# Meta-analysis of status and trends in breeding populations of black-fronted terns (*Chlidonias albostriatus*) 1962–2008

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**Abstract:** Black-fronted tern (*Chlidonias albostriatus*) breeding populations on braided rivers in the South Island, New Zealand, are assumed to be in decline as their habitat comes under increasing pressure from exotic pests, hydroelectric power development and water abstraction. We collated 326 index counts of black-fronted terns from 2313 km of surveys on 84 rivers throughout their breeding range to test this assumption. Black-fronted terns were observed on 73% ($n$ = 61) of rivers surveyed, and the sum of the most recent counts was 8325 birds. However, >200 black-fronted terns were counted on only 14% of rivers. We used generalised linear modelling to assess whether population trends could be detected using data from 29 rivers where counts were repeated 4–18 times between 1962 and 2008. We detected significant declines on eight rivers (range 5.5–15.8% p.a.), a significant increase on one river (Eglinton; 16.3% p.a.) and no trends on the remaining 20 rivers. The Eglinton River is the only site at which sustained predator control (aimed at mustelids) occurred throughout the monitoring period. Rivers on which declines have occurred are characterised by having relatively low flows (<30 $m^3 s^{-1}$). At such rates, populations on low-flow rivers (64% of rivers surveyed, representing 51.4% of black-fronted terns counted on the oldest counts) would decline by a further c. 90% within 25 years. Based on these results we predict that if flows were reduced significantly on higher-flow rivers, rates of population decline would accelerate. We conclude that the IUCN status of 'Endangered' is appropriate for black-fronted terns, based on a predicted population reduction of around 50% over the next three generations (c. 30 years). This conclusion is supported by previous studies that described significant loss of habitat, low breeding success and vulnerability to predation by introduced mammals, and population models that predict continued declines towards extinction if management aimed at recovering populations is not instigated with some urgency.

**Keywords:** endangered species; flows; population trend; predators; rivers; weeds; *Sterna albostriata*

## Introduction

Globally, populations of freshwater and marine bird species are declining, some dramatically, and numerous species are classed as threatened with extinction (Dehorter & Guillemain 2008; Nebel et al. 2008; IUCN 2010). The major threats include habitat loss, invasive species, overexploitation and climate change (e.g. McGowan et al. 1998; Kingsford 2000; O'Donnell 2000; Dowding & Murphy 2001; Mills et al. 2008). A major challenge for conservation managers is determining rates and causes of population decline so that management aimed at recovering species can be targeted appropriately (Mace & Lande 1991; Caughley & Gunn 1996). Braided rivers in which the physical structure of the riverbed is still governed by natural processes are becoming rare in the developed world (Dynesius & Nilsson 1994). New Zealand braided rivers remain relatively unmodified and support a diverse range of flora and fauna (Gray & Harding 2007).

Declines are thought to be occurring among the endemic freshwater bird species on braided rivers of New Zealand, particularly black stilts (*Himantopus novaezelandiae*), wrybill plovers (*Anarhynchus frontalis*), black-fronted terns (*Chlidonias albostriatus*), black-billed gulls (*Larus bulleri*) and banded dotterels (*Charadrius bicinctus*) (Pierce 1989; Rebergen et al. 1998; Maloney 1999; O'Donnell 2000; Keedwell & Sanders 2002; Keedwell et al. 2002a, b; Sanders & Maloney 2002; Keedwell 2004; McClellan 2009). Declines appear to result from an interaction of threats on braided rivers, particularly loss of habitat and direct predation by introduced mammals (O'Donnell & Moore 1983; Rebergen et al. 1998; Dowding & Murphy 2001; Keedwell & Brown 2001; Sanders & Maloney 2002; Keedwell & Sanders 2002; McClellan 2009). Significant reduction in river flows, through abstraction for irrigation and diversion or impoundment for hydroelectric power generation, may be reducing foraging habitat availability and increasing the accessibility of breeding colonies to introduced predators, leading to reduced productivity and survival (Hughey 1985a; O'Donnell 2000). In addition, reduction in flows is thought to facilitate increased weed invasion of nesting habitats, making these habitats unavailable (Balneaves & Hughey 1990).

Braided rivers of the type found in New Zealand are rare habitat types internationally. They are characterised by highly unstable flows with high spring–summer peaks and rapid and frequent flooding, multiple and constantly changing channels, extensive areas of active shingle bars, and islands and wide beds (sometimes several kilometres wide) (Miall 1977; Gray & Harding 2007). There are 307 rivers in New Zealand with braids on at least some of their sections. While these rivers can be found throughout much of the country, most are in the South Island (Department of Conservation (DOC) Rare Ecosystems Database; D. Brown, pers. comm.). Collectively, areas of braided river cover > 250 000 ha in New Zealand (Wilson 2001). They support a diverse range of foraging and breeding habitats for a bird fauna of >80 species, some of which are threatened. About 20 wetland bird species are characteristic of braided rivers and are found widely on them (O'Donnell & Moore 1983). Some of these birds are highly adapted for living on these rivers, with specialised morphological features, foraging and breeding behaviours, and migration patterns (Beer 1966; O'Donnell & Moore 1983; Robertson et al. 1983; Hughey 1985a; O'Donnell 2000, 2004).

Black-fronted terns nest only on gravel rivers in the South Island, although most migrate to coastal marine areas throughout the country when not breeding (Lalas 1979; Latham 1981; Heather & Robertson 2000; Keedwell 2005). They were classified as endangered by DOC in 2005 and 2008 (Hitchmough et al. 2007; Miskelly et al. 2008) and by the World Conservation Union (IUCN) in 2007 (IUCN 2010). This classification was based on their small world population size (Keedwell 2002), apparent declines in numbers at two wintering sites and on one well-monitored river (Latham 1981; O'Donnell 1992), poor breeding success resulting from predation by introduced mammals (Keedwell et al. 2002b; Keedwell 2005), and continuing declines predicted from simulations derived from population viability analysis (Keedwell 2004).

Black-fronted terns are difficult to monitor because they are so mobile and nest in areas that are difficult to survey. As a result there has been little quantitative evaluation of current population trends in this species, and there is uncertainty about whether declines are occurring across the full range of the species and, if they are, at what rate. Such information is essential for prioritising the timing and location of conservation actions for this species. The aims of this paper are to: (1) assess whether population trends are apparent in standardised counts of black-fronted terns from surveys of braided river beds during the period 1962–2008; (2) quantify landscape-scale factors that may explain patterns in distribution and population trend; and (3) use these data to comment on the appropriateness of the threat status given to this species.

# Methods

## Source of counts

Initially, we collated as many counts from surveys of black-fronted terns from as many sources as we could find ($n$ = 84 rivers, Appendix 1). Counts generally came from unpublished sources, often from the former New Zealand Wildlife Service and DOC file reports and from members of the Royal Forest and Bird Protection Society and the Ornithological Society of New Zealand.

