Figure 6). The number of plots sampled in each of the three basins of the Upper Taiari Scroll Plain was roughly proportional to area of mapped wetland in each: Paerau basin (1,067 ha of mapped wetland, 72 plots), Māniatoto basin (1,098 ha of mapped wetland, 74 plots), and Tunaheketaka (76 ha of mapped wetland, 5 plots).

Within each of the Paerau and Māniatoto basins we further restricted the placement of 20 plots to areas thought to be grazed and 20 plots to areas thought to be currently un-grazed. This made a total of 80 plots (40 per basin), with 40 plots per treatment (20 grazed Paerau plots and 20 un-grazed Paerau; 20 grazed Māniatoto plots and 20 un-grazed Māniatoto). Our initial information around grazing regimes for the basins turned out to be incomplete, so during the survey any evidence of grazing in/around the plot was recorded (e.g. cropped or trampled vegetation, and/or faecal matter present). We also used this information about grazing in our analyses.

As we thought distance to the river would be a good proxy for wetness (including likelihood and length of water ponding/flooding), we checked that the plot placement covered a range of distances from the river. In addition, at the request of the ORC, 12 of the 151 plots (5 in Paerau and 7 in Māniatoto) were co-located with the ORC's continuous water-monitoring stations and boreholes.

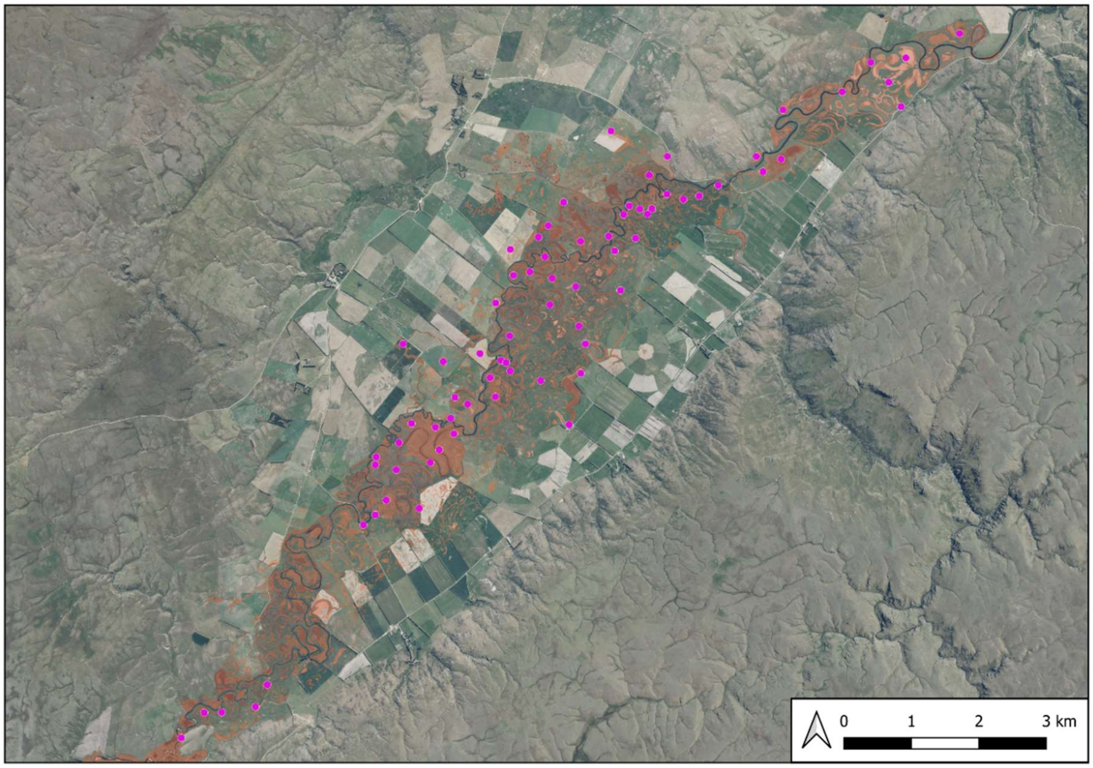

Figure 4. The Paerau basin's 72 plot locations (pink dots). Brown polygons are the mapped wetland polygons from Pyatt and Konlechner (2022).

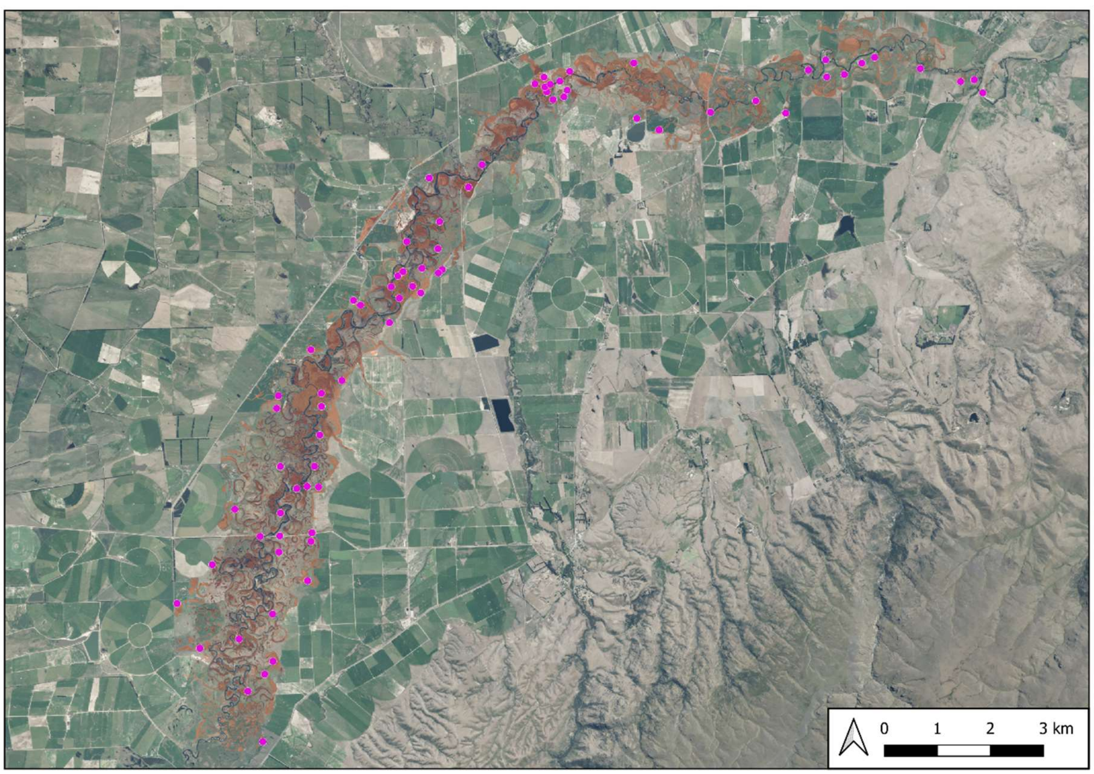

Figure 5.The Māniatoto basin's 74 plot locations (pink dots). Brown polygons are the mapped wetland polygons from Pyatt and Konlechner (2022).

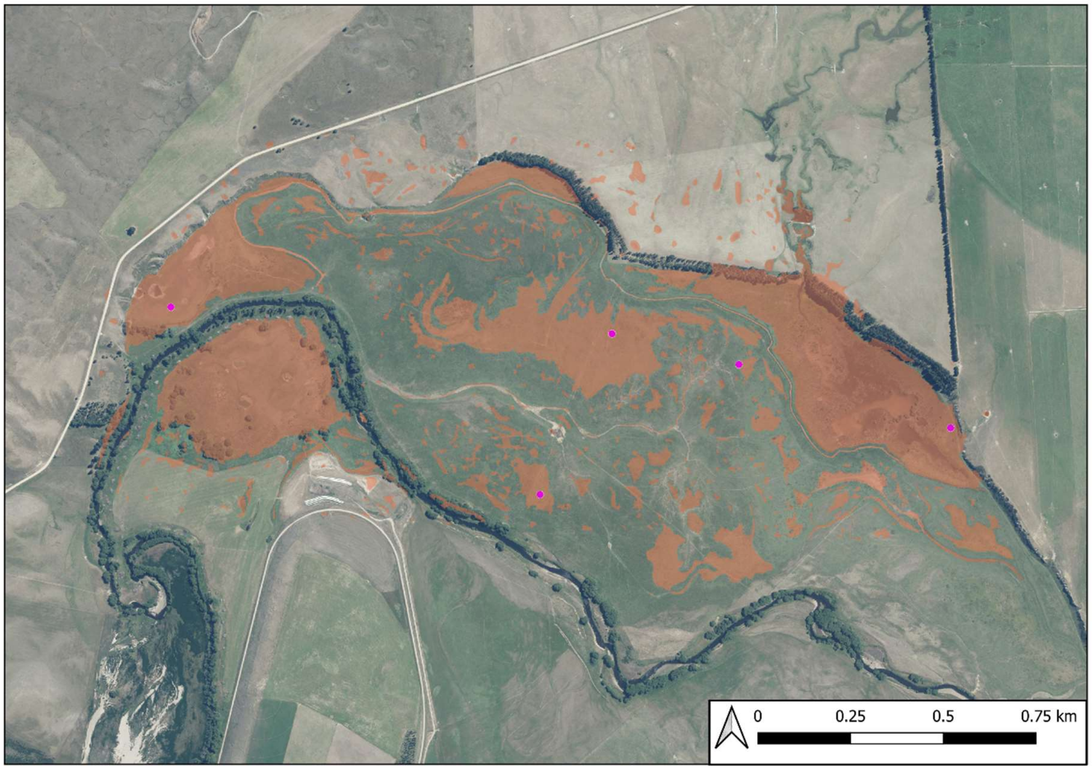

Figure 6. Tunaheketaka, showing 5 plot locations (pink dots). Brown polygons are the mapped wetland polygons from Pyatt and Konlechner (2022).

For each plot, we navigated to within 1 m of the GPS waypoint using a handheld GPS (Garmin 64s, average accuracy 3 m in open areas). We then consulted printed maps of the wetland polygons: if the point landed on a polygon edge, the on-the-ground point location was assessed for topography (in a hollow or depression) and then for vegetation type to check the sampling point was inside the mapped wetland area; if the point landed outside the wetland, the sample point was moved to the nearest wetland. A plot was never moved more than c. 10 m. The need for systematic flexibility in plot placement was an artefact of the mapping accuracy of what were frequently very small polygons. The 5 × 5 m plot was laid out as detailed in Clarkson et al. (2004). All plots were established with the same aspect, starting at the south-west corner and running a 20 m tape around the edge of the plot. The south-west corner was permanently marked with an aluminium peg engraved with the plot name; the other three corners were temporarily marked.

4.2 Plant and vegetation cover

In all plots, the percentage cover across all height tiers (using the alive and dead attached photosynthetically active biomass shoot biomass for each species) and cover classes in each height tier (<0.3 m, 0.3 – 1 m, 1–2 m, 2–5 m, 5–12 m, 12–25 m) was recorded for all vascular plant species. As species overlap (because of multiple layers of plants), total plant cover can sum to more than 100%. The maximum and average height for each species in the plot was recorded. The proportion of cover of all vegetation <1.35 m, (i.e. bryophyte, litter, bare ground, and water) was recorded for the plot (a vertical projection of cover below 1.35 m, i.e. birds eye view).

