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Population size, breeding success and predators of black-fronted tern (*Chlidonias albostriatus*) in the Upper Clarence River catchment, New Zealand

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Abstract Breeding success of the endemic black-fronted tern (*Chlidonias albostriatus*) and the identity of predators was studied in the upper Clarence and Acheron Rivers (Molesworth Recreation Reserve), South Island, New Zealand in the 2012, 2013 and 2014 breeding seasons. The catchment supports a nationally and therefore internationally significant population of over 720 breeding birds. A combined total of 1,510 nests were monitored over 3 seasons. Breeding success was poor with only 42.7% of nests hatching at least 1 egg, and average productivity of only 0.13 chicks fledged/nest. Breeding success varied between years and rivers, primarily due to differing predation rates. Predation and nest abandonment following nocturnal predator disturbance were the primary causes of nest failure. A total of 110 filmed predation events at nests identified ferret (*Mustela furo*), feral cat (*Felis catus*) and hedgehog (*Erinaceus europaeus*) as the main predators. Following a beech and tussock masting event, predation by ship rats (*Rattus rattus*) was significant in 2014. This is the first time predator increases following mast seeding has been shown to impact braided river birds. In contrast, avian predation was low and varied across rivers. Productivity was higher in large colonies (>25 nests) than small colonies, and in early colonies (colony formation before 31 October). A management programme to improve black-fronted tern productivity has been initiated given the national importance of this population, the ease of access to these colonies, and the identification of the invasive predators responsible for current levels of poor breeding success.

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Keywords black-fronted tern; *Chlidonias albostriatus;* Clarence River; Acheron River; breeding success; predation; introduced mammals; ferret; hedgehog; feral cat; mast seeding

INTRODUCTION

The black-fronted tern (*Chlidonias albostriatus*) is endemic to New Zealand and only breeds on the gravel-bed rivers of the eastern South Island from Marlborough to Southland, and a few Buller and Westland rivers. In the non-breeding season, birds disperse to coastal areas, including those on the North Island (Higgins & Davis 1996; Checklist Committee 2010). Most of New Zealand's endemic Charadriiformes species are currently threatened, including 5 of the 6 species breeding in braided river habitats. Black-fronted terns are classed as Nationally Endangered under the New Zealand Threat Classification system (Robertson *et al.* 2017) and the national population size is estimated at 10,000 birds or less (O'Donnell & Hoare 2011). Predation and disturbance by introduced mammalian predators is the major cause of decline in black-fronted tern populations (Dowding & Murphy 2001; Murphy *et al.* 2004); with predators reducing breeding success, by lowering hatching success and therefore productivity (Keedwell 2005; O'Donnell & Hoare 2011; Cruz *et al.* 2013).

A range of mammalian predators of black-fronted tern have been identified, including feral cat (*Felis catus*), ferret (*Mustela furo),* hedgehog

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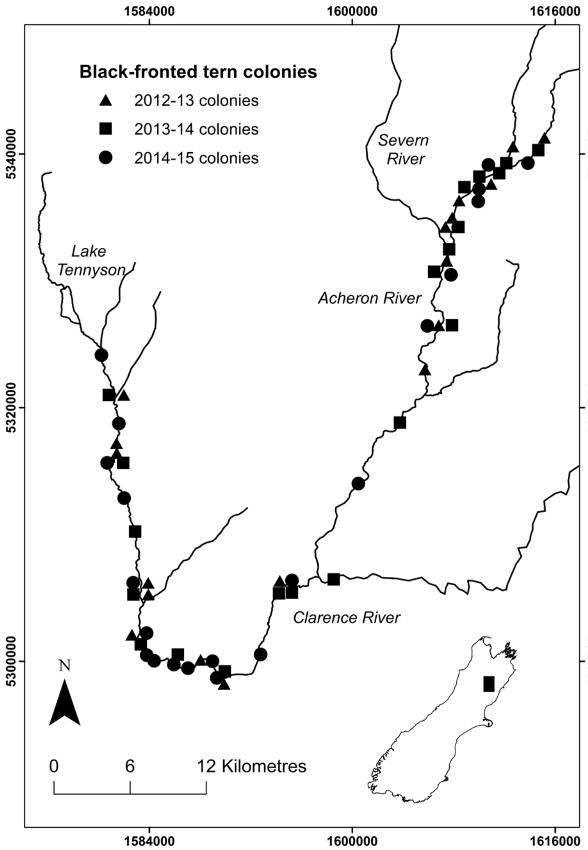
Fig. 1. Location of black-fronted tern colonies recorded in the upper Clarence catchment during the 2012, 2013 and 2014 breeding seasons.