## Counting methods and timing

A walk-through index method using skilled observers and standardised protocols was employed to count birds on their riverbed breeding grounds (O'Donnell & Moore 1983; Sanders 2000). All wetland birds seen on a braided river, or on representative reaches of a river, were counted simultaneously. Counts usually spanned one day, although on longer rivers counts sometimes spanned two days. A group of observers spread themselves at approximately 50-m intervals across the riverbed and walked downstream at the same pace, counting all birds seen as they passed them, and remaining in a line perpendicular to the flow of the river throughout the survey. The full width of riverbed encompassing all potential riverbed habitats was counted. Binoculars were used to identify and count birds accurately. Rules to minimise potential double counting were used. For example: (1) birds were only counted when the observers passed them; the only exception was if a bird(s) flew off the river in front of the observer without circling back, (2) hand signals or radios were used to tell other observers on the line that a particular bird had been recorded as it passed up stream, and (3) one or two people were delegated to record the tally for bird colonies, in consultation with other members of the team. All-terrain vehicles or farm bikes were used along the margins of several small, dry riverbeds. Rivers were generally surveyed in sections (10–20 km long) with different groups of observers counting simultaneously.

Black-fronted terns generally begin arriving on their breeding grounds in late August and leave again between December and February (O'Donnell & Moore 1983). Surveys included in this analysis were conducted in the middle of the breeding season, between late October and early December when nesting was at a peak and numbers of birds most stable. Relatively little variability has been detected in counts that have been conducted at the peak of the breeding season (Robertson et al. 1983, 1984; Sanders 2000; Boffa Miskell 2006).

Counts such as these are often viewed as a 'census' or 'population count'. However, in reality they are 'indices of relative abundance' because not all birds that use a river are present at any one time because of imperfect detection of birds on a count. For example, not all birds will be visible; birds sheltering behind vegetation may go undetected or there may be variability in the skills of observers (Rappoldt et al. 1985; Brown & Robinson 2009). Analyses are therefore based on the assumption that the total number of birds counted is representative of the total population using the river.

## Counts used in trend analyses

We identified surveys that had been repeated in relatively standardised ways and generally covered the same riverbed reaches (Table 1). Counts were excluded from analyses if they: (1) were incomplete because they were one-off counts of single colonies; (2) sampled markedly different stretches of river on each survey; (3) represented only small proportions of the potential available nesting habitat on the rivers; or (4) represented a compilation of surveys spanning more than a week from different reaches. Counts for sections of riverbeds flooded under Lakes Pukaki, Benmore, Ohau and Ruataniwha in 1962–1965 were excluded from analysis.

We undertook a meta-analytical assessment of population trend estimates calculated from non-standardised counts from all rivers in the final dataset, largely because counts from individual rivers had many gaps in their time series and were carried out irregularly. Meta-analytical approaches are commonly used to detect population trends from multiple sites over time (Henry et al. 2008; Lengyel et al. 2008; Marsh & Trenham 2008).

## Factors influencing the counts

We collated river-scale variables for each river that we predicted may influence either the number of terns present or their population trends. These were: (1) total river area (ha) derived from DOC's 'Rare Ecosystems Database'; (2) mean river flow, categorised as 'low' = < 10 $m^3 s^{-1}$, 'medium' = 10–29 $m^3 s^{-1}$, 'high' = 30–99 $m^3 s^{-1}$ or 'very high' = ≥ 100 $m^3 s^{-1}$ (provided by Environment Canterbury, the Otago Regional Council and Environment Southland for 25 rivers and estimated for the

**Table 1.** Summary statistics for black-fronted tern counts on 29 braided rivers in the South Island (only rivers on which four or more counts have been undertaken were included).

| Site | First count (year) | Last count (year) | No. of counts | Median count | Most recent count | Min. count | Max. count |
|---|---|---|---|---|---|---|---|
| Ahuriri | 1962 | 2001 | 11 | 573 | 363 | 351 | 888 |
| Ashburton | 1981 | 2008 | 18 | 202 | 197 | 41 | 642 |
| Ashburton (N branch) | 1981 | 2007 | 14 | 28 | 0 | 0 | 142 |
| Ashley | 1981 | 2008 | 9 | 81 | 81 | 26 | 194 |
| Cameron | 1982 | 2006 | 4 | 12 | 36 | 4 | 36 |
| Cass | 1979 | 2005 | 7 | 114 | 114 | 14 | 450 |
| Conway | 1980 | 2008 | 4 | 24 | 24 | 11 | 30 |
| Dart | 1967 | 2008 | 9 | 73 | 73 | 44 | 221 |
| Eglinton | 1992 | 2008 | 17 | 20 | 50 | 2 | 162 |
| Hakataramea | 1962 | 1984 | 6 | 79.5 | 42 | 22 | 216 |
| Hopkins | 1962 | 1994 | 6 | 116.5 | 21 | 21 | 149 |
| Hunter | 1969 | 2007 | 6 | 144.5 | 157 | 38 | 186 |
| Hurunui | 1978 | 2008 | 4 | 337 | 336 | 285 | 494 |
| Makarora | 1966 | 2006 | 8 | 43.5 | 89 | 0 | 89 |
| Manuherikia | 1967 | 1991 | 4 | 9 | 0 | 0 | 71 |
| Matukituki | 1971 | 2008 | 7 | 104 | 58 | 50 | 276 |
| Ohau | 1962 | 2008 | 6 | 162.5 | 129 | 117 | 425 |
| Opihi | 1983 | 2007 | 8 | 69.5 | 19 | 19 | 133 |
| Orari | 1984 | 2006 | 7 | 38 | 0 | 0 | 162 |
| Pukaki | 1962 | 2008 | 9 | 25 | 0 | 0 | 408 |
| Rakaia (lower) | 1975 | 2007 | 4 | 84.5 | 122 | 41 | 174 |
| Rangitata (lower) | 1982 | 2007 | 5 | 284 | 345 | 240 | 484 |
| Rees | 1974 | 2008 | 6 | 51 | 0 | 0 | 106 |
| Shotover | 1968 | 2008 | 5 | 4 | 0 | 0 | 126 |
| Tasman | 1962 | 2008 | 10 | 105.5 | 101 | 47 | 217 |
| Tekapo | 1962 | 2008 | 13 | 370 | 597 | 152 | 776 |
| Twizel | 1962 | 1994 | 5 | 37 | 12 | 12 | 188 |
| Waimakariri (lower) | 1980 | 2008 | 4 | 279.5 | 423 | 74 | 423 |
| Waitaki* | 1974 | 2005 | 5 | 470.5 | 633 | 331 | 633 |

*Averages of five replicate counts in 2001 and 2005.

four rivers for which flow information was unavailable); (3) percentage riverbed vegetation cover, which was the area of riparian willows, scrub (e.g., broom *Cytisus scoparius* and yellow lupin *Lupinus arboreus*) and tussock intersecting with river polygons from the New Zealand Land Cover Database Version 1 (from Wilson 2001); and (4) presence and degree of predator control for introduced mammals within the riverbed environment, categorised as 'yes' = predator control throughout the site for the entire period during which terns were counted, 'partial' = predator control for part of the site and/or for part of the time during which counts were undertaken, or 'no' = no predator control.

**Trend analysis**

We conducted two analyses to investigate relationships between black-fronted tern population trends and (1) time and (2) their potential correlations with geographic variables. In the first analysis, we used generalised linear models to investigate potential influences of site (river) and time (year, using 1985 as the reference level; as predictor variables) on black-fronted tern counts (as a response variable). Models were fitted with a negative binomial distribution to account for over-dispersion in the data. Akaike's Information Criterion (AIC; Burnham & Anderson, 2002) was used in model selection to compare additive and interactive models with the null model. The best fitting model was then used to estimate annual rates of change in tern populations on each river and to evaluate whether these trends were significant. In the second analysis, we used analyses of variance (ANOVAs) to evaluate whether mean flow, river area, percentage vegetation cover or pest control (as predictor variables) influenced the annual rate of change in tern populations (the response variable) estimated in the first GLM analysis. That is, we used a summary measure (annual rate of change in tern populations) to deal with the repeated-measures nature of the data (Everitt 1995). Cumulative effects over time of the estimates of annual rates of change were calculated in Microsoft Office Excel using the power analysis spreadsheet BatPowAlpha (O'Donnell & Langton 2003).

