Management Opportunities to Increase Climate Change Resilience in the Taiari Upland Wetlands

Contract Report No. 7486

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1.0 Introduction

The upland wetlands of the Taiari catchment are diverse and in many cases nationally or internationally unique (Johnson *et al.*, 2022; Rapson *et al.*, 2006). These wetlands have been assessed as having a high risk to climate change impacts; of particular concern are reduced frosts, more frequent floods and droughts, higher temperatures, and increased seasonality of rainfall (Closs *et al.*, 2024; Goldsmith, 2023). The Taiari catchment is located in the Otago Region, extending across four territorial authorities: Dunedin City Council, Central Otago District Council, Clutha District Council, and Waitaki District Council. The catchment covers twelve ecological districts, including a wide diversity of ecosystems, climates, and landforms. Upland wetlands within the Taiari catchment are defined as those above 600 m altitude, occupying several different mountain/hill systems, including:

- Lammerlaw-Lammermoor Ranges.
- Rough Ridge.
- Rock and Pillar Range.
- Ida Range.
- Kakanui Range.
- Taiari Ridge.
- Mauka Atua (also spelt Maungatua).
- Swampy Summit.

Much of this land is on public conservation land (PCL), including Te Papanui Conservation Park, Rock and Pillar Conservation Area, Oteake Conservation Park, and Maukaatua Scenic Reserve. These upland wetlands are key areas of biodiversity within the Taiari catchment. They also provide a number of key cultural, economic, and recreational contributions to people. Alongside climate change, these wetlands also face a variety of other threats as a result of human activity and invasive species. The aim of this report is to review possible management options to increase the climate resilience of the Taiari upland wetlands. These management interventions aim to reduce other pressures on the wetlands, as mitigating climate change itself is a broader challenge. In so doing, we can ensure that these ecosystems have the resilience to tolerate or adapt to changing climatic conditions.

This report was commissioned as part of the Department of Conservation (DOC) Ngā Awa-funded Te Mana o Taiari river restoration project; a collaboration between Te Rūnaka o Ōtakou, Kāti Huirapa Rūnaka ki Puketeraki, Otago Regional Council and DOC. As part of Te Mana o Taiari's catchment-scale approach to river restoration, DOC Ngā Awa commissioned a Climate Change Vulnerability Analysis (CCVA) of the freshwater ecosystems and species of the Taiari (Closs et al. 2024). In the CCVA, the alpine wetlands of the Taiari were identified as already at risk from climate change pressures including increasing drought, decreased snow and ice, and conversely more intense seasonal rainfall events. The present study was commissioned by DOC Ngā Awa from Wildlands to examine the management opportunities available to increase the resilience of the Taiari's unique and extensive alpine and upland wetlands to degradation by climate change. DOC requested a qualitative cost:benefit analysis to help stakeholders compare management opportunities, particularly those that can be considered 'easy wins' versus those that require more effort and planning.

2.0 Scope

This report covers the following topics:

- The ecological and social values of Taiari upland wetlands, including ecosystem diversity, unique flora/fauna, cultural significance, and ecosystem services.
- The current non-climate threats to the upland wetlands.
- The impacts that these wetlands are expected to face under climate change, with a review of previous reports, in light of the most recent MfE climate projections.
- A review and discussion of the available management actions to improve the climate resilience of upland wetlands.
- A cost-benefit analysis of the potential management actions, to identify those that are most practical and cost-effective.
- An analysis of how these management actions should be prioritised.

Our review focuses on Taiari upland wetlands, defined as those above 600 m altitude within the Taiari catchment. Previous reports have focused on alpine wetlands, which are defined as those above 800 m altitude. We use the broader term “upland”, to also include similar wetlands in the 600-800 m elevational zone. Wetlands are defined broadly here, including all naturally uncommon ecosystems (**NUE**s; also termed historically rare ecosystems) included under the wetland class, such as tarns and snowbanks.

The following are out of scope for this project:

- Wetlands below 600 m asl. Specifically, this altitudinal cut-off excludes the Upper Taiari Wetlands Complex, which reaches a maximum altitude of 580 m asl and is already covered by several other initiatives.
- Adjacent wetlands outside the Taiari catchment, such as those in the western portion of the Lammerlaw Range. These are only discussed where relevant to give ecological context.
- The threats and management of upland non-wetland ecosystems (such as tall tussock grasslands) are only reviewed in terms of how they interact with wetlands.
- No new mapping is undertaken for this report. The aim of this report is to compile and review existing material, but not to conduct any further delineation of biodiversity features beyond what is already available.
- Cultural values beyond what is known from public sources. Iwi consultation was beyond the scope of this project.
- Freshwater invertebrate values in upland wetlands. Only terrestrial invertebrates and freshwater fish are looked at in this report.

3.0 Biodiversity Values

3.1 Ecosystems

Upland wetlands in the Taiari catchment span a wide range of different wetland classes and ecosystem types. Particularly notable are the numerous peat-forming bogs and fens found in the undulating subalpine Te Papanui/Lammerlaw-Lammermoor ranges (Johnson *et al.*, 2022). Many wetlands in the

Taiari uplands represent **NUE**s, including cushion bogs, ephemeral wetlands, seepages and flushes, snow banks, and tarns. Upland wetlands are a key habitat for non-migratory galaxiids, and are also important for provisioning water to the downstream Taiari catchment (Goldsmith, 2023).

It is important to note that the wetlands of the Taiari uplands are a surface expression of the hydrology of the whole upland environment. Groundwater in these uplands is significantly influenced by non-wetland vegetation, with snow tussocks (*Chionochloa* spp.) playing an important role in groundwater provisioning. Snow tussocks have low transpiration rates, and may also draw moisture from fog (Fahey *et al.*, 2011). Areas with dense snow tussock cover have significantly higher groundwater levels than woody vegetation or short grassland (Fahey & Payne, 2017; Mark & Dickinson, 2008). Snow tussocks also catch snow drift and contribute to the formation of snowbanks, which have implications for water supply through the spring and into early summer.

3.1.1 Wetland ecosystem types present in the Taiari uplands

Mapping of wetlands in the Taiari catchment was taken from Current Indigenous Ecosystems mapping for the Otago Region Wildland Consultants (2020b). Snowbank vegetation and tarns were also included; our sources for mapping these are described below. Based on this mapping, the following wetland ecosystems from the Singers & Rogers (2014) classification are present above 600 m asl:

- **WL8: Herbfield/mossfield/sedgeland** — These are peat-forming wetlands (fens and bogs) that are relatively common in cooler and permanently wet sites. *Sphagnum* mosses (particularly *S. cristatum*) are the dominant peat-forming vegetation, associated mainly with fens. Boggy areas that do not receive fresh groundwater contain a wide variety of short statured herbs, sedges, mosses, and lichens.
- **WL9: Cushionfield —** Bogs dominated by cushion-forming species. Cushion species are tolerant of very low temperatures and nutrient levels, with cushion bogs forming primarily in alpine and sub-alpine areas. These have not been extensively mapped in the Taiari catchment; however additional patches of cushion vegetation are likely to be present within areas mapped as WL8.
- **WL14: Herbfield (ephemeral wetland)** — Turfs associated with ephemeral wetlands. These are located primarily between 600-800 m asl on depressions atop impervious schist ridges, hills, and plateaux. They are particularly common on Rough Ridge and Taiari Ridge. Schist-substrate ephemeral wetlands are unique to the Otago region, and have received little ecological study.
- **WL16: Red tussock, *Schoenus pauciflorus* tussockland** — A common wetland type present in montane and subalpine settings throughout the Taiari catchment, typically in better drained and more fertile locations than WL8. Dominated in Otago by copper tussock (*Chionochloa rubra* subsp. *cuprea*) with *S. cristatum* also common.
- **WL17: *Schoenus pauciflorus* sedgeland (alpine seepages/flushes)** — A common wetland type present on steeper terrain where groundwater comes to the surface, often dominated by bog rush (*Schoenus pauciflorus*). These wetlands are numerous in hilly/mountainous terrain in the Otago region. They are typically small, often grading upstream into snowbanks, and downstream into larger wetland systems. This wetland type is included in the “seepages and flushes” NUE.
- **WL22: Carex, *Schoenus pauciflorus* sedgeland** — This ecosystem is present in swamps and marshes below 800 m, typically in gully floors. In the Taiari uplands there are areas of this wetland above 600 m in the milder southeast of the catchment. This ecosystem is dominated by various species of *Carex* sedge, as well as both native and introduced species of *Juncus* rushes. Small-leaved species of *Coprosma* and *Olearia* may also be present.
- **Snowbank vegetation** — Snowbank vegetation on the eastern flank of the Rock and Pillar range was mapped in Wildland Consultants (2020) as *Celmisia haastii* herbfield. Snowbank habitat may be present elsewhere in the Taiari catchment, however this ecosystem has not been widely

mapped. The presence of snow for long periods of the year allows the soils in these habitats to stay saturated into summer. Snowbank vegetation plays an important role in regulating groundwater provision to other habitats, often grading downstream into seepages.

- **Tarns** — Tarns were mapped using the Toitū Te Whenua - Land Information New Zealand (LINZ) NZ Lake Polygons dataset. A quick visual check was made to remove polygons that were clearly represented man-made reservoirs, however there may be some overlap between these polygons and the mapping of ephemeral wetlands.

The area occupied by each wetland type is presented in Table 1. Figure 1 contains a map showing the locations of all the wetlands and related ecosystems listed above, although note that comprehensive mapping of all wetlands in the Taiari catchment has yet to be undertaken. Note that the symbols do not reflect the area occupied by each wetland.

Table 1 – Breakdown of wetlands, tarns, and snowbanks currently mapped above 600 m altitude in the Taiari catchment.

Wetland Types	Area (ha)	Number of Polygons
WL16: Red tussock, *Schoenus pauciflorus* tussockland	4,382.7	1,108
WL8: Herbfield/mossfield/sedgeland	1,698.3	461
WL17: *Schoenus pauciflorus* sedgeland (alpine seepages/ flushes)	817.2	460
Snowbanks	188.1	57
WL22: Carex, *Schoenus pauciflorus* sedgeland	113.8	99
WL9: Cushionfield	91.3	72
Tarns	35.9	146
WL14: Herbfield (ephemeral wetland)	23.1	211
Total	**7,350.4**	**2,614**

3.1.2 Te Papanui/Lammerlaw-Lammermoor peat wetlands

The most extensive systems of upland wetlands in the Taiari catchment are peat forming wetlands (bogs and fens) located primarily above 800 m asl in the Te Papanui/Lammerlaw-Lammermoor ranges, as well as adjacent areas of the Rock and Pillar range and Rough Ridge. These mountains have undulating tops of impervious schist rock with numerous small gullies. The dominant non-wetland vegetation in these ranges is snow tussock grassland dominated by *C. rigida*. These peatlands fall into two broad types, described below.

Large wetland systems occupy valleys and basins that have been filled in by peat. The most notable of these are Red Swamp (Johnson, 1986b) and the remnants of Te Paruparu-a-Te-Kaunia/Great Moss Swamp (Johnson, 1986a; now largely submerged by the Loganburn Reservoir). The dominant peat-forming vegetation in these wetlands is *Sphagnum* moss, primarily *S. cristatum*. Johnson (1986b, 1988) describes the pattern of vegetation development in these wetlands as follows:

1. *Sphagnum* growth and peat accumulation occurs where fresh groundwater arrives from the surrounding slopes.
2. Peat accumulation produces areas where either ponding of surface water or the formation of raised peat above the groundwater inhibits further *Sphagnum* growth.

3. Ponded and raised areas are taken over by sedges and cushion species, gradually leading to the development of raised cushion bog vegetation that is isolated from fresh groundwater and has slower peat accumulation than *Sphagnum*-dominated areas; comb sedge (*Oreobolus pectinatus*) is particularly important in this process.
4. Peat accumulation and cushion growth alter the flow of groundwater, leading some areas of cushion vegetation to be recolonised by *Sphagnum*.

The final step restarts the process of peat formation and eventual cushion development, an example of cyclical succession. Small areas of hebe (*Veronica odora*) and bog pine (*Halocarpus bidwillii*) shrubland are also present in Red Swamp, and the margins of the wetland are surrounded by red tussock (*Chionochloa rubra*). In other similar wetlands, the margins may be dominated by narrow-leaved snow tussock (*Chionochloa rigida*). Comparable wetlands are found elsewhere in the Lammerlaw range outside the Taiari catchment, such as the Teviot Swamp.

Along with these large valley/basin wetlands, there are numerous small–medium sized “ribbon fens” occupying subalpine gullies (Johnson & Lee, 1988; Rapson *et al.*, 2006). These often run from the gully crests up to 300 m downhill. There are 113 of these ribbon fens in the Te Papanui/Lammerlaw-Lammermoor ranges, some of which are outside of the Taiari catchment (Rapson *et al.*, 2006). They represent a globally unique type of patterned mire, characterised by a linear series of stepped pools, separated by terraces of peat-forming *Sphagnum* and cushion vegetation. The formation of the pool-terrace system has a variety of possible causes, including:

- Dams in the underlying bedrock.
- Dam formation by cushion vegetation or *Sphagnum* moss blocking water flow.
- Downslope movement of peat creating a series of hollows and scarps.
- Landslips from adjacent slopes damming the water flow.

The left and right margins of these string mires can feature different vegetation, due to variation in aspect and exposure. The vegetation patterning in these wetlands is similar but distinct from the “string mire” Naturally Uncommon Ecosystem. Peat formation in these wetlands is estimated to have originated less than 7500 years ago, however older layers of peat contain organic matter from sedges (perhaps cushion species) and woody vegetation. Extensive *Sphagnum* peat-formation is estimated to have initiated around 600 years ago. This is presumably when burning by humans lead to widespread replacement of woody vegetation by snow-tussock grassland, with increased groundwater levels promoting *Sphagnum* growth.

The wetlands of the Te Papanui/Lammerlaw-Lammermoor uplands are fed by groundwater from the surrounding snow tussock grasslands. The groundwater-provisioning role of the snow tussocks, the relatively regular rainfall with frequent cloud-cover, and reservoirs within schist bedrock all contribute to consistently wet conditions that allow peat-forming vegetation to develop (Johnson & Lee, 1988; Stewart & Fahey, 2010).

3.1.3 Regionally significant wetlands

The following Regionally Significant Wetlands (RSWs) are present above 600 m asl in the Taiari catchment (those above 800 m are in **bold**):

- **Te Paruparu-a-Te-Kaunia/Great moss swamp.**
- Lamb hill fen complex.
- **Maungatua summit wetland management area.**

- Peat moss hills fen complex.
- Red bank wetland management area (partial, one small polygon is within the Taiari catchment).
- Styx ephemeral wetland management area.
- Swampy summit swamp (partially within the Taiari catchment).
- **Timber creek seepage.**
- Trig Q ephemeral pool.

The location of these wetlands is shown in Figure 2.

3.1.4 Naturally uncommon ecosystems

The following Naturally Uncommon Ecosystems (Wiser *et al.*, 2013) of the wetland category are present in the Taiari uplands:

- Cushion bogs.
- Ephemeral wetlands.
- Seepages and flushes.
- Snowbanks.
- Tarns.

The ribbon fens of the Te Papanui/Lammerlaw-Lammermoor ranges might also fall under the “String mires”, if a broad definition of that NUE is used (Mark *et al.*, 1995). The “Lake margins” NUE may also be present around some of the tarns in the Taiari catchment.

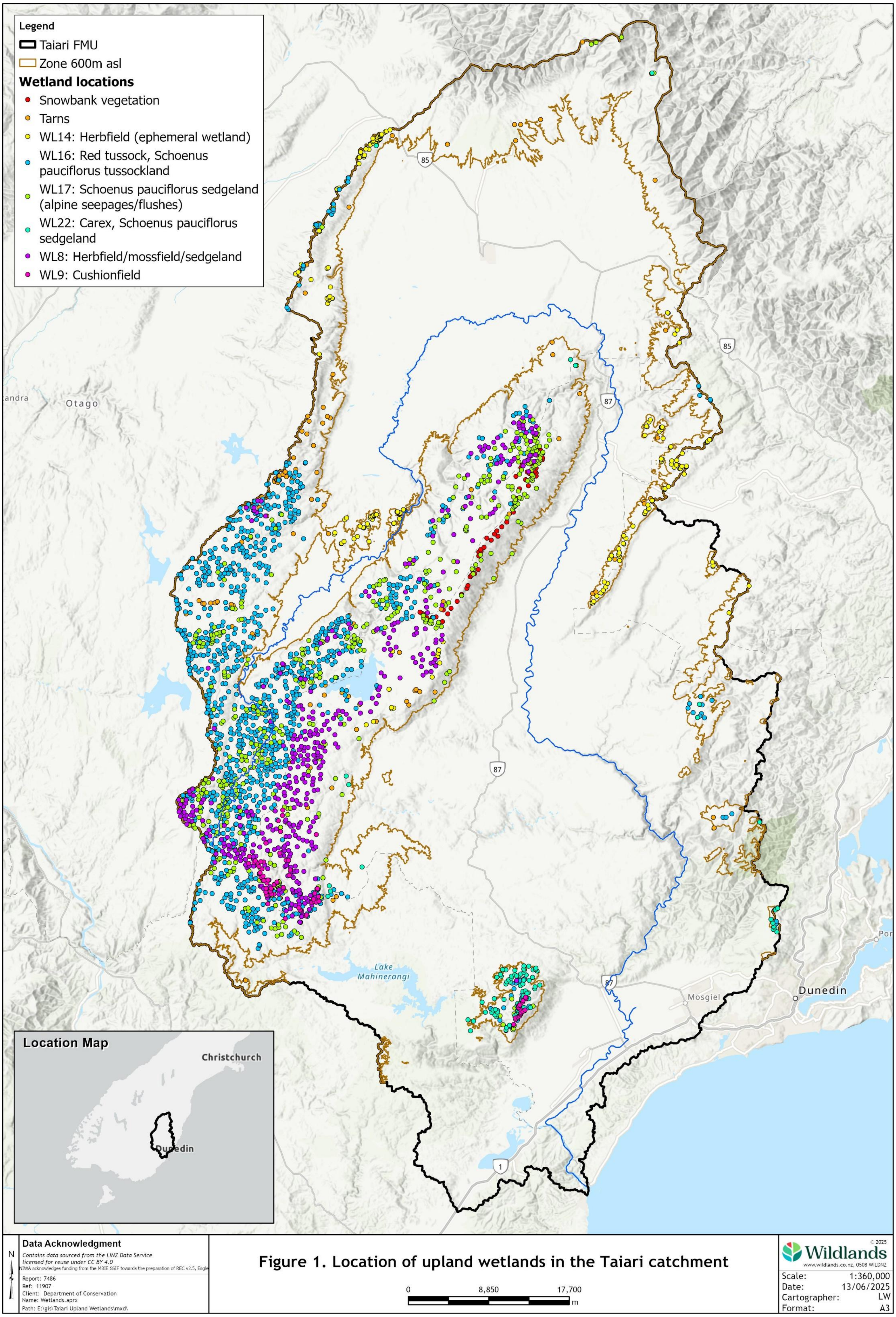
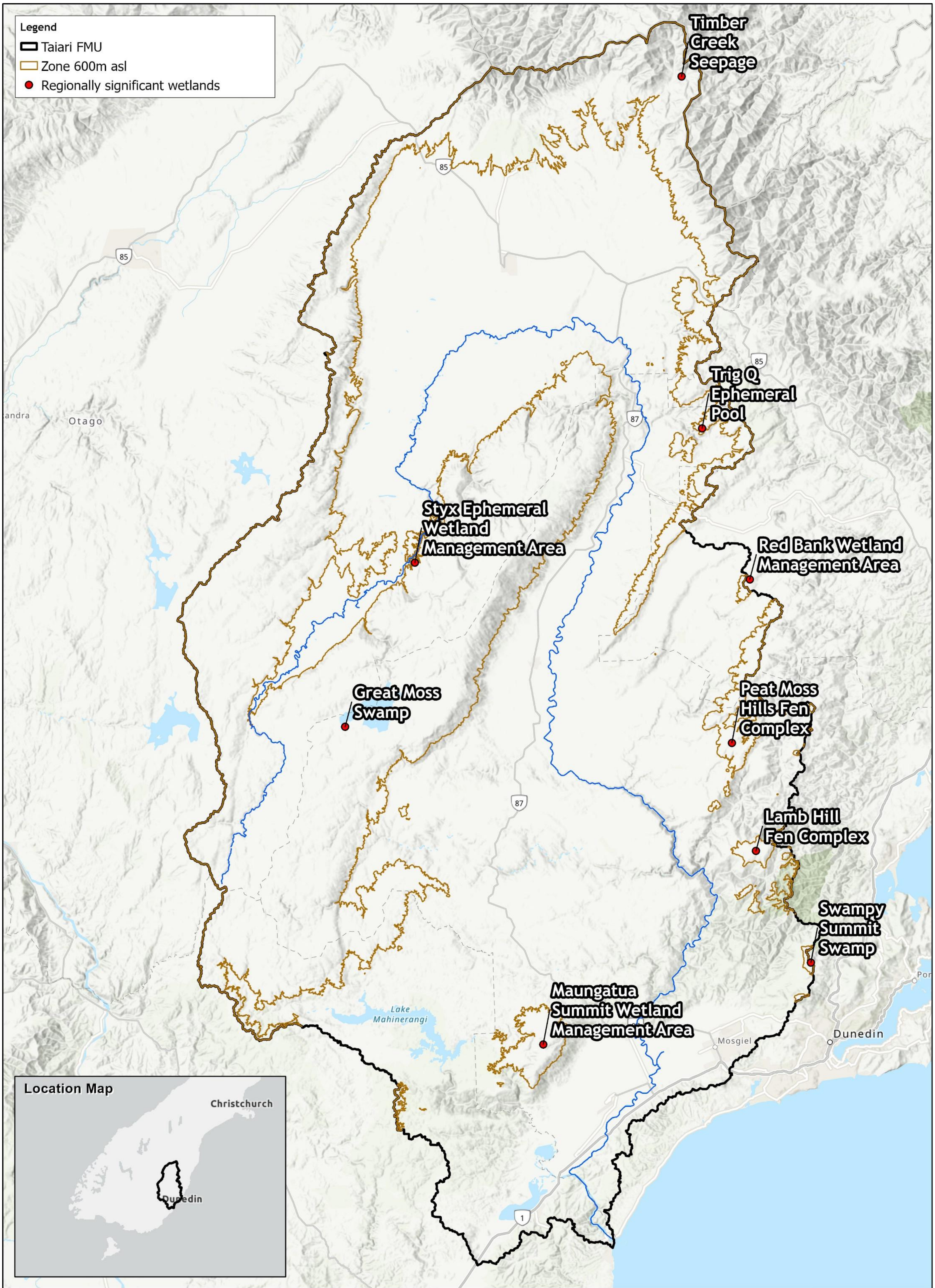


Figure 1. Location of upland wetlands in the Taiari catchment



Data Acknowledgment

Contains data sourced from the LINZ Data Service licensed for reuse under CC BY 4.0

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Figure 2. Location of Regionally Significant Wetlands in the Taiari uplands

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3.2 Flora and fauna

3.2.1 Flora

Plant diversity in the wetlands of the Taiari catchment is much higher than in the surrounding snow tussock grasslands (Johnson, 1988). One hundred and eighteen (118) indigenous vascular plant species were recorded across Red Swamp, Teviot Swamp, and the Fortification Stream scroll plains (Johnson, 1986b; the latter two wetlands are just outside the Taiari catchment in the northwestern Lammerlaw Range but are likely to reflect similar diversity patterns). Seventy-five (75) vascular plant species were recorded from Te Paruparu-a-Te-Kaunia/Great Moss Swamp (Johnson, 1986a). Ryder & Tocher (2020) identified 24 vascular plant species and four lichens within the Taiari catchment that had a threat classification of Nationally Threatened (De Lange *et al.*, 2024). Fourteen of the vascular plant species were wetland species, although not all of these may be present in above 600 m asl. Wildland Consultants (2022) identified 45 notable plant species in the vicinity of Lake Onslow. This area is just outside the Taiari catchment in the north-western Lammerlaw Range, including the Fortification Creek Wetland Management Area, Boundary Swamp, and Boundary Creek Fen RSWs. Notable plant species are those that are nationally classified as Threatened or At Risk, or Range Restricted in the region. An abridged list of these species (excluding non-wetland species) including photos is included in Appendix 1.

Ephemeral wetlands are also key sites for unique flora, with 89 indigenous plant species identified as being restricted to the turf vegetation characteristic of ephemeral wetlands and lakeshores (Johnson & Rogers, 2003). Myrrh (*Chaerophyllum colensoi* var. *delicatulum*; Threatened – Nationally Endangered) and Aotearoa/New Zealand mousetail (*Myosurus minimus* subsp. *novae-zelandiae*; At Risk – Declining) are notable species of Otago ephemeral wetlands.

