



Manaaki Whenua
Landcare Research

Increasing wader abundance: vital rates of tōrea and residual pest indexing

**Interim report on year 2 on research to increase wader
abundance**

Prepared for: Environment Canterbury and Department of Conservation

June 2022



Increasing wader abundance: vital rates of tōrea and residual pest indexing

Contract Report: LC4138

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Contents

Summary	v
1 Introduction	1
2 Background	1
3 Objectives	2
4 Methods	3
4.1 Nest survival	3
4.2 Chick survival	4
4.3 Survival and connectivity of sites throughout the annual cycle	4
4.4 Predator monitoring using cameras	5
5 Results	7
5.1 Nest survival	7
5.2 Chick survival	9
5.3 Movements and survival	11
5.4 Predator monitoring	12
6 Discussion	18
7 Recommendations	19
8 Acknowledgements	20
9 References	20

Appendix 1 – Species richness and spatial variation in detection of predators in the upper Rangitata and Rakaia valleys	23
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Summary

Project and client

- Manaaki Whenua – Landcare Research (MWLR) and the Department of Conservation (DOC) have formed a research partnership to inform the conservation of New Zealand’s inland migrant bird species, with tōrea (South Island pied oystercatcher, SIPO, *Haematopus finschi*) as the focal species.
- MWLR’s aim is to develop a spatial population model. DOC’s focus is building richer data on flyways and nodes. BirdsNZ is an additional project partner, supporting banding and re-sighting efforts through citizen science.
- Co-funding (2021-28-020 A1/DOC-6748756) through the Braided River Initiative Fund by Environment Canterbury and DOC has enabled the indexing of predator abundance with cameras at the MWLR tōrea study site in the upper Rangitata River valley and at an additional site in the upper Rakaia River valley without predator control.
- This is the second year of a 3-year MWLR research project on mobile avian species.

Objectives

- To provide an overview of the field research on tōrea in the upper Rangitata valley, and of predator indexing using remote cameras in the upper Rangitata and Rakaia River valleys. This involved:
 - 1 determining reproductive success, survival, and connection to wintering sites of tōrea in the upper Rangitata valley in 2020 and 2021
 - 2 indexing mammalian predator abundance through camera trapping, and determining differences between sites (upper Rangitata and Rakaia valleys) and years (Rangitata valley only, 2020 and 2021).

Methods

- Tōrea nest and chick survival in the upper Rangitata valley was determined by locating breeding pairs and regularly monitoring them. Unbanded individuals were banded with an orange alphanumeric flag for identification, and mark-resight surveys and GPS-GSM tags (on subset of individuals) were used to estimate survival.
- We modelled nest and chick survival in farmland and riverbed over two seasons, 2020 and 2021.
- Eighty camera traps baited with rabbit meat and Erayz lure were deployed for 21 days in the upper Rangitata (October 2020 and 2021) and Rakaia valleys (October 2021).
- All animals recorded in photos were identified to species level. We calculated indices of abundance (i.e. the camera trap index, CTI) for each species and across all species based on the number of encounters per 2,000 camera hours.
- We compared the CTI of target species between sites and seasons.

Results

- We monitored 53 nests in 2021 in the upper Rangitata valley, in addition to the 58 monitored in 2020. Nest survival varied with habitat and season.
- We monitored 63 chicks in 2021, confirming the fledging of 33 chicks and the death of 15. Chick survival also varied with habitat and season, but was higher overall in 2021 compared to 2020.
- A further 73 tōrea were banded and 19 additional GPS/GSM tags were fitted. Movement and survival data collection is ongoing.
- All species of mammalian predators of braided river birds were recorded on camera apart from weasels. Hedgehogs were the most commonly encountered species.
- Avian predators (southern black-backed gulls and Australasian harriers) occurred mostly in the background of the camera trap images rather than interacting with the bait. Because cameras would not have been consistently triggered by their movement, we made no further comparisons of avian predators.
- Mean CTI for all mammalian predators combined was 48.8 ± 11.7 (SE) in the upper Rangitata compared to 22.6 ± 4.94 in the upper Rakaia valley. There were fewer possum detections in the upper Rangitata valley compared to the Rakaia valley, but detection of other mammalian predators was similar between valleys.
- Mean CTI across all mammalian predators did not differ between 2020 (35.8 ± 10.9) and 2021 (48.8 ± 11.7) in the upper Rangitata valley. Detections of hedgehogs, cats, and ferrets increased from 2020 to 2021, and other species showed slight increases, although with large confidence intervals around estimates. Notably, stoats were not detected in river habitat in either 2020 or 2021.

Discussion

- The demographic data collected on tōrea will allow us to understand how spatial and temporal variation in demography contributes to local and regional population growth. Population model development is planned for 2023.
- Camera monitoring enables indices of abundance of mammalian predators and community composition to be calculated and compared between sites and seasons.
- Ongoing monitoring is required to detect changes in the predator community over time and to investigate complex interactions between introduced mammals and biodiversity outcomes.

Recommendations

- Collect additional data on tōrea nest and chick survival, and focus efforts on re-sighting and/or recapturing adult tōrea to estimate adult survival to assess variation between habitats and seasons in the upper Rangitata valley.
- Continue the camera monitoring established so far, and carry out new monitoring at additional sites to understand variation in predator communities across sites.
- Prioritise research into understanding the relationship between density and CTI at sites with and without predator control to better interpret changes in CTI.

- Investigate the interactions between smaller mammals (hedgehogs and rats) and larger apex predators (e.g. cats), ideally using a before-after-control-impact (BACI) experimental design.
- Test whether weekly surveys (using transects or point-count methods) would be an effective indexing method for avian predator abundance.

1 Introduction

Manaaki Whenua – Landcare Research (MWLR) and the Department of Conservation (DOC) have established a research partnership to inform the conservation of New Zealand's inland migrant bird species. Tōrea (South Island pied oystercatcher, *Haematopus finschii*) has been chosen as a focal species for a pilot study. MWLR's aim is to develop a spatial population model linking the wintering and breeding sites of tōrea populations in different habitats and under different management regimes. DOC's aim is to gather richer data on flyways and nodes by catching, tagging, and banding birds on wintering grounds around the country.

MWLR commenced a field study in September 2020 in the upper Rangitata River valley to monitor vital rates of tōrea during the breeding season and to attach GPS-GSM tags and coloured flag bands to fledglings and adults to monitor juvenile and adult survival during their annual cycle. MWLR also indexed predator abundance with camera monitoring (Gillies 2018) to understand the relationship between predator abundance and vital rates on breeding grounds.

This is an interim report of the field research of year 2 of a 3-year MWLR project, with a focus on how to increase the abundance of migratory shorebirds breeding and wintering within New Zealand.

2 Background

In New Zealand, 46 threatened species spend crucial parts of their annual cycle outside of the DOC network of protected ecosystem and species management units. Such species use habitats across multiple territorial jurisdictions (e.g. council, LINZ-administered, and private land) and rohe. One key group are the Charadriiformes (shorebird) species that breed in inland dryland or braided river ecosystems and migrate to coastal areas in winter.

Understanding how complex spatial (sites/fragments, wintering/breeding sites) and temporal (annual or life cycle) processes of animals interact to influence population growth and subsequent persistence is currently still lacking. The aim of our research project in the upper Rangitata valley is to measure vital rates of tōrea to calibrate a spatially explicit, full-annual-cycle model and understand how breeding vital rates are related to predator abundance.

High predation pressure has been identified as a key threat to nesting Charadriiformes (Keedwell 2004; O'Donnell & Hoare 2011; O'Donnell et al. 2016). Increased numbers of native southern black-backed gulls (*Larus dominicanus*) and Australasian harriers (*Circus approximans*) reduce the survival of eggs or chicks (Steffens et al. 2012; Schlesselman et al. 2018). Similarly, introduced mammals can reduce survival of eggs, chicks, and adults directly through predation, or indirectly by causing desertion of nests through disturbance (Sanders & Maloney 2002). Mammalian predators present in braided rivers include

- feral cats (*Felis catus*)
- possums (*Trichosurus vulpecula*)

- ferrets (*Mustela furo*)
- stoats (*Mustela erminea*)
- weasels (*Mustela nivalis*)
- rats (*Rattus norvegicus*)
- hedgehogs (*Erinaceus europaeus*)
- mice (*Mus musculus*) (Pickerell et al. 2014).

Current management of braided river birds by DOC comprises predator control, predominantly at breeding sites. Ecological monitoring is fundamental for determining whether these management interventions yield the anticipated outcomes (i.e. reduced predator populations and increased nesting success; Lindenmayer & Likens 2010). Detailed monitoring of the abundance of the complete suite of predators of braided river birds is challenging due to the cryptic nature of species, large home range sizes, and the difficulty of mark–recapture studies.

As a result, standardised indices of relative abundance are often used to understand the effectiveness of predator control. Ideally an index of relative abundance has the key attributes (Engeman 2005) of:

- being practical to apply
- being sensitive to changes of actual abundance
- allowing for precision in index values by having an inherent variance formula (i.e. separate transects)
- relying on as few assumptions as possible.