In addition, we compared maximum count recorded per river and earliest count per river with mean flow of rivers for which we had flow data ($n$ = 57) using linear regression. Earliest and maximum counts were used because they best reflected numbers of terns using rivers before flow was modified (earliest count) and years in which conditions were optimal for breeding (maximum count). Statistical analyses were undertaken using the statistical programme 'R' (version 2.8.0; R Development Core Team 2007). We checked that models met the assumptions for each test.

## Results

A total of 326 peak-breeding season counts were found for 84 rivers (11 on the West Coast, 2 in Nelson, 7 in Marlborough, 47 in Canterbury, 12 in Otago and 5 in Southland; Appendix 1).

Total length of rivers surveyed was c. 2313 km. These braided rivers cover c. 125 000 ha and the survey areas covered c. 88 000 ha (70%) of that riverbed habitat. Average estimate of vegetation cover was 45%, but ranged between 15% and 87%. Three large rivers were divided into standard reaches (regarded as the unit of analysis), which were consistently surveyed but not always in the same year (Rakaia = 3 survey reaches, Rangitata = 2 reaches, Waimakariri = 2 reaches; Appendix 1), bring the sample size to 88 survey reaches.

Counts spanned 47 years (1962–2008). Frequency of counts on individual rivers was highly variable, with the number of surveys per river varying between one and 18 (mean = 3.7 ± 0.5 SE) spanning zero (= one-off counts) to 47 years (mean = 14.6 ± 1.8). Twenty-nine survey reaches had only a single count, 16 had two counts, 11 had three counts and the remainder four or more counts ($n$ = 32, 38%). Only one river, the Waitaki, had counts that were replicated at the peak of breeding within years (in 2001 and 2005). The length of survey reaches varied considerably, depending on the overall length of each river, the distribution of braided river habitat on each river, and logistic constraints (mean = 26.5 ± 2.8 km, range = 3–115).

Numbers of black-fronted terns detected on standard survey reaches ranged from zero to 1617 birds per survey. The largest count was on the Wairau River in Marlborough (19% of all terns observed on the most recent counts). The smallest river on which black-fronted terns were recorded nesting was Edwards Stream in the Mackenzie Basin (10 km, 156 ha). It was not possible to sum counts from multiple rivers to achieve an estimate of total population size because few surveys were conducted simultaneously and terns may not display site fidelity among years. However, the sum of the earliest count from each river was 9675 terns, and the sum of the most recent counts was 8325 terns (14% lower).

Black-fronted terns were distributed widely across the east coast of the South Island. When considering the most recent counts, 21.4% of birds were counted in Marlborough (but with the majority on the Wairau River (see above), 0.6% in Nelson, 0.7% on the West Coast, 60.1% in Canterbury, 6.6% in Otago and 10.6% in Southland. These percentages are similar to a distribution of 14.2% of birds counted in Marlborough, 0.4% in Nelson, 0.2% on the West Coast, 69.3% in Canterbury, 8.0% in Otago and 7.9% in Southland when using data from the earliest count on each river.

Black-fronted terns were not recorded on all rivers and the numbers counted were variable. Terns were recorded on 61 of the 84 rivers surveyed (73%). No terns were recorded on nine rivers on the West Coast, 10 rivers in Canterbury, three rivers in Marlborough and one river in Otago (Appendix 1). When considering the most recent counts, > 200 black-fronted terns were counted on only 12 rivers (14% of rivers: Ahuriri, Aparima, Hurunui, Mararoa, Oreti, Rakaia, Rangitata, Tekapo, Waiau (Canterbury), Waimakariri, Wairau, and Waitaki). These rivers accounted for a disproportionate number of terns counted in the most recent surveys (6553 terns, 79%).

### Trend analyses

We undertook trend analyses for 29 of the 32 rivers for which we obtained four or more standardised counts (range = 4–18 counts). Two rivers (Arawhata and Waitaha) were excluded because no terns were recorded on any survey and another (Buller) was excluded because survey reaches were different on each count. Survey results used in the analysis were not necessarily those reported during the original surveys. We tried to standardise survey lengths for comparisons among years as much as possible, thus excluding some outlying reaches that were sampled rarely or inconsistently (Appendix 1). The trend analysis included good representation of Canterbury (72%) and Otago (24%) rivers, but long-term monitoring data were only available for one river in Southland.

For the 29 rivers included in the analysis, median counts ranged from four terns (Shotover) to 573 terns (Ahuriri; Table 1). Trends in black-fronted tern counts were highly site-specific. An interactive model including both site and time explained the data substantially better (d.f. = 59, ΔAIC = 0) than the null model (d.f. = 2, ΔAIC = 158.5) or models including either site (d.f. = 30, ΔAIC = 57.3) or time (d.f. = 3, ΔAIC = 156.8). The model detected significant changes in the order of >6%. Significant declines were found on eight rivers (mean = 9.9% ± 1.4 SE, range = 5.5–15.8% p.a.), a significant increase on one river (Eglinton; 16.3% p.a.) and no significant trends on the remaining 20 rivers (Table 2; Fig. 1). For the rivers on which significant declines were detected, annual rates of decline correspond to an average population decline of 92.6% over 25 years (range = 75.7–98.6%).

### Factors influencing trend count trends

Of the 29 rivers, two rivers (Eglinton and Tasman) were excluded from ANOVAs investigating the influence of river characteristics on trends in tern populations, because they were outliers with undue leverage on the models. The Eglinton was the only river with full and continuous pest control and the only one on which the population of black-fronted terns increased significantly over the study period, and the Tasman was the largest river in the study group but had very few terns. For the remaining 27 rivers analysed, both pest management and flow influenced the annual rate of change in tern populations (Table 3; Fig. 2). We did not detect a correlation between either increasing riverbed area or exotic vegetation cover and trends in tern populations (Table 3).

Of the rivers on which tern populations declined between 1962 and 2008, three rivers had low mean flows (< 10 $m^3$ $s^{-1}$; Ashburton (North Branch), Opihi, Twizel) and five had medium mean flows (10–29 $m^3$ $s^{-1}$; Manuherikia, Orari, Pukaki, Rees and Shotover) (Table 2, Fig. 2). When these trends were generalised across all rivers for which flow data exist, numbers of terns were positively correlated with mean flow ($R^2$ = 0.54, Fig. 3). The trend was similar, but the relationship weaker, when the earliest counts for each river were correlated against mean flow ($R^2$ = 0.29). We did not detect trends in tern populations on rivers with mean flow greater than 30 $m^3$ $s^{-1}$ (Fig. 2). Wherever declines in black-fronted tern populations were detected they were on rivers with no pest control (Table 2).

## Discussion

### Data limitations

There are a number of limitations to the data collated for these analyses. Counts from individual rivers were carried out irregularly. Few bird counts were specifically undertaken to monitor long-term trends in numbers of black-fronted terns; rather, they were often initiated as an inventory of the species composition and relative significance of sites (O'Donnell & Moore 1983).