The Global Biodiversity Information Facility (GBIF.org, 2024[1]) and Australasian Virtual Herbarium (https://avh.chah.org.au/, 2024[2]) were searched for plant records within the mapped polygons of upland wetlands, snowbanks, and tarns in the Taiari catchment. Using these sources, a total of 94 indigenous vascular plant species were identified within the currently mapped wetland polygons, including five species that are nationally classified as At Risk, shown in Table 2.

Table 2 – Plant species classified as nationally At Risk recorded within Taiari upland wetlands (de Lange *et al.*, 2024). This list is unlikely to represent the full diversity of Threatened and At Risk flora present.

Species	Threat Classification	Habitat
Bidibidi/piripiri (*Acaena buchananii*)	At Risk – Declining	Tussock grassland and riverbeds.
Brachyscome montana	At Risk – Naturally Uncommon	Alpine grassland and herbfield (including snowbanks).
Silver cushion mountain daisy (*Celmisia argentea*)	At Risk – Naturally Uncommon	Snowbanks, damp grassland, cushionfields, and bogs.
Kelleria paludosa	At Risk – Naturally Uncommon	Alpine snowbanks, swamps, bogs, seepages, and tarns
Leptinella pusilla	At Risk – Declining	Open sites e.g. sparse grassland, rocky outcrops, bare ground.

[1] GBIF.org (15 February 2025) GBIF Occurrence Download https://doi.org/10.15468/dl.5t5aw3

[2] ala.org.au (15 February 2025) Atlas of Living Australia Occurrence records download https://doi.ala.org.au/doi/10.26197/ala.94e12142-0fb3-458c-b49c-46228ac4a9fe

3.2.2 Freshwater fauna

To assess the species commonly found in highland areas in the Taiari catchment, fish records from the New Zealand Freshwater Fish Database (NZFFD; Crow, 2017) were filtered to show records in the Taiari catchment above 600 m elevation. Of the 780 records present, species that had over 10 records were considered to be common.

Of the species present in these upland areas, the most common are non-migratory galaxiids. There are four main species found in the upper Taiari catchment, and two less common species (Table 3). These species are generally found in small tributaries and headwaters, above waterfalls and other impediments to introduced salmonids (Woodford & McIntosh, 2013). They are often confined to these areas, and normally only one species is found within each sub-catchment. The other main fish species recorded in the Taiari uplands is the introduced brown trout.

Non-migratory galaxiids species are commonly found in small headwater streams which can be associated with wetlands areas. Juveniles of some species prefer pelagic environments such as slow flowing areas and pools. Wetland habitat containing pools and moving water are used by Eldon's galaxias (McQueen & Morris, 2013); this may be similar for other non-migratory galaxiids. All galaxiid species are threatened by land use changes, which impact the streams in which galaxiids live, increasing sedimentation, changing natural flows through water abstraction, and reducing the amount of habitat available for spawning (Table 3).

3.2.3 Invertebrates

A terrestrial invertebrate desktop survey was conducted by searching the Global Biodiversity Information Facility (GBIF.org, 2024[1]) for species records. Amateur and expert observations alike are stored in GBIF, and though some data standards are applied, a desktop survey is no substitute for a field survey by a qualified entomologist.

The invertebrate records were filtered down to those inside mapped polygons of wetlands, tarns, and snowbanks within the Taiari catchment, as well as those within 100 m of these polygons. The Scientific Name filter was also applied, using the terms Arachnida, Athoracophoridae, Rhytididae, Insecta, and Onychophora to represent spiders, leaf-veined slugs, indigenous giant land snails, insects, and velvet worms respectively.

From the records retrieved by the GBIF search, freshwater invertebrates were removed. This dataset was used to characterise the fauna based on the most commonly-represented orders. Observations that were not identified further than order, or were marked as doubtful, were then deleted. All remaining records were scanned for notable species[2]. These were compared with vegetation and habitat on-site to judge the likelihood of each notable species occurring within the project area.

Within wetlands

Within the wetland habitat, the GBIF search retrieved records of 13 terrestrial invertebrate taxa that met the search terms. The invertebrate fauna was characterised mainly by moths and butterflies. Of these records, ten had been identified to species and could be assessed. These were dominated by indigenous species.

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[1] GBIF.org (09 February 2025) GBIF Occurrence Download https://doi.org/10.15468/dl.k8h8ys

[2] Notable species are locally endemic, known or suspected to be declining, particularly sensitive to habitat loss or predation by introduced mammals, or listed as Threatened or At Risk.

Table 3 – Freshwater fauna in the Taiari uplands. Information sourced from McQueen & Morris (2013), Ryder & Tocher (2020), and the Department of Conservation Non-migratory galaxiids webpage (http://www.doc.govt.nz/nature/native-animals/freshwater-fish/non-migratory-galaxiids/).

Species Name	Common Name	Threat Classification	Life History	Threats
Galaxias eldoni	Eldon's galaxias	Nationally Endangered	They can live up to 12 years. They live in small headwater streams set among alpine tussock land forests. Occur in small fast flowing streams to small wetland pools, usually undercover near the water's edge.	Over the last decade 20% of known Eldon's populations have been lost. This can be directly linked to the spread of sports fish (trout and brook char), which eat galaxiids. Other negative pressures are stock access to streams, reduction of native vegetation, land development, and forest harvesting.
Galaxias anomalus	Central Otago roundhead galaxias	Nationally Endangered	Short lived (up to four years), can co-exist with trout unless habitat limiting; *c.*22 ha of habitat remains. Central Otago roundhead galaxias live in headwater tributaries of the Taiari (upstream of Sutton) and Manuherikia rivers (tributaries of the Pool Burn and Ida Burn), with population strongholds in the Ewe Burn and Kye Burn. They occupy mid-reaches of low gradient waterways, ranging from weedy drains to braided cobble streams.	The main threats to Central Otago roundhead galaxias are habitat loss from land development and predation by trout. Being short-lived, they are highly vulnerable to predation and drought. Some larger river habitats have enough space for galaxiids and trout to co-exist. Changes in land use, such as stock access to streams, reduction of native vegetation, and forest harvesting also contribute to this species' decline.
Galaxias pullus	Dusky galaxias	Nationally Endangered	They can live up to 20 years. With only 25 known populations, dusky galaxias are increasingly rare. Their total remaining habitat can fit in an area less than seven hectares. Dusky galaxias are found in eastern areas of Otago in small tributaries of the Waipori River surrounding Lake Mahinerangi. A few populations have been discovered in pockets of the Clutha and Taiari rivers. They make their home under banks and amongst the gravels of very small headwater streams (small enough to step across). These streams are typically about 400–1000 m above sea level and are surrounded by vegetation such as tussocks, mānuka (*Leptospermum scoparium*), hebes (*Veronica* spp.), and *Coprosma* spp.	Over the last decade we have lost 25% of known dusky populations. This can be directly linked to the spread of sports fish (trout and brook char), which eat galaxiids. Changes in land use, such as stock access to streams, reduction of native vegetation, and forest harvesting also contribute to this species' decline.

Species Name	Common Name	Threat Classification	Life History	Threats
Galaxias depressiceps	Taieri flathead galaxias	Nationally Vulnerable	Their entire remaining habitat totals only 21 hectares. They can live up to eight years. Taieri flathead galaxias are found in tributaries of the Taiari, Waikouaiti and Shag rivers, as far as Akatore Creek in the north. They make their home in headwater streams with substrate ranging from mud to gravel. Streams can be small enough to step across and are surrounded by grasses and tussocks.	Over the last decade, we have lost 25% of known galaxiid populations. This can be directly linked to the spread of sports fish (trout and brook char), which eat galaxiids. Changes in land use, such as stock access to streams, reduction of native vegetation, and forest harvesting also contribute to this species' decline.
***Galaxias* "Teviot"**	Teviot flathead galaxias	Nationally Critical	Teviot flathead galaxias are extremely geographically restricted, mostly near the Teviot River. There is a population in Red Swamp in the Taiari catchment. Teviot flathead galaxias are evolutionarily close to the Taieri flathead galaxias.	Over the last decade, 3 out of 7 known Teviot populations have been lost. This can be directly linked to the spread of sports fish (trout and brook char), which eat galaxiids; and changes in land use such as stock access to streams, reduction of native vegetation, land development and forest harvesting.
***Galaxias* "species D"**	Clutha flathead galaxias	Nationally Critical	Clutha flathead galaxias (Galaxias 'species D') are predominantly found in the upper tributaries of the Clutha River upstream of Roxburgh, however, there is a population in the top of Totara Creek, in the Taiari catchment. They live in small headwater streams and seepages that are surrounded by grasses and tussock.	Over the last decade, 35% of known Clutha flathead populations have been lost. This can be directly linked to the spread of sports fish (trout and brook char), which eat galaxiids. Changes in land use is also a threat, such as stock access to streams, reduction of native vegetation, land development and forest harvesting.

Within 100 m buffer

Within the wetland habitat and 100 m buffer around each wetland, the GBIF search retrieved records of 91 terrestrial invertebrate taxa that met the search terms. The invertebrate fauna was characterised mainly by beetles, moths and butterflies. Of these records, 78 had been identified to species and could be assessed. These were also dominated by indigenous species. Two species are listed as At Risk — Declining in the New Zealand Threat Classification System, the moth *Heloxycanus patricki* (Hoare *et al.*, 2017) and the short-horned grasshopper *Sigaus campestris* (Trewick *et al.*, 2022).

All notable species are presented in Table 4.

Table 4 – Notable invertebrate species recorded within upland wetland habitat (denoted with *) or within 100 m of it.

Species Name	Common Name	Threat Classification	Notability	Likelihood of Being On-Site
*Argyrophenga antipodum**	Common tussock butterfly	Not assessed	Genus is endemic to the South Island, vulnerable to introduced predators and parasitoids.	Highly likely
*Argyrophenga janitae**	Janita's tussock butterfly	Not assessed	Genus is endemic to the South Island, vulnerable to introduced predators and parasitoids.	Highly likely
Heloxycanus patricki	Sphagnum porina moth	At Risk – Declining	Declining due to habitat loss.	Highly likely
Holcaspis placida	Ground beetle	Not assessed	Locally endemic.	Highly likely
Scopodes bryophilus	Ground beetle	Not assessed	Vulnerable to habitat loss, limited dispersal ability.	Highly likely
Scopodes cognatus	Ground beetle	Not assessed	Vulnerable to habitat loss, limited dispersal ability.	Highly likely
Sigaus campestris	Short-horned grasshopper	At Risk – Declining	Declining.	Likely

The results of the desktop survey are not likely to be representative of the full assemblage of species present, as wetlands often have a high diversity and abundance of invertebrates which is unlikely to be sampled without targeted efforts. Wetlands are important habitats for invertebrates, particularly for flies, moths, and beetles, whose larvae often depend on wetland vegetation as a source of food, shelter, and moisture. The damp environment provided by wetlands is valuable in helping them regulate their internal temperature and hydration, as unlike birds they cannot use metabolism for thermoregulation and their small size often makes them more prone to desiccation than lizards. Moist vegetation, soil, and water are often used as larval habitats, as larvae are often more vulnerable to desiccation than adults.

Wetland invertebrate species are often distinct from those in drier habitats, mostly due to the different moisture levels and types of vegetation present as a food source. The high diversity and abundance of invertebrates in wetlands increases competition and predator-prey relationships, so that wetland invertebrate species must be adapted to live alongside others exploiting similar niches or higher trophic levels.

In addition to the terrestrial invertebrate species that were within the scope of this desktop assessment, a wide array of aquatic invertebrates such as mayflies and dragonflies also rely on wetland habitats.

3.2.4 Avifauna

An avifauna desktop search was conducted for eBird records from 1 January 1975 to 31 December 2024, limiting the data to above 600 metres above sea level within the project area.

The desktop assessment identified 50 species, including 33 indigenous and 17 exotics (Table 5). Additionally, the likelihood of occurrence of each species in upland wetlands is presented. Of these, ten indigenous and five exotic species are likely or highly likely to use the wetlands; 23 indigenous and 12 exotic species were noted in the eBird assessment as unlikely to use the wetland areas.

Of the indigenous species that are likely to be using these wetlands, two are classified as Threatened – Nationally Vulnerable (kārearea/eastern falcon, *Falco novaeseelandiae novaeseelandiae* and pūteketeke/Australasian crested grebe, *Podiceps cristatus australis*), and three are classified as At Risk – Declining (pihoihoi/New Zealand pipit, *Anthus novaeseelandiae novaeseelandiae;* South Island fernbird, *Poodytes punctata punctata;* and tōrea/South Island pied oystercatcher, *Haematopus finschi*).

Other indigenous species are recorded within the Taiari uplands but are unlikely to use the upland wetlands — two are classified as Threatened, including the Nationally Critical matuku-hūrepo/Australasian bittern (*Botaurus poiciloptilus*) and the Nationally Vulnerable pārera/grey duck (*Anas superciliosa*). Four species are classified as At Risk, including the Declining pohowera/banded dotterel (*Charadrius bicinctus bicinctus*), the Naturally Uncommon Australian coot (*Fulica atra australis*), and two Relict species: māpunga/black shag (*Phalacrocorax carbo novaehollandiae*) and little shag (*Microcarbo melanoleucos brevirostris*).

The remaining 22 indigenous species are classified as Not Threatened; five of these are considered likely to use the upland wetlands: grey duck - mallard hybrids *Anas superciliosa × platyrhynchos*), kuruwhengi/Australasian shoveler (*Spatula rhynchotis*), pāpango/New Zealand scaup (*Aythya novaeseelandiae*), pūtangitangi/paradise shelduck (*Tadorna variegata*), and southern black-backed gull (*Larus dominicanus dominicanus*).

While kārearea/eastern falcon breed in native and exotic forest, dry tussockland, and farmland in the hills along the eastern side of the Southern Alps, kārearea/eastern falcon may hunt within wetland and surrounding areas at different times of the year. These areas provide important hunting grounds as kārearea/eastern falcon are territorial, particularly during the breeding season.

Pūteketeke/Australasian crested grebe will breed within subalpine and alpine lakes where open water is available with aquatic vegetation for building and anchoring their nest, but they will move to coastal waters during the winter months. As pūteketeke/Australasian crested grebe prefer lakes from glacial origins, the wetlands with clear open water will provide important breeding and foraging areas during September to March.

Pihoihoi/New Zealand pipit will forage within alpine tussock and herb fields and may breed within areas containing dry grass, bracken fern, under fallen logs or in hollows within a bank (August to March). Pihoihoi/New Zealand pipit will use the area during the summer months and relocate to lower altitudes to their wintering grounds. These wetlands areas will provide important habitat and resources for Pihoihoi/New Zealand pipit during the breeding season.

South Island fernbird will forage and breed within the vegetative margin of the wetland areas. They are reluctant to move or fly between areas, with juvenile birds only moving up to 20 kilometres from their natal ground. The upland wetland areas provide important habitat and resources all year round.

Tōrea/South Island pied oystercatcher breed and forage within subalpine bogs east of the Southern Alps (August to January). During late December to early March, tōrea/South Island pied oystercatcher will migrate to their wintering grounds within coastal estuaries and harbours. The upland wetland areas provide important habitat and resources during the breeding season.

Although matuku-hūrepo/Australasian bittern are not classed as an alpine species, two individuals have been recorded within the 600-metre elevation zone (April 2024) and individuals may occasionally forage within areas containing *Carex* and *Juncus* during the summer months. The wetlands areas may provide important habitat and resources for birds migrating throughout the region.

3.2.5 Lizards

Observations from the Department of Conservation BioWeb Herpetofauna Database within one kilometre of upland wetlands within the Taiari catchment and within the last 30 years were assessed to inform an assessment of lizard values (Table 6). Additional species not recorded within one kilometre of upland wetlands in the BioWeb Database, but considered to potentially be present within wetlands or a 100-metre buffer zone, are also included in the assessment.

The desktop assessment includes twelve species known from the upland Taiari catchment.

While no lizard species are likely to inhabit areas of wetland where there is standing water, some species are associated with herbfield, damp tussockland, and other dense groundcover vegetation that can be found around wetland margins. These species include Burgan skink (*Oligosoma burganae*), Otago green skink (*Oligosoma* aff. *chloronoton* “eastern Otago”), herbfield skink (*Oligosoma murihiku*), and tussock skink (*Oligosoma chionochloescens*). It is therefore considered likely that, within their known distributions, these species could be present within wetlands in relatively drier marginal areas.

While McCann’s skink (*Oligosoma macccannii*) is commonly found in drier areas of tussockland as well as rocky habitats, this species is widespread and often abundant throughout large areas of the Taiari catchment, and is likely therefore to also be present around some wetland margins.

Oteake skink (*Oligosoma* aff. *inconspicuum* “North Otago”) currently has a highly restricted known confirmed distribution in North Otago, but this species could potentially be present in surrounding tussockland or drier marginal areas of upland wetlands within Oteake Conservation Park.

Jewelled gecko (*Naultinus gemmeus*) are the only other species considered to potentially be found close to or in marginal areas of wetlands, and may be present amongst dense ground cover vegetation such as narrow-leaved snow tussock in the Te Papanui/ Lammermoor-Lammerlaw area.

Other lizard species are more associated with drier areas of tussockland and rocky habitats and are unlikely to be found within wetlands, such as *Woodworthia* geckos, Otago skink (*Oligosoma otagense*), and grand skink (*Oligosoma grande*). However, within their known distributions, these species have either previously been recorded or are considered likely to be present within a 100-metre buffer zone around upland wetlands, as there is often appropriate habitat in these areas (e.g., tussockland with rock tors/outcrops).

To incorporate adverse effects of long-term climate trends and/or extreme climatic events on the threat status of lizards, a ‘Climate Impact (CI)’ qualifier is included within the National Threat Status assessment (Hitchmough *et al*. 2021). Lizard species that have the ‘CI’ qualifier are listed in Table 6.

Table 5 – Indigenous and exotic bird species recorded above 600 metres above sea level (asl) within the project area from eBird records from 1 January 1975 to 31 December 2024.

Common Name(s)	Scientific Name	Threat Classification 2021	Preferred Habitat	Likelihood of Occurrence in Upland Wetlands
Indigenous				
Matuku-hūrepo/Australasian bittern	*Botaurus poiciloptilus*	Threatened – Nationally Critical	Tall, dense beds of raupō and reeds of freshwater wetlands, wet habitats with a mixture of water purslane and willow weed, and damp pasture infested with large clumps of rush or introduced tall fescue.	Highly unlikely
Kārearea/eastern falcon	*Falco novaeseelandiae novaeseelandiae*	Threatened – Nationally Vulnerable	Hilly dry tussockland, farmland, open country, native and exotic forest edges	Likely
Pārera/grey duck	*Anas superciliosa*	Threatened – Nationally Vulnerable	Wetlands, small lakes, ponds, slow-flowing rivers and tidal waters surrounded by forest. Rare on urban lakes.	Unlikely
Pūteketeke/Australasian crested grebe	*Podiceps cristatus australis*	Threatened – Nationally Vulnerable	Clear shallow freshwater lakes and ponds with mud, clay or sandy bottoms with emergent vegetation. Breed on lowland lakes west of Southern Alps, subalpine and alpine lakes within and east of main divide. Wintering sites include coastal lakes and estuaries.	Likely
Mātātā/South Island fernbird	*Poodytes punctata punctata*	At Risk – Declining	Dense, low-growing vegetation in wetlands, swamps, and marshes. They are also found in drier shrubland and tussock habitats	Likely
Pīhoihoi/New Zealand pipit	*Anthus novaeseelandiae novaeseelandiae*	At Risk – Declining	Beaches, riverbeds, high-country riverflats, gravel roads and verges, rough pasture, tussockland, cleared areas of exotic forests.	Highly likely
Pohowera/banded dotterel	*Charadrius bicinctus bicinctus*	At Risk – Declining	Sandy coastlines near streams or river mouths. Riverbeds, river terraces, coastal lagoons, lakes and beaches.	Unlikely

Common Name(s)	Scientific Name	Threat Classification 2021	Preferred Habitat	Likelihood of Occurrence in Upland Wetlands
Tōrea/South Island pied oystercatcher	*Haematopus finschi*	At Risk – Declining	Breed on braided riverbeds, farmland, fringes of lakes, subalpine bogs. Estuaries and sandy beaches outside of breeding.	Likely
Little shag	*Microcarbo melanoleucos brevirostris*	At Risk – Relict	Breed in sheltered coastal waters, estuaries, harbours, rivers, dams and lakes up to the subalpine zone. Commonly in willows or silver poplars overhanging fresh water or estuaries, but sometimes on maimai or river gorge ledges or sea cliffs.	Unlikely
Māpunga/black shag	*Phalacrocorax carbo novaehollandiae*	At Risk – Relict	Sheltered coastal waters, estuaries, harbours, rivers, streams, dams and lakes up to subalpine zone.	Unlikely
Australian coot	*Fulica atra australis*	At Risk – Naturally Uncommon	Shallow, sheltered bays in freshwater fringed with submerged vegetation, reeds and raupō beds.	Unlikely
Grey duck – mallard hybrid	*Anas superciliosa × platyrhynchos*	Not Threatened	Wetlands, lakes, slow flowing rivers, calm tidal waters.	Likely
Kāhu/swamp harrier	*Circus approximans*	Not Threatened	Open country, wetlands, farmlands, grasslands, high-country tussockland, forest margins, riverbeds.	Unlikely
Kakīānau/black swan	*Cygnus atratus*	Not Threatened	Lowland coastal lakes and lagoons, estuaries.	Highly unlikely
Kererū/New Zealand pigeon	*Hemiphaga novaeseelandiae*	Not Threatened	Native lowland forests dominated with podocarps, tawa, taraire and puripuri, bush patches on farmland, gardens, parks.	Highly unlikely
Korimako/bellbird	*Anthornis melanura melanura*	Not Threatened	Native forest and scrubland, exotic plantations, river margins and urban environments with native bush (e.g., parks).	Highly unlikely
Kōtare/New Zealand kingfisher	*Todiramphus sanctus vagans*	Not Threatened	Coastal bush, tidal estuaries, mangrove swamps, farmland with scattered trees, inland rivers and lakes, native and exotic forests.	Highly unlikely
Kuruwhengi/Australasian shoveler	*Spatula rhynchotis*	Not Threatened	Fertile and shallow wetlands, waterways, sewage ponds.	Highly likely
Matuku moana/white-faced heron	*Egretta novaehollandiae*	Not Threatened	Open country, swampland, lake shores, estuaries, farm dams and creeks, wetlands, riverbeds, mudflats, harbours, rocky shores and sandy beaches.	Highly unlikely

Common Name(s)	Scientific Name	Threat Classification 2021	Preferred Habitat	Likelihood of Occurrence in Upland Wetlands
Ngirungiru/South Island tomtit	*Petroica macrocephala macrocephala*	Not Threatened	Mature native forests, especially open beech, second-growth manuka/kanuka scrub, older stands of exotic plantations.	Highly unlikely
Pāpango/New Zealand scaup	*Aythya novaeseelandiae*	Not Threatened	Large deep lakes, infrequently found on shallow coastal lakes, lagoons and rivers.	Likely
Pipipi/brown creeper	*Mohoua novaeseelandiae*	Not Threatened	Regional: High altitudes in mountain/silver beech forests (N and W of S. Alps); red/silver beech forests on river flats (E. of S. Alps, Fiordland and Stewart Island); dry scrub, coastal hills (Marlborough, Banks Peninsula and S. Canterbury), pine forests (Nelson and Otago) and native forests (Dunedin and Catlins).	Unlikely
Pīpīwharauroa/shining cuckoo	*Chrysococcyx lucidus lucidus*	Not Threatened	Linked to distribution of primary host, riroriro/grey warbler.	Highly unlikely
Pīwakawaka/South Island fantail	*Rhipidura fuliginosa fuliginosa*	Not Threatened	Forest, scrubland (second growth), farmland with scattered trees, suburban environments.	Highly unlikely
Poaka/pied stilt	*Himantopus himantopus leucocephalus*	Not Threatened	Riverbeds, estuaries, wetlands, paddocks, lake margins, inland lakes, coastal lagoons.	Unlikely
Pūtangitangi/paradise shelduck	*Tadorna variegata*	Not Threatened	Grassland, pond, tussockland, farmland, lakes, riverbeds.	Likely
Riroriro/grey warbler	*Gerygone igata*	Not Threatened	Temperate forest, scrubland, pasture, and urban environments. From sea level to subalpine zone.	Highly unlikely
Southern black-backed gull	*Larus dominicanus dominicanus*	Not Threatened	Estuaries, harbours, open coastlines, rivers, lakes, wet pasture, lambing paddocks, farmland, rubbish tips and urban environments.	Highly likely
Spur-winged plover	*Vanellus miles novaehollandiae*	Not Threatened	Arable land and pasture, riverbeds, coastal and lake shores, urban parks.	Unlikely
Tauhou/silvereye	*Zosterops lateralis lateralis*	Not Threatened	Native forest, scrubland, exotic plantations, suburban gardens.	Highly unlikely
Tētē-moroiti/grey teal	*Anas gracilis*	Not Threatened	Shallow coastal lakes and lagoons, often with margins of swamp and willow. Often feed on estuaries and exposed mudflats.	Highly unlikely