4.3 Soil cores and analyses

Two soil cores (10 cm diameter x 7 cm deep) were collected from the south-west corner of the plot or from the lowest point in the plot. Depth to the water table was measured, and a hole dug to a depth of 60 cm, where required. If water wasn't present within the top 60 cm, the depth to water table was recorded as greater than –60 cm. Where a water table was present or there was standing water on the plot, pH, temperature, and conductivity were measured using a TPS WP81 conductivity and pH meter. Peat condition was assessed where applicable using the von Post decomposition index. For each plot a set of photos were taken from the south-west corner looking east and north. Additionally, notes on presence of birds or other fauna, and grazing or other land uses were made.

Seventy-five of the 151 soil cores were analysed for soil chemistry (all 5 from Tunaheketaka, n = 35 from the Māniatoto basin, and n = 35 from the Paerau basin). We selected these from a representative sample of the vegetation types from the Māniatoto and Paerau basins, using k-means clustering (see 'Data analysis' section) on the vegetation data for each basin separately. For both basins, clustering gave five groups, so seven soil samples were randomly selected from each group. All data analysis was carried out in R (R Core Team 2022).

Each soil sample was analysed for: bulk density, water content, conductivity, pH, organic carbon, and total nitrogen, phosphorus, and potassium (Gradwell & Birrell 1979; Metson et al. 1979; Blakemore et al. 1987).

4.4 Data storage

Vegetation data were entered into NVS (National Vegetation Survey databank, https://nvs.landcareresearch.co.nz/Data/DatasetDetails/5156/36437). The soils data were entered into a private version of the Wetland Database. A copy of the vegetation and soils data, photos, and plot meta data are stored in DataStore: https://datastore.landcareresearch.co.nz/dataset/upper-taiari-scroll-plain-wetland-vegetation-survey-2023

4.5 Data analysis

The presence and cover-abundance of wetland plant species is a key metric for describing wetlands. To assess the degree of wetland-preferring species in each plot we calculated the Dominance Test and Prevalence Index (Ministry for the Environment 2022).

For the Dominance Test, a plot is classified as wetland if more than 50 per cent of dominant species across all strata are rated OBL, FACW or FAC using the 50/20 rule (Table 1). The 50/20 rule states that the dominant species are the most abundant plant species (when ranked in descending order of abundance, e.g. in a plot, and cumulatively totalled) that equal or immediately exceed 50 per cent of the total cover for the stratum, plus any additional species comprising 20 per cent or more of the total cover for the stratum.

The Prevalence Index a calculates a weighted percentage cover of wetland indicator status groups. A plot is considered to be wetland if the Prevalence Index is ≤3.0 (i.e. the vegetation is considered hydrophytic).

We assigned species wetland indicator status following the New Zealand Wetland Plant List 2021, Table 1 (Clarkson et al. 2021).

Table 1. Wetland indictor status group definitions

Code	Group	Definition
OBL	Obligate Wetland	Almost always is a hydrophyte, rarely in uplands (non-wetlands).
FACW	Facultative Wetland	Usually is a hydrophyte but occasionally found in uplands
FAC	Facultative	Commonly occurs as either a hydrophyte or non-hydrophyte
FACU	Facultative Upland	Occasionally is a hydrophyte but usually occurs in uplands.
UPL	Obligate Upland	Rarely is a hydrophyte, almost always in uplands.

For species not on the New Zealand Wetland Plant List 2021, we consulted the USDA plant list (https://plants.usda.gov/home) for the exotic and non-endemic species and with expert plant ecologists for the endemic species. Eight FACW and OLB species were added to the list as a result, these were submitted to Manaaki Whenua – Landcare Research (MWLR) to be assessed for inclusion in the next iteration of the New Zealand wetland plant list. Plants listed as genus only were not classified if different taxa within the genus had hydrophyte and non-hydrophyte classifications. Plant species are a good indicator of wetland extent and condition as they integrate the hydrological regime and other disturbances over long time periods. Grouping species based on their hydrological tolerances [OBL (obligate wetland), FACW (facultative wetland), FAC (facultative), FACU (facultative upland), and UPL (obligate upland)] allows for trends to be detected across multiple sites where there is high variability in the species pool (Johns et al. 2015).

We assigned species threat status to indigenous plants following de Lange et al. (2018). We followed NVS BioStatus classification to assign species 'native' or 'exotic' status. For grazing we scored each plot for presence/absence of grazing evidence and where possible what species was grazing (cattle, sheep, and/or bird). Then we calculated plot level summary statistics to explore how cover of different groups (e.g. native, exotic, wetland, non-wetland) differ between the three areas and for the different grazing types and regimes.

In the Paerau basin there is a grazing chronosequence, with areas that hadn't been grazed for >10 years, 5–7 years, and 1 year. On the ground these areas appear very different from one another and from grazed areas. We investigated using this sequence to further examine impacts of grazing. However, as we didn't have baseline data and because of environmental variability, we were unable to disentangle the confounding factors from the influence of grazing, so will not present these analyses.

We scored and calculated wetland condition for each of the three areas separately using the regional council version (Clarkson & Bartlam 2017) of the wetland record sheet (Clarkson et al. 2004).

Additional environmental variables (plot elevation relative to the river and distance to the river) were included to identify the influence of the water table and flooding on plant community composition. Plot elevation relative to the river was determined using the 25 cm digital elevation measurement (DEM) of the wetlands provided by the ORC. Distance to river was measured as a straight line between plot and closest point of the river in QGIS. We tested the relationships between these variables, and vegetation composition using permutational multivariate analysis of variance (PERMANOVA). Additionally, these environmental variables, along with the soil chemistry data, were combined with the vegetation data to help describe the various habitats within the scroll plains.

We used k-means cluster analysis to group plots based on plant species presence. We determined the number of clusters by optimising the within-cluster sums of squares using the R package factoextra (Kassambara & Mundt 2020). On a plot of the within-cluster sums of squares versus the number of clusters, the location of the bend (knee) is an indicator of the appropriate number of clusters. Non-metric Multidimensional Scaling was used to examine the patterns in vegetation, and we overlaid the environmental variables using the envfit function (Oksanen et al. 2022). All analyses were run in R (R Core Team 2022).

5 Results

5.1 Vegetation

We recorded 151 vascular species from across the 151 plots (see full plant species list in Appendix 1), with a mean of 11 species recorded per 5 m x 5 m plot. The most species-rich plot (*n* = 22) was in wet grassland in the Māniatoto section at the base of a terrace. The most species-poor plots were underwater or on recently exposed silts; while these plots had sparse vegetation cover, the species present were native ('mud turf 'species). Only 30 species occur in more than 10% of plots (i.e. 15 plots): 25 of these species are exotic and 5 native. Grasses/forbs were split equally between native and exotic species, and the only tree/shrub taxa were exotic, namely willows. The most commonly occurring species were: foxtail – *Alopecurus geniculatus* (FACW, exotic, occurred in 50% of the plots), white clover – *Trifolium repens* (FACU, exotic, occurred in 40% of the plots), and autumn hawkbit – *Scorzoneroides autumnalis* (UPL, exotic, occurred in 46% of the plots). *Trifolium repens* and *S. autumnalis* were likely to co-occur in plots.

Thirty percent of the 151 plots contained exclusively exotic species, mainly dominated by exotic grasses. Fifteen of these exotic-only plots were in cultivated fields (i.e. tilled and planted fields). Thirty-two percent of the 151 plots had 50% or more cover of exotic non-wetland species (i.e. FACU and UPL species). This means these plots are highly modified and wouldn't be classified as wetland (following NPS-FM methods). The only woody species recorded were two species of willow (both invasive exotics) – *Salix cinerea* and

Salix xfragilis. *Salix* species were recorded in 13% of the plots (20 plots) and were dominant in 12 of those plots (all 20 plots were in the Māniatoto section).

Of the 106 plots with native species present, just three plots contained solely native species; these plots all had standing water. Just 7% of the 151 plots had greater than 50% cover of native species (5 plots in the Māniatoto basin and 6 plots in the Paerau basin). Out of the 52 native species recorded across all the plots, 7 are classified as threatened or at-risk plant species (Appendix 1). These species are a mixture of wetland grasses and monocotyledons (4 species) and small herbs (3 species) often found in wetland turfs. The threatened or at-risk plant species were recorded from 24 plots in the Māniatoto and Paerau basins (with 2 plots containing 2 threatened or at-risk species).

The mean cover of obligate wetland species across all the plots was 9% for native OBL species and 10% for exotic OBL species. For facultative wetland, the mean cover was 2% for native FACW species and 40% for exotic FACW species. This probably reflects the life history of weedy exotics, and that these species able to outcompete the native species. Figure 7 summarises exotic versus native percentage cover by scroll plain section.

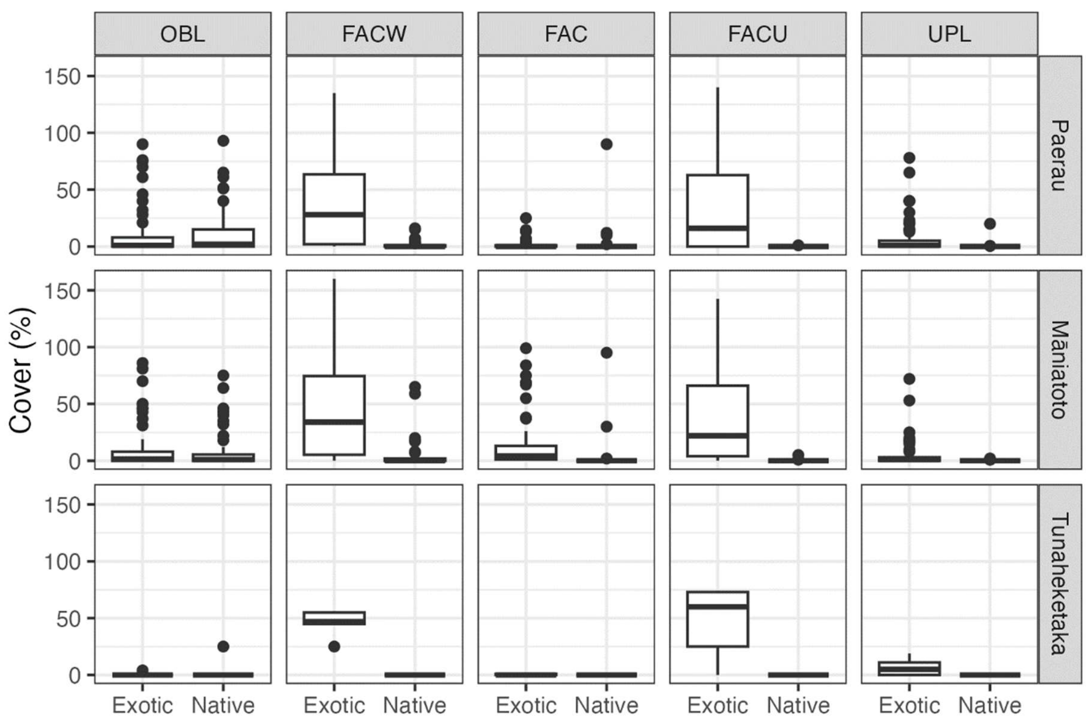

Figure 7. Boxplot of percentage cover of exotic and native species in each of the sections, grouped by wetland ratings OBL: Obligate Wetland, FACW: Facultative Wetland, FAC: Facultative, FACU: Facultative Upland, and UPL: Obligate Upland. Horizontal line = median, boxes = interquartile range, whiskers = minimum and maximum values, dots = outliers (Note: as species overlap each other, cover can sum to more than 100%.)