(*Erinaceus europaeus*), stoat (*Mustela erminea*), Norway rat (*Rattus norvegicus*) and ship rat (*R. rattus*). In addition, several avian predators have also been identified, such as swamp harrier (*Circus approximans*), black-backed gull (*Larus dominicanus*) and South Island pied oystercatcher (*Haematopus finschi*) (Keedwell 2005; Steffens *et al.* 2012). The relative importance of predators can vary by site so the local predator guild needs to be considered when implementing a predator control regime (Steffens *et al.* 2012).

The black-fronted tern is predicted to decline to extinction without urgent management (O'Donnell & Hoare 2011). Unfortunately, no consistently effective predator-control regime has been developed that is specifically aimed at the management of black-fronted terns (O'Donnell & Hoare 2011, Cruz *et al.* 2013). However, effective control has been achieved in the Eglinton River by controlling stoats (O'Donnell & Hoare 2011) and in the Ohau River by controlling a range of mammalian predators (Anderson & Woolmore 2014). Following the discovery of significant numbers of black-fronted terns in the upper Clarence River catchment in 2011, studies were initiated to determine: (i) breeding population size, (ii) breeding success rates, and (iii) predator identity, with the aim of developing a viable management programme. This paper reports the results of those studies.

MATERIALS AND METHODS

The study site included two reaches within the upper Clarence catchment, inland Marlborough: (1) 'upper Clarence River', which comprises the upper Clarence River from the gorge (above the Dillion River confluence) to Lake Tennyson; and (2) 'Archeon River', which comprises the full reach of the Acheron River (Fig. 1). Birds breeding on the lower reaches of the Saxton River, which drains into the Acheron were included as part of the Acheron River tern counts. Although terns were known to breed on the Severn River, breeding success and predator identity were not measured there. The entire study area is within the Molesworth Recreational Reserve, and is grazed by cattle

Table 1. Number of active black-fronted terns nests during peak breeding, Acheron and upper Clarence Rivers.

River	2012	2013	2014
Acheron	202	209	149
Upper Clarence	177	151	154
Total	379	360	303

managed by Landcorp New Zealand under a lease agreement with the Department of Conservation.

The study was conducted during 3 breeding seasons (2012, 2013 and 2014), with field work starting on 15 October and continuing until 10 January each season. Nest monitoring of black-fronted terns was similar to methods used by Keedwell (2005). Nests were marked with a small stone cairn 1-2 m upstream and the position recorded on a handheld GPS. Colonies were visited 2-4 times a week to monitor breeding activity and locate new nests. Nests were monitored until eggs hatched and chicks moved beyond the nest area, or the nest failed. As nestlings are semi-precocial, fledging success was determined by banding chicks 1-3 days after hatching and before chicks left the nest area. During subsequent monitoring visits to colonies, all chicks encountered were checked for bands. Only after multiple visits with no identification of an individual banded chick was it assumed to have died.

Infra-red video monitoring recorded the outcomes of a sub-set of nests. Methods were similar to those used by Sanders & Maloney (2002) and Steffens *et al.* (2012); however, Ltl Acorn 5210A trail cameras were used in the current study. These were set up 2-3 m from nests on low (50 cm high) wooden stands held in place with river stones. Cameras were motion activated and were programmed to record a 10-20 second video clip when triggered and then to not record again for a further 60 seconds. Videos were stored on a 16 gigabyte SD card. At these settings, data from a period of 4-6 days could be recorded, although cameras were usually checked every 2-4 days. Cameras were set at nests with eggs. Following predation or hatching, cameras were shifted immediately to a new nest. A total of 10, 20 and 40 cameras were used 2012, 2013 and 2014 respectively.

Breeding population size was determined by calculating the number of active nests and recently preyed on nests (those preyed on <5 days previously, in which the birds would not have had time to re-nest) on November 30, which was determined to be peak breeding in all years.

