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Distributions and statuses of three highly threatened calcicolous plants in limestone habitats of South Canterbury, New Zealand

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CONTENTS

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Abstract

Limestone ecosystems provide habitat for a number of endemic, calcicolous, herbaceous plants, most of which are threatened. South Canterbury has at least six such taxa, but information about their ranges, distributions, population sizes and particular threats has been limited. This study surveyed limestone habitats in South Canterbury for three of these taxa – *Ranunculus callianthus*, *Gentianella calcis* subsp. *manahune* and *G. calcis* subsp. *taiko* – all of which are classified as Nationally Critical under the New Zealand Threat Classification System. *Ranunculus callianthus* and *G. calcis* subsp. *manahune* were both found on only one limestone escarpment in extremely small and fragmented populations. The number of *R. callianthus* plants has declined by c. 72% over a period of 12 years, while *G. calcis* subsp. *manahune* plants in the main sub-population have decreased by c. 63% in the same period. Weed invasion and grazing pressure seem to be the main reasons for the drastic declines of these taxa, both of which face extinction and require urgent intervention. Observations for *G. calcis* subsp. *taiko* confirmed that there are two main sub-populations as well as plants at several smaller, isolated sites, which represents a range extension for this subspecies. While numbers are slightly higher than for the other two taxa, sites face similar threats from introduced grasses, clover (*Trifolium* spp.), and weeds such as hawkweeds (*Pilosella* spp.), stonecrop (*Sedum acre*) and, in some cases, pōhuehue (*Muehlenbeckia australis*) and gorse (*Ulex europaeus*). Conservation measures for all three taxa are suggested and discussed.

Keywords: endemic calcicolous plants, *Ranunculus callianthus*, *Gentianella calcis* subsp. *manahune*, *Gentianella calcis* subsp. *taiko*, conservation, grazing, weed competition, weed control

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1. Introduction

Limestone formations, which include cliffs, outcrops, scarps, boulder fields, pavements and screes, are recognised as distinct landforms and ecosystems in New Zealand (Williams et al. 2007; Rogers et al. 2018) and often contain a specialised flora. In South Canterbury, limestone outcrops occur in the hinterland between the coastal lowlands and the foothills of the Southern Alps/Kā Tiritiri o te Moana (Fig. 1), often along the edges of river valleys, where they create prominent visual landmarks in the wider landscape – although several scarps are somewhat hidden inside valleys or away from public roads. As in most other parts of New Zealand, they are not a continuous landscape feature and cover a very small area of the region, occurring on only c. 25 km^2 (c. 0.2%) of the 13 745 km^2 land area of South Canterbury. These landforms, which are considered to be historically rare terrestrial ecosystems, exhibit high biotic diversity, providing habitats for plants, birds, bats, lizards, invertebrates and micro-snails (Worthy 1997; Frank 2018). However, these important ecosystems are classified as Vulnerable (Holdaway et al. 2012; Wiser et al. 2013) and the indigenous vegetation that occurs here is acutely threatened (Walker et al. 2006; Cieraad et al. 2015).

Most limestone areas in South Canterbury are on private land, and much of their indigenous vegetation has been modified and depleted in the last few centuries through land development (Pawson & Holland 2008). However, due to their difficult terrain, they have mostly escaped the drastic modification that has occurred in surrounding areas and have retained remnants of native vegetation, acting as refuges for once widespread biodiversity, particularly plants. In addition to typical plants of the lowland environment, the calcareous substrate provides conditions for a range of plants that are adapted to or need a high level of calcium. These calcicolous plants must also be able to survive in extreme weather conditions. They show high levels of endemism due to variations in formation and substrate composition, aspect, altitude, weather conditions, microclimate, and especially the fragmentation and isolation of limestone ecosystems by surrounding landforms (Rogers et al. 2018; Heenan & Rogers 2019) – and this is particularly true of the herbaceous plants that occur here.

South Canterbury's calcicolous flora did not receive much interest from scientists until the end of the 20th century. Fraser Ross, a local conservationist, explored limestone areas from the late 1970s and worked to raise awareness for their biodiversity values, including advocating for their recognition in district plans. Additionally, Brian Molloy, then with the Botany Division of the Department of Scientific and Industrial Research (DSIR), visited many limestone sites in the region from the early 1980s onwards (F. Ross, pers. comm.; Heenan & Rogers 2019) and drew attention to the unique biodiversity of this ecosystem, particularly the limestone-obligate plants.

From the work of Brian Molloy (e.g. Molloy 1994) and others, it is known that South Canterbury's limestone formations provide habitats for a number of calcicolous plants. Most of these plants are threatened and at least six taxa are endemic to the region, with others awaiting further ecological and taxonomic research (Heenan & Rogers 2019). The six endemic perennial herbs currently recognised in this region are *Gentianella calcis* subsp. *manahune* and *Gentianella calcis* subsp. *taiko* (Glenny 2004), *Cardamine caesiella* and *C. integra* (Heenan 2017), and the recently described *Geranium socolateum* (which also has a small population in North Otago) and *Ranunculus callianthus* (Heenan & Molloy 2019), all of which are classified as Nationally Critical under the New Zealand Threat Classification System (de Lange et al. 2018). However, previous research has focused on the taxonomy and conservation status of these taxa, with no detailed information being available on their distributions, population sizes, habitat preferences and threats.

