Black-fronted tern (*Chlidonias albostriatus*) colony dynamics in New Zealand braided rivers

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Abstract: Black-fronted terns (*Chlidonias albostriatus*) are globally endangered and are one of six endemic bird species that rely on New Zealand's braided river ecosystems for breeding. Like other marsh tern species, black-fronted terns are predicted to have low breeding-site fidelity due to the instability of their breeding habitat, small colony sizes and high predation rates. We used breeding colony location data collected from nine South Island rivers for 3–12 years (2004–2015) to investigate the breeding-site fidelity in black-fronted terns. The distribution of breeding colony locations from seven of the nine rivers analysed were not significantly different to a simulated random distribution. The tendency of black-fronted terns to form breeding colonies near past breeding site compared to new sites was only significant for two of the nine rivers analysed. Overall, there was low breeding-site fidelity in black-fronted tern colonies from year to year across the rivers analysed.

INTRODUCTION

The black-fronted tern (*Chlidonias albostriatus*) is one of six endemic bird species that rely on New Zealand's braided river ecosystems for breeding. Black-fronted terns have a small, declining population and are classified as globally endangered (BirdLife International 2012), primarily due to predation. The current black-fronted tern population is estimated to be less than 10,000 mature individuals (Keedwell 2002; O'Donnell & Hoare 2011). The black-fronted tern is one of the approximately 13% of all bird species that breed in colonies (Rolland *et al*. 1998), along with more than 95% of seabirds and all other tern species (Jones & Kress 2012; Palestis 2014). Breeding-site fidelity (also known as philopatry or tenacity) is the tendency of individuals to return to the same colony site, usually in succeeding breeding seasons (Austin 1949). The level of breeding-site fidelity demonstrated by different species can be impacted by many factors including age (Austin 1949; Freer

1979), past breeding success (Burger 1982; Cuthbert 1988; Thibault 1994; Porneluzi 2003) and habitat stability (McNicholl 1975; Freer 1979; Visser & Peterson 1994; Burger & Gochfeld 2001).

High breeding-site fidelity can have significant adaptive implications for different species. Familiarity with a site generated through high breeding-site fidelity facilitates mate retention and reduces the energy and time expenditure required to locate suitable breeding sites and food resources (McNicholl 1975; Collar 2013). However, environmental changes can render past breeding habitat sub-optimal, dangerous or unusable. Environmental cues contribute to settlement decisions even in species with high breeding-site fidelity, as birds will abandon a historical breeding site if conditions change to the extent that costs of remaining are outweighed by the benefits of abandonment (Burger 1984). High breeding-site fidelity in species with limited behavioural plasticity can be highly detrimental to survival, such as a species naive to predation which may be unable to identify and respond appropriately to novel threats presented by introduced mammalian predators in their environment (Igual et al. 2007).

There are substantial differences in the site fidelity exhibited by different tern species. As a general rule, larger colonies in more stable habitat (e.g. rocky islands) tend to have greater site fidelity compared with smaller colonies in less stable habitats (e.g. sand bars) (Palestis 2014). For example, marsh terns (Chlidonias spp.) are believed to exhibit site fidelity to a lesser degree than other tern species due to the dynamic nature of their breeding habitats (Palestis 2014). Most of the marsh tern group breed on floating weeds and vegetation in wetlands and marshes, except for black-fronted terns, which breed in gravel braided river beds (Lalas 1977). Braided rivers are highly dynamic systems characterised by high habitat turnover resulting in a dynamic mosaic of channels, bars, islands, and ponds (Tockner et al. 2006; Gray & Harding 2007). Both braided river and marshland breeding habitats appear similarly dynamic and dependent on water levels and flows, potentially making strong site fidelity disadvantageous, or difficult to achieve.

We predict black-fronted terns to have low breeding-site fidelity, similar to those observed in other Chlidonias spp., because of their dynamic braided river breeding habitat and small colony sizes. However, the evidence for this is equivocal and there are studies that suggest instances when black-fronted terns exhibit higher breeding-site fidelity than expected. For example, Pierce (1983) noted that in the Cass River (1977–1980) six to eight breeding colonies were present each season, usually in the same localities. Similarly, Keedwell (2002)

identified 'main colony sites', in which colonies formed consistently, especially following seasons of successful breeding. In contrast, Robertson et al. (1983) suggested that black-fronted tern colony locations changed each year following observations of a region of the Ahuriri River that contained a single black-fronted tern colony in 1975 and four colonies in 1982. O'Donnell & Moore (1983) also referenced the changing of colony locations each year as an adaptation to the dynamic braided river environment.

