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**Colony dynamics and social attraction in black-fronted terns,
*Chlidonias albostratus***

A thesis
submitted in partial fulfilment
of the requirements for the Degree of
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at
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by
Courtney H. Hamblin

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Courtney H. Hamblin

Black-fronted terns (*Chlidonias albostratus*) are 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, primarily due to predation. Unlike many other endangered species in New Zealand, black-fronted terns cannot be translocated to offshore, predator-free islands as braided river habitat exists only on the mainland. Currently, predator control, at varying scales, and habitat enhancement are the primary management strategies for black-fronted terns, neither of which have proven more than locally effective at reversing current population declines. Effective black-fronted tern management is challenging, not only due to the dynamic and unpredictable nature of the braided river environment, but also the behaviour of the terns themselves. Black-fronted terns frequently change their breeding colony locations both within and between years. The current research aimed to investigate black-fronted tern colony dynamics, and determine the viability of social attractants as a tool for black-fronted tern conservation.

The location and size of black-fronted tern breeding colonies have been recorded from braided river bird surveys conducted over 13 years (2004-2015). Black-fronted terns are believed to have low site-fidelity due to the instability of their breeding habitat, small colony sizes and exposure to high predation rates. Two out of nine rivers analysed had colony distributions significantly different to random, a further two rivers had significant clustering of colony locations. Although the clustering was only significant in two rivers, the trend of clustering was consistent across all rivers analysed. There was no overall trend between colony size and the proximity of colonies in the previous or following seasons. Overall, these results support our a priori hypothesis of low site-fidelity in black-fronted terns, although, consistent clustering and spatial distribution trends suggest that they may exhibit greater fidelity to sites which remain suitable.

Social attractants, decoys and audio playback, were deployed at ten sites within nine Canterbury braided rivers in the 2016 breeding season. We found that the terns interacted significantly ($P < 0.001$) more with the social attractants compared to the control plots (social attractants absent). Differences in tern interactions observed could not be explained by the differences in habitat between the experimental plots. Nearest tern breeding was recorded for eight of the ten sites, with five of these nesting records occurring within 300 m of the experimental plots. These results suggest that social attraction has the potential for use in black-fronted tern conservation. However, further research is required to determine the most attractive social attractant set up and whether the attractants can influence tern breeding colony locations. Camera traps were also trialled, recording tern behaviour at the experimental plots. At this stage, camera traps are not recommended as a replacement for human observation.

Keywords: Black-fronted tern, *Chlidonias albobriatus*, social attraction, colony dynamics, decoys, audio playback, site fidelity, braided rivers, Canterbury.

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Chapter 1

General Introduction



Black-fronted tern in flight (C. Hamblin)

The black-fronted tern (*Chlidonias albostrigatus*) is one of four species in the *Chlidonias* genus, commonly known as the marsh terns. The black tern (*C. niger*), white-winged black tern (*C. leucopterus*) and whiskered tern (*C. hybrida*) make up the other three marsh tern species. The black-fronted tern is an endemic New Zealand species whose small, declining population has resulted in their classification as an endangered species in 2000 (Birdlife International 2012, Robertson et al. 2012). The current black-fronted tern population is around 5,000-10,000 mature individuals, and was estimated to be 8,325 in 2011 (O'Donnell and Hoare 2011). Accurate estimates of the black-fronted tern population are difficult to obtain due to the difficulty of national surveying. Population declines have been observed in many rivers where black-fronted terns breed. In the Ashburton river, the black-fronted tern breeding population declined from >750 birds to approximately 200 in a nine year period (1981-1990) (Taylor 2000, O'Donnell and Hoare 2011). O'Donnell and Hoare (2011) estimated that if current trends continue, the black-fronted tern population would decline by 50% in the next three generations, with some at risk sub-populations predicted to face a 90% decline in the same time frame.

Black-fronted terns are small, grey terns with a black cap, bright orange bill and legs. In full breeding plumage the black cap extends from the bill to nape with a white line at the lower border. Outside of the breeding season this changes to flecking around the eyes and nape (Lalas and Heather 1980). Juveniles and immature individuals appear similar to non-breeding birds with flecking, although the bill colour is often a darker red/brown (Lalas and Heather 1980). Most terns will have moulted by May and all breeding birds are in full breeding plumage as they return to their breeding grounds from June to early November.

Black-fronted terns breed almost exclusively in gravel braided riverbeds. Braided rivers are highly complex gravel-bed systems, characterised by a dynamic mosaic of channels, bars, islands and ponds (Tockner et al. 2006). The dynamic nature of braided river environments generate a diverse range of habitats, allowing them to support equally diverse communities of flora and fauna (Robinson et al. 2002). Today, braided rivers are among the world's most endangered ecosystems as extensive anthropogenic modification has converted many of them into single-channel rivers (Tockner et al. 2006). Few braided rivers have avoided significant modification and retain their highly dynamic, natural state. These relatively unmodified rivers are concentrated in the extreme northern reaches of Alaska, Canada and Eurasia, as well as in New Zealand (Gray and Harding 2007).

New Zealand's braided rivers represent a significant proportion of the global braided river ecosystem without substantial anthropogenic modification (Gray and Harding 2007). New Zealand contains 307 rivers with braided sections, encompassing more than 250,000 ha in total area (O'Donnell and Hoare 2011). The majority of New Zealand's braided rivers are concentrated on the east coast of the South

Island. Black-fronted tern breeding populations are similarly concentrated in the eastern South Island with strongholds in the Canterbury and Southland regions (O'Donnell and Moore 1983, Taylor 2000, O'Donnell and Hoare 2011). Smaller numbers are also found in Nelson, Buller and the West Coast. Historically, black-fronted terns were far more abundant and widespread, breeding across the Canterbury plains (Hughey 1985), in the North Island (Sibson 1948, Taylor 2000), and at altitudes of up to c. 1,720m in Central Otago (Child 1986).

Outside of the breeding season, black-fronted terns migrate to coastal regions. They begin their migration in late December through February, with the last birds leaving by May (Lalas 1979, Robertson et al. 1983). Their migrations follow a general northward trend, with populations found overwintering as far north as the Hawkes Bay, the Bay of Plenty and Kaipara harbour (Taylor 2000), although some terns will migrate as far south as Stewart Island (O'Donnell and Moore 1983). In late July to early August, black-fronted terns return to breed in braided rivers, with populations peaking in September (Lalas 1979). Migration is one adaptation that black-fronted terns have to survive in the highly dynamic braided river environment. Migrating to the coasts allows the terns to avoid the harsh winter conditions and limited food availability.

1.1 Black-fronted tern breeding biology

Black-fronted terns breed in small, dispersed colonies. Colonies generally contain less than 50 nests with inter-nest distances up to 100 m, and a mean of 0.4 nest/100 m² (Higgins and Davies 1996, Bell 2013). This is consistent with the general trend among terns; smaller species, like the black-fronted tern, tend to have more dispersed colonies compared with larger terns, which may have inter-nest distances of <3 m (Steele et al. 2009).

The dispersed nature of black-fronted tern colonies contrasts with another colonially breeding, braided river specialist, the black-billed gull (*Larus bulleri*). Black-billed gulls nest in very dense colonies (mean inter-nest distances of 49 cm), most often located on high points of braided river islands where they have some protection from flooding events (Beer 1966, Hughey 1985, McClellan 2009). The black-fronted tern colonies, often covering a range of potential nest heights, appear to be more vulnerable to flooding. In the Rangitata River, Hughey (1985) found that flood events capable of destroying some nests in a black-fronted tern colony, resulted in complete destruction of the colony in almost all cases. Nesting on high points of braided river islands appears to be advantageous for colonial species breeding in this environment. The black-fronted terns contrasting strategy may indicate that they are not braided river specialists, rather restricted generalists.

The factors driving black-fronted tern breeding site selection have not been explored. In general, breeding site selection in seabirds is highly complicated and based on a range of different factors

including private and public information, conspecific attraction and direct habitat assessment (Serrano et al. 2004). Breeding site selection in black-fronted terns is likely to incorporate aspects from each of these different factors. Private information refers to information gleaned from an individual's own experiences. Keedwell (2002) found that black-fronted terns reused all four colony sites which had high chick survival (>20 chicks fledged) in the previous breeding season, indicating that personal information may play a role in site selection.

Breeding colonies which are successful are generally observed to grow in size, indicating that birds recruited to the colony may be using public information, information obtained through observation of conspecifics (Doligez et al. 2002). This may be the case for black-fronted terns, for example, the 'Tern Island' colony in the upper Ohau River increased from 418 individuals at its peak in 2011, to 494 in 2012 after a season of high breeding success (Woolmore et al. 2012b). Black-fronted terns take two years to reach sexual maturity, so the increased colony size could not be explained by the chicks which successfully fledged in 2011 returning to breed in 2012. This colony also experienced complete failure in 2010 so there would not have been any first breeding birds returning to their natal colony in 2012 (Woolmore et al. 2012a). It's possible that the increase in colony size could be related, in part, to the use of public information about the breeding success at that colony, as several first year birds were observed at the site in 2011. However, the number of non-breeding birds observed was not enough to account for the increase in the 'Tern Island' population. Alternatively, conspecific attraction, the tendency of individuals to settle near conspecifics, may have played a role in the increased colony size (Schlossberg and Ward 2004, Ward et al. 2011). The use of conspecific cues by breeding birds can facilitate more efficient location of suitable breeding habitat and has the potential to increase breeding success (Ahlering and Faaborg 2006). Conspecific attraction reduces the time and energy required to locate suitable habitat, particularly beneficial for species, like the black-fronted tern, which breed in highly dynamic habitat which changes considerably between breeding seasons (Ward et al. 2011). A large colony, like that on 'Tern Island', may have been highly attractive to the terns, strongly indicating the quality of the habitat.

Direct habitat assessment, in which individuals assess the quality of a potential habitat based on their species specific requirements, also contributes to breeding site selection decisions (Burger and Gochfeld 1988). Black-fronted terns require bare gravel areas for breeding, often showing preference for islands (O'Donnell and Moore 1983, Robertson et al. 1984, Hughey 1985). However, more specific nesting habitat specifications have not been explored. Colony site selection in black-fronted terns is likely due to a combination of a range of factors. The importance of different factors may change based on the situation. For example, Nocera et al. (2009) found that in grassland passerines, older individuals used their past experience to determine breeding sites whereas younger or first time breeders based these decisions on conspecific cues.

Like site selection, little is known about black-fronted tern colony dynamics. Colony dynamics are primarily governed by group adherence, the preference to nest with the same individuals, and site fidelity (also known as philopatry or tenacity), the tendency for individuals to return to the same colony (natal or breeding) location (Austin 1949, Palestis 2014). Group adherence is indicated when groups of individuals move together to new colony locations. For example, common terns (*S. hirundo* Linnaeus) banded together on Tern Island, Cape Cod, Massachusetts, were found nesting together on a different island several years later (Austin 1951). The dynamic nature and instability of the braided river habitat make it most likely that black-fronted terns will demonstrate strong group adherence (Palestis 2014). Group adherence would facilitate rapid re-establishment of a colony following desertion due to flooding or predation events.

Breeding in black-fronted tern colonies is asynchronous between, and synchronised within, black-fronted tern sub-colony groups (Robertson et al. 1983). Synchronisation of breeding within a colony is often an anti-predator defence strategy (Southern et al. 1982, Clode 1993, Reed and Dobson 1993). If all of the chicks in a colony hatch in a short time frame the effects of predation are diluted and there is a greater chance that some chicks will survive. However, the synchronisation of tern breeding within sub-colony groups lends more support to the theory of group adherence in black-fronted terns (Robertson et al. 1983). Sub-colony groups may move together to a breeding site, facilitating synchronised breeding within their group.

The low site-fidelity predicted for black-fronted terns corresponds with the low site-fidelity demonstrated by terns in general (Jones and Kress 2012). Site fidelity is often found to be positively correlated with habitat stability (McNicholl 1975, Steele et al. 2009) and past reproductive success (Burger 1982, Cuthbert 1988, Thibault 1994). Black-fronted terns' highly unstable braided river breeding habitat, small colony sizes and low reproductive success, support the prediction of low site-fidelity (O'Donnell and Hoare 2011).

Black-fronted terns have a rapid breeding cycle and are capable of re-nesting within a breeding season. Both these life history traits allow black-fronted terns to exploit ephemeral habitat and optimise their chance of breeding success in the braided river environment. After arriving at a potential breeding site black-fronted terns can form a nest within a day or two and lay eggs within a week (Stead 1932, O'Donnell and Moore 1983, Maloney 1999). Keedwell (2002) observed a black-fronted tern pair initiate a new nest just six days after the loss of their chicks. Rapid re-nesting in black-fronted terns is facilitated by their small clutch size of 1-4 eggs, with 2 egg nests being most common (O'Donnell and Moore 1983). Predation, flooding and other disturbance events result in a substantial proportion of re-nesting attempts every breeding season. Keedwell (2002) estimated that

20% and 21% of monitored nests were re-nesting attempts in 1999 and 2000 respectively in the lower Ohau River.

Black-fronted tern nests differ from the other species of *Chlidonias* terns. Other *Chlidonias* spp. will construct their nests on floating piles of weed and vegetation in wetlands and marshes, which is where the name 'marsh terns' comes from (Lalas 1977). In contrast, black-fronted terns do not construct nests, but lay their eggs in simple nest scrapes, a strategy which is common among *Sterna* spp. Robertson et al. (1983) recorded black-fronted tern nests as nest cups constructed from dry grasses and twigs. However, the nest scrapes, areas cleared of larger substrate with no attempt to form a traditional nest, described by Buller (1888) are more commonly reported. In upper rivers, nest scrapes are often made among larger stones or on banks for protection against the strong nor' west winds (Stead 1932, Steele et al. 2009). Black-fronted terns are rarely found nesting outside of riverbeds, with the exception of a few records on river terraces or adjacent land. Records in the 1880s reference black-fronted tern breeding on the Canterbury plains prior to agricultural development (Hughey 1985). Based on these historical breeding records, Hughey (1985) discusses the possibility that black-fronted terns may actually be generalists for which braided rivers are a remnant of their former range.

1.2 Threats

Degradation and loss of braided river habitat, as well as predation, represent the two major threats facing black-fronted terns. Flooding is also a threat to black-fronted tern breeding success, but it is one which they have adapted to minimise (Robertson et al. 1983). Increasing demands on water resources for irrigation schemes and hydroelectric development have resulted in the loss and degradation of braided river habitat (Gray and Harding 2007). Hydroelectric development can result in substantial loss of habitat through permanent inundation (formation of man-made lakes) of braided river flood plains (Nilsson and Dynesius 1994). Both hydroelectric development and irrigation schemes divert water from its natural course through a braided river system, modifying and disrupting flow regimes. Low flow regimes can reduce food availability, facilitate weed encroachment, disrupt natural erosion processes and increase predator accessibility in black-fronted tern breeding habitat (O'Donnell and Hoare 2011). Declines in black-fronted tern populations have been found to correlate with low-flow rates, suggesting the importance of rivers with high flows to the survival and success of black-fronted terns (Hughey 1985). O'Donnell and Hoare (2011) also found that declines in black-fronted tern numbers (1962-2008) were found in rivers with relatively low flows ($<30 \text{ m}^3\text{s}^{-1}$).