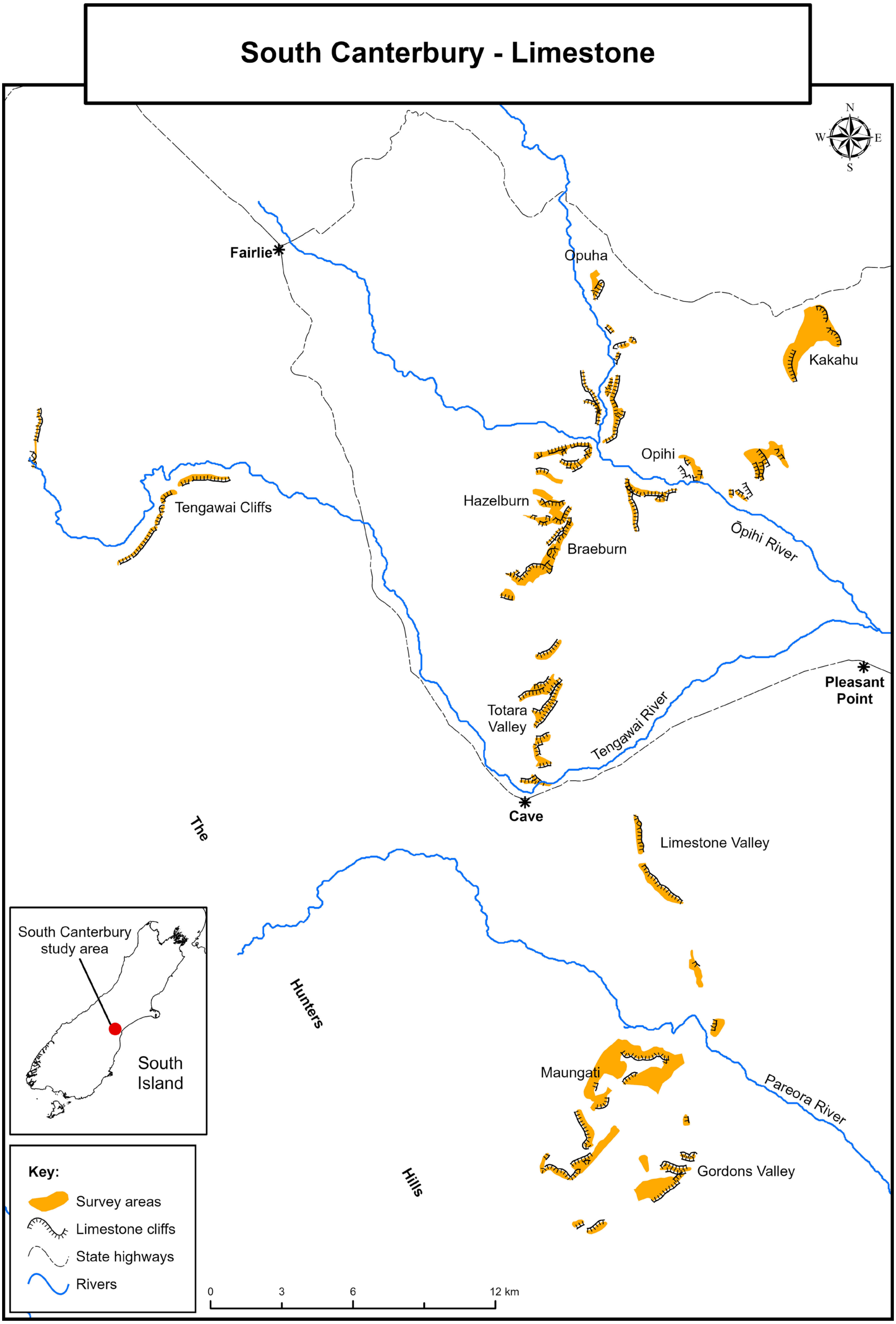

Figure 1. Limestone areas surveyed in South Canterbury.

From 2002 to 2004, the Raukapuka Area Office of the Department of Conservation Te Papa Atawhai (DOC) initiated a basic field survey of plants inhabiting limestone areas of South Canterbury (Pender et al. 2004). This survey aligned with property boundaries and covered 34 properties between Kakahu in the north and the Waihao Downs in the south. However, this survey work was limited to one visit per site during the summer months, access was not possible to some important limestone habitats, and the report for each property usually only provided a species inventory and some notes on the conservation status, with few further details.

From 2005 to 2016, an estimated 90% of limestone habitats in the Timaru District were surveyed as part of the Significant Natural Areas (SNA) mapping programme and a report was written for each surveyed property (Harding 2016). However, limestone habitats in the Waimate and Mackenzie districts still await SNA assessments, and the SNA reports again contained mainly species lists. Furthermore, while the reports did elaborate on the particular ecosystem, threatened plants, other values and issues, such as weed infestation, they provided little data on particular taxa and will not be accessible to the public until they become official documents in the district plan.

Heenan & Rogers (2019) suggested that the first steps to preserving and possibly restoring ecological values are basic surveys, including an inventory and assessment of the ecosystem and the population status and threats for individual species. This study aims to provide additional information for three of the calcicolous plants that are endemic to South Canterbury: *Ranunculus callianthus*, *Gentianella calcis* subsp. *manahune* and *Gentianella calcis* subsp. *taiko*.

2. *Ranunculus callianthus* (Manahune buttercup)

2.1 Background

According to Heenan & Molloy (2019), *R. callianthus* was first collected from a limestone scarp at Manahune in South Canterbury by Brian Molloy in November 1992. The species was given the tag name *Ranunculus* aff. *stylosus* and first appeared in a threatened species list in a 1999 revision of ‘Threatened and uncommon plants of New Zealand’ (de Lange et al. 1999), where it was placed in the category ‘Taxonomically indeterminate taxa’ and assessed as Endangered. In the subsequent revision of that publication (de Lange et al. 2004), it was assessed as Nationally Endangered with the qualifiers Human Induced and One Location, being known only from the western end of an extensive limestone escarpment above the Tengawai River. In the latest revision of the list (de Lange et al. 2018), which used the criteria of Townsend et al. (2008), the species was considered Nationally Critical with the qualifiers A(1) (i.e. ≤ 250 mature individuals) and One Location.

The DOC surveys conducted between 2002 and 2004 included all of the properties of the Tengawai Cliffs except one, named property B in this paper. This survey confirmed the presence of *Ranunculus* aff. *stylosus* at the known location with the comment ‘locally abundant at the southwestern end’, but no estimates of the population size or precise locations were given. A small population ‘with less than 10 plants’ was also noted at the eastern end of the escarpment, named property A here, on 20 December 2003 (Pender et al. 2004).

In November and December 2007, Alice Shanks surveyed property A and the southwestern part of property E for rare plants on behalf of DOC. She recorded 42 *Ranunculus* plants on the limestone scarp of property A and 259 plants in the southwestern part of property E (Shanks 2015).

In preparation for a study of lizards in limestone areas of South Canterbury in 2008 (Frank & Wilson 2011), the author visited properties along the same limestone scarp on two dates in spring 2007 and noticed a considerable number of *Ranunculus* plants in flower in parts of the limestone section of the station that had not been included in the DOC surveys. A rough count was made of the flowering plants in the two main sub-populations on that property, resulting in 254 flowering plants being recorded on 20 October 2007. In December 2015, Peter Heenan (Landcare Research) visited the original site and noted c. 80–90 *Ranunculus* plants (pers. comm.). The species was formally described as *Ranunculus callianthus* in 2019 (Heenan & Molloy 2019).

2.2 Study area and methods

The author started annual surveys for *R. callianthus* in 2016 which continued through to 2019. The main focus of this survey work was the prominent escarpment west of Albury along the upper reaches of the Tengawai River, referred to here as the Tengawai Cliffs (see Fig. 1). Although the Tengawai Cliffs are up to 40 m high, they are mostly hidden from public view by a ridge. The total length of the escarpment is about 7 km, intersected by five side gullies or stretches of land without exposed limestone. The width of the land covered by exposed limestone (cliffs, pavements), rock stacks and boulder fields varies from approximately 70 to 150 m and the land area is c. 70 ha. The section near the northeastern end (c. 2 km long) faces north, while the other parts mainly face northwest. Elevation increases from 320 m above sea level (a.s.l.) at the base of the cliffs in the northeast to 524 m a.s.l. at the top of the cliffs in the southwest. The escarpment is exposed to extreme weather changes, with northwesterly winds in particular reaching gale force at times, which can cause quick drying and wind erosion of the soils.

The limestone sections of the Tengawai Cliffs are part of five private farming properties (here named A–E from northeast to southwest; Fig. 2). The property boundaries run roughly perpendicular to the escarpment through sections without exposed limestone, except in one case where the boundary occurs approximately halfway along the particular scarp section (between D and E). The land is used for grazing sheep, cattle, deer and, on one property, goats – this flock of goats is kept to control thistles in the limestone blocks of the farm.

Very little is known about the original vegetation cover of the limestone scarp. Smith (1885) mentioned that 'the district around the Tengawai Gorge is particularly rich in native vegetation and the spurs are clothed with *Veronicas* and *Celmisias*'. However, it is unlikely that this also applies to the limestone escarpment, as Smith also reported that 'The limestone range is overgrown with *Anthericum hookeri*' (now known as *Bulbinella hookeri*), indicating that the vegetation near the limestone escarpment was more open at the time. Incidentally, this indigenous plant species has not been recorded there in recent times.