Statistical tests were carried out on the parameters collected using the data analysis functions in Microsoft Excel.

RESULTS

Breeding population size and distribution

A count of active nests at peak breeding (last week in November) in 2012 recorded a total of 379 nests, which declined to 303 nests by 2014. The number of nests in the upper Clarence River declined from 177 in 2012 to 154 in 2014, and in the Acheron River from 202 to 154 (Table 1).

During the 3 seasons, a total of 59 colonies were followed, with an average of 25.6 nests (range = 1-60) per colony (Fig. 1). Black-fronted tern breeding occurred in similar sections of each river in successive seasons, and often colonies formed on the same islands within the rivers (Fig. 1).

Breeding success

A total of 1,510 breeding attempts were followed, comprising 568 in 2012, 508 in 2013 and 434 in 2014 (Table 2). Similar numbers of nests were monitored on both the Acheron River (800 nests) and the upper Clarence River (710 nests), although the numbers followed on each river changed annually (Table 2).

Hatching success was low (Table 2), with only 42.7% of nests hatching at least 1 egg. Hatching success was significantly different between the 3 seasons ($\chi^2 = 6.4395$, $P = 0.03996$; Chi-square test), with lower hatching success in 2012 (39.4%, $n = 568$) than in 2013 (47.1%, $n = 508$) and 2014 (42.2%, $n = 434$). Overall, hatching success was significantly higher on the Acheron River (47.5%, $n = 800$; $\chi^2 = 6.125$, $P = 0.0133$; Chi-square test) than the upper Clarence River (39.4%, $n = 710$).

Predation was the primary cause of nest failure during incubation, with 37.6% of nests preyed upon (Table 2). There was a significant difference in levels of predation between years ($\chi^2 = 10.8507$, $P = 0.0044$; Chi-square test), with more nests, and a higher percentage of nests, preyed upon in 2013 (43.3%) than in 2012 (34.9%) and 2014 (34.3%). When results from all years were pooled, there was no significant difference in predation rates between the Acheron River (35.4%, $\chi^2 = 3.4313$, $P = 0.0639$; Chi-square test) and the upper Clarence River (40.0%). Nest abandonment (14.8% of all nests), flooding (2.6%), eggs failing to hatch (2.0%), and trampling of nests by stock (0.5%) also contributed to nest failure (Table 2).

When combining all years, productivity was very low with only 0.13 chicks fledged/nest (Table 2). There was no significant difference in productivity between seasons ($\chi^2 = 0.857$, $P = 0.651$; Kruskal-Wallis test). Further, there was no significant difference in

Table 2. Hatching success, fledging success and cause of nest failure during incubation of black-fronted tern nests in the upper Clarence and Acheron rivers, 2012-2014.

Year	River	Nests	Cause of nest failure					Hatched	Chicks fledged (chicks/nest)
			Preyed upon	Abandoned	Flooded	Failed to hatch	Trampled		
2012	Acheron	291	102 (35.0%)	56 (19.2%)	20 (6.9%)	6 (2.1%)	0	107 (36.8%)	14 (0.05)
	Upper Clarence	277	96 (34.7%)	35 (12.6%)	17 (6.1%)	10 (3.6%)	2 (0.7%)	117 (42.2%)	86 (0.31)
	Sub total	568	198 (34.9%)	91 (16.0%)	37 (6.5%)	16 (2.8%)	2 (0.4%)	224 (39.4%)	100 (0.18)
2013	Acheron	294	117 (40.0%)	20 (6.8%)	0	7 (2.4%)	0	152 (51.7%)	34 (0.12)
	Upper Clarence	214	103 (48.1%)	23 (10.8%)	1 (0.5%)	0	0	87 (40.7%)	8 (0.04)
	Sub total	508	220 (43.3%)	43 (8.5%)	1 (0.2%)	7 (1.4%)	0	239 (47.0%)	42 (0.08)
2014	Acheron	215	64 (29.8%)	38 (17.7%)	1 (0.5%)	3 (1.4%)	2 (0.9%)	107 (49.8%)	34 (0.16)
	Upper Clarence	219	85 (38.8%)	52 (23.7%)	0	4 (1.8%)	3 (1.3%)	76 (34.7%)	24 (0.11)
	Sub total	434	149 (34.3%)	90 (20.7%)	1 (0.2%)	7 (1.6%)	5 (1.4%)	183 (42.2%)	58 (0.13)
Total		1510	567 (37.6%)	224 (14.8%)	39 (2.6%)	30 (2.0%)	7 (0.5%)	646 (42.8%)	200 (0.13)

productivity between rivers (Z = -0.218, P = 0.827; Mann-Whitney U test).