Indices derived from camera trapping have the advantage of being able to monitor multiple species (e.g. Gillies & Brady 2018; Evans et al. 2019), being sensitive to changes in abundance due to predator control (e.g. Comer et al. 2018; Nichols et al. 2021), and providing the ability for survey designs to calculate the precision of indices by enabling the calculation of standard errors around estimates (e.g. Van Hespen et al. 2019).

3 Objectives

This report provides an update of the field research undertaken from September to December 2021 and summarises results from the previous field season from September to December 2020. Specifically, we aimed to:

- 1 determine the reproductive success of tōrea breeding in riverbeds and on farmland with a large-scale predator control network in place in the upper Rangitata valley
- 2 attach GPS-GSM tags and coloured bands to breeding individuals and fledglings to gain information on survival and connection to wintering sites of tōrea
- 3 index mammalian predator abundance through camera trapping in the upper Rangitata valley in October 2020 and 2021, and in the Rakaia valley in October 2021, to determine:

- a the suitability of cameras to index the variety of predators (avian and mammalian) present in braided rivers
- b whether relative abundance of predators differs between the upper Rangitata valley with landscape-level predator control ('treatment') compared to the nearby upper Rakaia valley without predator control ('non-treatment')
- c whether relative abundance of predators was lower in 2021 (year-round trapping) compared to 2020 (seasonal summer trapping) in the upper Rangitata valley.

4 Methods

4.1 Nest survival

We monitored nests across farmland and riverbed on the true right of the upper Rangitata River from September to November in 2020 and 2021, searching areas from Bush Stream to Forest Stream (Figure 1). Nests of tōrea were located by searching river habitat on foot, searching farmland habitat on foot, and driving laneways to spot breeding pairs. Once a nest was found, it was marked with white electric fence standards (on farmland) or a small rock cairn (on riverbeds). A wildlife camera (Reconyx Hyperfire) was set up within 1 m of every nest. Nest contents were checked on a 2–5-day interval. Nests were considered successful if one or more eggs hatched. Successful hatching, timing, and reason of failure were determined through camera footage.

Eggs were floated in lukewarm water to determine incubation stage (Liebezeit et al. 2007) and assist with determining optimal times for catching adults. In addition, length, width, and breadth of eggs were measured to determine differences in size between sites and/or clutches.

We used a random effects logistic-exposure model (Shaffer 2004) to estimate daily nest survival rate (DSR), and to compare nest survival across seasons and between river and farmland nests. By including exposure, it is possible to appropriately account for clutches of different ages monitored and avoid bias towards older clutches being more likely to succeed (Mayfield 1961, 1975). We also compared nest survival between habitats (farmland or river) and seasons. The response variable was survival, and we included either an additive or interactive term of habitat and season as predictors, nest ID as a random effect to account for repeat visits to the same nests, and a binomial error term. We evaluated support for the two candidate models by calculating ΔAIC_c (Burnham & Anderson 2002).

Daily survival was converted to hatching success by $(DSR)^h$, where h is the length of the average hatching period for a nest (i.e. 28 days for tōrea; Sagar et al. 2000). The R package lme4 (Bates et al. 2015) was used to construct the models.

4.2 Chick survival

We assessed chick survival in the upper Rangitata valley from October to December in 2020 and 2021 through radio tracking one chick per clutch (Lees et al. 2019). A small VHF-tag (0.9 g Holohil BD-2) was attached to one chick per clutch, and handheld TR-4 or Ultra transceivers and yagi antennas were used for radiotracking these chicks every 3–4 days. The surrounding area was searched for siblings. We measured mid-toe-tarsus length, bill length, weight, and wing length (once pin feathers emerged) for each chick to estimate growth in farmland and river sites and fledging times.

We used mark–recapture models to account for variation in detectability between clutches and individuals. Daily chick survival (DCS) was estimated using Cormack-Jolly-Seber models with 1-day encounter intervals. We first assessed the most appropriate structure of encounter probability (p) by comparing models that included either season (2020 or 2021), site (river/farmland), or tag (yes/no) with a constant model of encounter probability. We evaluated their ΔAIC_c support while holding survival constant. The strongest support was received for encounter probability varying by tag status.

We then compared models of survival probability (ϕ) that accounted for the variation in encounter probability. We compared whether ϕ varied between seasons, site, with age of chick (in days), and additive or interactive effects of site and season. Support for models of ϕ was evaluated by calculating ΔAIC_c (Burnham & Anderson 2002), and we regarded models as receiving substantial support if they were $\leq 2 AIC_c$. The model of DCS combined the best model of encounter probability and survival probability. Daily chick survival was converted to fledging success by $(DCS)^b$, where b is the length of the average brooding period for a chick; i.e. 37 days for tōrea. Chick survival models were constructed with the R package RMark (Laake 2013).

4.3 Survival and connectivity of sites throughout the annual cycle

Adults were caught with a drop-trap on the nest in the upper Rangitata valley after replacing eggs with dummy eggs (Sagar et al. 2000). Fledglings were caught by hand. In 2021 a feather sample was taken from each individual for carrying out molecular sexing of individuals. Each individual was banded with an orange flag with white lettering (three-letter code for adults, two-number code for fledglings) in addition to metal bands to enable re-sighting on wintering grounds and in future seasons

After testing different GPS-GSM tag types and attachment methods in 2020, we attached Druid Omni (originally called Lego by the supplier, Interrex; 9 g) on additional adults and Druid Omni or Mini (6 g) on additional fledglings using silicon leg-loop harnesses in 2021. Druid GPS-GSM tags provided more consistent data than originally tested Milsar tags, and leg-loops were a much quicker method (<10 min) for attaching GPS-GSM tags compared to backpack harness systems. Each tag was programmed to collect a GPS-GSM location at least every hour, or more frequently on movement. We ensured the weight of the GPS-GSM tag did not exceed 3% of the bodyweight of any individual.

Because a Level 4 Covid lockdown delayed the start of our 2021 field season, it was not possible to search the entire study site for banded birds at the beginning of the breeding

season as planned. Instead, we collated *ad hoc* recordings of already-banded tōrea in the field (including bands read on the footage collected with nest cameras). At the end of the breeding season, a 2-day survey of the entire study site was carried out (29 and 30 November 2021) with two observers using cameras as well as scopes to identify bands. Further re-sightings of banded individuals at their wintering grounds are received from bird watchers around New Zealand.

4.4 Predator monitoring using cameras

We established 10 transects (≥ 1 km apart), each with four cameras (Bushnell Core DS) at 200 m spacing in the upper Rangitata valley and set at these 40 cameras for 3 weeks in spring 2020 and again for 3 weeks in spring 2021. In spring 2021 we established a further 40 cameras in the Rakaia valley and set these for 3 weeks. The locations of cameras are shown in Figures 1 and 2.