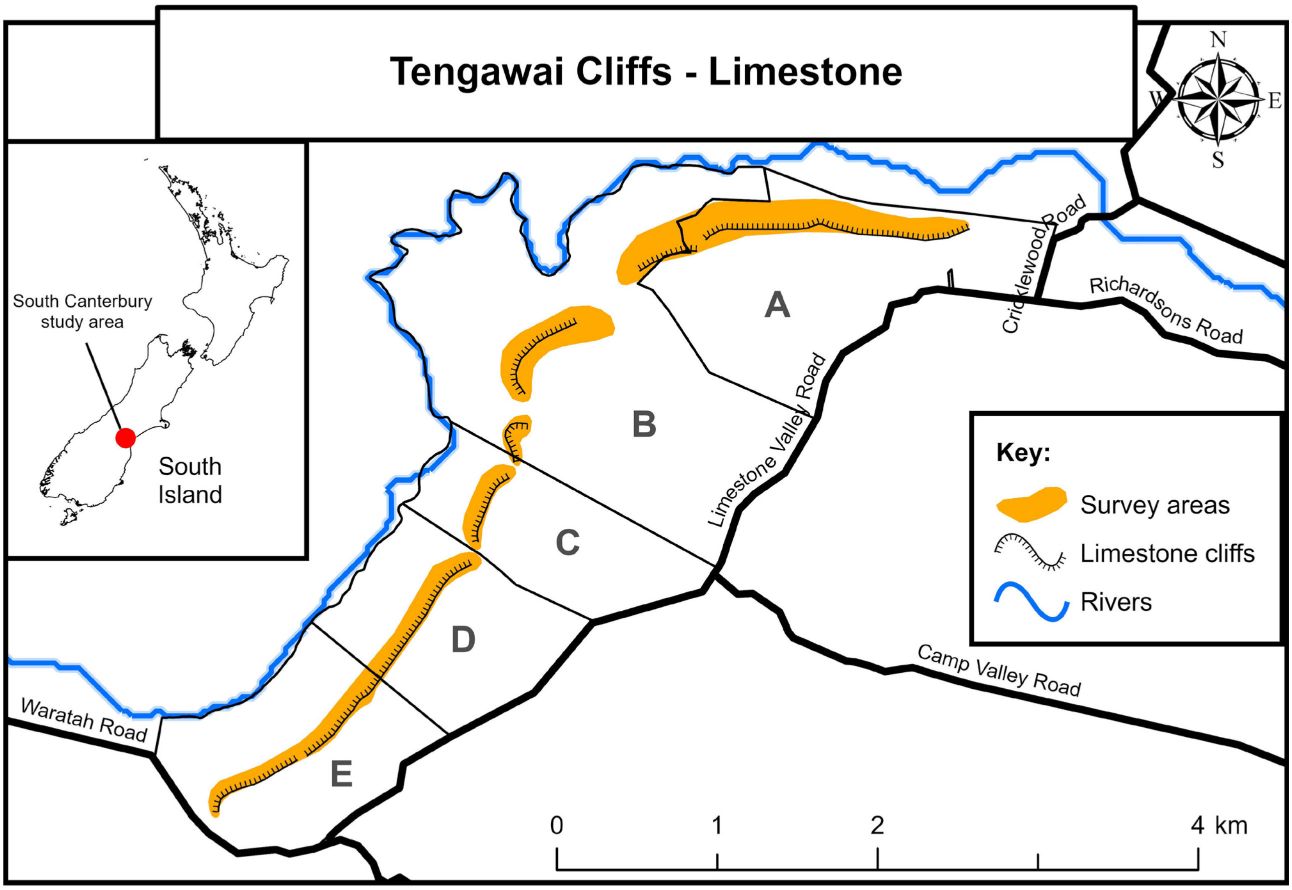

Figure 2. Property boundaries and limestone areas on the Tengawai Cliffs (see text).

The indigenous vegetation in this area has been highly modified, with only remnants remaining and exotic grasses, herbs and shrubs mostly growing in its place. Property A at the northeastern end has better native vegetation cover with higher diversity, but also shows high infestations of weedy species, especially barberry (*Berberis glaucocarpa*) and horehound (*Marrubium vulgare*). Moving southwest, areas have increasingly less woody vegetation and even shrubland is sparse. At the southwestern end, the shrublands appear to have been sprayed within the last decade. The limestone part of property C was protected by a Queen Elizabeth II National Trust (QEII) covenant in 2018.

All areas along the escarpment with potentially suitable habitat for *R. callianthus* were surveyed during the later part of the flowering season, which runs from mid-September to November, due to access restrictions at lambing time. Outside the flowering period, plants are inconspicuous and difficult to find, especially in places that are not easily accessible. All potential locations were searched at least once. Binoculars and a compact digital camera with a large zoom lens (max. 720 mm equivalent) were used to survey inaccessible places, although no *Ranunculus* plants were detected with this method. All searches were conducted only by the author, with the exception of one occasion when another person joined for a morning, and survey efforts were increased in the spring seasons of 2018 and 2019. The total number of person hours spent surveying were approximately 7 hours in each of 2016 and 2017, 22 hours in 2018, and 27 hours in 2019. Access could not be gained to one property in 2017 and to another until autumn 2019 due to changes in ownership or lease agreements. Access to private properties has generally become more difficult over the years due to concerns about health and safety regulations and biosecurity issues. Established contacts with landowners and knowledge of the areas acquired through the lizard surveys were advantageous for the buttercup survey as well as the gentian work (see sections 3 and 4). Other limestone places in South Canterbury (e.g. near the Pareora Gorge, in the Limestone Valley near Taiko, in the Totara Valley and near Raincliff) were also searched for *R. callianthus* in spring 2018 and 2019.

2.3 Results

Ranunculus callianthus (Fig. 3) is restricted to the Tengawai Cliffs and was found on only two of the properties (B and E) plus one small adjacent site in a neighbouring property D. The small population on property A that was recorded in 2003 and 2007 could not be found despite extensive searches and seems to be extinct. During the spring surveys of 2019, the only year when it was possible to get a result for the full escarpment, 153 flowering and 46 non-flowering plants were found. If any flowering plants were overlooked, it will have been a very small number in inaccessible places. A summary of the results is provided in Table 1. B1, B2, E1, E2 and E3 in Table 1 represent specific areas where sub-populations grew within properties B and E, with the number of plants at each site within these areas ranging from 1 plant to clusters of 11 plants. The maximum number of flowering plants within a sub-population was 61 plants. To assist further work on these taxa, more detailed versions of this table and subsequent tables in the report that include GPS coordinates are available from the author or South Canterbury Museum upon request.

Sub-populations and individual plants or small clusters were widely scattered in the study area. The distance between sites in properties B and E was c. 3.5 km, and distances between individual plants or small clusters within the areas, especially E1 and E2, varied from 30 m to 240 m, indicating that all these sites were highly isolated. The main sub-populations were all found growing in shallow, often bare rendzina soil facing northwest to west. In 2007, the sub-population in B1 had 89 flowering plants spread over an area of c. 1900 m^2, while in 2019 there were only 16 plants in an area of c. 50 m^2 plus 6 plants in two separate sites. Individual plants or clusters of up to 11 plants mostly grew in rock cracks or gaps between rocks facing north to west (Fig. 4).

Table 1. Numbers of *Ranunculus callianthus* plants recorded on the Tengawai Cliffs. Results are shown for surveys undertaken in December 2003 by the Department of Conservation Te Papa Atawhai (2003), 2007 by the author (2007A), November/December 2007 by Alice Shanks (2007B) and 2016–2019 in the present study. Rc A–E3 = areas with *Ranunculus callianthus* sites on properties A–E; fl = flowering plants; non-fl = non-flowering plants.

SITE	ASPECT	2003	2007A	2007B	2016		2017		2018		2019	
					FL	NON-FL	FL	NON-FL	FL	NON-FL	FL	NON-FL
Rc A	NW	<10		42	0	0	No access		0	0	0	0
Rc B1	NW		89		No access		No access		No access		22	10
Rc B2	NW–W		165								61	22
Rc C					0	0	0	0	0	0	0	0
Rc D	NW				0	0	0	0	4	0	4	0
Rc E1	N–W				4	0	20	0	16	0	22	9
Rc E2	N–W				14	0	17	0	13	4	23	4
Rc E3	W	Abundant		259	25	3	23	5	34	2	21	1
Total			**254**	**301**	**43**	**3**	**60**	**5**	**67**	**6**	**153**	**46**

Figure 3. *Ranunculus callianthus* in flower (area B1, 29 September 2007).

Figure 4. Cliffs with a small stand of *Ranunculus callianthus* in the bottom left corner (area E1, 14 October 2017).