Common Name(s)	Scientific Name	Threat Classification 2021	Preferred Habitat	Likelihood of Occurrence in Upland Wetlands
Tūī/tui	*Prosthemadera novaeseelandiae novaeseelandiae*	Not Threatened	Mainly forest and scrub, though outside of breeding can enter rural and suburban environments.	Highly unlikely
Warou/welcome swallow	*Hirundo neoxena neoxena*	Not Threatened	Lowland open country, less common in open high country.	Highly unlikely
Exotic				
Australian magpie	*Gymnorhina tibicen*	Introduced and Naturalised	Hedgerows, grassland, open pasture, forest patches, suburban environments.	Highly unlikely
California quail	*Callipepla californica*	Introduced and Naturalised	Open country, low scrub, tussockland, rough pasture, especially manuka scrub, wild Irishman, gorse, bracken, broom and briar. Riverbeds with lupin.	Highly unlikely
Canada goose	*Branta canadensis*	Introduced and Naturalised	High country lakes and rivers, dry tussockland, estuaries, coastal lakes.	Highly likely
Chaffinch	*Fringilla coelebs*	Introduced and Naturalised	Hedgerows, grassland, native and exotic forests, farmland. Sea level to alpine scrub.	Unlikely
Common redpoll	*Acanthis flammea*	Introduced and Naturalised	Farmland, tussockland, coastal dunes, forest and scrub margins, subalpine scrub.	Unlikely
Dunnock	*Prunella modularis*	Introduced and Naturalised	Hedgerows, grassland, Native and exotic forests, scrubland, suburban environments. Sea level to alpine scrub.	Unlikely
Eurasian blackbird	*Turdus merula*	Introduced and Naturalised	Suburban environments, paddocks, hedgerows, grassland, scrub and native forests.	Unlikely
Goldfinch	*Carduelis carduelis*	Introduced and Naturalised	Low altitudes. Farmlands and suburban environments.	Highly unlikely
Greenfinch	*Chloris chloris*	Introduced and Naturalised	Farmlands, pine plantations, hedgerows grasslands and suburban environments.	Unlikely
House sparrow	*Passer domesticus*	Introduced and Naturalised	Arable farmland, rural and urban environments.	Highly unlikely

Common Name(s)	Scientific Name	Threat Classification 2021	Preferred Habitat	Likelihood of Occurrence in Upland Wetlands
Mallard	*Anas platyrhynchos*	Introduced and Naturalised	Wetlands, ponds, rivers and estuaries in both rural and urban environments.	Highly likely
Rock pigeon	*Columba livia*	Introduced and Naturalised	Arable farmland, rural and urban environments.	Highly unlikely
Skylark	*Alauda arvensis*	Introduced and Naturalised	Open country, grassland, dunes, farmland, tussockland. Sea level to subalpine herbfields.	Highly likely
Song thrush	*Turdus philomelos*	Introduced and Naturalised	Hedgerows, farmland, orchards and suburban environments.	Highly unlikely
Starling	*Sturnus vulgaris*	Introduced and Naturalised	Hedgerows, grassland, farmland, rural and suburban environments, forest edges.	Highly unlikely
Wild turkey	*Meleagris gallopavo*	Introduced and Naturalised	Mature hardwood forests, such as mixed conifer-hardwoods with scattered openings like pastures, fields, orchards, and seasonal marshes	Likely
Yellowhammer	*Emberiza citrinella*	Introduced and Naturalised	Farmland, orchids, open tussockland from sea level to subalpine herbfields.	Likely

Table 6 – Results of the Department of Conservation BioWeb Herpetofauna Database search within one kilometre of upland wetlands in the Taiari catchment, species not recorded but considered potentially present within a 100-metre buffer zone around wetlands, and an assessment of the likelihood of the presence of these species. Conservation status as per Hitchmough *et al*. (2021) and Jarvie *et al*. (2023). Records older than 30 years were excluded from the database search. The likelihood of occurrence for each species is based on their known habitat preferences and distribution in the region. Database accessed in December 2024.

Species	Common Name	National Threat Status	National Threat Status 'Climate Impact' qualifier	Regional Threat Status	Closest Record Distance to Wetlands (metres)	Distribution and Habitats Within Upland Taiari Catchment	Likelihood of Occurrence Within Upland Wetlands	Likelihood of Occurrence Within 100-metre Buffer
Oligosoma maccanni	McCann's skink	Not Threatened	No	Regionally Not Threatened	<10 m (2009)	Often highly abundant and found in a variety of open habitats, such as tussockland and rock outcrops. Particularly associated with dry and rocky habitats, but some individuals likely to be found around dry margins of wetlands and surrounding areas. Widespread in Taiari catchment in appropriate habitat west of Dunedin area.	**Likely at low densities** (in dry marginal areas but not considered favourable habitat)	**Highly likely** (previous records and appropriate habitat)
Oligosoma chionochloescens	Tussock skink	At Risk – Declining[1]	No	Regionally Declining	75 m (2009)	Found in a variety of open habitats with sufficient ground cover vegetation, such as tussockland and exotic grassland. **Often prefers damper areas, including around wetlands**. Found throughout Taiari catchment in appropriate habitat.	**Highly likely** (in relatively drier marginal areas)	**Highly likely** (previous records and appropriate habitat)

[1] Tussock skink is a recently described species (Jewell, 2022) derived from a taxonomic split of southern grass skink (*Oligosoma* aff. *polychroma* Clade 5) which has not yet been attributed a national threat classification. It is likely to be attributed a threat classification of 'At Risk – Declining' - the same as southern grass skink.

Species	Common Name	National Threat Status	National Threat Status 'Climate Impact' qualifier	Regional Threat Status	Closest Record Distance to Wetlands (metres)	Distribution and Habitats Within Upland Taiari Catchment	Likelihood of Occurrence Within Upland Wetlands	Likelihood of Occurrence Within 100-metre Buffer
Oligosoma aff. *inconspicuum* "North Otago"	Oteake skink	Nationally Vulnerable	Yes	Regionally Vulnerable	700 m (2018)	Found in tussockland, rocky shrubland and talus. Could potentially be found in tussockland around wetland margins. Known confirmed distribution endemic to the upland Taiari catchment (Oteake Conservation Park).	**Possible** (outside of known distribution but could be present in relatively drier marginal areas)	**Possible** (outside of known distribution)
Oligosoma murihiku	Herbfield skink	At Risk – Declining	No	Regionally Declining	2,150 m (1996)	Found in tussockland, rocky shrubland, herbfield and **dense ground cover vegetation in and around wetland areas**. Confirmed populations within the upland Taiari catchment are from the Macraes area. However, populations could be found in other upland areas of the catchment around Dunedin and Waipori, as the species is also known from the lowland Dunedin area.	**Moderately likely** (in relatively drier marginal areas but limited wetland areas within known distribution)	**Moderately likely** (appropriate habitat but limited wetland areas within known distribution)
Oligosoma burganae	Burgan skink	Nationally Endangered	Yes	Regionally Vulnerable	15 m (2018)	Found amongst **dense ground cover vegetation in subalpine herbfield and likely including around wetland areas**. Current recorded distribution is endemic to the upland Taiari catchment (the Te Papanui/ Lammermoor-Lammerlaw area and Rock and Pillar Range), but could be present in upland areas in the western Te Papanui/Lammermoor-Lammerlaw area.	**Likely** (in relatively drier marginal areas)	**Highly likely** (previous records and appropriate habitat)

Species	Common Name	National Threat Status	National Threat Status 'Climate Impact' qualifier	Regional Threat Status	Closest Record Distance to Wetlands (metres)	Distribution and Habitats Within Upland Taiari Catchment	Likelihood of Occurrence Within Upland Wetlands	Likelihood of Occurrence Within 100-metre Buffer
Oligosoma aff. *chloronoton* "Eastern Otago"	Otago green skink	At Risk – Declining	Yes	Regionally Declining	600 m (1997)	Found in tussockland, rocky shrubland, herbfield and **dense ground cover vegetation in and around wetland areas**. Confirmed populations within the upland Taiari catchment are from the Macraes area. However, populations could be found in other upland areas of the catchment as the species is also known from Oteake Conservation Park north of the Ida Range, has been recorded in the western Te Papanui/ Lammermoor-Lammerlaw area, and has historically been recorded in the Kakanui Mountains.	**Moderately likely** (in relatively drier marginal areas but limited wetland areas within known distribution)	**Moderately likely** (appropriate habitat but limited wetland areas within known distribution)
Oligosoma otagense	Otago skink	Nationally Endangered	No	Regionally Endangered	80 m (1996)	Found in creviced rock outcrops, particularly along gullies, in the Macraes area.	**Highly unlikely** (prefers dry and rocky habitat)	**Possible** (some appropriate habitat but species distribution increasingly restricted and limited wetland areas within current confirmed distribution)
Oligosoma grande	Grand skink	Nationally Endangered	Yes	Regionally Endangered	80 m (1996)	Found in creviced rock tors and outcrops in the Macraes area.	**Highly unlikely** (prefers dry and rocky habitat)	**Possible** (some appropriate habitat but species distribution increasingly restricted and limited wetland areas within current confirmed distribution)

Species	Common Name	National Threat Status	National Threat Status 'Climate Impact' qualifier	Regional Threat Status	Closest Record Distance to Wetlands (metres)	Distribution and Habitats Within Upland Taiari Catchment	Likelihood of Occurrence Within Upland Wetlands	Likelihood of Occurrence Within 100-metre Buffer
Naultinus gemmeus	Jewelled gecko	At Risk – Declining	Yes	Regionally Declining	150 m (2018)	Found in narrow-leaved snow tussock (*Chionochloa rigida*) in the Te Papanui/ Lammermoor-Lammerlaw area and Ida Range. **May be found in narrow-leaved snow tussock or other dense ground cover vegetation around the margins of wetlands**.	**Possible** (around wetland margins)	**Likely** (appropriate habitat in surrounding areas)
Woodworthia "Central Otago"	Schist gecko	At Risk – Declining	Yes	Regionally Declining	25 m (1996)	Found in rocky tussockland and creviced rock tors and outcrops on the Rough Ridge. *Woodworthia* geckos in upland areas west of Paerau and Serpentine will also be either this species or kōrero gecko.	**Highly unlikely** (prefers dry and rocky habitat)	**Highly likely** (previous records and appropriate habitat in surrounding areas)
Woodworthia "Otago/Southland large"	Kōrero gecko	At Risk – Declining	No	Regionally Declining	105 m (2004)	Found in rocky tussockland, screes and creviced rock tors and outcrops throughout the upland Taiari catchment except the Ida Range and Rough Ridge. *Woodworthia* geckos in upland areas west of Paerau and Serpentine will also be either this species or schist gecko.	**Highly unlikely** (prefers dry and rocky habitat)	**Highly likely** (appropriate habitat in surrounding areas)
Woodworthia "Southern Alps"	Southern Alps gecko	At Risk – Declining	No[1]	Regionally Declining	780 m (2006)	Found in rocky tussockland, screes and creviced rock tors and outcrops in the Ida Range and northern end of the Kakanui Mountains.	**Highly unlikely** (prefers dry and rocky habitat)	**Likely** (limited wetlands within species distribution)

[1] Not listed as a specific qualifier for Southern Alps gecko but detailed in the conservation status report (Hitchmough *et al*. 2021) that an understanding that invasive predator impacts are likely to increase in the future under the influence of climate change influenced the decision to increase the threat status of Southern Alps gecko to 'At Risk – Declining'.

4.0 Cultural Values and Land Use

4.1 Cultural and economic values

The wetlands of the upper Taiari are valued for aesthetic, cultural, and recreational reasons. The wetlands of the Te Papanui/Lammermoor-Lammerlaw uplands are used for fishing, with the wetlands containing small streams and ponds where trout can be caught. The wetlands are of economic importance as they ensure water supply for irrigation downstream during the most critically dry months. The stable supply of water that upland wetlands provide is also important in mitigating floods and droughts that harm the health of downstream mahika kai sites, particularly Te Nohoaka o Tukiauau (Sinclair Wetlands), part of the larger Waipōuri/Waihora wetland complex.

Sphagnum harvesting has also occurred in the Te Papanui/Lammerlaw-Lammermoor uplands (Johnson, 1988), although there is no information on whether this practice has continued. The Taiari uplands, particularly Mauka Atua, were also historically important as a site for the harvesting of taramea (*Aciphylla aurea*; spaniard/speargrass) resin, which was used as a fragrance and perfume (Dobson-Waitere *et al.*, 2022).

4.2 Land use

Most of the land above 600 m altitude in the Taiari catchment is private land (55%), with crown pastoral land (CPL) and PCL each representing around 20% of the uplands (Table 7). There are smaller areas of land in DOC and QEII covenants, with no Nga Whenua Rahui kawenata present.

Most private and pastoral lease land is used for low intensity livestock grazing. Some areas of plantation forestry are also present, particularly in the areas near Naseby, Macraes, and Lake Mahinerangi. Mahinerangi wind farm is present in the southeastern Te Papanui/Lammermoor range. Some areas of farmland, particularly at lower altitudes, have been developed for more intensive agricultural uses such as dairying (Johnson *et al.*, 2022).

Table 7 – Breakdown of land ownership above 600 m altitude in the Taiari catchment.

Land Ownership	Area (hectares)	% of Total
Public conservation land	40,459.1	20.6%
DOC Covenant	4,045.3	2.1%
QEII Covenant	2,017.9	1.0%
Crown pastoral land	41,107.9	20.9%
Other (predominantly private)	78,025.3	55.4%

4.3 Ecosystem services

Upland wetlands are very important to the entire Taiari catchment for their role in water provisioning. Because of their water-holding capacity, these wetlands store water during periods of high flows, releasing it gradually afterwards (Clarkson *et al.*, 2013). This has the benefit of improving the consistency of water flows throughout the catchment. The lowlands of the Māniatoto and Strath Taiari basins receive relatively low levels of rainfall, so a stable supply of water from the uplands is important for downstream land use, biodiversity values, and hydroelectricity generation, as well as mitigating flood events (Department of Conservation, 2009). In the Taiari uplands, peat wetlands and snowbanks may be particularly important in ensuring a stable water supply. The deep organic soils and high water-holding capacity of *Sphagnum*-dominated wetlands may make them particularly important in stabilising downstream water levels. Snowbanks are also likely to be important, as they trap and store moisture from snow, which is gradually released through spring and summer; snowbanks are often the initial source of moisture for downslope wetlands such as seepages, fens, and bogs. Peat-forming wetlands, especially bogs, are also a major contributor to terrestrial carbon storage (Ausseil *et al.*, 2015). The deep *Sphagnum* peat of these wetlands is relatively recently formed (see section 3.1.2), suggesting that these wetlands are still actively accumulating peat at a significant rate. If the current peat-forming conditions continue, these wetlands are likely to be powerful carbon-capture systems.

It is also worth emphasising that the organic matter stored in the upland peatlands has the potential to act as a significant ecosystem disservice if it erodes and washes downstream into the Taiari lowlands. This could lead to blackwater events, where the decomposition of organic matter in the warmer lowlands creates anoxic freshwater conditions that are harmful to aquatic life. Maintaining stable groundwater levels and indigenous vegetation cover in these peatlands is key to avoiding this scenario.

5.0 Threats to Wetlands

Upland wetlands in the Taiari catchment face a variety of threats. Previous reports on the impacts of climate change on the Taiari catchment have identified alpine wetlands as being the most vulnerable ecosystem to climate change impacts (Closs *et al.*, 2024; Goldsmith, 2023; Tonkin & Taylor Ltd, 2021). Later sections of this report review the potential climate change impacts in more detail and provide updated risk assessment that incorporates updated climate change data.

Alongside the threats posed by climate change, there are a variety of non-climatic threats to Taiari upland wetlands. Some of these are direct threats to the biodiversity and ecosystem function of the wetlands (e.g. invasive fauna). Additionally, because many upland wetlands are hydrologically linked to the surrounding non-wetland ecosystems, impacts on the wider upland habitat can also indirectly threaten the wetlands — these are reviewed below.

5.1 Fire

Frequent burning of snow tussock can lead to the degradation of snow tussock grasslands, especially in combination within grazing pressure (Department of Conservation, 2009; Johnson, 1986a). Degraded tussock grasslands often have *Chionochloa* species replaced by various short tussock species and invasive weeds. Reduction in snow tussock cover has a negative effect on groundwater levels, potentially causing wetlands to contract or dry out and be invaded by non-wetland species (Mark & Dickinson, 2008). It is worth noting that the extensive tussock grasslands were originally formed by human-originated fire that destroyed the previous woody vegetation (McGlone, 2001). If fire is completely absent over long time periods, it is plausible that tussock grassland may gradually transition back to some level of woody vegetation (Day *et al.*, 2023; Lord *et al.*, 2022; Mark & Dickinson, 2003; Ropars *et al.*, 2018), with a subsequent reduction in groundwater levels and reduction in the extent of wetlands.

5.2 Invasive predators and herbivores

Wetlands in the Taiari uplands are impacted by both aquatic and terrestrial predators. Salmonids predate the various non-migratory galaxiids present in the Taiari uplands, and have extirpated them from many waterways. Mustelids, rodents, hedgehogs, and cats prey on indigenous birds, invertebrates, and lizards (Watts & Peters, 2010).

Invasive herbivores in the Taiari uplands include deer, pigs, goats, rabbits, hares, Canada geese, and potentially wallabies. Johnson & Lee (1988) report hare damage to *C. argentea* snowbank vegetation in the Te Papanui/Lammerlaw Range. At the 2025 Taiari Wai River Festival, a member of the public mentioned that there were large numbers of pigs in the Makarara/Deep Stream headwaters, which were damaging the wetlands. Trampling by large-hoofed mammals such as pigs, deer, and goats can damage wetland vegetation, compact soils (particularly peat), and spread weeds into wetlands. Grazing by geese, rabbits, and hares may be less harmful to some wetlands, as these species do not cause trampling damage in the same manner as ungulates. The droppings of introduced waterfowl may also add nutrients to wetlands. Indigenous avifauna probably had similar effects in the past, and this effect should not be considered entirely unnatural. Nevertheless, present day avifauna assemblages may result in different impacts than those recorded historically. For example, colonies of black-backed gulls (*Larus dominicanus*) while indigenous to Aotearoa/New Zealand, have expanded dramatically in response to human modification of the landscape. These colonies result in more nutrient deposition in wetlands than historic assemblages would have. Additionally, waterfowl may also act as vectors for weed invasion in wetlands.

5.3 Invasive weeds

A number of weeds are of concern to upland wetlands. Wilding conifers are a major pest in the Otago high country. Some species of wilding conifer, such as lodgepole pine (*Pinus contorta*), can spread rapidly in upland environments from seed sources at lower altitudes. Woody weeds such as wilding conifers have the potential to alter wetland hydrology, due to increased evapotranspiration and crown interception of rainfall. This can significantly decrease ground water levels where conifers replace snow tussock grassland (Mark & Dickinson, 2008). Despite this, many wetlands do persist in conifer plantations. Invasive conifers can significantly alter the soil in areas where they have invaded, making it difficult to restore habitats even after the conifers have been cleared, and potentially making it easier for other weeds to subsequently invade (Dickie *et al.*, 2014). Wilding conifers may also increase the risk of wildfires occurring (Taylor *et al.*, 2017).

Hawkweeds (*Hieracium* and *Pilosella* spp.) are an abundant weed in the Taiari uplands. They can be vigorous invaders of high-country grasslands, herbfields, and shrublands, forming dense mats of low-growing vegetation that supress indigenous plants. The spread of hawkweeds is typically a consequence of overgrazing and fire in upland tussock grasslands, and they may provide an ecosystem service by covering up bare ground. Hawkweeds are unlikely to be a problem for healthy indigenous vegetation.

Alongside the weeds that are currently impacting the Taiari uplands, there are several other weed species that are currently present just below 600 m altitude, that could move into the uplands as the climate warms (e.g. broom and grey willow). Invasion of lowland weeds into alpine environments, facilitated by climate change, has been observed globally. Because many of the Taiari uplands consist of flat-topped ranges, there are large areas of habitat that could become available to weeds all at once.

5.4 Land-use change

Afforestation for timber and/or carbon credits presents a potential risk to upland wetlands. Exotic conifer plantations significantly lower local water tables, especially when compared to snow tussock grassland (Mark & Dickinson, 2008). In this way, they may indirectly negatively affect wetlands within the catchment even if they are planted at a distance. Plantations may also be a source of wilding conifer spread (see above), especially if the site and species are not chosen wisely.

Pasture intensification poses a threat to upland wetlands at lower altitudes, this often involves over-sowing and topdressing of former tussock grassland. More intensive agriculture can increase nutrient run-off into wetlands from effluent and fertiliser application. Higher densities of stock can increase trampling and herbivory damage to unfenced wetlands, and cattle are more destructive to wetlands than sheep, notably targeting younger wetland sedge species (Cyperaceae) in spring. Tillage for cropping can also destroy smaller/shallower wetlands. Shallow ephemeral wetlands may be particularly vulnerable to these threats, as they are often found on flatter terrain in the lower 600-800 m altitude zone (Johnson & Rogers, 2003), and because their value is often overlooked by land managers.

5.5 Large-scale infrastructure projects

There is also potential for large-scale infrastructure projects to threaten Taiari upland wetlands — particularly irrigation and energy generation/storage. Reservoirs and pumped storage hydroelectricity dams inundate wetlands, particularly those in valley floors. The most notable instance of this is the drowning of much of the Te Paruparu-a-Te-Kaunia/Great Moss Swamp under Loganburn Reservoir. The reservoir level has subsequently been raised in 2014, and any future raising of the reservoir would threaten what remains of the swamp. The proposed Lake Onslow pumped hydro scheme would similarly flood the Fortification Creek wetland management area RSW.

Mahinerangi windfarm is the only windfarm currently present in the Taiari uplands, with 12 turbines. However, a second stage of this wind farm could see up to 88 additional turbines installed. Other large wind farms have been unsuccessfully pursued, such as Project Hayes in the Te Papanui/Lammermoor range. The construction of wind turbines and associated roading and other infrastructure could cause damage to upland wetlands and surrounding snow tussock grasslands, while the ongoing operation of wind turbines poses a potential threats to indigenous bird biodiversity (Powlesland, 2009). Wind turbines also have an impact on the local microclimate, evening out the day-night temperature cycle by several degrees (Baidya Roy & Traiteur, 2010). Whether this could have positive or negative effects on upland wetlands has not been studied.

5.6 Stock grazing

Stock (particularly cattle) can directly damage alpine wetlands, although they often avoid deeper wetlands such as bogs (Johnson & Lee, 1988). Sheep avoid wetter wetlands. Droppings and carcasses can add nutrients when present on bogs, providing local sites for weed invasion (Department of Conservation, 2009). The extent to which additional nutrients comprise a serious threat to wetlands depends on the quantity of additional nutrients and the hydrology (particularly, the water exchange) of the wetland. Trampling (particularly by cattle) can damage wetland vegetation (P. J. Johnson, 1987; Johnson & Lee, 1988), especially in fens and bogs, with cushion plants being particularly vulnerable. Trampling can also compact peaty soils, altering the hydrology of the wetland.

Over-grazing can also lead to the degradation of the surrounding snow-tussock grasslands, reducing groundwater levels that supply upland wetlands. It is worth noting that for ephemeral wetlands, light grazing from sheep and/or rabbits may help to suppress weed growth in favour of native turf plants (Johnson & Rogers, 2003). Prior to human arrival in Aotearoa/New Zealand, native waterfowl may have grazed on these turfs, however they are unlikely to have trampled the turfs to the extent that large ungulates do.

5.7 Vehicle damage

Wetlands are vulnerable to vehicle damage, which can crush flora and fauna, compact soils, and alter the hydrology of wetlands. Reckless off-roading presents a potential threat to Taiari upland wetlands, especially to bogs and fens that have short statured vegetation and peat soils especially prone to vehicle damage.

It is worth noting that, although reckless off-roading has been reported along Old Dunstan Road (Block, 2018), this report has not identified any direct evidence that that this off-roading is damaging wetlands within the Taiari uplands. Many of the Taiari upland wetlands are located in steep gullies that are less accessible. Wetland damage from off-roading has occurred elsewhere in Otago however, such as in near Queenstown (Pattermore, 2024), and is visible through aerial imagery on top of the Old Man range — in the vicinity of NZTM E1299473, N4960606.