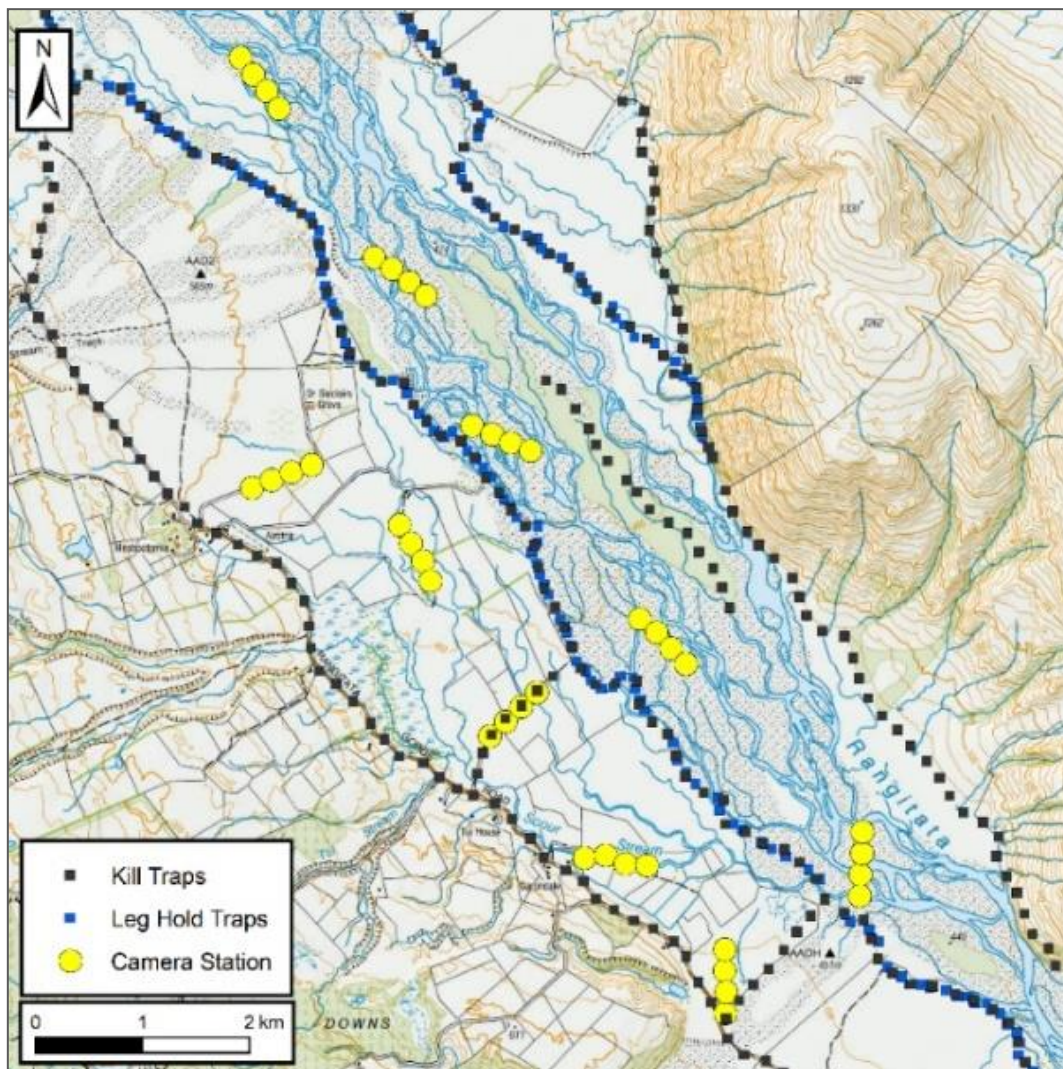


Figure 1. Map of study area for tōrea and camera monitoring in the upper Rangitata valley. Each camera station is shown by a yellow circle, with each line consisting of four camera stations, black and blue squares show traps. Camera monitoring was carried out for 21 days in October 2020 and 2021.

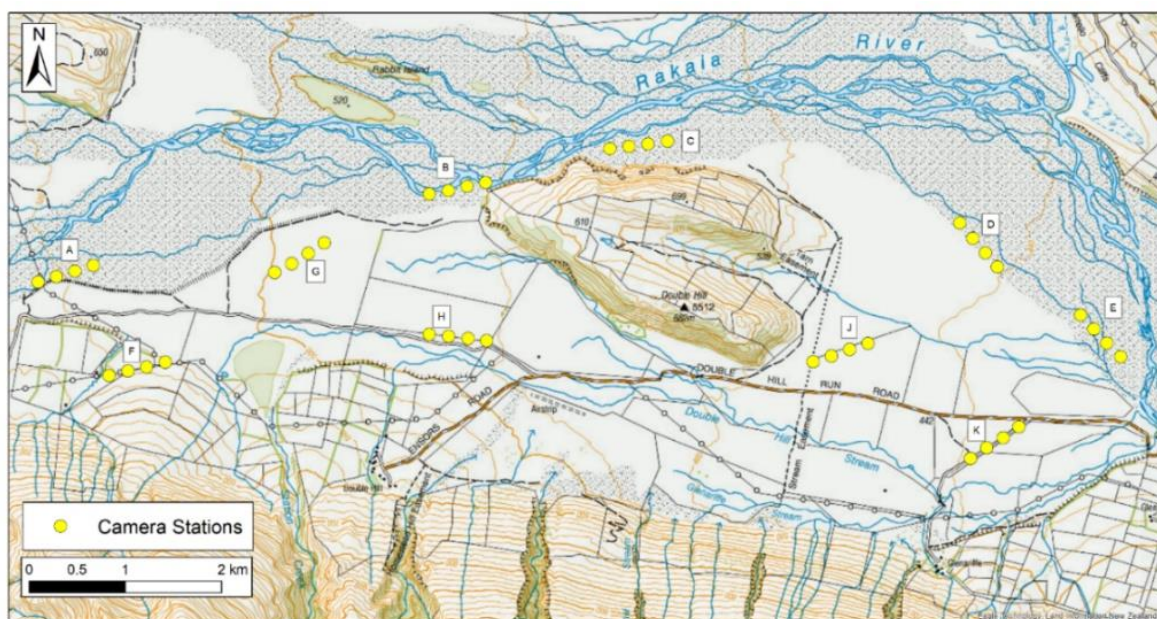


Figure 2. Map of study area for camera monitoring at the non-treatment site (i.e. no predator control) in the upper Rakaia valley in October 2021. Each camera station is shown by a yellow circle, with each line consisting of four camera stations.

At each site, transects were stratified according to habitat, with five transects placed on riverbanks in farmland and five in the riverbed. Cameras were preferably angled southeast to avoid the prevailing wind and therefore regular dust storms, which leads to polishing of the camera lenses. Each camera was set at 6–20 cm above ground and slightly angled down onto a lure station 1–1.5 m away. The lure consisted of 150 g rabbit meat and two pieces of Connovation rabbit paste lure wrapped in chicken wire and pegged to the ground (Gillies 2018). Vegetation was removed as much as possible to avoid false triggers. Cameras were set to take a burst of three photos when motion-triggered (medium sensitivity), followed by a 5 min stand-down period (Gillies 2018). In 2021 cameras were tested by holding a sign in front of the lure to ensure the cameras were angled appropriately and fully operational during installation, and again on collection. Cameras were set up for at least 21 consecutive days.

Images were curated and manually tagged using ExifPro software. Focal predators were identified to species level. Images were discarded when it was not possible to identify the species with certainty.

Detection rates

Detection rates are the main metric calculated as an abundance index of animals caught on cameras (i.e. the number of encounters per number of camera hours) because these metrics can be scaled to account for length of survey time (e.g. Rovero & Marshall 2009). To avoid autocorrelation, we used a 30 min cut-off between pictures of animals of the same taxon (i.e. an encounter is considered independent at an individual camera if observations were separated by more than 30 min; Garvey et al. 2017). We calculated the mean camera trap index (CTI) per line as the number of encounters per species per 2,000 camera hours (C. Gillies, DOC, pers. comm.). Mean CTI transforms the raw number of

independent detections into an index of predator abundance, which takes into account the number of operational cameras per line and the non-independence of cameras on a line.

Comparison of camera trap indices between times and seasons

We used t-tests to compare the mean CTI of all mammalian predators (used as a measure of predation pressure) between:

- a the upper Rangitata valley (with landscape-level predator) control and the Rakaia valley (without predator control)
- b the upper Rangitata valley in 2021 (after year-round trapping had commenced) and 2020 (with only seasonal trapping).

We then compared indices of individual predator species across sites and seasons. Because CTI violated assumptions about normality and heterogeneity, we used a generalised linear mixed model (GLMM) of independent detections per taxon with a Poisson error. The response variable was the number of independent detections, the predictor was either location (Rangitata or Rakaia valley) or season (2020 or 2021), and the random effect was camera station nested within line to account for non-independence of the sampling stations within a line. We considered differences to be significant if 95% confidence intervals of estimates excluded zero.

5 Results

5.1 Nest survival

A total of 113 tōrea nests were monitored across the two breeding seasons and sites (Table 1). An additional 10 nests in 2020 and two nests in 2021 were monitored, but disturbance through research activities was suspected to have caused desertion, and these nests were excluded from further analyses.

Table 1. Overview of number of tōrea nests monitored in the upper Rangitata valley

Season	Number of nests monitored		
	Farmland	River	Total
2020	27	30	57
2021	28	28	56
Total	55	58	113

Thirty-four nests failed to hatch chicks. The most common (known) reasons for failure were abandonment and predation by harriers (Table 2). Abandonment in 2021 was attributed in one case to interference by a possum, as fur was found next to the nest, the adult showed an abrasion on its leg, and the camera was knocked out of alignment, but

the cause was unknown in the second case. In 2020 adults broke eggs and subsequently abandoned one nest. Causes of abandonment of other nests are unknown.

Table 2. Reasons for failure of tōrea nests, showing the percentages and numbers (in parentheses) of nests that failed due to particular reasons

Reason for failure	Season	Farmland	River	Total failed
Abandoned	2020	4% (1)	13% (4)	6% (7)
	2021	7% (2)	0	
Predation, harrier	2020	4% (1)	10% (3)	6% (7)
	2021	7% (2)	4% (1)	
Predation, hedgehog	2020	0	0	2% (2)
	2021	4% (1)	4% (1)	
Flooded	2020	0	3% (1)	2% (2)
	2021	0	4% (1)	
Infertile	2020	0	0	3% (3)
	2021	7% (2)	4% (1)	
Trampled/farming associated	2020	7% (2)	0	3% (3)
	2021	4% (1)	0	
Unknown	2020	11% (3)	16% (5)	9% (10)
	2021	4% (1)	4% (1)	
Total		14% (16)	16% (18)	30% (34)

Nest survival varied between sites and seasons (Figure 3), with slightly higher support for interacting effects of season and habitat on nest survival ($\Delta \text{AICc} = 1.85$). Nest survival in farmland was slightly lower in 2021 compared to 2020 (0.60 [95% CI: 0.37–0.77]) cf. 0.68 [0.44–0.83]) while at river sites nest survival was higher in 2021 compared with 2020 (0.79 [0.54–0.92]) cf. 0.48 [0.29–0.65]).