Carrying out surveys of braided rivers is complex, difficult and weather- and observer-dependent, particularly on large

**Table 2.** Black fronted tern statistics from rivers in which four or more counts were conducted within the period 1962–2008 ($n = 29$). Mean river flow was categorised as 'low' = < 10 $m^3 s^{-1}$, 'medium' = 10–29 $m^3 s^{-1}$, 'high' = 30–99 $m^3 s^{-1}$ or 'very high' = ≥ 100 $m^3 s^{-1}$. Entries are ordered by annual rate of change in numbers of terns counted. Rivers in bold indicate that *P*-values are significant at $P < 0.05$.

| River | River flow | Pest management | Annual rate of change (%) | SE (%) | *z* value | *P* value |
|---|---|---|---|---|---|---|
| **Eglinton** | **Medium** | **Yes** | **16.3** | **3.7** | **4.786** | **<0.001** |
| Cameron | Low | No | 5.8 | 3.6 | 1.612 | 0.107 |
| Waimakariri (lower) | Very high | No | 5.4 | 3.0 | 1.826 | 0.068 |
| Hunter | High | No | 3.5 | 2.2 | 1.629 | 0.103 |
| Ohau | Medium | Partial | 1.7 | 1.6 | 1.065 | 0.287 |
| Makarora | Medium | Partial | 1.6 | 1.9 | 0.851 | 0.395 |
| Dart | High | Partial | 1.1 | 1.9 | 0.601 | 0.548 |
| Hurunui | High | No | 0.3 | 2.8 | 0.092 | 0.926 |
| Conway | Low | No | 0.1 | 3.1 | 0.042 | 0.967 |
| Rangitata (lower) | Very high | No | 0.0 | 3.3 | 0.003 | 0.998 |
| Tekapo | Medium | Partial | 0.0 | 1.4 | −0.018 | 0.985 |
| Tasman | Very high | Partial | −0.1 | 1.4 | −0.093 | 0.926 |
| Waitaki | Very high | No | −0.3 | 3.0 | −0.087 | 0.930 |
| Rakaia (lower) | Very high | No | −0.4 | 2.5 | −0.154 | 0.877 |
| Ahuriri | Medium | No | −1.2 | 1.6 | −0.753 | 0.451 |
| Hopkins | High | No | −2.0 | 2.0 | −0.964 | 0.335 |
| Matukituki | High | No | −2.5 | 2.2 | −1.085 | 0.278 |
| Ashley | Low | Partial | −2.9 | 3.0 | −0.941 | 0.347 |
| Ashburton | Medium | Partial | −3.3 | 1.8 | −1.834 | 0.067 |
| Hakataramea | Low | No | −4.9 | 3.1 | −1.520 | 0.129 |
| **Ashburton (N branch)** | **Low** | **No** | **−5.5** | **2.0** | **−2.598** | **0.009** |
| Cass | Medium | No | −5.6 | 3.4 | −1.612 | 0.107 |
| **Opihi** | **Low** | **No** | **−5.8** | **2.8** | **−1.987** | **0.047** |
| **Orari** | **Medium** | **No** | **−6.8** | **3.1** | **−2.114** | **0.035** |
| **Twizel** | **Low** | **No** | **−8.4** | **2.7** | **−2.965** | **0.003** |
| **Shotover** | **Medium** | **No** | **−10.7** | **2.4** | **−4.263** | **<0.001** |
| **Rees** | **Medium** | **No** | **−12.6** | **3.0** | **−3.948** | **<0.001** |
| **Pukaki** | **Medium** | **No** | **−13.7** | **1.9** | **−6.754** | **<0.001** |
| **Manuherikia** | **Medium** | **No** | **−15.8** | **3.9** | **−3.663** | **<0.001** |

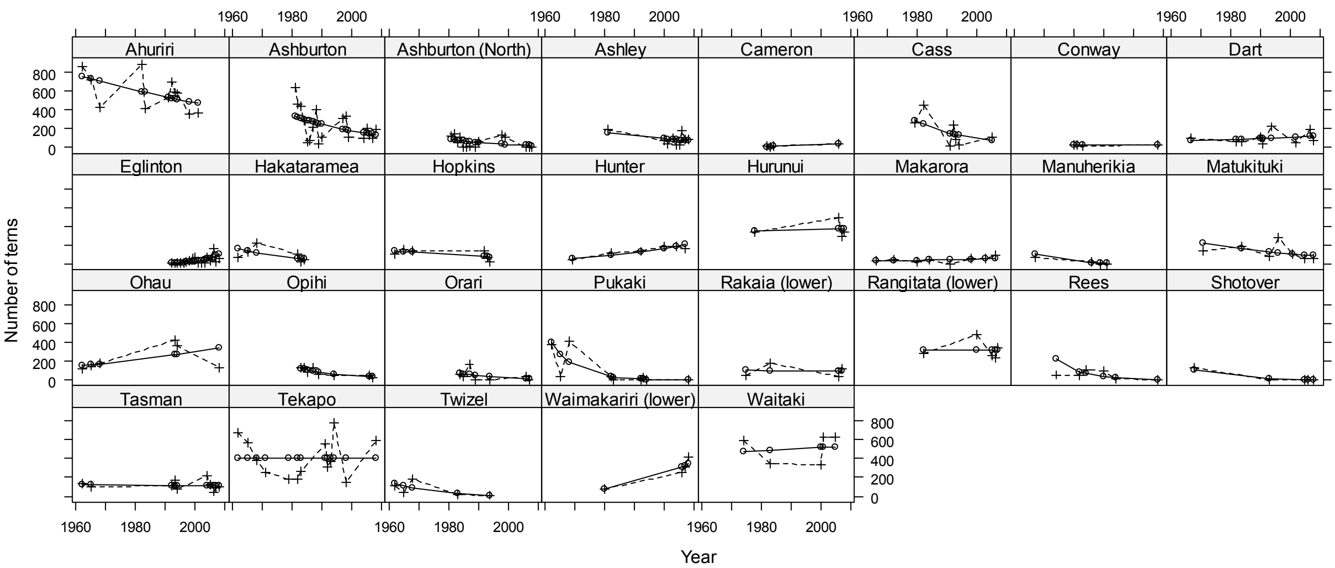


**Figure 1.** Number of terns (log scale) counted on 29 South Island braided rivers between 1962 and 2008. Symbols: + and hashed lines represent actual values, o and solid lines represent fitted values from the best generalised linear model.

**Table 3.** Influence of river characteristics on annual rates of change in black-fronted tern populations on 27 South Island braided rivers⁺. Factors shown in bold type influenced annual rates of change in terns.

| | d.f. | *F* value | *P* value |
|---|---|---|---|
| **Flow*** | 3 | 3.552 | **0.033** |
| River area (ha) | 1 | 2.005 | 0.172 |
| Vegetation (% cover) | 1 | 0.107 | 0.747 |
| **Pest management** (presence/absence) | 1 | 4.996 | **0.037** |

⁺The Eglinton and Tasman rivers were excluded from analyses as they exerted a disproportionate influence on models; all other braided rivers on which black-fronted terns counts have been completed four or more times were included. *Flow was categorised as 'low' (<10 $m^3 s^{-1}$), 'medium' (10–29 $m^3 s^{-1}$), 'high' (30–99 $m^3 s^{-1}$) or 'very high' (≥100 $m^3 s^{-1}$).