6.0 Climate Change Impacts in the Taiari Catchment

6.1 Updated climate data

Previous reports on climate change impacts in the Taiari catchment have assessed alpine wetlands as being at high risk of climate change impacts, both in the present and future (Closs *et al.*, 2024; Goldsmith, 2023; Tonkin & Taylor Ltd, 2021). Of particular concern are:

- Higher temperatures.
- Increased drought frequency and intensity.
- Increased rainfall seasonality and flood risk.
- Reduced snow and ice.

Collectively, these impacts make it more likely that wetlands will dry out or contract over summer months, even if annual precipitation stays the same or increases slightly. In particular, reductions in snow and ice are consistently identified as having an especially high-risk rating.

Since the publication of these reports, the MfE Climate Projections Insight website[1] has been published. The updated climate projections provided on this website are based on an update of six Global Climate Models (GCMs) that have been re-averaged and radically downscaled to Aotearoa/New Zealand by the National Institute of Water and Atmospheric Research (NIWA). This dataset provides more recent analysis regarding predicted climate change in the catchment than the previous iteration, in addition to being spatially explicit.

6.2 Climate change projections in the Taiari catchment

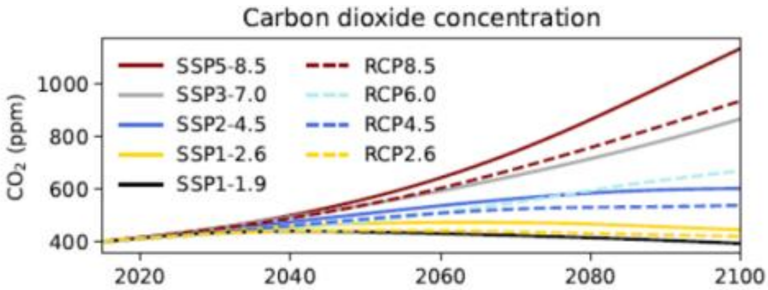
6.2.1 Methods

We compared these most recent climate change predictions against those used to infer climate change impacts in previous reports, meticulously looking over maps of projected predictions throughout the Taiari catchment.

[1] www.environment.govt.nz/facts-and-science/climate-change/climate-change-projections/climate-projections-insights-and-publications/

Previous assessments considered the impacts of climate change using two climate change scenarios: RCP 4.5 (Representative Concentration Pathway; the 'low-mid' stabilisation pathway) and RCP8.5 (a high greenhouse gas emissions scenario, 'business as usual'), relative to a baseline period of 1986 to 2005. We used the same baseline period for comparison (1985 to 2005). The predicted future periods that predictions were made for were also similar. Previous predictions made for the 2040s (i.e. 2031 to 2050) were compared to recent predictions for 2041 to 2060. Previous predictions made for the 2090s were compared to recent predictions for 2080 to 2099.

Predictions provided in the Sixth Assessment Report (AR6) no longer use RCPs, which were the standard form of "climate narrative" in previous iterations of climate forecasts. Instead, in the AR6, Shared Socio-economic Pathway (SSP) scenarios were used. The SSPs base their emission scenarios on a wide array of socio-economic drivers, and have been developed to provide narratives of a broad range of possible futures. Some SSP- and RCP-based scenarios reach the same radiative forcing (i.e. climate change impact) by 2100, but the greenhouse gas concentration pathways taken to reach that radiative forcing are different. The figure below is reproduced from Ministry for the Environment (2023) and indicates how these different scenarios compare to one another. In the new assessment, SSP 3-7.0 was used in lieu of RCP 8.5. In 2040, these scenarios are very similar. By 2090, this is a more moderated scenario than RCP 8.5. In comparison, SSP2-4.5, used in lieu of RCP 4.5, is a slightly more pessimistic scenario in both the 2040s and 2090s. An additional difference in comparisons is that previous assessments used annual mean temperature. For the current assessment, average daily air temperature was used and it is unclear whether this is calculated differently.



Notes: SSPs = solid lines. RCPs = dashed lines. Data is sourced from Meinshausen et al. (2011) and Meinshausen et al. (2020). Figure from the full Aotearoa New Zealand Climate Change Projections guidance (2022).

The climate change prediction comparison provided should be interpreted in the context of these altered emissions scenarios. That is, the most extreme predictions are, in some cases more muted. This is, in part, because the new climate predictions are made for a more moderate emissions scenario.

Additional metrics have been provided that were not considered in previous climate change assessments. These were included in our analysis because of their potential to provide other assessed data. These were:

- Drought exposure (expressed as potential evapotranspiration deficit, PED). This differs from the number of dry days because it incorporates the interaction between rainfall and temperature, to provide an assessment of the amount of water that is available to plants.
- The number of days with very heavy rain (in the 99th percentile). This is more likely to inform an assessment of catastrophic events than the number of heavy rainfall days (>25mm).

6.2.2 Outcomes

Table 8 identifies new climate predictions for the catchment and how they compare to predictions used in previous reporting. Some aspects of climate change affecting upland wetlands are consistent with previous predictions (e.g. mean annual air temperatures), some are less dramatic (e.g. the most extreme predictions of extreme hot days have now been de-escalated), while others are increased (e.g. the reduction in the number of frost days is now expected to be greater than it was previously).

The frost prediction is of significant concern, as subzero temperatures support the persistence of snowbanks into spring/summer, ensuring a more stable supply of groundwater for wetlands. Previous reports have identified a decrease in frost/snow to be a climate change impact that is already having a medium-high impact on alpine wetlands. Frozen soils also seasonally limit the infiltration of groundwater, supporting higher water tables and more expansive wetlands (Xu *et al.*, 2024).

6.3 Impacts of climate change on upland wetlands

6.3.1 Wetland ecosystems

General impacts

Changing temperatures and precipitation patterns pose a variety of potential threats to upland wetlands, including impacts on the water level in wetlands, reduced snowbank formation and persistence, altered peat formation/decomposition rates, and increased disturbance from extreme weather events such as droughts, floods, and storms.

The most immediate potential impact is that the combination of higher drought exposure and fewer frost days (thus, less reliable water provision to wetlands in the spring from meltwater) could lead to wetlands drying out over summer. In the long term, this could lead to the progressive shrinkage and loss of wetlands. Similar impacts are predicted elsewhere, e.g. in North America, where the combination of higher summer evapotranspiration and more rapid snow/frost melt in winter are predicted to reduce wetland extinct in many regions, especially under high-emissions climate scenarios (Xu *et al.*, 2024). As wetlands are exposed to more frequent climate-change induced drought, they risk switching from a carbon sink to carbon source as organic matter decomposition increases (Salimi *et al.*, 2021). Larger wetlands store significant amounts of water, and are likely to be well buffered against seasonal droughts, especially where annual precipitation stays the same or increases. Smaller and shallower wetlands are likely to be more vulnerable to droughts. The severity of these impacts may differ between different areas of the uplands, because trends in rainfall seasonality and quantity of overall rainfall are spatially complex.

Warmer temperatures, as well as more frequent disturbances from droughts and storms, could increase the weed invasion risk for the Taiari uplands. In addition to causing vegetation disturbance, more frequent storms may also increase the amount of invasive seed dispersal from the surrounding lowlands. Wilding conifers are a particular concern here, as they are disproportionately spread by infrequent high-wind events. As an example, the invasive contorta pines in the vicinity of Loganburn Reservoir are estimated to originate from just two dispersal events — four and eight years ago, probably from a single shelterbelt (Pete Oswald, Central Otago Wilding Conifer Control Group, personal communication, 21 March, 2025). Weed invasions would have direct impacts if they spread into the wetlands themselves. However, weed invasion of the surrounding grasslands could also supress indigenous snow tussock cover and lower the water table, potentially drying out wetlands.

Heavy rainfall events are of lesser concern for upland wetlands, as wetlands are generally well buffered against these events, and help to mitigate downstream impacts. However, heavy rainfalls could cause erosion and disturbance in the surrounding grasslands. This could lower water yields, create sites for weed invasion, and lead to sedimentation in wetlands.

A combination of higher temperatures, a windier climate, and more weed growth, could also combine to increase the fire risk in the Taiari uplands. This might occur as a result of natural/unintentional fires starting more easily, but could also result from planned burns becoming more frequent and/or having a higher risk of spreading out of control. While some lowland bogs in Aotearoa/New Zealand have a natural fire regime, this is unlikely to be the case for the wetlands of the Taiari uplands. As well as the risk of direct fire damage to wetlands, increased fire would also degrade the surrounding snow tussock grasslands, reducing water runoff into wetlands and potentially facilitating weed invasion. Sedges that die back seasonally — e.g. rautahi (*Carex coriacea*) — can be highly flammable, spreading fire to other less fire-tolerant wetland vegetation.

Warmer temperatures in the uplands could also lead to increased land use pressures. Higher temperatures may allow stock to be grazed in the uplands for longer periods of time, and larger bodied stock such as cattle and deer may also be grazed at higher altitudes; trampling of wetlands by these species is more damaging compared to sheep. More intensive agriculture may also move to higher altitudes; the use of fertilisers, herbicides, pesticides, cultivation and over-sowing of exotic pasture plants, and tillage for cropping all pose potential risks to upland wetlands; these impacts are likely to be most pronounced in the 600-800 m altitude range. Finally, increasing drought exposure in the lowlands may raise demand for water abstraction from the uplands. Direct water take could lower the upland water table, while the construction/raising of irrigation dams could inundate wetlands.

Peatlands

The peat-forming processes that occur in many Taiari upland wetlands are likely to be highly vulnerable to climate change. These wetlands occur in locations where there is a net increase in the amount of undecomposed dead plant matter in a wetland — organic matter accumulation exceeds decomposition. While warmer temperatures are likely to increase decomposition, they are also likely to increase the production of organic matter; peatlands can be found across all temperature zones in Aotearoa/New Zealand. Summer drying is a greater concern to peat wetlands than temperature changes; the permanent waterlogging of bogs and fens is the key factor that keeps oxygen levels low, limiting decomposition. At the same time, biomass accumulation by wetlands species is likely to be reduced during droughts, meaning that decomposition increases at the same time that growth decreases. Similar *Sphagnum* bogs and fens from alpine regions of Australia have been identified as being highly vulnerable to climate-change driven drought and reduced snow cover (Department of the Environment, 2015).

Because drought events are likely to occur during summers, the impacts of higher temperatures may combine with those of drought events, leading to periods of significant peat loss. This means that droughts could have severe negative impacts on peatlands that would be difficult to recover from. These impacts may be most pronounced at the upper and lower altitudinal margins of peat wetlands. The top terraces of gully-head ribbon fens are fed directly by groundwater from the range tops, whereas the water supply to lower terraces is buffered by the uphill system of pools and peat dams (Rapson *et al.*, 2006). This makes it much easier for the top pool to dry out; once this occurs it is unlikely to refill even if water levels return to normal (Gillian Rapson, wetland ecologist, Massey University, personal communication, 28 March 2025). At the lower altitudinal limits of subalpine peatlands, warmer temperatures and more drought-prone summers may make it possible for peatlands to be replaced by non-peat forming vegetation such as snow tussocks or invasive weeds.

As peat dries, it also tends to shrink, and once dry can be strongly hydrophobic. This means that extreme drought or fire can make peat wetlands resistant to re-wetting. Once a peat wetland has fully dried out, the associated peat-forming processes may not restart. Dried peat soils are much more vulnerable to erosion and fire; dried peat is highly flammable and can burn for months, years, or even decades — peat fires could be catastrophic if they occurred in these wetlands. Although such extreme impacts have a low chance of occurring in the Taiari uplands, they represent an irreversible worst-case scenario that could result from especially severe drought and fire intensification under climate change.

In addition to the impacts of drought and higher temperatures on peat formation, it is also possible that heavy precipitation events may impact peat wetlands. Floods in peat wetlands could cut channels into the ground and break through peat dams, lowering the immediate water table, draining pools, and possibly arresting the growth of *Sphagnum* moss. At the same time, it is also possible that heavy precipitation could fill pools and recharge the water table in these wetlands, making them more resilient to drought events.

Table 8 – Previous and current climate impact predictions for the Taiari catchment.

Factor	Area	Goldsmith (2023)	Tonkin & Taylor Ltd (2021)	Current predictions	Difference
Temperatures: mean annual air temperature	Māniatoto basin	Historical records show average air temperature increased by about 1.5°C since 1923. Average temperature by the 2040s is predicted to increase by 0.5°C (RCP 4.5) to 1.5 °C (RCP8.5). By the 2090s the increase could be by 0.5 (RCP 4.5) to 3°C (RCP8.5).	Seasonal mean temperatures are projected to increase across the Otago region, by 0.5-1.5°C in 2040 to 1.5-3.5°C by 2090.	Average daily temperature changes are relatively uniform across all parts of the Taiari. Average temperatures are likely to increase by 1-1.5°C by the 2040s and 2-3°C by the 2090s.	Magnitude of change currently predicted is consistent with previous predictions. Previously-predicted spatial trends (indicating larger increases in average temperatures in the Māniatoto basin and uplands) are no longer predicted.
	Strath Taiari	Average temperature by the 2040s is predicted to increase by 0.5 °C (RCP 4.5) to 1.5 °C (RCP8.5). A 0.5 °C (RCP 4.5) to 2.5°C (RCP8.5) increase is expected by the 2090s.			
	Lower Taiari Plain	Records from Dunedin Airport show average temperature has increased by more than 1°C since 1960. Average temperature is predicted to increase by 0.5 (RCP 4.5) to 1.5 (RCP8.5) by the 2040s, or 0.5 to 2.5°C by the 2090s.			
	Uplands	Average temperature is predicted to increase by 0.5 (RCP 4.5) to 2 (RCP8.5) by the 2040s, or 0.5 to 3°C by the 2090s.			
Extreme hot days[1]	Māniatoto basin	At present, the Māniatoto can experience as many as four extreme hot days per year. Between two and six additional 'extreme' hot days (>30°C) are predicted by the 2040s. Between six and 30 additional extreme hot days are predicted by the 2090s.	Central Otago and inland areas are likely to experience significant increases in the number of extreme hot days. By 2040 6-10 more extreme hot days for parts of Central Otago; fewer near the coast. By 2090 30-40 more extreme hot days in parts of Central Otago. Lower increases in coastal areas (1-4 days).	The number of extreme hot days is predicted to increase by three to five days per year by 2040, although increases of up to four to 13 days may be possible around Ranfurly and Pātearoa, particularly under the high range scenario.	Predictions for 2040 are relatively consistent. However, for 2090, newer modelling indicates that the number of extreme hot days is unlikely to increase as dramatically as previously predicted.
	Strath Taiari	At present, Strath Taiari can experience as many as four extreme hot days per year. Between one and six additional extreme hot days are predicted by the 2040s. Between eight and 20 additional extreme hot days are predicted by the 2090s.		The number of extreme hot days in the Strath Taiari is predicted to increase by zero to two days per year by 2040, although increases of up to four to five days may be possible locally around Middlemarch, particularly under the high range scenario. By 2090 four to eight additional extreme hot days are expected, although the highest increases are expected around Middlemarch of around 12 additional days.	More muted changes are predicted throughout the basin, particularly in the most extreme predictions. A clearer spatial pattern has emerged with highest rises in hot days locally around Middlemarch.
	Lower Taiari Plain	At present, the Lower Taiari Plain can experience as many as four extreme hot days per year. Between one and six additional extreme hot days are predicted by the 2040s. Between two and 20 additional extreme hot days are predicted by the 2090s.		The number of extreme hot days in the lower plain is predicted to increase by between zero and two days per year by 2040, and by up to eight by the 2090s.	More muted changes are predicted, particularly in the most extreme predictions.
	Uplands	At present, the more elevated parts of the catchment (e.g., the Rock and Pillar Range and the Kakanui Mountains) experience very few extreme hot days (up to one per year). Between zero and two additional extreme hot days are predicted by the 2040s. Between one and 10 additional extreme hot days are predicted by the 2090s.		Under both scenarios, few additional hot days are predicted by 2040. By 2090, portions of the uplands may have one to two additional hot day.	Predictions are similar. The most extreme predictions are substantially muted.

[1]An extreme hot day is considered to occur when the maximum temperature is above 30°C

Factor	Area	Goldsmith (2023)	Tonkin & Taylor Ltd (2021)	Current predictions	Difference
Reduced frost days	Māniatoto basin	About 10 fewer frost days are predicted by the 2040s. Between 10 and 40 fewer frost days are predicted by the 2090s.	The number of frosts is expected to decrease across the region, with larger reductions projected for further inland areas: by 2040, 10-15 fewer frost days and by 2090, 20-40 fewer frost days per year for inland areas.	The Māniatoto basin will have 15 to 25 fewer frost days by 2040, and 25 to 40 fewer frost days are predicted by 2090.	Changes in the number of frost days are more dramatic than those previously predicted throughout the region. In particular, extreme predictions and those for the uplands have increased.
	Strath Taiari	Between five and 10 fewer frost days are predicted by the 2040s. Between 10 and 30 fewer frost days are predicted by the 2090s.		The Strath Taiari will have 15 to 20 fewer frost days by 2040, and 27 to 40 fewer frost days are predicted by 2090.	
	Lower Taiari Plain	Between one and five fewer frost days are predicted by the 2040s. Between one and 10 fewer frost days are predicted by the 2090s.		The plains will experience 11 to 15 fewer frost days by 2040, and 21 to 27 fewer frost days are predicted by 2090.	
	Uplands	About 10 fewer frost days are predicted by the 2040s. Between 10 and 40 fewer frost days are predicted by the 2090s.		The uplands will all receive fewer frost days, and reductions in frost days are greater than in the basins. For example, in the Rock and Pillar range, around 30 fewer frost days are expected by 2040. Forty-five to 60 fewer frost days are expected by 2090.	
Frequency and intensity of heavy rainfall events	Māniatoto basin	Mean annual rainfall will stay relatively stable through the 2040s (<5% change). By the 2090s, more rainfall may occur (5-15%). Patterns of rainfall will change: high flow events may be larger and occur more frequently. Extreme and highly disruptive flood events may also occur more often. The number of heavy rainfall days may increase by up to one additional day in some parts by the 2040s, and one additional day throughout the basin is likely by the 2090s.	Annual rainfall is expected to increase across Otago: by 2040, a 0-10% annual increase. By 2090, increases of 10-20% are predicted for the majority of Otago with smallest increases expected near Ranfurly of 0-5%. Extreme, rare rainfall events are likely to increase in intensity in Otago, by 2040 an 8% higher likelihood of an extreme rainfall event is predicted, and by 2090 35% higher. In general, Otago is projected to experience an increase in Mean Annual Flood (MAF) by up to 50-100% in some places by 2040, and a >20% increase across the whole region by 2090.	More rainfall is expected, although predictions vary throughout the basin. By 2040, 0-5% more rainfall is expected around Ranfurly and Paerau, while Naseby and the Kakanui range may have up to 5% less precipitation locally. By 2090, up to 15% more rainfall is expected in the south and up to 7% less in the north. The number of very rainy days is expected to rise a little throughout the basin, with up to one extra day in by 2090 in the highest change scenario. The number of days with extremely heavy rainfall (the 99th percentile) will rise more dramatically: by up to 13% by 2040 and 18% by 2090 particularly in the south of the catchment.	Predictions are similar, although more spatial pattern has been predicted, with some areas receiving less, rather than more rainfall. A new metric for predicting extreme rainfall events indicates that these will increase.
	Strath Taiari	Mean annual rainfall will stay relatively stable through the 2040s (<5% change). By the 2090s, more rain may occur (5-10%). Patterns of rainfall will change: high flow events may be larger and occur more frequently. Extreme and highly disruptive flood events may also occur more often. The number of heavy rainfall days may increase by up to one additional day in some parts of the Strath Taiari by the 2040s, and one additional day throughout the basin is likely by the 2090s.		The total precipitation in the Strath Taiari will not change substantially by 2040, with parts of the catchment receiving -0.7% to +4%. More rainfall is predicted throughout the area, with up to 8% more rainfall. The number of very rainy days is not expected to change substantially (less than 1 day of change predicted across all four predictions). The number of days with very heavy rain (in the 99th percentile) is predicted to change, by up to 15% more in 2090.	Short-term predictions are similar, however long-term predictions indicate more rain. A new metric for predicting extreme rainfall events indicates that these will increase.
	Lower Taiari Plain	Average rainfall and rainfall intensity (storms) have increased since about 1950. Mean annual rainfall will stay relatively stable through the 2040s (<5% change). By the 2090s, more rain may occur (5-20%). Patterns of rainfall will change: high flow events may be larger and occur more frequently. Extreme and highly disruptive flood events may also occur more often. The number of heavy rainfall days will not change substantially by the 2040s, although one to five additional days are likely in some parts of the lower Taiari plain by the 2090s. High flows will continue to have an impact on the Lower Taiari Plain.		Overall precipitation, or the number of very rainy days in the lower plains are not expected to change substantially in any prediction. The number of days with very heavy rain (in the 99th percentile) are not predicted to change substantially, except in the most severe scenario by 2090, where an increase of around 8% is expected.	Predictions for the lower Taiari Plain are more muted than previous predictions, although the incidence of extreme rainfall events is predicted to increase.

Factor	Area	Goldsmith (2023)	Tonkin & Taylor Ltd (2021)	Current predictions	Difference
	Uplands	Mean annual rainfall will stay relatively stable through the 2040s (<5% change). By the 2090s, more rain may occur (5-15%). Patterns of rainfall will change, though not as dramatically as in the basins. The number of heavy rainfall days will not change substantially by the 2040s, although one to two additional days are likely by the 2090s.		The uplands will generally have a modest amount more annual rainfall, with between 0-5% more rain by 2040, and up to 10% more precipitation by 2090. Naseby and the highlands around it may have up to 5% less precipitation locally. The number of very rainy days is not expected to change substantially, increasing by up to 1 more by 2090, except around Naseby and the Kakanui range. The number of days with very heavy rain (in the 99th percentile) are predicted to increase, with the most dramatic changes in the uplands around Paerau, which may have 20% more of these days.	Predictions are similar, although more spatial pattern has been predicted, with some areas receiving less, rather than more rainfall. A new metric for predicting extreme rainfall events indicates that these will increase.
Frequency and intensity of droughts	Māniatoto basin	Ranfurly, which is already very dry (with up to 275 dry days per year) may experience an additional four dry days per year by 2040, and Naseby may experience an additional six days by 2090. In the upper catchment (upstream of Paerau, and across Pātearoa/Rock and Pillar Range), an additional two to 10 dry days may be experienced by 2090. There will be less water in tributary streams during extended dry periods, particularly those draining from the Kakanui Mountains.	The number of dry days Is likely to decrease in parts of Central Otago, with the remaining parts experiencing increases. Seasonally fewer winter dry days for western Otago and more summer dry days for western and inland parts of Otago. By 2040, decreases in annual dry days (one to four fewer) are projected for coastal and some central parts of Otago, with increases of two to eight dry days per year for many remaining parts of Otago. By 2090, decreases in annual dry days of two to six days are projected for coastal and some central parts of Otago, with increases of two to ten more dry days per year for many remaining parts of Otago.	Much of the Māniatoto basin will have between zero and one extra dry day by 2040, although the Kakanui Ranges are likely to have four fewer dry days. By 2090, there may be fewer dry days (by up to two) in the basin, while the Kakanui ranges may experience up to seven additional dry days. Drought exposure is expected to increase throughout the basin across all climate change predictions. The greatest increases are predicted in the Kakanui ranges (up to 125mm more by 2040 and up to 185 by 2090). Increases around Pātearoa are weaker, with 30-50 mm more by 2040 and by between 50-70 mm by 2090.	Predictions in rainfall have become more muted in the newer predictions in the basin itself, although spatial patterns remain consistent. Drought exposure contextualises these mixed rainfall effects and shows that drought pressure is nevertheless likely to increase.
	Strath Taiari	Most of the Strath Taiari basin also receives about 275 dry days per year. Fewer dry days are likely on the eastern side of the basin (one to two less) with more dry days further west (one to two more) by 2040. By 2090 the west-east trend in change will be retained, however local changes will become more dramatic with six fewer dry days in some parts of the catchment and up to six days more in others.		The number of dry days in the Strath Taiari is likely to remain relatively constant into 2040 (+/- one day). By 2090, an increase in the number of dry days is expected throughout this area, by up to three additional dry days. Drought exposure is expected to increase throughout the basin across all climate change predictions: 30-85mm by 2040, and 45-125mm by 2090. Drought exposure increases are expected to be particularly high in the eastern side.	Predictions of changes in the number of dry days are slightly more muted compared to previous predictions. Previous predictions of decreasing dry days in the eastern part of the basin are no longer clearly predicted. Incorporating drought exposure adds to the picture, indicating that overall water stress will be higher throughout the area.
	Lower Taiari Plain	This area currently receives between 225 and 250 dry days each year. The lower Taiari plain will experience fewer dry days. By the 2040s, zero to four fewer dry days are expected. By 2090, this may be as high as six fewer dry days.		By 2040, an additional zero to two dry days are predicted, by 2090 this rises to between zero and four additional dry days. Drought exposure increases in all scenarios: by 2040 27-70 mm, by 2090 increases of 35-95mm are expected.	Predictions of changes in the number of dry days are slightly more muted compared to previous predictions. Drought exposure supports a modest increase in drought pressure in the lower plains.
	Uplands	The uplands will have more dry days, particularly for highlands that are further west. By 2040 four more dry days are likely in many parts of the highlands. By the 2090s, this trend will be more pronounced. In particular, the Rock and Pillar Range may experience up to 10 additional dry days. The Lammerlaw ranges may have fewer dry days, particularly in the East.		By 2040, zero to two more dry days are expected, although the Lammerlaw ranges may have very weak increases or decreases in dry days, and the Kakanui Ranges are likely to have four fewer dry days. By 2090, all upland areas are predicted to have some increase in the number of dry days, although this varies by range, with up to five additional dry days in the Rock and Pillar range, seven in the Lammerlaw ranges, and the upper Kakanui ranges experiencing up to ten additional dry days. Drought exposure is predicted to increase in all upland areas, by about 35-70 mm by 2040 and 45-125mm by 2090, with the exception of the upper Kakanui ranges which are to experience harsher drought conditions under all scenarios.	The magnitude of the trend predicted remains similar. However, some of the spatial trends that were previously predicted are no longer as pronounced. Instead, increasing drought conditions are expected throughout all upland areas.