Even in those exposed locations, some plants were struggling to compete with introduced weeds such as stonecrop (*Sedum acre*), black medic (*Medicago lupulina*) and hawkweeds (*Pilosella* spp.) (Figs 5 & 6). Stonecrop had established in area E2, where it had formed closed bands along exposed limestone margins (Fig. 7). However, exotic grasses, especially red fescue (*Festuca rubra*), are occupying many sites and pose the main competition. Numbers of *R. callianthus* plants were declining at some sites (e.g. from 11 plants in 2017 to 2 plants in 2019 at a site in area E2, or from 9 plants in 2017 to 2 plants in 2019 at a site in area E1) due to grass competition (Fig. 8). In some areas, *R. callianthus* plants were clearly being affected by browsing or trampling by goats or sheep. The effects of grazing were observed in both of the main sub-populations, especially after periods of heavy grazing as seen on visits in autumn 2020 (Fig. 9).

Figure 5. *Ranunculus callianthus* plant competing with grasses and stonecrop (*Sedum acre*) (area E2, 14 October 2017).

Figure 6. *Ranunculus callianthus* plant amongst grasses and hawkweeds (*Pilosella* spp.) (area E1, 3 November 2017).

Figure 7. Stonecrop (*Sedum acre*) along exposed limestone margins that had been sprayed (area E2, 3 November 2017).

Figure 8. *Ranunculus callianthus* plant struggling under grass competition (area E2, 25 January 2019).

Figure 9. Effects of grazing on *Ranunculus callianthus* plant (area B2, 1 May 2020).

2.4 Discussion

Ranunculus callianthus is seriously threatened with extinction, with the species now being absent from property A, showing a decline of 67% over 12 years on property B, and exhibiting an even more dramatic decline of 83% in areas E2 and E3 on property E. If the data for the full range of the taxon are analysed, it can be safely estimated that a minimum of c. 555 plants were present on the escarpment in 2007 compared with the 153 flowering plants counted here in 2019, representing a decline of c. 72% in 12 years. It is most likely that the actual decline is higher because property B was not searched thoroughly in 2007 and Alice Shanks did not survey the eastern part of property E in the same year.

The reasons for the severe decline of this species over this 12-year period are currently unclear, though there are some indications. On property B, grasses seemed to be better established in 2019 than during the previous survey. Stonecrop had also spread since 2007, when it seemed to have been new to the area, but it was not at a level where it would have impacted the *Ranunculus* plants substantially as it did not form mats, most likely due to disturbance by stock. However, some other stress factors seemed to be present. For instance, one plant was seen flowering in March 2019, which could be an indication of stress-induced flowering, possibly due to chemical changes in soil composition as a result of fertiliser spread or the congregation of stock. Sites on property A where the species was found in 2007 had large numbers of dandelion (*Taraxacum officinale*), which also suggests a change in soil composition. However, the most important threat to *R. callianthus* seems to come from grazing pressure, as suggested by the substantial effects of browsing, so additional plants might have been grazed to the point of being visually undetectable, and weeds, such as dense patches of hawkweeds, might also prevent the establishment of young plants. Seed viability and recruitment do not seem to be an issue at some sites as they had good numbers of seedlings (Fig. 10).

Weeds and stock pressure also seem to have been the main reasons for the drastic decline of this species on property E, exacerbated by the presence of goats. On at least one occasion in 2017, the limestone areas of property E were top-dressed, which most likely increased grass competition further and possibly changed the soil chemistry. Additional nutrients from stock camps can filter down on slopes and into crevices, and even sites that may have provided marginal habitat for *R. callianthus* (e.g. in rock cracks where there was less competition by exotic plants at the time of establishment) had been invaded by grasses and weeds.

Ranunculus callianthus is also threatened by high fragmentation and isolation of its sub-populations, which might be preventing the exchange of genetic material. The resulting inbreeding might lower the long-term viability and limit the resilience of this species (Walker et al. 2008).

For *R. callianthus* to survive on limestone outcrops, intervention is urgently required. A combination of conservation measures is necessary, some immediate and others longer term. Short-term measures that are needed to secure current sites are hand-weeding around the plants to reduce competition from exotic grasses and herbs and the installation of wire-netting enclosures to protect the plants from browsing. These sites will then need to be monitored over the long term to evaluate the effectiveness of these measures. At the time of writing, three sites with clusters of up to seven plants each had been covered with wire netting and were showing encouraging results. Within a year, plants had recovered and were considerably larger than unprotected plants (Fig. 11), with diameters of up to 10 cm compared with the 3–4 cm of most unprotected plants. The timing of hand-weeding appears to be critical though, as some plants that had been hand-weeded in January showed what looked like sunburn later on, possibly due to the sudden removal of shade that the grasses might have provided.

Figure 10. *Ranunculus callianthus* recruitment – seven plants can be seen (area B2, 21 May 2020).

Figure 11. *Ranunculus callianthus* plants in a trial enclosure (area E2, 10 October 2019).

More widespread weed control is also needed to provide new micro-habitat for *R. callianthus*. This could be achieved by applying chemicals using a hand-sprayer or knapsack-sprayer. Stonecrop control with herbicides has been carried out since 2017 on property E and since 2018 on properties A, B, C and D. This has been undertaken by volunteers and, in the QEII covenant, through the engagement of specialist contractors at sites where abseiling was necessary. These efforts have brought stonecrop numbers down to a level where most time is now spent searching for small plants. Timing also seems to be important for the success of chemical applications, with weed control being very successful when carried out between late October and the end of December during the growing period, but spraying after December being less successful, with a considerable percentage of stonecrop plants surviving.

The most crucial action required to protect *R. callianthus* is the modification of farm management practices in limestone habitats, including a change in the grazing regime, the cessation of top-dressing and, on property E, the withdrawal of goats. Stopping grazing altogether might have other negative effects as it would further increase grass and weed competition for these small herbs. However, there are few long-term data available regarding the effects of grazing withdrawal. Therefore, as a first and immediate step, it may be necessary to fence off particular outcrops or other smaller areas that provide suitable habitat for *R. callianthus* and are of a size that can be sufficiently managed. These sites would require considerable resources for regular monitoring and weeding but would allow comparisons to be made with non-managed sites to improve our understanding of the ecological requirements of *R. callianthus* and provide guidelines for further management. Increasing native shrub cover could increase habitat niches over time, and soil tests taken at selected sites over a number of years could give a better understanding of what soil conditions might be suitable for *R. callianthus* and what changes are occurring over time.

Ex situ conservation measures should also be considered, including the collection and storage of *R. callianthus* seeds and the growing of plants in cultivation, but this should be only a small part of the protection strategy. The main goal needs to be to protect and improve the situation for wild populations.

3. *Gentianella calcis* subsp. *manahune* (Manahune gentian)

3.1 Background

Gentianella calcis subsp. *manahune* was first noted and collected on the southwestern end of the Tengawai Cliffs by Brian Molloy in May 1992 (Glenny 2004). It was given the tag name *Gentiana* aff. *astonii* (c) (CHR 542276; Manahune) in the 2004 revision of 'Threatened and uncommon plants of New Zealand' (de Lange et al. 2004), where it was placed in the category 'Taxonomically indeterminate taxa' and assessed as being Nationally Critical with the qualifier One Location. In the same year, David Glenny (2004) published a revision of the genus *Gentianella* in New Zealand, in which the *G. astonii* complex was divided into two calcicolous species: *G. astonii* of Marlborough and a new species, *G. calcis* of North and South Canterbury. Four subspecies of *G. calcis* were described: subspp. *calcis, waipara, manahune* and *taiko*. Glenny noted that *G. calcis* subsp. *manahune* was described from limited material because of the rarity of the subspecies and his photograph in the revision shows a small specimen. Glenny also mentioned that only 35 plants were seen by himself and Molloy on a brief visit to Manahune in May 1999 and that it was 'likely that the population consisted of c. 100 plants, though parts of suitable habitat could not be searched because of their steepness'. In the 2008 revision of 'Threatened and uncommon plants of New Zealand' (de Lange et al. 2009), *G. calcis* subsp. *manahune* was assessed as Nationally Critical with the qualifiers Extreme Fluctuations and One Location. In all subsequent threatened plant lists, the subspecies has remained in the category Nationally Critical with the qualifier A(3) (Total area of occupancy ≤ 1 ha) and One Location (de Lange et al. 2013, 2018).

