Manaaki Whenua
Landcare Research

Review of 6-year upper Rangitata River predator control project

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Review of 6-year upper Rangitata River predator control project

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Summary

Project and client

- The upper Rangitata River (URR) predator control project was initiated by the Department of Conservation (DOC) in 2014 with the aim of increasing the survival and productivity of endemic braided river birds by reducing predation pressure.
- In May 2021 DOC, in collaboration with Environment Canterbury, contracted Manaaki Whenua – Landcare Research to synthesise the data collected and analyse outcomes in order to review the project.

Objectives

- Summarise predator diversity and abundance, as determined from those removed from the system via the suite of control methods employed.
- Quantify tarapirohe/black-fronted tern (*Chlidonias albostriatus*) and ngutu parore/wrybill (*Anarhynchus frontalis*) nesting and fledgling failure and success.
- Provide key findings of the study relevant to threatened river bird conservation on the URR and bird conservation in braided rivers more generally.
- Determine the methods employed and whether they were (1) fit for purpose for the questions being asked and (2) consistently applied over time.
- Provide recommendations.

Methods

- Landscape-level predator control and nest monitoring of black-fronted terns and wrybills have been carried out for six breeding seasons (2015/16–2020/21) to measure hatching and fledging success.
- For comparison purposes, nest monitoring data prior to any predator control for wrybills had been collected, and additional monitoring was carried out for black-fronted terns in the lower Rangitata River (LRR) where no predator control was in place.
- Predator and bird outcome monitoring measures from the URR were summarised, and factors affecting nesting success in general were analysed and the outcomes compared prior to any predator control for wrybills in the URR and without predator control for black-fronted terns in the LRR.

Results

- Nine predator species (eight mammalian and one avian) of native braided river birds were trapped each season. Trap captures were dominated by hedgehogs in each season.
- Nesting success in the URR (based on daily nest survival) was 0.65 ± 0.06 for wrybills and 0.35 ± 0.06 for black-fronted terns. Depredation and flooding were the most common reasons for nest failure for both species.
- Wrybill chick survival was 0.79 (95% CI: 0.57–0.89). Black-fronted tern fledglings were observed only in 2016/17 and 2020/21 in the URR.
- Black-fronted tern (but not wrybill) nesting success depended strongly on river flows and predator abundance.
- Apparent uncorrected nesting success (not corrected for length of observation) of wrybills increased after predator control.
- Nesting success (based on daily nest survival) was higher for black-fronted terns in the URR with predator control than in the LRR without predator control.
- Inconsistencies in monitoring protocols combined with data unavailability impeded a complete assessment of the effectiveness of the management programme.

Conclusions

- It is not possible to fully assess the effectiveness of seasonal (July–March) landscape-level predator control because other unmeasured factors, such as predator abundance before predator control, vegetation cover by weeds, and different predator guilds in the LRR, are likely to have affected nesting success.
- Nevertheless, for wrybills, nesting and fledging success was similar to that reported for the Tasman River, where year-round predator control was carried out (from 2004/05 to 2009/10), showing nesting success of 0.76 and chick survival of 0.62 (based on daily survival). In contrast, and based on previous population modelling, nesting success for black-fronted terns was below the levels required for population growth (≥0.74 and 0.5 nest and chick survival, respectively).

Recommendations

- Continue sustained (year-round) predator control targeting the entire predator guild (mammalian and avian) to increase nesting success, particularly of black-fronted terns.
- Use an independent assessment of predator abundance (besides trap captures), such as wildlife cameras or cat-sized tracking tunnels, spotlight counts for rabbits, and braided river bird surveys and colony counts for avian predators. Use measures of residual predator abundance for each predator species to confirm that residual abundance is reduced and understand the level that cannot be exceeded to achieve an increase in populations of threatened river birds.
- Continue nest monitoring of black-fronted terns and wrybills, using nest cameras to accurately determine nest outcome and identify nest predators.
- Prioritise river bird counts to assess the population trends of other threatened species and native avian predators.

- Undertake population viability analysis for wrybills to determine the optimal survival of eggs, chicks, and adults for population increase.
- Update nest monitoring protocols for consistency within the programme and across different braided river bird monitoring programmes. Specifically:
  - ensure methods are always outlined clearly in each report
  - use methods consistently across projects, seasons and staff, particularly for monitoring fledging success
  - record search effort
  - ensure detailed observations on nest visits are entered (including date, colony for black-fronted terns, behaviour and observations) and data are error-checked
  - store data in an accessible central repository to ensure easy relocation and use.
  - Consider banding chicks to identify individuals when they become more mobile. Unique identification would allow tracking of individual fates and reduce uncertainty about survival when chicks are not seen during several visits.
  - Continue monitoring wrybill chicks for 40 days after hatching.

1 Background

In 2014 DOC initiated the upper Rangitata River predator control project with the objective (Appendix A1):

> *to maintain and increase braided river bird populations, especially of wrybill and black-fronted tern, and increase our understanding of predator management through the application of predator control within an adaptive management framework.*

Landscape-level predator control and nest monitoring of tarapirohe / black-fronted terns (*Chlidonias albostriatus*) and ngutu parore / wrybills (*Anarhynchus frontalis*) have been carried out for six breeding seasons to measure nesting and fledging success. For comparison purposes, nest monitoring data prior to any predator control for wrybills had been collected, and additional monitoring for black-fronted terns was carried out in the lower Rangitata River (LRR) where no predator control was in place. In June 2021 DOC, in collaboration with Environment Canterbury (ECan), contracted Manaaki Whenua – Landcare Research to analyse and review outcomes of the upper Rangitata River predator control project.

1.1 Landscape-level predator control

Management to maintain and increase braided river bird populations through landscape-level predator control (hereafter 'predator control') from the confluence of the Potts River downstream to White Rock Station was initiated in 2015, and set-up of the trap network was completed in 2016. The total trap network covered 10,000 ha, and multiple parallel trap lines were set along the river and farmland (Figure 1). The rationale for this set-up was to maximise the extent and intensity of control, ensuring that:

- an area large enough to adequately protect meaningful populations of wrybills and black-fronted terns was encompassed
- predator control was on a scale that captured resident predators within their core home range areas, which could be as large as 10–12 km.

The aim was to reduce populations of target pests within the trapping area (Appendix A1).

The target species included seven introduced mammals: feral cats (*Felis catus*), ferrets (*Mustela furo*), stoats (*M. erminea*), weasels (*M. nivalis*), ship rats (*Rattus rattus*), Norway rats (*R. norvegicus*), and possums (*Trichosurus vulpecula*); plus two native bird species: southern black-backed gulls (*Larus dominicanus*) and harriers (*Circus approximans*). Hedgehogs (*Erinaceus europaeus*) and mice (*Mus musculus*) were expected to be present and to constitute by-catch in kill-traps, but control methods were not deemed to be effective at reducing their populations (Appendix A1).

Five kill-trap types were used at 200 m spacing distances:

- 280 DOC250 single traps (for ferrets and stoats)
- 332 DOC150 double traps (for stoats, weasels, and rats)
- 177 Timms cat traps
- 82 double Twizel cat traps (for cats and possums)
- 20 A24s (trialled for 1 year from 2016 to 2017 for rats and stoats).

The exact numbers of traps varied slightly from season to season due to losses through flooding or malfunction. Apart from the A24 trial in 2016/17, traps were operational for around 7–8 months each season, from July until late summer/early autumn. Each kill trap was closed (i.e. not set) for winter to achieve a balance between staff costs and maximum benefit to breeding birds.

In addition, 397 live-capture traps (Victor 1.5 soft-jaw leg-hold traps for feral cats and harriers) at 100 m spacing distances were used in two sessions before and after the bird breeding season; i.e. late winter / early spring (July–September) and autumn (March/April). During each session, traps were checked daily and were generally open for 10 consecutive nights. Live trapping most likely started in March/April 2016 (pers. comm., C. Schlieman, ranger, DOC Raukapuka/Geraldine), but data were only available from September 2016 onwards. Since mid-2018 live-capture traps in the open were set underneath plywood covers to reduce captures of harriers, due to reputational concerns (Fraser 2020; Schlieman et al. 2021).

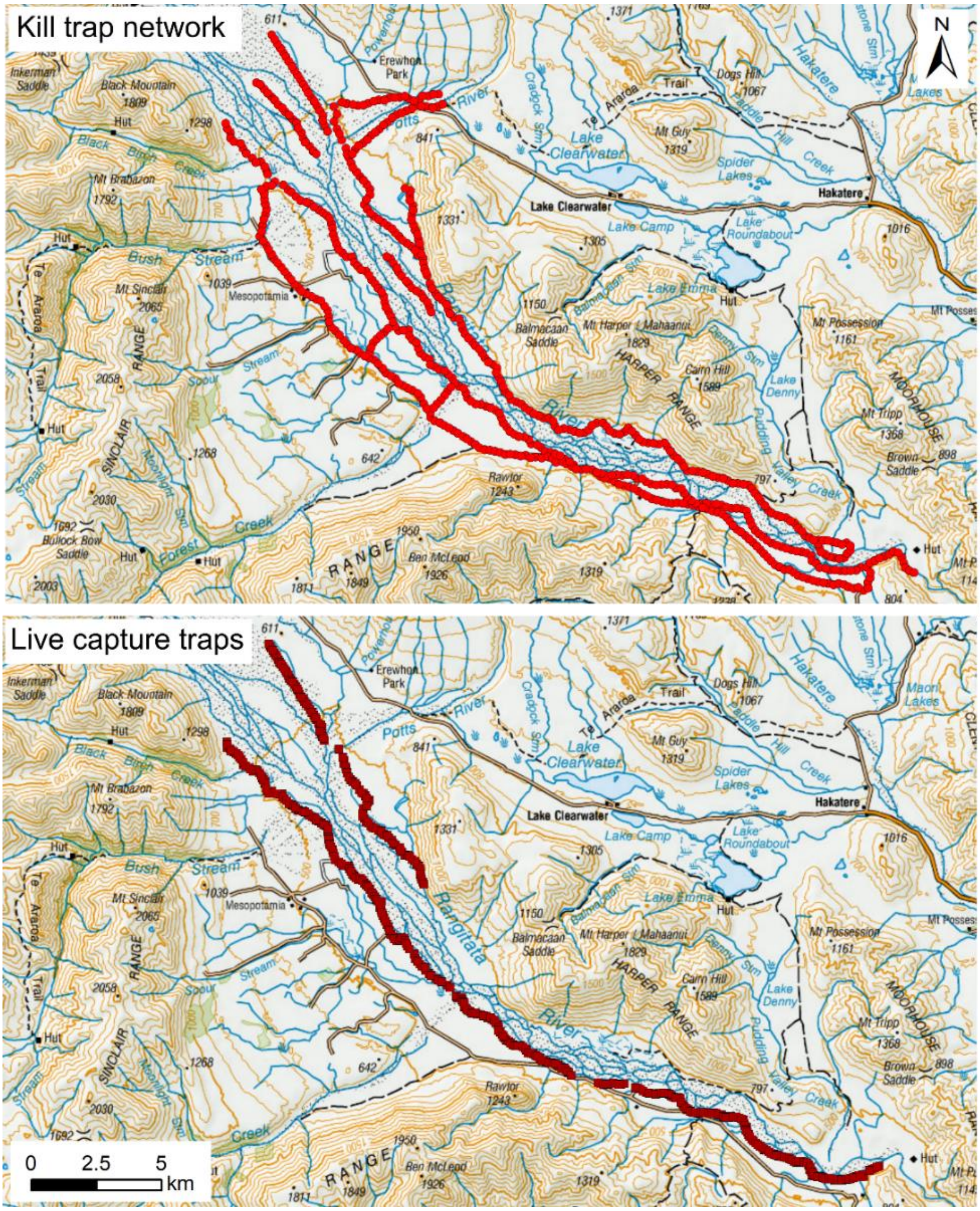

Figure 1. Distribution of traps on the URR after predator control was implemented.

1.2 River bird outcome monitoring

Bird monitoring was carried out annually between September and February by DOC Raukapuka staff. Detailed methods are described in the Rangitata bird monitoring protocol (Appendix A2) and are summarised below.

1.2.1 Wrybills

Wrybills are solitary nesters. To determine their nesting success, the aim was to locate 30 nests within the predator control (i.e. treatment) area. Where possible, at least one wrybill adult of each nesting pair was banded (with a stainless-steel C-band on the left tibia and two wrap-around colour bands on each tarsus) for identification purposes. Nests were generally visited weekly between September and January until eggs hatched or the breeding attempt failed. Nest cameras were used on a subset of nests to determine cause of loss (e.g. Armstrong et al. 2017), but causes of nest failure were mostly determined by documenting signs around the nest.

Wrybill pairs that hatched at least one chick were monitored weekly to determine the fate of each chick. In the first four breeding seasons (2015/16 to 2018/19), chick monitoring ceased after 28 days, whereas in the last two breeding seasons (2019/20 and 2020/21), chicks were monitored for 40 days. A chick was considered fledged if it was observed with adult plumage and lack of down feathers, observed fluttering or flying, or if chick behaviour was observed between estimated fledge dates or within 7 days of the latest fledge date. In addition, more effort was invested in broods with a banded parent compared to unbanded pairs with chicks (pers. comm., C. Schlieman, ranger, DOC Raukapuka/Geraldine).

1.2.2 Black-fronted terns

Black-fronted terns nest in loose colonies. The aim was to locate all colonies within the predator control (i.e. treatment) area and monitor up to 30 nests per colony (and up to 100 nests within the predator control area). To compare the nesting success of black-fronted terns without predator control (i.e. non-treatment site), colonies in the LRR below the gorge were monitored (Figure 2). Sites were independent and over 30 km apart.

Black-fronted tern nests were also generally visited weekly between September and January until eggs hatched or the breeding attempt failed. Nest cameras were used on a subset of nests in each colony to determine cause of loss (e.g. Armstrong et al. 2017), but, again, causes of nest failure were mostly determined by documenting signs around the nest.

Because black-fronted tern chicks leave nests within 2–3 days of hatching, it is not possible to follow individual chicks to fledging. Instead, the aim was to undertake regular counts of chicks in crèches from a distance, or if this was not possible, by systematically walking through colonies.

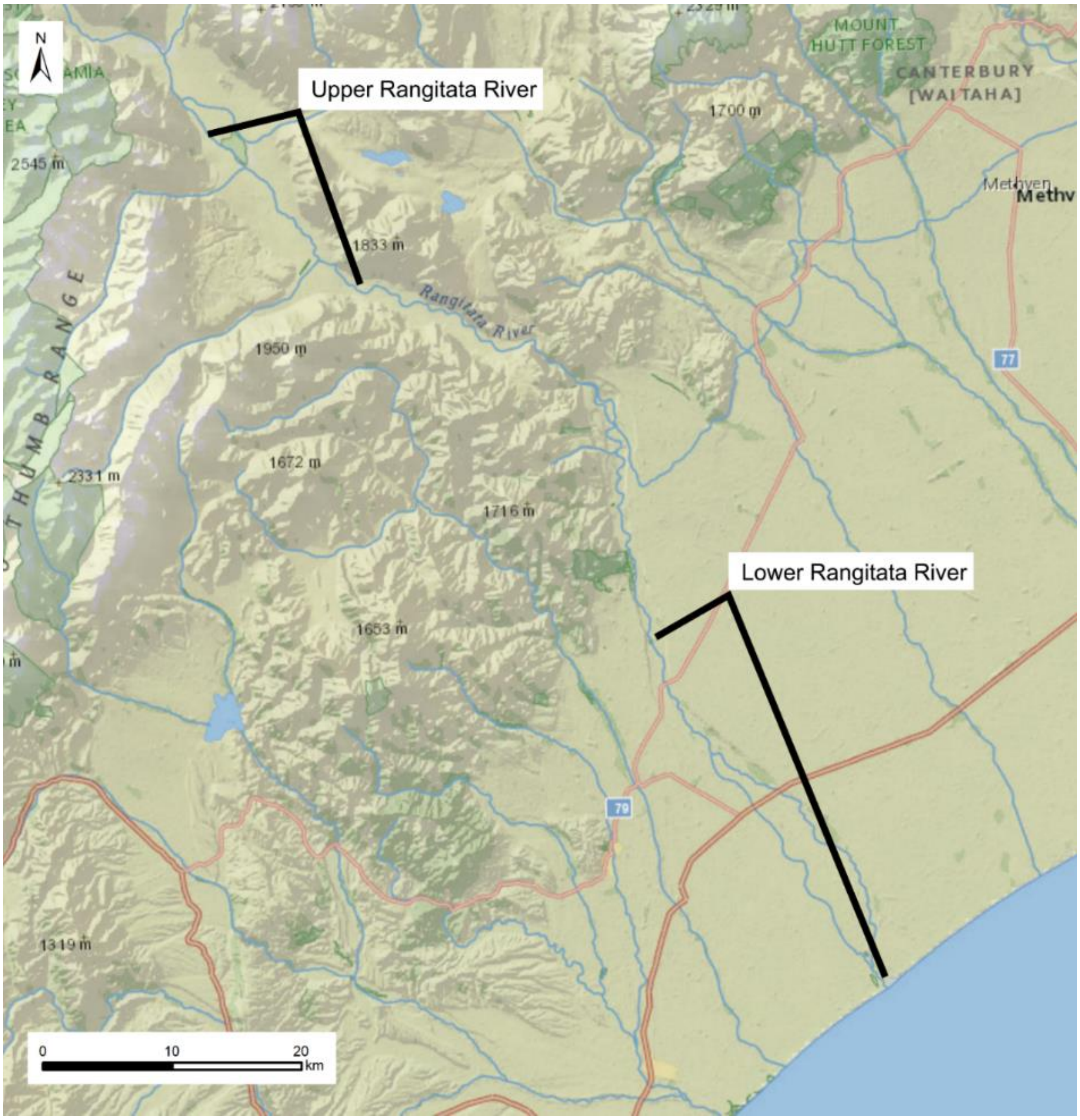

Figure 2. Monitoring reaches of black-fronted terns in URR and LRR. Predator control during the breeding season only occurred in the URR.