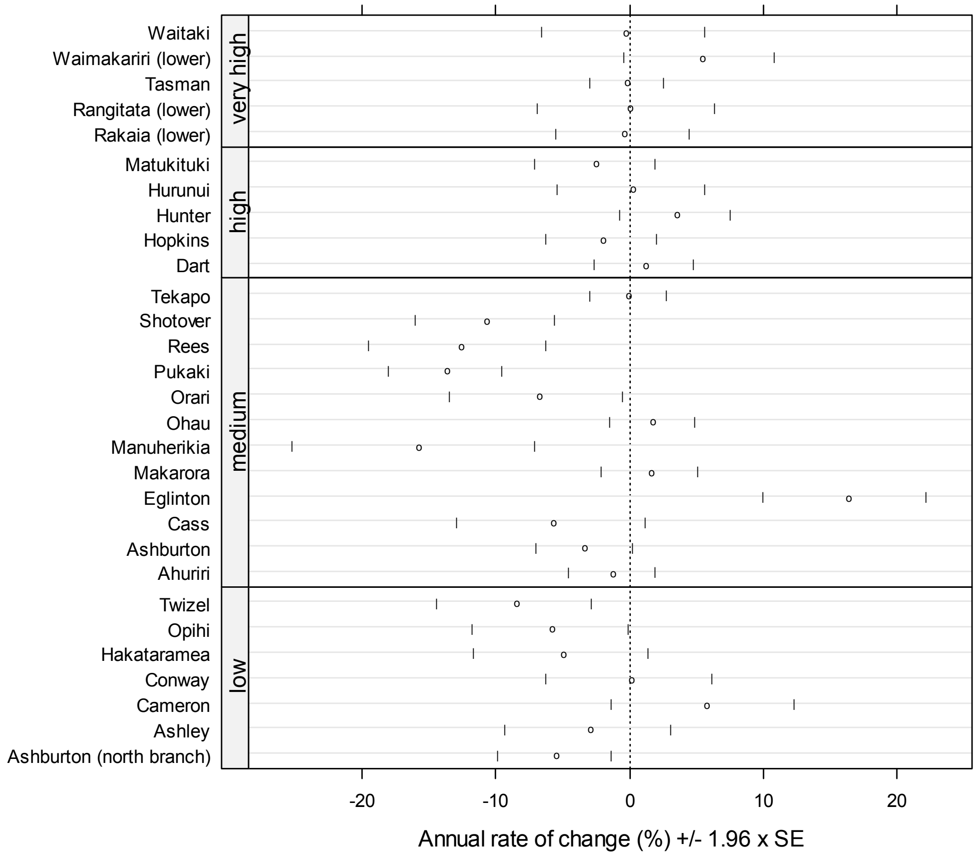


**Figure 2.** Annual rates of change and confidence intervals (1.96 × SE) for black-fronted terns on 29 South Island braided rivers between 1962 and 2008. Rivers grouped according to flow rate.

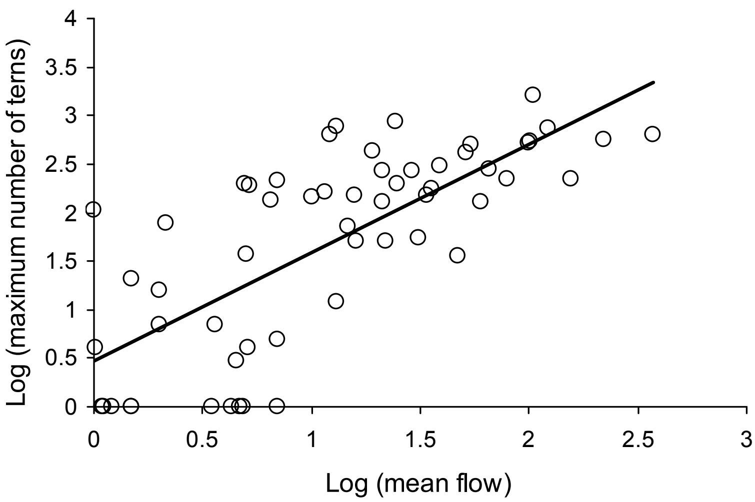


**Figure 3.** Generalisation of the relationship between mean river flow ($m^3 s^{-1}$) and the maximum number of terns counted on braided rivers ($n = 57$ rivers for which data were available). Data are expressed on a log scale to better illustrate trends. $R^2 = 0.54$.

rivers. Therefore, it is rarely possible to conduct regular and simultaneous counts across all rivers. Because of these problems, the time series for the larger rivers in our study is limited compared with those for the smaller rivers, and the larger-river surveys, when done, were necessarily limited to specific river sections (with the exception of the Waitaki, Boffa Miskell 2006). In addition, there is limited knowledge of tern movements and we have concerns that terns move among rivers both within and between seasons, suggesting that birds may have been either missed or double counted, depending on the year. Despite such limitations, water bird counts repeated in a standardised manner over many years, even when intervals are irregular, can provide information on changes in status and trend in numbers of birds (Henry et al. 2008; Lengyel et al. 2008; Marsh & Trenham 2008) and the analyses used in this study were designed to address the problem of irregular counts from individual rivers and small sample sizes (Everitt 1995).

### Population size and distribution

Our data confirm that black-fronted terns breed through much of the South Island, with stronghold populations in Canterbury, Southland and Marlborough. They were absent historically from central and south Westland (Oliver 1955; Falla et al. 1970), despite an abundance of braided rivers, and only nest on four rivers in the Buller region of Westland and Nelson.

It was not possible to calculate current total population size from the surveys. However, the sums of the oldest (9635) and most recent counts (8325) are of a similar order of magnitude to Keedwell's (2002) estimate of c. 10 000 birds. Our results support the notion that black-fronted terns have a relatively small total population size, making the species vulnerable to decline. Two main factors preclude a precise estimate of population size from these surveys. First, only a small proportion of rivers were ever surveyed in the same year. Black-fronted terns are highly mobile and it is thought they can shift between adjacent rivers within and between seasons depending on conditions on individual rivers. Second, the numbers of terns recorded on a few of the larger rivers were probably underestimates because the surveyed reaches did not fully represent each river as a whole. For example, extended surveys of the Waiau River (Canterbury) in 2008 counted 520 terns of which 264 were on the standard survey reach. Similarly, 1882 terns were counted on the Wairau River in 2006 (1617 on the standard reach). Short-term variability in counts on individual rivers from year to year may reflect variation in annual breeding success (Keedwell 2005; Steffens 2008; S. Cranwell, DOC, Renwick, pers. comm.), environmental conditions (e.g. frequency of flood events) and the fact that a small proportion of birds may be feeding off-river at the time of survey (Robertson et al. 1983).

### Population trends

It is clear that there have been substantial historical declines in numbers and range of black-fronted terns. They formerly bred in parts of the North Island (Oliver 1955; Falla et al. 1970). Stead (1932) believed that black-fronted terns had declined substantially on their breeding grounds during the period 1895–1915, but that numbers changed little between then and 1930. Considerable numbers used to winter in the southern half of the North Island (e.g. flocks of up to c. 320 birds; Falla et al. 1970), but by the late 1970s there were fewer than 200 remaining (Keedwell 2002).