Low flow regimes also modify the frequency and extent of flooding in braided river systems, restricting channel mobility, changing the natural erosion/deposition processes and limiting habitat turnover (O'Donnell and Moore 1983). Reduced flood periodicity facilitates more rapid weed establishment on braided riverbeds. Weeds, such as lupin (*Lupinus polyphyllus* and *L. aboreus*), gorse (*Ulex europaeus*), Scotch broom (*Cytisus scoparius*) and crack willow (*Salix fragilis*), take over the bare gravel areas, degrading braided river bird breeding habitat (O'Donnell and Moore 1983). Willows are a particularly problematic. Once established willows confine a river's course, they facilitate further weed establishment and eventual plant succession on braided river flood plains (Pierce 1983, Maloney et al. 1999).

Human disturbance is also a form of habitat degradation. Human disturbance comes in many forms, ranging from recreational river use through to gravel extraction and bridge construction. The extent of disturbance mirrors this range from the mild disturbance, causing terns to leave and defend their nests, to major disturbance, which may destroy tern nests and cause colony desertion. Human disturbance is likely a major cause of nest failure in black-fronted terns (Hughey 1985). Although it has not been estimated for black-fronted terns, human disturbance was found to be responsible for >50 % of reproductive failures in least tern (*Sterna antillarum*) colonies (Burger 1984). Disturbance may be a substantial threat to black-fronted terns; in other tern species, even mild disturbance, if experienced frequently, may result in colony desertion (Palestis 2014).

Predation by introduced mammals is probably the largest threat faced by black-fronted terns (Keedwell 2003). Black-fronted terns are well adapted to avoid predation from their avian predators, swamp (Australasian) harriers (*Circus approximans*) and southern black-backed gulls (*Larus dominicanus*). These predators only hunt during the day and use visual cues to detect their prey. Black-fronted terns use group defence to effectively deter diurnal threats, aggressively mobbing and chasing potential predators away (Higgins and Davies 1996). The cryptic colouration of black-fronted tern eggs and chicks, and a young chick's instinct to freeze when they sense a threat, reduce the chance of being detected by visual predators (Dowding and Murphy 2001, Keedwell 2002). These adaptations may be completely ineffective against introduced mammalian predators.

Introduced mammalian predators found in braided river environments and known to prey upon black-fronted terns include: feral cats (*Felis catus*), ferrets (*Mustela furo*), stoats (*Mustela erminea*), Norway rats (*Rattus norvegicus*) and hedgehogs (*Erinaceus europaeus*) (Keedwell et al. 2002, Sanders and Maloney 2002). Cats and stoats cause the greatest concern as they commonly prey upon black-fronted terns at every life stage (Sanders and Maloney 2002, Dowding et al. 2015). Both rats and hedgehogs also contribute substantially to black-fronted tern nest failure. It is believed that some predators may use colonies as a consistent food source, returning multiple times to prey on both

eggs and chicks (Jones et al. 2005, Keedwell 2005). All of these predators are primarily nocturnal and use a combination of visual, auditory and olfactory cues to locate their prey (Dowding and Murphy 2001). Black-fronted terns do not appear to possess anti-predator behaviours effective at deterring nocturnal, mammalian predation. Their colonies are silent at night and adult birds make no attempt to deter nocturnal intruders. A single predator is capable of decimating an entire black-fronted tern colony (Keedwell 2002, 2005). One such case occurred in the Rangitata River (2006), where on one night a single cat caused the loss of at least 76% of the nests and 10% of the adults in a black-fronted tern breeding colony (O'Donnell et al. 2010).

Nocturnal predation and disturbance events generally have large impacts on terns, often leading to the abandonment of colonies (Palestis 2014). Although desertion protects adult birds relatively effectively, it leaves eggs or chicks completely exposed. Video footage from Keedwell (2002) showed that not only did night time disturbance by known predators, such as cats and hedgehogs, result in colony desertion, but so too did disturbance from more benign animals including rabbits and mice (Keedwell 2005). Keedwell (2002) found that predation and desertion accounted for >90 % of black-fronted tern nest failure events in the flood-free Ohau River (1998-2000).

The threats facing black-fronted terns may be further exacerbated by global climate trends. Climate change will further alter the hydrodynamics of rivers already subject to substantial flow modification. Current climate predictions suggest that the large Southern Alps fed rivers, such as the Rangitata and Waimakariri, will experience more frequent flooding (Hollis 2014). In contrast, smaller foothill rivers, including the Ashley-Rakahuri and Ashburton, will experience increased low flows (Hollis 2014). River scenarios for both Southern Alps and foothill-fed rivers may have mixed effects for the terns. In the mountain-fed rivers, greater flood frequency may assist in clearing both weeds and introduced predators which have established on the riverbed. More flooding may also mean greater disturbance during the breeding season, likely requiring multiple nesting attempts and potentially impacting tern reproductive success. In foothill-fed rivers, increased periods of low flows would reduce the risk of nest failure due to flooding. However, low flows would also increase terns' vulnerability to predation. Flowing channels surrounding black-fronted tern colonies deter mammalian predators (Rebergen et al. 1998, Duncan et al. 2008, Pickerell 2015). Reducing these braids to low or no flow increases the accessibility of tern colonies to predators. The lack of major flood events in low-flow rivers facilitates weed establishment, reducing the available breeding and foraging habitat. Overall, it is probable that current climate trends will exacerbate rather than ameliorate the threats which are causing black-fronted tern population declines.

1.3 Current management

Predator control is generally accepted as essential to the future survival of black-fronted terns and other endemic braided river bird species (Taylor 2000, Keedwell 2005, O'Donnell and Hoare 2011). However, this is no simple task. Braided rivers are long, linear environments that experience high immigration rates of predators making them very difficult to manage. The rate of predator immigration into braided river environments may increase following the removal/control of predators within this environment (Keedwell and Brown 2001). Similar results were found in a study in San Francisco Bay, CA, where predators were removed from areas important for nesting waterbirds (Meckstroth and Miles 2005). High densities of predators neighbouring the removal sites facilitated rapid recolonization of the cleared sites.

Rabbits also play a major role in the dynamics of predator guilds and predation in braided river habitat. Rabbits are the primary prey for some introduced mammalian predators, in particular cats and ferrets. Large rabbit populations are able to sustain large numbers of predators. But when the rabbit numbers crash, the predators can no longer be sustained by the rabbits and they prey switch, increasing their predation of native birds (Dowding and Murphy 2001, Norbury and Heyward 2008). The prey switching ability of the introduced mammalian predators in braided river environments has been demonstrated both in response to the release of Rabbit Haemorrhagic Disease (Murphy et al. 2005) and lethal rabbit control (Pierce 1987, Norbury and Heyward 2008). In each of the aforementioned cases, the predation pressure on nesting braided river birds increased following the decline in rabbit abundance in the surrounding areas. Successful predator control for the protection of black-fronted terns may require the coordination of both predator and rabbit control.

Currently, there are two major predator control strategies for the benefit of black-fronted terns. The first is landscape scale, composed of two parallel trapping lines (one on either side of the river) protecting a stretch of riverbed (Steffens 2008). This strategy has the potential to reduce predation not only of black-fronted terns but also any other braided river bird species which nest in the controlled area. The landscape (catchment) scale approach has been trialled in the Tasman River valley in the Mackenzie basin since 2003 (Cruz et al. 2013, Woolmore et al. 2014). In the first nine years of the project black-fronted tern success remained low with fledging success of 0-27%, with predation consistently being the primary cause of nest failure (Woolmore et al. 2014). With changes made to the program, trapping timing and black-backed gull control, black-fronted tern fledging success in recent years indicate a positive trend (Nelson 2017). The other major strategy is to intensively manage trapping lines surrounding established breeding colonies (Steffens 2008). This strategy is either reactive to the terns' choice of colony location, or reliant on the terns returning to a

past colony location. Therefore, colony scale management risks wasting large amounts of time and resources if the terns do not behave as predicted.

In addition to predator control, habitat enhancement and protection is also being carried out for the benefit of black-fronted terns. Habitat enhancement activities, including the clearing of vegetation on braided riverbeds and island creation, aim to generate suitable breeding habitat for black-fronted terns. These habitat enhancement activities have the potential to increase black-fronted terns' success but again, only if the terns choose to nest in the enhanced areas. We are again faced with the issue that large investments of time and resources may be wasted if the enhanced habitat is not used by the terns.

Black-fronted tern breeding habitat, and that of other braided river birds, can be protected through education and physical prevention of riverbed use during the breeding season. Signs detailing the importance of the braided river habitat for these birds during the breeding season and how people can minimise their disturbance to the birds are posted at river access ways. In some rivers, such as the Ashley Rakahuri River, there are restrictions on vehicle river access throughout the breeding season. Large concrete blocks are placed across the river access ways to enforce this.

There are several strategies for the conservation of black-fronted terns which have proven the ability to halt or reverse local declines in black-fronted tern populations. For example, increases in tern numbers have been reported in the Eglinton (O'Donnell and Hoare 2011) and the Ashley-Rakahuri Rivers (Spurr and Ledgard 2016), both of which have sustained predator control. However, thus far we have been unable to reverse the global declines in the black-fronted tern population. Currently, most predator control operations and habitat enhancement targeting black-fronted terns are either reliant on the terns choosing to nest in the management areas, or reactive to where the terns do choose to breed. If we could predict or dictate where the terns formed their breeding colonies we may be able to drastically improve the effectiveness and efficiency of black-fronted tern management.

1.4 Sensory-based conservation

Sensory-based conservation describes conservation techniques which use the natural communication or signalling behaviours of target species in order to protect or manage wild populations (Friesen et al. 2016). All animals use a variety of sensory cues to survive daily life, from the location of food and mates to the avoidance of predators. In birds, visual and auditory cues play fundamental roles in the communication, foraging and reproduction (Capuska et al. 2011). More recently, we have begun to understand the importance of olfactory cues to many bird species. Some

species, particularly *Procellariiformes* spp., have highly developed olfactory sensory systems. For example, olfactory cues are known to facilitate mate recognition in Wilson's storm petrels (*Oceanites oceanicus*) (Jouventin et al. 2007) and nest location identification in blue petrels (*Halobaena caerulea*) (Bonadonna et al. 2001).

Social attraction is a type of sensory-based conservation, and is a common management tool used worldwide for the establishment of seabird breeding colonies (Arnold et al. 2011, Jones and Kress 2012). Social attraction techniques harness a target species' conspecific attraction (i.e. the tendency to settle near conspecifics) by mimicking a productive colony, and luring birds to form breeding colonies in these predetermined locations (Schlossberg and Ward 2004). Social attraction techniques were pioneered in the successful re-establishment of Atlantic puffins (*Fratercula arctica*) at their historic nesting sites on Eastern Egg Rock Island, Maine in 1973 (Jones and Kress 2012).

Social attractants have primarily been used in the establishment or re-establishment of permanent colonies. It will often take several breeding seasons for a colony to truly establish and be self-sustainable (Kress 1983). In the pioneering puffin project, using a combination of decoys and chick translocations, it took four years for the first puffins to return and eight years for the first breeding attempt (Jones and Kress 2012). Stronger conspecific attraction, like that found in species with low site-fidelity, is likely to result in a more rapid response to social attraction techniques (Ward et al. 2011). Black-fronted terns' braided river breeding habitat is essentially ephemeral, often causing their breeding colony locations to change. Strong conspecific attraction is likely to be demonstrated by black-fronted terns as a strategy to cope with frequently changing colony locations to increase their chance of locating a breeding colony (Gummer 2003).

The breeding habitat of least terns is ephemeral and reshaped by regular flooding (Burger 1984). This is similar to black-fronted terns' braided river breeding habitat. Least terns have proven very responsive to social attractants (Burger 1989, Ward et al. 2011). For example, decoys and audio playback were used to attract least terns to nest on a floating sandbar (made from two barges) in the Mississippi River, 75 km from the most recent breeding location on the river. The attractants facilitated the establishment of a colony of thirty-two least terns which successfully produced twenty-seven fledglings in the first season. It is likely that black-fronted terns will demonstrate a similar response to least terns due to the similar habitat traits. Past trials of social attractants in black-fronted terns have demonstrated positive yet inconclusive results due to inadequate observations or equipment (Anderson et al. 2007, Steffens 2008).

1.5 Aim

To investigate black-fronted tern colony dynamics based on historic breeding colony locations and determine if social attractants are a viable tool for black-fronted tern conservation.

1.6 Objectives

- I. Use historical data of black-fronted tern colony locations to determine how colony locations change between breeding seasons
- II. Investigate the relationship between colony size and site fidelity
- III. Determine if decoys and audio playback can attract black-fronted terns to specific sites

Chapter 2

Historical colony locations used to explore colony dynamics in black-fronted terns



Black-fronted tern fledgling (C. Hamblin)

2.1 Introduction

Approximately 13% of all bird species breed in colonies (Rolland et al. 1998), including more than 95% of seabirds and all tern species (Jones and Kress 2012, Palestis 2014). The dynamics and movements of seabird colonies vary substantially across the different colonial species. Breeding-site fidelity (also known as philopatry or tenacity) is the tendency of individuals to return to the same colony site, and plays a major role in determining colony site dynamics (Austin 1949). Individuals of many species demonstrate high site-fidelity, returning to the same established colony locations and, in some cases, even the same nesting sites every breeding season for decades or more.

Breeding site selection and fidelity can be affected by many factors, such as age, past reproductive outcomes and the stability of the breeding habitat. Site fidelity has been found to increase with age in common terns (*Sterna hirundo*) (Austin 1949). Freer (1979) observed the same trend in bank swallows (*Riparia riparia*) along with a significant correlation between site fidelity and past breeding success. Past breeding success has also been correlated with increased nest-site fidelity in Cory's shearwaters (*Calonectris diomedea*) (Thibault 1994), male ovenbirds (*Seiurus aurocapillus*) (Porneluzi 2003), caspian terns (*Sterna caspia*) (Cuthbert 1988), and black skimmers (*Rynchops niger*) (Burger 1982), among other species. Burger (1982) also found that the cause of reproductive failure impacted the likelihood of breeding site abandonment in black skimmers. Lower site fidelity was found when predation was the cause of nest failure rather than flooding, and Burger (1982) suggested that the predictability of reproductive failure may explain these differences in site fidelity.

Burger (1982) suggested predation as a predictable form of nest failure as consistent predator populations at a site result in a high probability of future loss; whereas, flooding was suggested as having low predictability due to seasonal variability. In the New Zealand braided river environment, populations of mammalian predators are often linked to population fluctuations of rabbits, their primary prey species in the surrounding environment (Pierce 1987, Murphy et al. 2005, Norbury and Heyward 2008). Therefore, nest failure events due to mammalian predation may not be as predictable for braided river species compared to species inhabiting environments with more consistent predator populations.

Flooding events are predictable in the sense that they are frequent occurrences in braided rivers. However, at the finer, within-colony scale, the risk of nest failure due to flooding can be highly unpredictable, depending on factors such as the size and timing of flooding events, and the height (above the nearest water level) of the nest site. The benefits of familiarity with a breeding site and its associated resources may outweigh the possibility of nest failure due to a flooding event, resulting in individuals returning to the same nesting site despite nest failure in the previous season. The link between past breeding success and site fidelity is not limited to an individual's own breeding success;

some species use conspecific reproductive success to assess habitat quality and assist in breeding site selection (Boulinier and Danchin 1997).