The locations and sizes of black-fronted tern colonies have been recorded over 12 years (2004–2015), through braided river bird surveys and other research projects; however, no analysis has yet been conducted on colony dynamics and site fidelity. The aim of this study was to determine whether black-fronted terns show signs of breeding-site fidelity in particular river sections. Analysis of past breeding colony locations will identify whether black-fronted terns exhibit strong breeding-site fidelity, identify particular areas or colony locations that are selected preferentially for black-fronted tern breeding, and inform targeted management approaches for black-fronted terns.

METHODS
Historical data collection
Bird counts have been carried out on braided rivers across the South Island of New Zealand since the 1960s. The majority of bird counts are collected following the standard walk-through survey method described in O'Donnell & Moore (1983). Eighty-four South Island rivers have been surveyed one or more times by volunteers and members of the former New Zealand Wildlife Service, Department of Conservation, the Royal Forest and Bird Protection Society, the Ornithological Society of New Zealand, Braided River Aid, and various river care groups (O'Donnell & Hoare 2011).

Since 2004, GPS coordinates for the colony and breeding locations of black-fronted terns were collected during most braided river surveys. Outside of the formal surveys, GPS colony coordinates have also been collected through research, and opportunistically by people working in and/or frequenting braided river systems.

A total of 598 black-fronted tern GPS breeding locations (≥1 pair) were recorded from 34 different South Island rivers and one wetland (the Ruataniwha wetland, Mackenzie Basin). Data were collected from 2004–2015, with a range of 1-12 years surveyed in each river.

Linearising data
River centrelines were used to assign a linear distance (measured from the downstream extent

of the surveyed area) to all GPS breeding locations. The Tasman River was too wide (up to 4 km) to linearize using a single centreline and so a centreline was generated for each half of the river survey area. Each breeding location was allocated a linear distance corresponding to its location along the centreline it was closest to. The two linearised data sets from the Tasman River are, henceforth, referred to as 'Tasman LHS' and 'Tasman RHS'.

Only data from rivers that had been collected consistently and for more than two years were included in the analysis. Therefore, data from nine rivers were included in the analysis (Table 1): Wairau, Waiau (Canterbury), Hurunui, Ashley-Rakahuri, Rakaia, Ashburton, Rangitata, Tasman, and Dart. Of the 26 rivers excluded, 20 contained < 3 years of data and six had inconsistent data collection (differential survey effort or inconsistent river sections surveyed). River areas deemed permanently unsuitable for black-fronted tern breeding (e.g. gorges) were excluded from the analysis of river lengths. For this analysis, each river was treated in isolation; although the reality is that rivers are not fully independent as some birds do move between river systems from one breeding season to the next (Keedwell 2002). The survey data provide a snapshot of tern colony locations at a point in time and there was no way to identify individuals or determine their origin or destination.

Colony distribution
The nature of black-fronted tern colonies, generally small (2–50 pairs) with nests widely distributed (inter-nest distances of 1–100 m), makes them difficult to define (Keedwell 2002; Bell 2013). For the purposes of this study, arbitrary 300 m continuous river sections were used to divide the surveyed area of each river. Using 300 m river sections allowed the

single GPS location recorded for each black-fronted tern colony to be generalised over a more realistic area. We also used the river sections to reduce potential inconsistencies in GPS location recording. There is currently no standard protocol for GPS colony location collection, therefore there is no way to determine what the GPS waypoint represented with respect to the colony's location, e.g. centre, upper, or lower limit.

Three variations of the river sections were generated, one starting at the downstream boundary of the survey area and the other two were offset upstream by 100 m and 200 m respectively. Three variations of river sections were used to counter the arbitrary assignment of the river sections and ensure that all colony locations in different seasons that were less than 300 m apart would be in the same river section in two of the three variations.

Colony locations were assigned to river sections based on their linear distance along the survey area. Three colony distributions were generated for each river, one for each of the three river section variations. For each river section variation, the frequency of black-fronted tern colonies was calculated using the presence/absence of black-fronted tern colonies in each river section, during each breeding season surveyed.

The mean observed frequency distribution of black-fronted tern colony locations (i.e. mean number of years a river section had a breeding colony) for each river was calculated and compared to a mean expected random distribution, generated using 1,000 replicates of random sample distributions matching each rivers specifications (number of sections and data points). The random distribution was generated under the assumption that each colony data point had equal probability of occurring in any particular 300 m river section.

Table 1. Summary data for the nine rivers (listed north to south) surveyed consistently and included in the colony distribution analysis.