The limestone survey undertaken by DOC confirmed the presence of *G. calcis* subsp. *manahune* at the original site in December 2002, with the comment 'locally abundant at the southwestern end'. At the eastern end of the Tengawai Cliffs, a small population 'with only less than 10 plants' was seen in December 2003, but it was suggested that the subspecies 'may occur on cliff ledges, that proved too dangerous to get to' (Pender et al. 2004). In November 2007, Alice Shanks (2015) recorded 357 plants on the southwestern part of property E. During 2007 and 2008, in connection with the lizard survey (Frank & Wilson 2011), the author observed limestone gentians on all five Tengawai Cliffs properties and a number of photographs were taken on each property, but no detailed notes were kept. However, a comparatively large population with strong plants was notable on a small scarp of property B.

3.2 Study area and methods

The study area was identical to that described for *R. callianthus* (see section 2), and a similar strategy for surveying was used (i.e. all accessible places were inspected and inaccessible sites were checked with binoculars and a camera with a zoom lens at least once). Some sites were known from pre-study visits in 2016 and earlier years, while five additional sites were found using binoculars and a camera and, where possible, the numbers of flowering plants at each were subsequently counted on photographs. Targeted surveys were carried out from 2017 to 2020 during the flowering period, which is between March and May for this subspecies, with mid- to late April proving to be the best period for detecting plants.

Property B could only be accessed in late May in 2017 and could not be accessed at all in 2018. The total number of person-hours during the autumn surveys were approximately 19 hours in 2107, 30 hours in 2018 and 30 hours in 2019. In 2020, visits were only possible late in the flowering season and only previously known sites were visited over a period of 16 hours due to a COVID-19 lockdown. Other limestone areas in South Canterbury were also searched during the survey period, mainly for *G. calcis* subsp. *taiko* (see section 4).

Plants were recorded as 'large flowering plants', 'medium flowering plants' or 'non-flowering plants'. 'Large flowering plants' were considered to have three or more flowering stems and to be of more than average size. This only provides an indication of the size of individual plants at a site as it leaves room for subjective judgement. It should be noted that it was often not possible to count the number of flowering stems precisely due to time or access constraints. Additionally, only flowering plants could be detected on photographs and flowering plants are generally easier to detect than non-flowering plants, making it likely that non-flowering plants are under-represented.

3.3 Results

Gentianella calcis subsp. *manahune* (Fig. 12) has been found only on the Tengawai Cliffs in all five properties. A summary of the survey results is provided in Table 2 (note that no total is given for 2018 because one important site could not be visited). In 2020, the last year of the survey, a total of 228 flowering plants and a minimum of 94 non-flowering plants were documented.

Figure 12. *Gentianella calcis* subsp. *manahune* (area D1, 10 April 2019).

There are considerable distances between each of the sites for this subspecies, ranging from approximately 350 m to 1200 m between properties and from 100 m to 650 m within property boundaries, with the majority of sites being over 250 m apart. There is no overlap in the habitats where *G. calcis* subsp. *manahune* and *R. callianthus* are found except in area E3 and to a lesser degree area E2. On property B, the two buttercup sites are on either side of the gentian area, and while these habitats more or less border each other, there are no plants of either species in the area inhabited by the other species. However, all of the gentian plants on this property are beyond the reach of stock.

Gentians are usually found in cracks and crevices on limestone cliff faces, on the ledges of cliff tops, on the tops of boulders or towers and, in less steep locations, in gaps between rocks, mostly at the margin of exposed limestone. The micro-sites where these plants were found were all well drained and exposed to weather changes, especially wind, with a mostly northwest to west aspect. Where micro-sites faced to the north, they were often protected from full sun exposure for parts of the day by other rocks or towers. The flowering time of this subspecies varies from March to May, but individual plants flower early in March every year. It was found that 2020 was a poor flowering year as fewer large flowering plants were observed and some plants that looked mature enough to flower had few flowers or did not flower at all. 'Large' plants of this subspecies can have a diameter of nearly 20 cm, but it was often difficult to establish whether such a plant was a single individual or two plants growing together. Plants that grow under competition by grasses can have a stem length of up to 20 cm, and individual plants can have up to 15 flowering stems with a stem length of up to 12 cm, but the number of flowering stems may vary from year to year. Gentian plants are threatened by competition from weeds such as hawkweeds, black medic and stonecrop, along with pasture plants such as clover (*Trifolium* spp.) and especially exotic grasses. Individual plants have been lost seemingly due to competition by grasses (Fig. 13), and important sites were threatened by invasion of stonecrop (Fig. 14).

Table 2. Numbers of *Gentianella calcis* subsp. *manahune* plants recorded on the Tengawai Cliffs. Results are shown for incidental observations in 2007/2008 and surveys undertaken in 2017–2020 (present study). Gcm A1–E3 = areas with *Gentianella calcis* subsp. *manahune* sites on properties A–E; large = large flowering plants; med = medium flowering plants; non-fl = non-flowering plants.

SITE	ASPECT	2007/2008	2017			2018			2019			2020		
			LARGE	MED	NON-FL	LARGE	MED	NON-FL	LARGE	MED	NON-FL	LARGE	MED	NON-FL
Gcm A1	NW	1	2	1		3			3	0	2	3	0	1
Gcm A2	NE					1			1			1		
Gcm B1	NW–W	Yes					No access		4	7	5	6	5	4
Gcm B2	NW		30	49	5				65	30	8	39	44	3
Gcm C1	W	4	2	2	3	4	1	1	4	0	1	4	2	1
Gcm C2	W	1	1	1	0	1	1	1	0	1	1	0	1	0
Gcm C3	NW		4	2	0	5	1	3	5	6	6	4	6	1
Gcm D1	NW		10	0	6	11	4	7	7	9	3	11	2	10
Gcm D2	NE		1	3	0	3	0	2	4	2	0	2	2	2
Gcm D3	W					4	3	7	4	4	8	4	10	4
Gcm D4	NW	Yes	7	10	1	9	8	0	11	12	1	8	4	2
Gcm E1	N–NW	3	1	2	0	2	3	0	2	2	0	1	1	1
Gcm E2	N–W	5	4	4	0	11	4	5	4	10	4	2	6	5
Gcm E3	W	Yes	22	100	25	119	120	40	50	122	5	7	53	60
Total			**84**	**174**	**40**				**164**	**205**	**44**	**92**	**136**	**94**

Figure 13. *Gentianella calcis* subsp. *manahune* with competing grasses (area E2, 2 April 2018).

Figure 14. *Gentianella calcis* subsp. *manahune* competing with stonecrop (*Sedum acre*) and hawkweeds (*Pilosella* spp.) (area D1, 25 January 2018).

3.4 Discussion

This study confirmed Glenny's (2004) remark that '*G calcis* subsp. *manahune* grows in limestone cracks on the top of an escarpment in very sunny, dry places, even having some preference for north-facing aspects', although it seems that the northwest aspect is dominant and partial shade is the more optimal habitat. Numbers for this gentian are somewhat higher than estimated by Glenny, but the taxon is restricted to one limestone escarpment in South Canterbury – and while it is found on all five properties along this escarpment, numbers are extremely low in some sub-populations and declining in others, and the sub-populations are very fragmented and isolated. Locations seem to be limited by the effects of grazing and weed invasion.