Past breeding success has also been implicated in changes in colony size. Seabird breeding colonies seem to go through stages, starting off as small numbers of pioneering birds selecting a new breeding location (Buckley and Buckley 2000). If the pioneering birds have a successful breeding attempt they are more likely to return, and to recruit other prospecting birds causing the colony to grow in size. Larger colonies, in general, have greater breeding success which increases the birds' fidelity to that site and facilitates further recruitment (Lombard et al. 2010). Seabird colonies in a stable, island habitat in which predation rates are low may remain in this phase of the colony cycle for many years. However, if something changes at that site rendering it less suitable or uninhabitable or reducing breeding success, colony size will likely decrease or be abandoned completely (Erwin et al. 1981).

Habitat stability has been found to positively correlate with breeding-site fidelity (Steele et al. 2009). McNicholl (1975) defined stable habitats as sites in which generations may be raised successfully with minimal increase in danger to the offspring. Habitat stability does not only include the physical stability of a breeding site, but also the stability of sufficient food resources in the area. The differences in site fidelity between barn (*Hirundo rustica*) and cliff (*Petrochelidon pyrrhonota*) swallows compared to bank swallows (*Riparia riparia*) have been attributed to the differences in breeding habitat stability (Freer 1979). Barn and cliff swallows use more permanent structures for breeding compared to the freshly disturbed sand banks preferred by bank swallows. Similarly, low-site fidelity (high colony turnover) has also been observed in Forster's (*Sterna forsteri*), least (*Sternula antillarum*) and gull-billed (*Sterna nilstica*) terns, all of which nest in unstable habitats, marsh islands, beach washover and sandy beaches, respectively (Visser and Peterson 1994, Erwin et al. 1998).

High breeding-site fidelity can have significant adaptive advantages and disadvantages for different species. Familiarity with a site generated through high site-fidelity facilitates mate retention and reduces the energy and time expenditure otherwise required to search for suitable breeding sites and food resources (McNicholl 1975, Collar 2013). High site-fidelity can also increase an individual's probability of breeding success, allowing more time and energy to be directed towards reproduction. However, in situations when past breeding habitat becomes sub-optimal or unusable due to environmental changes, continuing to nest there would be disadvantageous. Environmental cues contribute to settlement decisions even in species with high site-fidelity, as birds will abandon a historical breeding site if the benefits of remaining fail to outweigh the costs of abandonment (Burger 1984). Breeding colonies of common terns have been found to abandon a historical breeding site due to an environmental change, only to return years later when the habitat is again suitable

(Austin 1949). High site-fidelity in species with limited behavioural plasticity can be highly detrimental to survival. Species naive to predation may be unable to identify and cue off novel threats presented by introduced predators in their environment. For example, Igual et al. (2007) found that Cory's shearwaters (*Calonectris diomedea*) did not cue off the presence of ship rats (*Rattus rattus*) as a reason to change breeding locations. Individuals demonstrated a habitat preference in their nest site selection and would re-nest in the selected habitat rather than cueing off nest failures due to predation. This may be common among other long lived seabirds which have evolved in stable, predator free environments.

2.1.1 Site fidelity in black-fronted terns

There are substantial differences in the site fidelity exhibited by different tern species. 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). Marsh terns (*Chlidonias spp.*) are believed likely to exhibit site fidelity to a lesser degree than other tern species due to the dynamic nature of their breeding habitat (Palestis 2014). Most marsh terns breed on floating weeds and vegetation in wetlands and marshes and the black-fronted terns braided river breeding habitat is the only exception (Lalas 1977). Both habitat types are similarly dynamic and dependent on water levels and flows which would make strong site-fidelity disadvantageous, or impossible to achieve.

Therefore, black-fronted terns are predicted to have low site-fidelity, based on their small colony sizes, dynamic braided river breeding habitat and the fidelity levels observed in other *Chlidonias spp.* Yet, there are some inconsistencies in the literature that suggest that there may be instances when black-fronted terns exhibit higher site-fidelity than expected. For example, Pierce (1983) noted that in the Cass River (1977-1980) 6 to 8 breeding colonies were located each season, usually in the same localities. Similarly, Keedwell (2002) found that there were 'main colony sites', in which colonies formed more consistently, especially after seasons of successful breeding. In contrast, Robertson et al. (1983) suggested that black-fronted tern colony locations changed each year following observations that a region of the Ahuriri River contained a single black-fronted tern colony in 1975 and four colonies in 1982. O'Donnell and Moore (1983) also referenced the changing of colony locations each year as an adaptation to the dynamic braided river environment.

Black-fronted tern colonies are generally small (2-50 pairs), however, colonies of over 250 pairs have been recorded (Bell 2013). In least (*Sterna antillarum*), common (*S. hirundo*) and roseate (*S. dougallii*) terns larger colonies were found to be more successful and have a greater probability of reuse in subsequent seasons (Buckley and Buckley 2000, Lombard et al. 2010). The relationship between

breeding success, site fidelity and colony size has not been explored in black-fronted terns. However, Keedwell (2002) noted that colony locations in which black-fronted terns were successful were more likely to be reused over locations in which colonies failed. If colony size can serve as an indicator of black-fronted tern breeding success and increased likelihood of breeding site reuse it could be extremely valuable from a conservation perspective.

The locations and sizes of black-fronted tern colonies have been recorded over many years and rivers during braided river bird surveys and through other work. However, no analysis has been conducted looking at a large sample of these colonies to identify whether site fidelity occurs, or what factors may impact the degree of site fidelity demonstrated. The aim of this chapter is to use historical breeding colony locations to investigate black-fronted tern colony dynamics. Analysis of past breeding colony locations may identify particular areas or colonies which are important for black-fronted tern breeding, and confirm whether high or low site-fidelity is the norm for this species. Identified areas may be used to inform more a targeted approach to black-fronted tern management.

2.1.2 Research questions

- Are black-fronted tern colonies distributed randomly throughout their braided river breeding habitat?
- Do black-fronted tern colonies cluster in regions of braided rivers?
- Does colony size relate to the proximity of previous or subsequent colony locations?

2.2 Methods

2.2.1 Historical data collection

Bird counts have been carried out on braided rivers across the South Island dating back to the 1960s. The majority of bird counts are collected following the standard walk-through survey method described in O'Donnell and Moore (1983). Walk-through surveys require a group of observers to spread evenly (no more than 200 m apart) across the width of the active riverbed and record all birds seen as they walk past them going downstream through designated river sections. All but a few of the smaller braided rivers are surveyed in sections (usually < 10 km in length) which have been established for many years. Consistent river survey sections facilitate greater consistency between counts as the same areas of the river are covered and reported in successive surveys. Surveys are completed over one or more days, with surveys of larger rivers taking longer to complete. 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 and Hoare 2011).

GPS coordinates for the colony and breeding locations of seven braided river bird species (black-billed gulls (*Larus bulleri*), black-fronted terns, black-backed gulls (*Larus dominicanus*), Caspian terns (*Hydroprogne caspia*), white-fronted terns (*Sterna striata*) and wrybill (*Anarhynchus frontalis*)) are now collected during most braided river surveys. The earliest records of GPS data I have been able to locate were from the 2004 breeding season. A standardised method of collecting these GPS data is yet to be established.

Unlike the rest of the dataset, the GPS data for black-fronted terns on the Ashley River was collected retrospectively. The Ashley-Rakahuri River has been formally surveyed since 2004 (12 consecutive years) by the Ashley-Rakahuri Rivercare Group (ARRG). The locations of all black-fronted tern colonies found during the surveys were described but no GPS locations were recorded. From these descriptions, Nick Ledgard (ARRG Chairman) and I generated GPS coordinates corresponding to all black-fronted tern colonies found through the 12 years of survey history.

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. My search resulted in 598 black-fronted tern GPS colony locations recorded on 34 different South Island rivers and one wetland (the Ruataniwha wetland, Mackenzie Basin). Colony data from 2004-2015, with 1-12 years of surveying, were collected (Appendix A).

2.2.2 Colony dynamics

Data checking

All GPS colony data was converted to New Zealand Transverse Mercator 2000 (NZTM2000) and imported into ArcGIS 10.3. Using a basemap of New Zealand Imagery and overlaying the colony locations, I was able to check the accuracy of the colony location data. Colony data points were excluded if: (1) the GPS coordinates were missing; (2) the GPS point was located outside of the river it was recorded to be in, or (3) the GPS point doubled up another location in the same year.

Nest data to colony data

Some GPS data collected for research and monitoring purposes have been collected as nest rather than colony locations. All nest data was transformed to single colony points in ArcGIS. The single

colony point was found using the GPS coordinate of the centre (by distance) of each cluster of nests. Most colonies were well defined, separated from other colony sites by large distances. Some colony boundaries were less well defined, resulting in groups of nest clusters in close proximity. In this case, colony coordinates were determined by the distance from the centre of the largest cluster to the centre of a peripheral cluster. If the distance between the two centre coordinates was <300 m the two clusters were deemed to be a single colony. If the distance was >300 m between the two cluster centres, they were treated as two distinct colonies. The number of terns in each transformed colony was recorded as two times the number of nests present. Three-hundred meters has been referenced to as the distance to account for small, local colony movements in least terns, with any movement greater than that deemed to be a new colony location (Erwin 1978). Based on this I reasoned that a distance of 300 m between two nest clusters may also represent different colonies in black-fronted terns. The accuracy of this assumption for black-fronted terns is not known.

Linearizing data

To investigate the occupancy of different regions of black-fronted terns' braided river habitat all of the colony GPS locations were converted into a linear dataset using ArcGIS. All colony locations, spanning the recorded breeding seasons, were combined to generate the linear dataset. In the linear dataset, each GPS colony location corresponds to a point along a linear line, the river. None of the available river data files had accurate river centrelines, with most straying substantially from the riverbed. The NZ Major Rivers layer file was used as a template to redraw a more accurate set of river centrelines, centred on the middle of the river fairway of the relevant rivers. The new centrelines were converted into routes. Linear reference tools were used to identify all the colony locations along their respective river centrelines and assign them a distance from the 0 point of the centreline i.e. the downstream end of the survey area (e.g. river mouth).

The length of each river was divided into 300 m continuous river sections. The distance of 300m has been referenced to account for small local movements which are common for species inhabiting dynamic and unstable habitats, such as braided rivers (Erwin 1978). The river lengths were extended to the nearest 300 m to ensure all river sections were the full 300 m. Each colony was allocated to its corresponding river section as dictated by its distance from the 0 point. Each river section could only contain a single colony point from each surveyed year, any double ups were excluded from the analysis. Gorge sections of the rivers were also excluded from the analysis as these areas are never suitable for black-fronted tern breeding. Three different start points, 100 m apart, were used to generate three different frequency distributions of the number of colonies per river section. The first start point was the farthest downstream location of the survey, the second and third start points were 100 m and 200 m upstream from this point respectively. Staggering the arbitrary river section

boundaries accounted for some of the GPS location error and ensured that all colony locations that were < 300 m apart were detected in at least one of the distributions.

For this analysis, each river was treated in isolation; however the reality is that rivers are not independent. Colonies of similar sizes have been recorded to disappear from one river and appear in another soon after, strongly suggesting that within seasons there may be colony movement between different river systems. Mark-recapture studies are required to confirm the anecdotal evidence for this. The current dataset precluded further investigation of colony movement between river systems. The surveys provide only a snap shot of tern colony locations at a point in time, and there was no way to identify individuals or determine where they may have come from.

The Tasman River was too wide to linearize using a single centreline so a centreline was generated for each half of the river. By using a single centreline, some the linear locations of some colonies were incorrectly assigned very similar distances from the origin; where in reality they were several kilometres apart across the width of the river. The distance separating these centrelines was set as being proportional to the width of the river. Each colony point was allocated a distance corresponding to its location along the centreline it was closest to. The two linearised data sets from the Tasman are henceforth referred to as 'Tasman LHS' and 'Tasman RHS'.

Colony distribution analysis

The observed distribution of black-fronted tern colony locations for each river (across all years for which locations were recorded) were compared to the mean expected random distribution. The mean expected dataset was generated using 1000 replicates of random sample distributions per river. The random sample distributions for each river corresponded to that river's parameters (number of river sections and colonies). Data were generated under the assumption that each colony data point had equal probability of occurring in any particular river section. The mean observed colony distribution for each river was compared to the corresponding mean expected distribution using Pearson's Chi-squared Goodness of Fit test with simulated a P-value.

Colony clustering analysis

Each river section in the observed datasets, described above, was assigned a value (cluster index) based on the presence or absence of a colony within that river section and either or both of its neighbours (Table 1). The cluster index values assigned to the first and last river sections were excluded from the rest of the analysis as the accuracy of the values assigned to these river sections is unknown as one of their neighbouring sections was not surveyed. The mean frequency of different clustering index values was calculated for each colony distribution within a river. These data were then transferred into a 2x3 contingency table to analyse the mean frequency of clustering of the colony location data for each river. 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 likelihood of having a colony present in a neighbouring river section based on the presence or absence of a colony in the central section.

Table 1: How cluster index values were assigned 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	
O	X	O	2
X	O	X	3
O	O	X	4
X	O	O	
O	O	O	5

Data from nine different rivers were included in this analysis. In these nine rivers black-fronted tern colony data were collected consistently and for more than two years. In a river with only two years of data the maximum colony frequency within a section is two. A colony frequency of two is expected to occur at a high rate due to random chance, making it very unlikely that non-random site selection would be detected. Colony frequencies of greater than two, which may occur in rivers with more than two years of data, are more likely to facilitate the detection of non-random site selection. Data collected inconsistently (not repeated over different survey years), or opportunistically (not part of a full river survey), could not reliably reflect the colony distributions and were therefore excluded.

2.2.3 Colony size

The distances from each colony location to the nearest neighbouring colony location were calculated using the 'Near' function in ArcGIS version 10.3. Two datasets were created to compare the colony size to the distance of the nearest colony: 1) in the following year, and 2) in the previous year. Colony data from rivers which were not monitored over consecutive years were excluded from the analysis. Linear regression models were used to determine the relationship between colony size and the distance to the nearest colony in both datasets. The significance of the relationship was determined using P-values and the fit of the model assessed using the coefficient of determination (R^2).

2.3 Results

2.3.1 Colony dynamics

Data from nine rivers were included in the analysis (Table 2): Ashley-Rakahuri, Ashburton, Dart, Hurunui, Rakaia, Rangitata, Tasman, Waiau and Wairau. Of the 26 rivers excluded, 20 contained ≤ 2 years of data and six had inconsistent data collection.

Table 2: Summary data for the nine rivers surveyed consistently and included in the colony distribution analysis.