The counts we collated appear to be representative of most of the current breeding range of black-fronted terns. There are 307 rivers with braided sections on them listed in DOC's database (D. Brown pers. comm.). Many of these are small – 92 cover <50 ha and 53 cover 50–99 ha. Many of the remaining rivers > 99 ha are outside the current breeding range of black-fronted terns (e.g. all of the North Island and West Coast rivers and high altitude areas on rivers of the east coast of the South Island). We used counts in the trend analysis from all rivers with four or more consistent surveys (48% of known breeding rivers).

We detected significant population declines on eight of the 29 rivers modelled and only one significant increase. We consider these data are sufficient to signal cause for concern in this species, especially when combined with other evidence for decline. Intensive studies on a few rivers have described the specialised habitat requirements of black-fronted terns, the significant loss of nesting habitat that has occurred, and the species' poor breeding success and vulnerability to predation by introduced mammals (Lalas 1977; Robertson et al. 1983; Wilson 2001; Keedwell et al. 2002b; Keedwell 2004, 2005). Using population viability analysis based on the particular vulnerability of breeding adults to predation, Keedwell (2004) predicted that black-fronted terns were declining steadily towards extinction.

Few counts from the Southland region were adequate for trend analysis although the results clearly showed that Southland is an important region for black-fronted terns. For example, 273 birds were counted on 40 km of the Mararoa River in spring 2008 (H. Edmonds, DOC, Te Anau, pers. comm.). Given probable declines in the populations of other braided river birds (e.g. Pierce 1984, 1989; O'Donnell 2000; Keedwell & Sanders 2002; Keedwell et al. 2002a) and especially dramatic declines in numbers of black-billed gulls on Southland rivers (McClellan 2009) it seems likely the declining trends observed elsewhere are also representative of Southland rivers.

### Factors influencing population trends

Our data support the hypothesis that the amount of water in a braided river is important for black-fronted terns. Tern numbers appeared to be highest on rivers with larger average flows and the largest contemporary counts of black-fronted terns were all from rivers with relatively high, little-modified flows. However, we know of no studies that investigate the specific form of this relationship.

Black-fronted terns appear to be dependent on aquatic habitats during the breeding season (Lalas 1977; Robertson et al. 1983, 1984). Flow is also correlated with the amount of food-producing habitat (Glova & Duncan 1985; Paetzold et al. 2008) and reduction in flow potentially manifests itself in a large number of ways, including reduced food availability, stabilisation of river channels, channelisation, weed encroachment and increased disturbance (O'Donnell 2000). We found few data on the actual amount of water that has been lost from rivers since abstraction or diversion commenced. Average flows on the Pukaki River, where we detected one of the greatest declines in terns, have been reduced by 97% from 132 $m^3 s^{-1}$ before diversion of the river for power generation to 4 $m^3 s^{-1}$ today (Gabites, Porter & Partners 1982). Flows on the Ashburton River have been reduced by 60% (Horrell 2001), whereas those on much larger rivers (Waimakariri, Hurunui) have been reduced by <15% (Duncan et al. 2008b). Higher flows are predicted to reduce predation risk on nesting islands and there is an interaction between amount of vegetation on the riverbed and cover for predators and their prey: the 'safe islands' concept (Pierce 1987; Pascoe 1995; Keedwell 2004; Zoellick et al. 2004; Duncan et al. 2008a, b). Further research is needed to clarify the relationships between river flows and population trends across a wide range of rivers.

A notable result is that the only river where a black-fronted tern population increased in number was at one site (the Eglinton) where flow has remained unmodified and continuous landscape-scale mammalian predator control was carried out over 10 years of the monitoring period. In the Eglinton Valley, mustelids have been trapped over the 50-km length of the valley since 1998. From 1998 to January 2009, 1976 mustelids, 5331 rats (*Rattus* spp.), 111 cats (*Felis catus*) and 323 hedgehogs (*Erinaceus europaeus*) have been caught in mustelid traps (G. Hill, DOC, Te Anau, pers. comm.). Several other bird species have also responded positively to predator control (Dilks 1999; Dilks et al. 2003). These results suggest predator control aimed at recovering black-fronted tern numbers is warranted.

### Threat classification for black-fronted terns

Black-fronted terns are classed as 'endangered' by the IUCN (2010) and 'nationally endangered' by DOC (Miskelly et al. 2008). We consider that the conservation status 'endangered' is appropriate for black-fronted terns. The IUCN uses multiple criteria for assessing threat status and applies the precautionary principle when there is doubt about the rate of decline and the relative contribution of threat processes (IUCN 2001). Classification of species into a threat category is based on meeting any one of five criteria.

Criterion A seems most applicable based on the findings reported here. It requires an observed, estimated, inferred or suspected population reduction in the order of 50% over the last ten years or three generations, whichever is longer, and the causes of decline to still be active. Mace and Lande (1991) proposed that population declines in the order of >1–2% per annum equated to unacceptable probabilities of extinction in many animals. Generation time is defined as the average age of breeding birds in any one breeding season (IUCN 2001). The generation time for black-fronted terns is unknown, although, one generation is likely to be in the order of 10 years or more. Keedwell (2004) estimates age of first breeding in black-fronted terns to be 2 years and longevity to be 25 years. Terns in general can live up to 35 years (average 23 years for 13 species; North American Bird Banding Program, http://www.pwrc.usgs.gov/bbl, downloaded 9 September 2009). The average age of the common tern (*Sterna hirundo*), which is of similar size to the black-fronted tern, is about 10 years (Terres 1980). Therefore, we estimate three generations to cover approximately 30 years.

Our models indicated that rates of decline varied between 5.5 and 15.8% per annum and averaged 10% per annum on low- to medium-flow rivers. At such rates, populations on these rivers are likely to be close to extinction (declining by a further c. 90%) within 25 years. Low- and medium-flow rivers make up 64% of the rivers surveyed. They supported 51.4% of black-fronted terns counted on the oldest counts for each river, but this total declined to 32.5% of terns counted on the most recent counts. On rivers with large flows we did not detect any significant population trends, either because tern numbers have not changed or because sample sizes were small, time series short, and confidence intervals wide.

Criteria B, C, and D are not relevant to black-fronted terns; they are based on there being a small area of occupancy of the species or fewer than 2500 mature individuals. Although the world population of black-fronted terns appears to be small and confined to New Zealand, it is likely to be in the order of 10 000 birds (this paper and Keedwell 2002). However, there has been no research conducted into the long-term demographics of this species, and information on recruitment and age structure of the population is particularly lacking.

Criterion E 'a species would be endangered if quantitative analysis showed the probability of extinction in the wild is at least 20% within five generations' is relevant to black-fronted terns. A population viability analysis by Keedwell (2004) predicted that black-fronted terns would decline by 60–75% over 25 years (approximately 2.5 generations) for a range of threat scenarios (−2.5% per annum for base model) based on research into breeding success conducted on the Ohau River. Thus black-fronted terns also qualify for IUCN 'endangered' status under Criterion E. More recent work has shown similar poor breeding success or predation of terns on other rivers (Murphy & Dowding 1995; Murphy et al. 2004; Bell 2005; Boffa Miskell & Urtica Consulting 2007).

Evidence from other studies (Keedwell et al. 2002a; Keedwell 2004) suggests that population decline is widespread and downward trends are likely on larger-flow rivers, albeit at a slower rate. Even if populations on larger rivers were stable, we predict the total population would decline by c. 50% over the next 25 years if trends on smaller rivers continue and if management focused on recovering populations is not instigated with some urgency.