River	Survey length (km)	Total number of colonies	Mean colonies/ year	Number of years surveyed	Range of years surveyed
Wairau	96.3	49	9.8	5	2009–2013
Waiau (Canterbury)	88.5	33	11.0	3	2008–2010
Hurunui	69.9	22	4.4	5	2006–2010
Ashley-Rakahuri	19.2	50	4.2	12	2004–2015
Rakaia	65.4	16	5.3	3	2011–2013
Ashburton	52.2	26	4.3	6	2007–2015
Lower Rangitata	45.6	36	8.8	4	2007–2015
Tasman LHS	15.3	54	5.4	10	2004–2015
Tasman RHS	14.7	20	2.9	10	2004–2015
Dart	18.0	14	3.5	4	2007–2010

The observed and expected colony frequency distributions for each river were compared using Pearson's Chi-squared Goodness of Fit test with a simulated P-value. All analysis was conducted in R (3.3.0) via R studio (0.99.903) and using dplyr (0.5.0), RVAideMemoire (0.9-64), and tidyr (0.6.1) packages. Plyr (1.8.4) and ggplot2 (2.2.1) were used to produce the graphs.

Colony clustering

Each 300 m river section in the observed datasets, described above, was assigned an arbitrary value (cluster index) based on the presence or absence of a colony (across all surveyed breeding seasons) within the river section being assessed and both of its adjacent river sections (Table 2). We also explored grouping the data into triplets, in which the presence/absence of colonies in each of the three river sections dictated the arbitrary cluster index value, rather than relating it to the river section being assessed. While this approach yielded similar results, it appeared to contribute less value

Table 2. The protocol for assigning cluster index values to river sections based on the presence (O) or absence (X) of colony locations in both the central and neighbouring river sections.

Neighbouring river section	Central river section	Neighbouring river section	Cluster index
X	X	X	0
X	X	O	1
O	X	X	1
O	X	O	2
X	O	X	3
O	O	X	4
X	O	O	4
O	O	O	5

from a management perspective, as you were unable to distinguish between areas of repeated colony use and those which were separated by river sections which had never had a colony establish. The cluster index values assigned to the first and last river sections on a river were excluded from the analysis. The mean frequency of cluster index values was calculated for each rivers' mean colony distribution. A 2x3 contingency table was used to analyse the mean frequency of clustering of the colony location data for each river. A Chi-square test of independence or Fisher's exact test (if there were less than five data points in the contingency table) was used to test for significant differences (P < 0.05) between the probability of having a colony

present in a neighbouring river section based on the presence or absence of a colony in the section being assessed. Analyses were conducted in R using the packages referenced above.

RESULTS
Colony distribution

The observed frequency distribution of black-fronted tern colonies was not significantly different to the expected distribution generated through random selection for seven of the nine rivers analysed. The Ashley (χ^2=68.095, P=0.003) and Tasman (RHS χ^2=44, P=0.013, LHS χ^2=66, P=0.016) Rivers were the exceptions, with their distributions differing significantly from the frequency distribution expected from random selection. Although nonsignificant, a further six rivers shared the trend that river sections, in which colonies were not observed, and those in which colonies were most frequently observed, occurred more than expected at random (Fig. 1). Main breeding areas (a river section in which the greatest colony frequency was recorded) were used for breeding in 30–100% (x=57.5±5.7% SE) of the breeding seasons recorded (Table 3). All rivers contained 1–2 main breeding areas in their surveyed lengths.

Colony clustering

Clustering of black-fronted tern colonies was significant for only two of the nine rivers analysed, the Ashburton (P=0.03) and Rakaia (P=0.02) Rivers. In these two rivers, if a colony in the central river section, it was significantly more likely that a colony would be present in the neighbouring river sections and vice versa. Although nonsignificant, this trend was consistent for the other seven rivers.

DISCUSSION

Black-fronted terns demonstrated low breeding-site fidelity. Only two of nine rivers had a spatial colony distribution significantly different to that expected due to random selection, indicating that black-fronted terns do not demonstrate strong tendencies to return to the same breeding locations from season to season. This is further supported by the lack of significant clustering of breeding locations in seven of the nine. Our *a priori* prediction was that black-fronted terns would exhibit low breeding-site fidelity because of the instability of their braided river breeding habitat (McNicholl 1975; Switzer 1993) and generally poor breeding success (Keedwell 2002, 2003; Anderson *et al*. 2007). Low breeding-site fidelity indicated by these results is comparable to that found in other marsh terns, i.e. black (*Chlidonias niger*), whiskered (*C. hybridus*) and white-winged black terns (*C. leucopterus*). Low

Table 3. Black-fronted tern use of main breeding areas (river section in which the greatest frequency of black-fronted tern breeding was recorded) in each river (listed north to south).