<table>
<tr><th>Factor</th><th>Area</th><th>Goldsmith (2023)</th><th>Tonkin & Taylor Ltd (2021)</th><th>Current predictions</th><th>Difference</th></tr>
<tr><td rowspan="4">Increased seasonality of rainfall.</td><td>Māniatoto basin</td><td rowspan="4">Seasonality was not directly assessed. Some general comments were made throughout this report:
Inland areas will have greater seasonality of rainfall
Upland areas are likely to experience greater seasonality (i.e., higher rainfall in winter and lower in summer)
Decreased snow and ice cover leading to water deficits
However, it is not entirely clear which part of the dataset they were relying upon and are therefore not readily comparable. Inland wetlands are considered to be at risk from increasing seasonality of rainfall.</td><td rowspan="4">In Otago, winter and spring are expected to be wetter, but with significant decreases in seasonal snow likely. The seasonality of climate in the Otago region is expected to become more pronounced, with larger seasonal differences through much of the region. Seasonally fewer winter dry days for western Otago and more summer dry days for western and inland parts of Otago.</td><td>The Māniatoto basin is unlikely to experience increased seasonality of rainfall: predicted rainfall changes are relatively similar across all scenarios. Summer rainfall increases in the basin in all climate scenarios (2040: 5-12%; 2090 7– 20%). Spring rain is likely to stay stable until 2040 (0-5%, however spring rainfall is likely to increase by 2090(5-12%). Autumn rain will increase by 2040 (1-5%) and 2090 (7- 15%). Winter rainfall will also increase by 2040 (2-15%) and by 2090 (10-20%). The exception to these trends is the Kakanui ranges, which are predicted to be drier under all climate scenarios.</td><td rowspan="4">Previous predictions of increasing seasonality of rainfall are not supported by the most recent modelling. Precipitation seasonality is likely to increase in some areas of the catchment but the effect is highly variable.</td></tr>
<tr><td>Strath Taiari</td><td>The Strath Taiari may see some altered precipitation seasonality: The spring may be drier, especially in the short term (2-8% by 2040 and by 0- 2% by 2090). In contrast, all remaining seasons are predicted to be wetter. In particular, summer rainfall is predicted to increase by up to 10% (by 2090).</td></tr>
<tr><td>Lower Taiari Plain</td><td>The lower plains are likely to experience some changes in seasonal rainfall, however trends are not clear or consistent among predictions. For example, winters may be wetter by 2040 (by 1.5-7% by 2040, and may be wetter or drier by 2090 (-3% to +6%).</td></tr>
<tr><td>Uplands</td><td>Seasonal predictions are relatively inconsistent. For example, the Lammerlaw ranges may be drier or wetter in winter, depending on the emissions scenario selected, although they are likely to be drier in summer. In contrast, the Rock and Pillar ranges are likely to receive increased rainfall, and Kakanui ranges decreased rainfall, throughout all seasons in all predictions.</td></tr>
</table>

Ephemeral wetlands

Ephemeral wetlands in Aotearoa/New Zealand form primarily in areas where there are strong seasonal differences in rainfall (Johnson & Rogers, 2003). Changing rainfall patterns and faster rates of evaporation are likely to alter the ponding regime in these wetlands, with longer dry periods over summer and greater variability between years. In some cases, permanently ponded tarns and other small water bodies may transition to ephemeral wetlands due to greater summer evaporation and more seasonal water provision. Ephemeral wetland vegetation is naturally tolerant of drought, inundation, and interannual rainfall variability, so may not experience significant climate impacts over the short-medium term (William Lee, personal communication, 19 March, 2025). In addition, there are thousands of ephemeral wetlands in the Taiari uplands. Many ephemeral wetland species are highly dispersive, making it possible for populations to persist and repopulate despite unfavourable conditions at individual wetlands. Over longer time spans, changes to the rainfall/evaporation balance across many years could still impact these systems, and the high threat classification of many ephemeral wetland species means that any change to these ecosystems is of concern.

Snowbanks and subalpine seepages

Snowbanks vegetation — as well as the seepages that form below snowbanks — are likely to suffer significant impacts from climate change, with the substantially reduced number of frost days causing more rapid melting of snowbanks. Being at higher altitudes, these ecosystems may be less threatened by weed invasion, however warmer temperatures and reduced snow/frost may cause them to be replaced by snow tussock grassland, particularly at their lower altitudinal limit.

6.3.2 Flora

Under climate change, alpine and sub-alpine flora can experience altitudinal range shift where they are pushed up to higher elevations as temperatures increase, being outcompeted at lower elevations by lowland plants that are also moving upwards. There can be long delays between increased temperatures and invasion by lowland plants; when these invasions do happen, they may be facilitated by disturbance events or other stressors e.g. drought (Schuchardt *et al.*, 2023). Alpine and nival (snow-dependent) plants can lose out during range shifts, as they are outcompeted at lower altitudes faster than they can move up to higher altitudes; these impacts can be particularly severe for plants that are already threatened (Geppert *et al.*, 2023; Rumpf *et al.*, 2018). Typically, mountains get narrower towards the top, and high-alpine specialist species' ranges can get smaller and more fragmented as they move up in altitude, or can be lost entirely through warming temperatures. Many of the Taiari mountain ranges have an uncharacteristic geomorphology: broad, flat or undulating, subalpine tops, with no higher alpine habitat above this. This means that the impacts of altitudinal shifts on flora may be very abrupt, as large areas of upland wetland are present in gullies and depressions just below the undulating tops, and have no higher altitudes to shift up to. It is worth highlighting that ecosystems of the Taiari uplands are historically dynamic, having undergone very significant changes associated with the ice-age glaciation cycles. Range shifts driven by changing temperatures are not an unprecedented occurrence in these ecosystems. However, the pace of warming under climate change is likely to be much faster than previous warming/cooling periods associated with glacial cycles, and climate change impacts are likely to be exacerbated by interactions with other stressors, such as plant invasion and land use change.

Flora associated with snowbanks, cushion bogs, and snowmelt-derived seepages are likely to be especially vulnerable to climate change, as these ecosystems are already restricted to the higher altitudes of the Taiari uplands. Snowbank plants are especially threatened due to the large decreases in frost days predicted under current climate models. Snowbanks provide shelter from wind-chill, frost-heave, and solar radiation, allowing unique plant communities to occur that could be extirpated if snowbanks do not persist long enough through the year.

Obligate wetland plants are also likely to be more strongly impacted by greater drought exposure, compared to facultative wetland plants that have some ability to persist in drier conditions. Notably, plant species that are most likely to be impacted are therefore specialists, a greater proportion of which are already threatened. Higher temperatures themselves are not necessarily a problem for most alpine plants, so long as the water table remains high and invasive plants are kept out. Plants that specialise in acidic/nutrient-poor organic substrates are also of concern, due to the variety of ways in which climate change could degrade peat wetlands, and the potentially irreversible nature of such degradation.

6.3.3 Freshwater fauna

The main impact of climate change on the fauna-supporting freshwater environments of Taiari upland wetlands is an increased likelihood of extreme conditions (droughts and floods) and a corresponding reduction in the stability of water levels.

More frequent summer droughts could seasonally reduce surface water in the wetland areas, decreasing the area of freshwater habitat such as streams and pools. Aquatic habitat that does not dry out will be impacted by increased temperatures, reducing the overall habitat quality and carrying capacity of the wetland aquatic environment. While many species of freshwater fauna in the Taiari uplands have some drought tolerance, increased frequency and duration of droughts will likely increase stress on local populations. Extreme droughts could lead to local population extinctions where the freshwater habitat becomes unable to support aquatic fauna. Cold-water invertebrate species are particularly vulnerable to higher temperatures. Climate-change driven changes to aquatic and riparian plant species assemblages may also result in altered physical conditions in aquatic environments and indirectly affect fauna. However, this effect is likely to vary spatially.

Freshwater fauna in the Taiari uplands display fragmented populations (e.g. non-migratory galaxiids) and high levels of endemism (e.g. some species of aquatic invertebrates). This means that once a population is locally extinct, it may not be able to be repopulated without human intervention, or it could be entirely lost (Closs *et al.*, 2024).

The trout-free status of the Taiari River upstream of Canadian Flats and other small headwater streams is of importance for populations of non-migratory galaxiids in the Taiari catchment (Jones & Closs, 2015). Specifically, the Nationally Endangered Eldon's and dusky galaxiids cannot coexist with trout; most of their populations are located upstream of barriers that prevent trout migration (Jones & Closs 2015). Large flood events could provide opportunities for trout incursions upstream of barriers, which would greatly impact the long-term survival of the local non-migratory fish population. Increased levels of drought may prevent colonisation of trout in some of these areas, but this will also reduce the habitat quality for local galaxiids, and will be of little importance if droughts wipe out entire galaxiid populations.

6.3.4 Invertebrates

The main impacts of climate change on invertebrates are likely to be due to habitat loss and increased incursions of invasive plant and animal species. The combination of climate and vegetation currently present in the Taiari catchment provides vulnerable habitat that is easily impacted or destroyed by fire, floods, and other effects of climate change. Changes in the vegetation of wetlands, as driven by climate change may also indirectly impact invertebrates by changing habitats and resources available to species.

Adult moths, flies, and beetles are usually resilient to fluctuations in temperature and moisture due to adaptations such as a hard exoskeleton, or behaviours such as seeking shade. However, their larvae are usually soft-bodied and flightless, and therefore less resilient to climatic fluctuations. Other soft-bodied invertebrates include molluscs such as leaf-veined slugs (Athoracophoridae), earthworms, spiders, and soil organisms such as centipedes and land shrimp (Amphipoda). Climate change is likely to reduce the amount of available habitat for these taxa as their internal temperature and desiccation resistance depend upon local environmental conditions (Nicolai & Ansart, 2017). Warmer temperatures, drought and flooding are likely to be particularly detrimental to soft-bodied invertebrates that are not adapted to such extremes. If extreme hot days are only occasional, heat-sensitive taxa such as slugs and snails are usually able to seek shelter and survive for a short while until temperatures return to normal. Increasing the number of hot days will reduce the ability of these taxa to survive (Nicolai & Ansart, 2017).

Locally-adapted invertebrates will likely suffer from the warmer temperatures leading to fewer frost days and snow cover reduction, as well as the increased pest invasion. These species will suffer from increased competition with species that have not adapted to harsh cold weather.

Alpine species typically move to higher altitudes in response to warming temperatures (Chinn & and Chinn, 2020). Over time, climate change may result in reduced habitat availability for alpine species (Bertoia, 2023) including those in wetland habitats. As discussed above, the opportunities for uphill migration are very limited in the Taiari uplands, due to their morphology. Therefore, impacts of climate change on invertebrate species are likely to result in abrupt responses. Introduced predators are likely to expand their ranges with warmer weather, threatening invertebrates in areas they expand into (Bertoia, 2023). Further, invasive mammalian predators, such as stoats, rats, and possums, are also increasing in density at higher elevations, where milder winters allow them to thrive (O'Donnell *et al.*, 2024). This increased predation pressure will put further pressure on invertebrate populations, with rodents being particularly problematic predators of invertebrates.

While inferences can be made based on invertebrate biology and research, the impacts of climate change on invertebrates are often difficult to predict. The huge variation in life histories and ecological niches occupied by invertebrates means that different groups of invertebrates will be impacted in different ways. Invertebrates also depend heavily on plants as sources of food and shelter, and are impacted by invasive species in many different ways, so that indirect impacts can be unpredictable and severe.

6.3.5 Avifauna

Climate change is impacting Aotearoa/New Zealand's alpine and above treeline ecosystems, with significant consequences for indigenous bird species. Warmer temperatures can lead to a gradual upward shift of vegetation zones, which reduces the extent of open alpine habitats. Due to milder conditions, species adapted to sub-alpine and alpine zones can lose key habitat as lower-elevation vegetation types expand into higher elevation zones. This upward vegetative expansion can affect avifauna by altering upland wetlands themselves, as well as associated terrestrial habitat that is used by wetland-dependant avifauna.

The reduction in snow cover, along with increasingly dry, warmer summers, together with changing vegetation patterns, can have significant effects on the hydrology of alpine areas. This can lead to the shrinking and loss of wetlands and tarns, which are critical habitats for breeding and foraging for some bird species, such as pūteketeke/Australasian crested grebe (*Podiceps cristatus australis* Threatened – Nationally Vulnerable) that can breed on subalpine and alpine lakes and mātātā/South Island fernbird (*Poodytes punctata punctata* At Risk – Declining) (Heather and Robertson 2025). As wetlands become increasingly dry, these breeding sites become scarcer, with reduced habitat and fewer foraging sources. Temporal changes in snow patterns may also disrupt seasonal cues for breeding, feeding and migration (Inouye *et al.*, 2000; Niffenegger *et al.*, 2023, 2025), which are often intimately linked to the historically predictable alpine climate cycles in higher-elevation species. These altered behavioural patterns may be additionally problematic if avifauna food requirements come to be out of sync with important seasonal food sources, which may respond to different cues.

Warmer temperatures will allow bird species that were historically associated with lower altitudes to expand their ranges into higher elevational zones. Although exotic birds are not classed as invasive, they outcompete many indigenous bird species for food and nesting sites (Weinhaupl and Devenish-Nelson 2024). This can put competitive pressure on higher-elevation species that are not as behaviourally or physiologically flexible. Furthermore, the expansion of exotic bird species can introduce avian pathogens, increasing the risk of disease spread amongst indigenous birds as their ranges overlap (Derraik *et al.*, 2008; Jackson *et al.*, 2014).

Avifauna, like invertebrates, will be affected by the increasing abundance of predators at higher elevations. This shift presents a significant increase in threat to indigenous birds that evolved in limited predator environment, which face increased predation risks under a warming climate.

6.3.6 Lizards

While impacts to wetlands may be less pronounced for lizards, which generally use more marginal areas of wetlands in comparison to invertebrates or freshwater fauna, lizards are likely to still be impacted by some effects of climate change in the Taiari uplands. The main impacts of climate change on lizards in upland wetland areas are considered likely to be habitat loss and degradation, such as through a higher incidence of fire events, and increased predation by introduced mammals, though the overall impacts on lizard populations are likely to be complex and unpredictable. Fire and increased predation are listed as key reasons in the New Zealand Threat Classification System (NZTCS) database assessment notes for the majority of lizard species that have the ‘Climate Impact (CI)’ threat status qualifier (Hitchmough *et al*. 2021; NZTCS database 2025: https://nztcs.org.nz/).

Increased temperatures and droughts may lead to a reduction in the extent of high-quality habitat for lizards that are often found in damper areas of tussockland and around wetlands, such as Otago green skink and herbfield skink, if these habitats become drier. A potential increase in fire events and fire intensity associated with increased temperatures and droughts in surrounding areas of narrow-leaved snow tussock would also likely be highly detrimental to lizard populations. Fire can cause direct mortality and injury to lizards as well as a severe reduction in habitat quality from the loss of protective ground cover vegetation.

An increase in the ranges and activity patterns of introduced mammalian predators is likely to also be a key impact of climate change on lizards, leading to a reduction in lizard populations due to increased predation pressure.

Increased grazing of upland areas as a result of warmer temperatures in the uplands is likely to detrimentally affect lizards. The habitat quality of surrounding areas of tussockland would be reduced through trampling and direct grazing of ground cover vegetation utilised by lizards. This will reduce or remove lizard refuges, leading to reduced population density or local extirpation.

Overall changes in vegetation composition and invertebrate populations from the effects of climate change may also have indirect effects on lizards. Lizards depend on complex, dense ground cover vegetation to provide refuges, and invertebrates, as well as plant species which produce berries, as food resources. Therefore, changes such as the increased spread of weeds which do not provide appropriate refuges or support equivalent invertebrate populations are likely to lower the carrying capacity of the habitat for lizards.

Table 9 – Predicted risk levels for a variety of direct and indirect climate impacts on Taiari upland wetland flora and fauna.

Effects	Avifauna	Flora	Freshwater Fauna	Invertebrates	Lizards
Direct Effects					
Higher average temperatures	Medium	Medium	High	Medium	Medium
More frequent extreme hot days	High	Low	High	Medium	Medium
Increased drought exposure	High	Medium	High	High	Medium
Locally reduced rainfall	Medium	Medium	Medium	Medium	Low
More frequent very heavy rainfall events	Medium	Low	High	Medium	Low
Fewer frost days, reduction in seasonal snow cover	Medium	High	Medium	Medium	Low
Indirect Effects					
Summer drying of wetlands	High	High	High	High	Medium
Gradual shrinkage of wetlands	High	Medium	Medium	High	Medium
Cessation of peat accumulation/increased peat decomposition	Low	Medium	Low	Medium	Low
Increased summer drying of ephemeral wetlands	High	Low	Low	Low	Low
Expansion of non-alpine specialists and weed invasion	High	High	Low	High	High
Expansion of lowland fauna	High (predatory mammals)	Low	Low	High (predatory mammals, other invertebrates)	Low (other lizards), High (predatory mammals)
Storm/flood erosion in wetlands and surrounding grasslands	High	Medium	Medium	Medium	Low
Increased fire risk	Medium	Medium	Medium	Medium	High
Increased agricultural pressures (grazing and water abstraction)	High	Medium	Medium	Medium	High (grazing), Low (water abstraction)

6.3.7 Climate impacts on land and resource use

Alongside the impacts of climate change on ecology, there are also likely to be economic and social shifts as a result of climate change that in turn impact ecology. Summer water availability is already a key limiting resource for agriculture in the Māniatoto and Strath-Taiari regions, and is likely to increase as a result of higher drought pressure under climate change. Competition over water will interact with an ongoing trend of increasing intensification in Aotearoa/New Zealand agriculture, as well as potentially increased pressure for farmers to reduce GHG emissions. It is likely that agricultural resources in the Māniatoto and Strath-Taiari will be increasingly focused on high-productivity irrigated agriculture in the lowland basins, with the possibility of long-term diversification in the hill country and uplands as current sheep-beef farming becomes less economically viable. This may reduce grazing and burning pressure on upland tussock grasslands, however it could also increase demand for water abstraction from the uplands.

6.3.8 Limitations

The potential climate change impacts discussed here are not likely to all occur together, and the combined outcome of the various impacts is very difficult to the predict. For example, it is plausible that more frequent heavy rain events will recharge groundwater in wetlands, allowing them to persist through hotter summer without shrinking; alternatively, heavy rainfall events could cut flood erosion channels into wetlands, lowering the water table and making them more vulnerable to subsequent droughts. Wetlands can respond in unique and idiosyncratic ways to external impacts, depending on localised differences in hydrology, topography, species assemblages, and the impacts of extreme disturbances (García-Alix *et al.*, 2017; Walker *et al.*, 2001). Making quantitative predictions about the overall outcome of the various climatic impacts discussed in this report would require modelling the environmental conditions of these ecosystems/species, in order to project how they would be likely to change under a warming climate. There is likely to be significant variation in climate change impacts across the Taiari uplands, as there is spatial variation in climate change impacts throughout the catchment, as well as variation in the sizes and depths of different wetlands.

7.0 Potential Management Actions

The goal of the management actions considered below is to improve the climate resilience of the Taiari upland wetlands by reducing the non-climatic stressors that these wetlands face, and by improving the volume and stability of groundwater in the uplands. Ecosystem resilience is defined as the capacity for an ecosystem to recover from disturbance and return to a pre-disturbance state, rather than becoming irreversibly altered. Resilient ecosystems may change with new environmental conditions, but maintain their structure (the species they can support) and function (how they work). Ecosystem resilience is not an easily measurable quality, it can only be assessed by observing how an ecosystem responds to a disturbance. In the context of the Taiari upland wetlands, a loss of resilience could include:

- Loss of, or substantial alteration to, wetland hydrology.
- Establishment of non-wetland plants, particularly infestation by woody weeds.
- Decomposition or erosion of peat substrate.
- Loss of characteristic flora and fauna species.

The ability of upland wetlands to absorb climate impacts will be undermined by other stressors, such as the threats described in section 5.0. By managing these threats, it becomes less likely that climate impacts will irreversibly alter upland wetlands. It also is worth noting that, regardless of the threat posed by climate change pressures, there is significant value in the improved management and ecological condition of the Taiari upland areas, due to the important ecosystem services and unique biodiversity values that these area support.

7.1 Direct actions

The following actions can be undertaken within public conservation land managed by DOC, and aim to either directly manage threats to the upland wetlands, or else mitigate the impacts of climate change on these wetlands.

7.1.1 Woody weed control

For the purposes of improving the resilience of Taiari upland wetlands to climate change impacts, management of woody weeds could include:

- Monitoring and ongoing control of wilding conifer spread in the Taiari uplands.
- Proactive removal of seed sources of wilding conifers.
- Surveying, monitoring, and proactive removal of species that could disperse into the uplands under climate change (potential future weeds).

A comprehensive and forward-looking woody weed control plan could avoid a number of negative ecological and social outcomes:

- Negative impacts on the upland water table as a result of water table as snow-tussock grassland is replaced by exotic species, leading to wetlands shrinking and becoming degraded.
- Loss of other ecological values associated with indigenous alpine and subalpine tussock grasslands (e.g. unique flora and fauna).
- The dispersal of new weeds into the uplands that are able to directly invade wetlands, e.g. willow.
- Loss of aesthetic and recreational values associated with open high-country tussock landscapes.
- Increased weed control costs for farmers, or else reduced agricultural productivity if weeds are not controlled.
- Increased risk of dangerous wildfires.

Alongside these benefits, there are some potential downsides to woody weed control:

- There may be some loss of agricultural productivity or cost to landowners associated with the removal or replacement of weedy shelterbelts.
- There may be some opposition to the use of spraying and drill-and-fill methods to control woody weeds, especially where dead vegetation is left standing.

Highest priority in a weed control plan should be given to proactive control of woody weeds in the Taiari uplands. Once reproducing populations of weedy species become established in the uplands, management will become significantly more difficult and costly. Currently, wilding conifer spread occurs through large, infrequent dispersal events from the lowlands, arriving in somewhat predictable locations dictated by wind direction and topography. If reproductive-aged populations establish within the uplands, further dispersal would occur more rapidly, with the potential to go in every direction — especially on flat-topped ranges such as the Te Papanui/Lammerlaw-Lammermoor, and Rock and Pillar.

The weed control plan should include surveys to ensure that no sources of potential spread are allowed to get substantially out of control. A notable site that may require monitoring under a warmer climate is a plantation of Douglas fir surrounded by a buffer of ponderosa pine (*Pinus ponderosa*) in the northern Te Papanui/Lammermoor range, 4km west of Loganburn reservoir (Pete Oswald, personal communication, 21 March, 2025). Other locations of possible future spread in the 600-800 m zone include Douglas fir plantations in the upper reaches of the Waipori catchment, conifer plantations around Naseby, and willow infestations along streams just below 600 m altitude to the south and west of Paerau in the Māniatoto. Note that this is not a comprehensive list of places to monitor, there are likely to be many more examples of specific sites that may become problematic under climate change.