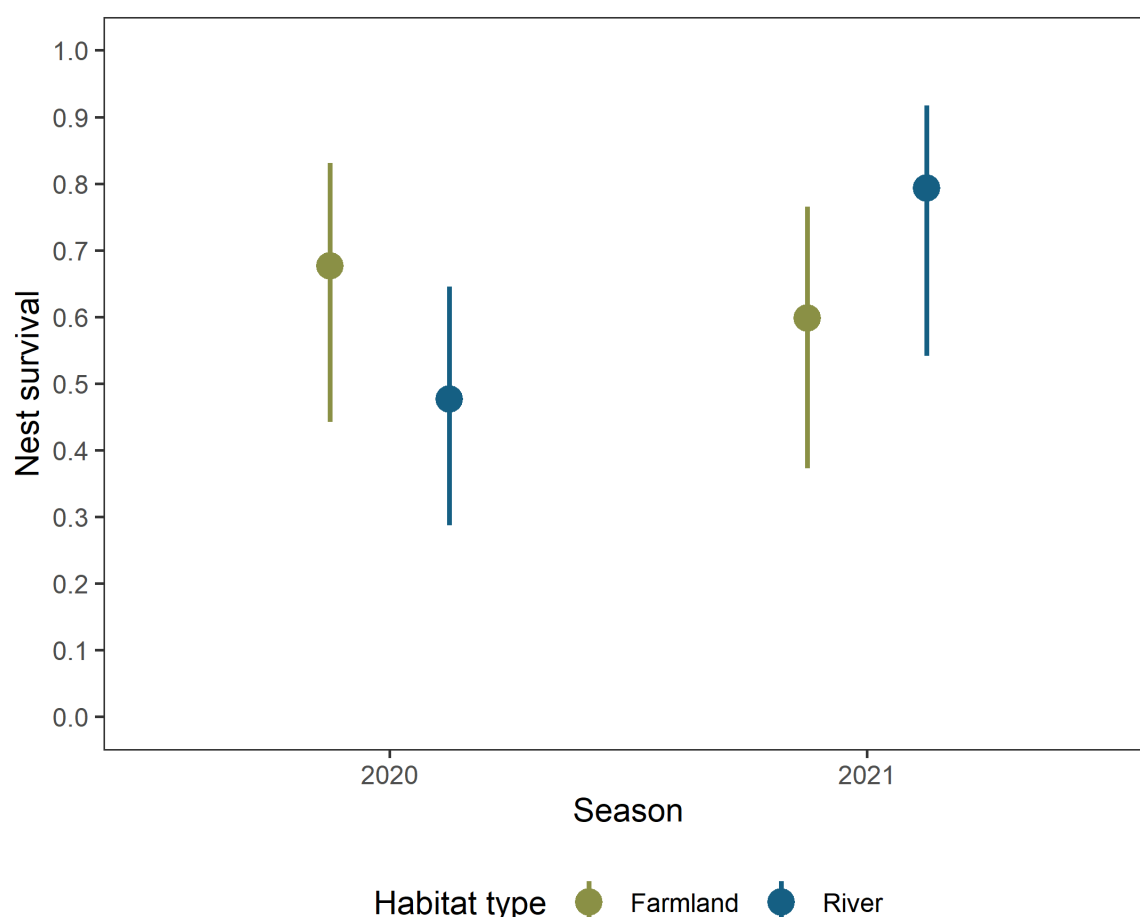


Figure 3. Probability (\pm 95% CI) of a tōrea nest surviving for 28 days in the upper Rangitata valley using farmland (green) or river (blue) areas in the 2020 and 2021 breeding seasons.

5.2 Chick survival

A total of 127 chicks were monitored across the two breeding seasons (Table 3). By extending the field season into early December in 2021 we had fewer unknown outcomes where chicks were only partially monitored (Figure 4). In 2020, 15 chicks were confirmed to have fledged and four to have died. In 2021, 33 chicks were confirmed to have fledged and 15 to have died. In 2021, predation or scavenging was confirmed for seven chicks through post-mortem analyses, although whether due to avian or mammalian predation was not always clear.

Table 3. Number of chicks monitored to assess fledging success in the upper Rangitata valley

Season	Number of chicks monitored		
	Farmland	River	Total
2020	32	32	64
2021	32	31	63

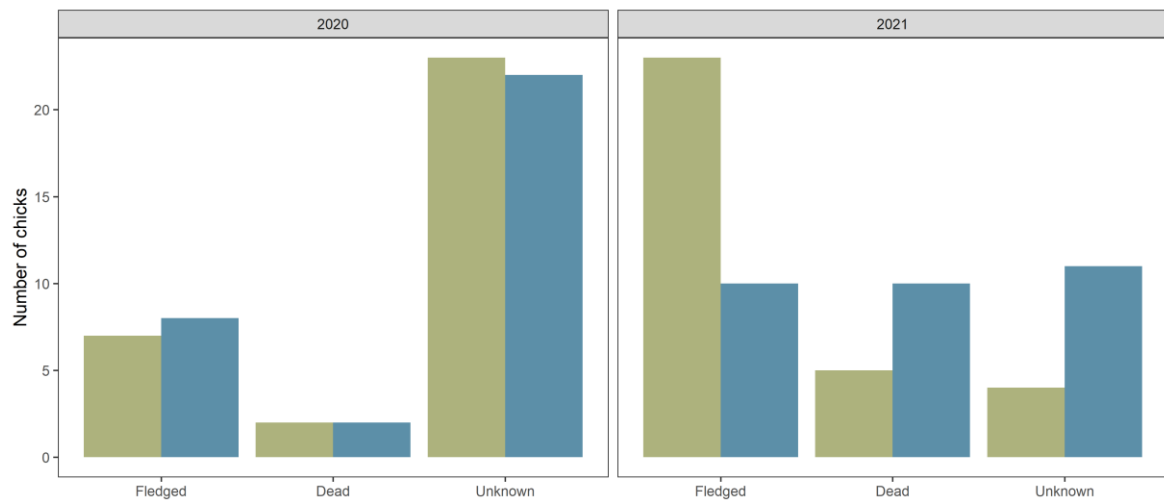


Figure 4. Fate of monitored chicks from farmland (green bars) and river (blue bars) territories in the upper Rangitata valley in 2020 and 2021.

We received strongest support for a model where encounter variability varied by tag status ($\Delta \text{AICc} = 25.25$). There was substantial support for survival depending on either season only or a combination of season and site ($\Delta \text{AICc} < 2$). Chick survival based on estimated daily survival was higher in 2021 (farmland: 0.77 [95% CI: 0.58–0.88]; river: 0.69 [0.47–0.84]) compared to 2020 (farmland: 0.47 [0.26–0.65]; river: 0.33 [0.17–0.51]) (Figure 5).

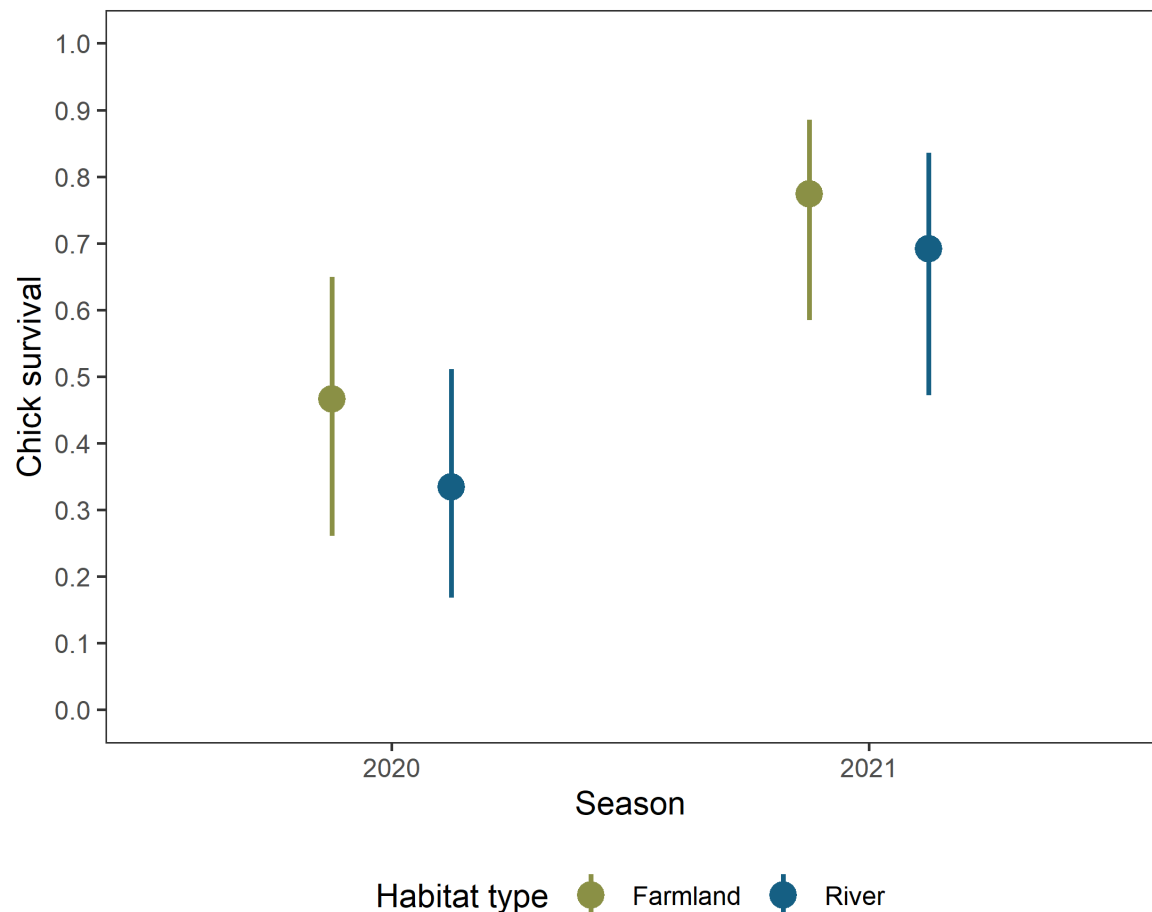


Figure 5. Probability (\pm 95% CI) of tōrea chicks surviving to 37 days (approximate fledging time) in farmland (green) and river (blue) territories to fledging (37 days) in the upper Rangitata valley in 2020 and 2021.