River	No. of seasons main breeding areas used	% of seasons main breeding areas used	No. of main breeding areas
Wairau	3	60.0	2
Waiau (Canterbury)	3	100.0	1
Hurunui	3	60.0	2
Ashley-Rakahuri	7	58.3	1
Rakaia	2	66.7	2
Ashburton	3	50.0	1
Lower Rangitata	2	50.0	2
Tasman LHS	5	50.0	1
Tasman RHS	3	30.0	1
Dart	2	50.0	2
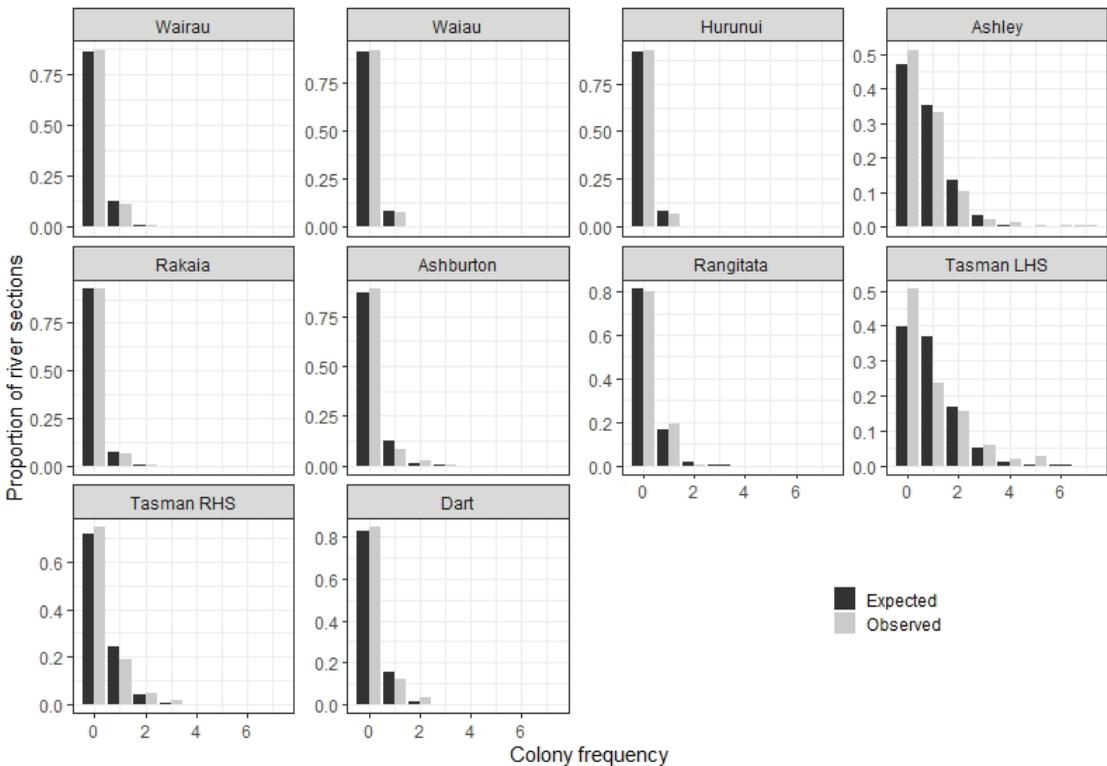
Figure 1. Observed (light grey) and expected (black) proportion of river sections containing different colony frequencies (number of colonies per river section).

breeding-site fidelity in other *Chlidonias* terns has been attributed to habitat instability, with year-to-year variability in vegetation, water levels and suitable nest site availability forcing changes in breeding colony locations (Shuford 1999; Ledwoń

et al. 2013).

Environmental conditions, predation events and experience may disrupt the connection of the terns to their breeding colony locations causing them to choose new sites. It may be that the terns

intend to return to the colony location from a previous year, but changes to river condition render it unsuitable (e.g. covered in vegetation). Past black-fronted tern breeding colony locations could easily become unsuitable from one season to the next due to changes in the river channels, weed invasion or island erosion. Rather than persisting in sub-optimal habitat the terns move to a more suitable location (but often close by the previous colony site). Burger (1984) found this to be the case for least terns. Least terns were observed returning to their previously used colony sites, but would abandon it if it was deemed unsuitable (Burger 1984). Alternatively, black-fronted terns are returning to a region that offer good breeding prospects (e.g. good food supply) and are then randomly locating colonies in any suitable habitat in that zone. For either option, strong breeding-site fidelity without the ability to cue of environmental factors (colony site factors, or wider factors, such as food supply) would likely be highly disadvantageous for black-fronted terns.