2 Objectives

Here I synthesise data collected over the 6-year study period to summarise predator management and bird outcome monitoring, assess if management actions have been effective, and evaluate findings for braided river ecosystems in general by:

1. summarising predator diversity and abundance, as determined from those predators removed from the system via the suite of control methods employed
2. quantifying black-fronted tern and wrybill productivity (including measures of nesting and fledging failure and success, and accounting for the methods employed):
    - in each season of the study
    - over the period 2015/16 to 2020/21
3. providing key findings of the study with respect to threatened river bird conservation on the URR by:
    - comparing black-fronted tern productivity between the upper and lower Rangitata River colonies, where possible
    - summarising wrybill productivity before and after predator control
4. providing key findings of outcomes relevant to bird conservation across braided rivers more generally by modelling the influence of predation and river flows on nest success of wrybills and black-fronted terns
5. determining the methods employed and whether they were:
    - fit-for-purpose for the questions being asked
    - consistently applied over time
6. providing recommendations that have arisen from the above.

3 Methods

3.1 Data collation

All river-flow, predator capture, bird nesting and fledging data, along with annual reports, were collated by Clara Schlieman (DOC, Raukapuka). In addition, data were standardised across seasons by Clara Schlieman.

Nest monitoring data were categorised as follows:

- depredated (e.g. broken eggs, disappearance before earliest possible hatch date)
- flooded (e.g. water moved through nest bowl)
- abandoned (e.g. cold eggs with grit on underside and no incubating adult present)
- other minor causes (infertile, destroyed by neighbouring pair, trampled by cattle, destroyed by vehicle, unknown).

The other minor causes of failure were unlikely to affect the results.

Data from wrybill chick monitoring surveys were standardised into three categories:

- chick alive: chick observed, or chick behaviour by parents observed (e.g. broken wing display)
- not seen: no chick or adult seen, or adult seen but not displaying chick behaviour
- presumed dead: pair re-nested, flooding shortly after hatching, or neither chick nor chick behaviour observed for a consistent period after hatch.

3.2 Data processing

For nesting success analyses I removed any record with no information of date of visit (URR: wrybills: n = 7, black-fronted terns: n = 8; LRR: n = 1).

For black-fronted terns, 16 nests in the URR and 22 nests in the LRR had unknown outcomes and were also excluded from analyses. Black-fronted tern colony identity was not directly recorded between 2016/17 and 2020/21 in the URR or for any breeding season in the LRR. In those instances, I mapped nest locations and assumed nests close to each other were from the same colony. Colony identity was used in further analyses to account for non-independence of nests within the same colony through, for example, the same predator preying on multiple nests within the colony or causing desertion of neighbouring nests.

3.3 River flow data

I used mean daily river flow data (m^3/s), measured at the Klondyke Station, situated at the downstream end of the Rangitata Gorge before the intake of the Rangitata Diversion Race water intake, to provide an overview of river flow during each breeding season. I then calculated rolling minimum and maximum flows over a 7-day window to assess the effects of low and high flows during the breeding season for bird nesting success.

3.4 Predator abundance and diversity

In 2021 DOC received funding to operate kill traps year-round; data were available until May 2021, inclusive. In summarising the abundance and diversity of predators based on trap capture data, only trapping data until mid-March 2021 were used to compare captures from similar seasons. For four seasons (2016/17, 2017/18, 2018/19, and 2020/21), the opening dates of traps were not recorded, and it was assumed that traps were opened on 15 July each season (pers. comm., C. Schlieman).

I estimated relative predator abundance using trap capture per unit effort (CPUE) because it accounts for varying numbers of traps used. CPUE was calculated as the total number of predator captures per 100 trapping nights, corrected for sprung traps, traps with non-target captures, or malfunctioning traps (Nelson & Clark 1973). Although CPUE is used to reflect relative abundance of predators (e.g. Cruz, Pech, et al. 2013), it does not account for differences in capture probability over time (e.g. dispersal of young, trap aversion) and season (e.g. food abundance). I calculated CPUE across the entire season (July–June) for kill and live traps to derive an index of abundance and a diversity of predators.

To understand how nesting success of wrybills and black-fronted terns related to relative predator abundance, I calculated CPUE for early (1 September to 10 November) and late (11 November to 20 January) periods of the nesting season. The distinction between early and late periods was made because predator activity varies throughout the bird breeding season (e.g. young stoats dispersing in early December; King & Veale 2021).

3.5 Bird outcome measures

An overview of the quantification of nesting and fledging failure and success for wrybills and black-fronted terns is provided in Table 1, including comparisons to before predator control and to reaches without predator control.

Table 1. Outcome measures calculated and modelled

Species	Measure or summary	Calculated as	Measurement period(s) and places, and models fitted	Notes
Wrybill	Nest outcome (% successful, failed)	Successful = % of nests where at least 1 egg hatched	2015/16 to 2020/21 in URR, summary statistics only	= uncorrected apparent nesting success (i.e. not corrected for observation length)
	Reasons for failure	% of nests ascribed to one of the following categories of causes: predation, flooding, abandonment, other	2015/16 to 2020/21 in URR, summary statistics and G-tests to test for change over time	
	Daily nest survival rate	Outcome of a series of Bernoulli trials (Shaffer 2004) method to reduce bias	2015/16 to 2020/21 in URR	
	Nesting success	(Daily nest survival)^h where h = 32 days mean incubation period	2015/16 to 2020/21 in URR, models fitted to determine factors affecting nesting success and inform management of other braided rivers	
	Fledging success	Number of fledglings/brood	2015/16 to 2020/21 in URR, summary statistics only	
	Daily chick survival rate	Cormack-Jolly-Seber mark-recapture model, accounting for bias	2015/16 to 2020/21 in URR	
	Chick survival	(Daily chick survival)^c where c = 36 days mean fledging period	2015/16 to 2020/21 in URR	Data truncated to 28 days due to differences in monitoring length between seasons
	Uncorrected apparent nesting success	% of nests hatching at least 1 chick	Comparison of **before** predator control began (2008/09 to 2013/14) and **after** (2015/16 to 2020/21), both in URR using G-tests	Not all raw data available for **before** period (see section 3.5.3), hence summaries in reports used

Species	Measure or summary	Calculated as	Measurement period(s) and places, and models fitted	Notes
Black-fronted tern	Nest outcome (% successful, failed)	Successful = % of nests where at least 1 egg hatched	2015/16 to 2020/21 in URR, summary statistics only	= uncorrected apparent nest success (i.e. not corrected for observation length)
	Reasons for failure	% of nests ascribed to one of the following categories of causes: predation, flooding, abandonment, other	2015/16 to 2020/21 in URR, summary statistics and G-tests to test for change over time	
	Daily nest survival rate	Outcome of a series of Bernoulli trials (Shaffer 2004) method to reduce bias	2015/16 to 2020/21 in URR	Accounting for non-independence of nests in colonies
	Nesting success	$(\text{Daily nest survival})^h$ where h = 25 days mean incubation period	2015/16 to 2020/21 in URR, models fitted to determine factors affecting nesting success and inform management of other braided rivers	
	Fledging success	Number of fledglings/nests in colony	2015/16 to 2020/21 in URR, summary statistics only	
	Nest outcome (% successful, failed)	Successful = % of nests where at least 1 egg hatched	2015/16 to 2020/21 in **LRR without predator control**, summary statistics only	= uncorrected apparent nest success (i.e. not corrected for observation length)
	Reasons for failure	% of nests ascribed to one of the following categories of causes: predation, flooding, abandonment, other	2015/16 to 2020/21 in **LRR without predator control**, summary statistics and G-tests to test for change over time	
	Daily nest survival rate	Outcome of a series of Bernoulli trials (Shaffer 2004) method to reduce bias	2015/16 to 2020/21 in **LRR without predator control**	Accounting for non-independence of nests in colonies
	Nesting success	$(\text{Daily nest survival})^h$ where h = 25 days mean incubation period	2015/16 to 2020/21 in **URR** and **LRR**, models fitted to compare nesting success with and without predator control	
	Fledging success	Number of fledglings/nests in colony	2015/16 to 2020/21 **LRR without predator control**, summary statistics only	

3.5.1 Summary of nest success in the URR

I summarised nest outcomes (percentage successful; i.e. at least one egg per nest hatched [Mischler & Maloney 2019), failed, cause of failure) for each species in each season over the period 2015/16 to 2020/21. I tested whether causes of nest failure changed over time using log-likelihood ratio tests (G-Test; Cruz-López et al. 2017).

3.5.2 Daily nest survival and factors affecting nesting success in the URR

I modelled daily nest survival rates using the generalised linear mixed modelling approach of Shaffer (2004). I fitted logistic-exposure mixed models specifying a binomial error distribution and a logit link function. Daily survival of a nest is modelled as the outcome of a series of Bernoulli trials, with 1 = nest still active or at least one chick hatched, and 0 = nest failed. This method accounts for the length of observation a nest was under and reduces bias of missing nests that failed early in incubation (Mayfield 1961).

To investigate the factors affecting nesting success in each species, I modelled daily nest survival for each species separately within each breeding season and for the entire period (2015/16 to 2020/21). For all models I initially assessed intercepts by building intercept-only models. For wrybills, these models contained either a constant or a seasonal intercept. For black-fronted terns the models contained a constant, seasonal, and colony intercept. I compared models based on their Akaike Information Criterion corrected for small sample size (AICc; Burnham & Anderson 2002). Nests that were not part of a substantial colony (i.e. colonies of less than 10 pairs) were grouped as solitary.

Based on the intercept model with the lowest AICc value, I built models including all covariates of interest to investigate relevant factors influencing nesting success. The covariates were:

- predator abundance (CPUE)
- time of season (FindDate)
- minimum flow (MinFlow)
- maximum flow (MaxFlow)
- the interaction between CPUE and MinFlow
- the interaction between CPUE and MaxFlow (Table 2).

Hypotheses for each covariate are described in Table 2.

Daily nest survival was converted to nesting success by (daily nest survival)^h, where h is the length of the average incubation period for a nest: 25 days for black-fronted terns (Keedwell 2005) and 32 days for wrybills (Hay 1984).

Table 2. Components and structure of statistical models of nest survival rates

	Variable	Units (link/offset/ transformation)	Analysis notes	Hypotheses
Response:	Daily nest survival rate	Binomial (logit exposure)	1 = nest still active or at least 1 chick hatched; 0 = nest failed	
Random intercepts	Season	Categorial	Due to austral spring summer periods, a breeding season spans 2 calendar years (e.g. 2015/16 = 1 season)	Particular differences between seasons not included by covariates (e.g. food availability) may lead to annual differences in nest survival
	Colony	Categorial	Included only for black-fronted terns	Nests within the same colony are not independent; for example 1 predator may cause desertion of nearby nests (O'Donnell et al. 2010)
Predictors	Relative predator abundance (CPUE)	Captures per 100 trap nights (scaled and centred)	Calculated across all pest species caught in kill traps during the early (September/October) and late (November–January) breeding season (Cruz, Pech, et al. 2013)	Higher abundance of mammals decreases nest survival through predation and disturbance (Cruz, Pech et al. 2013; Norbury & Heyward 2008)
	Time of season (FindDate)	Days (scaled and centred)	Day after 1 August when nest was found	Birds in higher body condition and with more breeding experience generally nest earlier, and potentially more or higher-quality resources (e.g. breeding territories) are available early in the season (Bell 2017; Perrins 1996)
	Minimum river flow (MinFlow)	m^3/s (log-transformed)	Rolling 7-day minimum flow of daily measured mean flow at Klondyke	Low minimum flows may decrease food availability (Hughey 1985; Lalas 1977)
	Maximum river flow (MaxFlow)	m^3/s (log-transformed)	Rolling 7-day maximum flow of daily measured mean flow at Klondyke	High maximum flows may lead to nest losses through flooding (Hughey 1985)
	Interaction CPUE x MinFlow			Mammalian predators are able to more easily access river habitat during low minimum flow, particularly to islands in the riverbed as channels dry up (Pickerell 2015)
	Interaction CPUE x MaxFlow			High river flow might increase isolation of part of the river bed and inhibit access by mammalian predators (Pickerell 2015)

3.5.3 Fledging success and chick survival of wrybills in the URR

For wrybills I calculated fledging success in each season over the period 2015/16 to 2020/21 as the number of fledglings produced per pair that hatched at least one chick (fledglings per brood). I did not calculate productivity (fledglings per number of nests), because uneven effort was invested in following broods.

In addition, I estimated daily chick survival using a Cormack-Jolly-Seber mark-recapture model, which accounts for temporal and stage-specific variation in encounter and survival probability, imperfect detection of chicks during monitoring surveys, and the inclusion of individuals with unknown fates. By modelling daily survival I was able to use data collected across all seasons and truncate data from all seasons to a period of 28 days of monitoring.

I modelled survival between monitoring surveys as missing data (Cruz-López et al. 2017). First, I assessed the most appropriate structure of encounter probability (p) by comparing models containing fixed constant, annual (breeding season), seasonal (hatch date), age of chick (in days), or quadratic age as variables and evaluating their AICc support while holding survival (ϕ) constant. I initially then fitted a model using the same habitat variables and respective interactions as for nesting success (Table 2) as well as season as covariates. However, on inspection of the resulting model, model fit was poor. I therefore only investigated whether daily survival varied between breeding seasons by comparing a model with breeding season to a null model of constant survival. Chick survival was estimated as (daily chick survival)^c, where c is the average fledging period (36 days for wrybills (Hay 1984)).

3.5.4 Fledging success of black-fronted terns in the URR

For black-fronted terns I summarised the number of fledged chicks per season and, where possible, fledging success as the number of fledglings observed per successful nests per colony. This method does not account for detection probability separate from survival probability. Low numbers of fledged chicks excluded additional analyses.

3.5.5 Comparison of nesting success of wrybill before and after predator control

I summarised uncorrected apparent nesting success (percentage of nests hatching at least one chick) and productivity (number of fledglings per breeding pair) before predator control began (2008/09 to 2013/14) from unpublished reports (Craig et al. 2012; Craig & Langlands 2014; Sullivan 2011). It was not possible to locate all the raw data, so no analysis of daily survival of nests or chicks was undertaken. I compared apparent (uncorrected) nesting success between the two time periods (before vs. after annual predator control) using a log-likelihood ratio test (G-test) to test whether there was a difference in the proportion of successful nests. Due to uncertainty in monitoring methods of chick survival before predator control, and missing data, no comparison between the number of chicks fledged per pair was made.

3.5.6 Comparison of nesting success of black-fronted terns with and without predator control

I compared nesting success of black-fronted tern nests with (URR) and without (LRR) predator control over the period 2015/16 to 2017/18 and in 2020/21 (data were not available from the LRR in 2018/19 or 2019/20). This resulted in 252 nests from the URR and 151 nests from the LRR being included in the analysis. The model contained time of season (FindDate) and predator control (factor: yes/no) as covariates, as well as intercepts based on initial comparisons.

3.5.7 Statistical analysis software and packages

I carried out all data processing and analysis using R (R Core Team 2021). Data exploration and model checking were undertaken following Zuur et al. (2009) for all nesting success models. I used the package 'lme4' (Bates et al. 2015) for fitting models of nesting success, and used the function sim (1,000 simulations) from the package 'arm' (Gelman & Su 2020) to calculate 95% credible intervals. Covariates were deemed statistically significant if their 95% credible intervals did not overlap zero. I used the package 'RMark' (Laake 2013) for building the Cormack-Jolly-Seber model of chick survival (Schwarz & Arnason 2009).

3.6 Review of methods employed

I assessed whether the methods employed were fit for purpose for the questions being asked, and whether these were consistently applied over time using the recommendations set by the Braided River Specialist Group as a framework (Appendix A1). I followed the recommendations document and separated monitoring of pest captures and residual pest densities (Appendix A1, section 8) and monitoring of biodiversity values (Appendix A1, section 9).