5.3 Movements and survival

Fifty GPS-GSM devices were attached to tōrea in the upper Rangitata valley (Table 4), and movement and behaviour data are transmitted when birds are in cellphone coverage. Apart from one adult, which is wintering in Motueka, all adults migrated to the North Island, including Kaipara, Manukau and Waitematā (Auckland) harbours, Whitianga in the Coromandel, the Firth of Thames, and Bay of Plenty. Fledglings generally migrated earlier than adults, used a wider range of flight paths, and moved to a wider range of locations, including Lake Brunner (West Coast), Farewell Spit, Mokau River, Bay of Plenty, and Kaipara, Manukau and Waitemata harbours. Flight paths and associated data are jointly stored with DOC on Movebank¹ and accessible using DOC's Mobile Threatened Species Workstream.

¹ <https://www.movebank.org>, a free, online, global database of animal tracking data hosted by the Max Planck Institute of Animal Behavior.

Table 4. Number of tōrea fitted with a GPS-GSM tag in the upper Rangitata valley.

	Farmland		River		Total
	2020	2021	2020	2021	
Adults	10	5	10	6	31
Fledglings	5	4	6	4	19
Total	15	9	16	10	50

A total of 132 tōrea were banded in the upper Rangitata valley in 2020 and 2021 (59 in 2020 and 73 in 2021; Table 5). In addition, 17 tōrea banded with white alphanumeric bands by Peter Langlands in the upper Rangitata valley between c. 2012–2014 have been re-sighted.

Overall, 40 banded tōrea, including one sub-adult, were re-sighted in 2021 in the upper Rangitata valley. Of these 40 individuals, 24 had been banded by MWLR in 2020. Nine adults banded by Peter Langlands were re-sighted in the upper Rangitata in 2020 and 2021. All banding data are jointly stored in the DOC banding data base FALCON. Re-sightings nationally have been emailed to us from Golden Bay, Coromandel, and Thames, and from Kaipara and Manukau harbours. We are working with the Banding Office to streamline access to re-sightings reported through the public reporting tool on FALCON.

Table 5. Number of tōrea newly banded in the upper Rangitata valley

	Farmland		River		Total
	2020	2021	2020	2021	
Adults	22	15	12	11	60
Fledglings	16	27	9	20	72
Total	38	42	21	31	132

5.4 Predator monitoring

Across both sites and seasons, a camera trapping effort of 2,289 camera trap nights generated 4,284 encounters with animals, of which 1,065 were by focal braided river bird predators (Table 6). Through either operational or technological problems, 11 cameras failed, which meant eight lines had only three out of four cameras working (two lines in the upper Rangitata in 2020, four lines in 2021, and two lines in the Rakaia in 2021), and one line had only one of four cameras working (Rakaia in 2021).

Table 6. Summary of camera trapping and numbers of independent observations of animals and 'focal predators' (possum, cat, ferret, stoat, Norway rat, mouse, hedgehog, black-backed gull, and harrier). No weasels were detected.

Study site	Season	Habitat	Camera traps	Camera trap nights	Detections	Focal predators
Treatment (Rangitata)	Oct-20	Farmland	20	420	939	283
		River	18	378	779	114
	Oct-21	Farmland	18	378	939	303
		River	18	378	695	157
Non-treatment (Rakaia)	Oct-21	Farmland	18	378	719	128
		River	17	357	213	80

Almost 70% (714) of all independent encounters with focal predators across all seasons and sites were on farmland, compared to 351 independent encounters on riverbeds (Table 7). No weasels were detected across all seasons and sites. Most of the other nine focal predators were detected by cameras in both river and farmland at both sites (Appendix 1, Figures A1–A4). The exceptions were stoats and mice in the upper Rangitata valley (not detected in riverbed in either 2020 and 2021) and mice in the Rakaia valley (not detected in farmland; Table 7).

Table 7. Number of independent observations of focal species across the different study sites and proportion of total encounters by a focal predator

Study site	Season	Habitat	Pos	Cat	Fer	Stoat	Rat	Hh	Mouse	SBBG	Harrier
Treatment (Rangitata)	Oct-20	Farmland	5	16	37	2	2	205	2	0	14
		River	0	10	13	0	1	64	0	18	8
	Oct-21	Farmland	5	27	4	3	36	211	0	0	17
		River	1	10	11	0	46	82	0	3	4
Non-treatment (Rakaia)	Oct-21	Farmland	25	5	3	1	19	69	0	1	5
		River	22	19	9	5	11	10	2	1	1
Total			58 (5%)	87 (8%)	77 (7%)	11 (1%)	115 (11%)	641 (60%)	4 (0.4%)	23 (2%)	49 (5%)

Notes: Pos = possum, Fer = ferret, Hh = hedgehog, SBBG = southern black-backed gull.

Across all study sites, independent observations consisted of 60% hedgehogs, 11% Norway rats, 8% cats, 7% ferrets, 5% each of possums and harriers, 2% black-backed gulls, 1% stoats, and 0.4% mice (Table 7). Although black-backed gulls and harriers were detected by cameras across sites, inspection of camera footage showed that individuals were often in flight in the background rather than interacting with the bait. As detections may depend on the amount of sky visible in the background of each camera station and cameras may not have been triggered consistently by movement in the distance, avian predators may not have been detected consistently across transects. We have therefore

not undertaken any further analyses of camera indices of southern black-backed gulls and harriers.

5.4.1 Does the relative abundance of predators differ between the upper Rangitata compared to the upper Rakaia valley?

We first compared combined CTI of all mammalian predators in the upper Rangitata valley (with landscape-level predator control) to the Rakaia valley (without predator control). Mean CTI (as an index of overall predation pressure) was more than twice as high in the upper Rangitata valley, with higher variability across transects (mean CTI $48.8 \pm \text{SE } 11.7$) compared to the Rakaia valley (22.6 ± 4.94). Therefore, there was only weak evidence that the relative abundance of predators was different in the upper Rangitata valley compared to the upper Rakaia valley (t-test = -2.07, df= 18, p -value = 0.053).

When comparing individual predator species, we considered differences between sites to be significant if 95% confidence intervals of estimates of the number of detections excluded zero. Positive estimates of β indicate higher number of detections in the upper Rangitata compared to the Rakaia valley. Hedgehogs and Norway rats were most frequently detected, particularly on farmland compared to riverbed habitat (Figures 6e and f). After taking variation across particular camera stations into account, 95% confidence intervals included zero for both hedgehogs (Poisson GLMM, $\beta = 0.93$ [95% CI: -0.55–2.42]) and Norway rats (Poisson GLMM, $\beta = 1.21$ [-0.47–2.88]).

The three larger predators (possums, cats, and ferrets) did not show a consistent pattern between treatments (Figure 6a–c). There were fewer detections of possums in the upper Rangitata compared to the Rakaia valley (Poisson GLMM, $\beta = -2.33$ [-4.10–-0.56]) and a similar number of detections of ferrets (Poisson GLMM, $\beta = 0.27$ [-1.50–2.03]) and cats (Poisson GLMM, $\beta = 0.37$ [-0.55–1.29]) in both valleys.

Stoats and mice had the fewest detections in the Rakaia and upper Rangitata valleys, and neither species was detected in river areas of the latter (Figure 6d & g). There was no difference in the number of detections of stoats between valleys (Poisson GLMM, $\beta = -0.82$ [-3.24–1.60]). There were too few detections of mice for statistical comparison.