5.2 Vegetation types

Using k-means clustering based on 149 plots (2 plots were excluded as they only had bare ground) we divided the plots into 4 plant communities (Table 2). The groups reflect both gradients of soil moisture and location through the basins. The indicator species for each group are given in Table 2 (Appendix 2 contains some example photos of each group.)

- Group 1 is wet herbfield / grassland, often with water at or just below the surface, found in both the Paerau and Māniatoto basins (Figure 8, Figure 9).
- Group 2 is exotic grassland / treeland found mostly in the Māniatoto basin.
- Group 3 is grassland / sedgeland dominated by *Festuca rubra* (exotic, FACU species), with no sign of peat development; this group was found mainly in the Paerau basin.
- Group 4 is composed of wetland obligate species forming a wet siltfield / herbfield, where water was often present on the plot and there were signs of early stages of peat development in some plots (almost decomposed vegetation in the soil, this group was found in both the Paerau and Māniatoto basins (Figure 8, Figure 9).

Three of the Tunaheketaka plots were in the exotic grassland community, one plot was in the wet herbfield/grassland community, and one plot in the grassland/sedgeland community (Figure 10).

All four groups contained plots with threatened species in them. Across all four groups, plots which contained threatened species had lower cover of exotics than plots without threatened species (Table 3), indicating that presence of threatened species is an indicator of intactness of native plant communities. The two plots with threatened species in the exotic grassland / treeland group had willows present, which is probably why these plots were classified into this group.

Table 2. The defining species (species belonging solely to one group) of the four plant communities from the cluster analysis on the full set of plots. Species marked * are exotic

Group	Community	Number of plots in the group	Species
1	Wet herbfield / grassland	39	*Eleocharis acuta*
			*Glyceria declinata**
2	Exotic grassland / treeland	50	*Achillea millefolium**
			*Bromus hordeaceus**
			*Cirsium arvense**
			*Cirsium vulgare**
			*Dactylis glomerata**
			*Lolium arundinaceum**
			*Lolium perenne**
			*Poa annua**
			*Salix xfragilis**
			*Stellaria graminea**
			*Stellaria media**
			*Taraxacum officinale**
3	Grassland / sedgeland	29	*Anthoxanthum odoratum**
			Carex tenuiculmis
			*Festuca rubra**
			Juncus edgariae
			*Poa pratensis**
4	Wet siltfield / herbfield	30	*Azolla rubra*
			Elatine gratioloides
			Lemna minor
			Limosella lineata
			Myriophyllum propinquum
			Potamogeton cheesemanii

Table 3. Summary of exotic and native cover in plots with and without threatened species for each vegetation group.

Group	Number of plots with rare species	Plots with rare species		Plots without rare species	
		Exotic cover	Native cover	Exotic cover	Native cover
Wet herbfield / grassland	8	60.81 ±_35.86	35.75 ±_32.95	103.61 ±_26.05	21.79 ±_24.71
Exotic grassland / treeland	2	52.5 ±_24.75	61 ±19.8	120.49 ±_44.44	3.67 ±_8.79
Grassland / sedgeland	12	116.83 ±_36.32	13.08 ±14.71	120.85 ±_28	3.35 ±_6.29
Wet siltfield / herbfield	2	5 ±_4.24	72 ±_42.43	57.29 ±_45.76	10.57 ±_19.73

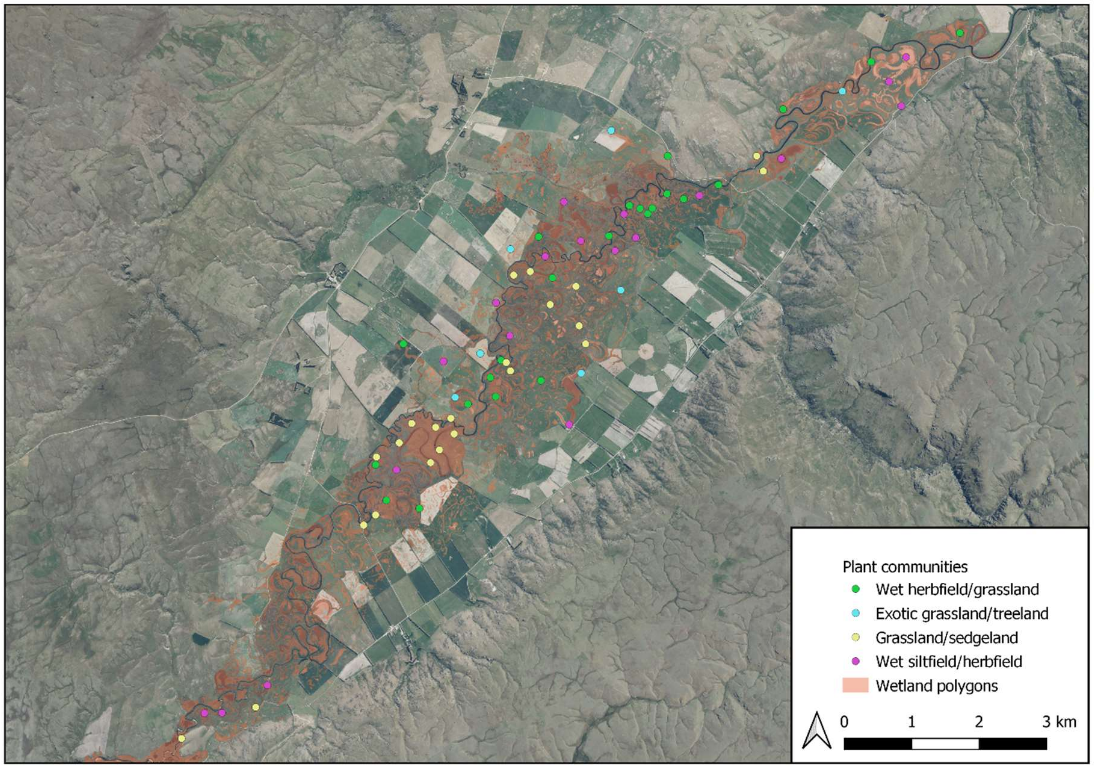

Figure 8. The Paerau basin's 72 plots; dot colour corresponds to the plant community from the k-means cluster analysis. Brown polygons are the mapped wetland polygons from Pyatt and Konlechner (2022).

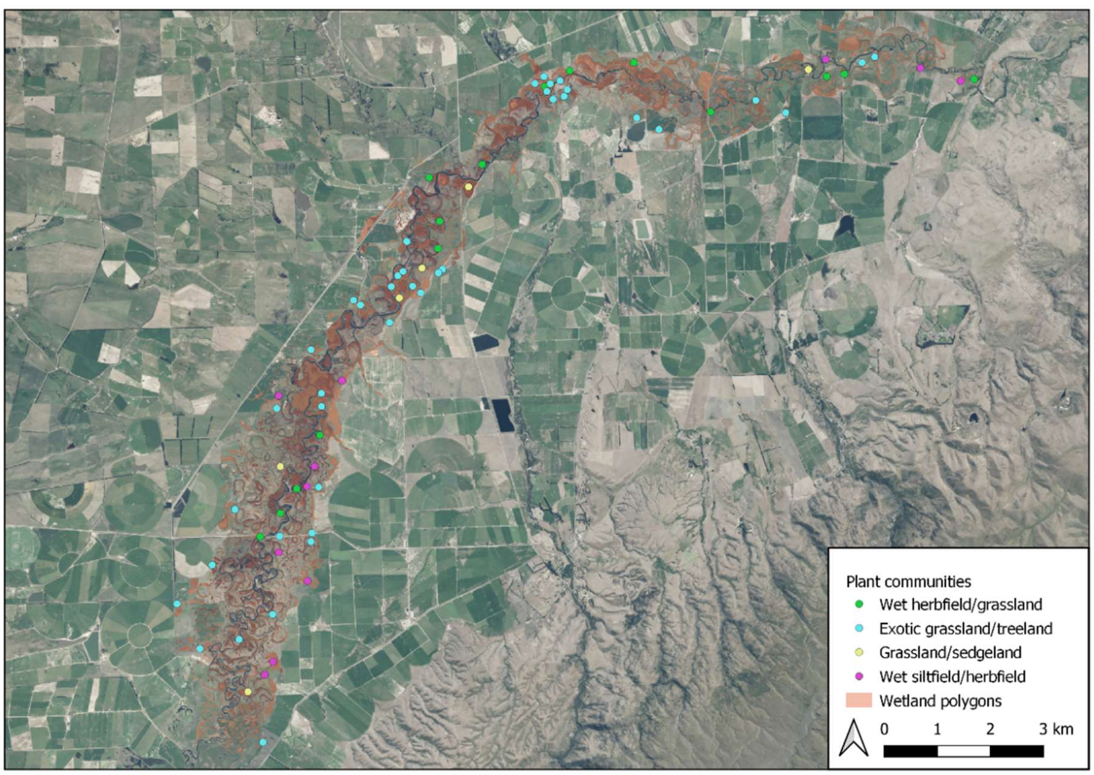

Figure 9. The Māniatoto basin's 72 plots; dot colour corresponds to the plant community from the k-means cluster analysis. Brown polygons are the mapped wetland polygons from Pyatt and Konlechner (2022).

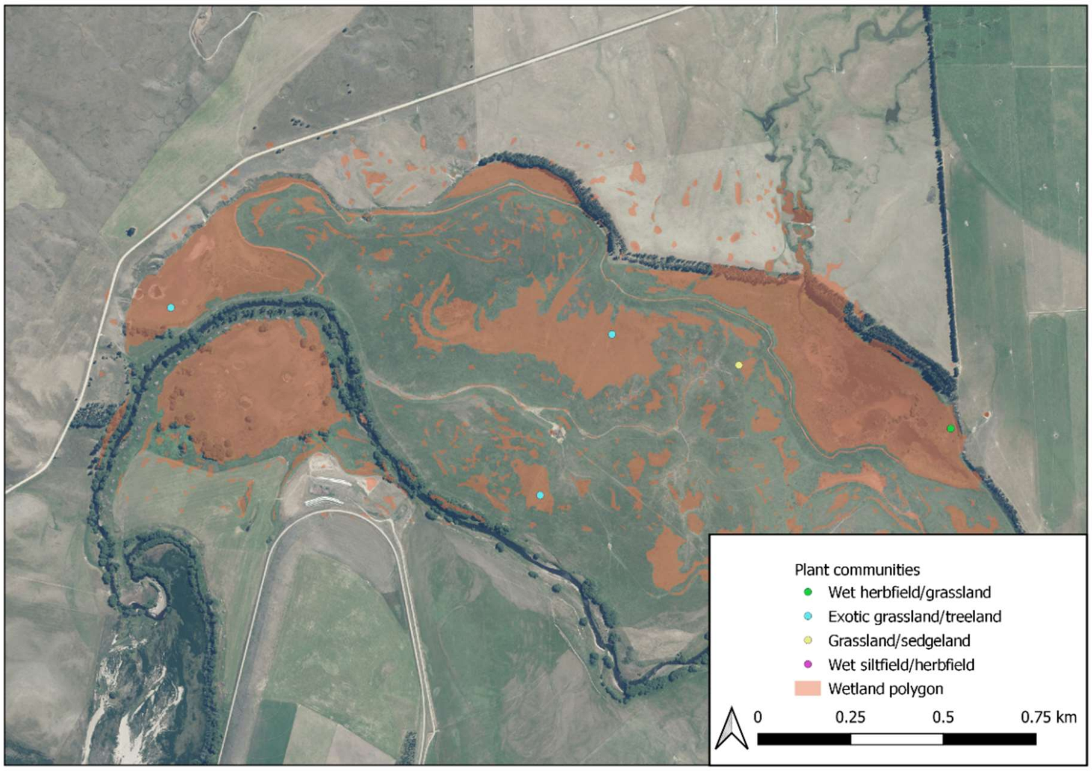

Figure 10. The 5 plots at Tunaheketaka; dot colour corresponds to the plant community from the k-means cluster analysis. Brown polygons are the mapped wetland polygons from Pyatt and Konlechner (2022).