I first evaluated whether the data provided or documented in annual reports (Anderson 2016; Armstrong 2018; Armstrong et al. 2017; Fraser 2020; Fraser et al. 2019; Schlieman et al. 2021) matched the advice provided by the Braided River Specialist Group in 2014 (Appendix A1). I did not assess reasons for deviations such as budget limitations, competing project priorities or similar. Deviations from original advice may have been done after consultation with the Braided River Specialist Group.

I categorised data collection as: (1) Yes = provided or (2) Unsure = may have been collected (either mentioned in annual reports or personal communications). I then assessed whether data were collected with consistency throughout the project and noted deviations from season to season. Based on data availability and consistency, I evaluated the impact of lack of such information on assessing the effectiveness of the management actions as: (1) high, i.e. resulting in a major hurdle to appropriately assessing management actions; (2) medium, i.e. some lack of information, which could be overcome by making assumptions; or (3) low (i.e. may have had a small impact on aspects of the programme). I excluded sections not covered in this report (e.g. monitoring of lizard or bittern populations, or braided river bird trend counts).

I then considered whether the methods were fit for purpose or whether additional or different monitoring would have improved the ability to answer the questions.

4 Results

4.1 River flow

Rangitata River flow fluctuates regularly throughout the year and between years (Figure 3). Annually over the period September to January, when braided river birds are nesting on gravel bars, river flow is generally below 100 m^3/s. Spring floods often increase flow to around 400 m^3/s. However, during the breeding season in 2018/19 and 2019/20 exceptionally large flows of over 1,400 m^3/s occurred (Figure 3).

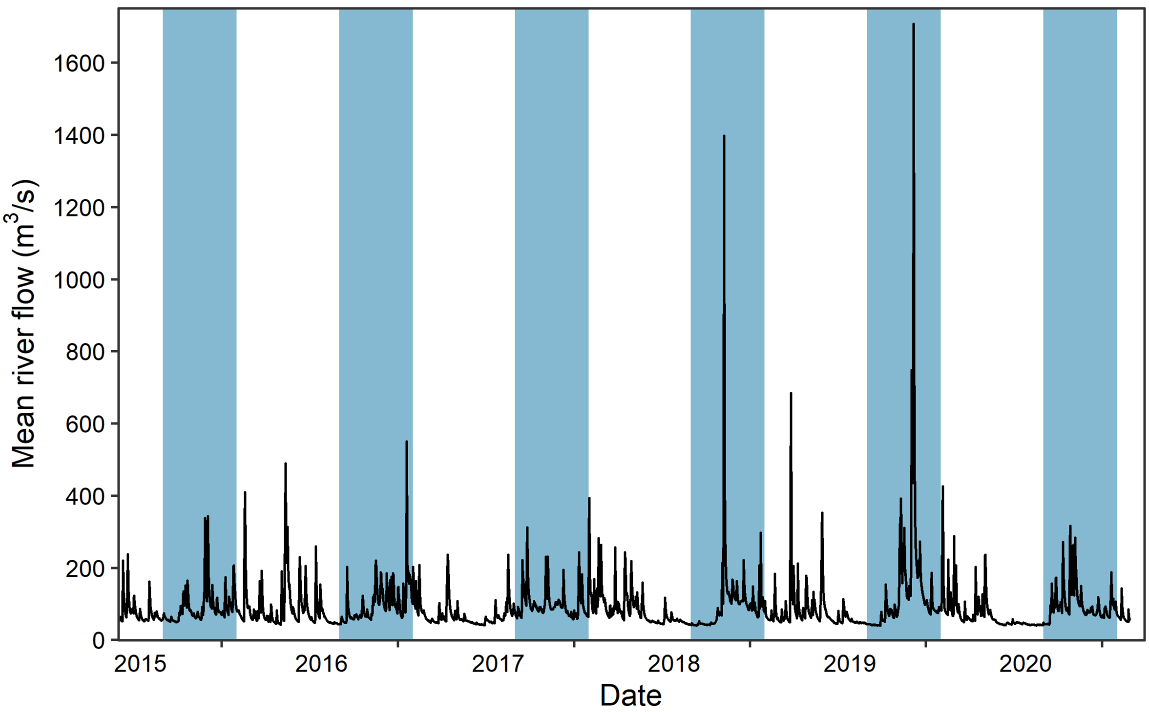

Figure 3. Mean daily flow (m3/s) of the Rangitata River measured at Klondyke. Blue bars indicate the primary nesting season of braided river birds (September to January).

4.2 Predator abundance and diversity

Trapping effort varied from season to season. Kill trap checks were closed each season between January and April, resulting in the total number of corrected trap nights across live and kill traps ranging from 11,428 to 14,749 (Table 3). Rates of capture of all target species (cats, ferrets, stoats, weasels, rats, possums, and harriers) were relatively low within each season (CPUE less than 2 captures per 100 trap nights). Hedgehogs dominated captures each season, with CPUE over 6 captures per 100 trap nights (Table 3).

Table 3. Summary of predator control efforts in the URR over the period 2015–2021

Season	Duration	CTN	CPUE										
			Cat	Ft	St	Ws	Rat	Po	Hh	Ha	Ms	Total	Target
2015/16	1 Jul to 22 Feb	11,428	0.6 (67)	0.5 (55)	0.5 (55)	0.2 (23)	0.6 (63)	0.4 (41)	6 (707)	0	0	9 (1,011)	0.03 (304)
2016/17	15 Jul* to 28 Mar	13,158	0.8 (110)	0.6 (75)	0.6 (78)	0.3 (35)	2 (225)	0.4 (53)	8 (997)	0	0.3 (46)	12 (1,619)	0.04 (576)
2017/18	15 Jul* to 14 April	13,129	0.7 (91)	1 (125)	0.5 (67)	0.3 (35)	2 (233)	0.5 (66)	10 (1,333)	0.5 (69)	0.3 (44)	16 (2,063)	0.05 (686)
2018/19	15 Jul* to 16 Jan	12,679	0.3 (39)	0.7 (89)	0.4 (55)	0.1 (14)	2 (233)	0.5 (61)	6 (788)	1 (166)	0.2 (20)	12 (1,465)	0.05 (657)
2019/20	1 Jul to 18 Mar	13,428	0.9 (125)	1 (190)	0.5 (66)	0.3 (34)	2 (308)	0.4 (53)	7 (954)	1 (154)	0.3 (42)	14 (1,926)	0.07 (930)
2020/21	15 Jul* to 12 Mar**	14,749	1 (148)	2 (228)	0.6 (85)	0.1 (21)	1 (167)	0.3 (44)	10 (1443)	0.8 (116)	0.2 (24)	15 (2,276)	0.05 (809)

Notes:

CPUE (captures per 100 trap nights) corrected for sprung or non-operational traps, with numbers caught shown in parentheses. Duration is opening times of kill traps. Live trapping sessions were also undertaken outside these periods. CTN = total corrected trap nights per season, including kill and live traps; Ft = ferret, St = stoat, Ws = weasel, Po = possum, Hh = hedgehog, Ha = harrier, Ms = mouse, Total = captures across all animal species, Target = captures excluding hedgehog and mouse captures, as the trap network was not designed to reduce numbers of those species.

* Actual opening time of traps unknown; assumed all traps were open by 15 July in each season.

** Kill traps checked each month from 2021; for this report only data until mid-March are included.

4.3 Bird outcome measures

4.3.1 Summary of nest success and reasons for failures in the URR

Overall, 246 wrybill nests were monitored over the period 2015/16 to 2020/21 (Table 4). The majority of wrybill nests hatched at least one egg (apart from the 2020/21 breeding season, when mean nesting success, based on daily survival rate, was below 0.5) (Figure 4). Across all seasons, estimated wrybill mean nesting success was 0.65 (±0.06).

Table 4. Overview of (uncorrected apparent) nest successes and failures of wrybills in the URR over the period 2015/16 to 2020/21

Season	Nests monitored	% successful	% failed	Reasons for failure			
				Depredated	Flooded	Abandoned	Other
2015/16	52	75% (39)	25% (13)	8% (4)	6% (3)	6% (3)	6% (3)
2016/17	55	67% (37)	33% (18)	20% (11)	2% (1)	7% (4)	4% (2)
2017/18	33	73% (24)	27% (9)	9% (3)	0	9% (3)	9% (3)
2018/19	29	93% (27)	7% (2)	0	3% (1)	0	3% (1)
2019/20	30	77% (23)	23% (7)	7% (2)	3% (1)	3% (1)	10% (3)
2020/21	47	55% (26)	45% (21)	15% (7)	23% (11)	6% (3)	0
Total	**246**	**72% (176)**	**28% (70)**	**11% (27)**	**7% (17)**	**6% (14)**	**5% (12)**

Notes: A nest was considered successful if ≥ one chick hatched. Percentages of total nests successful and failed shown with numbers of nests in parentheses. Other = infertile or unknown reason for failure.

A total of 358 black-fronted tern nests (21 colonies and four isolated or very small colonies) were monitored over the period 2015/16 to 2020/21 (Table 5). Mean nesting success of black-fronted terns was generally low, with a mean estimated nesting success of 0.35 (±0.06) across all seasons (Figure 4). Nesting success varied widely between colonies, ranging from 0.002 to 0.61 (Figure 5).

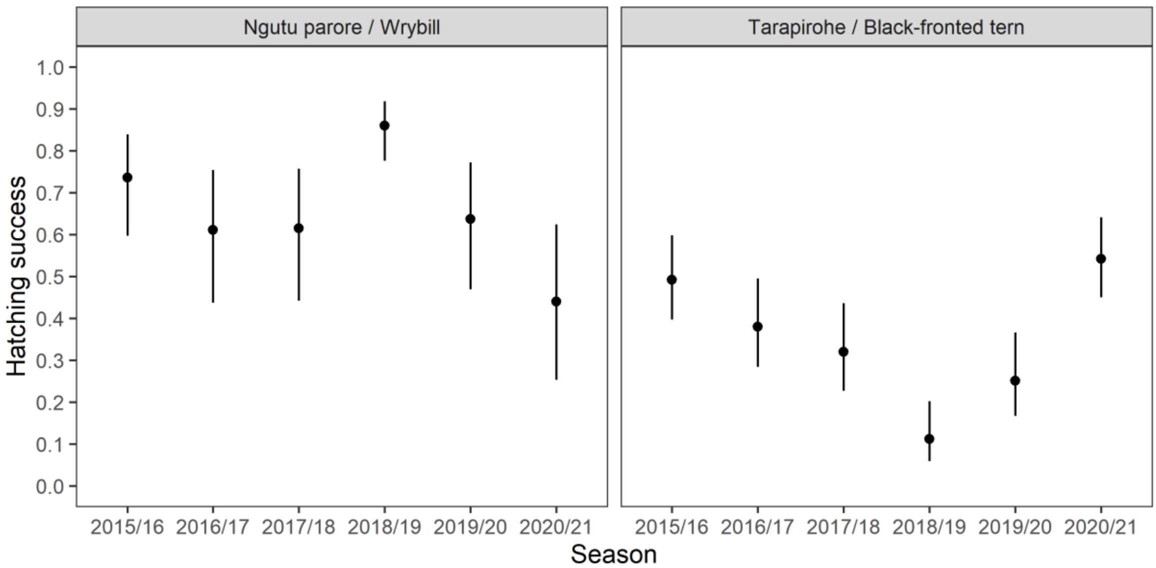

Figure 4. Estimates of annual mean nesting success (proportion of nests that hatched at least 1 egg) of wrybills and black-fronted terns over the period 2015/16 to 20/21.
Note: Error bars are 95% Bayesian credible intervals.

Table 5. Overview of (uncorrected apparent) nest successes and failures of black-fronted terns in the URR over the period 2015/16 to 2020/21

Season	Nests monitored	% successful	% failed	Reasons for failure			
				Depredated	Flooded	Abandoned	Other
2015/16	74	43% (32)	57% (42)	14% (10)	32% (24)	7% (5)	4% (3)
2016/17	62	44% (27)	56% (35)	34% (21)	5% (3)	5% (3)	13% (8)
2017/18	40	32% (13)	68% (27)	45% (18)	0	10% (4)	12% (5)
2018/19	83	8% (7)	92% (76)	43% (36)	27% (22)	5% (4)	17% (14)
2019/20	23	26% (6)	74% (17)	9% (2)	57% (13)	0	9% (2)
2020/21	76	75% (57)	25% (19)	4% (3)	4% (3)	12% (9)	5% (4)
Total	**358**	**40% (142)**	**60% (216)**	**25% (90)**	**18% (65)**	**7% (25)**	**10% (36)**

Notes: Categories as described above.

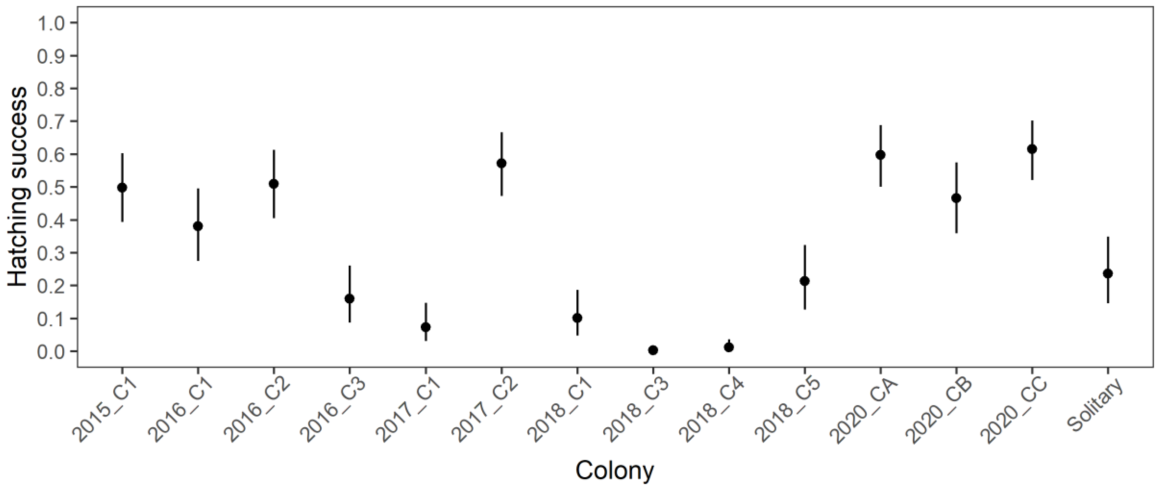

Figure 5. Estimates of mean nesting success (proportion of nests that hatched at least 1 egg) of black-fronted terns in different colonies over the period 2015/16 to 2020/21.
Notes: Error bars are 95% Bayesian credible intervals.

For both species across all seasons the majority of nesting failures were due to predation or flooding (Tables 4 and 5). However, the causes of nest failures changed from season to season for both species (G-test: wrybills: $G = 31.99$, $df = 15$, $P = 0.006$; black-fronted terns: $G = 85.13$, $df = 15$, $P < 0.001$). For both species, the proportion of failed nests due to predation or abandonment was higher in seasons when fewer nests were lost to flooding.

4.3.2 Factors affecting nesting success in the URR

Intercept-only model comparisons indicated improved fits for wrybill nesting success models using a season intercept (Δ AICc = 4.39), and for black-fronted tern nesting success models using a colony intercept (Δ AICc = 6.03).

For wrybills, none of the factors considered substantially affected nesting success (i.e. 95% CI of estimates overlapped zero; Table 6). There was only a suggestive negative trend between predator abundance (as measured by CPUE) and wrybill nesting success, with a fairly large CI around the estimate (–2.166; 95% CI: –7.3 to 3.40; Table 7 & Figure 6a).

For black-fronted terns, several factors affected nesting success (Table 6). There was an interaction between predator abundance and maximum river flows. If predator abundance was high, nesting success was low, regardless of maximum river flows. However, if predator abundance was low in addition to low maximum river flows, nesting success was relatively high (Figure 6b). Nesting success decreased with lower minimum river flows and later in the breeding season (Figures 6c and 6d).

Table 6. Parameter estimates (logit-scale) from models investigating factors affecting nesting success of wrybills and black-fronted terns

Parameters	Nesting success model estimates for:	
	Wrybill	Black-fronted tern
Intercept type	Season	Colony
TimeSeason	0.04 (–0.195, 0.271)	**–0.287 (–0.51, –0.009)**
CPUE	–2.166 (–7.25, 3.403)	–8.038 (–11.758, –4.26)
MinFlow	–0.787 (–2.295, 0.638)	**2.549 (1.176, 3.855)**
MaxFlow	–0.735 (–1.556, 0.041)	–0.889 (–1.531, –0.317)
CPUE*MinFlow	0.123 (–1.442, 1.773)	0.648 (-0.583, 1.978)
CPUE*MaxFlow	0.29 (–0.493, 0.977)	**0.927 (0.324, 1.537)**

Notes: 95% credible intervals (CI) in parentheses. Estimates where 95% CI do not overlap zero are highlighted in bold; Negative estimates mean a decrease in the probability of nesting success with an increasing parameter whereas positive estimates mean an increase in the probability of nesting success.