The stability of a breeding site is only one of several factors that may contribute to breeding site selection; past breeding success, colony size and predation rates have also been linked to breeding-site fidelity (Burger 1982; Switzer 1993; Keedwell 2002; Lombard *et al*. 2010). However, the increased breeding-site fidelity linked to high chick survival found by Keedwell (2002) is one of very few studies have investigated these factors in relation to potential breeding-site fidelity in black-fronted terns. Further investigation of these factors may contribute substantially to more targeted and effective management of black-fronted terns.

Greater use of colony locations in rivers or river sections that remain stable and suitable for extended time frames is expected. The 'main colony sites' presented by Keedwell (2002) appear to support the reuse of stable sites. She monitored eleven colony sites, of which three were used in all four years of the study and five for three years leading to the suggestion that there were sites where the terns nested more consistently (Keedwell 2002). Bell (2017) also found that black-fronted terns tended to consistently breed in river areas, sometimes on the same islands. These trends were seen in colony distributions in the Ashley and Tasman rivers and were significantly different to a random distribution. These two rivers also had the longest survey records of ten and twelve years, respectively, and had long-term programs of predator control in place. It may take extended periods of surveying to be able to identify these preferred locations over those that may be used for two or three seasons before being abandoned. For example, in the Waiau River, a colony has been recorded on the large and relatively stable gravel beds near the Shark's Tooth for all three surveyed years, and anecdotally is referenced to have been present at this location most years. However, overall the colony distribution was not different to random and the presence of clustering was not significant. It is possible that the movement of colony locations in other, more dynamic areas of the river may have impacted on the significance of the reuse of the Shark's tooth location.

Tern Island, a 300 m long island in the Upper Ohau River, is another example of the repeated use of stable, suitable colony locations by black-fronted terns. Data from the Tern Island colony were not included in the current analysis as the data were not collected as part of a full survey. Tern Island has had a black-fronted tern breeding colony for more than 10 (and possibly up to 25) successive breeding seasons prior to 2017. The Upper Ohau River is relatively stable because its flow has been artificially stabilised since 1991, reducing natural fluctuations in flow and the frequency and size of flooding events, and this in turn has allowed the continued existence of Tern Island beyond the life of the average braided river island. In addition, Tern Island was the focus of an intensive "best effort" predator control project by Project River Recovery (Anderson & Woolmore 2009). Tern Island appears to be an example of how greater habitat stability and protection from predation can facilitate repeated use of black-fronted tern colony locations. It also demonstrates that this species is capable of high breeding-site fidelity if the environment is stable.

Interpretation of the GPS colony location data may be complicated by the lack of a standard protocol for the collection of GPS colony data, and GPS location inaccuracies may result in some error around the actual location of colonies. Generation of a standard protocol for the collection of colony GPS locations would facilitate a more accurate interpretation of colony dynamics data in the future. In the current study, broad (300 m) river sections were used to generalise the colony GPS locations and reduce the influence any error in the data.

Our ability to interpret the results is limited because we were unable to determine whether the same terns are returning to these clustered colony locations, or whether different groups of terns were attracted to the clustered colony locations each year because of some general environmental factor (e.g. suitable habitat or a food source). However, the dynamic nature of the braided river environment dictates that the location of 'ideal' habitat or a food source will most likely change dramatically from one breeding season to the next. Therefore, factors associated with site fidelity seem more likely to be the reason for the regional clustering of colony locations observed. Further research using individual marking is required to determine the importance of site fidelity in determining black-fronted tern colony dynamics.

Black-fronted terns are confronted with a relatively dynamic and unstable environment that has been linked to low breeding-site fidelity in other tern species (Gummer 2003; Palestis 2014). Analysis of historical black-fronted tern colony locations supports our *a priori* hypothesis of low breeding-site fidelity. The instability of their braided river habitat likely forces the terns to change colony sites in response to environmental cues. Black-fronted terns may exhibit greater fidelity to breeding colony locations that remain suitable, an unusual occurrence in this ecosystem type, such fidelity is supported by other studies by Keedwell (2002) and Rebergen & Woolmore (2016). Additionally, tools such as social attraction, may be used to facilitate the establishment or re-establishment of black-fronted tern colonies in 'safe' locations (Hamblin 2017). It may be possible to explicitly test the link between an unstable environment and low site fidelity if each section of river can be ranked in terms of stability. From this likelihood models can be developed to predict whether colonies will remain in the same relative position from year to year. Greater consistency in the location of black-fronted tern colonies would substantially increase the efficiency and effectiveness of their management, particularly in determining which sites to invest in managing weeds and predators.

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