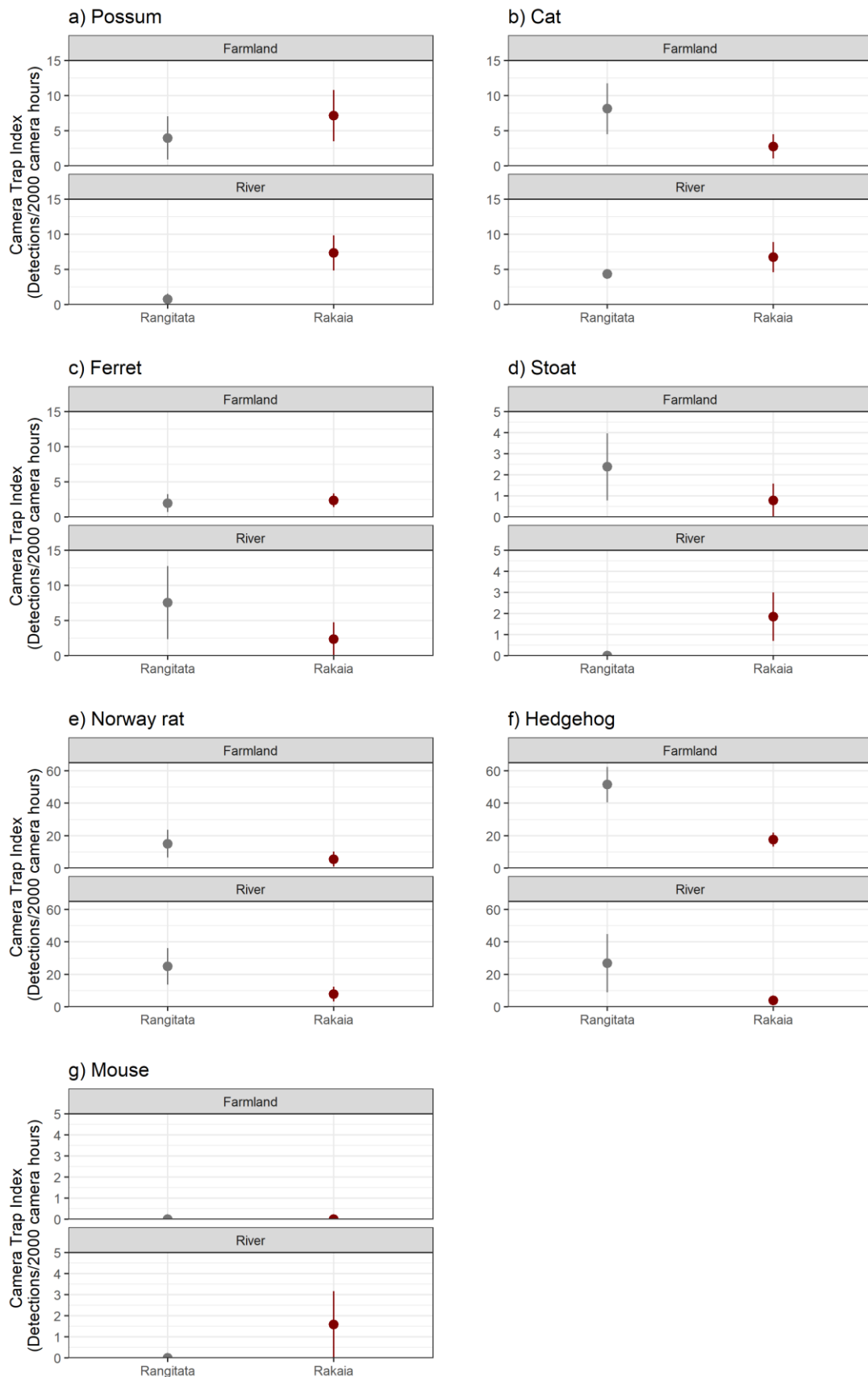


Figure 6. Mean CTI (± 1 SE) measured as detections per 2,000 camera hours for seven mammalian predators of braided river birds at a site with landscape-level predator control (treatment) in the upper Rangitata valley and a non-treatment site in the upper Rakaia valley. Note the different scales on the y-axes.

5.4.2 Has there been a reduction in relative abundance of predators between 2021 and 2020?

To test whether the change in trapping regime after 2021, from seasonal trapping (beginning in July and ending in March) to year-round trapping, was associated with a difference in the mammal predator community, we compared CTIs from 2020 and 2021 from the upper Rangitata valley. In 2020, the mean CTI was $35.8 \pm \text{SE } 10.9$ compared to 48.8 ± 11.7 in 2021, and a t-test indicated no significant difference between 2020 and 2021 ($t = -0.812$, $df = 18$, $p = 0.428$).

As for the comparison between sites, we considered differences between individual species using a Poisson GLMM. Positive estimates of β indicate an increased number of detections in 2021 compared to 2020. We considered changes in the number of detections to be significant if the 95% confidence intervals excluded zero.

In both 2020 and 2021, hedgehogs were most commonly detected (Figure 7f). Overall, the number of detections of hedgehogs across farmland and river areas was similar between 2020 and 2021 (Poisson GLMM, $\beta = 0.13$ [-0.38–0.65]). Cats also showed similar number of detections in river and farmland in 2021 compared to 2020 (Figure 7b; Poisson GLMM, $\beta = 0.38$ [-0.26–1.02]) as did ferrets (Figure 7c; Poisson GLMM, $\beta = -0.56$ [-2.52–1.39]).

The number of detections of rats in 2021 had increased significantly across both river and farmland (Figure 7e; Poisson GLMM, $\beta = 2.92$ [0.95–4.88]). Similarly, there was a slight increase in the number of detections of possums (Figure 7a; Poisson GLMM, $\beta = 0.08$ [0.08–0.09]). After taking variation across particular camera stations into account, the number of stoat detections was similar in 2021 compared to 2020 (Poisson GLMM, $\beta = 0.13$ [-4.07–4.33]). Notably, stoats had never been detected in river habitat (Figure 7d). There were too few detections of mice for a statistical comparison.

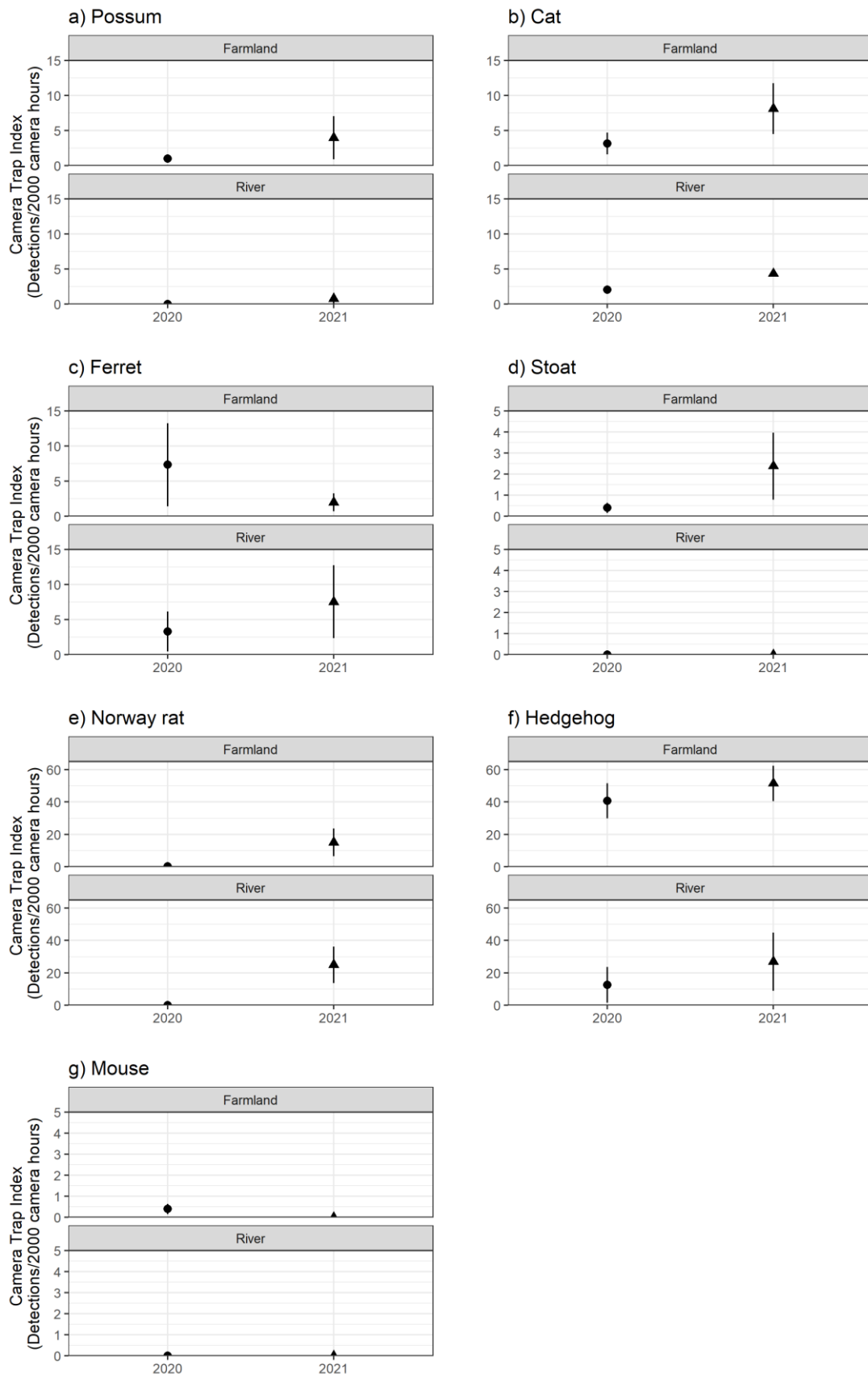


Figure 7. Mean CTI (± 1 SE) measured as detections per 2,000 camera hours for seven mammalian predators of braided river birds in the upper Rangitata valley in October 2020 (seasonal predator control) and in October 2021 (year-round predator control started). Note the different scales on the y-axes.