Overall hatching success was positively correlated to colony size (Fig. 2; r = 0.388, P = 0.0049; Pearson correlation), with hatching success significantly higher within colonies of >25 nests (mean colony size) (44.8%, n = 27; χ^2 = 6.315, P = 0.012; Chi-square test) than colonies of ≤25 nests (30.8%, n = 24). Productivity was also positively correlated to colony size (Fig. 3; r = 0.312, P = 0.026; Pearson correlation), with significantly higher productivity in colonies >25 nests (0.18 chicks/nest, n = 27; Z = 2.66, P = 0.007; Mann-Whitney U test) than in colonies of ≤25 nests (0.04 chicks/nest, n = 24).

Hatching success was not correlated with colony start date (Fig. 4.; r = -0.105, P = 0.424; Pearson correlation), with early colonies (where laying started on or before 31 October) having similar hatching success (37.5%, χ^2 = 2.75, P = 0.09; Chi-square test) to late colonies (after 1 November; 31.4%, n = 21). However, productivity was negatively correlated to colony start date (Fig. 5; r = 0.344, P = 0.0076; Pearson's correlation); early colonies had significantly higher productivity (0.14 chicks/nest, n = 38, Z = -2.306, P = 0.021; Mann-Whitney U test) than late colonies (0.03 chicks/nest, n = 21).

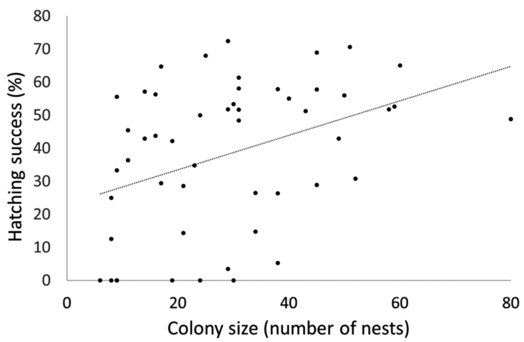


Fig. 2. Percent hatching success in relation to colony size of black-fronted tern colonies in upper Clarence catchment during the 2012, 2013 and 2014 breeding seasons.

Predator identification

Trail cameras recorded predation events at 110 nests (13 in 2012, 34 in 2013 and 63 in 2014; Table 3). Mammalian predators were the most common nest predator, with ferrets the most frequently observed predator (39 predation events, 35.5% of all recorded events; Table 3). The next most common predators were hedgehogs (21 events, 19.1%), feral cats (19

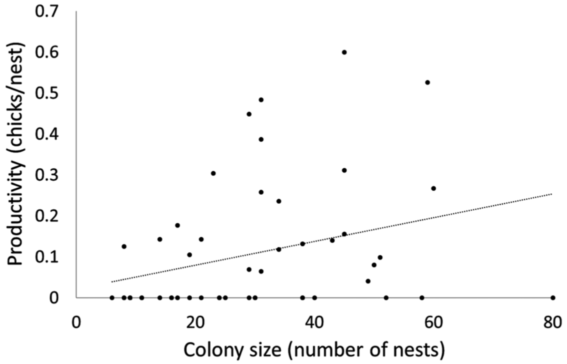


Fig. 3. Productivity in relation to colony size of black-fronted tern colonies in upper Clarence catchment during the 2012, 2013 and 2014 breeding seasons.