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**Appendix 1** Black-fronted tern population data: river reaches used in the analysis.

| River | *n* | Year of first count | Year of last count | Span of counts (yrs) | Survey area (ha) | Survey length (km) | Earliest tern count | Most recent tern count | Source |
|---|---|---|---|---|---|---|---|---|---|
| Ahuriri | 11 | 1962 | 2001 | 39 | 1155 | 75 | 856 | 363 | Bell (1994), Robertson et al. (1983), Robertson et al. (1984), Maloney et al. (1997), C. Woolmore (DOC Files) |
| Aparima | 2 | 1985 | 1995 | 10 | 700 | 50 | 155 | 200 | R. McClellan (pers. comm.), W. Cooper (pers. comm. in Keedwell 2002). |
| Arawata | 4 | 1985 | 2007 | 22 | 2500 | 50 | 0 | 0 | Child (1986); O'Donnell & Dilks (1986), T. Stephens, P. van Klink (pers. comm.). |
| Ashburton | 18 | 1981 | 2008 | 27 | 1527 | 75 | 642 | 197 | O'Donnell (1992), C. O'Donnell (DOC Files) |
| Ashburton North Branch | 14 | 1981 | 2007 | 26 | 500 | 34 | 120 | 0 | O'Donnell (1992), C. O'Donnell (DOC Files) |
| Ashley | 9 | 1981 | 2008 | 27 | 778 | 40 | 194 | 81 | O'Donnell & Moore (1983), A. Grant (DOC Files) |
| Awatere | 1 | 1997 | 1997 | 0 | 1000 | 32 | 50 | 50 | Hallas (2003) |
| Buller | 4 | 1995 | 2007 | 12 | 250 | 14 | n/a | 62 | Steffens (2007) |
| Cameron | 4 | 1982 | 2006 | 24 | 263 | 4 | 10 | 36 | O'Donnell & Moore (1983), C. O'Donnell (DOC Files) |
| Cass | 7 | 1979 | 2005 | 26 | 1039 | 27 | 264 | 114 | Pierce (1983), Maloney et al. (1997), Sedgeley & O'Donnell (2006), C. Woolmore (DOC Files) |
| Clarence | 2 | 1992 | 2008 | 16 | 3065 | 100 | 147 | 50 | Hallas (2003), P. Gaze (pers. comm.) |
| Clutha | 1 | 1995 | 1995 | 0 | 127 | 160 | 12 | 12 | Hughey et al. (1986). |
| Conway | 4 | 1980 | 2008 | 28 | 500 | 15 | 30 | 24 | Cowie (1981), C. O'Donnell, A. Grant (DOC Files) |
| Cook | 1 | 1986 | 1986 | 0 | 600 | 15 | 0 | 0 | O'Donnell & Dilks (1986) |
| Cox | 1 | 1987 | 1987 | 0 | 200 | 18 | 0 | 0 | C. O'Donnell (DOC Files) |
| Dart | 9 | 1967 | 2008 | 41 | 1254 | 18 | 93 | 73 | Lawrence (2007), B. Lawrence pers. comm. |
| Dobson | 3 | 1992 | 1994 | 3 | 800 | 15 | 33 | 53 | Maloney et al. (1997), C. Woolmore (DOC Files) |
| Edwards | 1 | 2002 | 2002 | 0 | 156 | 10 | 20 | 20 | Sedgeley (2003) |
| Eglinton | 17 | 1992 | 2008 | 16 | 428 | 40 | 5 | 50 | C. O'Donnell (DOC Files) |
| Eyre | 1 | 2008 | 2008 | 0 | 459 | 30 | 0 | 0 | A. Grant (DOC Files) |
| Fork | 1 | 2005 | 2005 | 0 | 200 | 13 | 2 | 2 | Sedgeley & O'Donnell (2006) |
| Godley | 3 | 1992 | 1994 | 3 | 3470 | 18 | 174 | 45 | Maloney et al. (1997), C. Woolmore (DOC Files) |
| Haast | 1 | 2007 | 2007 | 0 | 2500 | 35 | 0 | 0 | C. O'Donnell, T. Stephens, P. van Klink (pers. comm.). |
| Hakataramea | 6 | 1962 | 1984 | 22 | 600 | 35 | 62 | 42 | Bell (1994), Robertson et al. (1983), Robertson et al. (1984), |
| Hanmer | 1 | 2008 | 2008 | 0 | 600 | 10 | 0 | 0 | A. Grant (DOC Files) |
| Hapuku | 2 | 2001 | 2008 | 7 | 150 | 6 | 0 | 0 | Hallas (2003), A. Grant (DOC Files) |
| Harper/Avoca | 1 | 1978 | 1978 | 0 | 300 | 13 | 11 | 11 | O'Donnell & Moore (1983) |
| Hawdon | 3 | 1983 | 1984 | 1 | 200 | 6 | 0 | 0 | C. O'Donnell (DOC Files) |
| Hokitika | 2 | 2007 | 2008 | 1 | 1630 | 31 | 0 | 0 | C. O'Donnell, J. Lyall pers. comm. |
| Hope | 1 | 2005 | 2005 | 0 | 800 | 16 | 35 | 35 | Sedgeley (2006) |
| Hopkins | 6 | 1962 | 1994 | 32 | 2730 | 26 | 100 | 21 | Bell (1994), Maloney et al. (1997) C. Woolmore (DOC Files) |
| Hunter | 6 | 1969 | 2007 | 38 | 1000 | 18 | 38 | 157 | Child (1960), Gaud (2007) |
| Hurunui | 4 | 1978 | 2008 | 29 | 1900 | 115 | 338 | 336 | O'Donnell & Moore (1983), A. Grant (DOC Files) |
| Kahutara | 2 | 2000 | 2008 | 8 | 300 | 10 | 15 | 8 | Hallas (2003), A. Grant (DOC Files) |
| Kakanui | 1 | 1983 | 1983 | 0 | 68 | 7 | 0 | 0 | Robertson et al. (1984) |
| Karangarua | 1 | 1986 | 1986 | 0 | 900 | 10 | 0 | 0 | O'Donnell & Dilks (1986) |
| Kowai | 2 | 2007 | 2008 | 1 | 50 | 3 | 0 | 0 | C. O'Donnell, A. Grant (DOC Files) |
| Kowhai | 2 | 2000 | 2008 | 8 | 300 | 10 | 0 | 0 | Hallas (2003), A. Grant (DOC Files) |