6 Discussion

Tōrea monitoring

Field data collected on tōrea are valuable for parameterising a spatially explicit full-annual-cycle population model. These data will allow us to take heterogeneous habitat into consideration and be able to understand what drives population changes on a local and regional scale. Predator indexing provides a critical component of understanding how different management options influence vital rates of tōrea.

Nest survival in the upper Rangitata valley ranged between 0.48 and 0.79 across seasons and farmland and river-nesting birds. These estimates from the Rangitata are similar to published estimates from the Mackenzie Basin of between 0.4-0.6 (Norbury et al. 2021). This is the first study to estimate daily chick survival of tōrea and collect data of first migrations of fledglings allowing to investigate at what age individuals start breeding and whether they return to natal sites.

In collaboration with DOC and BirdsNZ, we are collecting ongoing national movement and survival data of adults in addition to data on fledglings throughout the annual cycle. An MSc project in collaboration with the University of Otago is currently being advertised (to be completed by the end of 2024) to investigate how body condition of individuals, habitat use, and reproductive success are linked. As part of the project, molecular methods will be used to determine the sex of otherwise monomorphic adults and chicks. Information on sex will also be helpful for understanding movement patterns and connectivity.

Camera trap indices of predators

Mean CTI of all mammalian predators combined did not differ in the upper Rangitata valley (with predator control) compared to the unmanaged Rakaia valley, nor in 2021 (with year-round predator management) compared to 2020 (with seasonal management only). Only the number of detections of possums was lower in the Rangitata compared to the Rakaia valley. Between 2020 and 2021, the numbers of detections of Norway rats and possums had increased in the upper Rangitata valley. Neither stoats nor mice have so far been detected in the riverbed in the upper Rangitata valley (in 2020 and 2021), but both were present in the Rakaia riverbed in 2021.

The relationship between camera trap indices and density of predators in braided river ecosystems has not been established. Camera trap indices are likely to be correlated with abundance of key predators, but the behaviour of individuals will also influence detection rates. For example, recent research based on camera surveys indicates that cats, ferrets, and stoats partition resources (different types of prey) across space and time to avoid overlap (Garvey et al. 2022). Through a paired BACI experiment, Garvey et al. (2022) showed that stoats were detected more frequently once cats and ferrets were suppressed. The outcome for threatened fauna may be similar whether the behaviour or abundance of smaller meso-predators changes, as increased activity will lead to increased encounter rates of predators with threatened fauna.

It is not possible to say, based on the available information, if the relative abundances of mammalian predators in the upper Rangitata valley were higher before any predator control in 2016 and that ongoing management has in fact reduced relative abundance and predation pressure on threatened birds. Although land use on river flats is similar in the Rakaia and Rangitata valleys, and both study sites are at similar elevation surrounded by steep mountain ranges, there may be fewer predators in the Rakaia valley and/or the predator population may have changed despite no management of predators at the site. Ongoing trapping of apex predators in the upper Rangitata valley may be influencing the activity and/or abundance of smaller predators such as hedgehogs and rats, leading to increased detections in the upper Rangitata compared to the Rakaia valley, but currently interactions between these species are not well understood.

Given the numerous and complex population interactions among mammalian predators (and other introduced species, such as rabbits; Cruz et al. 2013; Norbury & Heyward 2008; Norbury et al. 2013), it is difficult to predict outcomes for biodiversity with certainty from a management action. This uncertainty justifies careful pre-control study of both the predator community and threatened fauna before initiating management. Long-term monitoring is crucial to assess the success of a management intervention for threatened fauna (Lindenmayer & Likens 2010).

7 Recommendations

- In spring (September to December) 2022, collect data on tōrea nest and chick survival, and focus efforts on re-sighting and/or recapturing adult tōrea to estimate adult survival in order to assess variation between habitats and seasons in the upper Rangitata valley.
- Also in spring 2022, carry out further camera monitoring at additional sites (in the upper Rangitata and other braided river systems) to understand the variation in predator communities across sites.
- Prioritise research into understanding the relationship between predator density and CTI at sites with and without predator control, to better interpret changes in CTI.
- Investigate the interactions of smaller species such as hedgehogs and rats with apex predators (cats, ferrets, possums, and stoats), with and without suppression of apex predators.
- Test whether weekly surveys (using transects or point-count methods) would be an effective indexing method for avian predator abundance.

8 Acknowledgements

We are grateful to Te Rūnanga o Arowhenua for their support in this project, and to Ally Crane for assisting with queries regarding the work in their rohe. Many people assisted with this work. Thank you to Malcolm and Sue Prouting (Mesopotamia Station) and Rikki Sinclair (Forest Creek Station) for permission and access to monitor tōrea and mammalian pests on farmland, providing information on nests, and accommodating the field team. Thank you also to Anna Hutchinson (Double Hill Station), Paul Ensor (Glenaan Station) and Mark Ensor (Glenariffe) in the upper Rakaia valley for permission and access to farmland to monitor mammalian pests. We are grateful to the staff at the Raukapuka/Geraldine DOC office for their time, knowledge, and help with aspects of the fieldwork.

Thank you to our dedicated contractors (Nikki McArthur, David Thomas, Holly Thompson) and MWLR staff (Morgan Coleman, Gretchen Brownstein, James Arbuckle, Luke Sutton) for pouring in so much effort to monitor tōrea and predators this year. Many thanks also to David Melville and Paul Sagar for their generous and expert involvement throughout this study and enthusiasm for the project; both provided considerable invaluable expert advice on monitoring and catching oystercatchers throughout the study.

Thank you to Emma Williams (DOC) for her support and hard work, both in the field and in the office, and to Colin O'Donnell for his assistance. We thank Frances Schmechel from Environment Canterbury for providing background to the different work already going on in the upper Rangitata Valley, and for linking projects and facilitating co-funding from the Regional Initiatives Fund. We also thank Ellery Mayence for feedback and support of this project.

Many thanks to Ray Prebble and Kate Boardman for assistance with editing and formatting.

All animal handling was undertaken under DOC Animal Ethics Approval AEC-363 and under wildlife permission as part of the Mobile Terrestrial Threatened Species Workstream.

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Appendix 1 – Species richness and spatial variation in detection of predators in the upper Rangitata and Rakaia valleys

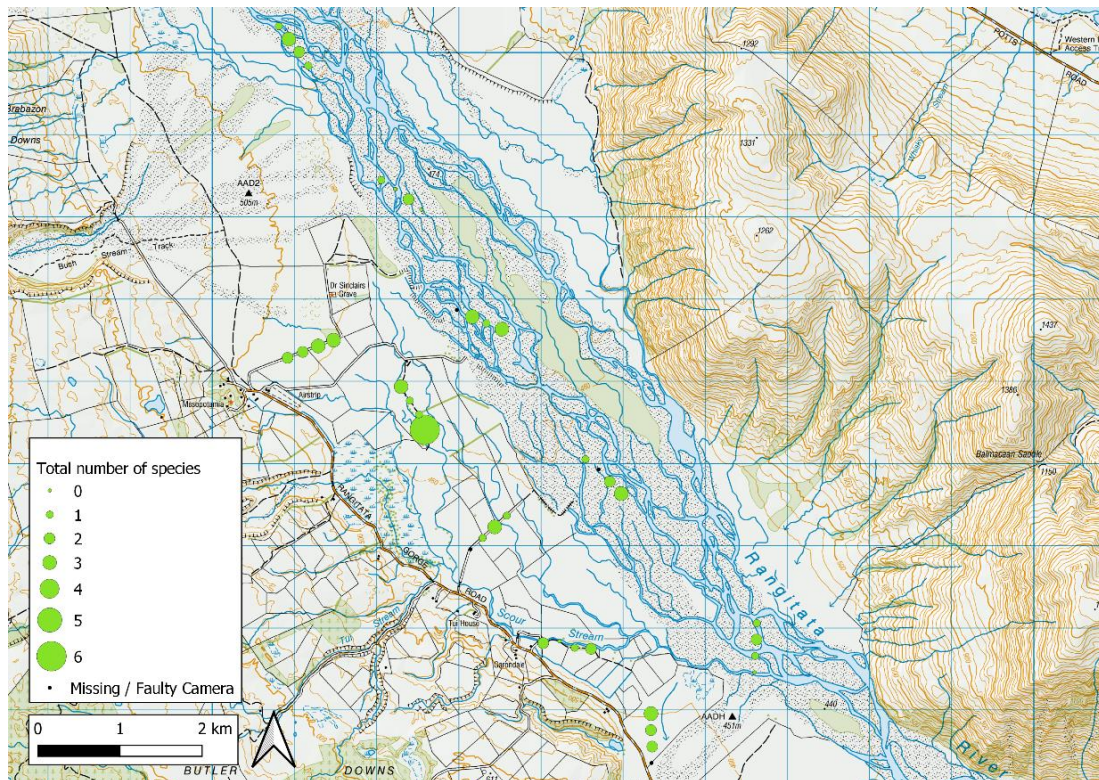


Figure A1. Overview of total number of predator taxa detected over a 21-day monitoring in October 2021 in the upper Rangitata valley.