The change in flowering plant numbers recorded in 2017 (258 plants) and 2019 (369 plants) is unlikely to reflect a true increase in numbers but is more likely a reflection of other factors. Only c. 60% of the 43 sites were known in 2017, although sites found in later years generally had a small number of plants. Additionally, parts of property B are not directly accessible, which made it more difficult to detect plants during the visit in late May 2017. Grazing effects cannot account for the difference here as stock animals have very limited or no access to sites in areas B1 and B2 – and if numbers for property B are excluded, numbers across all other sites indicate a substantial decline from 2018 (308 plants) to 2019 (263 plants) and 2020 (134 plants).

The overall population decline trend is largely due to decreases in areas E2 and E3. Based on numbers recorded in these areas by Shanks (2015) in summer 2007, these important sub-populations of *G. calcis* subsp. *manahune* have declined by 63% in 12 years. These are the only large sites on rendzina soil and are relatively easy to access, so the numbers recorded are likely to be reliable. There were notable fluctuations in the recorded plant sizes, possibly due to variation in the grazing regimes between years, which can affect both plant size and flowering. Gentians showed severe effects of grazing and this was particularly obvious in autumn 2020 (Fig. 15). Plants will survive occasional browsing but succumb to regular browsing and then disappear altogether.

Figure 15. Grazing pressure on *Gentianella calcis* subsp. *manahune* (area E3, 28 April 2020).

Figure 16. Recovering *Gentianella calcis* subsp. *manahune* in a trial enclosure (area D1, 1 May 2020)

Mature *G. calcis* subsp. *manahune* plants on all other properties were found growing on sites that were not accessible by stock. These plants might have prevailed for years and their sizes were more consistent over the years. Plants continued to persist in 2020 in all 14 sites where gentians were observed in 2007/2008. Young plants growing in the vicinity of mature specimens on two sites on property D that were accessible to stock and showed the effects of browsing were subsequently covered with wire netting. Within a year, these young plants had recovered and a number of them flowered the following year (Fig. 16).

Like *R. callianthus*, *G. calcis* subsp. *manahune* is seriously threatened and needs urgent intervention. Conservation measures would be similar to those recommended for the buttercup, with a combination of general weed control, micro-management of sites, protection from browsing and adaptation of pasture management including stocking regimes required to turn the decline around. Some form of intervention, management and monitoring needs to be considered for all sites, but the main populations and especially the southwestern end of the scarp where the gentian and buttercup co-occur should be given particular attention. Parts of these areas would be suitable for closing off, although the terrain might cause some challenges. A further three threatened species (*Cardamine caesiella*, *Geranium socolateum* and *Gingidia enysii*) and other indigenous herbs including *Plantago spathulata*, *Chaerophyllum novae-zelandiae*, a *Senecio* species and a *Lagenophora* species also occur in this location (Shanks 2015; H. Frank, unpubl. data).

There are few biological data available for *Gentianella calcis* subsp. *manahune*, so detailed research into its micro-habitat requirements, pollination, recruitment and ability to compete with weeds would assist its management. For example, individual plants of this gentian persist over a number of years, possibly over decades, so it would be of interest to mark selected plants and determine the longevity and demography of the population. As there is no historical information available, it is unclear if sites where this subspecies is found currently provide the most suitable habitat or are marginal habitat that provides refuge from grazing. Therefore, an understanding of the optimum habitat is required to find new locations for possible restoration trials.

The collection of seeds for storage and *ex situ* propagation should also be considered, as gentians can also be grown in cultivation from cuttings (P. Heenan, pers. comm.; H. Frank, unpubl. data). However, it is unlikely that restoration attempts would be successful using propagated plants in this harsh environment, so sowing seeds *in situ* seems to be more promising.

4. *Gentianella calcis* subsp. *taiko* (Taiko gentian)

4.1 Background

Gentianella calcis subsp. *taiko* has a slightly longer history of scientific research than the two other taxa described above. It was first collected by Airini Woodhouse, a local naturalist, in April 1969 and then by Bryony MacMillan, DSIR, in April 1973 from sites in the Limestone Valley near Taiko (Glenny 2004). It first appeared in a threatened species list as an addition to the 1993 revision of the 'Threatened and local plant lists' (Cameron et al. 1993), where it was placed in the category 'Taxonomically Indeterminate' under the tag name *Gentiana* "Pareora" (!) and assessed as Endangered. It remained unchanged in the 1995 revision of that publication (Cameron et al. 1995) and then appeared under the tag name *Gentiana* (b) (CHR 529111; Pareora River) in the 1999 edition of 'Threatened and uncommon plants of New Zealand' (de Lange et al 1999), where it was still in the Endangered category. The specimen the tag name was based on had been collected at Limestone Valley Road by Brian Molloy in April 1992 (Glenny 2004). In the next revision (de Lange et al. 2004), the threat status was changed to Nationally Critical with the qualifier One Location and the tag name was slightly altered to *G.* aff. *astonii* (b) (CHR 529111; Pareora River). As mentioned earlier, David Glenny (2004) published his revision of *Gentianella* in the same year and the taxon was formally named *Gentianella calcis* subsp. *taiko*, with the comment that 'the subspecies is currently known from one population of fewer than 250 plants'. In subsequent revisions of the threatened plants listings, the threat assessment for this subspecies remained Nationally Critical but the qualifiers changed from Extreme Fluctuations in 2008 to A(3) (Total area of occupancy ≤ 1 ha) and Extreme Fluctuations plus One Location in 2012, and to A(3) Range Restricted in 2017 (de Lange et al. 2009, 2013, 2018).

The DOC surveys conducted between 2002 and 2004 confirmed the presence of *G. calcis* subsp. *taiko* at Limestone Valley locations, and also noted its occurrence at five previously unknown sites: two near the Pareora Gorge, two in the Totara Valley area and one north of the Ōpihi River (Pender et al. 2004). The surveys also covered the limestone areas near the Waihao River west of Waimate, but the subspecies was not found there. The reports gave few details about exact locations, population sizes and other relevant factors, but the results clearly extended the range for this subspecies. During the lizard survey in 2008 (Frank & Wilson 2011), *G. calcis* subsp. *taiko* was observed in all these locations (except one of the small sites), as well as at another property in the Totara Valley that had not been included in the DOC surveys. Aside from photographs, records were only kept for a few sites. Some of the new locations were also confirmed during SNA surveys (Harding 2016).

Wildland Consultants Ltd (Wildlands) undertook a survey of gentian locations in two QEII covenant areas on the Limestone Valley escarpment in March 2007 for the QEII National Trust (Lloyd 2007a, b). The resulting reports contained locations and plant numbers for 14 sites, brief information about some of the sites, and a brief discussion of general threats. Alice Shanks and Lorraine Cook from DOC subsequently carried out a gentian census of the Limestone Valley formations on 30 March and 15 April 2010 (Shanks 2010a), unaware of the Wildlands reports, and discovered plants at nine sites, two of which were different from those identified in the 2007 survey. Shanks recorded detailed information about these sites, i.e. coordinates, number of plants, aspect, threats and other plant species in association. A total of 656 plants, including non-flowering plants, were counted across those nine sites, with population sizes ranging from 1 to 300 plants per site. Shanks also made suggestions for further monitoring.

4.2 Study area and methods

The survey included all of the main limestone formations in South Canterbury, excluding the areas west of Waimate (see Fig. 1). These formations have diverse sizes, aspects, structures, land use and vegetation cover. Many of the limestone outcrops are linear cliff systems up to 30 m high and several kilometres long, with variable aspects, some of which span multiple properties, while others are smaller clusters of rocks and pavements. Extensive continuous cliffs are intersected in places by small valleys or gullies, and below the cliffs, slopes with varying inclines and widths (up to 300 m) generally extend to the valley floor, with boulders of various sizes and structures often scattered on them. These formations occur from Gordons Valley, Maungati and Pareora Gorge in the south, to Limestone Valley, Cave and Totara Valley in the middle, through to the wider Raincliff area and Kakahu in the north. The elevational range is from 150 m to 340 m a.s.l. All properties surveyed are on private land, but the limestone parts of two properties in the Limestone Valley are protected by a QEII covenant for about 20 years. A valley with limestone cliffs in the Maungati locality also has a QEII covenant in place, as do smaller fenced-off limestone sections of two other properties in the same area and a limestone block near Cave.