Woody weed control would be most effective if undertaken in a holistic and coordinated manner across the whole landscape. It may be simplest for DOC to focus first on controlling woody weeds within PCL, however this will be of little long-term benefit if woody weed infestations persist on adjacent private land. Working with the wider community will be especially important in the proactive removal of lowland seed sources. Shelter belts are a necessity for livestock wellbeing in the lowlands of the Māniatoto and Strath-Taiari, it will take time for new shelter belts of non-spreading species to grow. It might be prudent to initially target only the most high-risk lowland seed sources, using local knowledge to identify sites for replacement.

7.1.2 Invasive herbivore control

Similar to the control of woody weeds, effective control of invasive herbivores would avoid a number of negative impacts:

- Direct degradation of upland wetland vegetation and soil through browsing and trampling.
- Reduced groundwater provision as a result of browser-driven degradation of snow tussock grasslands.
- Costs to farmers to control feral browsers, and lost productivity where they are not controlled.

We recommend the following prioritisation:

- ***Feral pigs*** should be the highest priority for control, as they as their rooting can cause substantial soil and vegetation damage to upland wetlands. They can also predate newborn lambs and act as secondary vectors for bovine tuberculosis, meaning that their control is also a key priority for farmers.
- ***Deer*** are the next highest priority, as they are large-bodied ungulates which can cause trampling damage to wetlands.
- ***Goats*** are the next priority, they are less likely to damage wetlands, but can still contribute to the degradation of upland vegetation.

- ***Hares and rabbits*** are a lower priority as they do not cause trampling damage, and do not occur in high numbers where there is dense indigenous vegetation or in very wet areas, however in degraded landscapes their numbers can be high, suppressing regeneration of native plants. Targeted control of hares and rabbits may be useful to facilitate the restoration of snow tussock cover in certain situations.
- ***Geese*** are the lowest priority, although their control may still have benefits in preventing aquatic weed spread into upland wetlands and water bodies as well as reducing nutrient input into wetlands. Although the control of geese, hares, and rabbits is a lower ecological priority, there may be more social license for culling these species as they are not targeted by hunters.

It may also be prudent to monitor for other herbivores that could disperse into the Taiari uplands. Himalayan tahr (*Hemitragus jemlahicus*) and chamois (*Rupicapra rupicapra*) are currently absent from the Taiari catchment, however these species are present the Hawkdun and St Marys ranges which are adjacent to the Taiari catchment. Bennet's wallabies (*Notamacropus rufogriseus*) have also been recorded spreading into the Taiari catchment from South Canterbury, where they have been recorded at over 1000 m altitude in the Hunter Hills.

A potential downside of controlling feral browsers is the loss of hunting opportunities for the local community if feral herbivore numbers are brought down.

7.1.3 Invasive predator control

Invasive predators such as rodents, mustelids, and possums are potential threats to many of the fauna found in upland wetlands and are likely to increase in density at high elevations as the climate warms. Rodents and possums can browse indigenous plants, with the former also acting as seed predators. Controlling these species would help to ensure the persistence of these flora and fauna that are vulnerable to these predatory species. These predators do not impact the structure and function of upland wetlands (and surrounding grasslands) in the same way that invasive weeds and large-bodied browsers do; however, indigenous upland fauna (e.g., insects, skinks, birds) are likely to support certain ecosystem functions such as pollination, seed dispersal, and nutrient-cycling that maintain healthy vegetation structure in the wetlands. Predator control may be more useful as a targeted action that can be undertaken as-necessary to protect populations of vulnerable or functionally important upland species. Possums also act as a disease vector, meaning there are wider social benefits to controlling their numbers. The importance of this action should also be reassessed in the future as predator densities increase under climate change.

7.1.4 Direct protection and restoration of wetlands

Protection and/or restoration of individual wetlands through fencing, weed/pest control, and replanting of indigenous vegetation would improve the biodiversity values and ecosystems processes of individual degraded wetlands. Wetlands in the 600-800 m upland zone are better candidates for this, as grazing and weed pressures are higher in this zone. At higher altitudes this management action is likely to be of limited use, as most of the wetlands have intact indigenous vegetation cover. Fencing close to the wetland itself also does little to improve the underlying water table, although the removal of pugging or rooting animals from wetlands can nevertheless have a substantial positive impact on its flora. Alpine and subalpine wetland plants are typically small-statured and slow growing, making replanting an impractical option even where degradation has occurred at higher altitudes. The high number of wetlands present in the Taiari uplands means that many would need to be protected or restored for this action to improve overall climate resilience. However, the protection and restoration of specific high-value wetlands could be important to preserve the most important sites, and to ensure that vulnerable species are able to persist in the landscape. It may be most beneficial to focus on maintaining a few intensively protected areas. Wetland habitats of moderate value would also benefit from fencing in situations where stock trampling or pig rooting is evident.

Due to the important ecosystem services that they provide, the largest and most high-value peat wetlands could also be targets for strategic nature-based solutions, to increase their resilience to drought, flood and storm events. This could involve enhancing the water retention of peatlands, stabilising peat dams, and repairing damage from floods. However, it has been demonstrated in many ecosystem types that protection of remaining value is more likely to result in biodiversity benefits than positive interventions. For these reasons, prioritising the protection of value is centred in large international and national frameworks, including the Resource Management Act (RMA).

Where restoration may also be valuable is in building community knowledge and appreciation of the upland wetlands. There are already a number of initiatives involved in wetland/riparian restoration in the Taiari lowlands. This could be particularly beneficial in the future, where climate change impacts may increase the number of upland wetlands in need of restoration. Currently, restoration of wetlands and riparian habitats below 600 m elevation is likely to be more cost effective and have greater ecological benefits.

7.1.5 Alpine species translocations

One potential action that may help to avert climate change impacts on ecological values is to develop plans for the translocation of alpine species to suitable locations elsewhere. While this action does not improve the climate resilience of upland wetlands, it aims to ensure that populations of alpine flora and fauna are able to persist elsewhere if suitable habitat is lost. Many species of the Taiari uplands are not obligate alpine specialists, and are likely to be able to persist under warmer climate so long as other ecosystem threats are managed appropriately. Only species that are very rare (e.g. Nationally Critical) and highly specialised should be considered for translocation. Further, translocated individuals should only be moved to areas that are targeted with other restoration efforts, such as stock fencing. Species translocations can involve a substantial amount of work and planning, and would require suitable translocation sites to be identified that would not face the same climate pressures. Given that only specialised species would be considered, and climate impacts would occur throughout Aotearoa/New Zealand’s alpine zone, it could be hard to find suitable translocation sites.

7.2 Indirect actions

7.2.1 Fire restrictions

The key benefit to restricting burning of grazed tussock grassland is to prevent the degradation of these grasslands, improving groundwater provision. Burning has already ceased on PCL, and is practiced less frequently on farmland than it was in the past. Crown pastoral lands also require consent in order to burn vegetation, and DOC provides input to LINZ in assessing these consents. DOC does not have any input into burn-offs on freehold land. Alongside improved groundwater, reductions in burning would be beneficial to a wide variety of upland flora and fauna. A reduction in the frequency of fires could also have some benefits for air quality. Fire also increases the risk of weed invasion by exposing bare ground that is easy for weeds to establish on.

There are however several downsides to fire restrictions that should be considered. Firstly, restricting burning may reduce agricultural productivity for the farmers that use burn-offs to improve grazing. Maintaining a positive relationship between DOC and farmers is critical to the coordination of other management undertaken across the uplands (e.g. weed and pest control). A collaborative approach to reducing burning on private land is recommended. In some cases, the increased water runoff under healthy snow tussock grassland could provide greater benefits to farming than the additional grazing that is facilitated by burning. Educating farmers about the increased water runoff generated by snow tussock may encourage them to cease burning these grasslands.

It is also possible that reducing the frequency of these burns could lead to a build-up of flammable material, increasing the risk of destructive uncontrolled fires. This increased fire-risk may be especially pronounced where woody weeds are spreading. Control of woody weeds should reduce the risk of destructive fire events. It is preferable to control weeds and cease burning, rather than maintaining burning as a substitute for proactive weed control. However, if there is a high risk of woody weeds establishing in the absence of fire, then occasional early season burns may be justified.

7.2.2 Grazing restrictions

Reducing the grazing of stock in the uplands has the potential to facilitate the natural regeneration of dense snow tussock grassland, with subsequent improvements to the upland water table and thus the climate resilience of upland wetlands. Cessation of more intensive pastural practices will have other benefits to wetland health, including reducing the impacts of cattle trampling and browsing, fertiliser/herbicide/pesticide runoff, and invasion by pasture grasses.

Education about the importance of upland wetlands and snow tussock grasslands could encourage grazing practices that are beneficial to these upland ecosystems. Completely ceasing seasonal grazing in the uplands is not likely to be feasible in many cases, and attempting to promote this could generate opposition from farmers. It would be more practical to encourage other changes to upland grazing, such as:

- Limiting stock densities.
- Only bringing sheep (rather than cattle) into the uplands.
- Ceasing over-sowing of pasture plants and the application of fertilisers, herbicides, and pesticides.
- Fencing off the highest altitude areas where snowbanks form — typically above 1100 m.

Educating landowners about the value of tussock grassland to water provision — and on how to identify when grazed snow tussock grasslands are becoming degraded — could also be a productive approach.

One notable location where a cessation or reduction in farming activity could be highly beneficial is in the upland catchments directly south of Loganburn Reservoir. Both wetlands and tussock grasslands in this area show signs of degradation (Peter Johnson, personal communications, 19 March, 2025). This area adjoins Te Papanui Conservation Park to the south, and Shepherds Creek contains unique upland scroll plain wetlands. Restoring healthy snow tussock cover in these catchments would have the key benefit of increasing water levels for Loganburn reservoir, which is essential for irrigation in the Māniatoto basin.

7.2.3 Infrastructure restrictions

The consenting process allows DOC and other parties to comment on, influence, support or sometimes oppose new infrastructure projects in the Taiari uplands. Major infrastructure projects can directly destroy areas of upland ecosystems, and the construction and transport involved can also cause disturbance, sedimentation, weed spread, and changes to the water table. DOC already provides comment on relevant consents - impacts on upland wetlands and their influence on climate resilience should be considered explicitly as part of this. Infrastructure projects can have a wide variety of both positive and negative benefits to the wider community and environment, and these costs and benefits are often unequally distributed. It is worth highlighting that both the infrastructure needs, and the relevant consenting processes, are likely to change across the coming decades, both as a result of societal changes, and new climate pressures. In particular, increasing drought and more intensive agricultural practices on the lowlands are likely to increase demand for water abstraction from the uplands. In order to avoid excessive drainage of the upland water table, a whole-catchment approach needs to be taken, looking at the cumulative impacts of all irrigation projects, as well as any other infrastructure that degrades the water-yielding snow tussock vegetation and water-storing wetlands. The cumulative negative impact of many small projects could be just as significant as individual "megaprojects". There are also potential opportunity costs (loss of potential gain) associated with blocking infrastructure projects that could have benefits to the wider community.

7.2.4 Vehicle access restrictions

Limiting or restricting public vehicle access to the Taiari uplands would help to prevent direct vehicle damage to upland wetlands from reckless off-roading by 4WDs and dirt bikes, as well as wider degradation to the surrounding tussock grasslands. DOC has limited ability and resources to restrict and police off-roading outside of PCL. In addition, Old Dunstan Road — which runs from the Strath-Taiari to the Māniatoto through parts of the Te Papanui/Lammermoor and Rock and Pillar ranges — is a public road, further limiting the possibility of keeping vehicle user out of the uplands. It may be more practical to allow vehicle use on formed tracks within a concentrated part of the uplands, and reduce access elsewhere (Bill Lee, personal communications, 19 March, 2025). Another productive avenue to minimise vehicle damage would be to educate the Taiari community about the value of upland wetlands — and the level of damage that off-roading can cause to them.

Public access to the Taiari uplands has the potential to be a contentious issue. Some farmers may benefit from a reduction of traffic through their property, but other community members may lose out, including those who travel through the uplands responsibly. There may be an economic opportunity cost in terms of lost tourism opportunities if access to the uplands is restricted.

7.3 Wetland monitoring

While the monitoring of upland wetlands would not directly improve the climate resilience of wetlands, it has the potential to improve the decision-making involved in planning and implementing other management actions. Monitoring will assist in understanding when and where climate change is impacting wetlands, and which specific climate change impacts are the most concerning. Monitoring can also provide the "hard evidence" of deteriorating wetland condition necessary to spur action and access wetland conservation/restoration resources. Effective monitoring makes it possible to quantify which climate impacts need to be managed, and which management actions are effective. There is also the wider benefit that monitoring of these wetlands will improve our general understanding of their ecology. They are unique and understudied elements of the landscape, and any high-quality data on them would be of ecological value.

Key wetlands to monitor include:

- Alpine snowbanks and seepages at higher altitudes, which are most vulnerable to warmer temperatures and reduced frost/snow, and are upstream of other wetlands. They are likely to be the wetlands with the earliest and most pronounced response to changes in seasonal snow cover.
- Wetlands in the 600-800 m zone, which are likely to be the first to be impacted by increased weed pressures, changes in land-use. These wetlands are also more likely to already show some level of degradation, making them useful for detecting improvements in wetland condition following successful management actions.

Wetland monitoring should prioritise long-term monitoring plots to best identify climate change impacts, and should attempt to capture a representative sample of wetlands.

The wetlands of the Taiari uplands are incredibly varied in terms of wetland class and type, local climate, altitude, hydrology, and topography. This means it could be difficult or cost-prohibitive to monitor a representative suite of all the upland wetlands. Regular ongoing monitoring of wetlands will be more effective at identifying climate impacts that ramp up gradually, however many of the worst climate impacts are likely to be abrupt and unpredictable, associated with infrequent extreme weather events such as droughts, floods, or heatwaves. It may be useful develop a wider list of wetlands for which data is collected, but that are not subject to ongoing monitoring. These can then be visited for targeted monitoring in the wake of extreme weather events. In particular, it would be useful to understand which factors predict the ability of wetland vegetation to recover from different types of disturbance events.

8.0 Analysis of Management Actions

8.1 Cost-benefit analysis

8.1.1 Methodology

Categories

In comparing the costs and benefits of different management options to include, we considered three categories of benefits, and two categories of costs.

Benefit categories:

- ***B1:*** The first category of benefits are the improvements to wetland climate resilience that a given management option is estimated to achieve. This category implicitly includes the wider ecosystem service benefits that come from improving wetland climate resilience.
- ***B2:*** The second category includes the wider ecological/conservation benefits of a management action. It is important to consider these benefits, as they have the potential to make gains and create cost efficiencies for DOC in other areas beyond wetland resilience.
- ***B3:*** The third category of benefits are those associated with social (including economic) benefits to the wider community. Management actions that benefit the wider community are likely to see greater public support; community members may be willing to contribute their own time and resources in assisting with these actions, if they are not doing so already.

Cost categories:

- ***C1:*** The first category of costs considers the direct financial cost associated with undertaking the works.
- ***C2:*** The second category of costs are the social costs to the wider community. The second category includes cultural, aesthetic and recreation costs, as well as direct economic costs to other stakeholders, and opportunity costs associated with ceasing or preventing certain economic activities. These costs may create public opposition to these management actions.

For each potential management action, the relevant costs and benefits under each category are listed, and the action is given a ranking by the report authors applying their expert knowledge of this ecosystem (Table 10). These cost/benefit rankings are assessed qualitatively, using a None-Low-Moderate-High scale to indicate the level of cost/benefit associated with the action.

Overall score

To generate overall cost-benefit scores, these assessments were converted into numeric scores ranging from 0 (no cost or benefit) to 3 (high cost or benefit), shown in Table 11. Overall benefit and cost scores were calculated as weighted averages, with B1 and C1 being given twice the weight of the other categories, as these represent the direct benefit to wetland climate resilience, and direct cost to DOC, respectively. Averaged costs and benefits were used to control for the fact that there are three benefit categories vs. two cost categories. These overall scores were used to calculate a benefit-cost ratio, with a higher ratio indicating greater benefits relative to costs. These scores are intended to allow the relative costs and benefits of different option to be compared. A positive or negative ratio does not necessarily imply that a management action is/is not financially justified.

Uncertainty

There is substantial uncertainty associated with assessing the costs and benefits of different management actions. A range is given where there is significant uncertainty in the cost or benefit assessment for a management action, e.g. the wider conservation benefits of invasive browser control are assessed as being moderate-high, meaning they could be either moderate or high. In the main cost-benefit assessment (Table 11), uncertain costs or benefits were given a numeric score in the middle of the uncertainty range, e.g. a low-medium cost estimate would receive a score of 1.5.

In order to see how uncertainty in costs and benefits impact the outcome of this assessment, two alternative scenarios were also considered:

- In the low benefit-high cost scenario (Appendix 2), uncertain benefits were assumed to be at the low end of the estimate, while uncertain costs were assumed to be at the high end of the estimate. This means that a low-medium benefit would be scored as a 1, while a low-medium cost would be scored as a 2.
- In the high benefit-low cost scenario (Appendix 2), uncertain benefits and costs were scored in the opposite manner, with benefits scored at the high end of the uncertainty estimate and costs scored at the low end.

Approach

A qualitative approach was used in this report; a full cost-benefit analysis all in dollar values would be a significant challenge, as it would require the financial estimation of:

- What the current ecosystem value is across all the Taiari upland wetlands.
- How much this value is expected to decline as a result of predicted climate impacts.
- How much of this decline can be mitigated by each management action.

Table 10 – Costs and benefits associated with different climate risk management actions for upland wetlands in the Taiari catchment.

Actions		Benefits						Costs			
		B1: Improvement in climate-change resilience	B1: Ranking	B2: Wider ecological benefits	B2: Ranking	B3: Wider social benefits	B3: Ranking	C1: DOC Monetary Costs	C1: Ranking	C2: Community Costs	C2: Ranking
Direct	**Weed control**	This increases the climate resilience of wetlands by maintaining weed-free tussock grasslands necessary for the water tables that support typical wetland structure and function. Also avoids future weeds that could directly invade wetlands.	High	Woody weed control will avoid substantial transformations of upland ecosystems. A wide variety of indigenous flora and fauna will benefit from maintaining weed free upland ecosystems.	Moderate-high	Reduced risk of weed spread onto private land. Maintenance of landscape/aesthetic values, reduced risk of wildfires.	Moderate-high	Ongoing wilding conifer control; proactive removal and replacement of lowland seed sources; survey/monitoring of future weed threats.	Moderate	Woody weeds provide few benefits, there would not be much opposition to their removal. There may be costs incurred and public opposition where shelter belts are removed, especially if they are not replaced with other suitable vegetation, or the new vegetation takes time to regrow. There may also be some opposition on aesthetic grounds.	Low
	Invasive browser control	This action would reduce direct browser damage on wetlands - especially pig rooting and trampling ungulates. This action would also improve the surrounding tussock grasslands that maintain high groundwater levels.	Moderate-high	Upland habitat improvement from controlling browsers also has wider benefits for upland flora and fauna. Controlling these species will be particularly beneficial for browse-vulnerable indigenous plant species.	Moderate-high	Invasive browsers are also a pest for farmers, especially pigs as they are disease vectors. Controlling them on PCL will reduce their spread onto private farmland.	Moderate	Ongoing costs associated with culling of ungulates; targeted rabbit/hare control at sites where they are clearly limiting vegetation recovery.	Moderate	May impact hunting opportunities.	Low
	Invasive predator control	Improved populations of upland fauna would maintain ecological functions such as seed dispersal, pollination, and nutrient cycling.	Low	Will benefit upland fauna populations, as well as some direct and indirect benefits for upland flora.	Moderate	There are few obvious wider social benefits to this action. Reducing the risk of possums acting as disease vectors.	None-low	Ongoing costs associated with control of mammalian predators.	Moderate	May be public opposition to poison use.	Low-moderate
	Alpine species translocation	This action does little to improve the climate resilience of upland wetlands. It could allow the long-term survival of structurally or functionally important upland biodiversity.	None-low	Translocations to suitable alpine locations elsewhere may prevent extinctions of climate-sensitive flora and fauna.	Low-moderate	There are few obvious social benefits to this management action. Species extinctions could be seen as a loss of mana for mana whenua; there is benefit in preventing this happening.	None-low	Identifying species that are suitable for translocation; identifying suitable receiving locations; specialised equipment and expertise required to transport species; monitoring and support to ensure that translocated populations are successful in their new environment.	High	No obvious negative social impacts.	None
	Direct wetland restoration: high value wetlands and 600-800 m altitude wetlands	Can improve the condition of degraded ecosystems, and help to maintain the structure and function of targeted high value wetlands.	Moderate	Can locally improve habitat for wetland flora and fauna, and improve downstream water quality for freshwater fauna. Planting of threatened and at-risk plant species could boost local populations.	Moderate	May encourage community members to learn about and appreciate upland wetlands.	Low	Fencing, planting, and potentially ongoing pest/weed management.	High	No obvious negative social impacts.	None

Actions		Benefits						Costs			
		B1: Improvement in climate-change resilience	B1: Ranking	B2: Wider ecological benefits	B2: Ranking	B3: Wider social benefits	B3: Ranking	C1: DOC Monetary Costs	C1: Ranking	C2: Community Costs	C2: Ranking
	Direct wetland restoration: other wetlands that are >800 m altitude	Similar to the action above, however most wetlands above 800 m altitude currently have good indigenous cover so this management action currently has limited ability to improve wetland structure and function.	Low	Similar to the action above, however most wetlands above 800 m altitude have good indigenous cover so this management action currently has limited ability to improve wider flora and fauna values.	Low	May encourage community members to learn about and appreciate upland wetlands.	Low	Fencing, planting, and potentially ongoing pest/weed management.	High	No obvious negative social impacts.	None
Indirect	**Wetland monitoring**	Can improve decision making in other management actions. Allows DOC to detect climate impacts early, and understand which factors allow wetlands to recover from these impacts.	Moderate-high	A side-benefit of wetland monitoring is that it would lead to more information being collected on upland ecosystems.	None-low	There are no direct social benefits to this management action, although community groups and citizen science could be engaged with to assist in monitoring. Presentation of results may increase public understanding of wetland value.	None-low	Cost associated with identifying a suitable selection of wetlands to monitor, and appropriate monitoring protocols; Ongoing monitoring to detect gradual climate impacts; Targeted monitoring following sudden climate impacts.	Low-moderate	Not likely to be any costs or negative impacts to the wider community.	None
	Fire restrictions	Improves the condition of snow-tussock grassland, maintaining high groundwater levels. Burning has already ceased on PCL, and DOC has limited means to prevent it occurring on private land.	Moderate	Limiting burning is likely to be beneficial to the whole upland ecosystem, although it has already ceased in many locations.	Moderate	May reduce smog/air pollution, reduces the risk of damage from burn-offs that get out of control.	Low	DOC input on CPL consents is business as usual, costs are recovered; outreach and education to reduce grazing impacts on uplands would not be very expensive.	Low	May reduce agricultural productivity, may increase weed levels in some locations. Potentially increased risk of costs associated with catastrophic fires.	Moderate
	Grazing restrictions	Restriction on grazing would allow degraded snow tussock to recover, prevent cattle trampling of wetlands, and reduce fertiliser/herbicide/pesticide/weed pressure. Light sheep grazing may help to control weeds in some situations. Grazing has already stopped on PCL, and DOC has limited ability to dictate grazing strategies on private land.	Moderate	Restricting grazing practices to those that degrade upland ecosystems would benefit a range of flora and fauna on private land.	Low-moderate	Retiring upland areas from grazing may benefit recreational uses of the uplands and make access easier.	None-low	DOC input on CPL consents is business as usual, costs are recovered; outreach and education to reduce grazing impacts on uplands would not be very expensive.	Low	May lead to reduced agricultural productivity. May also require changes to farming practices, which could have high up-front costs. May increase weed levels in some locations.	Moderate
	Infrastructure restrictions	Restriction on infrastructure projects could avoid significant degradation to upland wetlands, although the impacts are likely to be localised and variable depending on what infrastructure is being proposed.	Low-moderate	Large infrastructure projects could threaten a wide variety of upland flora, fauna, and ecosystems.	Low-moderate	Maintains landscape/aesthetics. May maintain access for upland recreational use.	Low-moderate	DOC would have input on major infrastructure projects anyway, so this action is unlikely to introduce new costs.	None-low	Some infrastructure projects could have significant social benefits, e.g. renewable energy, irrigation. Restricting such infrastructure could have significant opportunity cost.	Low-high
	Vehicle access restrictions	Difficult to assess how much damage off-roading is doing. Damage is likely to be localised around formed roads/tracks. DOC has limited ability to influence this beyond education/outreach and CPL consenting.	Low	Destruction of vegetation and fauna can occur, although the damage is most pronounced in wetlands.	Low	May reduce the risk of remote vehicle incidents. Can improve the experience of trampers and cyclists.	Low	Outreach and education to encourage responsible travel through uplands would not be too expensive. Restricting access on PCL would not be expensive.	Low	Could limit recreational access to the uplands, potentially missing out on tourism opportunities. Has the potential to alienate locals.	Low-moderate

Table 11 – Costs and benefit scores of climate risk management actions for upland wetlands in the Taiari catchment, including uncertainty range (See Appendix 2 for a breakdown of uncertainty in costs and benefits).