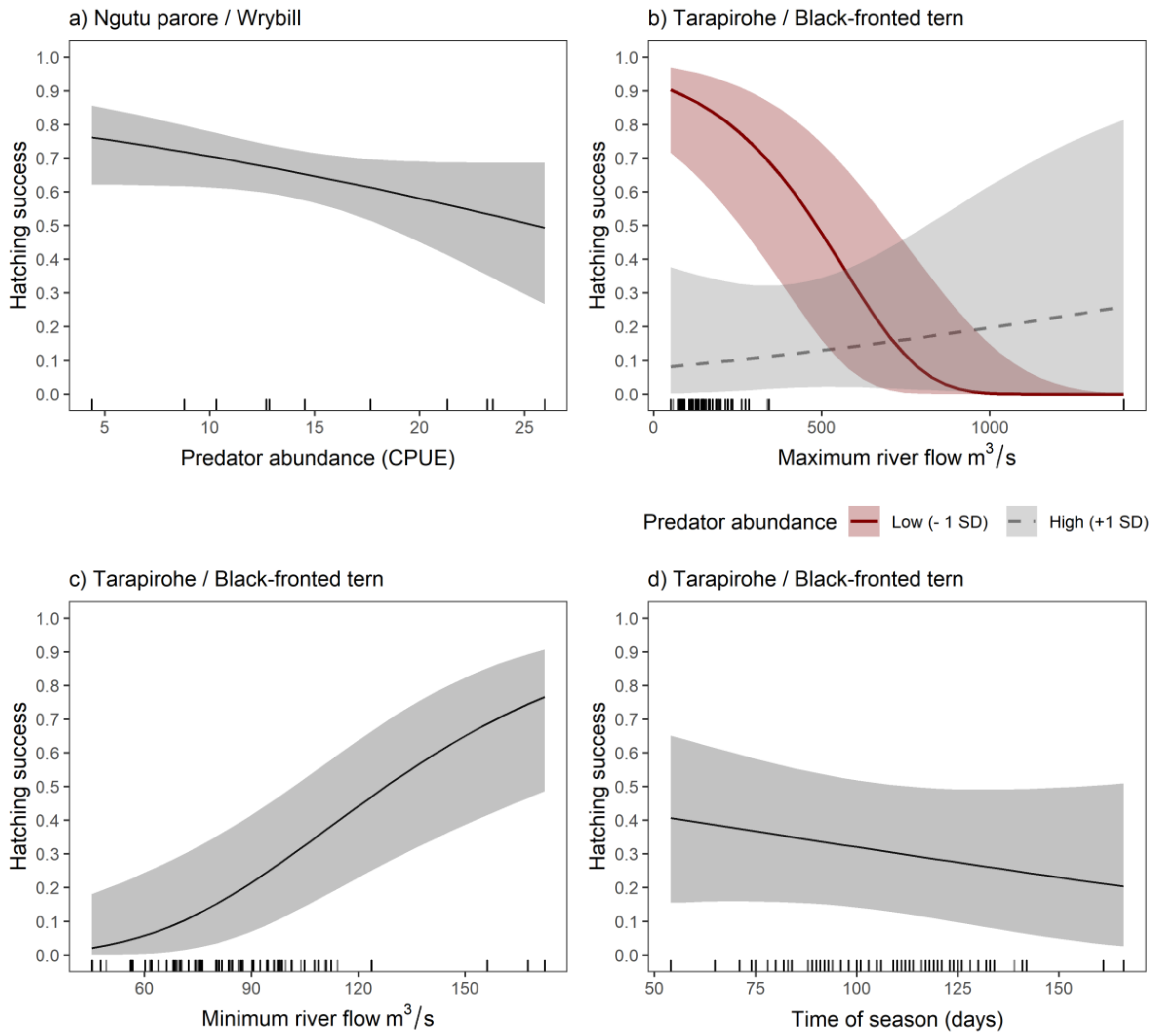

Figure 6. Predicted mean nesting success (proportion of nests that hatched ≥ 1 egg ±95% CI based on daily survival rate) of (a) wrybills in relation to predator abundance (captures per 100 trap nights) and (b) black-fronted terns in relation to maximum river flow (7-day rolling maximum mean daily flow) with high (mean predator abundance + 1 SD, grey dashed line) and low (mean predator abundance – 1 SD, red solid line) predator abundance, represented by total CPUE, (c) black-fronted terns in relation to 7-day rolling minimum mean daily river flow, and (d) black-fronted terns in relation to the time of season (days after 1 August). Notes: Short vertical lines on the inside of the x-axis show available data.

4.3.3 Fledging success in the URR

Over the period 2015/16 to 2020/21, 148 wrybill pairs with chicks were followed until the chicks fledged or were considered dead (Table 7). Across all seasons a minimum of 103 chicks survived for >28 days. Productivity ranged from 0.64 to 1.08 fledglings per pair in the first four breeding seasons, when monitored for 28 days after hatching. Productivity was lower in the last two breeding seasons, when monitoring was extended to 40 days after hatching (Table 7). Wrybills fledge between 35 and 37 days (Hay 1984). Daily chick survival was best described by a model containing an annual effect on detection probability (Appendix A3, Tables S1 and S2), but constant survival probability across seasons (Δ AICc = 5.159). Overall chick survival was 0.79 (95% CI: 0.57–0.89) accounting for differences in encounter rates between seasons through, for example, changing field staff or river access difficulties.

Table 7. Overview of numbers of wrybill broods monitored, number of fledglings, and fledging success (fledglings/brood)

Season	No. of broods monitored	Total no. of fledglings (28 of monitoring)	Total no. of fledglings (40 of monitoring)	Fledglings per brood
2015/16	33	21	No data	0.6
2016/17	32	29	No data	0.9
2017/18	17	11	No data	0.7
2018/19	26	28	No data	1.1
2019/20	23	No data	6	0.3
2020/21	17	No data	8	0.5
Total	**148**	**89**	**14**	**0.7 (0.8[a])**

[a] fledglings per brood included only the first four breeding seasons.

No monitored black-fronted tern chicks fledged in four of the six seasons (2015/16 to 2020/21) monitored in the URR (Table 8). In the two seasons chicks did fledge (2016/17 and 2020/21), black-fronted tern chick survival was estimated at 0.5 and 0.11, respectively.

Table 8. Overview of numbers of black-fronted tern chicks fledged in the URR

Season	No. of chicks presumed fledged across all colonies
2015/16	0
2016/17	15
2017/18	0? (15 mobile chicks observed in 1 colony)
2018/19	0
2019/20	0
2020/21	7
Total	**22**

4.3.4 Comparison of nesting success of wrybills before and after predator control

Wrybills were monitored for six seasons (2008/9 to 2013/14) prior to implementation of predator control. Complete data on the proportion of successful nests or on productivity were not available for each season (Table 9). Across five breeding seasons, 243 nests were monitored. Based on uncorrected apparent nesting success, a greater proportion of nests hatched at least one chick after predator control was established in the URR (G-test: G = 7.165, df = 1, P = 0.007). Mean uncorrected apparent nesting success increased from 57% ± 10 SE (2008/09 to 2013/14) to 73% ± 5 SE (2015/16 to 2020/21).

Table 9. Uncorrected apparent rates of nest successes and failures of wrybill nesting success and chick survival in the URR prior to predator control (2008/09 to 2013/14)

Season	Nests monitored	% successful	Pairs	Fledglings	Fledglings per brood	Study
2008/09	31	42% (13)	No data	No data	No data	Sullivan, 2011
2009/10	56	77% (43)	No data	No data	No data	Sullivan, 2011
2010/11	72	70% (50)	72	15-18	0.21-0.25	Sullivan, 2011
2011/12	41	71% (29)	30	29	0.97	Craig et al., 2012
2012/13	No data	No data	No data	No data	0.41	Craig and Langlands, 2014
2013/14	43	26% (11)	30	7	0.23	Craig and Langlands, 2014
Total	**243**	**60% (146)**	**132**	**51-54**	**0.39-0.41**	

Notes: 2012/13 data limited to productivity estimate.

4.3.5 Comparison of nest and fledging success of black-fronted terns with and without predator control

A total of 151 black-fronted tern nests in five large and five solitary or very small colonies were monitored in the LRR, outside the predator control area. No colonies were monitored in 2018/19 and 2019/20 due to none being located in the LRR despite searches (Fraser 2020). Extensive spread of tree lupin (*Lupinus arboreus*) and false tamarisk (*Myricaria germanica*) and large numbers of southern black-backed gulls were noted by rangers (Fraser 2020; Fraser et al. 2019).

Nesting success in the LRR was particularly low in the first three breeding seasons, with all nests failing in 2016/17 and 2017/18 (Table 10). Again, reasons for nest failure varied substantially from season to season (G-test: G = 107.64, df = 9, P < 0.001). In the first three breeding seasons, predation and flooding were the major causes of nest failure; in 2017/18 predation was the main cause (Table 10). In 2020/21 the reasons for failure were mostly unknown.

The best model comparing black-fronted tern nesting success with predator control and without predator control (non-treatment) used a colony and season intercept (Δ AICc = 5.372 compared to a model without seasonal intercepts). Black-fronted tern nests in the

URR with predator control had substantially higher nesting success compared to nests in the LRR (mean nesting success of 0.41 in the URR vs 0.03 in the LRR) for those seasons when data were available from both sites (Figure 7; Appendix A3, Table S3).

No fledglings were confirmed in the LRR in the four seasons when colonies were located. In the first year, 40 fledged black-fronted tern were observed, but it is unclear whether these observations were in one or more colonies. In 2020/21 six mobile chicks were observed, but no fledglings from monitored colonies were confirmed.

Table 10. Overview of monitored nest outcomes of black-fronted terns outside the predator control area in the LRR, from 2015/16 to 20/21

Season	Nests monitored	% successful	% failed	Reasons for failure			
				Depredated	Flooded	Abandoned	Other
2015/16	92	5% (5)	95% (87)	16% (15)	50% (46)	18% (17)	10% (9)
2016/17	18	0	100% (18)	78% (14)	6% (1)	17% (3)	0
2017/18	19	0	100% (19)	100% (19)	0	0	0
2020/21	22	55% (12)	45% (10)	5% (1)	0	0	41% (9)
Total	**151**	**11% (17)**	**89% (134)**	**32% (49)**	**31% (47)**	**13% (20)**	**151**

Notes: Percentages of total nests successful and failed shown with numbers of nests in parentheses. Other = infertile or unknown reason for failure.

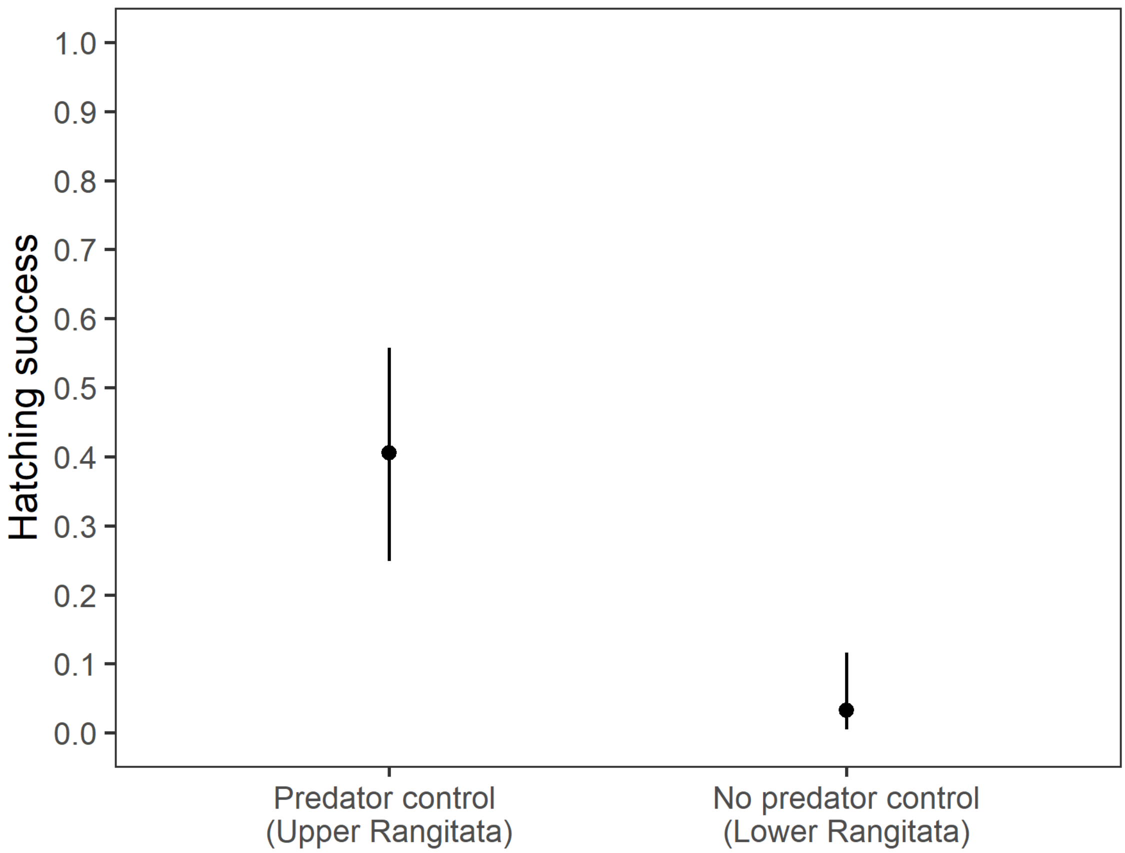

Figure 7. Predicted mean hatching success (proportion of nests that hatched ≥ 1 egg ± 95% CI based on daily survival rate) of black-fronted tern nests in the URR and LRR.

4.4 Review of monitoring methods

Four specific recommendations for output monitoring focusing on pest captures and residual pest densities were provided by the Braided River Specialist Group, along with six recommendations for biodiversity monitoring, targeting nest outcome monitoring of wrybills and black-fronted terns as key species (Appendix A1).

For each of these 10 recommendations, I provide my evaluation of data availability, along with notes on consistency and impact on the assessment of effectiveness of predator control (Tables 10 and 11). My assessment does not evaluate reasons or processes for deviations from those initial recommendations.

My evaluation found that for four recommendations (tracking tunnel indices of pests to determine residual pest numbers, black-backed gull colony counts, rabbit spotlight counts, and nest camera monitoring data) it was uncertain whether data were collected, or whether data were in a ready-to-use format (Tables 11 and 12). The greatest impact on assessing the effectiveness of the predator control was either through the uncertainty of data availability (e.g. residual predator abundance, nest camera monitoring) or the lack of consistency in monitoring protocols (e.g. wrybill data before predator control and fledging success measures).

Table 11. Overview of output monitoring of pest captures and residual pest densities as recommended by the Braided River Specialist Group (Appendix A1), evaluation of data availability, and consistency and potential impact on assessment of effectiveness of predator control

Section	Output monitoring recommendation	Data collection	Consistency	Impact
8a–c	Predator monitoring using cat-sized tracking tunnels in spring and autumn	Unsure		High
8d	Trap capture rates	Yes	Opening of kill traps was not recorded each season, leading to uncertainty when correcting for trap nights	Medium
			Re-baiting and checks of traps were at times delayed due to staffing constraints (e.g. in 2018/19 traps were not checked in January, but left armed until April)	Low
			In 2019/20 and 2020/21 live-capture traps in the open were set underneath a plywood cover to reduce captures of harriers due to reputational concerns (Fraser 2020; Schlieman et al. 2021)	Low
8f	Black-backed gull colony locations and sizes of all colonies recorded in November as well as river bird counts	Unsure	In 2018/19 and 2019/20 the annual report refers to sustained black-backed gull control having occurred for prior breeding seasons reducing the abundance of black-backed gulls from 2,000 to 200 individuals (Fraser et al. 2019; Fraser 2020). It is not clear what methods were used for the initial control. Targeted control using shooting of adults and chicks and egg destruction were carried out in 2018/19 and 2020/21.	High
8g	Rabbit spotlight counts in January and July	Unsure	Rabbit spotlight count occurred after rabbit control with rabbit calicivirus in 2019 (Fraser 2020). Uncertain if counts were carried out in previous seasons,	Low

Notes: Unsure = data may have been collected; High impact = major gap for assessing effectiveness of predator control; Medium impact = limited assessment of effectiveness, but could potentially be overcome by assumptions; Low impact = negligible effect. Detailed descriptions of each recommendation are found under section headings in Appendix A1.