5.3 Grazing

The scroll plain wetlands have a long history of stock grazing, and current grazing was evident across parts of all locations and all vegetation types. As we were unable to use our stratified grazing plot design, we report the results from observed grazing. Grazing or evidence of recent grazing (e.g. cropped or trampled vegetation, and/or faecal matter present) was noted in more than half (88) the 151 plots (Table 4), this includes 40% of the "non-grazed" treatment plots.

Table 4. Summary of number of plots for each grazing type by area

Grazing type	Paerau	Māniatoto	Tunaheketaka	Total
Cattle	11	5	1	17
Cattle/sheep			4	4
Cattle/bird	2			2
Sheep	10	6		16
Bird	8	10		18
Unspecified	16	15		31
None	27	36		63

The presence of grazing was not correlated with species richness (linear model: $F_{1,147}$ =0.347, P = 0.557, Figure 11), percentage cover of obligate wetland species (linear model: $F_{1,149}$ =0.065, P = 0.798), or percentage cover of native species (linear model: $F_{1,147}$ = 2.868, P = 0.092, Figure 12). But plots where goose grazing was noted had higher cover of native species (22% ± 31%) than plots without goose grazing (11% ± 13%), although not a statistically significant difference. There were no significant relationships between types of grazers (cattle, sheep, bird, or combination of) and native species cover, wetland species cover, or species richness.

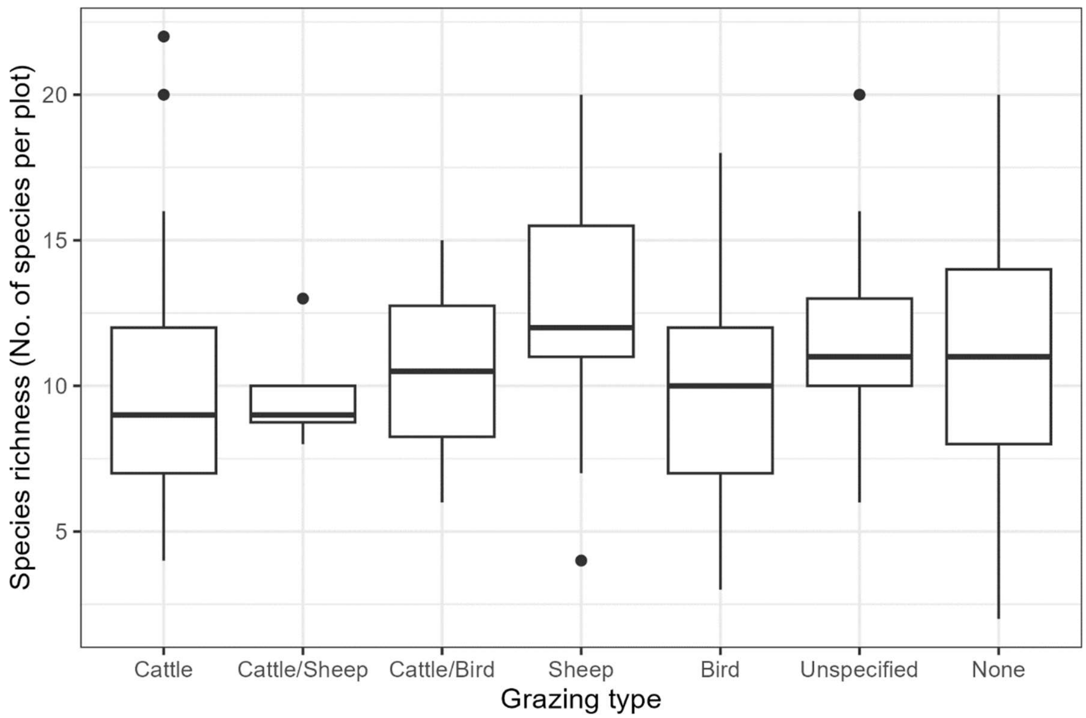

Figure 11. Boxplot of species richness under different grazing types; horizontal line = median, boxes = interquartile range, whiskers = minimum and maximum values, dots = outliers. Plots in tilled/planted areas were excluded.

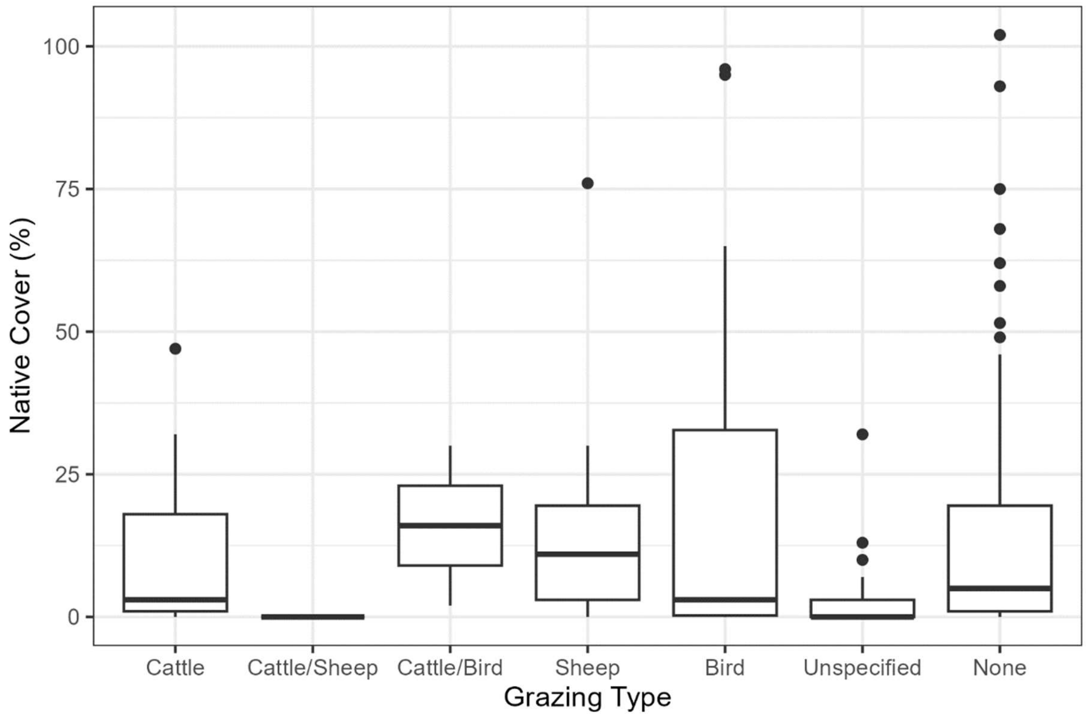

Figure 12. Boxplot of native plant cover (%) under different grazing types; horizontal line = median, boxes = interquartile range, whiskers = minimum and maximum values, dots = outliers. Plots in tilled / planted areas were excluded.

5.4 Soils

The soil chemistry varied with scroll plain location, and to some degree with grazing (Table 5). Both soil pH and conductivity (EC) increase with distance down catchment from Paerau to Tunaheketaka (Figure 13). The highest total nitrogen value, 2.71%, was recorded in Paerau, from a plot that was in a slow-moving side stream downslope of tilled fields. Paerau basin tended to have higher nitrogen, potassium, and phosphorus than the other two areas (Figure 13, Table 5). Soil bulk density increases under stock grazing consistently across the scroll plains (Table 5).

Table 5. Soil chemistry (mean ± standard deviation) for the each of the three locations. Sample size: 35 samples each from Paerau and Māniatoto basins, 5 samples from Tunaheketaka. CN ratio = carbon: nitrogen ratio, N = nitrogen, K = potassium, P = phosphorus, EC = conductivity.

	Paerau		Māniatoto		Tunaheketaka
	No grazing	**Grazed**	**No grazing**	**Grazed**	**Grazed**
pH	4.99 ± 0.22	5.4 ± 0.38	6.11 ± 0.88	6.46 ± 1.17	7.16 ± 1.4
CN ratio	13.4 3± 1.45	12.52 ± 2.48	12.2 ± 2.08	12.4 5± 2.21	12.2 ± 3.83
Total N (%)	0.86 ± 0.35	0.69 ± 0.5	0.66 ± 0.68	0.59 ± 0.34	0.76 ± 0.9
Total K (%)	1.56 ± 0.6	1.58 ± 0.42	1.44 ± 0.39	1.38 ± 0.46	1.71 ± 0.8
Total P (%)	0.12 ± 0 .03	0.1 ± 0.04	0.08 ± 0.03	0.08 ± 0.04	0.07 ± 0.05
Organic C (%)	11.57 ± 5 .45	9.21 ± 8.7	8.97 ± 11.46	7.78 ± 6.37	12.2 ± 18.67
EC (dS/m)	0.14 ± 0.06	0.17 ± 0.17	0.38 ± 0.42	0.4 ± 0.35	0.52 ± 0.22
Soil bulk density (T/m^3)	0.37 ± 0.18	0.74 ± 0.33	0.6 ± 0.37	0.75±0.35	0.9 ± 0.48

Soil chemistry also varied with vegetation group: the exotic grassland / treeland was more nutrient poor, with higher conductivity and soil bulk density than the other three groups (Table 6). The wet siltfield / herbfield had the widest range of soil values (Figure 14).