Actions		**Benefits**				**Cost**			**Benefit-cost ratio**	**Possible range**
		Improvement in climate-change resilience score	Wider ecological benefit score	Wider social benefit score	**Overall benefit score**	DOC monetary cost score	Community cost score	**Overall cost score**		
Direct	**Weed control**	3	2.5	2.5	**2.75**	2	1	**1.67**	1.65	1.5 – 1.8
	Invasive browser control	2.5	2.5	2	**2.38**	2	1	**1.67**	1.43	1.2 – 1.65
	Invasive predator control	1	2	0.5	**1.13**	2	1.5	**1.33**	0.61	0.50-0.75
	Alpine species translocation	0.5	1.5	0.5	**0.75**	3	0	**2.00**	0.38	0.13 – 0.63
	Direct restoration: high value wetlands and 600-800 m altitude wetlands	2	2	1	**1.75**	3	0	**2.00**	0.88	NA
	Direct restoration: other wetlands that are >800 m altitude	1	1	1	**1.00**	3	0	**2.00**	0.50	NA
Indirect	**Wetland monitoring**	2.5	0.5	0.5	**1.50**	1.5	0	**1.00**	1.50	0.75 – 3.0
	Fire restrictions	2	2	1	**1.75**	1	2	**1.33**	1.31	NA
	Grazing restrictions	2	1.5	0.5	**1.50**	1	2	**1.33**	1.13	0.94 – 1.31
	Infrastructure restrictions	1.5	1.5	1.5	**1.50**	0.5	2	**1.00**	1.50	0.60 – 6.0
	Vehicle access restrictions	1	1	1	**1.00**	1	1.5	**1.17**	0.86	0.75 – 1.0

8.1.2 Results

This subjective and qualitative analysis indicates that of the six direct actions, weed control and invasive browser control both have the highest benefit:cost ratios. These actions both have the potential to deliver moderate-high benefits across all three categories. These benefit:cost ratios are relatively stable across the different cost-high scenarios, making it fairly certain that weed control and invasive browser control are among the best available options. The other direct management actions have consistently lower benefit:cost ratios across all three scenarios, primarily due to having high direct costs.

The indirect management actions show a wider uncertainty in the balance of potential benefits and costs. Wetland monitoring and restrictions on large-scale infrastructure projects have high benefit:cost ratios under the standard and high benefit-low cost scenarios; however, these management actions have noticeably lower benefit:cost ratios under the low benefit-high cost scenario. Fire and grazing restrictions generally have positive benefit:cost ratios, although there is uncertainty around whether grazing restrictions offer as much benefit as fire restrictions. Vehicle-use restriction has a poor benefit:cost ratio compared to other management options across every scenario.

8.1.3 Distribution of costs and benefits of land-use change in the Taiari uplands

The wider social costs and benefits associated with several of the indirect management actions are not evenly shared throughout the community. It is primarily low-intensity high country sheep and beef farming that uses the uplands for seasonal grazing during summer months. This means that these farmers would bear all of the costs associated with lost agricultural productivity from cessation of burning or grazing in tussock grasslands. In contrast, the benefits that come from improved groundwater provision and retention under dense snow-tussock cover are spread throughout the entire catchment. Land users in the lowlands benefit from higher and more stable water flows in the Taiari catchment — as well as often directly drawing water from the uplands for irrigation, the general public benefits from improved water quality, and mana whenua benefit from healthy freshwater conditions supporting the provision of mahika kai. This means that even where the overall benefit-cost ratio for these actions is clearly positive, it may not be in the interest of upland farmers to make these changes. Finding ways to address this asymmetry of costs vs. benefits is likely to significantly increase uptake of these management actions, as well as reducing the potential for future conflict over scarce water resources.

8.2 Prioritisation of management actions

As well as understanding the costs and benefits of each management action, other factors also need to be taken into account in determining which management actions to prioritise. The DOC climate change adaptation action plan proposes 15 factors to consider for the prioritisation of climate adaptation actions (Christie *et al.*, 2020, Appendix 2). This looks at a variety of factors covering the benefit, urgency, and likelihood of success for different management options, shown in Table 12. Each of the proposed management actions is considered against these factors. The second column, “benefits exceed costs”, was based on whether or not a management action had a positive benefit-cost ratio. As discussed in section 8.1.1, because the costs and benefits are assigned subjective rankings rather than directly comparable dollar values, these ratios don’t directly indicate whether costs exceed benefits. Instead, they indicate which actions have comparatively larger benefits relative to costs. This is appropriate for comparing the relative priority of the different management actions, but does not capture the uncertainty associated with each action, or the difficulty of comparing different categories of costs and benefits.

Table 12 – Prioritisation table ranking potential climate risk management actions according to benefit, urgency, and likelihood of success.

Actions	Benefit					Urgency						Likelihood of Success				Overall Priority	
	Provides a range of benefits	Benefits exceed costs	Provides cultural, pest control, and/or mitigation co-benefits?	Developed in partnership with Treaty partners?	Provides active protection to Māori conservation outcomes	Unable to respond in future if action is not taken now	Effects build up over time such that inaction now will cost more later	Other actions depend on this action being accomplished first	Effects large in scale, pervasive, or irreversible	Effects can tip upland wetlands over a threshold into another state if not addressed	Legal or reputational risk of not acting	Tools and processes that will enable this action to succeed are in place. The action is not sequential or reliant on something else occurring beforehand to be successful	Action likely to be effective	Technical, scientific, and implementation skills readily available	Does the action respect tikanga and matauranga Māori, and support their appropriate application to conservation planning, monitoring and decision-making?	Score	Rank
Weed control	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Maybe	13.5	1
Invasive browser control	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Maybe	11.5	2
Infrastructure restrictions	Yes	Yes	No	No	Yes	Yes	Maybe	No	Yes	Yes	Yes	Yes	Maybe	Yes	Yes	11	3
Direct restoration: high value wetlands and 600-800 m altitude wetlands	Yes	No	Yes	No	Yes	No	Maybe	No	No	Yes	Yes	Yes	Yes	Yes	Yes	9.5	4
Wetland monitoring	Yes	Yes	No	No	No	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	9	5-6
Invasive mammal control	Yes	No	Yes	No	Yes	No	Maybe	No	Yes	No	Yes	Yes	Yes	Yes	Maybe	9	5-6
Fire restrictions	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	No	No	Maybe	Yes	Yes	8.5	7-8
Grazing restrictions	Yes	Yes	Yes	No	Yes	No	No	No	Yes	Yes	No	No	Maybe	Yes	Yes	8.5	7-8
Direct restoration: other wetlands above 800 m altitude	No	No	No	No	Yes	No	No	No	No	Yes	Yes	Yes	Maybe	Yes	Yes	6.5	9-10
Alpine species translocation	No	No	No	No	Yes	Yes	No	No	Yes	No	Yes	Maybe	Maybe	Maybe	Yes	6.5	9-10
Vehicle access restrictions	Maybe	No	No	No	Maybe	No	No	No	No	Yes	No	No	Maybe	Yes	Maybe	4	11

Of the eleven actions, woody weed control comes out as the highest priority, while vehicle access restriction is the lowest priority. Managing woody weeds has a high benefit-cost ratio, a wide range of co-benefits, avoids increased costs if the problem is left unchecked, prevents irreversible changes to upland ecosystems from wilding conifer invasion, and helps to avoid weed problems associated with other management actions (e.g. restricting burning or grazing). Limiting vehicle access to the Taiari uplands would have relatively minor benefits (at the risk of community opposition), is not especially urgent, and — due to being difficult to enforce/police — has an uncertain likelihood of success.

In general, the results of prioritisation analysis broadly mirror the cost-benefit analysis; weed control, invasive browser control, and infrastructure restrictions receive the highest priority scores, while wetland restoration above 800 m, vehicle access restriction, and alpine species translocation receive the lowest scores. Notably, invasive mammal control and direct restoration of high value wetlands/those in the 600-800 m altitude zone receive priority rankings other actions with higher benefit:cost ratios. These actions score highly on the "likelihood of success" criteria, while also receiving decent scores in the other two categories. Restrictions on burning or grazing in the uplands have lower priority ranking than expected given their benefit:cost scores. This is because of a relatively low urgency, and an uncertain likelihood of success in restricting burning and grazing. Upland tussock grasslands have been grazed and burned for a long time, and regeneration does not depend on an immediate cessation of these practices. At the same time, the need to work with the farming community in order to undertake these management actions means that there is more social/economic complexity involved compared to some of the other management actions. That does not mean that these actions should not be undertaken, however immediate action may not be a priority. A more gradual and thoughtful approach that achieves buy-in from the rural community is likely to improve the chances of success for these actions.

9.0 Future Research Avenues

There are several directions in which future work could be undertaken to better understand management for climate resilience in upland wetlands.

One would be to improve the understanding of peatlands in the Te Papanui/Lammerlaw-Lammermoor ranges. These wetlands are understudied, especially considering that they are numerous, ecologically unique, sometime very large, and occupy the source waters of the Taiari catchment. Key questions to investigate include:

- How old are the successive peat layers?
- What type of vegetation was present prior to dense *Sphagnum* moss?
- How much carbon and water is stored in these peatlands?
- Are these peatlands still actively accumulating peat?
- What factors control the lower elevational limit of these peatlands?

Answering these questions would be particularly informative to quantifying the services provided by these ecosystems. This research would also indicate how much (and how quickly) these ecosystems have changed in the past, which is relevant to understanding how they are likely to change in the future.

Related to this, research into the overall hydrology of the Taiari uplands would be useful for understanding the relationship between climatic conditions, vegetation cover, underlying geology, and wetlands in controlling the upland water table. Specifically, if the geology of the Taiari uplands allows rainfall to be stored as groundwater over long time periods, then the upland wetlands may be more resistant to climate change than currently thought.

Ways to incentivise or compensate upland farmers for the wider benefits gained from transitioning upland grasslands away from burning and grazing require attention. This would involve educating the wider community about how land management in the uplands impacts the whole catchment. Burning and grazing practices can vary widely in how they impact snow tussock grasslands; comparing different farming practices to understand the best ways to minimise these impacts on tussock cover would be very useful.

More broadly, a thorough understanding of possible future land-use changes in the Taiari catchment would be very useful in order to better understand the social and economic context in which future management actions will take place. Further expert discussion on this area is strongly recommended.

Finally, there are a variety of other potential management actions or initiatives that could improve the climate change resilience of the Taiari upland wetlands, beyond the nine options that were explored in this report. These could include providing advocacy, education, and field experience to promote the biodiversity values of these wetlands to the wider community. Further expert discussion would be valuable on many of the issues raised in this report, including weed control, burn-off practices/fire risk, vehicle access, irrigation and water abstraction, land-use change, and the financing of biodiversity values/ecosystem services. Support for catchment management groups could also be considered, given the importance in coordinating landscape-scale management, as well as supporting the resilience of the community.

10.0 Conclusion

The upland wetlands of the Taiari catchment are diverse and support a wide range of ecological and social values. These wetlands are the source for the whole Taiari catchment, meaning that any impacts to them will have downstream effects. Of particular interest — and concern — are the extensive peat-forming fens and bogs of the Te Papanui/Lammerlaw-Lammermoor uplands, which are highly biodiverse, play a role in downstream water-provisioning and quality, and show unique patterns of peat-formation. Many of the upland wetlands are fed by groundwater derived from surrounding tall-tussock grassland, meaning that the whole upland hydrological system needs to be taken into account when considering threats and management of Taiari upland wetlands.

Using the latest climate projections, some impacts appear to be more muted in comparison to past predictions, such as rainfall seasonality and extreme hot days. However, the number of frost days is now predicted to decline more drastically than previously predicted. The predicted changes to the climate of the Taiari uplands increase the likelihood that a larger proportion of wetlands dry out in summer, which could result in a changed floristic composition and faunal assemblage in those wetlands. These changes may be detrimental — particularly if paired with other climate change impacts — or may result in an altered geographic distribution of these mosaic habitats without reducing overall diversity. Shrinking or disappearing of wetlands over time with climate change is commonly reported internationally (Closs *et al.*, 2024; Department of the Environment, 2015; Tonkin & Taylor Ltd, 2021; Xu *et al.*, 2024), and this could particularly occur in wetlands that are currently small, shallow, or ephemeral. Snowbank vegetation is likely to be especially vulnerable to the negative impacts of climate change. Climate change is also likely to drive changes in floral communities, as well as altering process such as peat formation in wetlands and groundwater provision from surrounding grasslands. There is also a high risk that climate change could facilitate weed invasion from the surrounding lowlands, including by species that are not currently a problem in the uplands. Alongside climate change impacts, a variety of other factors threaten upland wetlands in the Taiari catchment, including exotic weeds and pests, agricultural grazing and burn-offs, reckless off-roading, and infrastructure impacts. Management of these threats would have the greatest positive impacts on the resilience of upland wetlands in the face of climate change impacts.

Based on the results of the qualitative cost-benefit analysis and prioritisation analysis, six of the nine management actions examined appear to have obvious merit as ways of improving climate impact resilience for the upland wetlands. Woody weed control and invasive browser control are the most straight-forward to recommend, as these actions have clear and direct benefits, low risk of wider social costs, and a high level of urgency. Wetland monitoring and restrictions on infrastructure in the uplands are also relatively high-priority actions, with the potential for significant benefits, although there is more uncertainty around the level of benefits relative to costs associated with these actions. The high uncertainty in the cost:benefit reflects the fact that infrastructure restrictions will be better assessed with specific projects to consider on a case-by-case basis. Restrictions on grazing and burning in the uplands both have positive benefit-cost ratios, although they have a lower priority ranking. These actions should be undertaken in a more planned and gradual manner, taking into account the social and ecological complexities associated with land-use change. Direct wetland restoration, restriction of vehicle access, and alpine species translocations have the lowest benefits relative to costs, and are not currently high priorities. However, these rankings are subjective, and particular management actions may be more justified either in the future or if examined more closely with more specific information (e.g., locations for direct wetland restoration).

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References

Ausseil, A.-G. E., Jamali, H., Clarkson, B. R., & Golubiewski, N. E. (2015). Soil carbon stocks in wetlands of New Zealand and impact of land conversion since European settlement. *Wetlands Ecology and Management*, *23*(5), 947–961. https://doi.org/10.1007/s11273-015-9432-4

Baidya Roy, S., & Traiteur, J. J. (2010). Impacts of wind farms on surface air temperatures. *Proceedings of the National Academy of Sciences*, *107*(42), 17899–17904. https://doi.org/10.1073/pnas.1000493107

Bertoia, A. J. (2023). *Critters in the cold: Understanding how large-bodied alpine invertebrates are influenced by introduced predators and climate change* [University of Otago]. https://hdl.handle.net/10523/16287

Block, G. (2018, December 22). Lowdown antics hit farmer on the high road. *Otago Daily Times*. https://www.odt.co.nz/news/dunedin/lowdown-antics-hit-farmer-high-road

Chinn, W. G. H., & and Chinn, T. J. H. (2020). Tracking the snow line: Responses to climate change by New Zealand alpine invertebrates. *Arctic, Antarctic, and Alpine Research*, *52*(1), 361–389. https://doi.org/10.1080/15230430.2020.1773033

Christie, J., Pearce, P., Phifer, P., Parsons, S., & Tait, A. (2020). *Department of Conservation climate change adaptation action plan* (R182607; p. 80). Department of Conservation. https://www.doc.govt.nz/globalassets/documents/our-work/climate-change/climate-change-adaptation-action-plan.pdf

Clarkson, B. R., Ausseil, A.-G. E., & Gerbeaux, P. (2013). Wetland ecosystem services. In *Ecosystem services in New Zealand – conditions and trends.* Manaaki Whenua Press, Lincoln, New Zealand.

Closs, G. P., Matthaei, C., Mora-Teddy, A. K., Clearwater, S. J., Kavazos, C. R. J., & Schallenberg, M. (2024). *Climate change vulnerability assessment of freshwater ecosystems and values of the Taiari River catchment and management options*. Department of Conservation. https://doi.org/10.13140/RG.2.2.35098.86728

Crow, S. (2017). *New Zealand Freshwater Fish Database. Version 1.2.* [Computer software]. The National Institute of Water and Atmospheric Research. https://niwa.co.nz/freshwater/nz-freshwater-fish-database

Day, N., Barratt, B., Christensen, B., Curran, T., Dickinson, K., Lavorel, S., Norton, D., & Buckley, H. (2023). Predicting ecological change in tussock grasslands of Aotearoa New Zealand. *New Zealand Journal of Ecology*. https://doi.org/10.20417/nzjecol.47.3549

De Lange, P. J., Rolfe, J. R., Barkla, J. W., Courtney, S. P., Champion, P. D., Perrie, L. R., Beadel, S. M., Ford, K. A., Breitwieser, I., Schönberger, I., Hindmarsh-Walls, R., Heenan, P. B., & Ladley, K. (2024). *Conservation status of vascular plants in Aotearoa New Zealand, 2023* (New Zealand Threat Classification Series 43, p. 105). Department of Conservation.

Department of Conservation. (2009). *Conservation Resources Report on Tenure Review of Beaumont Pastoral Lease* (PO362). Land Information New Zealand.

Department of the Environment. (2015). *National Recovery Plan for the Alpine Sphagnum Bogs and Associated Fens* (p. 46). Department of the Environment.

Derraik, J. G. B., Tompkins, D. M., Alley, M. R., Holder, P., & Atkinson, T. (2008). Epidemiology of an avian malaria outbreak in a native bird species (*Mohoua ochrocephala*) in New Zealand. *Journal of the Royal Society of New Zealand*, *38*(4), 237–242. https://doi.org/10.1080/03014220809510558

Dickie, I. A., St John, M. G., Yeates, G. W., Morse, C. W., Bonner, K. I., Orwin, K., & Peltzer, D. A. (2014). Belowground legacies of *Pinus contorta* invasion and removal result in multiple mechanisms of invasional meltdown. *AoB PLANTS*, *6*, plu056. https://doi.org/10.1093/aobpla/plu056

Dobson-Waitere, A., MacIntosh, R., Ellison, M. F., Smallfield, B. M., & van Klink, J. W. (2022). Taramea, a treasured Māori perfume of Ngāi Tahu from *Aciphylla* species of Aotearoa New Zealand: A review of Mātauranga Māori and scientific research. *Journal of the Royal Society of New Zealand*, *52*(1), 1–17. https://doi.org/10.1080/03036758.2020.1856147

Fahey, B., Davie, T., & Stewart, M. (2011). The application of a water balance model to assess the role of fog in water yields from catchments in the east Otago uplands, South Island, New Zealand. *Journal of Hydrology (New Zealand)*, *50*(2), 279–292.

Fahey, B., & Payne, J. (2017). The Glendhu experimental catchment study, upland east Otago, New Zealand: 34 years of hydrological observations on the afforestation of tussock grasslands. *Hydrological Processes*, *31*(16), 2921–2934. https://doi.org/10.1002/hyp.11234

García-Alix, A., Jiménez-Espejo, F. J., Toney, J. L., Jiménez-Moreno, G., Ramos-Román, M. J., Anderson, R. S., Ruano, P., Queralt, I., Delgado Huertas, A., & Kuroda, J. (2017). Alpine bogs of southern Spain show human-induced environmental change superimposed on long-term natural variations. *Scientific Reports*, *7*(1), 7439. https://doi.org/10.1038/s41598-017-07854-w

Geppert, C., Bertolli, A., Prosser, F., & Marini, L. (2023). Red-listed plants are contracting their elevational range faster than common plants in the European Alps. *Proceedings of the National Academy of Sciences*, *120*(12), e2211531120. https://doi.org/10.1073/pnas.2211531120

Goldsmith, M. J. (2023). *Climate change impacts and risks for the Taiari River catchment – a compilation of current research to support local decision-making.* GHC Consulting Limited; Department of Conservation. https://www.doc.govt.nz/globalassets/documents/our-work/nga-awa-river-restoration/summary-of-climate-change-impacts-and-risks-for-the-taiari-catchment-2023.pdf

Hitchmough, R. A., Barr, B., Knox, C., Lettink, M., Monks, J. M., Patterson, G. B., Reardon, J. T., van Winkel, D., Rolfe, J., & Michel, P. (2021). *Conservation status of New Zealand reptiles, 2021* (New Zealand Threat Classification Series 35, p. 27). Department of Conservation.

Hoare, R. J. B., Dugdale, J. S., Edwards, E. D., Gibbs, G. W., Patrick, B. H., Hitchmough, R. A., & Rolfe, J. R. (2017). *Conservation status of New Zealand butterflies and moths (Lepidoptera), 2015* (New Zealand Threat Classification Series 20, p. 13). Department of Conservation.

Inouye, D. W., Barr, B., Armitage, K. B., & Inouye, B. D. (2000). Climate change is affecting altitudinal migrants and hibernating species. *Proceedings of the National Academy of Sciences*, *97*(4), 1630–1633. https://doi.org/10.1073/pnas.97.4.1630

Jackson, B., Harvey, C., Galbraith, J., Robertson, M., Warren, K., Holyoake, C., Julian, L., & Varsani, A. (2014). Clinical beak and feather disease virus infection in wild juvenile eastern rosellas of New Zealand; biosecurity implications for wildlife care facilities. *New Zealand Veterinary Journal*, *62*(5), 297–301.

Jarvie, S., Campbell, C., Knox, C., Monks, J. M., & Reardon, J. T. (2023). *Conservation Status of Reptile Species in Otago* (1; Otago Threat Classification Series, p. 24). Otago Regional Council.

Jewell, T. (2022). *Discovery of an abrupt contact zone supports recognition of a new species of grass skink in southern New Zealand*. *Occassional Publication #2022B*, 10–16.

Johnson, P. N. (1986a). *Great Moss Swamp: Preliminary report on botany and proposed reserves.* (575; p. 8). DSIR.

Johnson, P. N. (1986b). *Lammerlaw Range wetlands: Botanical report* (567; p. 27). DSIR.

Johnson, P. N. (1987). *Great Moss Swamp- Longburn Reservoir: Report on botany and proposed reserves.* (603; p. 18). DSIR.

Johnson, P. N. (1988). *Sphagnum moss in Otago: A discussion report.* (650; p. 17). DSIR.

Johnson, P. N., & Lee, W. G. (1988). *Lammerlaw Range uplands: Botanical report* (627). DSIR.

Johnson, P. N., Lee, W. G., & Khan, S. (2022). *Wetlands of the Otago Region* (p. 44). Manaaki Whenua – Landcare Research; Otago Regional Council.

Johnson, P. N., & Rogers, G. M. (2003). *Ephemeral wetlands and their turfs in New Zealand* (230; Science for Conservation, p. 109).

Johnson, P. N., & Rogers, G. M. (2033). *Ephemeral wetlands and their turfs in New Zealand* (Science for Conservation 230, p. 109). Department of Conservation.

Jones, P. E., & Closs, G. P. (2015). Interspecific differences in larval production and dispersal in non-migratory galaxiids: Implications for metapopulation structure. *Marine and Freshwater Research*, *67*(10), 1479–1492. https://doi.org/10.1071/MF14309

Lord, J. M., Schloots, C.-L., & Steel, J. B. (2022). Flammability trajectories following destocking and forestation: A case study in the New Zealand high country. *Restoration Ecology*, *30*(8), e13696. https://doi.org/10.1111/rec.13696

Mark, A. F., & Dickinson, K. J. (2008). Maximizing water yield with indigenous non-forest vegetation: A New Zealand perspective. *Frontiers in Ecology and the Environment*, *6*(1), 25–34. https://doi.org/10.1890/060130

Mark, A. F., & Dickinson, K. J. M. (2003). Temporal responses over 30 years to removal of grazing from a mid-altitude snow tussock grassland reserve, Lammerlaw Ecological Region, New Zealand. *New Zealand Journal of Botany*, *41*(4), 655–667. https://doi.org/10.1080/0028825X.2003.9512876

Mark, A. F., Johnson, P. N., Dickinson, K. J. M., & McGlone, M. S. (1995). Southern hemisphere patterned mires, with emphasis on southern New Zealand. *Journal of the Royal Society of New Zealand*, *25*(1), 23–54. https://doi.org/10.1080/03014223.1995.9517481

McGlone, M. S. (2001). The origin of the indigenous grasslands of southeastern South Island in relation to pre-human woody ecosystems. *New Zealand Journal of Ecology*, *25*(1), 15.