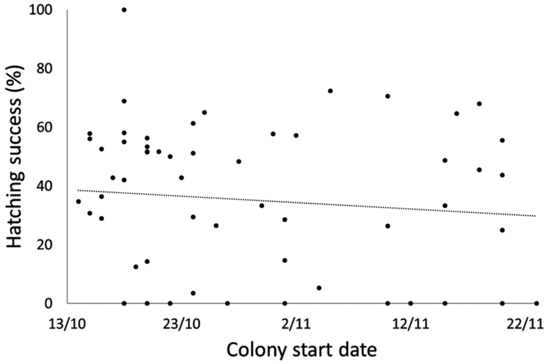


Fig. 4. Hatching success in relation to colony start date of black-fronted tern colonies in upper Clarence catchment during the 2012, 2013 and 2014 breeding seasons.

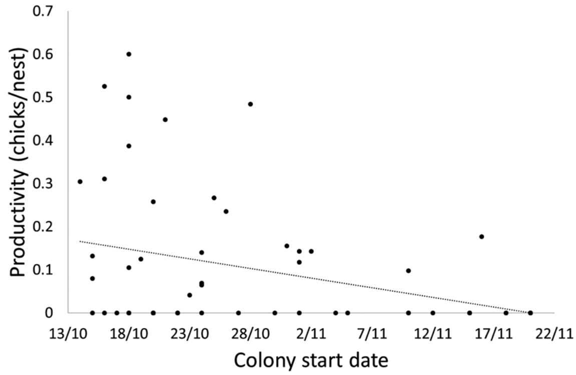


Fig. 5. Productivity in relation to colony start date of black-fronted tern colonies in upper Clarence catchment during the 2012, 2013 and 2014 breeding seasons.

events, 17.3%) and ship rats (14 events, 12.7%), although ship rats were only recorded preying on nests in 2014 (Table 3). Stoats were only recorded preying on 2 nests, and a hare (*Lepus europaeus*) was filmed consuming eggs at one nest. Avian predators included swamp harrier, South Island pied oystercatcher, banded dotterel (*Charadrius bicinctus*), black-backed gull and even black-fronted tern were recorded taking eggs from nests (Table 2).

All predators recorded approaching nests preyed on the nest. However, in addition to recording predation events, trail cameras recorded at total of 16 nest abandonment following nocturnal disturbance. Terns were flushed off their nest at

Table 3. Predators recorded at black fronted tern nests using infrared videos on the Acheron and upper Clarence rivers; 2012 (10 cameras), 2013 (20 cameras) and 2014 (40 cameras) breeding seasons.

Predator	2012	2013	2014	Total
Ferret	5	19	15	39 (35.5%)
Hedgehog	3	4	14	21 (19.1%)
Feral cat	3	7	9	19 (17.3%)
Ship rat			14	14 (12.7%)
Stoat	1		1	2 (1.8%)
Hare	1			1 (0.9%)
South Island pied oystercatcher		1	2	3 (2.7%)
Banded dotterel		1	2	3 (2.7%)
Harrier		2		2 (1.8%)
Black-fronted tern			2	2 (1.8%)
Cattle (trampling nest)			2	2 (1.8%)
Black-backed gull			2	2 (1.8%)
Total	13	34	63	110

Table 4. Cause of nest abandonment following nocturnal disturbance recorded at black-fronted tern nests using infrared videos on the Acheron and upper Clarence rivers; 2012, 2013 and 2014 breeding seasons.

Cause	2012	2013	2014	Total
Cattle	2	1	1	4
Deer			2	2
Hare	1	1	2	4
Rabbit	3	1	2	6
Total	6	3	7	16

night by either rabbits, hare, cattle or red deer, and never returned to resume incubation (Table 4).

No video footage was recorded showing chick predation as chicks quickly move away from nests, but black-backed gulls were observed taking chicks at 4 colonies. In addition, a feral cat was observed walking through a colony with chicks. Cat and ferret tracks were regularly recorded in colonies, and it is assumed that both of these predators prey on black-fronted tern chicks.

DISCUSSION

The population of black-fronted terns on the upper Clarence catchment is internationally significant, with over 720 birds present, thereby making it one of the largest populations in the country and containing an estimated 7% of the world population (O'Donnell & Hoare 2011). Unfortunately, there are no comparative counts in other years to determine population trends, with previous counts from the Clarence River only including the lower reaches below the gorge (Hallas 2003).

The breeding distribution of black-fronted tern in the upper Clarence catchment has been similar each season; with colonies found in the same sections of river in successive seasons, and often on the same islands within the river. This suggests that black-fronted tern are showing some degree of site fidelity, although this aspect of the birds behaviour requires further study.