Table 12. Overview of output monitoring of biodiversity values

Section	Output monitoring recommendation	Data collection	Consistency	Impact
9b	Existing pre-treatment data on wrybill breeding success	Yes	Not all data/reports were possible to relocate. Methods employed for determining reasons for nest failure and successful fledging of chicks were uncertain.	High
9c i	Nesting success of wrybills and black-fronted terns on 3–4-day return interval	Yes	Wrybill nest monitoring on c. 7-day intervals. Intervals increased to an average of 14 days after Christmas, affecting late nests, but across all seasons this only affected 14 nests Black-fronted tern nest monitoring on c. 7-day return intervals. Intervals increased to an average of 10 days after Christmas, particularly in 2018/19 and 2019/20. Nest outcomes unknown for 4 nests in 2019 as contracts ended for field staff at the end of January. Data collection focused on Forest Creek and Dr Sinclair's Grave access points rather than across entire predator control area.	Medium
	Record egg and nest outcomes	Yes	Failures have not been consistently documented over the years. 2015/16 and 2020/21 appear to be largely lacking notes	
9c ii	Fledging success of wrybills through weekly location of family group, 3-day checks close to hatching	Yes	Chicks were counted as fledged once 28 days old between 2015/16 and 2018/19, but monitored for 40 days in 2019/20 and 2020/21 In later seasons, chicks with banded pairs were prioritised over unbanded pairs with chicks.	High
9c iii	Fledging success of black-fronted terns	Yes	Development stage of chicks has not always consistently been documented throughout the years, and observation of colonies from a distance once chick hatched not always carried out (pers. comm., C. Schlieman, ranger, DOC Raukapuka/Geraldine).	Medium
9c v	Identification of cause of nest failure using 20 cameras each on wrybill and black-fronted tern nests, run continuously	Unsure	Unsure how many cameras were used each season and if/how outcomes were recorded	High
10d	Nesting and fledging success of black-fronted terns at non-treatment sites (lower reaches of Rangitata, Ashburton and/or Rakaia River) of 5 colonies at weekly intervals	Yes	Collected from LRR only. Uncertain about search effort in years when no colonies were located. Note in annual report 2018/19 report on flooding precluding access to river (Fraser et al. 2019). Visits were generally weekly.	Medium

Notes: Categories and details as described above.

5 Discussion

Overall, it has not been possible to determine whether predator abundance has been decreased by the trapping regime (large-scale, but trapping only operational from July to March) and whether the predator control adequately protected native threatened species. Nine predator species have been trapped each season, with hedgehogs dominating captures.

The nesting success of wrybills was relatively high, and at least uncorrected apparent nesting success increased compared to before predator control was in place. Analyses of fledging success and productivity of wrybills were constrained by monitoring methods, and so it was not possible to adequately compare data to before predator control.

Although nesting success of black-fronted tern was higher in the URR compared to the LRR without predator control, nesting success was generally low in the URR. No fledglings were observed in the URR in most seasons. By modelling nesting success in relation to river flows and predator abundance, I was able to show that, at least for black-fronted terns, very low flows, very high flows in addition to high predator abundance, and late nesting lead to lower nesting success, which has important implications for other braided river systems. Uncertainty over whether data were collected and inconsistencies in monitoring impeded my ability to draw definite conclusions on the effectiveness of the predator control, as initially designed.

Although predation by introduced mammals is a key threat for braided river birds, control of the large number of predator species over large scales to levels that benefit several native species has proven difficult (Cruz, Pech et al. 2013; O'Donnell et al. 2016). Building on existing knowledge, the URR predator control project was set up with the aim of maximising the extent and intensity of predator control with the resources available, and focusing biodiversity outcome measures on the two most threatened bird species present: wrybill and black-fronted tern (Appendix 1). Ecological monitoring is fundamental for providing baselines for ecosystem-based management and for determining whether management interventions yield the anticipated outcomes (Lindenmayer & Likens 2010). However, it is a challenge to detect these outcomes against a backdrop of environmental gradients and other ecological change. When considering the effects of predator control, it is important to consider the wider range of interacting factors that threaten native bird species nesting in braided rivers (Figure 8), the traits of native species and their resulting vulnerabilities, and the specific attributes of river systems.

In the following, I first discuss constraints on assessing the effectiveness of predator control in (section 5.1) and suggest how these could be improved in the future. The suggestions cover predator indexing, camera monitoring of nests, and general outcome monitoring, as well as data consistency. They are made so that future assessment of the effectiveness of management is possible. I then detail the biodiversity outcomes measured in the URR (section 5.2) and expand on how the Rangitata River project is able to inform other braided river systems (section 5.3). Last, I provide a summary of recommendations for future projects.

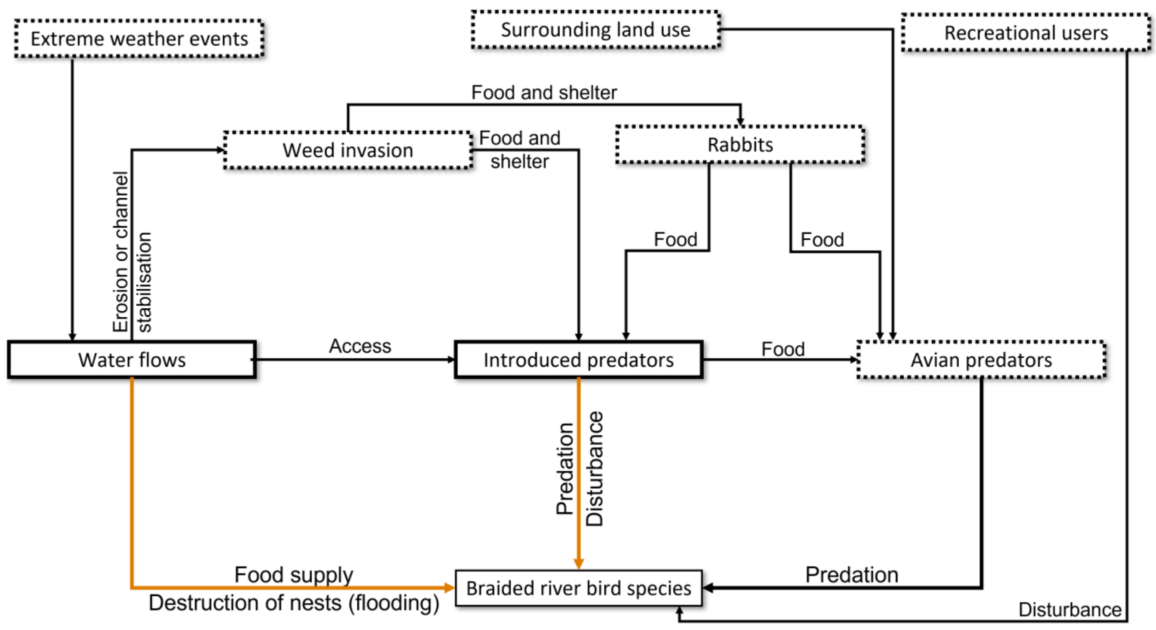

Figure 8. Inter-relationships among threats to bird species nesting in braided riverbeds (based on Keedwell 2004).
Notes: Orange arrows and solid box frames indicate threat factors assessed in this review. No data were available to assess factors in dotted box frames.

5.1 Constraints on determining predator control effectiveness

The two greatest constraints on the ability to determine whether the predator control was effective were the lack of a reliable method of assessing residual predator numbers, and the absence of nest camera monitoring each season.

Currently, the only metric used to assess relative abundance of mammalian predators is CPUE. However, it can be difficult to assess predator abundance accurately using CPUE because it only relates to the number of animals removed, and does not account, for example, for immigration of new animals (e.g. Lazenby et al. 2014). 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),
- and relying on as few assumptions as possible.

Apart from being practical (the data are automatically collected when checking traps), CPUE does not fulfil any of the other attributes and is therefore not useful. Standardised indices of predator abundance are a measure of predator control effectiveness, e.g. estimating residual abundance of the predator to determine if it is different to without predator control. It also can be in combination with biodiversity responses measured, a target to aim at.

It is not possible to determine if predators were ever reduced in the URR based on CPUE alone. It is uncertain if indices of predator abundance were estimated in the URR, but none were estimated before predator control was initiated, nor were they estimated in the LRR, as only bird outcomes were monitored.

Rabbit abundance is directly linked to the abundances of some predators (Cruz, Glen et al. 2013; Norbury 2017). If rabbit numbers are suddenly reduced (through disease or poisoning), larger predators such as ferrets and feral cats switch from their primary prey (rabbits) to threatened river birds. As a result, sudden decreases in rabbit abundance negatively affect nesting and fledging success, and potentially adult survival of threatened species (Norbury & Heyward 2008; Rebergen et al. 1998). Once rabbit abundance is reduced, however, there is the opportunity to regulate predator abundance by sustained control of rabbits (Cruz, Glen et al. 2013; Norbury 2017).

Southern black-backed gulls and harriers prey on braided river bird nests (Schlesselmann et al. 2018; Steffens et al. 2012), and control of both species occurs to some level in the URR. It is uncertain how numbers of southern black-backed gulls were assessed each year and how control measures were carried out. Some information on the abundances of both bird species may exist through braided river bird counts. Although many braided river bird species move between river catchments (Keedwell 2002; Schlesselmann et al. 2020), counts of breeding adults generate population trends and provide further understanding of the effectiveness of management on target predators, as well as threatened species populations.

For future projects I recommend collecting data on residual pest numbers, including predators and their prey (rabbits) as well as avian predators (as originally recommended). Residual predator density can be indexed by using standardised large cat-sized tracking tunnel transects (Pickerell et al. 2014) or cameras (Garvey et al. 2017). Rabbit abundance can be indexed using spotlight transect counts. Southern black-backed gull and harrier abundances can be estimateded by braided river bird counts of the entire URR and targeted counts of southern black-backed gull colonies. Changes in any of the abundance indices would indicate that changes in trapping intensity may be required (e.g. more or less trapping or targeting of certain species). Therefore, such indices provide direct feedback on the effectiveness of actions and can indicate when additional effort is required.

In addition, obtaining reliable estimates or indices of residual predator abundances alongside nest and chick survival data would provide the basis for deriving relationships between residual predator abundances and nest survival of the key species (e.g. Innes et al. 1999). Although the number of predator species is large (up to 10 mammalian and avian species), formulating predator density-impact functions (DIFs) based on standardised monitoring methods of predator species (Norbury et al. 2015) would provide clearer guidance across braided river systems of the residual predator abundance targets required to increase nest success. For example, for kōkako (*Callaeas wilsoni*), ship rat tracking tunnel indices and possum trap catch above 5% lead to fewer than 40% of the pairs fledging young. Predator control that does not achieve these thresholds is unlikely to increase nesting success.

The inconsistency around the use of nest cameras and data availability constrain the ability to determine which predators are mostly responsible for losses at the nest, whether predator identity has changed over time, and whether certain species require more trapping effort. For example, camera monitoring of snowy plover (*Charadrius nivosus*) nests in Utah (USA) has shown that both coyote (*Canis latrans*) and kit foxes (*Vulpes macrotis*) prey on nests, but solely reducing coyote populations would have little effect on nesting success of snowy plovers because such nests would otherwise be preyed on by kit foxes (Ellis et al. 2020). Similar effects were found for gull and mammal predation of snowy plover nests in Utah (Ellis et al. 2020).

In addition, the assumption that nests failed due to predation based on disappearance of eggs before the probable hatch date may not be valid because nests are found at unknown ages. Using yolk or the presence of ants in a nest to determine predation may not be accurate, as signs around nests can vary significantly. A field team led by Nikki McArthur tested the assignment of fates of 200 pohowera/banded dotterel, wrybill, and tōrea/South Island pied oystercatcher nests monitored during the 2017/18 season in the Cass, Macaulay, and Tekapo rivers before checking camera footage. The observer team correctly determined nest fate only 52% of the time when basing this assessment on a combination of nest sign and expected hatch dates (pers. comm., N. McArthur, ornithologist). This is not much better than flipping a coin.

Reasons why field sign at nests appears to be relatively uninformative are: (1) the birds often clean up the evidence following a hatch or failure (pers. obs.), as females often eat the eggshell remains to presumably recycle the calcium or at least take eggshells away from the nest (Steffens et al. 2012), or (2) predation events are seldom single events caused by one predator – often a predation event is followed by a scavenging event (A. Schlesselmann, unpubl. data), with the scavenger often leaving the most obvious field sign behind. Camera monitoring is the only way to determine the identity of predators and the nest outcome with high certainty (Norbury et al. 2021). The method of using nest cameras appears to be safe because there is no suggestion from studies of New Zealand braided river birds (Sanders & Maloney 2002), nor from overseas studies of shorebirds that nest cameras significantly influence nest survival (Mcguire et al. 2021).

I therefore strongly recommend the use of nest cameras for reliably assigning nest fate and identity of predator. If this is not feasible, then at least determining the age of clutches by floating eggs would provide a more reliable estimate of hatching date, and monitoring schedules could be increased around the estimated hatch date (Liebezeit et al. 2007).

Further constraints on assessing the effectiveness of management were uncertainty about which monitoring methods were used, lack of consistency in monitoring methods, and unavailability of prior data. Particularly for wrybills, it is uncertain whether the change in monitoring time of chicks (28 days during 2015/16 to 2018/19 vs 40 days during 2019/20 to 2020/21) or a change in the environment led to reduced fledging rates in the later two seasons compared to the preceding four seasons.

I recommend ensuring:

1 data are collected in the same manner each season, even when field staff change

2 detailed note-keeping of nest visits and river searches (even when no nests are found, so that effort can be tracked) is carried out

3 error checking of data (particularly dates, colony, and nest names) is consistently carried out at the end of the field season

4 data are stored in a national repository.

The initial recommendation document proposed creating a modified Access database available for all outcome monitoring data, with a single data gate-keeper (Appendix 2, section 11 h). It is unclear if that has occurred.

5.2 Conservation of threatened river birds on the URR

Evidence for an effect of predator control on nest success of wrybills and black-fronted terns was equivocal, because there are several confounding factors that make it difficult to fully assess the effectiveness of the landscape-scale trapping during the breeding season with the data available. Based on uncorrected apparent nesting success, the proportion of successful wrybill nests increased after predator control. However, it was not possible to ascertain whether the predator abundance had been reduced by the pulsed seasonal control (as opposed to year-round control).

Similar to other studies of solitary nesting braided river birds in New Zealand (Cruz, Pech et al. 2013; Norbury & Heyward 2008), nest survival of wrybills was unrelated to CPUE in the URR after predator control was in place. It was not possible to determine factors influencing wrybill chick survival in the URR. Other studies suggest that threats may be stage-dependent; i.e., different predators or factors affecting survival of eggs versus chicks (Cruz, Pech et al., 2013; Dowding et al. 2020).

Although it is important to keep in mind site- and time-specific factors, there are indications from studies of wrybill in the Tasman River that year-round-trapping is beneficial. After predator control was implemented in the URR, mean nesting success (based on daily survival rates) across all seasons was lower (0.65) than in the Tasman River from 2004/05 to 2009/10, where year-round predator control is carried out (0.76; Cruz, Pech, et al. 2013). However, chick survival (based on daily survival rates) was higher (0.79) in the URR than in the Tasman River (maximum of 0.62; Cruz, Pech, et al. 2013). Dowding et al. (2020), suggested that while annual productivity was highly variable in the Tasman River over the period 1997/98 to 1999/2000 (mean 0.55 chicks fledged per pair), apparent annual adult survival (mean 0.9) was increased by predator trapping, resulting in population growth. Keedwell (2004) carried out population viability analyses for banded dotterels, South Island pied oystercatchers, and black-fronted terns, but available data in 2004 precluded carrying out a similar analysis for wrybills. Given the intensive monitoring of wrybills in the Tasman and Rangitata rivers, it would now be possible to repeat such analyses to understand the rates of egg, chick, and adult survival required for population growth.

Nesting success of black-fronted terns based on daily survival was greater in the URR with predator control compared to the LRR without predator control, but fledgling success was very low at both sites. It is possible that nesting success would be higher in the URR irrespective of predator control, as other factors affecting nest survival are also likely to differ between these sites. Non-native plant cover is greater in lower sections of braided rivers, resulting in lower-quality breeding habitat for braided river birds and increased cover and food for mammalian predators (Brummer et al. 2016; O'Donnell et al. 2016; Williams & Wiser 2004). Mammalian predator guilds differ between lower and upper river reaches (Pickerell 2015) and greater numbers of native avian predators are present around lower sections, which is likely to be a consequence of more intensive land use in surrounding areas (Bell & Harborne 2018). Regardless of the reason for higher nesting success in the URR, egg and chick survival were still below levels required for population increase, based on population viability modelling by Keedwell (2004).

5.3 Outcomes for bird conservation across braided rivers more generally

Black-fronted terns are particularly vulnerable to catastrophic nest failures due to their colonial nesting habit (Keedwell 2005; O'Donnell et al. 2010; Schlesselmann et al. 2018). My models showed that nesting success of black-fronted terns was lower with low minimum river flow, later in the season, and with high predator abundance if maximum river flows were low. In contrast, my models did not show a significant effect of river flows on wrybills.