Table 6. Soil chemistry means and standard deviation for each of the vegetation groups (k-means cluster analysis for the entire scroll plain)

	Wet herbfield / grassland	Exotic grassland / treeland	Grassland / sedgeland	Wet siltfield / herbfield
Number of plots	15	28	14	18
pH	5.37 ±0.56	6.31 ±1	5.11 ±0.38	6.17 ±1.28
CN ratio	13.33 ±2.29	12.5 ±2.36	13.07 ±1.9	11.72 ±2.16
Total N (%)	0.85 ±0.59	0.52 ±0.42	0.64 ±0.32	0.86 ±0.62
Total K (%)	1.64 ±0.63	1.36 ±0.45	1.53 ±0.45	1.58 ±0.42
Total P (%)	0.11 ±0.03	0.08 ±0.04	0.11 ±0.04	0.1 ±0.04
Organic C (%)	12.21±11.08	7.24 ±8.34	8.65 ±5.24	11.08 ±10.29
EC (dS/m)	0.23±0.24	0.35±0.35	0.13±0.08	0.36±0.34
Soil bulk density (T/m^3)	0.49 ±0.36	0.84 ±0.33	0.63 ±0.26	0.53 ±0.37

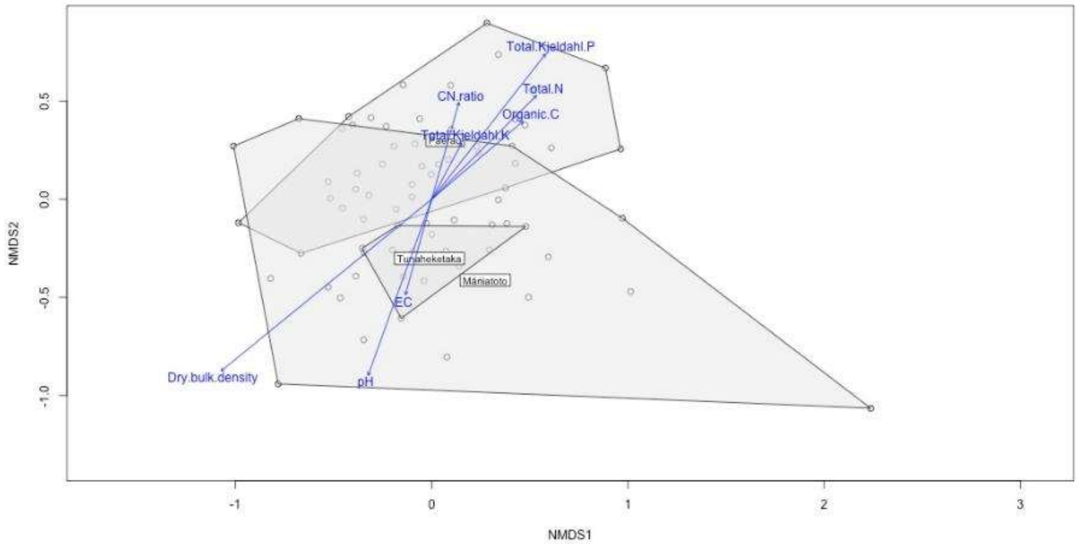

Figure 13. NMDS axis 1 and 2 showing how soil chemistry relates to plots and the main locations. Figure includes only the 75 plots for which soil chemistry was analysed.

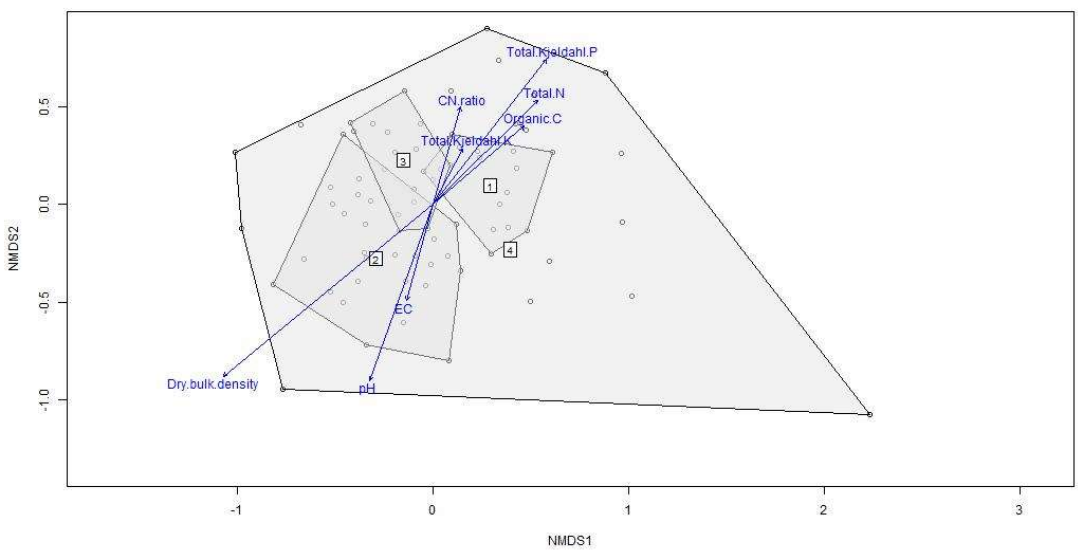

Figure 14. NMDS axis 1 and 2 showing how soil chemistry relates to plots and the four vegetation clusters: Group 1 = wet herbfield / grassland, Group 2 = exotic grassland / treeland, Group 3 = grassland / sedgeland, 4 = wet siltfield / herbfield. Figure includes only the 75 plots for which soil chemistry was analysed.

Across the whole of the Taiari Scroll Plain sampling area we found just a few local indications of peat developing (as scored using the von Post decomposition index), reflecting the marsh wetland ecosystem. The very low percentage of soil carbon (Table 6) and the suit of plant species present in the plots are also indicative of marsh and swamp ecosystems. The plots with well-developed peat were in wetland areas at the base of a terrace (Māniatoto basin) or at the back edges of oxbows (Paerau basin), which we speculate was due to the water levels being more stable in these areas.

5.5 Relative river elevation

Elevation relative to the river (as calculated from the 25cm DEM provided by the ORC) was a significant predictor of vegetation type and composition (Elevation above river: pseudo-$F_{1,146}$ = 2.93, $P_{perm} \leq 0.001$), while distance from river was not associated with vegetation (Distance from river: pseudo-$F_{1,146}$ = 1.41, P_{perm} = 0.115). Plots with elevations closer to that of the river tended to have higher cover of native species and tended to have more wetland species (FACW and OBL). Plots higher above the river are drier, with more dry upland species. The depth to water table was not correlated with plot elevation relative to the river (Figure 15), but this may be due to the sampling period spanning two months over the summer period: field observations indicate several plots appear to have dried out just before sampling.

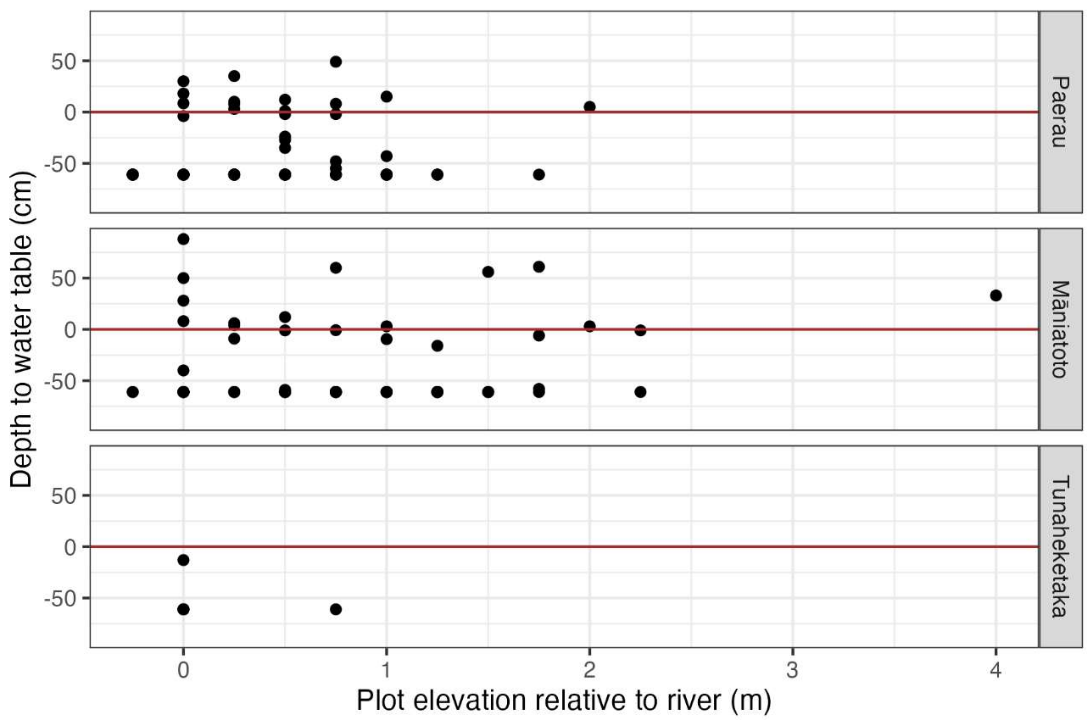

Figure 15. Plot elevation relative to the river vs depth to water table for each of the three main study areas. The brown line (at 0) is soil surface. If water was not encountered in the first 60 cm below the soil surface, water table was recorded as at greater than –60 cm.

5.6 Wetland delineation – vegetation test

We applied the Dominance Test (>50% dominants OBL, FACW, or FAC) and the Prevalence Index (PI ≤3.0) to each plot. Overall, 89 of the 151 plots meet both tests, meaning that 59% of the plots surveyed meet the wetland delineation vegetation requirements (Table 7), and as such qualify as wetlands. The vegetation tests were uncertain for a few plots (i.e. 23 plots passed only one of the vegetation tests). For these uncertain plots the soil and hydrology tests should be applied to determine whether they are in fact wetlands. In addition, two plots were bare siltfields, so had no vegetation to assess, but would probably be classified as 'wetland' based on soils and hydrology. The locations for the plots that passed both vegetations tests ('wetland plots') are shown in Figures 16–18. There does not appear to be a simple spatial explanation for these wetland plots (i.e. distance from river) within the floodplain, suggesting the importance of local conditions. Also, plots at elevations more similar to that of the river are more likely to be wetland plots (Figure 19).

Table 7. Percentage (and number) of plots that passed the Dominance Test, Prevalence Index, and both criteria. Number of plots surveyed: Paerau = 72, Māniatoto = 74, Tunaheketaka = 5

Location	Dominance Test	Prevalence Index	Both criteria
Paerau	79% (57)	65% (47)	62% (45)
Māniatoto	65% (48)	59% (44)	57% (42)
Tunaheketaka	100% (5)	40% (2)	40% (2)
Total	73% (110)	61% (93)	59% (89)

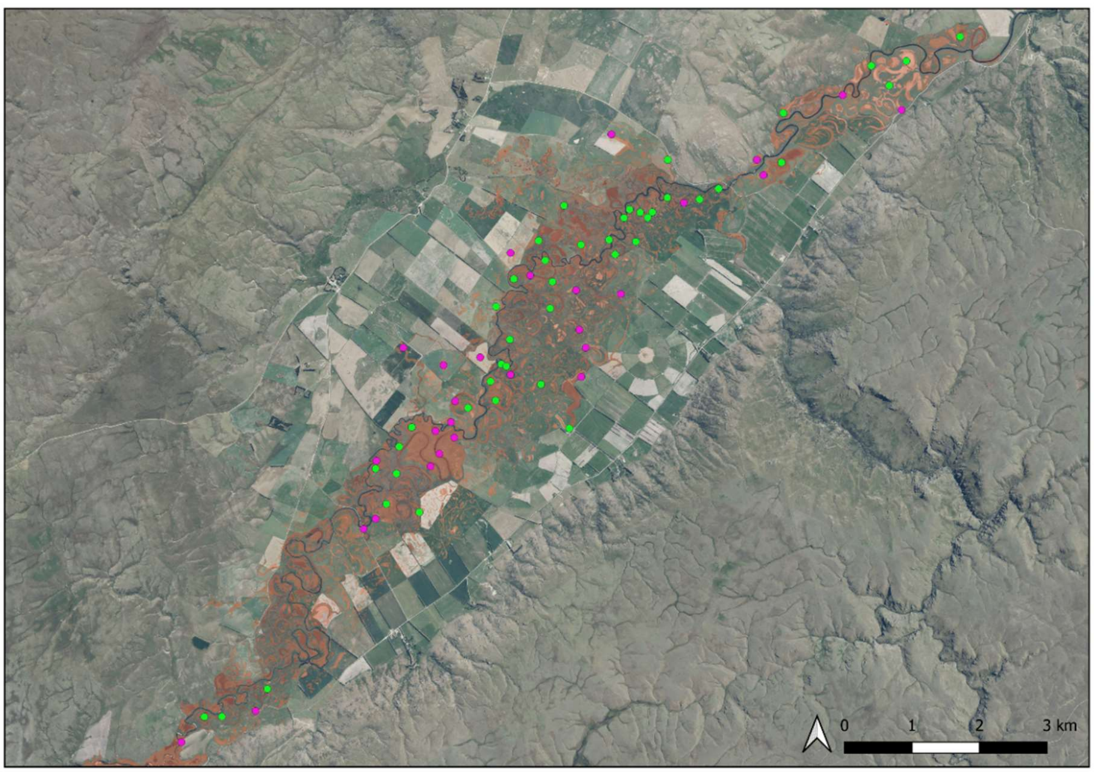

Figure 16. Paerau basin wetland plots (plots that passed both the Dominance and Prevalence Index tests, green dots) and non-wetland plots (pink dots). Brown polygons are the mapped wetland polygons from Pyatt and Konlechner (2022).