| River | *n* | Year of first count | Year of last count | Span of counts (yrs) | Survey area (ha) | Survey length (km) | Earliest tern count | Most recent tern count | Source |
|---|---|---|---|---|---|---|---|---|---|
| Landsborough | 3 | 1986 | 2008 | 22 | 800 | 50 | 0 | 0 | O'Donnell & Dilks (1986), C. O'Donnell (DOC Files) |
| Lottery | 1 | 1988 | 1988 | 0 | 250 | 10 | 6 | 6 | A. Crossland pers. comm. |
| Macaulay | 3 | 1992 | 1994 | 3 | 765 | 9 | 35 | 25 | Maloney et al. (1997), C. Woolmore (DOC Files) |
| Maerewhenua | 1 | 1983 | 1983 | 0 | 126 | 10 | 2 | 2 | Robertson et al. (1984) |
| Makarora | 8 | 1966 | 2006 | 40 | 800 | 15 | 35 | 89 | Golding (2006) |
| Manuherikia | 4 | 1967 | 1991 | 24 | 100 | 10 | 71 | 0 | Child (1975), McKinlay (1990), Schweigman (1991) |
| Mararoa | 1 | 2008 | 2008 | 0 | 500 | 40 | 273 | 273 | H. Edmonds pers. comm. |
| Maruia | 2 | 1979 | 2008 | 29 | 350 | 15 | 15 | 0 | Gaze (1988), C. O'Donnell (DOC Files) |
| Mason | 1 | 2008 | 2008 | 0 | 100 | 5 | 3 | 3 | A. Grant (DOC Files) |
| Matakitaki | 3 | 1995 | 2007 | 12 | 315 | 10.5 | 18 | 35 | Steffens (2007) |
| Mataura | 2 | 1983 | 2001 | 18 | 600 | 20 | 111 | 130 | R. McClellan pers. comm., Keedwell (2002). |
| Matukituki | 7 | 1971 | 2008 | 35 | 1000 | 25 | 137 | 58 | Thorne (2005) |
| Motueka | 1 | 2007 | 2007 | 0 | 260 | 13 | 16 | 16 | Golding (2007) |
| Nevis | 1 | 1967 | 1967 | 0 | ? | ? | 32 | 32 | Child (1975) |
| Ohau | 6 | 1962 | 2008 | 33 | 400 | 19 | 117 | 129 | Bell (1994), Maloney et al. (1997), C. Woolmore (DOC Files) |
| Okuku River | 1 | 2007 | 2007 | 0 | 70 | 7 | 2 | 2 | C. O'Donnell (DOC Files) |
| Opihi | 8 | 1983 | 2007 | 24 | 700 | 40 | 133 | 19 | Overmars (1983), O'Donnell (1987), Hughey (1985b), Schweigman (1994) |
| Orari | 7 | 1984 | 2006 | 22 | 550 | 35 | 65 | 0 | Overmars (1983), O'Donnell (1987), Hughey (1985b), Schweigman (1994), A. Grant (DOC Files) |
| Oreti | 1 | 1986 | 1986 | 0 | 800 | 40 | 298 | 298 | Gaze (1988) |
| Pareora | 1 | 2008 | 2008 | 0 | 150 | 15 | 0 | 0 | A. Grant (DOC Files) |
| Paringa | 1 | 1984 | 1984 | 0 | 300 | 15 | 0 | 0 | O'Donnell & Dilks (1986) |
| Poulter | 1 | 1986 | 1986 | 0 | 800 | 17 | 0 | 0 | C. O'Donnell (DOC Files) |
| Pukaki | 9 | 1962 | 2008 | 32 | 455 | 12.5 | 375 | 0 | Robertson et al. (1983, 1984), Bell (1994), Maloney et al. (1997), C. Woolmore (DOC Files) |
| Rainbow River | 2 | 1995 | 1999 | 4 | 249 | 6 | 94 | 46 | Ure (1995, 1999) |
| Rakaia (lower) | 4 | 1975 | 2007 | 32 | 3120 | 23 | 47 | 122 | O'Donnell & Moore (1983), Robertson et al. (1984), A. Grant (DOC Files) |
| Rakaia (middle) | 3 | 1979 | 2007 | 28 | 2000 | 20 | 120 | 48 | O'Donnell & Moore (1983), A. Grant (DOC Files) |
| Rakaia (upper) | 1 | 1978 | 1978 | 0 | 2500 | 32 | 403 | 403 | O'Donnell & Moore (1983) |
| Rangitata (lower) | 5 | 1982 | 2007 | 25 | 2080 | 30 | 284 | 345 | O'Donnell & Moore (1983), Butcher (2001), A. Grant (DOC Files) |
| Rangitata (upper) | 2 | 1986 | 2008 | 22 | 1600 | 13 | 248 | 105 | Moore (1986a), C. O'Donnell (DOC Files) |
| Rees | 6 | 1967 | 2008 | 27 | 400 | 25 | 54 | 0 | McKinlay (1995), B. Lawrence pers. comm. |
| Selwyn | 1 | 2007 | 2007 | 0 | 200 | 20 | 0 | 0 | C. O'Donnell (DOC Files) |
| Shotover | 5 | 1968 | 2008 | 40 | 170 | 5 | 126 | 0 | McKinlay (1994), B. Lawrence, D. Palmer pers. comm. |
| Taramakau | 1 | 1985 | 1985 | 0 | 3220 | 46 | 0 | 0 | Moore (1986b) |
| Tasman | 10 | 1962 | 2008 | 48 | 2500 | 16 | 134 | 101 | Bell (1994), Maloney et al. (1997), Cleland et al. (2008), C. Woolmore (DOC Files) |
| Te moana | 2 | 1985 | 2006 | 21 | 20 | 14 | 6 | 0 | Hughey (1985b) |
| Tekapo | 13 | 1962 | 2008 | 48 | 1293 | 40 | 676 | 597 | Robertson et al. (1983, 1984), Bell (1994), Maloney et al. (1997), C. Woolmore (DOC Files) |
| Temuka | 3 | 1985 | 2006 | 21 | 59 | 10 | 4 | 0 | Hughey (1985b) |
| Tengawai | 2 | 1985 | 2006 | 21 | 20 | 10.5 | 3 | 0 | Hughey (1985b) |

| River | *n* | Year of first count | Year of last count | Span of counts (yrs) | Survey area (ha) | Survey length (km) | Earliest tern count | Most recent tern count | Source |
|---|---|---|---|---|---|---|---|---|---|
| Twizel | 5 | 1962 | 1994 | 32 | 71 | 10 | 107 | 12 | Robertson et al. (1984), Bell (1994), C. Woolmore (DOC Files) |
| Waiau Canterbury (upper) | 2 | 1975 | 2008 | 33 | 2560 | 30 | 217 | 264 | O'Donnell & Moore (1983), A. Grant (DOC Files) |
| Waiau Southland | 3 | 1993 | 1999 | 6 | 780 | 26 | 39 | 60 | Sagar (1994), McClelland (1996, 1999) |
| Waihi | 1 | 1985 | 1985 | 0 | 11 | 17 | 0 | 0 | Hughey (1985b) |
| Waima | 2 | 1997 | 2008 | 11 | 200 | 10 | 0 | 0 | Hallas (2003) |
| Waimakariri (lower) | 4 | 1980 | 2008 | 28 | 4800 | 41 | 74 | 423 | O'Donnell & Moore (1983), A. Grant (DOC Files) |
| Waimakariri (upper) | 2 | 1981 | 1995 | 14 | 2700 | 33 | 69 | 303 | O'Donnell & Moore (1983), DOC (1995) |
| Waipara | 3 | 1993 | 2002 | 9 | 200 | 13 | 0 | 0 | Crossland & Butcher (2008), A. Crossland pers. comm. |
| Wairau | 3 | 1985 | 2006 | 21 | 4700 | 80 | 1136 | 1617 | Hallas (2003), DOC Files |
| Waitaha | 4 | 2005 | 2008 | 3 | 800 | 15 | 0 | 0 | C. O'Donnell (DOC Files) |
| Waitaki | 5 | 1974 | 2005 | 31 | 3922 | 66 | 597 | 633 | O'Donnell & Moore (1983), Robertson et al. (1983, 1984), Boffa Miskell (2006). 2001 and 2005 counts included 5 replicates |
| Wilberforce | 1 | 1978 | 1978 | 0 | 2880 | 24 | 87 | 87 | O'Donnell & Moore (1983) |