Hatching success was low and varied between seasons and colonies. This is similar to other studies on black-fronted tern which also recorded an overall low hatching success with high variability between years (Keedwell 2005; Cruz *et al.* 2013). Fledging success was particularly low, with productivity of 0.13 chicks fledged/pair. This was somewhat lower than the productivity of 0.23-0.34 chicks fledged/nest recorded by Keedwell (2005). Keedwell *et al.* (2002) found that predation continued until birds dispersed from the natal colony; consequently, overall reproductive success is likely to be even lower than what we report here (fledging success) as fledglings will continue to be preyed upon until they disperse from colonies.

Breeding success was low primarily due to high predation rates. The variation observed between colonies probably reflects localised predator abundance and/or predator behaviour (e.g. single predators targeting colonies). Keedwell (2005) reported predators as the most significant cause of nest loss; however, Cruz *et al.* (2013) found hatching success was not influenced by overall predator abundance. Single individual predators are known to cause significant impacts at black-fronted tern colonies (Keedwell 2005; Steffens *et al.* 2012; O'Donnell *et al.* 2012; Cruz *et al.*2013), and these likely operate independently of predator abundance. Nocturnal predators have a greater impact than just predation, as we recorded nest abandonment following nocturnal disturbance. Keedwell (2005) found that nest desertion often follows nocturnal disturbances and rates can be high.

A range of predators were identified at black-fronted tern nests, with ferrets, feral cats and hedgehogs being the most common. In 2014, predation by ship rats was high; following a rat eruption likely caused by a beech and tussock mast seeding event (King 2005). This is the first time data has suggested a braided river species has been impacted by an increase in predator numbers following mast seeding. Seasons with predator eruptions will further reduced breeding productivity accelerating population declines of braided river birds. This study adds to the growing body of evidence that introduced mammalian predators are the primary cause of population declines of native birds recorded on most rivers in the country (O'Donnell & Hoare 2011). However, the relative importance of predators can vary and this needs to be considered when implementing a predator control regime (Steffens *et al.* 2012). Although these results are similar to other studies implicating introduced mammalian predators (Sanders & Maloney 2002; Keedwell *et al.* 2002), another study on the Wairau River determined avian predators to be the most significant egg predator (Steffens *et al.* 2012), showing that avian predator pressure can vary among rivers or over time.

Some predators appear opportunistic and relatively unimportant. Although DeGraaf (1995) recorded snowshoe hares (*Lepus americanus*) predating artificial eggs in northern hardwood forests, hares are likely to be only occasional chance predators of ground nesting birds in New Zealand. Oystercatchers have been recorded preying on nests, and banded dotterel pecking abandoned tern eggs (Steffens *et al.* 2012; Sanders & Maloney 2002). The results of the current study confirm that oystercatchers are a minor egg predator on the braided rivers in the upper Clarence catchment, and that banded dotterel opportunistically feed on abandoned eggs there.

Breeding success was correlated to colony size, with larger colonies more productive than smaller ones. Keedwell (2005) found colony size did not affect breeding success of black-fronted terns, but improved productivity with increasing colony size has been recorded for similar *Sterna* species (Morris *et al.* 1976). Furthermore, early colonies were more productive than later colonies; which has also been recorded from other studies on *Sterna* species (Burger *et al.* 1996; Arnold *et al.* 2004). Larger colonies may have reduced nest abandonment and spread predation risk; either from having nests spread across a wider area where individual birds find semi-protected sites, or by providing some form of protection from the impacts of predators, for example black-fronted terns have been observed mobbing avian predators. Further, larger colonies which start being successful, may attract birds failed from other colonies, leading to a further increase in colony size. As black-fronted tern populations continue to decline, colony size is also likely to decline, potentially further accelerating population declines.

Molesworth Station is administered by the Department of Conservation with a grazing lease held by Landcorp New Zealand. This site favours management given its relatively simple land tenure combined with road access, a nationally significant population, low black-fronted tern productivity and our knowledge of predator identity gained from this study. As a result, a management programme combining predator control and habitat enhancement has been initiated on the Upper Clarence River to improve the breeding success of black-fronted tern.

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