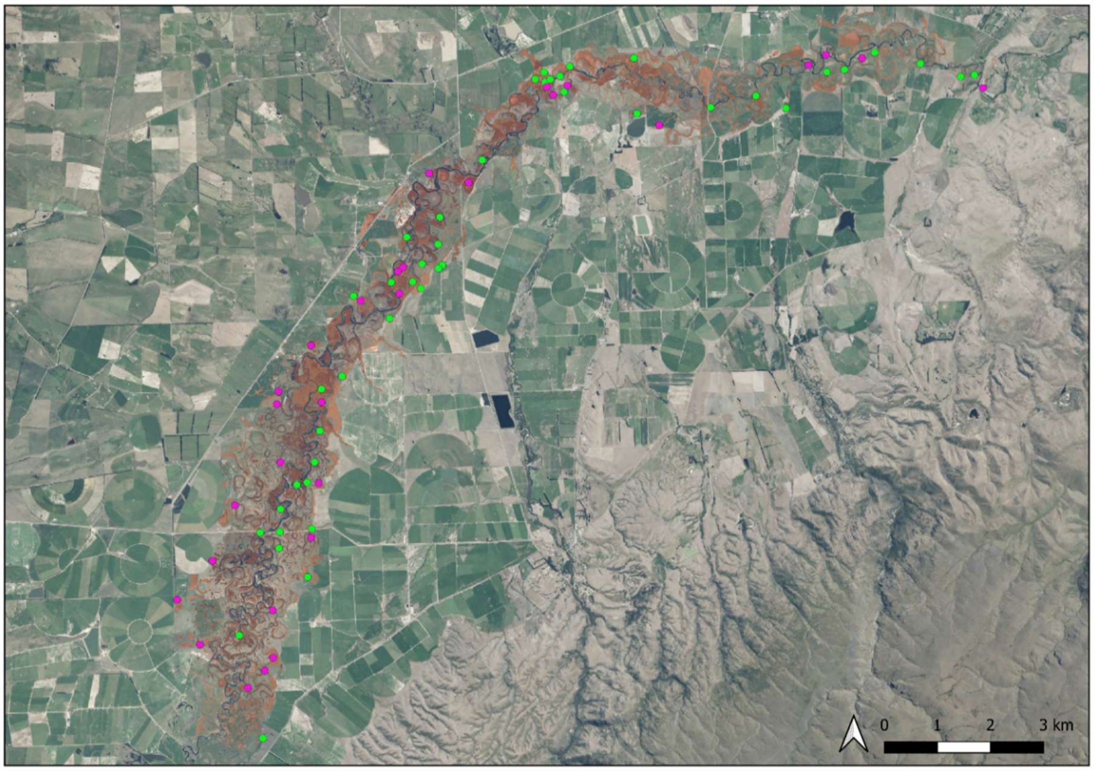

Figure 17. Māniatoto basin wetland plots (plots that passed both the Dominance and Prevalence Index tests, green dots) and non-wetland plots (pink dots). Brown polygons are the mapped wetland polygons from Pyatt and Konlechner (2022).

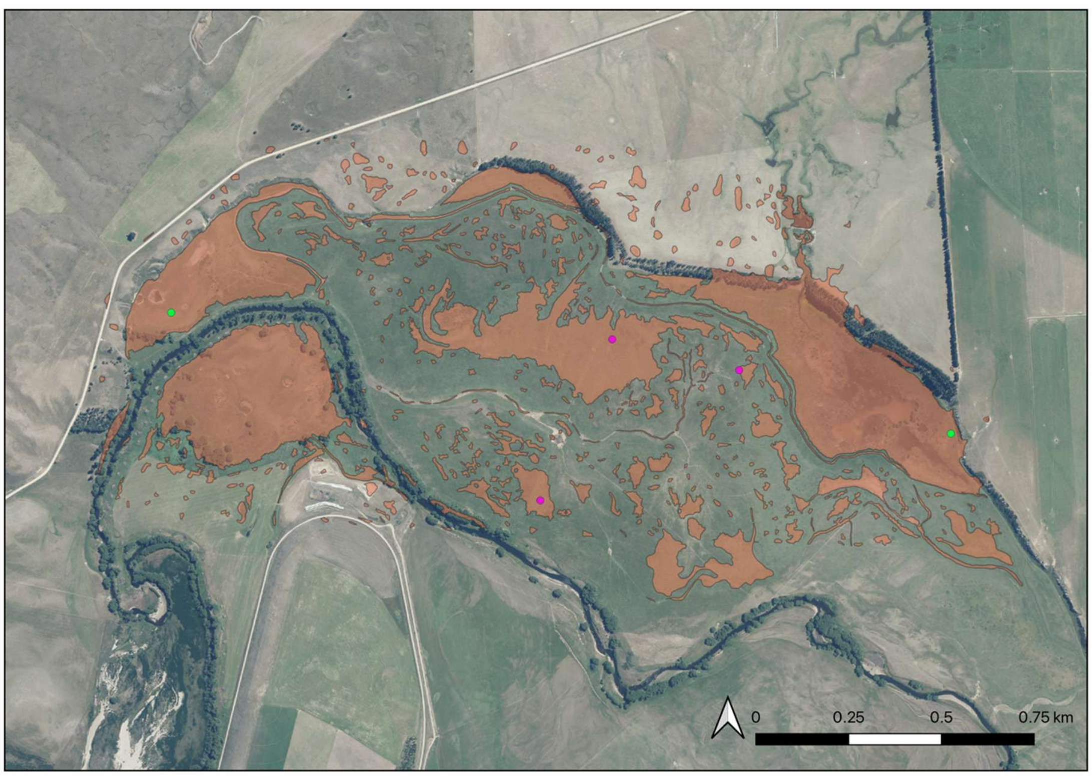

Figure 18. Tunaheketaka wetland plots (plots that passed both the Dominance and Prevalence Index tests, green dots) and non-wetland plots (pink dots). Brown polygons are the mapped wetland polygons from Pyatt and Konlechner (2022).

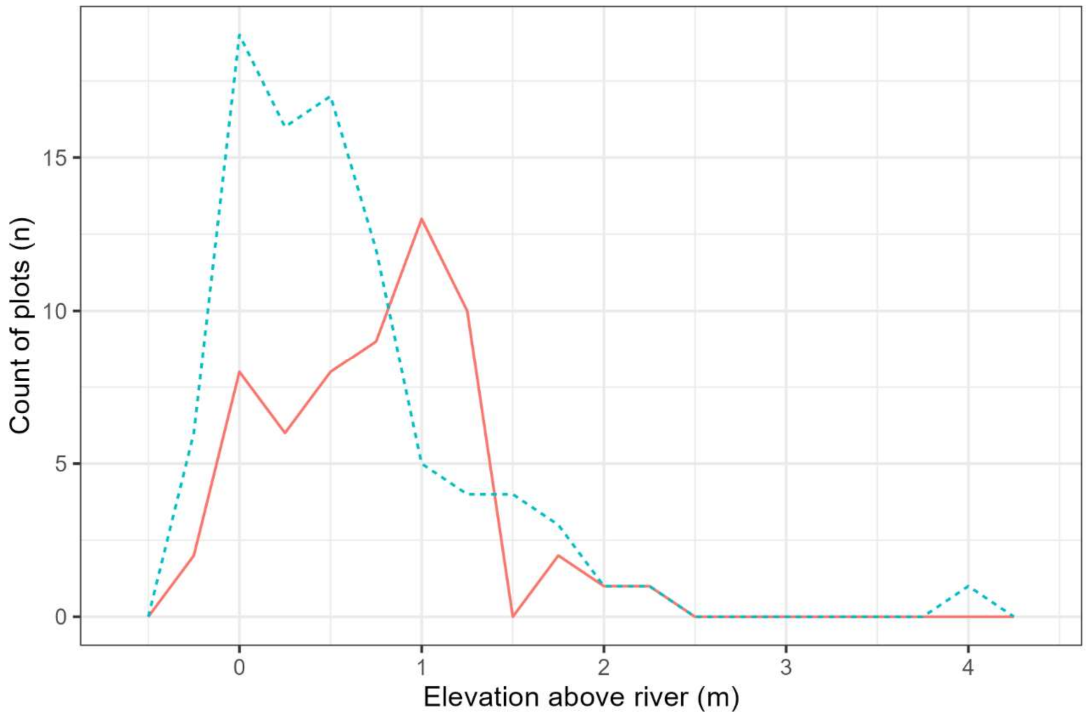

Figure 19. Frequency of wetland (dashed blue line) and non-wetland (red line) plots at each elevation above the river (bin width 0.25m).

5.7 Wetland condition

We scored each of the three main scroll plain areas for wetland condition according to Clarkson et al. (2004) and Clarkson and Bartlam (2017). Table 8 presents the summarised results. For the indicators of current state (condition) both Paerau and Māniatoto scored 13.75 and 13.4 out of 25, respectively, while Tunaheketaka scored the lowest (worst), at 11.3 out of 25. This low score is due to the historical draining of Tunaheketaka (scored a 1.6 for hydrological integrity).

For pressures likely to affect future condition Tunaheketaka scored the highest (worst) at 21 out of 30; while Paerau and Māniatoto scored 18 and 19 out of 30, respectively (Table 9). Again, Tunaheketaka scored poorly due to hydrological modifications (it no longer functions as a lake system).

Table 8. Summary of wetland indicators of current state for Paerau, Māniatoto, and Tunaheketaka. Scored on a 0–5 scale for each indicator; higher scores denote better condition

Indicator	Paerau	Māniatoto,	Tunaheketaka
Hydrological integrity	3.6	3	1.6
Physico-chemical parameters	3	3.5	3.5
Ecosystem intactness	3.3	3.3	2.6
Browsing, predation & harvest	2.25	2	2
Dominance of native plants	1.6	1.6	1.6
Total wetland condition index (max 25)	13.75	13.4	11.3

Table 9. Summary of wetland pressures for Paerau, Māniatoto, and Tunaheketaka. Scored on a 0–5 scale for each indicator; higher scores denote more pressure (i.e. are worse)

Pressure	Paerau	Māniatoto	Tunaheketaka
Modifications to catchment hydrology	3	3	5
Water quality decline in catchment	3	2	3
Animal access	4	4	4
Key undesirable species	1	3	2
% catchment in introduced vegetation	4	4	4
Other land use threats	3	3	3
Total wetland pressure index (max 30)	18	19	21

6 Conclusions

Our survey of the Upper Taiari Scroll Plain highlighted the spatial complexity of this wetland ecosystem and the importance of the hydrological drivers for creating and maintaining the vegetation patterns we observed. These scroll plains are the largest and most complete examples of this wetland type in New Zealand. Although modified throughout (and acknowledging that a significant baseline shift has already occurred) they retain important representatives of our indigenous wetland flora, including several threatened and/or at-risk species.