Surveys for *G. calcis* subsp. *taiko* were carried out during the flowering season, following the same methodology as for *G. calcis* subsp. *manahune*. *Gentianella calcis* subsp. *taiko* usually flowers from the end of February to early May, which is earlier than the other South Canterbury subspecies, with the optimal time for searches being March to mid-April, and each location was visited at least once during the flowering period. It should be noted that non-flowering plants are under-represented on sites that were only partly accessible, especially for the six sites that would only have been accessible with ropes and so plants were counted from photographs. The approximate person hours for the autumn surveys in South Canterbury limestone areas, excluding the Tengawai Cliffs, were 49 hours in 2017, 84 hours in 2018 and 129 hours in 2019. Surveys in autumn 2020 were limited due to the COVID-19 lockdown, so only about 36 hours were spent surveying some smaller limestone sites that had not been previously covered.

4.3 Results

Gentianella calcis subsp. *taiko* (Fig. 17) was found on two properties near the lower Pareora Gorge (A and B), three properties in the Limestone Valley (C to E) and four properties in the Totara Valley area (F to I) (Table 3). Property H in the Totara Valley, which had not been included in the DOC surveys, contained the most plants (1009 flowering plants in 2019). A separate location also exists on a scarp north of the Ōpihi River, about 15 km north of the Totara Valley sites (property J). A total of 1852 flowering plants and 385 non-flowering plants were recorded in 2019. The results are shown in Table 3 for all properties and sites. Numbers and conditions varied widely across the sites and a summary like that presented for the other two taxa above would not adequately represent these variations. Letters and numbers in Table 3 (e.g. A1, A2) refer to specific sites where plants grew within properties A to J.

Gentianella calcis subsp. *taiko* was most abundant on sites facing south, southwest or west. Very few individual plants were found facing other directions, an exception being a group of plants in property J. Gentians generally grow on the tops of boulders, on the edges of rocks or cliffs, or along the margins of exposed limestone patches. Plants can persist over a number of years, and older plants can have up to 12 flowering stems that can grow 15 cm long in competition with exotic grasses up to 25 cm tall. In some places plants struggle to survive or have been lost to competition with exotic grasses, particularly red fescue (Fig. 18).

Table 3. Numbers of *Gentianella calcis* subsp. *taiko* plants recorded in limestone areas of South Canterbury. Results are shown for incidental observations made in 2007/2008, surveys undertaken in the Limestone Valley in 2007 by the Queen Elizabeth II Trust (QEII) and 2010 by the Department of Conservation Te Papa Atawhai (DOC), and surveys undertaken in 2017–2019 in the present study. Gct A1–J7 = *Gentianella calcis* subsp. *taiko* sites on properties A–J; large = large flowering plants; med = medium flowering plants; non-fl = non-flowering plants.

SITE	ASPECT	2007/ 2008	2007 QEII	2010 DOC	2017			2018			2019		
					LARGE	MED	NON-FL	LARGE	MED	NON-FL	LARGE	MED	NON-FL
Gct A1	W				0	6	21	0	5	11	0	10	6
Gct A2	S–E				2	10		4	13		9	12	
Gct B	W										2	15	5
Gct C1	SW	≥ 7	15		0	5	0	0	5	2	0	3	0
Gct C2	S	Yes	45		4	21		20	14		22	20	
Gct C3	SE		23	11		6		4	10		4	9	
Gct C4	SW		7			5		3	1		3	1	
Gct C5	SW							0	6	3	0	4	2
Gct C6	S	2				0			0			0	
Gct D1	SE–W	≥ 10	13	21	6	2	1	7	2	0	9	2	0
Gct D2	S–E	Many	32	300	10	25	5	11	32	5	7	21	1
Gct D3	S	Many	115	94	2	40	37	16	56	78	40	47	34
Gct D4	SW	Yes	75	122		12	25	2	51	55	6	46	34
Gct D5	S	Yes		50				0	4	11	0	7	8
Gct D6	SW	Many	30	55		19	10	2	59	38	3	25	28
Gct D7	E			1				0	1	0	0	2	0
Gct D8	S	Yes						8	4	3	5	4	20
Gct D9	SW–E	Yes	30			15	4	10	29	7	10	30	3
Gct D10	S				1			2	2	3	1	2	3
Gct D11	SE–W	Many	75		6	15	8	14	14	14	17	18	8
Gct D12	SW				0	3	0	2	4	5	3	5	9
Gct D13	SW		4	2		9			13		4	7	
Gct E1	S	41			3	22	0	12	20	0	26	41	10
Gct E2	S										0	1	0

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Table 3 continued

SITE	ASPECT	2007/ 2008	2007 QEII	2010 DOC	2017			2018			2019		
					LARGE	MED	NON-FL	LARGE	MED	NON-FL	LARGE	MED	NON-FL
Gct F1	S				0	1	1	1	5	7	0	3	11
Gct F2	S				3	90	172	12	142	66	7	63	33
Gct F3	S				0	3	5	0	3	3	0	2	4
Gct F4	SE				0	4	8	0	5	3	0	2	2
Gct F5	SW				0	1	13	0	15	9	0	6	7
Gct G1	S							0	16	0	1	3	0
Gct G2	SW							9	9	0	9	8	0
Gct G3	SW				0	15	0	1	12	1	0	15	0
Gct G4	S–SW							5	10	1	0	7	1
Gct G5	S–SW				4	28	0	12	36	3	2	30	8
Gct G6	SW							0	1	0		?	
Gct G7	SW				0	8	10	8	37	15	0	24	18
Gct G8	SW							1	3	0	0	5	0
Gct G9	S										1	2	0
Gct G10	S–SW				9	8	0	23	22	0	11	24	0
Gct H1	SW	Yes			5	5	0	8	5	2	6	5	6
Gct H2	SW				12	122	0	50	61	11	103	123	25
Gct H3	S	Yes			0	1	1	0	2	0	1	1	0
Gct H4	SW	Yes			1	23	0	15	30	0	24	56	5
Gct H5	S				0	3	0	2	2	0		1	0
Gct H6	S										7	13	1
Gct H7	S				0	5	0	1	12	0	1	12	0
Gct H8	S–SW				6	219		6	200		34	220	23
Gct H9	S–SW					134	50		134	50	31	132	25
Gct H10	S–SW				1	44	0	3	17	0	3	40	2
Gct H11	S–SW				0	5	0	0	1	0	0	2	1
Gct H12	S				4	12	0	6	9	0	4	8	1
Gct H13	S–SW				3	14	5	4	12	6	6	24	4
Gct H14	SW				13	115		16	62		27	113	18
Gct H15	S				2			2					
Gct H16	S										8	4	3

Continued on next page

Table 3 continued

SITE	ASPECT	2007/ 2008	2007 QEII	2010 DOC	2017			2018			2019		
					LARGE	MED	NON-FL	LARGE	MED	NON-FL	LARGE	MED	NON-FL
Gct I	S										2	3	1
Gct J1	SW							3	4	3	1	6	0
Gct J2	SW							16	24	17	16	33	13
Gct J3	SW							10	12	2	16	9	0
Gct J4	NE							1			6	3	
Gct J5	S										9	5	1
Gct J6	W/N							2	2	0	4	1	1
Gct J7	NE							1	0	0	1	0	0
Total					**97**	**1075**	**376**	**335**	**1250**	**434**	**512**	**1340**	**385**

Figure 17. *Gentianella calcis* subsp. *taiko* (site D1, 26 February 2020).

Figure 18. *Gentianella calcis* subsp. *taiko* struggling with grass competition (site D2, 11 March 2019).