River	Survey length (km)	Number of colonies	Mean colonies/year	Number of years surveyed	Range of years surveyed
Ashley-Rakahuri	19.2	50	4.2	12	2004-2015
Ashburton	52.2	26	4.3	6	2007-2015
Dart	18	14	3.5	4	2007-2010
Hurunui	69.9	22	4.4	5	2006-2010
Rakaia	65.4	16	5.3	3	2011-2013
Lower Rangitata	45.6	36	8.8	4	2007-2015
Tasman -LHS	15.3	54	5.4	10	2004-2015
-RHS	14.7	20	2.9	10	2004-2015
Waiau (Canterbury)	88.5	33	11	3	2008-2010
Wairau	96.3	49	9.8	5	2009-2013

Colony distribution

There was a significant difference between the mean observed and the mean expected colony distributions in the Ashley ($\chi^2=68.095$, $P = 0.003$) and Tasman (RHS $\chi^2=44$, $P = 0.013$, LHS $\chi^2=66$, $P = 0.016$) Rivers. This difference was not significant for any of the other rivers. However, in general, river sections in which there was no colony present and those which contained the greatest colony frequencies observed at each river, were observed more often than expected (Figure 1). This general trend was consistent for eight out of the nine analysed, the Lower Rangitata was the only exception. In the Lower Rangitata River sections in which colonies were absent and the maximum colony frequency (two colonies per river section) were observed less than expected. The greatest observed colony frequencies observed per river section ranged from two in the Rangitata and Rakaia, to seven in Ashley River.

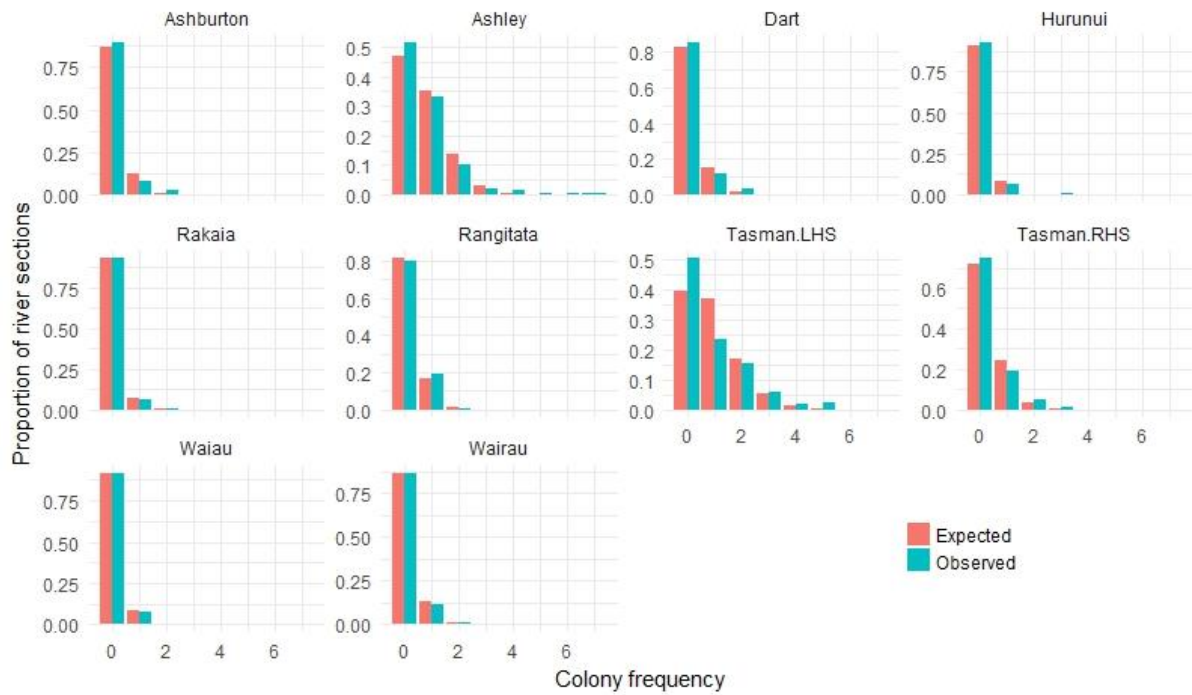


Figure 1: Observed (blue) and expected (red) proportion of river sections containing different colony frequencies (number of colonies per river section).

Colony clustering

Overall, black-fronted terns tended to be clustered. If a colony was present in the central river section, it was more likely that a colony would be present in the neighbouring river sections. If no colony was present in the central river section, there was less likely to be one present in the neighbouring river sections (Figure 2). This trend was consistent for all and significant for two of the nine rivers analysed, the Ashburton ($P = 0.03$) and Rakaia ($P = 0.02$) Rivers.

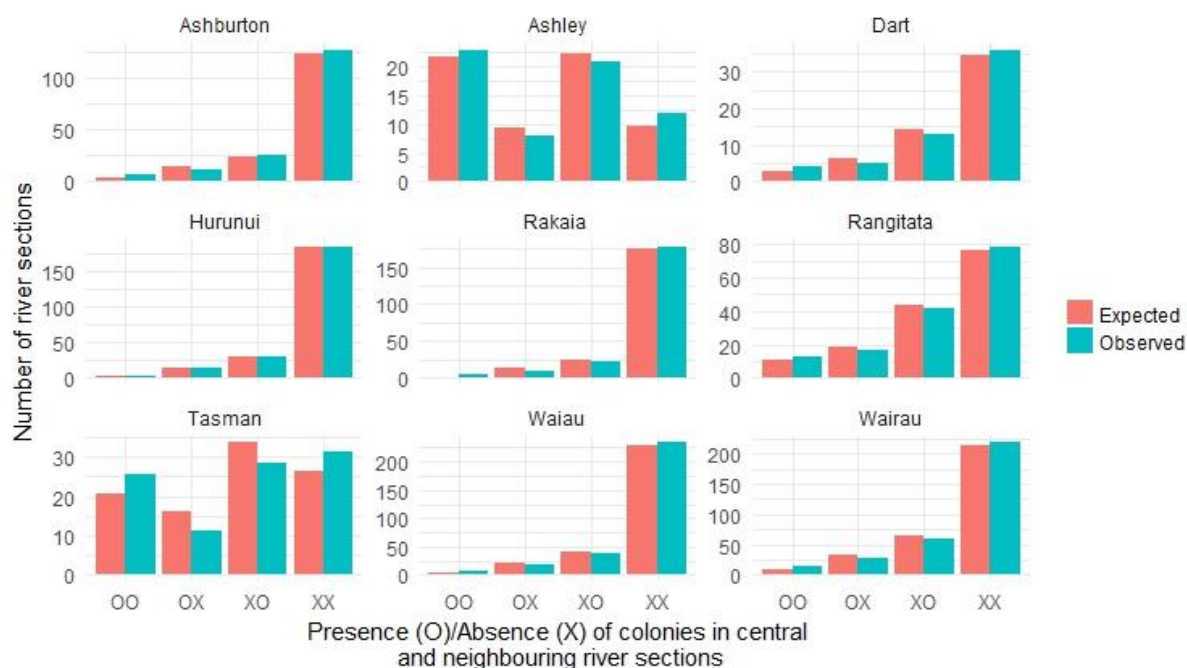


Figure 2: Colony clustering results comparing the observed (blue) and expected (red) number of river sections in the different categories: OO- colony in the central river section and a colony in either or both of the neighbouring sections, OX- Colony in the central river section but not in either neighbour, XO- No colony in the central river section but a colony in either or both of the neighbours and XX-no colonies located in the central or neighbouring river sections.

2.3.2 Colony size

Data from twelve rivers was included in the analysis of colony size having been collected consistently and on consecutive years. Across all rivers, there was no significant difference between the size of a colony and its proximity to its nearest neighbouring colony in the previous ($P = 0.305$) or following year ($P = 0.164$). Overall, more sites had negative relationships between colony size and the distance to the nearest colony location: eight and nine out of twelve rivers for the previous and following year respectively. The negative relationship was significant in the Waimakariri River ($P = 0.028$) for colony size and the distance to the closest colony in the following year (Figure 4). This suggests that in the Waimakariri, colony locations in the following year are likely to be found in closer proximity to large colony locations than to smaller colonies in the previous season. Two river populations had significant, positive relationships between colony size and the distance to the nearest colony, indicating that as the colony size increased so too did the distance to the nearest colony location. The Orari ($P = 0.035$) in relation to colony locations in the previous year, and the Ashley River in relation to both colony locations in the previous ($P = 0.039$) and following ($P = 0.045$) years (Figures 3 & 4).

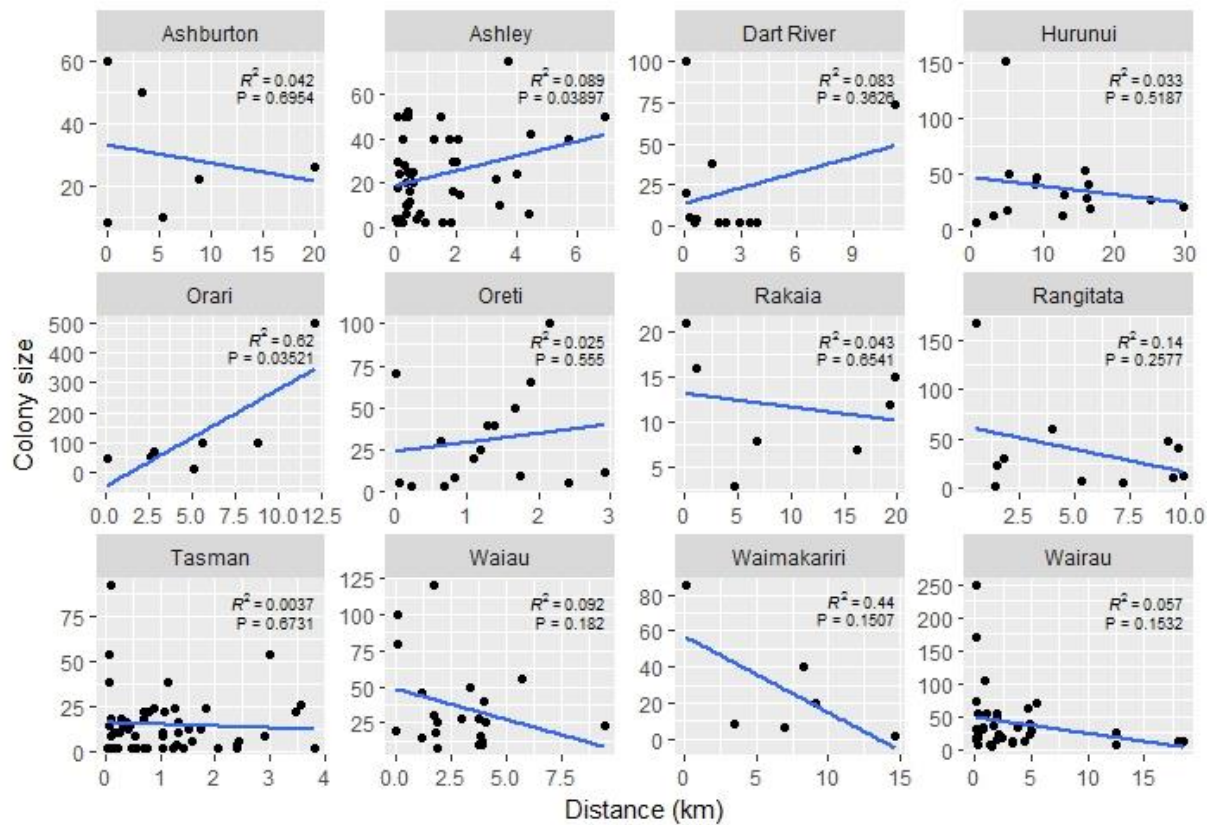


Figure 3: Linear regression results for the relationship between colony size and the distance (km) from the nearest colony location in the previous year. The results are broken down by river.

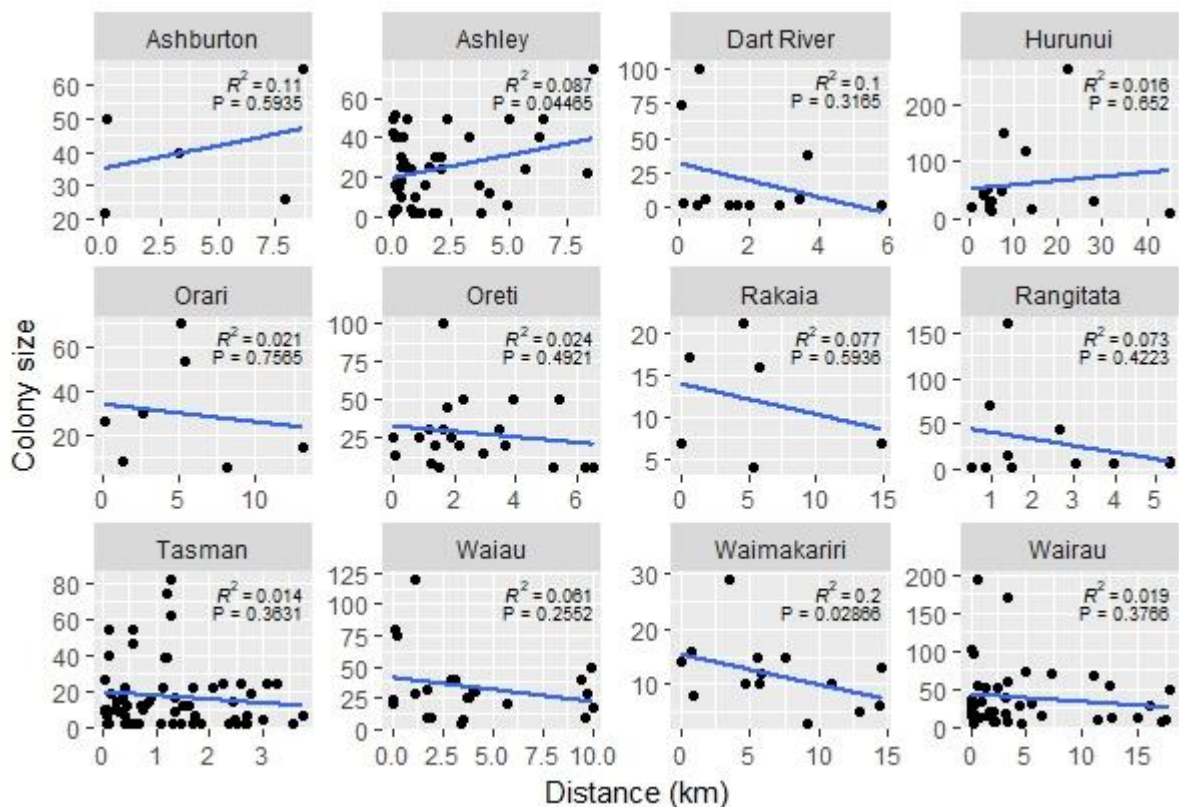


Figure 4: Linear regression results for the relationship between colony size and the distance (km) from the nearest colony location in the following year. The results are broken down by river.

2.4 Discussion

Overall there is support for the prediction that black-fronted terns demonstrate low site-fidelity. Only two out of nine river populations had a spatial colony distribution significantly different to that expected due to random chance, indicating that black-fronted terns do not tend to return to the same breeding locations. Our *a priori* prediction was low site-fidelity because of the instability of their braided river breeding habitat and poor breeding success (McNicholl 1975, Switzer 1993). Low site-fidelity indicated by these results is comparable to that found in other marsh terns (black (*Chlidonias niger*), whiskered (*C. hybridus*) and white-winged black terns (*C. leucopterus*). Like black-fronted terns, the low fidelity in other *Chlidonias* terns is also 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).