Neither the vegetation types or species composition and abundance varies with distance to the river. Instead, the major environmental gradient is linked to elevation above the river, suggesting that a water table coupled with regular flooding across the entire flood plain is most influential for determining vegetation types. It is probably the local floodplain topography (e.g. the meander scars, oxbows, swales, and ridges) that determines how much and for how long water is held which drives the vegetation patterns. The vegetation groups derived through our cluster analysis appear to be linked with the various landforms found in the floodplain of the Upper Taiari Scroll Plain. These plant communities ranged from drier rough pasture communities growing on the higher berms between oxbows to wet, sparsely vegetated, mud turf communities growing in the recently inundated pond areas.

Inundation timing and length appear to be major drivers of vegetation patterns. In and around ponds that stayed wet for longer, we tended to find more native species. Sites we visited at the end of January in the Paerau basin, which had recently dried out, had higher numbers of native species than sites in similar topography and position that we visited in December. Other studies of ephemeral wetland systems in New Zealand have observed similar patterns (Tanentzap et al. 2014), and the patterns are perhaps related to the differing life histories of exotic versus native species. Maintaining the natural patterns and variation in duration, timing, and depth of inundation is important for maintaining the range of native vegetation types (Catford et al. 2011). This is especially true for the mud turfs as these species require disturbance (in the form of silt deposition and inundation) to establish and grow (Brownstein et al. 2016). The seasonal flooding is also very important for waterbirds, fish, and other wildlife, as it creates large sheets of shallow fertile water, producing large amounts of food for wildlife (Grove 1994).

In contrast to wetlands surveyed elsewhere in New Zealand, the depth to the water table was often greater than 60 cm below soil surface. This indicates that periodic flooding leading to semi-permanent ponding is important for this system. We were sampling during the middle of summer (and, for the second half of the sampling, during a drought), so would expect most of the surface water to have evaporated. If we had sampled earlier in the season, we would have encountered surface water more often.

Much of the scroll plains can probably be classified as marsh due to the presence of mineral soils and very little peat. In terms of soil chemistry, the values for pH, carbon, nitrogen, and phosphorus reported here fit within values reported for swamps and marshes in other parts of New Zealand (Clarkson et al. 2015). These plant communities appear to be growing mainly on recent, gley-like soils. The few notable places we did find evidence of organic soils (and potentially peat) was where the floodplain meets the base of the terraces. It might be that these areas have suitable conditions for peat development because of a combination of continuous seeps from the terrace and seasonal flooding maintaining high soil moisture. Plots in these areas were some of the more diverse in terms of wetland plant species, e.g. the threatened – nationally critical wetland obligate plant, *Triglochin palustris,* was recorded here; and this was one of the few places *Carex secta* was recorded, a native wetland obligate species that provides important habitat for invertebrates (Grove 1994).

Grazing did not appear to change the vegetation composition. We expected to see differences between grazed and ungrazed, and the type of grazer (i.e. sheep, cattle, and bird). Grazing by livestock is known to significantly change species composition and functional structure (Reeves & Champion 2004). The type of grazer should have an effect: avian grazing should favour native turf species, while stock grazing may favour tough grasses/sedges (Lee et al. 2010). It appears that the whole of the scroll plain has been grazed at some point and to some extent, which may be why we were unable to detect any differences between currently grazed and ungrazed plots.

We considered an analysis of a grazing chronosequence (a space-for-time substitution study of grazing) in the Paerau basin where it appears there are clear cut differences between areas which haven't been grazed for different periods of time (18 months, 5–7 years, and 10+ years), but several confounding factors made the results unreliable. We know that the most recent area to have grazing excluded was set aside as it contained high conservation values compared to the surrounding areas. We suspect all four areas differed before cessation of grazing, but there is no baseline data, so we are unable to assess what changes in vegetation have occurred within each site. Chronosequences in grassland systems are also best used at the decadal scale (Walker et al. 2010), and we lack the data to do this. As discussed above, the vegetation communities are related to landscape topographical factors and are frequently disturbed by flooding. This means we cannot rely on the assumption that time is the main driver of ecological change, which is a key assumption of a chronosequence analysis (Matthews & Whittaker 1987). To robustly address questions around effects of grazing in the Taiari Scroll Plain a Before-After Control-Impact (BACI) grazing experiment would be needed.

6.1 Wetland state indicators and pressure indices

The overall wetland condition scores (current state indicators and pressure index) show the Taiari Scroll Plain is a highly modified system, and significant pressures remain. The area in poorest condition and with the highest pressures is Tunaheketaka, where the hydrology was the most highly modified by the removal of the natural dam in the 1940s, draining the lake. Tunaheketaka has received a large amount of sedimentation; this was clearly visible in one of the soil core holes (Figure 20). The hydrology has also been modified in the Māniatoto basin (the river has been straightened and drainage ditches dug) and the Paerau basin (drainage ditches dug).

The condition index (and the plot data) show there is low native vegetation cover throughout the entire scroll plain, with native species most often dominating in the patches with surface water. The most intact plant communities are likely to be the ephemeral mud turf communities in the Paerau basin. Almost completely missing from the scroll plains are natural native woody species: no native woody species were recorded in the vegetation plots, although there are a few *Coprosma* and *Olearia* species in the surrounding landscape.

Figure 20. A Tunaheketaka soil core hole showing how the organic soil (indicated by dark colours) is buried by 38 cm of a silty, mineral deposit.

The intensity and proximity of farming, including animal access to the wetlands, was another reason the wetlands scored low. For more than 100 years there has been farming, including dairy, sheep, cattle, and cropping on the fans and other landforms draining into the wetlands. Owing to the complex landforms of the Taiari Scroll Plain, a patchwork of pastures and fields have developed throughout the wetlands (Figure 21). Increased sedimentation and nutrient enrichment due to surrounding land use are two of the most common physicochemical parameters affecting New Zealand wetlands at the wetland-wide scale (Clarkson et al. 2004). While sedimentation was outside the scope of this study, our soil analysis from across the plains indicate that pH and conductivity increased from Paerau to Tunaheketaka, and these are potential indicators of increased effluent and manure run-off. Plots with grazing did have more compacted soils (higher soil bulk density). The compacted soils are also partly due to the number of tilled/oversown plots categorised as ‘grazed’, so soil compaction may be best related to farming practices in general. Soil compaction is a major problem in agricultural systems worldwide, impeding infiltration of water and enhancing water run-off with associated nutrients into waterways.

Figure 21. The complex landforms of the Upper Taiari Scroll Plain mean pastures have been knitted into the wetlands. This 0.2 ha wetland is surrounded by crops.

In terms of invasive wetland weeds, the two species of willow present threats to the scroll plains in the Māniatoto basin and Tunaheketaka. In the Paerau basin, willow is present but is currently being controlled. These exotic species alter habitats, change water courses, and may impact nutrient accumulations.

6.2 Restoration

Despite the vegetation being highly modified, the Upper Taiari Scroll Plain is valuable habitat for native animals and plants (Grove 1994; Barkla et al. 2003). While there is low cover and number of native plant species, the Upper Taiari Scroll Plain contains important populations of both wetland and dryland native plant species, e.g. *Lepidium sisymbrioides*[5], *Carex tenuiculmis* and *Deschampsia cespitosa* (Barkla et al. 2003). In the DOC reserves, which were established to protect wetland values, the occurrence of dry landforms within their boundaries means these reserves also contain populations of both rare wetland and rare dryland species (Barkla et al. 2003). Overall, the key areas for improvement would be control of willow and gorse, and increase cover of native species, especially wetland and woody species.

It is vital to manage the scroll plains to maintain and enhance native plant species, especially those with restricted habitat types (e.g. wetland obligate) or missing altogether (woody species). Native shrubland communities could be established on the higher, dryer parts of the conservation areas already gazetted, replacing the exotic grasslands. The willow could be replaced with a wetland species like kahikatea (this is being trialled in the North Island).

A carefully designed BACI grazing experiment could be used to test effects of grazing intensity, timing, and type on the recovery and maintenance of wetland vegetation. For example, using sheep or even avian grazing as a form of willow, weed, or exotic grass control. In other ecosystems in New Zealand, sheep grazing has been used to help maintain or restore the native turf plant communities (Korsten et al. 2013; Brownstein et al. 2014; Rogers & Monks 2016). But care needs to be taken as using grazing to assist with restoration can result in different and or unwanted post-restoration plant communities (Sonnier et al. 2023). If such an experiment were carried out, it needs to be at hectare scale and include replication within both the main sections of the scroll plain. It would also need to be on an ecologically relevant time scale (i.e. in the order of 10+ years).

6.3 Future monitoring and reporting

We make the following suggestions for future monitoring and reporting for wetland extent and condition.

- Change in extent of invasive woody species (willows) – use time series aerial imagery to map change in extent of willows.
- Change in extent of wetland polygons – use time series aerial imagery to map.
- Select a subset of the established plots to monitor for wetland vegetation condition (e.g. divide the 150 plots into 3 sets, and monitor 50 plots every second year, so plots are monitored once every 6 years).

[5] This species wasn't recorded in our study but is potentially still present.

7 Recommendations

- Manage the Upper Taiari Scroll Plain to maintain and enhance native plant species, especially those with restricted habitat types, e.g. mud turf, by maintaining or restoring natural hydrological processes, controlling invasive weeds and restoring native shrubland on drier, elevated sites.
- Remeasure wetland extent and condition at 6-year intervals.
- Investigate conducting a BACI-type experiment to better understand the long-term influence of stock grazing in the different parts of the scroll plain.

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9 References

Allen RB 1985. Vegetation report, Taieri Lake Botany Division, DSIR. 5 p.

Ausseil A-G, Newsome P, Peter J 2008. Wetland mapping in the Otago region Landcare Research Contract Report LC0708/115. 51 p.

Barkla JW, McKinlay B, Neilson M 2003. Upper Taieri Wetland assessment: a report and recommendations to the Central Otago Area Office, Department of Conservation, Alexandra Internal report DOCDM-1253768.

Blakemore LC, Searle PL, Daly BK 1987. Methods for Chemical Analysis of Soils. New Zealand Soil Bureau Scientific Report 80. 103 p.

Brownstein G, Lee W, Monks A 2016. *Isolepis basilaris* on the Tasman River delta, Lake Pukaki monitoring report: year three, summer 2016 Landcare Research Contract Report LC2644. 30 p.

Brownstein G, Lee WG, Pritchard DW, Wilson JB 2014. Turf wars: experimental tests for alternative stable states in a two-phase coastal ecosystem. Ecology 95(2): 411-424.

Catford JA, Downes BJ, Gippel CJ, Vesk PA 2011. Flow regulation reduces native plant cover and facilitates exotic invasion in riparian wetlands. Journal of Applied Ecology 48(2): 432-442.

Clarkson BR, Bartlam S 2017. State of the environment monitoring of Hawke's Bay wetlands: Tukituki Catchment Landcare Research Contract Report LC2713. 42 p.

Clarkson BR, Fitzgerald N, Overton JM 2014. A methodology for monitoring Bay of Plenty wetlands Landcare Research Contract Report LC1779. 15 p.