McQueen, S., & Morris, R. (2013). *A Photographic Guide to Freshwater Fishes of New Zealand*. New Holland Publishers.

Nicolai, A., & Ansart, A. (2017). Conservation at a slow pace: Terrestrial gastropods facing fast-changing climate. *Conservation Physiology*, *5*(1), cox007. https://doi.org/10.1093/conphys/cox007

Niffenegger, C. A., Hille, S. M., Schano, C., & Korner-Nievergelt, F. (2025). Rising Temperatures Advance Start and End of the Breeding Season of an Alpine Bird. *Ecology and Evolution*, *15*(2), e70897. https://doi.org/10.1002/ece3.70897

Niffenegger, C. A., Schano, C., Arlettaz, R., & Korner-Nievergelt, F. (2023). Nest orientation and proximity to snow patches are important for nest site selection of a cavity breeder at high elevation. *Journal of Avian Biology*, *2023*(3–4), e03046. https://doi.org/10.1111/jav.03046

Pattermore, L. (2024). 'Concerning' 4WD damage prompts DOC appeal. *Crux*. https://crux.org.nz/crux-news/concerning-4wd-damage-to-otago-tracks-prompts-doc-action/

Powlesland, R. G. (2009). Impacts of wind farms on birds: A review. *Science for Conservation 289. Department of Conservation*, 51.

Rapson, G. L., Sykes, M. T., Lee, W. G., Hewitt, A. E., Agnew, A. D. Q., & Wilson, J. B. (2006). Subalpine gully-head ribbon fens of the Lammerlaw and Lammermoor Ranges, Otago, New Zealand. *New Zealand Journal of Botany*, *44*, 351–375.

Ropars, P., Comeau, É., Lee, W., & Boudreau, S. (2018). Biome transition in a changing world: From indigenous grasslands to shrub-dominated communities. *New Zealand Journal of Ecology*, *42*(2). https://doi.org/10.20417/nzjecol.42.26

Rumpf, S. B., Hülber, K., Klonner, G., Moser, D., Schütz, M., Wessely, J., Willner, W., Zimmermann, N. E., & Dullinger, S. (2018). Range dynamics of mountain plants decrease with elevation. *Proceedings of the National Academy of Sciences*, *115*(8), 1848–1853. https://doi.org/10.1073/pnas.1713936115

Ryder, G., & Tocher, M. (2020). *Review of Values, Freshwater Restoration Programmes and Research Needs Within the Taieri Catchment*. Ryder Consulting Limited. https://www.doc.govt.nz/globalassets/documents/our-work/nga-awa-river-restoration/taiari-river-review.pdf

Salimi, S., Almuktar, S. A. A. A. N., & Scholz, M. (2021). Impact of climate change on wetland ecosystems: A critical review of experimental wetlands. *Journal of Environmental Management*, *286*, 112160. https://doi.org/10.1016/j.jenvman.2021.112160

Schuchardt, M. A., Berauer, B. J., Giejsztowt, J., Heßberg, A. V., Niu, Y., Bahn, M., & Jentsch, A. (2023). Drought erodes mountain plant community resistance to novel species under a warming climate. *Arctic, Antarctic, and Alpine Research*. https://www.tandfonline.com/doi/abs/10.1080/15230430.2023.2174282

Singers, N. J. D., & Rogers, G. M. (2014). *A classification of New Zealand's terrestrial ecosystems* (Science for Conservation 325, p. 91). Department of Conservation.

Stewart, M. K., & Fahey, B. D. (2010). Runoff generating processes in adjacent tussock grassland and pine plantation catchments as indicated by mean transit time estimation using tritium. *Hydrology and Earth System Sciences*, *14*(6), 1021–1032. https://doi.org/10.5194/hess-14-1021-2010

Taylor, K. T., Maxwell, B. D., McWethy, D. B., Pauchard, A., Nuñez, M. A., & Whitlock, C. (2017). *Pinus contorta* invasions increase wildfire fuel loads and may create a positive feedback with fire. *Ecology*, *98*(3), 678–687. https://doi.org/10.1002/ecy.1673

Tonkin & Taylor Ltd. (2021). *Otago Climate Change Risk Assessment* (1008813.3000.v0.4). Otago Regional Council.

Trewick, S., Hegg, D., Morgan-Richards, M., Murray, T. J., Watts, C., Johns, P., & Michel, P. (2022). *Conservation status of Orthoptera (wētā, crickets and grasshoppers) in Aotearoa New Zealand, 2022*. Department of Conservation.

Walker, S., Steel, J. B., Rapson, G. L., Roxburgh, S. H., King, W. M., Watkins, A. J., Myers, T. E., Keogh, J. A., McQueen, A. A. M., & Wilson, J. B. (2001). A *Chionochloa* / *Sphagnum* / Cushion Valley Bog in East Otago, New Zealand. *New Zealand Journal of Ecology*, *25*(1).

Watts, C., & Peters, M. (2010). Chapter 11: Pests. In *Wetland restoration: A handbook for New Zealand freshwater systems* (pp. 185–242). Manaaki Whenua Press, Landcare Research.

Wildland Consultants. (2020a). *Mapping of Indigenous and Exotic Vegetation Cover Across Dunedin City District*. Wildland Consultants Contract Report No. 4934. Prepared for Dunedin City Council. 13pp.

Wildland Consultants. (2020b). *Mapping of Potential Natural Ecosystems and Current Ecosystems in Otago Region*. Wildland Consultants Contract Report No. 5015a. Prepared for Otago Regional Council. 20pp.

Wildland Consultants. (2022). *Assessment of Options to Address the Ecological Effects of the Proposed Lake Onslow Pumped Hydro Scheme*. Wildland Consultants contract report No. 6390. Prepared for Ministry of Business and Innovation 129 pp.

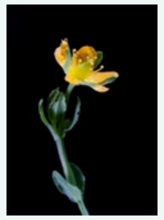
Wiser, S. K., Buxton, R. P., Clarkson, B. R., Hoare, R. J. B., Holdaway, R. J., Richardson, S. J., Smale, M. C., West, C., & Williams, P. A. (2013). New Zealand's naturally uncommon ecosystems. In J. R. Dymond (Ed.), *Ecosystem services in New Zealand – conditions and trends.* (p. 14). Manaaki Whenua Press, Landcare Research.

Woodford, D. J., & McIntosh, A. R. (2013). *Effects of introduced trout predation on non-diadromous galaxiid fish populations across invaded riverscapes.* (320; Science for Conservation, p. 27). Department of Conservation.

Xu, D., Bisht, G., Tan, Z., Sinha, E., Di Vittorio, A. V., Zhou, T., Ivanov, V. Y., & Leung, L. R. (2024). Climate change will reduce North American inland wetland areas and disrupt their seasonal regimes. *Nature Communications*, *15*(1), 2438. https://doi.org/10.1038/s41467-024-45286-z

Appendix 1

Lake Onslow notable wetland plant species

Species	Photograph	Distribution	Habitat	Life Cycle	Threats	Info Source
Anemonastum tenuicaule		Endemic. New Zealand, North and South Islands from the Tararua Ranges south	Upper montane to subalpine habitats (c.900-1,300 m a.s.l.) where it occurs in herbfield and short to tall tussock grassland. Usually in damp sites, flushes or seepages.	Hooked achenes are dispersed by attaching to fur, feathers and clothing	• Biologically sparse • Some lowland populations are threatened by competition from weeds.	https://pubmed.ncbi.nlm.nih.gov/29881324/ - phylogenetics https://www.nzpcn.org.nz/flora/species/anemonastrum-tenuicaule/
Halocarpus bidwillii		Endemic. New Zealand: North, South and Stewart Islands.	Lowland to subalpine. A shrub or small tree of wetland margins, bogs, poorly draining heathland, frost-flats, river beds and also dry, stony ground and tussock grassland.	Arrilate seeds are dispersed by frugivory	• In decline in some parts of its range.	https://www.nzpcn.org.nz/flora/species/halocarpus-bidwillii/
Hypericum rubicundulum		Endemic. North and South Island (Nelson - Southland except Marlborough and Westland)	A species growing on the margins of lakes and tarns and other wet depressions and seepages in drought-prone and dry-climate areas of inland South Island.	Seeds are wind and water dispersed.	• Confined to a very specific habitat. • Habitat under pressure because of water abstraction for dairy farms and residential developments.	https://www.nzpcn.org.nz/flora/species/hypericum-rubicundulum/ Heenan, P.B. 2008: Three newly recognised species of *Hypericum* (Clusiaceae) from New Zealand. *New Zealand Journal of Botany 46*: 547-558.
Isolepis basilaris		Endemic. North and South Islands from Hawkes Bay to Southland	Coastal, lowland to upland habitats, up to 700 m altitude. On damp, sandy or silty margins of lagoons, tarns, ephemeral lakes and rivers, freshwater or brackish.	Nuts are dispersed by water and possibly granivory and attachment	• Domestic and feral cattle, sheep, horses and pigs are the serious threats throughout this species range, mainly through browse, trampling • Spread of weeds. • Competition from taller vegetation • Development (e.g. road widening) and erosion • 4-wheel drive vehicles.	https://www.nzpcn.org.nz/flora/species/isolepis-basilaris/
Juncus pusillus		Endemic. North and South Islands from Bay of Plenty south.	Open, swampy ground, in cushion bogs and alongside tarn, lake and river margins. Coastal to alpine. Often associated with *Juncus novae-zelandiae*.	Mucilaginous seeds are dispersed by attachment, wind and water	• Naturally uncommon	https://www.nzpcn.org.nz/flora/species/ juncus-pusillus/
Leptinella maniototo		Endemic. North and South Island, mainly eastern from southern Marlborough to Central Otago and Lake Te Anau	Lowland to upper montane at least (0-1000 m a.s.l.), growing around lake, slow flowing stream, tarn, and kettlehole margins, and also in damp seepages and hollows within tussock grassland. It favours ephemeral wetlands and sites subject to seasonal flooding and drying episodes.	Papery cypselae are dispersed by wind and possibly attachment	• Susceptible to being out-competed by taller and more aggressive introduced grasses and flat weeds which are spreading in its habitat	https://www.nzpcn.org.nz/flora/species/leptinella-maniototo/
Lobelia ionantha		Endemic. New Zealand: South Island (Marlborough, Canterbury, Otago, and Southland).	Lowland to subalpine. A species of the margins of lake, tarn and ephemeral wetlands, stream banks, and seepages in tussock grassland, where it grows with other short turf and small herb species.	Likely primarily on water, maybe some animal dispersal	• Wetland habitats modified by changes in land use • Naturalised plant species.	https://www.nzpcn.org.nz/flora/species/lobelia-ionantha/ https://ourarchive.otago.ac.nz/bitstream/handle/10523/2149/GrayAbeG2012MSc.pdf?sequence=3&isAllowed=y

Species	Photograph	Distribution	Habitat	Life Cycle	Threats	Info Source
Epilobium angustum		Endemic. South Island, east of the main divide from Marlborough to Fiordland.	In the short turf around the margins of lakes and tarns and other seasonally inundated hollows of glacial origin; 180-820 m. Generally in open clay or stony areas in places that are periodically inundated with water, barely venturing far into the surrounding tussock grassland.	"Unknown"	• Intensification of farming practices and land modification. • Ploughing, pugging, and other disturbance • Infiltration of competitive weed species into the delicate turf communities	https://www.nzpcn.org.nz/flora/species/epilobium-angustum/ https://www.tandfonline.com/doi/pdf/10.1080/0028825X.1974.10428639
Montia angustifolia		Endemic. Known only from the South Island, east of the main divide from Nelson to Southland	An inhabitant of the marginal turf communities of lake and tarns.	"Unknown"	• Very specific habitat requirements • Sporadic distribution • Habitats heavily modified • Invaded by taller growing weed species.	https://www.nzpcn.org.nz/flora/species/montia-angustifolia/
Parahebe canescens (Veronica lilliputiana)		Endemic. New Zealand: South Island from Canterbury to Fiordland. Recorded on the Otago Peninsula.	Coastal (Otago Peninsula) but otherwise confined to montane areas where it inhabits the margins of ephemeral pools tarns and lakes, usually in places that dry out in summer.	"Unknown"	• "Unknown"	https://www.nzpcn.org.nz/flora/species/veronica-lilliputiana/
Pseudognaphalium ephemerum		Endemic. New Zealand, South Island, eastern from the upper Wairau River to Southland.	Montane to subalpine. Usually in intermontane basins where it is a plant of ephemeral wetlands, kettlehole, tarn and lake margins, strictly in places which are flooded in winter and dry out in summer.	"Unknown"	• Sparse, naturally uncommon plant • Reliant on suitable wetland habitats. • Weeds invading into ephemeral wetland habitat.	https://www.nzpcn.org.nz/flora/species/pseudognaphalium-ephemerum/
Carex tenuiculmis		Endemic. South, Stewart and Chatham Islands (both Chatham (Rekohu) and Pitt Islands)	A sedge of lowland to montane slow flowing stream sides, lake margins, tarns, ponds and associated wetland vegetation. This species usually grows in association with other carices including *Carex coriacea* Hamlin, *C. diandra* Schrank, *C. gaudichaudiana* Kunth, *C. secta* Boott and *C. virgata* Sol. ex Boott. It does not like tall vegetation.	Nuts surrounded by inflated utricles are dispersed by granivory and wind	• Naturally uncommon • Some populations at risk from development • Does not like tall vegetation.	https://www.nzpcn.org.nz/flora/species/carex-tenuiculmis/
Mentha cunninghamii		Endemic. New Zealand: North, South, Chatham and Stewart Islands	Coastal to alpine. Sparse component of grassland and other open places such as cliffs, riverbanks, lake sides, grey scrub, occasionally in swampy ground.	"Unknown"	• Habitat degradation by livestock, irrigation, drainage; weed competition	https://www.nzpcn.org.nz/flora/species/mentha-cunninghamii/ https://nativeplants.co.nz/index.php/product/mentha-cunninghamii-nz-mint
Pterostylis tanypoda		Endemic. South Island, east of the main divide from Marlborough to Southland.	Montane to subalpine, usually in intermontane basins, on river terraces or on low relief foothills, amongst tussock grasses, in grey scrub or in shingle. Sometimes found in grassland- dominant by exotic species.	Minute seeds are wind dispersed	• Naturally uncommon • Its preferred habitat has been extensively modified	https://www.nzpcn.org.nz/flora/species/pterostylis-tanypoda/
Olearia lineata		Endemic. South Island, easterly from north Canterbury south to Southland and Stewart Island.	Lowland to montane (10-300 m a.s.l.) grey scrub, tussock grassland and forest margins. Often on river terraces in or near seepages and ephemeral wetlands, on occasion even growing in shallow water. Also found on the margins of steep river gorges, and in and amongst rock outcrops, boulder field and at the toe of alluvial fans.	"Unknown"	• At times locally abundant otherwise only widely scattered sites with few individuals. • Recruitment is often lacking • Competition from weeds • Modification of habitat	https://www.nzpcn.org.nz/flora/species/olearia-lineata/ https://ir.canterbury.ac.nz/bitstream/handle/10092/10910/Michelle_Lambert_final_thesis_2015.pdf?sequence=1

Species	Photograph	Distribution	Habitat	Life Cycle	Threats	Info Source
Carex buchananii		Endemic. New Zealand: North and South Islands. In the South Island more widespread and at times locally common, though often sporadically distributed.	Coastal to montane (up to 1,000 m a.s.l.). On beaches, lagoon, lake and stream margins, or in damp ground within open forest or short tussock grassland.	Nuts surrounded by inflated utricles are dispersed by granivory and wind	• Drainage and modification of wetland habitats and weed competition, especially in lowland sites.	https://www.nzpcn.org.nz/flora/species/carex-buchananii/ https://rarespecies.nzfoa.org.nz/species/buchanans-sedge/
Cardamine mutabilis		North and South Islands. South Island: southeastern Nelson, Canterbury, and Otago. Holotype: Otago, Lake Onslow, Fortification Stream, 700 m, gently sloping turfy edge of old stream oxbow in red tussock grassland,	Usually occurs on the periodically inundated turfy margins of montane and inland tarns and lakes, and also in wetlands associated with the banks and edges of streams. When associated with tarn and lake margins it occupies the marginal turf zone as water retreats and the margin dries out. It has also been collected from wet ground in tussock-grassland and herbfields.	"Unknown"	• Lake and tarn margin habitat is dependent on fluctuations in water level for suitable habitat • Intensive management is required for weed control	https://www.nzflora.info/factsheet/taxon/Cardamine-mutabilis.html
Carex purpurata		Endemic. South Island, Canterbury (Fox Hill), Otago (hills near Dunedin, Ben Lomond, Mt Benger and other peaks and ranges of Central Otago) and Southland	A species of damp, open ground under montane forest and subalpine scrub, in tall tussock grassland, in grey scrub and in or near cliff faces. It prefers damp sites in seepages, near small springs or under rock overhangs.	Granivory and wind (inferred from related taxa)	• Biologically sparse, naturally uncommon sedge.	https://www.nzpcn.org.nz/flora/species/carex-purpurata/ https://www.nzpcn.org.nz/site/assets/files/0/55/951/carex-species-of-southland-vol2.pdf
Brachyscome humilis		Endemic. South Island: Central Otago (Rock and Pillar Range)	Alpine. Inhabiting snowbanks and hollows above 1200 m	Pappate cypselae are dispersed by wind	• Probably Naturally Uncommon but threat status unresolved	https://www.nzpcn.org.nz/flora/species/brachyscome-humilis/
Chaerophyllum colensoi var. *delicatulum*		Endemic to New Zealand, North and South Islands. Mainly easterly distribution in the South Island.	A plant of ephemeral wetlands, subalpine flushes, and tarn margins. Strictly subalpine in the North Island but descending to lower montane habitats in the South Island.	"Unknown"	• Habitats vulnerable to invasion by faster growing and taller weeds. • Changes in the hydrology of wetlands	https://www.nzpcn.org.nz/flora/species/chaerophyllum-colensoi-var-delicatulum/
Crassula multicaulis		Endemic. North and South. In the South Island scarce in North West Nelson, southern Marlborough and Canterbury, North and Central Otago.	Coastal, lowland to alpine (0- 1800 m a.s.l.) in open, seasonally damp ground, such as clay or salt plans or around tarn margins. It has also been collected from braided river beds.	Minute follicles are dispersed by wind and water and possibly also by attachment	• Habitats are largely drained • Exotic weeds.	https://www.nzpcn.org.nz/flora/species/crassula-multicaulis/
Deschampsia cespitosa		Indigenous. New Zealand: North, South, Stewart and Chatham Islands.	Wetlands and lake margins. Coastal to subalpine damp grass or sedge swards near lakes, rivers and swamps. Also found in estuarine margin communities.	Florets are wind dispersed	• Grazing and trampling by cattle (chief cause of decline) • Contamination or replacement of NZ forms of Deschampsia with imported forms	https://www.nzpcn.org.nz/flora/species/deschampsia-cespitosa/

Species	Photograph	Distribution	Habitat	Life Cycle	Threats	Info Source
Euchiton paludosus		Endemic. North, South and Stewart Islands. In the South Island local from Nelson to Southland.	Montane to subalpine mainly in bogs, or occasionally along stream and tarn margins, seepages and flushes within forest, shrubland, tussock grassland or herbfield.	Pappate cypselae are dispersed by wind and water	• Naturally uncommon, biologically sparse • Threatened at some sites by weeds	https://www.nzpcn.org.nz/flora/species/euchiton-paludosus/
Myosotis bryonoma		Endemic. New Zealand, South Island, Otago	In damp to saturated high-elevation (subalpine to alpine) bogs, seepages, flushes, hollows, swamps, wetlands, and snow-melt streams and banks; on silt, peat, schist, basalt in exposed, sunny, flat or gently sloping open areas of smooth, short mossy bog turf containing mixed bryophytes, cushions -plants and small herbs	"Unknown"	• Biologically sparse • Tied to small areas of suitable alpine bog habitat.	https://www.nzpcn.org.nz/flora/species/myosotis-bryonoma/
Myosurus minimus subsp. novae-zelandiae		Endemic to New Zealand, North and South Islands. In the South Island it is known only from the eastern side, from Marlborough south to Lake Manapouri.	Lowland to upland. Damp and slightly salty depressions in pastures and short tussock grassland, on the margins of tarn and kettle holes, and in damp dune hollows, gravel flats and alluvium.	Adapted for epizoochoric dispersal. seeds in moa coprolites	• Biologically sparse • Habitats invaded by faster growing, taller or turf forming, perennial weeds such as Plantago coronopus. • Changes in hydrology, caused by land use: conversion of upland mixed sheep/cattle to dairy. Canalisation and use of bore water reducing the number of ephemeral wetlands, kettle holes and tarns.	https://www.nzpcn.org.nz/flora/species/myosurus-minimus-subsp-novae-zelandiae/ https://www.tandfonline.com/doi/pdf/10.1080/00288250709509720?needAccess=true
Ranunculus macropus		Endemic to the North and northern South Islands. In the South Island always scarce (2010), a population was found at Canadian Flats (Taiari River), and scattered populations are present in Canterbury.	Coastal to lowland. Usually found in raupō (*Typha orientalis*)-dominant wetlands where it grows in still moderately deep to deep water.	"Unknown"	• Naturally scarce • Wetland drainage, modification • Spread of weeds. • Hybridisation	https://www.nzpcn.org.nz/flora/species/ranunculus-macropus/ https://www.researchgate.net/publication/265087649_The_vegetation_and_flora_of_'Matukureia_Swamp'_Puhinui_South_Auckland_-_with_notes_on_Ranunculus_macropus
Carex talbotii (Carex berggrennii)		Endemic. North and South Islands. In the South Island mainly easterly from Lake Tennyson south.	A montane to subalpine (rarely lowland in the southern part of its range) wetland species inhabiting lake, tarn, pond, and stream side margins. It has also been collected from turfs bordering ephemeral wetlands.	"Unknown"	• A biologically sparse species • Some populations at risk through competition from taller and faster growing wetland weed species.	https://www.nzpcn.org.nz/flora/species/carex-talbotii/ https://www.researchgate.net/publication/341999662_Carex_talbotii_Cyperaceae_a_replacement_name_for_Berggren's_Sedge https://www.fs.fed.us/r6/icbemp/science/newhousebruce.pdf (carex dispersal is mixed)

Appendix 2

Scoring tables

LOW BENEFIT-HIGH COST SCENARIO SCORING TABLE

Actions		Benefits				Cost			Benefit-Cost Ratio
		Improvement in Climate-Change Resilience Score	Wider Ecological Benefit Score	Wider Social Benefit Score	Overall Benefit Score	DOC Monetary Cost Score	Community Cost Score	Overall Cost Score	
Direct	**Weed control**	3	2	2	**2.50**	2	1	**1.67**	1.50
	Invasive browser control	2	2	2	**2.00**	2	1	**1.67**	1.20
	Invasive predator control	1	2	0	**1.00**	2	0	**1.33**	0.50
	Alpine species translocation	0	1	0	**0.25**	3	0	**2.00**	0.13
	Direct wetland restoration	1	1	1	**1.00**	3	0	**2.00**	0.50
Indirect	**Wetland monitoring**	2	0	0	**1.00**	2	0	**1.33**	0.75
	Fire restrictions	2	2	1	**1.75**	1	2	**1.33**	1.31
	Grazing restrictions	2	1	0	**1.25**	1	2	**1.33**	0.94
	Infrastructure restrictions	1	1	1	**1.00**	1	3	**1.67**	0.60
	Vehicle access restrictions	1	1	1	**1.00**	1	2	**1.33**	0.75

HIGH BENEFIT-LOW COST SCENARIO SCORING TABLE

Actions		Benefits				Cost			Benefit-Cost Ratio
		Improvement in Climate-Change Resilience Score	Wider Ecological Benefit Score	Wider Social Benefit Score	Overall Benefit Score	DOC Monetary Cost Score	Community Cost Score	Overall Cost Score	
Direct	**Weed control**	3	3	3	**3.00**	2	1	**1.67**	1.80
	Invasive browser control	***3***	3	2	**2.75**	2	1	**1.67**	1.65
	Invasive predator control	1	2	1	**1.25**	2	0	**1.33**	0.75
	Alpine species translocation	0	2	0	**0.50**	3	0	**2.00**	0.63
	Direct wetland restoration	1	2	1	**1.25**	3	0	**2.00**	0.63
Indirect	**Wetland monitoring**	3	1	1	**2.00**	1	0	**0.67**	3.00
	Fire restrictions	2	2	1	**1.75**	1	2	**1.33**	1.31
	Grazing restrictions	2	2	1	**1.75**	1	2	**1.33**	1.31
	Infrastructure restrictions	2	2	2	**2.00**	0	1	**0.33**	6.00
	Vehicle access restrictions	1	1	1	**1.00**	1	1	**1.00**	1.00

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