Despite strong indications of low site-fidelity overall, black-fronted tern colony locations were more clustered than expected; colony locations were more likely to be found in proximity to past breeding locations (within 900m) than areas in which breeding colonies had not been recorded. Clustering of colony locations may indicate that terns have a tendency to breed in particular regions of rivers. For example, in the Ashley River three river sections (900 m stretch of river) contained colony locations for ten out of twelve seasons, compared to the mean expected occupancy of 2.33 colony locations in twelve seasons. The potential for 'regional' fidelity in black-fronted terns is supported by the 'main colony sites' presented by Keedwell (2002). Of the eleven colony locations monitored by Keedwell (2002), three were used 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.

Environmental conditions 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. the island may no longer exist). Rather than persisting in sub-optimal habitat they move to a more suitable location. 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). 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. Therefore, as with least terns, strong site-fidelity without the ability to cue of environmental factors would be highly disadvantageous for black-fronted terns.

On the other hand, greater use of colony locations in rivers or river sections which remain stable and suitable for extended time frames are expected. These trends were seen in the colony distributions in the Ashley and Tasman rivers which were significantly different to random chance. These two

rivers also had the longest survey records of ten and twelve, respectively. It may take extended periods of surveying to be able to identify these preferred locations over those which 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 referred 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.

In the Upper Ohau River there is another example of the reuse of stable, suitable colony locations. Data from the Upper Ohau were not included in the current analysis as data around the Tern Island colony was not collected as part of a full survey. 'Tern Island', a 300 m long island in the Upper Ohau River, has had a black-fronted tern breeding colony present for more than ten successive breeding seasons to date. The Upper Ohau River flow has been artificially stabilised since the 1991, reducing natural fluctuations in flow and the frequency and size of flooding events. As a result, the Upper Ohau River is relatively stable, facilitating the continued existence of Tern Island beyond the life of the average braided river island. Since 2009, Tern Island has been the focus of an intensive "best effort" predator control project by Project River Recovery (Anderson and Woolmore 2009). This project combines current best practice methods for the control of predators in a 1 km radius surrounding Tern Island. In the five years of intensive management around the island, the colony has increased from a peak population of ~220 birds in 2010 (Woolmore et al. 2012a) to at least 696 in 2014 (S. J. Anderson, personal communication, 2017). 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.

Interpretation of the GPS colony location data may be complicated by the lack of standard protocol for the collection of GPS colony data. The spread out nature of black-fronted tern colonies results in colonies spanning an average of 12,000 m² (based on mean of 48 nests at 0.4 nests/100m² measured by Keedwell (2002)). GPS points recorded at either end of the same colony could be several hundred meters apart. Inconsistent recording of the GPS colony locations could impact how accurately the colony clusters reflect the real distribution of colony locations. 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, conclusions were drawn from trends in the data from eight and twelve rivers for the spatial distribution and colony size analyses respectively. Using data from multiple rivers and averaging the results across multiple arbitrary river section boundaries reduced the influence any error may have in the data.

Additionally, there is no way to determine whether the same terns are returning to these clustered colony locations from this historic dataset. It is possible that different groups of terns were attracted to the clustered colony locations each year because of some 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 role of site fidelity in black-fronted tern colony dynamics.

Colony size mostly negatively related to the proximity of colony locations in the previous or following breeding seasons. This negative trend was significant in the Waimakariri River with respect to the proximity of a colony the following year. This finding supports our *a priori* hypothesis and current views in the literature, the locations of larger colonies have been found to have a greater probability of being reused, whereas smaller colonies were more likely to be abandoned (Buckley and Buckley 2000, Lombard et al. 2010).

The current analysis does not account for movements of colonies between river systems. Black-fronted tern individuals and colonies do move between neighbouring river systems. For example, Keedwell (2002) found that 23% of the re-sighted terns which were banded in the Ohau River, were found in the adjacent rivers, the Tekapo or Twizel Rivers. It is likely that the significant positive relationship in the Orari River, with respect to colony locations in the previous year, was due to the movement of a colony between river systems. The trend was largely driven by one colony of 500 terns, recorded in 2010, which was more than 20 km from the nearest Orari colony location in the previous year. This colony appeared in the Orari following the loss of a similar sized colony in the Lower Rangitata River earlier that same year (R. Maloney, Department of Conservation, personal communication). When this colony point is removed from the analysis the relationship remains positive but is no longer statistically significant ($P = 0.134$).

In the Ashley River, large colonies were further away from other colony locations compared with small colonies, in both the previous and following years. The Ashley River is subject to substantial human disturbance and periods of low or no river flow. Low-flow rates increase the colony accessibility to predators, facilitate weed encroachment and decrease the availability of breeding and foraging habitat. Under these conditions black-fronted terns are likely to fail frequently and their breeding success to decline (Hughey 1985, Keedwell 2002). Keedwell (2002) found that lower breeding success in a black-fronted tern colony substantially reduced the likelihood that a breeding colony location would be reused the following season. Whereas, breeding colony locations where black-fronted terns bred successfully were always used in the following breeding season. Variable

breeding success has been recorded for black-fronted terns on the Ashley River. However black-fronted breeding success in the Ashley has not been substantially lower than that recorded in other river systems and is therefore unlikely to explain the movement of colony sites. Alternatively, the significant movement of colony locations in this river may be explained by potentially large distances between areas of suitable breeding habitat. Weed encroachment in these rivers can rapidly render sections unsuitable for tern breeding (O'Donnell and Moore 1983, Hughey 1985, Taylor 2000), thus forcing the birds to use areas further away from desired or previous sites.

In conclusion, analysis of historical black-fronted tern colony locations supports our *a priori* hypothesis of low 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 which remain suitable. This is supported by the clustering of black-fronted tern colony locations observed in my results and the findings of other studies, such as Keedwell (2002) and Rebergen and Woolmore (2016). Black-fronted terns may more reliably return to suitable 'safe' locations which are relatively stable and can be protected from predation. Tools such as social attraction may be used to facilitate the establishment or re-establishment of black-fronted tern colonies in these 'safe' locations. The use of social attraction tools for black-fronted terns is explored in Chapter 3. Greater consistency in the location of black-fronted tern colonies would substantially increase the efficiency and effectiveness of their management.

Chapter 3

The potential of social attractants as a conservation tool for black-fronted terns



Black-fronted tern colony in the upper Ashburton River (C. Hamblin)

3.1 Introduction

Social attraction is a sensory-based conservation technique in which attractants are used to establish, or re-establish breeding colonies (Arnold et al. 2011, Jones and Kress 2012). Social attraction techniques simulate active breeding colonies to manipulate conspecific attraction (the attraction of individuals to other members of their species) in the target species and lure them to a chosen location (Jones and Kress 2012). Most colonial seabirds use conspecific cues as indicators of habitat quality, which can increase their probability of breeding success (Ahlering and Faaborg 2006, Arnold et al. 2011). Social attraction using a combination of decoys and chick translocations, was successfully used to restore Atlantic puffins (*Fratercula arctica*) to a historical nesting site on Eastern Egg Rock Island, Maine in 1973 (Jones and Kress 2012). Since that pioneering work, social attraction techniques have been used in restoration projects on at least 49 seabird species at 100 sites in 14 countries (Jones et al. 2011, Jones and Kress 2012).

A variety of social attractant techniques, are now used in seabird restoration projects around the world. Terns are one group of seabirds for which social attractant techniques are often used. Decoys, audio playback (non-aggressive calls) and mirrors (simulating larger colonies and turning prospecting birds into living decoys) are the most common techniques utilised for the attraction of tern species (Parker et al. 2007, Jones and Kress 2012). Less common techniques include the use of fake nests, eggs, chicks, even guano (Gummer 2003). In general, rounded, three dimensional decoys, painted to resemble the target species, have been found to be most effective for the attraction of tern species (Podolsky 1990, Feare et al. 2015). Painted, 3D carved wooden decoys are commonly used in social attractant projects (Kress 1983, Blokpoel et al. 1997). For many species, the actual shape of the decoys seems to be less important for an attractant, so long as it is rounded and has the colouration of the target species (Kotliar and Burger 1984). Burger (1989) found that painted conch shells were just as attractive to least terns (*Sterna antillarum*) when used to supplement carved decoys. Similarly, Feare et al. (2015) observed positive responses from sooty terns (*Onychoprion fuscatus*) to painted crow decoys which were considerably larger than the terns themselves.

The arrangement and number of decoys used in different social attractant projects have varied considerably. For terns, the most attractive decoy arrangement has been found to be the combination of both paired (placed closer together) and single decoys (Burger 1988, Podolsky 1990). The overall number of decoys used in different projects has ranged from three decoys for fairy terns (*S. nereis davisae*) (Jeffries and Brunton 2001), 10-20 for least terns (Burger 1988) and 28-50 decoys for Arctic terns (*S. paradisaea*) (Kress 1983, 1997), to 99 decoys for Caspian terns (*Hydroprogne caspia*) (Collis et al. 2002). It is likely that the natural colony size and density for a particular species may provide an indication of the most attractive set up for that species. Least terns, for example,

were more attracted to larger groups of tern decoys, 20 rather than 10 decoys, and to larger decoy spacing, 1.5 m rather than 0.5 m spacing, correlating with their natural inter-nest distance of 0.5-6.8 (Burger 1988).

Audio lures have been identified as primary proximate cues signalling an active colony and driving nest site selection in common terns, with decoys acting as secondary cues which are only attractive in the presence of audio playback (Arnold et al. 2011). The addition of audio playback using non-aggressive, active colony sounds have generally been found to elicit stronger positive responses to social attractants when compared to decoys alone (Arnold et al. 2011, Feare et al. 2015). The combination of both visual and audio attractants is most commonly used and has been found to facilitate a greater response from most species than either alone (Arnold et al. 2011, Feare et al. 2015).

Terns, as a group, have proven to be very responsive to social attractants. Social attractants have facilitated the re-establishment of tern colonies to historical sites including the restoration of Arctic terns (*Sterna paradisaea*) to Eastern Egg Rock, (Maine, USA), using decoys and audio playback (Kress 1983), as well as common terns (*S. hirundo*) to Ice Island in the St. Lawrence River, (Ontario, Canada) using decoys only (Blokpoel et al. 1997). Both studies also required gull (family Laridae) control to be successful. Gulls both compete for breeding habitat and prey on the eggs and chicks of terns leading to colony abandonment. Great black-backed (*Larus marinus*) and herring gulls (*L. argentatus*) breeding colonies were eliminated prior to the use of attractants in Maine, and ring-billed gulls (*L. delawarensis*) required constant exclusion using a grid of microfilament lines which deterred gull landing. Social attractants were also used to establish Caspian, least and Forster's (*S. forsteri*) tern colonies on temporary barges in Commencement Bay in Washington State, on the Missouri River in Missouri State and at four lake sites in North-eastern Illinois State (Collis et al. 2002, Ward et al. 2011).

In New Zealand, social attractant researchers have found significant positive responses in fairy terns (*S. nereis davisae*) (Jeffries and Brunton 2001) and decoys have facilitated the establishment of a new Australasian gannet (*Morus serrator*) colony at Young Nick's Head Peninsula (Sawyer and Fogle 2013). Buxton et al. (2015) found that grey-faced petrels (*Pterodroma gouldi*) and fluttering shearwater (*Puffinus gavia*) responded significantly to audio playback, contrasting with the lack of attraction demonstrated by the flesh-footed shearwater (*Puffinus carneipes*). Social attractants, combined with chick translocations, also facilitated the successful establishment of common diving petrels (*Pelecanoides urinatrix*) and fairy prion (*Pachyptila turtur*) populations on Mana Island (Jones et al. 2011). Ongoing social attraction trials are being conducted on Caspian terns in Port Waikato (K.

Opie, personal communication, February 2016) and black-billed gulls (*Larus bulleri*) in multiple locations throughout New Zealand (Scrimgeour 2016, Popenhagen 2017).

Two social attraction trials have been attempted for black-fronted terns, with inconclusive results. A trial conducted in the Ruataniwha wetlands, Mackenzie Basin, deployed attractants at two sites within the wetlands, one a historical breeding site and the other where no previous breeding had been recorded (Anderson et al. 2007). Two different decoy types, moulded plaster and printed pictures glued onto both sides of foam blocks, and an audio playback system were deployed at each treatment site (Anderson et al. 2007). A second trial was in the Upper Wairau Valley on a historical nesting site, again using the combination of decoys and audio playback (Steffens 2008). The decoys used in the Wairau trial were wooden and much larger than those used in Ruataniwha, more than double life-sized. The larger size of the decoys used in the Wairau trial may have been based on the idea that they would act as super-stimulus and generate a greater response. Both trials were unclear in their results and no robust conclusions could be made about the efficacy of social attractants for black-fronted terns. A nest scrape was located close to the Ruataniwha experimental site and two nests were located close to Wairau site, suggesting that at least some terns may have been attracted to breed at the sites. However, a lack of monitoring prevented further conclusions from being made (Anderson et al. 2007, Steffens 2008).

Use of social attractants to dictate the locations of breeding colony has facilitated the establishment of colonies in new, safe locations and the re-establishment of historic colonies (Kress 1983, Gummer 2003). Black-fronted tern colonies are frequently found in new locations within and between breeding seasons, making it difficult to manage river reaches for their protection. Social attractants may be used to facilitate the formation of black-fronted tern breeding colonies in locations which can be managed effectively. If the terns can be encouraged to breed consistently in certain sites it would allow the establishment of predator and weed control focussed on managing black-fronted terns and their habitat. Alternatively, attractants may allow the terns to be lured to existing management areas.

In this chapter I investigate the behaviour of black-fronted terns in response to social attractants and determine whether it is possible to attract them to chosen locations. Previous trials with black-fronted terns and studies on other similar species suggest that the terns should show positive responses to social attractants as they are likely to demonstrate strong conspecific attraction due to the instability of their habitat and lack of permanent breeding colony locations.

3.1.1 Research Questions

- Are black-fronted terns attracted to interact with social attractants?
- Can camera traps effectively capture black-fronted tern behaviour around social attractants?
- Does habitat influence the attraction of black-fronted terns to social attractants?

3.2 Methods

3.2.1 Study area

The Canterbury region is a stronghold for braided rivers in New Zealand, containing 59% of the nation's braided rivers, within which breed 60% of the black-fronted tern population (O'Donnell and Hoare 2011). Social attractants were deployed in nine braided rivers throughout Canterbury from the Upper Waimakariri River in the north to the Ahuriri River in the south (Figure 5). The rivers included in the study were selected based on four factors: the presence of black-fronted terns in the river catchment, a range of high and low river flow rates, the presence and absence of pest management, and river reaches with low to high levels of weed invasion (Table 3).