Reduced black-fronted tern nesting success with decreased minimum flows could be due to increased access by mammals to nesting colonies (Pickerell 2015) or reduced food availability. The negative effect on nesting success of reduced minimum flows suggests that reduction in minimum flows resulting from water abstraction in other braided rivers (no water abstraction occurring in URR) may affect nesting success of at least this threatened braided river species.

My models showed that nesting success of black-fronted terns in the URR decreased later in the breeding season, which has also been documented in the Clarence/Acheron and lower Waitaki rivers (Bell 2017; Schlesselmann et al. 2018). One potential explanation is that different predator species target nests at different times of the breeding season or that life-stages or behaviour of predators changes throughout the season (e.g. increased nutrient requirements to provide for offspring or dispersal of stoats at the start of December) Alternatively, nesting is often more synchronous early in the season, and higher nesting density may provide 'greater safety in numbers' as well as higher-quality resources potentially being available to individuals earlier in the season (Norbury & Heyward 2008; Perrins 1996; Schlesselmann et al. 2018).

Understanding competing risks to nesting success from different predators (e.g. mammals vs. birds) in braided river systems through nest camera monitoring can provide a better understanding of the necessary management actions (Ellis et al. 2020). Flooding is part of a braided river ecosystem, and braided river birds are adapted to nest losses due to flooding. Due to the increased predation pressure from introduced mammals, nest survival of black-fronted terns is low with high predator abundance, even when not under the additional pressure from nest losses due to flooding. These results suggest that while losses to floods in some years are to be expected, reducing predator abundance reduces the additional risk to nest survival in most years.

Overall, the responses of braided river birds to threats are both species- and site-specific. The simultaneous monitoring of wrybills and black-fronted terns has been valuable, as these species have different nesting and feeding habits and respond to threats differently. The results from the URR predator control project are consistent with other studies, which have found that responses to predator control depend on the traits of the threatened species such as colonial nesting (Cruz, Pech et al. 2013). However, at least for black-fronted terns, it appears that seasonal predator control was insufficient to increase nesting and fledging success such as to lead to a population increase. Further work incorporating nesting and fledging success with adult survival is required to determine the levels required to increase wrybill populations.

6 Recommendations

General recommendations

1. Continue sustained (year-round) predator control targeting the entire predator guild.
2. Collect an index of residual predator abundance by using:
    - cat-sized tracking tunnels or cameras for mammalian predators
    - spotlight counts for rabbits
    - braided river bird surveys and colony counts for avian predators.
3. Continue nest monitoring of wrybills and black-fronted terns in the URR using nest cameras.
4. Prioritise river bird counts to assess the population trends of other threatened species and native avian predators.
5. Undertake population viability analysis for wrybills.

Specific recommendations for updating nest monitoring protocols

- Ensure methods are always outlined clearly in each report
- Use methods consistently across projects, seasons and staff, particularly for monitoring fledging success
- Nests within black-fronted tern colonies are not independent, and single predation events can lead to desertion of neighbouring pairs (Keedwell 2005; O'Donnell et al. 2010; Schlesselmann et al. 2018), so it is important to record colony identity for every nest to allow appropriate analysis of nest success.
- Record detailed notes on nest visits, noting the behaviour of adults and chicks and any observations of the nests. The data are unusable if there is no record of date of a nest visit or if there are no notes on observations during the nest visit because this creates uncertainty about the ultimate fate of the nest. Mischler and Maloney (2019) detail best-practice nest monitoring, data recording, and data management.
- Record search effort in a spreadsheet so that it is possible to determine whether, when no nests are found, breeding birds were absent or search effort was constrained by limited available time and accessibility of the river-bed.

- Carry out detailed error-checking of data (particularly dates, nest, and colony names). In the case of dates, check that a date is always recorded, and that the correct year is recorded, particularly for records in January.
- Ensure data are stored in multiple locations, and create a national, easily accessible repository.
- Consider banding chicks to identify individuals when they become more mobile. Unique identification would allow tracking of individual fates and reduce uncertainty about survival when chicks are not seen during several visits.
- Continue monitoring wrybill chicks for 40 days after hatching.

7 Acknowledgements

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Appendix A1 – Braided River Specialist Group Advice: Rangitata Predator Control Proposal

Department of Conservation
Te Papa Atawhai

Our Ref: Proposed Braided River Specialist Group Advice - Rangitata Predator Control Proposal

DOCDM-1436598

1 September 2014

TO:	Paul Gasson, Services Biodiversity Senior Ranger
Cc:	Braided River Specialist Group members
FROM:	Richard Maloney (BRSG co-ordinator) for the proposed Braided River Specialist Group

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SUBJECT: **Advice on undertaking predator control in upper Rangitata River**

Thank you for sending your request for “Science Advice required for planning a large-scale predator control operation in the Rangitata Valley.”

Colin O’Donnell, Kerry Brown, Andy Grant and Richard Maloney from the proposed Braided River Specialist Group provided this advice.

The recommendations below aim to provide guidance on the complete set-up design of the predator control operation and related output and outcome monitoring requirements for the Upper Rangitata site. We have listed the methods for predator control and monitoring, and rationale for these methods. While we agree there are choices around the scale at which the programme can be rolled out, we have provided the preferred option to maximise benefit for river birds, without over-extending the predator control effort.

Context:

The advice below follows the principles and priorities set out in the *Strategy for New Zealand Braided Rivers: Biodiversity values, issues and priority actions* (O'Donnell et al. in prep, DOCDM-1023479). Much of the background rationale for predator control in braided rivers is covered in that document that should be read in conjunction with this advice.

There are few examples of predator control that have been shown to significantly benefit braided river species, and as such all new braided river predator control programmes should be considered experimental in their approach. In order to develop best practise for management of biodiversity values in braided rivers, programmes need to be established with a clear set of questions and methods to be tested, and with robust monitoring in place.

Recommendations:

1. **Objective:**

   To maintain and increase braided river bird populations, especially of wrybill and black fronted tern, and increase our understanding of predator management through the application of predator control within an adaptive management framework.

2. **Confirmation of site and scale of trap set-up**
   a. Spatial extent of predator control and the intensity of control are the two main considerations in design of this programme. The aim is to maximise both the extent and intensity of control. Small scale very intense programmes (such as the Upper Ohau tern colony programme) provide good protection but are too resource hungry to scale up beyond 1-2km scales. Larger scale, low intensity control programmes operating over 10 km's of river length but limited to the bird breeding season and to single lines of traps have repeatedly failed (Keedwell et al 2002, Wairau predator control summary report DOCDM-734784). Successful landscape-scale programmes are on the scale of 20-50 km (e.g., Tasman & Eglinton projects), and are multi-line year-round control operations. The rationale for managing on this scale is as follows: (1) Braided rivers are dynamic environments where bird population use of habitat changes on kilometre scales - smaller areas are unlikely to adequately protect meaningful populations of wrybill and black-fronted terns; and (2) predator movements within river environments are linear and home-ranges are overlapping. For example, daily cat movements of 10-12 km of river length have been regularly recorded, so predator control must be on a scale that captures resident predators within their core home range areas.
   b. We therefore recommend multi-line, multi-season control at 20 km scales as the preferred option. Applied in the Upper Rangitata catchment, the braided river predator control programme should extend from about the Potts River confluence at the upstream end, and downstream to about White Rock station.

c. The aim should be to setup all lines concurrently over the full length of the area, limited only by which access arrangements can be made. We do not recommend limiting setup to the lower section of river below Forest Creek because we consider this is too small a scale and will not adequately protect wrybill populations. We anticipate that the current budget will be adequate to support trapping across the full site.
d. We accept that there might be a need to have a staged setup because of logistical constraints. In that case, the site should be divided into two sections (Site A = Potts River to Forest Creek, Site B = Forest Creek to White Rock Station), with the Potts River section being setup first. Control lines should be placed on both the TL and TR of the river.
e. An outline map of sites is given in Appendix 2 (and see map link for the GIS project).
f. The size of the predator control area is approximately 7600 ha (Site A= 4600 ha, Site B = 3000 ha). The Area of breeding habitat protected is approximately 3300 ha (Site A = 1800 ha, 10km length, Site B = 1500 ha, 18 km length). In comparison, the Tasman River project encompasses ~20,000 ha of predator control area and ~9000 ha of riverbed (20 kms in length).
g. Assuming access agreements, double lines of traps should be set on each bank of the river wherever possible (e.g., along the road and against the river margin on the True Right side of the river). Additional lines should be set within the riverbed on large tussock islands where these can be accessed.
h. Single line sets can be used along narrow sections such as the bluff area on the TL opposite Ben McLeod Station, and it is not necessary to run additional lines up the Mt Harper hillside, as these will be too inefficient to regularly service.

3. Trap and line spacings

a. Trap spacing of 200m is current best practise and adequate to ensure that there are several traps per predator home range along trap lines, based on estimated home range sizes of >500 ha for cats, 300 ha for ferrets and 150 ha for stoats (1km x 1km = 100 ha).
b. Given all of the above, this equates to approximately 500 - 700 kill trap sites over the entire area (with multiple traps at some sites, see 5 (a) below). The Tasman Valley project currently has 700 sites over a similar scale, and this is about to be expanded to ~800+ sites, so the scale and effort requirements should work.
c. Additionally, lines should also be extended along vehicle access routes on the TL side (e.g., from Potts Bridge downstream) because these are obvious routes for predator movement from the Ashburton Lakes Basin towards the river.
d. Quad biking of lines is preferred over walking in all areas, and will increase site coverage significantly.
e. Leg-hold traps should be run in lines adjacent to the river. The aim should be cover most of the accessible length of the river margins in a block-by-block staged approach over the year. These traps would ideally be run by the trapping crew for some of the periods in-between monthly kill trap checks.

4. Target animal pest species

Six mammalian predators and two native avian predators are known to be important predators in braided river environments. The impact of possums and weasels in riverbeds is less well known, although possums are known nest-predators in forest environments.

The following species should be targeted with specific control methods.

a. Feral cats
b. Ferrets
c. Stoats
d. Weasels
e. Black-backed gulls
f. Harriers
g. Rats (targeted at wetland sites, most likely to be Norway rats)
h. Possums

The following species of pests will be caught as by-catch but should not be specifically targeted, because control methods will not be fine-scale enough to reduce populations of these pests:

i. Hedgehogs
j. Mice

5. Recommended animal pest control techniques

Our recommended best practise for predators in braided rivers is to use a range of tools to maximise effectiveness of control. When control methods are applied individually, only alphachloralose bait application for black-backed gull control is likely to be effective. Specific best practise tools are as follows:

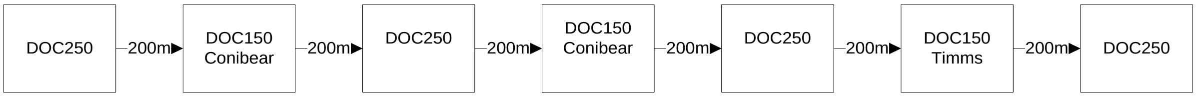
Tool	Cat	Ferret	Stoat	Weasel	Rat	Possum	Harrier	Black-backed Gull
Conibear (Twizel set)	√							
DOC250		√	√					
DOC150			√	√	√			
Timms	√					√		
Victors 1.5 soft jaw leg-hold trap	√	√	√	√		√	√	
Havahart cage trap	√	√	√	√			√	
Alphachloralose toxin								√
Hand-laid bait bags						√		
Anticoagulant toxin in tunnels					√			
Shooting	√							

Lay-out for each control method

a. Kill traps

i) Design trap lines to minimise time taken to walk or drive the line. Use loops wherever possible.

ii) Alternate traps to provide for a spread of trap types along each line: i.e.,



iii) Use double traps per trap box for Conibear and DOC150 traps (“x2” in above diagram).

iv) Allow a move of up to 20m for trap placement at each site when initially setup to allow for site specific details (e.g., level sites, adjacent to features or points of interest).

b. Live capture traps

i) Design trap lines to minimise time taken to walk or drive the line. Use loops wherever possible.

ii) Allow a move of up to 20m for trap placement at each site when initially setup to allow for site specific details (e.g., level sites, adjacent to features or points of interest).

iii)Run victors and cage trap lines separately. Cage traps should be used only within 1 km radius of households with domestic cats.

iv) Suggest leg-hold traps are opened in block of about 100 traps per person, for minimum periods of 10 days. This is because the time taken to open and haze traps is relatively large, but once open they are relatively easy to check.

c. Toxins

Follow best practise advice directions for appropriate toxin use for possums, black-backed gulls and rats: **Link to best practise advice for animal pests**.

Tool	Recommended spacing between traps	Number of traps per box
Conibear (Twizel set docdm-339829)	200 m	2
DOC250	200 m	1
DOC150	200 m	2
Timms	200 m	-
Victors 1.5 soft jaw leg-hold trap	100 m	-
Havahart cage trap	200 m	-
Alphachloralose toxin	Throughout colony	-
Hand-laid bait bags	100 m	-
Toxin baits in tunnels	100 m	-

6. Opening times, bait types and check frequency for each control method

a. Kill traps should be opened in July and closed at the end of February trapping session (a 7 month trapping period per annum). The rationale for this is mostly based on reducing trapper effort in the non-bird breeding season, but still allowing for the capture of locally bred stoats, ferrets and cats in Jan-Feb. There is some risk that predators only susceptible to capture during harsher winter months will not be targeted with this approach, and the approach should be reviewed after three years with the view to increasing the check period to year-round if outcome monitoring success variables remain static, or if predator capture rates remain high and stable.
b. Kill traps should be baited and checked monthly at all times of year. If extra resources are available, then effort should be put into additional opening sessions for live trapping, rather than more frequent checks of kill traps.
c. Live traps should be opened for 10 day periods in late winter/early spring (July-September) and in autumn (March- April). Spring trapping is aimed at catching predators prior to the bird breeding season, and autumn trapping is aimed at contributing towards removal of dispersing animals. A more regular schedule for leg-hold trapping (e.g., every second month) may be necessary to cover all blocks (see point 1.i), and this is supported.
d. Live traps must be checked daily when open, and as soon as possible after daylight.
e. For kill trap and live traps, fresh rabbit baits should be used (skinned but not boned) as the primary bait. Occasional use (up to two 1 month checking periods per year for kill traps) of alternate baits is encouraged so long as it is used for the full month checking period within traps. Bait types can be mixed within and among lines if necessary. Eggs (punctured, whole) and fish (canned or fresh) are good alternate bait type options. The rationale is to provide occasional novel bait in an attempt to attract hard-to-catch predators.

7. Output (results) monitoring of pest captures and residual pest densities

a. Output monitoring provides a semi-independent means of determining residual pest densities in sites of interest. This is a useful tool when a change in tracking rates indicate that a change in trapping intensity is needed (more or less trapping), and to help inform situations where outcome monitoring for braided river species are equivocal.
b. Large size cat tracking tunnels are preferred over standard tunnels, and should track a wider range of species. There is no best practise design for tracking tunnels in riverbeds. We suggest expanding on Pickerell et al. (2014), and placing standard lines of 20 large tracking tunnels at 800 m spacings (i.e., a 16 km line) on the TR, and 10 tunnels on the TL.
c. Large tracking tunnels should be set for 20 nights, and have baits and tracked papers replaced every 4 days. Tunnel lines should be orientated parallel to river flow (i.e., northwest-southeast) in order to fit entire lines into the landscape. Ideally tunnels would be left *in situ* between set periods, but this may depend on tunnel security. Tunnels should be set twice per year (in early Spring (Aug-Sep) and Autumn (Mar-Apr)) which are periods of predicted annual lows and highs in detection rates.

d. Trap catch rates need to be recorded, and should be corrected for traps that catch animals and sprung traps. Trapping data can indicate large changes in base predator populations, and like tracking tunnels, may help indicate when a change in intensity of control is required. Data should be assessed annually.

e. Future comparisons using trail cameras and predator dogs along the same tracking tunnel routes would allow tests of the most efficient method among these techniques. This is a useful research objective, and should be considered at a later date.

f. Black-backed gulls should be counted during standard annual river bird surveys in spring. Additionally, all colony locations and colony sizes within and adjacent to the predator control area should be recorded and mapped in November.

g. Rabbit spotlight counts should be undertaken on a standard driving route of at least 20 km, over three repeated survey nights in January and in July. January and July are the periods most likely to represent highest and lowest rabbit abundance. The same route should be used for every survey. The route should follow the TR riverbank and be away from the road. Rabbit numbers should be recorded every km, and the total number of rabbits and average number of rabbits per km reported. Rabbit spotlight counts will indicate changes in rabbit densities over time, and because predator abundance is related to rabbit density in most dry-land sites, then rabbits may be a useful indicator of predator abundance and distribution. At present rabbit numbers are reported to be low, but the Rangitata is a moderate to high rabbit-proneness area, and rabbit numbers are expected to rise in the future. An alternative to rabbit spotlight counts would be to use Regional Council data on surrounding farmland areas, but this needs to be comprehensive in coverage, robustly collected and spatially relevant.