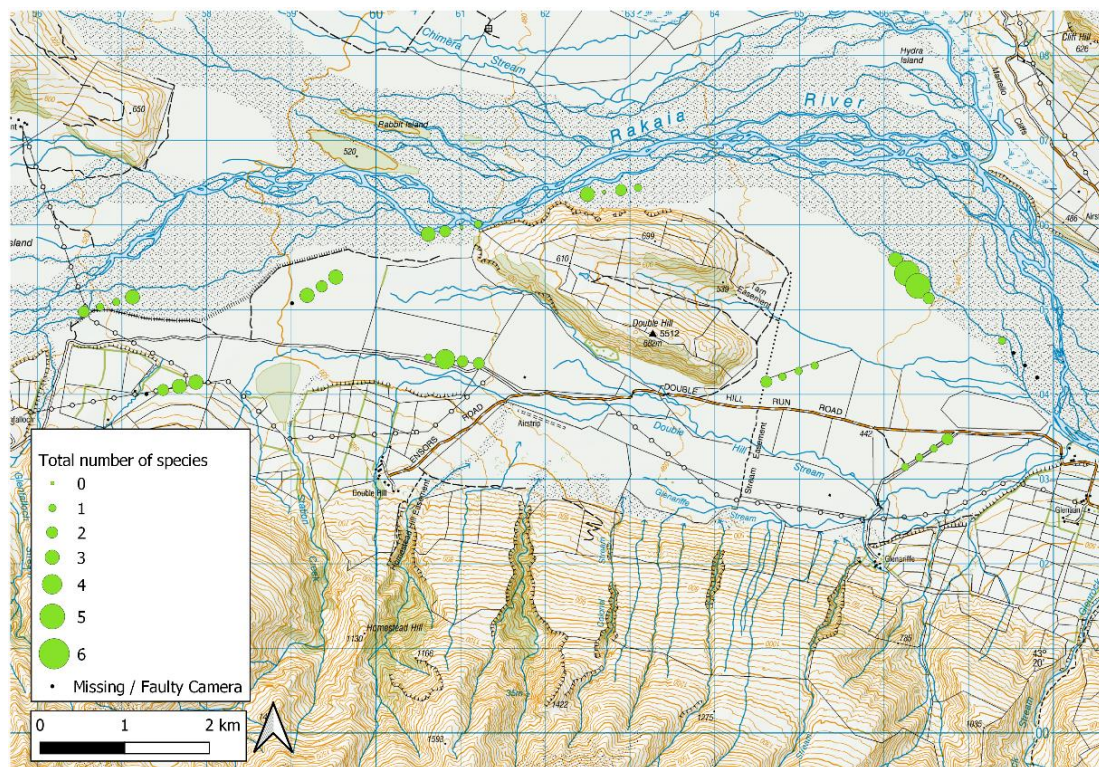


Figure A2. Overview of total number of predator taxa detected over a 21-day monitoring in October 2021 in the upper Rakaia valley.

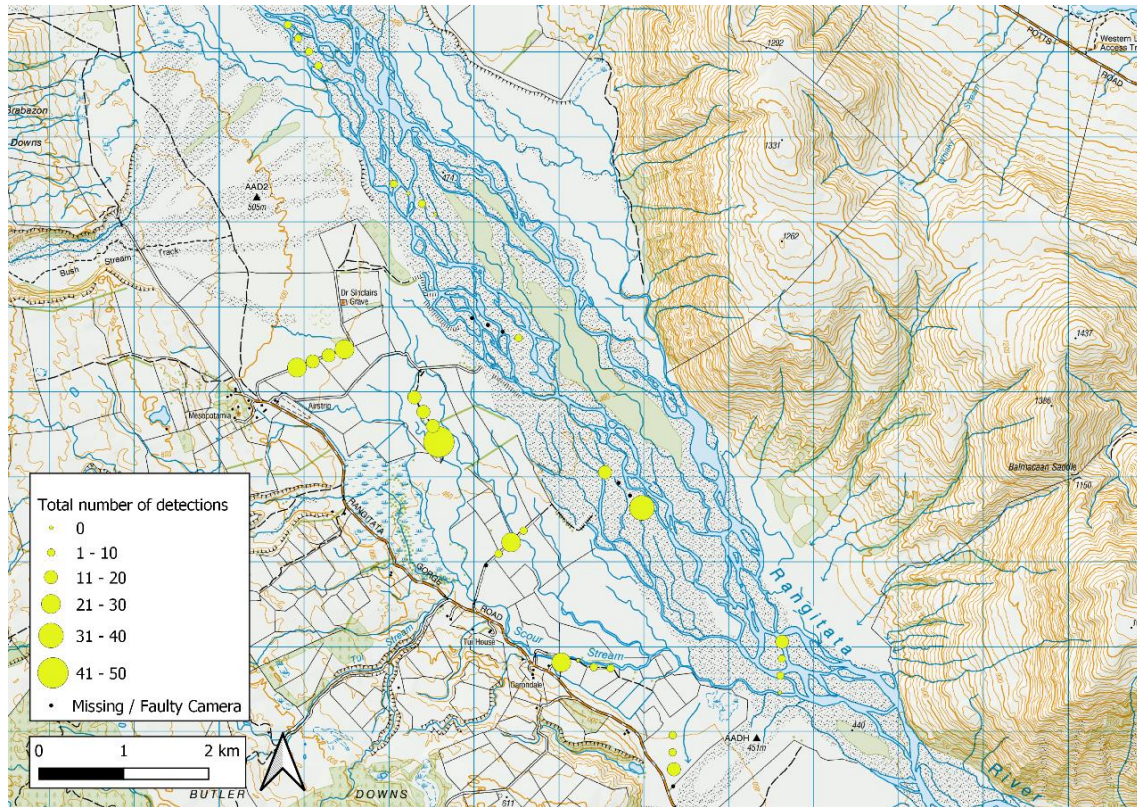


Figure A3. Number of detections of predators over a 21-day monitoring in October 2021 in the upper Rangitata valley.

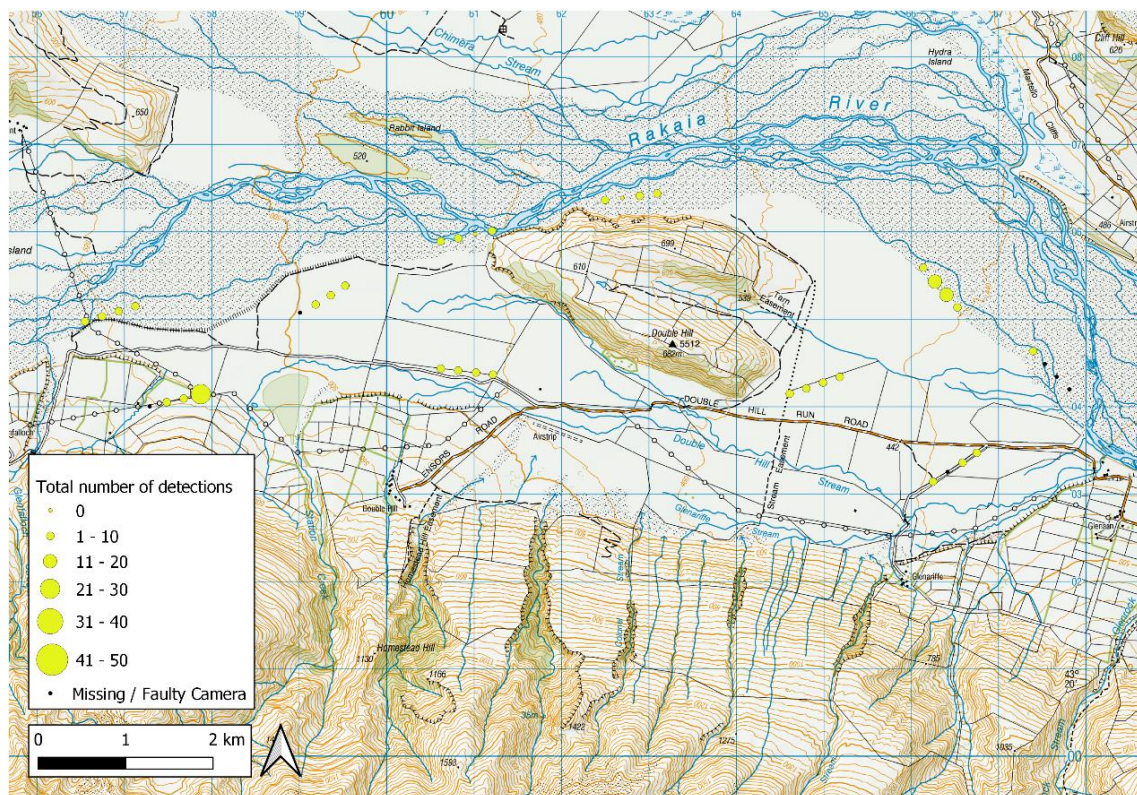


Figure A4. Number of detections of predators over a 21-day monitoring in October 2021 in the upper Rakaia valley.