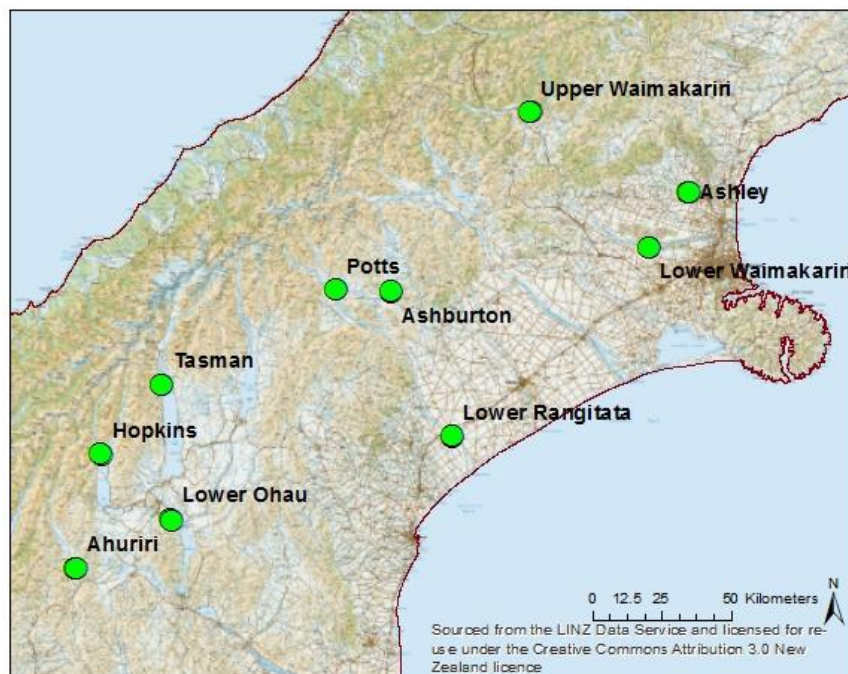


Figure 5: Map of the ten social attractant experimental site locations

Site selection

Within each river, a combination of expert advice (Richard Maloney, DOC), logistic viability, flood protection and avoidance of previous nesting sites (where known), dictated the site and plot (treatment and control areas within a site) selection. The Ashley River was an exception to these selection guides. The Ashley River plots were on predetermined islands which had been machine cleared from weeds, using bulldozers, for the braided river birds by the Ashley-Rakahuri Rivercare Group. Two plots were set up at each site and were at least 200 m (284 ± 98 , $n = 10$) apart to avoid sound contamination of the control plot. At the first site (Ashley River) selected plots were randomly assigned to either treatment or control. The rest of the sites alternated which plot was upstream or downstream of the other plot.

3.2.2 Social attractants

Audio playback

Tracks were played through a USB sound anchor system (Department of Conservation Electronics Unit) with a horn speaker and powered by a 12V SLA battery. The sound anchor system plays tracks from a SD card on a schedule programmed into the USB sound anchor software program. Tracks played through the sound anchor system at their maximum volume (audible from ~150m directly in front of the speaker, under calm conditions). Audio systems were housed in a live capture possum cage traps which were wired closed with zip ties to deter human or animal interference.

Two different playback schedules and two sets of audio tracks were used. The first set up (audio #1) used a black-fronted tern recording (track 37, 1 min 10 sec in length) from the McPherson Natural History Unit Sound Archive (sound recordist, Les McPherson). Audio #1 was played from 6:30am-5:00pm (approximately just after sunrise until just before sunset) on a 5 minute playback schedule of 1 minute on and 4 minutes off from the 28 August through to the week of October 12. After that time, all sites were changed to audio #2. Audio #2 was composed of three tracks, each ~10 minute long combining the original audio #1 track with recordings from a tern colony in the Ahuriri River (recorded by the author). The audio tracks included a variety of different black-fronted tern calls, including 'fish', 'begging' and 'kit' ('ki') calls described by Lallas (1977). Audio #2 was also played from 6:30am-5:00pm, but on an approximately 10 minute on 10 minute off schedule. The change to audio #2 was made to increase the variability and duration of the play-back calls, and reduce the chance of the birds acclimatising to the recording. Audacity® and Raven Lite 2.0, Cornell Lab of Ornithology, were used to edit and remix the all of the audio tracks used.

Table 3: Descriptors of the rivers included in this study. Mean flow rates are classified as low (<10 m³s⁻¹), moderate (10-29 m³s⁻¹), high (30-99 m³s⁻¹) or very high (>100 m³s⁻¹), following O'Donnell and Hoare (2011). * Counts from nest or colony monitoring, not complete surveys

Region	River	Flow (High, Moderate, Low)	Weed status (none, low, moderate, high)	Predator control	BFT population at last known survey	Reference
North Canterbury	Ashley	Low	High	Y	128 (2015)	Ledgard (2016)
	Lower Waimakariri	Very High	Moderate	N	424 (2009)	DOCDM 95401
	Upper Waimakariri	Very High	Low	N	401 (2014)	Jolly (2015)
Mid Canterbury	Upper Ashburton	Low	None	Y	21 (2015)	DOCDM 443900
	Lower Rangitata	Very High	Moderate	N	603 (2015)*	Edwards (2016)
	Potts	Low	Moderate	Y	16 (2014)*	DOCDM 1502112
South Canterbury	Ahuriri	Moderate	None	N	363 (2001)	O'Donnell and Hoare (2011)
	Hopkins	High	None	N	21 (1994)	O'Donnell and Hoare (2011)
	Lower Ohau	Low (controlled)	Moderate	N	408 (2009)*	DOCDM 172676
	Tasman	Very High	None	Y	318 (2016)	S. Cleland, Department of Conservation, Twizel

Decoy construction

Decoys were moulded from Victor® utility plaster using the two part plaster mould created for the first DOC social attractant trial in 2006 (Anderson et al. 2007). Moulds were covered in a layer of Vaseline and then lined with glad wrap prior to pouring the plaster. The first half of the mould was poured with plaster and tooth picks were used as a scaffold to help link the two halves together. Once the first half of the mould had set, the second half was poured and the first half (set) was aligned and placed on top allowing the two halves to set and be joined together. Each half mould required at least half an hour to set. Decoys were gently removed from the moulds, excess plaster was removed and any cracks or breaks mended with wet plaster. Decoys were left for at least two weeks to dry completely before being sanded and painted. All decoys received three full coats of Resene® sureseal (used to ensure a waterproof finish) exterior paint tinted to a slate grey colour. The coloured details were added last using Resene® test pot colours sun, black and white for the beak, black cap and white stripe respectively (Figure 6).



Figure 6: Photos of a decoy, on the left, an up close view, and on the right, one in the field (Potts site).

Set up

Ten decoys were placed in each treatment plot in a hexagonal arrangement alternating between single and paired decoys (facing toward each other $\sim 0.3\text{-}0.5$ m apart) around a single central decoy (Figure 7). All single or pairs of decoys were ~ 2 m from any other decoys and faced either up or downstream. Black-fronted terns generally have very large inter-nest distances, although they can vary substantially, Lalas (1977) measured inter-nest distances ranging 4.5-48m with a mean minimum of distance of 16m. The decoy spacing used in the current study more closely approximated the clustering of black-fronted terns which occurs when terns settle and roost at a breeding site in the weeks before they establish nests (Steele et al. 2009; personal observation). The horn speaker was placed facing either up or downstream, directing the sound away from the control plot and over the decoys, to reduce the chance of sound contamination between plots.

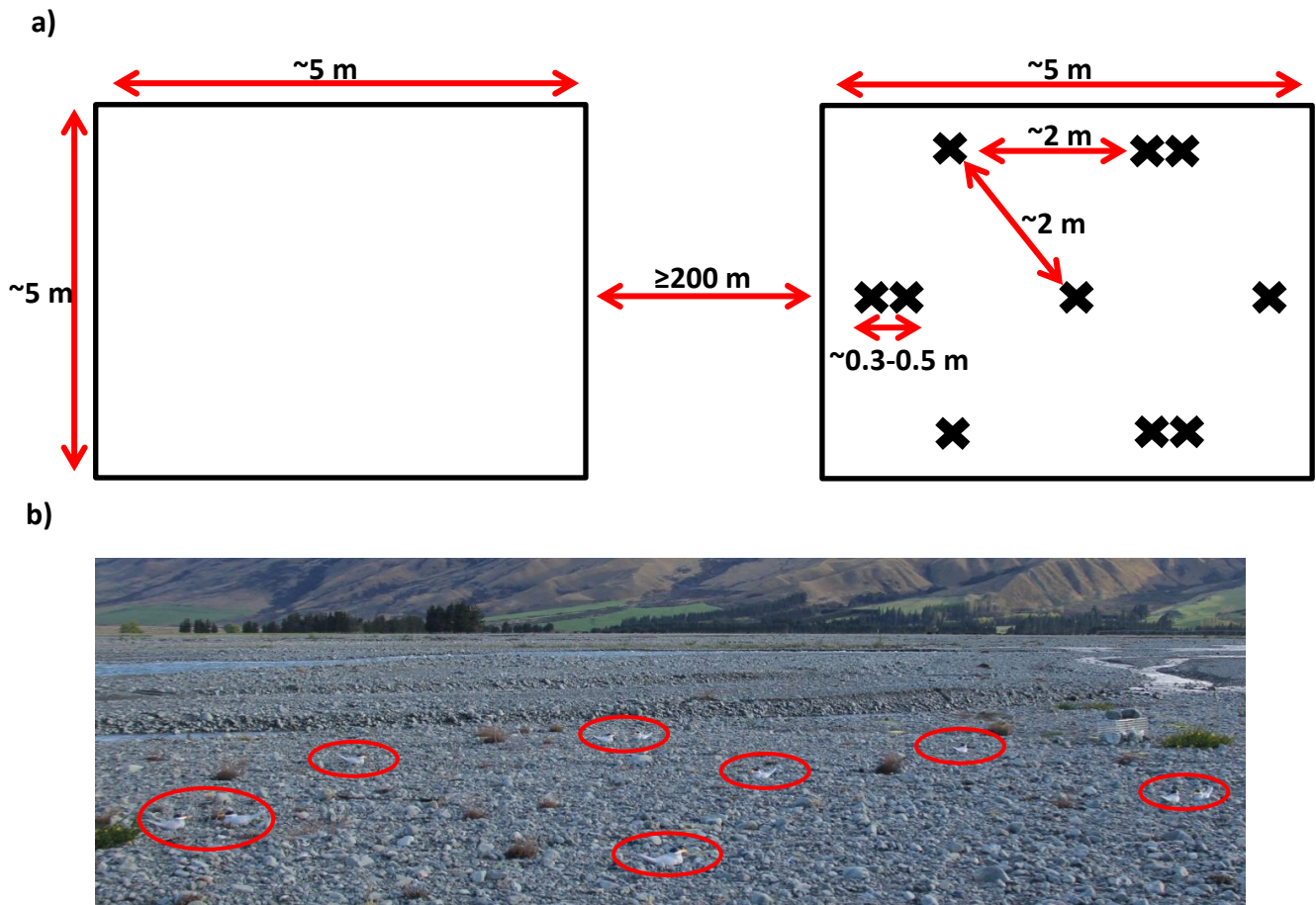


Figure 7: Site and treatment plot decoy set up. a) Diagram of the plot positions, control plot on the left and treatment plot on the right. In the treatment plot the decoy arrangement is shown by the black crosses. b) Photo of the treatment plot in the Potts River, the decoys are circled in red.

3.2.3 Behavioural observations

Behavioural observations were recorded from a site 50-80 m from the plot. Observation sites were chosen to have a clear view of the plot, using a vantage point slightly higher than the nest sites where possible in order to observe ground behaviours more accurately. Tern behaviours were recorded with respect to the centre of the plot area occupied by the attractants at the treatment plot ($\sim 25 \text{ m}^2$) or equivalent area at the control plots, and the larger area of $\sim 100 \text{ m}$ radius within which the terns' behaviour may be reliably influenced by the attractants. Five tern behaviours were recorded continuously throughout the hour's observation on the Neukadye Timestamped Field Data[®] app (version 1.3) with extra notes taken in a notebook (Table 4).

All observations were carried out between 7:30 am and 5:00 pm. The time at which observations were carried out at any particular site was varied for each visit by changing the order in which sites were visited each day. This was to control for differences in tern activity based on the time of day.

Table 4: Tern behaviours recorded during observations sessions.

Behaviour	Behaviour description
Pass	A tern which passes through the plot area without demonstrating any interest or interaction with the plot.
Circle	A tern either completely or partially circles the central plot.
Hover	A tern comes to a complete stop, either holding its position against the wind or flapping rapidly to maintain its position over the central plot.
Land-in	A tern lands within the central plot (~25m ²).
Land-out	A tern lands outside the central plot but within the 100 m radius. The approximate distance and location with respect to the plot were recorded.

Intensive monitoring was carried out for the first ten days in the Ashley and Lower Waimakariri rivers, starting the 31 August. For this intensive monitoring period both sites were visited daily and the plots observed for successive 90 minute sessions. The remaining eight sites were set up by 14 September, after which observations were carried out across all ten sites at least once every two weeks and for an hour at each of the treatment and control plots at each site. Observations plots (treatment and control) were observed either concurrently using a field assistant, or successively. For concurrent observations, observers alternated which plot they observed at a particular site. If a single observer was conducting the observations, the observation sessions were completed successively and the order in which the plots were observed was alternated on each visit to a particular site.

Environmental conditions were estimated and recorded at the start of each observation session (Table 5). Site condition data were collected to examine interaction between tern attraction and the site characteristics. Observations were not completed in unsuitable weather conditions, such as rain or gale force winds, above ~70 km/hr. If the conditions deteriorated during an observation period, that period was cut short and the length of observation completed was recorded. A scan count was also completed at the start and end of each observation session, where the observer stood at the observation site and used binoculars to count all visible terns. The maximum number of terns observed for the entire observation session, including the scans, was also recorded.

Recorded behaviours were split into two data sets, one containing central plot interactions (circle, hover and land-in events) and the other containing land-out events. Only the behaviours observed in the first hour of the initial 90 minute sessions, in the Ashley and Lower Waimakariri Rivers, were included to be comparable with the rest of the data. For both datasets, the association between the total number of interactions and the plot type (control vs treatment) was modelled using a negative binomial GLM.

Table 5: Conditions recorded at the start of each observation session. Temperature degree and wind speed classifications are approximate. All wind values are in km/hr and temperature in °C. wind speed classifications were based on Russell (2010).

Condition	Levels				
	Cloud cover	Clear (0-25%)	Some cloud (26-50%)	Cloudy (51-75%)	Overcast (76-100%)
Wind	Calm (<1)	Light (1-19)	Moderate (20-38)	Strong (39-50)	Very Strong (>50)
Temperature	Cold (<5)	Cool (6-12)	Mild (13-18)	Warm (19-25)	Hot (>25)

The negative binomial model was the more appropriate than the Poisson model based on the Akaike’s Information Criterion (AIC). A backward elimination model selection was then used to determine the most parsimonious model based on both AIC and chi-squared LRT P-values (see below). The following explanatory variables were assessed for potential inclusion as fixed effects in the model: plot, site (river), observer (see below), time of day, cloud cover, temperature, wind strength and time of year. The time of year variable was tested in two forms, monthly and biweekly, on both datasets. The observer variable was unbalanced as one observer completed 67% of the observations and others did not conduct observations at all sites. The unbalanced nature of the observer data resulted in the exclusion of this variable from the model. Data from the Hopkins site was also excluded from the model. Observations at this site were ended early, due to the low number of terns and flood risk to equipment, essentially making the time of year variable unbalanced at this site. Observations with missing environmental condition data, 21 out of 276 observations, were also removed prior to final model selection.

Starting with the full model, variables with the highest P-values (> 0.05) were dropped sequentially, until the minimum adequate model (MAM) was obtained. After all non-significant variables were eliminated from the model, the interaction between plot and site was tested for significance. This interaction was investigated to determine whether any difference in the number of interactions between plots were consistent among sites. Model predictions from the MAM were then estimated using least-squared means, and multiple Tukey contrasts were carried out to determine the significance of different levels of any significant categorical variables. All analysis was conducted in R (3.3.0) via R studio (0.99.903) and using dplyr (0.5.0), MASS (7.3.45), lsmeans (2.25), multcomp (1.4.6) and lubridate (1.6.0) packages.