In most areas, plants persist only beyond the reach of stock. However, some of the sites with good populations on sloped, shallow soils on property H in the Totara Valley area are grazed (sites H8 to H14). It seems that a consistently light grazing regime has been applied over the years, but the number of 'large flowering plants' seems to fluctuate more widely at these sites.

4.4 Discussion

The findings of this study confirmed David Glenny's (2004) observation that *G. calcis* subsp. *taiko* 'grows in a moister habitat than *G. calcis* subsp. *manahune* as the limestone boulders it grows on are shady and damp'. Mosses or algae were often observed on rocks close to the gentians. The population in location J needs further research, as these plants showed some characteristics that were different from plants in other locations, indicating that this may be an undescribed subspecies (D. Glenny and P. Heenan, pers. comm.). The current tag name is *Gentianella* 'Mt Donald'.

The geographical range for *G. calcis* subsp. *taiko* is wider than previously thought. While the Limestone Valley remains a stronghold of the taxon, with 21 sites and c. 455 flowering plants in 2019, populations in the Totara Valley area are equally important, with 32 sites and 1239 flowering plants. The distance between these two locations is c. 9 km, making it unlikely that gene flow is occurring between the populations. The three smaller populations are also widely scattered and isolated, with distances of c. 4 km, 7 km and 8 km, respectively, between them or one of the larger populations. These observations suggest that the current populations are remnants of a wider distribution in the past. Populations might have disappeared from other suitable limestone habitats as a result of grazing pressure and competition by adventive plants, and fragmentation is likely to have been exacerbated by habitat loss brought about by agricultural development.

The findings of this study suggest that a one-off survey might be inadequate to assess the population sizes and distribution for this subspecies. This is particularly demonstrated in the Limestone Valley area, where the QEII survey found 14 sites (one with just a single plant has disappeared since then) and the 2010 census found 9 sites, whereas searches over multiple years located 21 sites, possibly supported by knowledge of local conditions. In addition, survey methods seemed to vary, as there are noticeable differences in the numbers of plants observed at some sites, which was likely further amplified by fluctuations in populations between years. Surveying gentian habitats during the flowering period is clearly the optimal method (Lloyd et al. 2020), and the use of drones might further increase the chances of finding and monitoring populations in inaccessible places in the future.

Numbers in the nine Limestone Valley sites (properties C and D) that were included in the 2010 census by Shanks (2010a) declined by 46% over 9 years. The most extreme example of this can be seen at site D2, where Shanks found c. 300 plants, mostly seedlings, in 2015 (although Lloyd had only recorded 32 plants in 2007), whereas only about 40 were observed in 2017, which slightly increased to 48 plants in 2018 and then declined to 29 plants in 2019. The area in which gentians are growing has been reduced over the years by advancing exotic grass cover, and sites with small numbers of plants (e.g. C6) have been especially vulnerable. Along with grasses and, increasingly, clover species, other weedy species such as hawkweeds, black medic and stonecrop also generate competition (Figs 19 & 20). Additionally, the native climber pōhuehue (*Muehlenbeckia australis*) was threatening to fully cover two rocks inhabited by gentians, which would smother all of the smaller plants, and gorse (*Ulex europaeus*) was starting to invade the important gentian site H2.

In some cases where stock have had access to the gentian site, trampling has reduced numbers over the years. For example, plants at site C1 declined from 15 in 2007 to 3 in 2019. And sites where measures have been put in place to protect gentians from stock are now threatened by weed and grass invasion. For instance, three rocks providing gentian habitat in the Limestone Valley area were fenced off around 2002 through a QEII initiative, but while this initially seemed to have some positive effects on the plants, grass competition has increased considerably since then and gentian numbers have declined, as observed at site D2.

In recent years, the author has undertaken experimental weed control, such as hand-weeding, spraying grasses and stonecrop, removing big *Muehlenbeckia* plants, and controlling gorse. However, this has not been without its challenges. For example, it is difficult to avoid damaging the gentians, sprayed patches are left bare after spraying and are often quickly colonised by other weeds, and only ongoing intervention can secure success. Also, some sites can only be accessed by skilled personnel using specialised equipment.

In 2019, the Timaru District Council, in cooperation with local landowners, funded a programme to control stonecrop in all limestone habitats in the Totara Valley area. This initiative needs to continue to achieve long-term results. Further intervention, such as the control of other weeds, especially grasses, at selected sites, also needs to be considered, and it is important that the traditional conservative stock management regime is maintained for grazed sites on property H. Long-term monitoring also needs to be established, especially at the most important sites. The Taiko Gentian Action Plan (Cook 2011), which was developed by DOC's Raukapuka Area Office for Limestone Valley sites after the 2007 and 2010 censuses, contains further practical conservation proposals, but was never implemented. As with the other two taxa, seed collection and storage and *ex situ* propagation should also be considered as additional security measures.

Figure 19. *Gentianella calcis* subsp. *taiko* with competing clover (*Trifolium* spp.) (site D2, 31 March 2018).

Figure 20. *Gentianella calcis* subsp. *taiko* and competing stonecrop (*Sedum acre*); also note the presence of *Gingidia enysii* (site H1, 11 April 2016).

5. Conclusion

The calcicolous taxa *Ranunculus callianthus*, *Gentianella calcis* subsp. *manahune* and *Gentianella calcis* subsp. *taiko* are currently classified as Nationally Critical under the New Zealand Threat Classification System (de Lange et al. 2018), and the findings of this study support this conservation status. Pasture management, especially stock pressure, and competition by adventive grasses and weeds seem to be the main factors contributing to the decline of these taxa, and intervention is urgently needed, particularly for *R. callianthus* and *G. calcis* subsp. *manahune*.

Conservation efforts for *R. callianthus* and *G. calcis* subsp. *manahune* need to be integrated with wider ecosystem management and restoration work and may also benefit other rare species. For example, the Tengawai Cliffs provide habitat for four other Threatened plant taxa (*Cardamine caesiella, Geranium socolateum, Australopyrum calcis* subsp. *optatum* and *Gingidia enysii*), four At Risk species (*Cardamine grandiscapa, Chenopodium allanii, Coprosma virescens* and *Teucrium parvifolium*) and at least one taxonomically indeterminate species (*Azorella* aff. *hookeri* "calcicole") (Pender et al. 2004; H. Frank, unpubl. data).

Habitats in the Limestone Valley locality where *Gentianella calcis* subsp. *taiko* occurs also support populations of at least five other Threatened and a further five At Risk plant species, namely *Cardamine integra, Geranium socolateum, Australopyrum calcis* subsp. *optatum, Gingidia enysii, Raoulia monroi, Anemanthele lessoniana, Coprosma virescens, Pseudopanax ferox, Chenopodium allanii* and *Mentha cunninghamii* (Pender et al. 2004; Shanks 2010b; H. Frank, unpubl. data). Some of the additional taxa that await formal description, including *Azorella* aff. *hookeri* "calcicole", *Brachyscome* aff. *montana* "Taiko", and *Craspedia* and *Senecio* species, are also likely to be classified as Threatened (Heenan & Rogers 2019). Similarly, limestone habitats in the Totara Valley area support the Threatened and At Risk plant species *Cardamine integra, Geranium socolateum, Gingidia enysii, Chenopodium allanii* and *Mentha cunninghamii*, as well as undescribed *Craspedia* and *Senecio* species (Pender et al. 2004; H. Frank, unpubl. data).

The proposed conservation measures can be achieved only with the cooperation of various groups, especially landowners, as well as improved communication and cooperation between scientists and agencies involved with conservation management on a regional and national level. Without this, it will not be possible to secure the future of these unique plants in natural ecosystems. These three calcicolous taxa highlight the importance of limestone ecosystems and the need for better recognition of them. Thus, the recognition of geopreservation sites within karst landscapes as being of 'International, National or Regional Significance' (Kenny & Hayward 1992, 2009; www.geomarine.org.nz/NZGI/) should be extended to limestone ecosystems in general.

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