Monitoring tool	Cat	Ferret	Stoat	Weasel	Rat	Possu	Hedge	Mice	Rabbit	Harrier	Black-backed Gull
Large tracking tunnel*	√	√	√	√	√		√				
Trap catch rate	√	√	√	√	√		√			√	
River bird surveys and colony counts											√
Trail cameras**	√	√	√	√	√	√	√	√			
Predator dog (cat focus)**	√										
Wax tags / chew sticks					√	√					
Spotlight counts									√		

*not shown to be useful for stoats, rats and weasels at low densities

** consider later as a research objective to improve tool efficacy

8. Monitoring of biodiversity values at the site

a. The aim of predator control is to benefit biodiversity values in the Rangitata River with a focus on reducing predation impacts on a range of river bird species. Key target species are wrybill and black-fronted terns, because these are the most threatened species at this site. Other fauna species are not excluded and trend counts of their populations should be regularly undertaken.

b. A range of pre-treatment monitoring data has already been collected from the site: There has been six years of breeding success measures collected for wrybill at the site, there are some data on breeding success of pied oystercatcher, locations of black-fronted tern colonies have been recorded, and there are annual bird surveys recoding trends in all river birds.

c. Protocols for river bird outcome monitoring is given in the Tasman River predator and outcome monitoring protocols document (DOCDM-43801). Based on this, we suggest using the following key performance measures:

    i. Hatching success for wrybill and black-fronted terns. Find and record locations of nests, monitor on 3-4 day return periods, record egg and nest outcomes. Individually band wrybill adults as required to aid identification of hatching and fledging outcomes.

    ii. Fledging success for wrybill. Weekly location of parents with chick behaviour and/or sight chicks, with 3 day checks from the week prior to fledging.

    iii. Fledging success for black-fronted terns. Monitor hatching dates in colony via parent behaviour and nest sample. Calculate fledging date, search for near fledged chicks (and just fledged chicks) on a 3-4 day return rate from when first chicks are due to fledge.

    iv. Breeding parameters are defined as follows (and see DOCDM-1207165, page 19):

        a. Hatching success (probability of ≥ 1 eggs in a nest surviving until they hatch),

        b. Egg success (probability of an egg hatching in a nest if it survives),

        c. Fledging success (probability of a chick fledging once it hatches; wrybills only),

        d. Breeding success (probability that an egg will successfully survive, hatch and fledge; wrybills only).

    v. Cause of nest failure should be recorded at all monitored nests, and evidence of predator events should be collected at a sample of nests using trail cameras for both wrybill and terns. We suggest 20 cameras are run continuously on nests of wrybills, and 20 cameras on nests of black fronted terns (i.e., as nests fail or hatch, camera's are redeployed). Cameras should be distributed geographically, and for terns across all monitored colonies.

    vi. Targets for productivity and survival (see table at end of this section).

    vii. Trends in populations over time. Use standard braided river survey protocols (see DOCDM-343951 for instructions and forms, Maloney et al. 1997, O'Donnell and Moore 1983).

    viii. Index of bittern presence and population size. Undertake one-off surveys every three years. Call counts on 3 nights in October (see Protocol 3 in O'Donnell & Williams in press; DOCDM-1289206;

Estimate (index) of number of booming males using triangulation on small wetlands (<250 ha).

ix. Index of lizard populations and change in distribution. A total of 6 lines, each with 10 ACO covers (double covers for geckos and skinks), set 20 m apart. Set and check monthly for three months from late February to April. Follow protocols for suitable climatic conditions during check rounds. Run for three years, then stop for three years. Leave in field if possible from first set, otherwise remove at the end of every three month set period. Set three of the lines on the river margins at the upstream, middle and downstream end of the TR side, and three in similar positions on the TL. Table of productivity and survival targets for wrybill and black-fronted terns. Wrybill modelled data from Leseberg et al 2005 (confirm baseline ranges for Rangitata wrybill data fall within the modelled ranges). Black-fronted tern data from Keedwell 2004.

Species	Measure	Baseline data ranges	Target change
Black-fronted tern	Hatching success	60%	Increase to 74%
	Fledging success	35%	Increase to 50%
	Adult mortality	12%	1% decrease to 11%
	Outcome		4.1% intrinsic rate of growth
Wrybill	0-1 mortality	50-95%	• If adult mortality is 5 %, then 0-1 year mortality must be less than 76 % to gain a population increase. • If adult mortality is 10 %, then 0-1 year mortality must be less than 70 %. • If adult mortality is 15 %, then 0-1 year mortality must be less than 68 %. • If adult mortality is 20 %, then 0-1 year mortality must be less than 63 %
	Adult mortality	5-30%	

9. Non-treatment sites for outcome monitoring

a. Measuring breeding parameters for river birds in non-treatment sites will allow more robust comparisons with the Rangitata site to be made. This needs to be traded-off against the extra resources needed to do monitoring at these sites. In addition, because no sites are true replicates of each other, it can be difficult to draw comparisons between treated and non-treated sites.
b. There is a large amount of site specific pre-treatment data for wrybill, and there is ongoing wrybill monitoring in the Rakaia River. There are limited recent data for breeding success for black-fronted terns in non-trapped sites (currently being collected in the Molesworth area in Marlborough), and for trapped sites in the Wairau, Ohau and Tasman Rivers.
c. River survey data are collated annually from a range of rivers throughout Canterbury, so background trends in population change across a range of species will be available.
d. Therefore, we recommend that non-treatment outcome monitoring is focused on black-fronted tern hatching and fledging success parameters. Five colonies in the lower reaches of the Rangitata River, the Ashburton River and/or the Rakaia River should be monitored. A sample of nests (a maximum of n=30 per colony), and fledging estimates for chicks should be recorded at each colony. Visits to colonies should be no more than twice weekly. We will be recommending a similar approach for the Tasman Valley project, giving a combined total of 10 colonies which are monitored in the absence of predator control.

10. Data management, audit and reporting

a. Annual reporting of data should be undertaken. The Tasman River project has standard tables for data that would work well in the Rangitata.
b. We suggest annual audit of predator control by an experienced trapper – this could be done by staff sharing with the Tasman project, and providing external audit to their project in return. Trapping audit should focus on random checks of a sample of traps focussed on trap set, set weight and bait presentation.
c. We suggest an annual review of results by the project management team and representatives of the (proposed) Braided River Technical Specialist group. The review would focus on adaptive management style changes to methods based on current results.
d. Three types of data are collected:
    i. Predator capture data
    ii. Output monitoring (pest) data
    iii. Outcome monitoring (bird species) data
e. These are the same data that are collected in the Tasman Valley project, and we should try to find ways of supporting a single collation and storage process among sites.
f. There are risks with all data that it will not be correctly captured and securely stored. The benefits are that combined data capture increases efficiencies, and provides better ability to undertake comparisons among sites.
g. We have assessed a range of data capture and storage options within the Department, recognising that there is no central repository or gate-keeper

for national datasets as yet, so as such projects are free to design and support local systems. Relevant points and options include:

i. There is no electronic device which has been proven in field collection of large scale braided river predator control operations
ii. Field data collection manually in notebooks needs to be considered against electronic field data capture for monitoring work
iii. Manually collected field data can be entered back in the office into excel or Access form views
iv. Field electronic data collection can be via ipads, or dataloggers (e.g., Archers, Junos etc), and uploaded back in office to data storage system. Simone Cleland has been working with National Office to design and field tested Juno data logger capability for outcome monitoring and trapping. Ipads are a better current solution.
v. Storage of master datasets in either Access or Excel (using database format i.e., one row for each entry, fields in columns).
vi. A robust Access databases covering banding, nest data and sightings have been built for Eglinton Valley project work, and can be modified for use easily (RM would do this).

Our recommendation is:

Now

vii. All monitoring data are collected on ipads in simple pre-loaded spreadsheets.
viii. All predator data are collected in notebooks, and transferred to electronic systems back in the office.
ix. A single data gate-keeper is assigned to data management for the combined Tasman and Rangitata data sets. This role would be responsible for ensuring field teams have entered up-to-date accurate data into the master datasets. The role is not about doing the data entry, this remains the responsibility of all field staff.
x. Predator-control data are maintained in Excel for the next year (Tasman), and when the Rangitata project is ready to set traps and record data, a standard system is available for their use.

In the immediate future

xi. Electronic data collection of predator data using ipads is trialled for predator trap checks over the next 6 months, and is immediately adopted if it is more efficient.
xii. By the end of September, Richard and Simone modify existing Access database designs for outcome monitoring and test these for use in the Tasman and Rangitata. This will become the Master dataset for all outcome monitoring data.

11. Working with other sites and with others

We would encourage close relationships with other braided river management sites. To ensure that opportunities are maximised and maintained, it would be useful to see these set up and scheduled into annual operation plans. Opportunities include:

a. Involving Tasman staff in on-the-ground set out of traps
b. A regular (annual?) among site workshop style forum focussed on details of improving methods and ensuring standards
c. Between site help with the set out and checking of lizard monitoring, large tracking tunnels and bird surveys
d. Involvement of the members of BRaid, ECAN and DOC where-ever possible to build up skills and knowledge across braided river sites.
e. We have provided this advice on the basis that Contact Energy is not now working in the Rangitata system. However, at any later date, if Contact Energy needs to resume work within the system, then they could take up the key elements of monitoring and control proposed here at the level that is required within their consent conditions. Given our predator control design is based on best practice principles and methods, there may be low impact on actual on-ground work due to having an additional funder supporting this work.

References

Key references are contained in: *Strategy for New Zealand Braided Rivers: Biodiversity values, issues and priority actions* (O'Donnell et al. in prep).

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Appendix 1

Full advice request from Paul Gasson

Title of advice request: Science Advice required for planning a large-scale predator control operation in the Rangitata Valley.

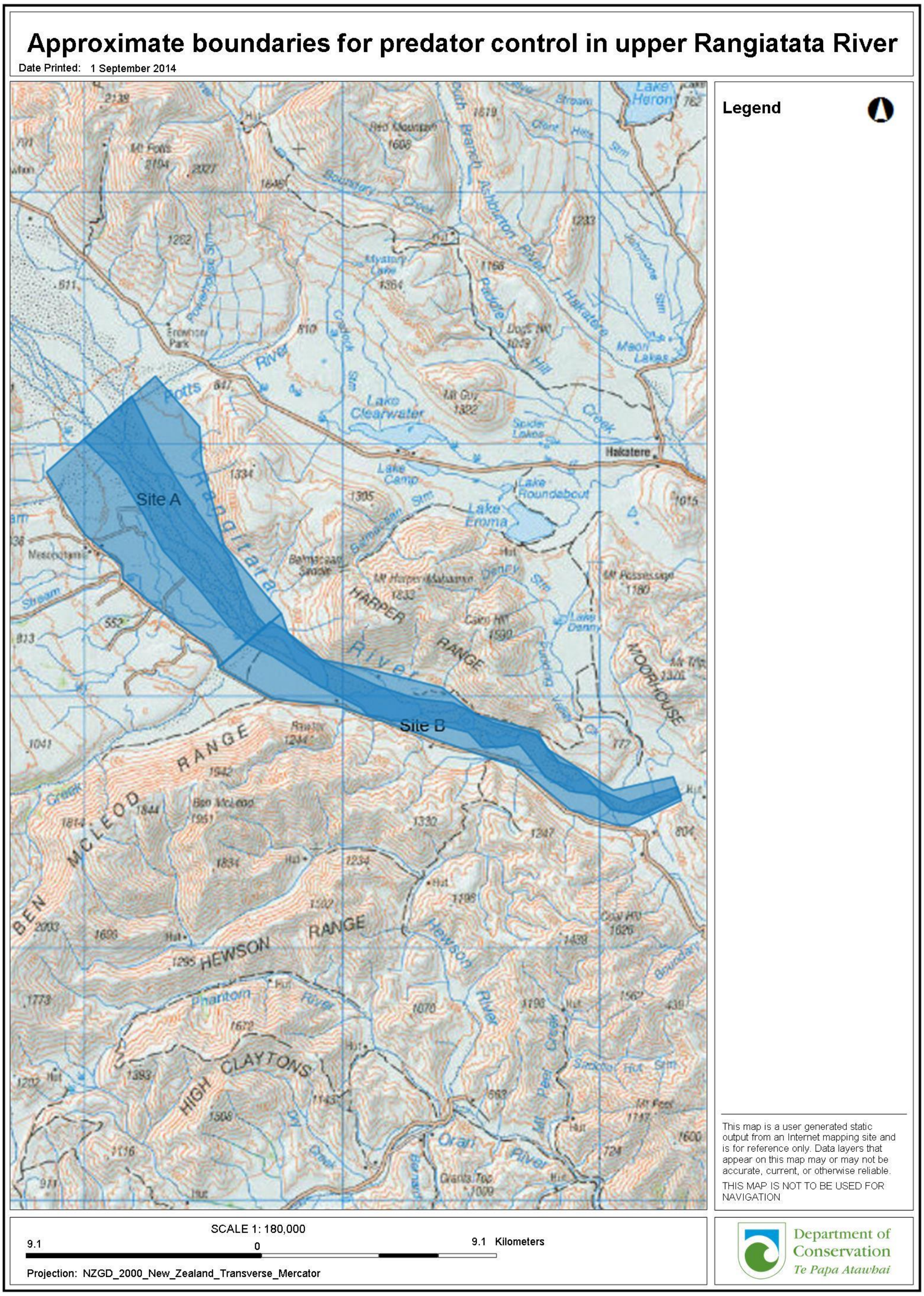
Description of advice request: Science Advice required for planning a large-scale predator control operation in the Rangitata Valley. The goal is to provide protection to wrybill and black-fronted terns nesting in the upper Rangitata, and to increase productivity and survival. Initial budget is 150k p.a.

The predator control design needs to take a range of ecological and logistical factors into account including: spatial variation and nesting habits of beneficiary species (wrybill and black-fronted tern); Predator behaviour and dispersal; Opportunities to investigate nationally important science questions; Budget limitations and flexibility to expand treatment if additional budget becomes available; Flexibility and opportunities to work with external stakeholders and funders (including Contact Energy, Environment Canterbury, Upper Rangitata Landcare Group); Local and seasonal variations in access to riverbed and privately held lands; The dynamic nature of braided riverbeds; outcome targets and monitoring methods.

The project is to be undertake as part of the O Tu Wharekai wetland restoration project, however additional work may be undertaken by Contact Energy and the Upper Rangitata Landcare Group. Contact Energy work may be required under a revised resource consent for the HMR windfarm, and our project design will need to be sensitive to this issue.

Appendix 2

Approximate recommended boundaries for predator control. Light blue polygons are approximate boundaries of the recommended area for predator control, and the dark blue polygons are approximate area of river bird breeding habitat.



Appendix A2 – Rangitata bird monitoring protocol

RANGITATA BIRD MONITORING PROTOCOL

Adapted from Tasman Valley Protocols DOCDM 43801, Protocols used by Environment Canterbury Parks staff on the Waimakariri River, & Rubbish comments by Brad Edwards.

Base Daily Field Equipment

-good quality binoculars 10x best

-permanent marker

-Notebook

-GPS

-spare batteries

Hatching and fledging success of black-fronted terns

Objective:

-All colonies within the predator control area identified and breeding success determined for each (max 30 nests per colony -100 nests monitored well clear of predator control area (max 30 nests per colony). Traditionally, BFT comparison area data came from monitoring carried out from SH road bridge to the coast but no colonies have formed there over the last several years so a shift has moved the monitoring effort to Arundel Bridge to SH Bridge.

-Walk the Lower Rangitata from SH on a monthly basis to coast to confirm no colonies form. Notes regarding Southern Black Back Gull density and nesting habitat availability will prove valuable at the end of year writeup

Design

Breeding data for black-fronted terns are collected between September and February each year. 30 nests (A maximum of 30 tern nests per colony) at each site are monitored until they hatch or fail with a goal of reaching 100 nests monitored in the Predator Control Area, and a sample of several colonies outside the Control Area.

In the Rangitata a complete record of all colonies is the ultimate goal for the season, so regular walk thru's of the whole project length are required. As a guide the bottom of your shorts indicates the maximum depth that seasonal staff find comfortable to ford and if current is fast and the depth above this alternative routes need to be prospected. Staff familiar with the riverbed, safe crossing points with no obstructions and with high water confidence can generally handle water up to their waists.

Once hatched, the remaining tern and gull chicks are monitored until they die/disappear or fledge. However, this depends on the number of nests found in a season and time restraints, and not all chicks may be monitored beyond hatching. Overall counts of chicks/fledglings in crèches may be made instead.

Field methods

Locating nests

Colony sites are identified by birds flying overhead or large congregations seen on the ground. Adults bring food to their mates on the nest and there is a constant coming and going of birds at a colony. As a colony is approached, adult terns start dive-bombing and screeching loudly.