Number of interactions over time

Central plot interactions at the treatment plot were used to investigate any trends in interaction over the monitoring period. The number of interactions recorded during each observation session was converted into a percentage of the total number of interactions per site. Cumulative graphs over

time were then produced for the number of interactions at each site, and the average number of interactions over time. Plyr (1.8.4) and ggplot2 (2.2.1) were used to produce the graphs.

3.2.4 Camera traps

The use of camera traps to replace live observation was trialled at five sites in the Ashley, Lower Waimakariri, Ashburton, Tasman and Lower Ohau rivers. Ltl acorn 5210A cameras were used with the camera settings of photo size 5 MP, 3 photo bursts with 0 sec interval and normal sense level. In each of the five sites one camera was mounted on an 800 mm waratah (metal post) and angled over each of the treatment and control plots. Cameras were placed 2-3 m from the edge of the central plot area (~ 5-6 m from the centre of the plot) (Figure 8). The exact camera placement was dictated by the substrate and the ability to secure the waratah in the ground. The batteries and SD cards were changed during each visit to the site. The cameras were running 24 hours/day. The number and species of all birds which triggered the cameras were recorded along with the date and time the photo was taken. Other species and notable events caught on camera were also recorded with the exception of hares and rabbits as they were ubiquitous across all sites and plots.



Figure 8: Picture of the treatment plot in the Upper Ashburton River. The black outline encloses the central plot area. The red circle is around the camera trap monitoring this plot.

Camera trap data was summarised into the following groups: black-fronted terns, avian predators, other native bird species, other introduced bird species, mammalian predators, disturbances (events likely to disturb breeding terns) and unknown (species/objects recorded in each group are recorded in Appendix B).

All groups were individually analysed using a GLM, using AIC to determine the best error link function, and P-values to determine significance of fixed effects, 'site and plot'. Again, the interaction

between the five sites and plot (treatment vs. control) was investigated. All model predictions were computed using least-squared means. All data was summarised using R packages lsmeans (2.25), lubridate (1.6.0) and dplyr (0.5.0) and presented in mean camera trap photos per trap day.

3.2.5 Nearest nesting

The nearest tern nesting locations to each plot and site were recorded throughout the breeding season. 'Near table' in ArcMap 10.3 was used to calculate the distances between treatment (from the audio set up) and control plots (centre of the plot) and from the experimental plots to the nearest recorded nest or colony GPS point. The distance to the nearest nest location was used where possible. Colony GPS points were substituted if nest GPS points were not recorded. Summary statistics on distances were calculated in R.

3.2.6 Habitat assessment

Habitat assessments were carried out at each treatment and control plot and in active colony sites where possible. Two 100 m parallel belt transects (10 m apart, to capture the diversity of the habitat) were walked following the line of the river, centred on either the plot or colony. Each transect was systematically sampled obtaining measures from twenty 1 m² quadrats. The percent cover of different substrate classes: sand and fine gravel (<10 mm), coarse gravel (10-49 mm), cobble (50-100 mm), boulder (>100 mm) were measured following Maloney et al. (1997). Vegetation cover within each quadrat was classified as none (0%), low (1-25%), moderate (26-50%) or dense (>50%) and the major vegetation type (ground cover, grass, herb, shrub, tree) was also recorded. The maximum and minimum distances from the nearest waterbody were recorded for both plots using the farthest and closest points of the central 25m² area. At sites where the nearest colony site was located, all nests were GPS recorded and the distance from the closest and farthest nests to water were recorded.

The analysis of the habitat data was completed using two different datasets. The first dataset compared habitat parameters at the treatment and control plots. The second dataset compared the habitat parameters at experimental plots, where breeding did not occur, to tern breeding sites near the trial sites. Both comparative datasets were analysed using the most parsimonious GLM for each habitat class, determined by the AIC values and P-values as detailed above. 'Site' was initially treated as a random effect but was changed to a fixed effect as it became clear that there were significant differences in habitat between sites. AIC values indicated that including 'site' as a fixed effect was a

much better fit. Ultimately, only fixed effects, 'site and plot', were significant in the model. Model predictions were then computed using least-squared means.

3.3 Results

3.3.1 Behavioural observations

Central plot interactions

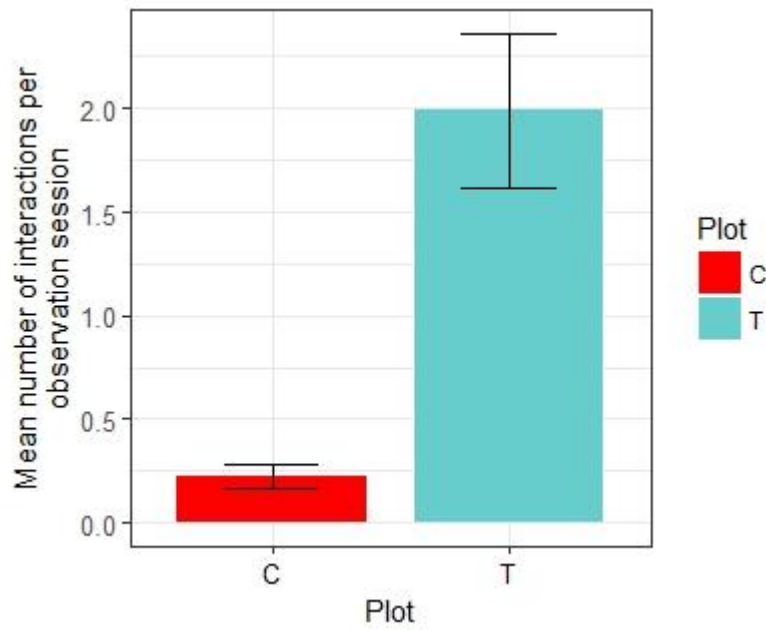
The minimum adequate model (MAM) for the central plot interaction data (including circle, hover and land-in behaviours) consisted of plot, site and date as main effects (Table 6). Overall, there were significantly more interactions at the treatment compared to the control plot ($P < 0.001$) (Figure 9a and 9b).

Table 6: AIC model selection table for the number of central plot interactions, all models are all negative binomial, except one labelled Poisson which was included for comparison. MAM only contains significant explanatory variables, $P < 0.05$ based on LRT (likelihood ratio tests).

Model	AIC	Δ AIC	K
MAM – number of interactions~plot+site+date	643.64	0	19
Number of interactions~plot+site+wind+date	645.68	2.04	24
Number of interactions~plot+site+temp+wind+date	645.10	1.46	29
Number of interactions~plot+site+time+temp+wind+date	646.64	3.00	33
Number of interactions~plot+site+time+cloud cover+temp+wind+date	651.66	8.02	36
Poisson link function - Number of interactions~plot+site+time+cloud cover+temp+wind+date	1021.6	377.36	36

The Ashburton site had the greatest number of predicted interactions with significantly ($P < 0.03$) more than five of the other eight sites (Lower Ohau, Lower and Upper Waimakariri, Potts and Tasman). Of the analysed sites, the Potts site had the fewest interactions, significantly less ($P < 0.02$) than the Ahuriri, Ashburton and Lower Rangitata sites. The greatest number of interactions, when all rivers were combined, occurred during the two week block starting 17 October, significantly more than in November or December ($P < 0.02$) (Figure 10).

a)



b)

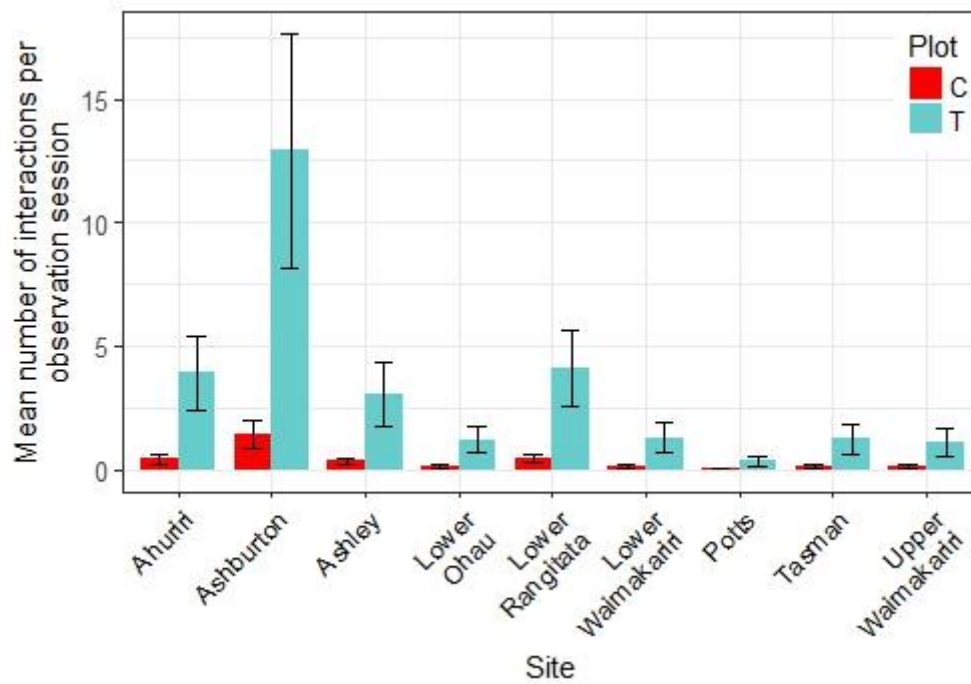


Figure 9: The number of central plot interactions a) by plot, b) by site and plot (red and blue colours represent the control and treatment plots respectively). The error bars represent \pm SE.

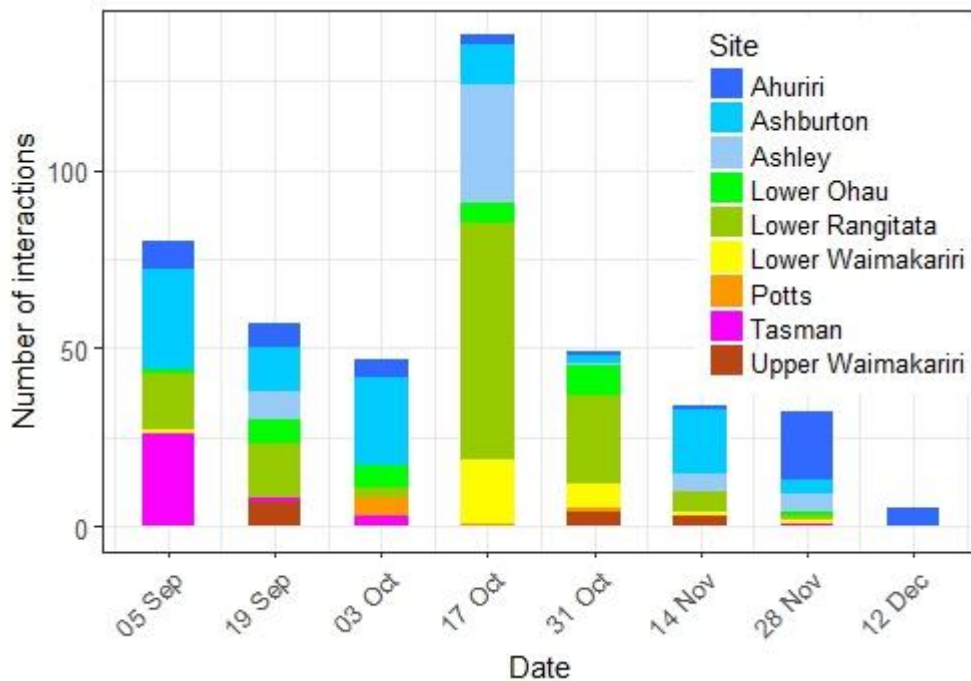


Figure 10: The number of central plot interactions by time of year (bi-weekly throughout the season) and site (colours represent the different sites).

Land-out event data

Three main effects (site, temperature and wind) were significant in the MAM for land-out event data (Table 7). Plot was not significant to the model. There were significant differences for land-out events between sites (Figure 11a). The Ashburton River had the greatest number of predicted events, significantly ($P < 0.03$) more than six other sites (Ashley, Lower Rangitata, Lower and Upper Waimakariri, Potts and Tasman). The predicted number of land-out events also differed significantly by temperature class (Figure 11b). Cold temperatures correlated with the greatest number of land out events, significantly more than three other classes ($P < 0.02$). Significantly more land-out events occurred under calm conditions compared to moderate winds ($P = 0.003$, Figure 11c).

Table 7: AIC model selection table for land-out interactions (number of interactions), all models are negative binomial with one exception of the full Poisson model included for comparison. MAM only contains significant explanatory variables, $p < 0.05$ based on LRT (likelihood ratio tests).

Model	AIC	ΔAIC	K
MAM – Number of interactions ~site+temp+wind	762.7	0	15
Number of interactions ~plot+site+temp+wind	762.9	0.2	20
Number of interactions ~plot+site+time+temp+wind	764.8	2.1	25
Number of interactions ~plot+site+time+temp+wind+month	773.5	10.8	28
Number of interactions ~plot+site+time+cloud-cover+temp+wind+month	780.5	17.8	32
Poisson - Number of interactions ~plot+site+time+cloud-cover+temp+wind+month	2247.1	1484.4	32

Interactions over time

Overall, there was a substantial amount of variation between sites with respect to the number of interactions over time. The percentage of total interactions observed during the first observation session (when the attractants were deployed) ranged from 0% in the Hopkins, Potts, Upper and Lower Waimakariri, to 86% in the Tasman (Figure 12). Based on the mean cumulative curve, more than 75% of the interactions were completed before the 31 October. Two sites deviated substantially from the mean, the Ahuriri and the Tasman. In the Ahuriri 55% of the interactions occurred in the last month of observation (after the 21 November). The Tasman had the opposite trend with 100% of the interactions recorded before 4 October.