Clarkson BR, Overton JM, Ausseil A-G, Robertson HA 2015. Towards quantitative limits to maintain the ecological integrity of freshwater wetlands: Interim report Landcare Research Contract Report: LC1933. 39 p.

Clarkson BR, Fitzgerald N, Champion PD, Forester L, Rance BD 2021. New Zealand Wetland Plant List 2021 Landcare Research Contract Report: LC3975. 66 p.

Clarkson BR, Sorrell BK, Reeves PN, Champion PD, Partridge TR, Clarkson BD 2004. Handbook for monitoring wetland condition. Coordinated monitoring of New Zealand wetlands. A Ministry for the Environment SMF funded project 74 p.

de Lange PJ, Rolfe JR, Barkla JW, Courtney SP, Champion PD, Perrie LR, Beadel SM, Ford KA, Breitwieser I, Schonberger I and others 2018. Conservation status of New Zealand indigenous vascular plants, 2017. New Zealand Threat Classification Series 22. 82 p.

Gradwell MW, Birrell KS 1979. Methods for physical analysis of soils New Zealand Soil Bureau Scientific Report 10C.

Grove P 1994. Maniototo ecological district : a survey report for the Protected Natural Areas Programme. NZ Protected Natural Areas Programme series, no. 30. 96 p.

Johns CV, Brownstein G, Blick RA, Erskine PD, Fletcher AT 2015. Testing the power of a wetland vegetation monitoring survey design to detect change based on visual cover estimates. Wetlands 35(6): 1055-1064.

Kassambara A, Mundt F 2020. factoextra: extract and visualize the results of multivariate data analyses. Version R package version 1.0.7.

Korsten AC, Lee WG, Monks A, Wilson JB 2013. Understanding the role of birds in sustaining indigenous turf communities in a lacustrine wetland in New Zealand. New Zealand Journal of Ecology 37(2): 206-213.

Lee WG, Wood JR, Rogers GM 2010. Legacy of avian-dominated plant-herbivore systems in New Zealand. New Zealand Journal of Ecology 34(1): 28.

Matthews JA, Whittaker RJ 1987. Vegetation succession on the Storbreen glacier foreland, Jotunheimen, Norway: a review. Arctic and Alpine Research 19(4): 385-395.

McGlone MS 2009. Postglacial history of New Zealand wetlands and implications for their conservation. New Zealand Journal of Ecology 33(1): 1-23.

Metson A, Blakemore L, Rhoades D 1979. Methods for the determination of soil organic carbon: a review, and application to New Zealand soils. New Zealand Journal of Science 22(3): 205-228.

Ministry for the Environment 2022. Wetland delineation protocols. 11 p.

Oksanen J, Simpson G, Blanchet F, Kindt R, Legendre P, Minchin P, O'Hara R, Solymos P, Stevens M, Szoecs E and others 2022. vegan: community ecology package.

Pyatt T, Konlechner T 2022. Mapping wetlands in the Upper Taieri Scroll Plain Complex, Otago Wildland Consultants Contract Report: 6200. 11 p.

R Core Team 2022. R: A Language and Environment for Statistical Computing. Vienna, Austria, R Foundation for Statistical Computing.

Raeside JD, Cutler EJB, Miller RB 1966. Soils and related irrigation problems of part of Maniototo Plains, Otago. Soil Bureau Bulletin.

Reeves PN, Champion PD 2004. Effects of livestock grazing on wetlands: literature review NIWA Client Report HAM2004-059. 33 p.

Rogers G, Monks A 2016. Restoring lost ecological function: ecological surrogates facilitate maintenance of coastal turf communities. New Zealand Journal of Botany 54(4): 393-411.

Sonnier G, Rothermel BB, Tucker RC, Boughton EH 2023. Post-restoration plant community changes in grazed and ungrazed seasonal wetlands in Florida. Wetlands 43(5): 55.

Tanentzap AJ, Lee WG, Monks A, Ladley K, Johnson PN, Rogers GM, Comrie JM, Clarke DA, Hayman E 2014. Identifying pathways for managing multiple disturbances to limit plant invasions. Journal of Applied Ecology 51(4): 1015-1023.

Walker LR, Wardle DA, Bardgett RD, Clarkson BD 2010. The use of chronosequences in studies of ecological succession and soil development. Journal of Ecology 98(4): 725-736.

Appendix 1 – List of plant species in plots

Table 10. List of species that occurred in the plots, including wetland rating (Clarkson et al. 2021), Threat status (de Lange et al 2018), and the number of plots the species occurred in. For explanation of the wetland rating see Table 1 in the main text. Exotic species marked with *

Species	Wetland rating	Threat status	Number of occurrences
*Achillea millefolium**	FACU		6
*Agrostis capillaris**	FACU		64
*Agrostis stolonifera**	FACW		54
Alga			3
*Alopecurus geniculatus**	FACW		75
*Alopecurus pratensis**	FAC		7
*Anthoxanthum odoratum**	FACU		16
Argentina anserinoides	FACW		6
*Avena fatua**	UPL		2
Azolla rubra	OBL		5
*Brassica species**			1
*Bromus diandrus**	UPL		1
*Bromus hordeaceus**	UPL		12
*Bromus lithobius**	UPL		1
*Bromus sterilis**	UPL		1
Callitriche petriei	OBL		20
*Callitriche stagnalis**	OBL		11
*Capsella bursa-pastoris**	FACU		2
Cardamine species			2
Carex coriacea	FACW		7
Carex dissita	FAC		3
Carex gaudichaudiana	OBL		25
Carex geminata	FACW		2
*Carex leporina**	FACW		64
Carex maorica	OBL		5
Carex secta	OBL		5
Carex sinclairii	OBL		1
Carex species			3
Carex tenuiculmis	OBL	At Risk- Declining	2
Carex virgata	FACW		4
*Cerastium fontanum**	FACU		15
*Cerastium species**			1

Species	Wetland rating	Threat status	Number of occurrences
Charophyte	OBL		1
*Chenopodium album**	FACU		9
*Cirsium arvense**	FACU		26
*Cirsium vulgare**	FACU		7
Crassula peduncularis	FACW	Threatened- Nationally Critical	1
Crassula sinclairii	OBL		5
*Crepis capillaris**	FACU		31
*Cynosurus cristatus**	UPL		10
*Dactylis glomerata**	FACU		8
Deschampsia cespitosa	FACW	At Risk- Declining	17
Deschampsia tenella	FAC		1
Elatine gratioloides	OBL		6
Eleocharis acuta	OBL		54
*Elodea canadensis**	OBL		1
*Epilobium ciliatum**	FAC		5
Epilobium pubens	FACU		1
*Erodium cicutarium**	UPL		3
Euchiton sphaericus	UPL		2
Festuca novae-zelandiae	UPL		1
*Festuca rubra**	FACU		33
*Galium aparine**	FACU		4
*Galium palustre**	OBL		51
Galium perpusillum	FAC		2
*Glyceria declinata**	OBL		9
*Glyceria fluitans**	OBL		40
*Holcus lanatus**	FAC		48
*Hordeum marinum**	UPL		11
*Hordeum species**			2
Hydrocotyle sulcata	FACW		6
*Hypochaeris radicata**	FACU		4
*Juncus acuminatus**	OBL		2
*Juncus articulatus**	FACW		49
Juncus australis	FACW		3
*Juncus bufonius**	FACW		8
Juncus edgariae	FACW		2
*Juncus effusus**	FACW		61
*Juncus inflexus**	FACW		6

Species	Wetland rating	Threat status	Number of occurrences
Juncus pusillus	OBL	At Risk- Naturally Uncommon	1
Juncus species			2
*Juncus tenuis**	FACU		10
Lachnagrostis filiformis	FACW		1
Lemna minor	OBL		15
*Leontodon saxatilis**	FAC		1
*Leontodon species**			1
Lepidosperma australe	FAC		1
Limosella lineata	OBL		5
Lobelia ionantha	OBL	At Risk- Declining	1
Lobelia perpusilla	FACW		8
*Lolium arundinaceum**	FAC		18
*Lolium multiflorum**	UPL		3
*Lolium perenne**	FACU		31
*Lotus pedunculatus**	FAC		4
*Lythrum portula**	OBL		11
*Malva species**			2
*Medicago lupulina**	FACU		1
*Medicago sativa**	UPL		1
Montia angustifolia	FACW	At Risk- Naturally Uncommon	2
*Myosotis laxa**	OBL		23
Myriophyllum propinquum	OBL		17
Myriophyllum species	OBL		1
Myriophyllum triphyllum	OBL		8
*Nasturtium species**	OBL		3
*Persicaria maculosa**	FACW		1
*Phalaris minor**	UPL		1
*Phleum pratense**	FACU		18
*Pilosella officinarum**	FACU		3
*Pisum sativum**	UPL		2
*Plantago coronopus**	FAC		3
*Plantago lanceolata**	FACU		2
*Plantago major**	FACU		4
*Poa annua**	FACU		5
Poa cita	FACU		2
*Poa pratensis**	FACU		35
*Poa trivialis**	FACU		6

Species	Wetland rating	Threat status	Number of occurrences
*Polygonum arenastrum**	FACU		2
*Polygonum aviculare**	FAC		3
*Polypogon monspeliensis**	FAC		1
Potamogeton cheesemanii	OBL		5
*Potamogeton crispus**	OBL		1
Potamogeton ochreatus	OBL		1
Pseudognaphalium luteoalbum	FACU		1
*Ranunculus flammula**	FACW		56
Ranunculus glabrifolius	OBL		4
Ranunculus limosella	OBL		4
*Ranunculus repens**	FAC		1
*Ranunculus sceleratus**	OBL		5
Ranunculus species			1
*Ranunculus trichophyllus**	OBL		2
Rorippa palustris	OBL		1
*Rumex acetosella**	FACU		5
*Rumex conglomeratus**	FAC		1
*Rumex crispus**	FAC		42
*Rumex obtusifolius**	FAC		2
Rumex species			1
*Salix cinerea**	FACW		1
*Salix xfragilis**	FACW		20
Schoenoplectus pungens	OBL		1
*Scorzoneroides autumnalis**	UPL		69
*Secale cereale**	UPL		1
*Solanum dulcamara**	FAC		1
*Solanum nigrum**	FACU		3
*Sonchus asper**	FACU		3
*Spergula arvensis**	UPL		1
Stellaria gracilenta	UPL		5
*Stellaria graminea**	FAC		11
*Stellaria media**	FACU		5
*Taraxacum officinale**	FACU		44
*Trifolium arvense**	UPL		1
*Trifolium dubium**	UPL		9
*Trifolium fragiferum**	FACU		3
*Trifolium pratense**	FACU		5

Species	Wetland rating	Threat status	Number of occurrences
*Trifolium repens**	FACU		73
*Trifolium tomentosum**	UPL		1
Triglochin palustris	OBL	Threatened- Nationally Critical	3
Triglochin species	OBL		1
*Tripleurospermum inodorum**	UPL		1
*Veronica arvensis**	FACU		1
*Veronica serpyllifolia**	FAC		2
*Vulpia bromoides**	UPL		1
*Vulpia myuros**	FACU		2

Appendix 2 – Example photos

Example photos for the four plant communities.

Group 1: Wet herbfield / grassland, plot TW018 (left) and plot TW076 (right).

Group 2: Exotic grassland / treeland, plot TW077 (left) and plot TW144 (right).

Group 3: Grassland/sedgeland, plot TW124.


Group 4: Wet siltfield / herbfield, plot TW095 (left) and plot TW130 (right).