Run track logs at all times when carrying out tern survey and save weekly into s:drive folder. This has been highlighted as critical information to be gathered.

S:\BIODIVERSITY\Bio Operations\OTW\Birds\Bird monitoring for Eva\

Monitoring nests to hatching

Tern colonies are visited every week or as time and river conditions allow. If possible, they are observed from a high vantage point with binoculars or a telescope, where the birds can be seen on their nests. For this technique, any new nests that are noticed at this time need to be checked and mapped. Birds incubating lone nests can often also be seen from a distance, so that one does not need to approach the nest.

Alternatively, nests can be found and checked by walking systematically through the colony site, tracking and GPS recording all nests. This is the mainstay of how monitoring has been traditionally done in our rivers.

Nests should be marked with a small cairn on the upstream end of the nest several metres from the nest. A permanent marker is used to write the nest gps number on the cairn and some operators choose to also note basic data like "2e".
For reach nest check the following must be record

- Nest gps reference/number
- Number of eggs present
- Number of chicks
- If an outcome is observed, then it should be recorded
- Confirmation the nest is still active/defended

So a typical notebook note may be

RU 45. 2e ✓ new xxxxxx-yyyyyy

which indicates in the Rakaia Upper River nest number 45 (as per gps), 2 eggs where present in the nest. It was defended by adults. It was a new nest never found before, and I like to record manually the gps coordinates in case my gps shuts out or we end up with two nests with the same name.

Some operators chose to change the graphic for the nests between active and inactive nests to allow the non-active nests to be easily ignored during future visits. E.g. the graphic for finished nests is often changed to a red cross and this means a visual representation of the colony nests needing checking is on hand.

By counting 30 days from the discovery of 2 eggs in the nest a probable hatch date can be calculated. After this point you should not be surprised to discover a vacant nest that is still defended. Look carefully as chicks often hide under the smallest of items.
If the adults continue to defend the nest in a spirited manor the chicks will be nearby and just note no chicks observed but nest behaviour still present. Chicks can be expected to remain at the nest for the first day or two but after that begin to wander.
Once estimated hatch dates have long passed and if eggs are still present carefully inspect them.
In the case of nest failure, the site should be inspected on hands and knees and observations acutely recorded.

Causes of nest failure can be recorded (not exclusively) as:

Predation:

Broken egg shell and/or spilled yolk and ants in nest bowl, tooth marks on egg shells. Eggs are also classified as preyed upon if they disappear before the earliest possible hatch date.

Desertion:

Eggs are cold and clammy with grit stuck to the underside and no sign of the pair.

Infertile:

Any unhatched eggs are opened and fertility is determined. Crack deserted eggs open and determine if a viable embryo started to form or if the egg was infertile.

Flooding:

Water has moved through nest bowl, and eggs are missing or lying outside the bowl or parents have deserted.

Cattle:

crushed egg debris, evidence of cattle standing on nest.

Vehicle:

Crushed egg debris, vehicle tracks run over nest.

Unknown:

Not enough checks to be able to categorise outcome, e.g. adults and eggs disappear but nest may have hatched or failed.

<u>Make as many additional notes as you feel are necessary. Later in the season you will find yourself looking back through your notebook to confirm these outcomes and the notes jog your memory. Be careful to record WHAT YOU SEE not what you interpret.</u>

Several cameras should be dispersed through the BFT nests each colony to record outcomes and assist in identifying predators. These should have data cards switched ideally weekly but at least fortnightly and downloaded into s:drive with the date of collection and nest number against them and a brief description of the outcomes in the title.

When a nest is finished move the camera to an adjacent active nest and record the event clearly in your notebook.

Monitoring chicks to fledging

When approaching colonies with chicks present it is advantageous to observe the colony for half and hour before influencing their behaviour, to allow colony structure to be observed through binoculars. Any creche formation should become apparent during this process.

Tern chicks can cover large distances within a colony and in large colonies they form crèches. If hatching is staggered it is possible to monitor individual chicks to fledging. However, if too many chicks hatch at the same time and form crèches, counts of tern chicks/ fledglings are carried out at colonies once a week until the last remaining chicks fledge. Creches are mobile and will move around the colony edge from week to week, so do not necessarily expect them in the same place on subsequent revisits.

Walking upstream and into wind through the colony tends to scatter chicks less. Chicks will either freeze or run, and observers need to be mindful of the impact of their presence in the colony and minimise exposure times by working efficiently.

Tern chicks have been observed communally creching is long grass and heavy cover adjacent to the colony. Only by adult behaviour -defending these areas, and observation of feeding returns will these be discovered.

Chicks on the brink of fledging are easily identified by different plumage to adults and ongoing begging behaviour. It is often best to sit down well away from the colony and quietly observe adults bringing food to these chicks to get a count.

During late season colony checks data records should include counts of chick numbers seen and presumed and if possible, the development stage the chicks are at.

Data entry

After each visit to nests and/or colonies, the nest and chick monitoring data are transferred from field notebooks to an Excel spreadsheet. A directory has been established to assist you.

Make sure to record the development phase of chicks as this will enable them to be ‘followed’.

Hatching and fledging success of wrybill

Objective

To record changes in wrybill hatching and fledging success over time to test whether predator control in the Rangitata valley benefits this species.

Design

Breeding data for wrybill are collected between September and February each year (peak months are September – December, Appendix 1). For hatching success, 30 nests within the predator control benefit area are located and monitored until they hatch or fail.

In the Rangitata a total of 30 monitored nests (this includes nests that lose eggs before hatch or have unknown outcomes) should be monitored. Landowner access will mean that the riverbed in front of Rata Peaks and Stew Point is unavailable for intensive bird monitoring. Traditionally Forest Ck, Dr Sinclair's and Potts River access have been utilised. Having nests on both sides of the Rangitata over a wider area gives the data more robustness but must be balanced by the monitoring team's ability to cover the ground and spend time efficiently observing birds.

Once hatched, the remaining wrybill chicks are monitored until they die, disappear, or fledge. Chicks are not banded but adult birds (at least 1 from each pair) are to allow chicks to be attributed to nests.

BFT monitoring should take precedence over wrybill monitoring if time is constrained. Camera monitoring is not a critical component of wrybill monitoring.

Field methods

Locating nests

Wrybill nests are located by walking high probability areas to enlist a response from nesting birds. Generally, wrybill camouflage is too cryptic to visually spot nests before they are seen running from their nests. Alternately, if the observer is near a wrybill nest, the adult birds frequently do a broken-wing display only 1-2 m away indicating the close proximity of a nest. The nest must only be approached if confident of its exact location.

Wrybill nests are very cryptic and it is better to move 50 m away and have the nesting bird return to the nests and resettle to confirm the location than to risk stepping on the eggs.

High probability search areas are going to be lower river terraces adjacent to main stem water with aggregate in the size class that starts to make travel awkward on ankles. Most nests are located within 60 m of water, and absolutely clean surfaces are preferred to those with any weed or covers present.

Once a wrybill nest is found, it is marked with a rock cairn placed ~ 2 m upstream of the nest bowl. All nest sites are mapped using GPS. Nest search effort is recorded continuously throughout the breeding season by tracking all movements when actively searching for nests, using the GPS track log function set at recording a location every 30 seconds (using a Garmin GPS 60). Like the BFT tracks this is a critical piece of information to be gathered.

Banding an adult on the nest:

Where possible, at least one bird of a pair is trapped on its nest using a rectangular drop trap with a remotely triggered light-weight wire frame covered with thin plastic. Care must be taken to cause minimal disturbance of the ground around the nest as this confuses the bird ability to return to the nest. Birds run on a road system mapped out in the bird's head and if birds are observed getting on and off the nest in a particular direction this should be left open to allow the bird to return in the known route.

Once caught, the bird is carefully retrieved from the trap, ensuring the eggs are not damaged. Set the trap so the edge is well away from the nest to avoid it hitting eggs or bird and preferably set into the wind. If the trap lid is too close to the ground or sways in the wind the bird will be reluctant to enter.

When removing the bird from the trap extra care must be taken of the top-heavy trigger unit as it is liable to tip.

The trap is removed from the nest and any rocks that were shifted are replaced in their original positions. This will allow the mate to return unhindered to the nest if the handled bird is held for a longer period. To avoid too much disturbance at the nest (by leaving scent and tracks), the bird is banded at least 50 m away.

Wrybills are banded with size C stainless steel bands, ROUNDED AND NOT OVAL and coloured plastic double wrap around bands of the same size (3.5 mm internal diameter). Wrybills receive two colour bands on each tarsus. The metal band is placed on the left tibia. Once on the birds, all colour bands are 'glued' closed using THF (tetrahydrofuran).

The chemical is applied to the gap between the overlapping plastic layers of the band with a small syringe. The band is rolled between thumb and forefinger and held a few seconds until set. Finally, the bird is sexed and released. No body measurements are taken. Appendix 4 provides a list of all outcome monitoring gear.

Monitoring nests to hatching:

Wrybill nests are visited WEEKLY (but ideally this would be every 3-5 days) until the nest hatches or fails. There are four possible scenarios for undertaking nest checks:

(1) The nest is approached using the GPS waypoint. As soon as the cairn becomes visible (~ 100-200 m away) focus on the area of the nest while walking slowly closer. At this stage it may be possible to see the incubating bird or the bird leaving the nest. If this happens, there is no need to approach the nest as it is clear that the nest is still active.

(2) While walking towards the nest, one or both of the birds are in the vicinity of the nest but were not seen leaving the nest. It is important at this stage to confirm that one of the birds is the banded bird as there may be several other pairs with nests nearby. If the pair displays the same 'nest behaviour' as when the nest was first found (agitation, calling, head bobbing), it is very likely they still have their nest. If time allows, back away from the area and observe one of the pair returning to the nest. If their behaviour has changed to heightened agitation with loud calling and flying around ('chick behaviour'), check the nest to see if it has hatched. In scenario 1, a bird may be seen on the nest but displaying chick behaviour, which indicates the chicks have hatched recently and are being brooded in the nest bowl.

(3) While walking towards the nest, one or both of the birds are in the vicinity of the nest but it is unclear by their behaviour whether they still have their nest. Pairs that lose nests often remain near the nest site for several days but their nest behaviour appears subdued and they are not particularly interested in people in the vicinity of the nest. Approach the nest and observe for a change in behaviour. If none occurs walk up to the nest and if eggs are present check their condition. Eggs may be missing or lie broken in the nest bowl, or they are cold and clammy with grit stuck to the underside. When present, such eggs are no longer being incubated and have been abandoned by the pair. Return 1-2 days later to confirm the outcome.

(4) If there is no sign of the pair at all while walking towards the nest, check the condition of the eggs as above. If time allows, do another check 1-2 days later to confirm the outcome.

Typically eggs that have hatched leave 1-2mm egg fragments in the nest grit, gently agitate the nest grit to look for this evidence. Radiate out from the nest searching for adults and chicks if this is present.

For both scenarios 3 and 4 it is quite possible that the unsuccessful pair will re-nest in the same area. A female can begin laying a new clutch ~ one week after having lost the last one.

At times a nest is found while still being laid and the clutch is incomplete (normal clutch size for wrybill: 2). In this case continue with nest checks until clutch size does not increase, then predict a hatch date using an **incubation period of 30 days for wrybill**.

Causes of nest failure are classified into one of the following (but not exclusively) categories:

Predation: broken egg shell and/or spilled yolk and ants in

nest bowl, tooth marks on egg shells. Eggs are also classified as preyed upon if they disappear before the earliest possible hatch date.

Avian predator: Gulls/ harrier/ sipo

Desertion: eggs are cold and clammy with grit stuck to the underside and no sign of the pair.

Flooding: water has moved through nest bowl, and eggs are missing or lying outside the bowl or parents have deserted.

Cattle: crushed egg debris, evidence of cattle standing on nest.

Vehicles: Crushed egg debris, vehicle tracks run over nest.

Unknown: not enough checks to be able to categorise outcome, e.g. adults and eggs disappear but nest may have hatched or failed.

Any eggs that failed to hatch one week after the remaining clutch has hatched, and any complete clutches that are deserted, are opened to determine whether they are infertile (i.e. no evidence of an embryo) or have died during incubation (i.e. embryo present).

***Monitoring chicks to fledging*:**

Fledging success of wrybill chicks should be checked once a week if time allows. **It is enough to confirm that chicks are alive based on the presence of chick behaviour by the parents, and it is not necessary to locate each chick of a clutch during each visit.** Three weeks after hatching, chicks are on the brink of fledging and it becomes more important to ensure all chicks are located and counted between then and the age of fledging.

All chicks are monitored until fledging is confirmed, either by seeing the chick fly or by knowing its exact age.

For the first couple of weeks after hatching, wrybill chicks remain close to their parents and in the vicinity of the nest bowl (within ~ 200 m radius of the nest). As the chicks grow older the family may move further away from the original nest site (up to ~ 500 m). If a family cannot be located, the area around the nest should be searched in ever widening circles for a sign of the banded parent displaying chick behaviour. **If the missing chicks are very young (< 2 weeks) and not near the nest, they are likely to have died and the parents left the area.** These searches need to be repeated as often as necessary to confirm the outcome.

If major flood events occur during chick development and no trace of either adults nor chicks can be found searches should persist in wider areas for several weeks, as chicks be transferred large distances in the riverbed during floods, yet show remarkable resilience to flooding.

***Data entry*:**

At least every week monitoring data are transferred from field notebooks to the *data capture excel spreadsheet*. All bird banding and re-sightings details should be recorded on a supplementary page in the document.

Camera Monitoring for Wrybill: is not necessary as there is a high degree of confidence in the monitoring technique but several cameras running on selected nests where predators are operating can provide supplementary information. Warning: overuse of nest cameras on wrybill nests is suspected to cause predators associating cameras with prey items.

ALL OF RIVER SURVEY

Objective

To record changes in the population size and distribution of all braided river bird species

Monitoring target

Annual surveys are carried out over one day between October and December in calm and dry weather conditions.

Design

The annual surveys record trends in the populations of all braided river species and provide further information on the population size of species.

Field methods

River surveys follow the methods recorded in Maloney et al. (1997). During a survey, river birds are counted as they move past each observer and are recorded on a datasheet. Observers must move along the river at the same speed, staying in a straight line with other observers. All juveniles and chicks are distinguished from adults and are counted separately. If time allows, colour banded birds are identified. In order to avoid double counting birds, observers carry hand-held radios and communicate with adjacent observers if birds fly across their two routes. Only one of the two observers records such birds on their datasheets.

All sightings of black-fronted tern and black-billed gull colonies or nests and all wrybill sightings are mapped using GPS during river surveys.

Data entry

At the office, each observer's count data are entered on an Excel spreadsheet and species totals are calculated. Data variable recorded as below Figure below.

River survey variable to record into Excel sheet
SEASON SURVEY DATE OBSERVER AREA RIVER SECTION SPECIES * # SEEN WEATHER COMMENTS

Appendix A3 – Additional tables

Table S1. Model selection results of encounter probability (p) for daily chick survival of wrybills in the URR between 2015/16 and 2020/21

Model	k	AICc	Δ AICc	w_i
Phi(~1)p(~season)	7	441.74	0.00	0.33
Phi(~1)p(~1)	2	442.78	1.04	0.19
Phi(~1)p(~Quadratic)	3	442.87	1.14	0.19
Phi(~1)p(~HatchDate)	3	443.16	1.42	0.16
Phi(~1)p(~Time)	3	443.53	1.80	0.13

Notes: Survival (phi) was held constant for all models while *p* was modelled as function of annual variation (season), seasonal variation (HatchDate), linear age of chick (Time) and quadratic age (Quadratic). *K* = number of parameters; ΔAICc = difference in Akaike's information criterion corrected for small sample size (AICc) value between a given model and the model with lowest AICc value, w_i = relative Akaike weight.

Table S2. Model estimates the best model of Cormack-Jolly-Seber model of daily chick survival of wrybill in the URR between 2015/16 and 2020/21. Daily survival probability (phi) was constant across breeding seasons, while encounter probability (p) depended on breeding season

Parameter	Estimate	Lower 95% CI	Upper 95% CI
Phi (constant)	0.993	0.984	0.997
p (2015/16)	0.682	0.535	0.800
p (2016/17)	0.770	0.639	0.864
p (2017/18)	0.595	0.407	0.758
p (2018/19)	0.879	0.767	0.941
p (2019/20)	0.759	0.591	0.872
p (2020/21)	0.682	0.484	0.831

Table S3. Parameter estimates from model comparing hatching success of black-fronted tern nesting in an area with landscape-level predator control (URR) and without predator control (lower Rangitata River, LRR) in the breeding seasons 2015/16, 2016/17, 2017/18, and 2020/21. Parameter estimates and 95% credible intervals (CI) in parentheses. Estimates where 95% CI do not overlap zero are highlighted in bold

Parameters	Estimates
Intercept type	Colony Season
Predator Control present	**1.382 (0.779, 1.941)**
TimeSeason	–0.036 (–0.226, 0.167)