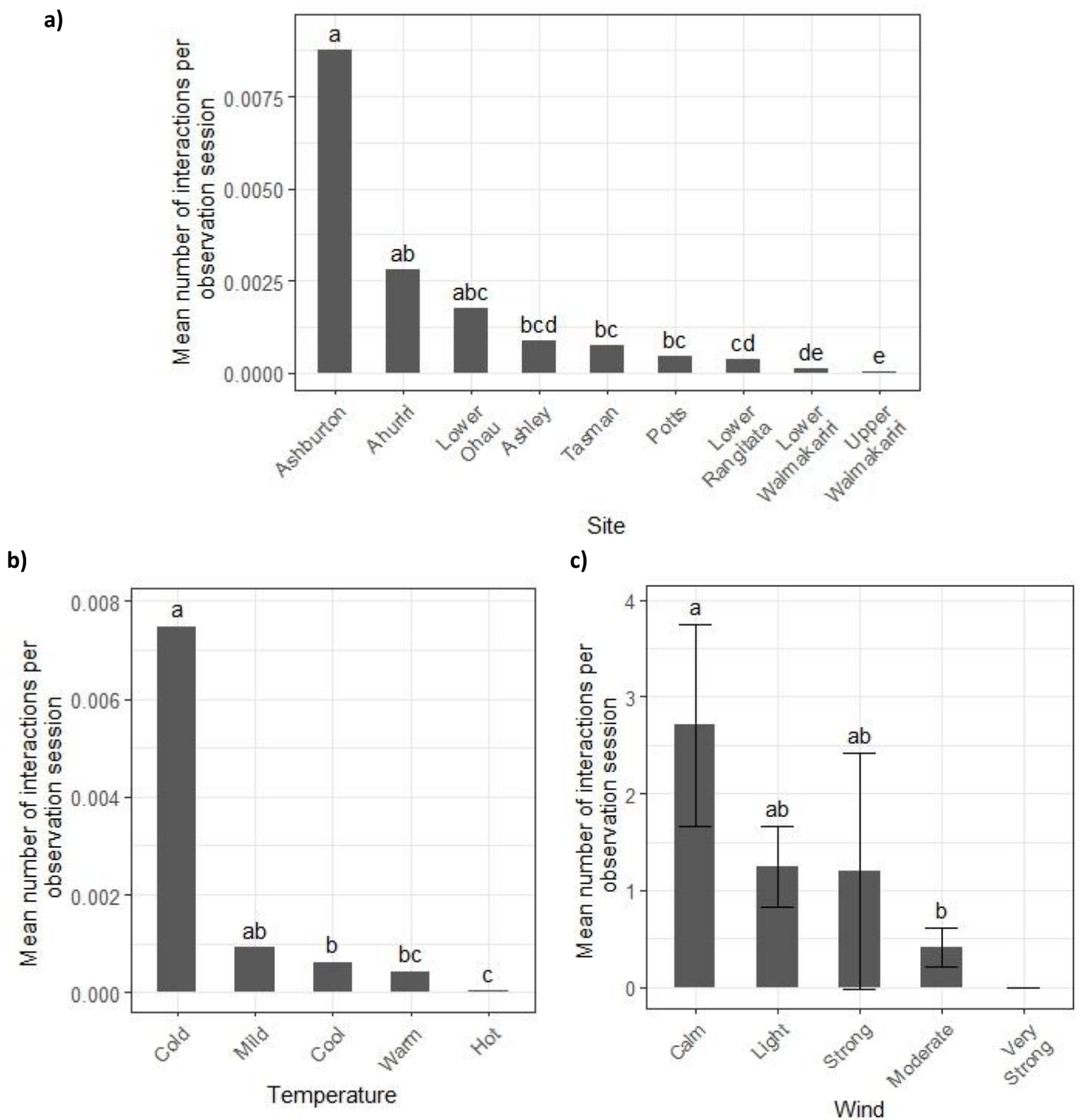


Figure 11: The mean number of land out events per observation session a) by site, b) by temperature, c) by wind speed. The data are presented in back-transformed means. The error bars represent SE and were excluded from (a) and (b) as the errors around the small values were too great for inclusion.

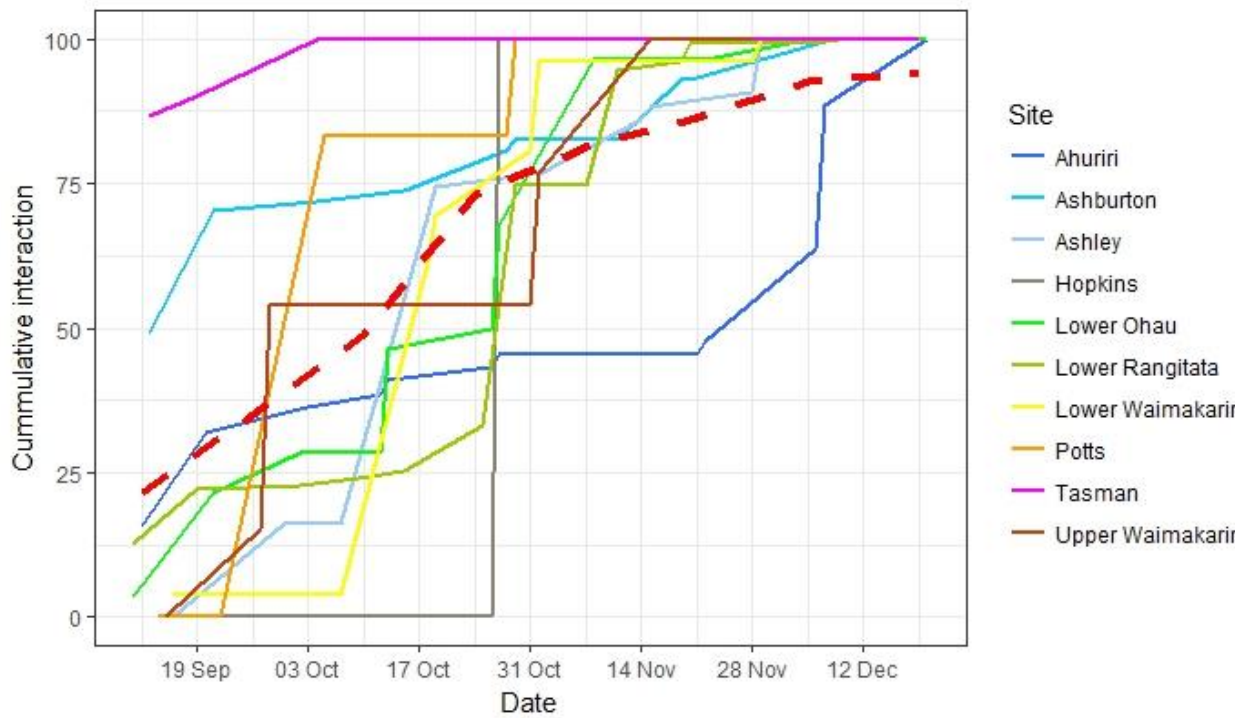


Figure 12: Cumulative graph of the percentage of the total number of interactions over time. The red dotted line represents the average cumulative curve.

3.3.2 Camera trap data

Over 783 trap days, across 10 cameras, a total of 436 camera trap photos contained objects of interest (0.557 photos/trap day). ‘Other birds’ was the most commonly recorded group (0.321 photos/trap day), recorded more frequently than all other groups combined (Table 8). Overall, more photos were recorded at the treatment sites compared to the control plot with 0.324 and 0.232 photos/trap day, respectively. Although this difference was not significant overall, there was a significant interaction between site and plot (Table 8). More photos were recorded at treatment plots compared to control plots for three of the five sites. This difference was significant for two of them, Lower Ohau ($P < 0.001$) and the Ashburton ($P < 0.001$) (Figure 13a). The remaining two sites had more photos at the control plot and this difference was significant for the Lower Waimakariri ($P < 0.001$).

Modelling each group individually, the interaction between site and plot was significant for terns, other birds and avian predators (Table 9). For tern photos, the Ashburton site had significantly greater records at the treatment compared to the control plot (Figure 13b). Differences between plots were not significant for any site for other birds. There were some significant differences in the number of photos recorded at different plots between sites. The Ashley had the greatest number of

photos recorded, with significantly more photos at both treatment and control plots than the Lower Ohau and Lower Waimakariri ($P < 0.001$) (Figure 13c).

Table 8: Camera trap data by group and plot given in the number of photos/trap day and the overall number of photos.

Group	Treatment	Control	Total	Number of photos
Other birds	0.171	0.149	0.321	251
Disturbance	0.041	0.041	0.082	64
Black-fronted terns	0.057	0.011	0.069	54
Unknown	0.031	0.017	0.047	37
Avian predators	0.018	0.006	0.024	19
Mammalian predators	0.006	0.008	0.014	11
Total Overall	0.324	0.232	0.557	436

Avian predators were the only group in which there was a significant overall difference between the control and treatment plots ($P = 0.0043$). The Ashburton was the only site with significant differences between the number of avian predator photos recorded at each plot ($P < 0.001$) (Figure 13d). The Ashburton also had significantly more photos recorded at the treatment plot than for the treatment plot at any other site ($P < 0.02$).

Table 9: AIC model selection table for all groups that could be modelled. Each model is based on the following GLM: number of group photos each trap day ~ Site + Plot, with the exception of a negative binomial with interaction in which there is an interaction between site and plot.

Group	Model	AIC	Δ AIC
Overall	Negative binomial with interaction	1266.8	0
	Negative binomial	1329.3	62.5
	Poisson	1758.7	491.9
	Normal	3130.7	1801.4
Black-fronted tern	Negative binomial with interaction	329.73	0
	Negative binomial	353.75	24.02
	Poisson	388.15	58.42
	Normal	674.54	344.81
Other birds	Negative binomial with interaction	760.35	0
	Negative binomial	775.89	15.54
	Poisson	1060.6	300.25
	Normal	2823.4	2063.05
Avian predator	Negative binomial with interaction	-593.73	0
	Normal	-584.47	9.26
	Poisson	190.62	784.35
	Negative binomial	192.42	786.15

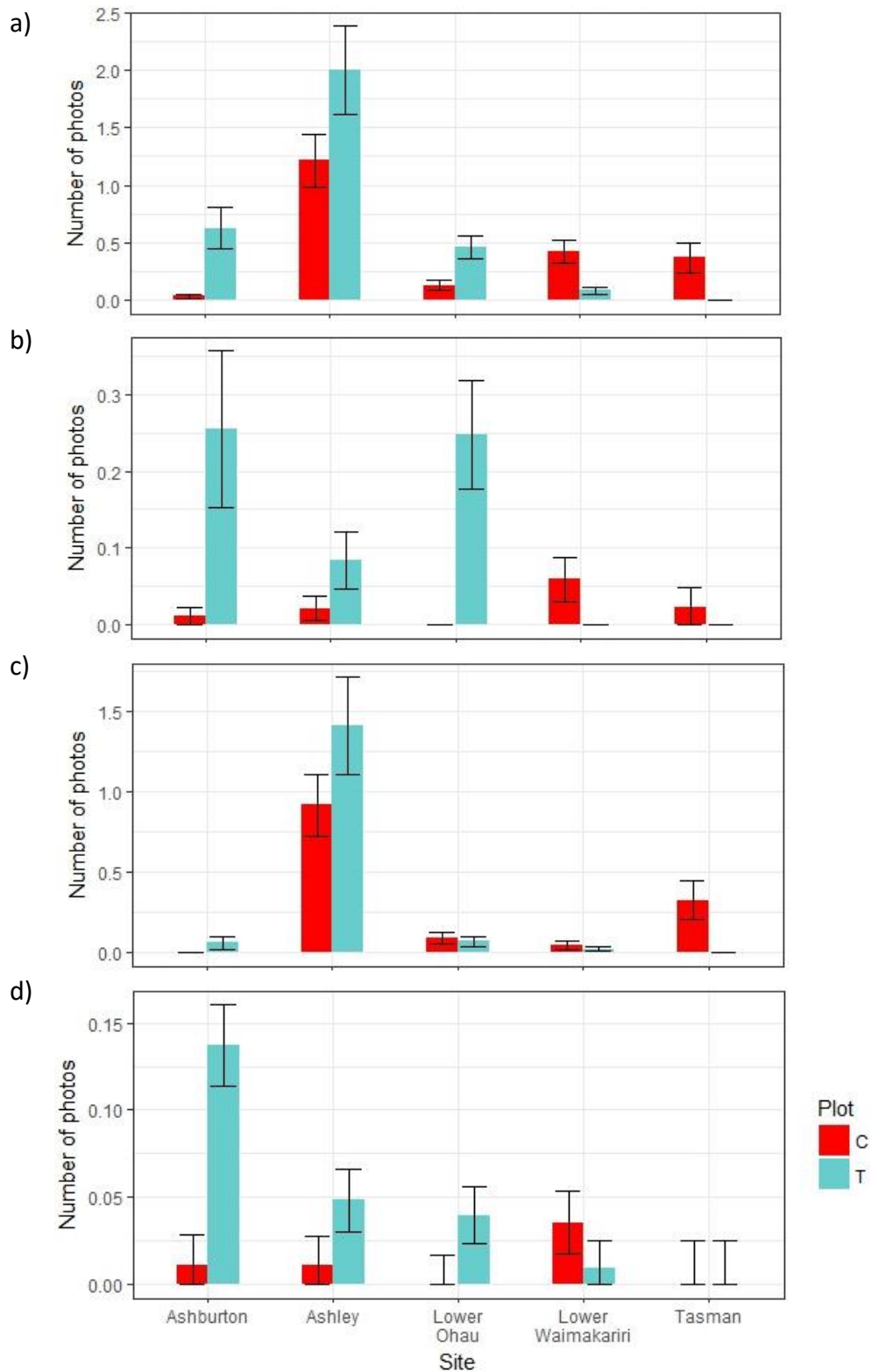


Figure 13: The number of camera trap photos by site and plot for each of the groups a) overall, b) black-fronted terns, c) other birds and d) avian predators. Error bars are SE. The red and blue bars represent the control and treatment plots respectively.

3.3.3 Nearest nesting

Tern nesting was recorded in proximity to 8 out of 10 sites. The distance to experimental sites were calculated using nest locations for six sites and colony locations for the remaining two (Ashley and Lower Waimakariri). The distance to nesting terns ranged from 31-7452 m and 14-7197 m for treatment and control plots respectively (Table 10). Terns bred less <300 m from both plots at 5 out of 8 sites.

Table 10: The distance from each experimental plot to the nearest recorded tern nesting activity. Two sites, Hopkins and Upper Waimakariri, are not included as no tern breeding was recorded in proximity to the plots.

Site	Distance of nesting to nearest plot (m)	
	Treatment	Control
Ahuriri	217	267
Ashley	5259	4808
Lower Ohau	45	98
Lower Rangitata	31	228
Lower Waimakariri	7452	7198
Potts	269	120
Tasman	1761	1992
Upper Ashburton	67	14
Mean	1888	1841

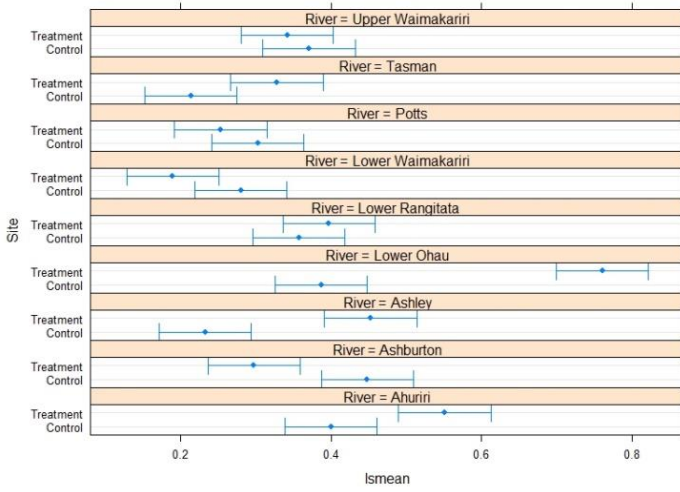
3.3.4 Habitat assessment

Linear models with interactions between plot and river, and an arcsine transformation for substrate classes, were the most parsimonious for all habitat variables (Table 11). A range of 1-4 of nine sites measured had significant differences in the percentage cover of substrates and 6 out of 9 sites had significantly different vegetation cover between plots ($P < 0.05$) (Figure 14). The differences between treatment and control were consistent across sites for 2 out of 5 substrate types: cobble, significantly greater cover at treatment (two sites), and gravel, significantly greater cover at control (one site). Significant differences between the habitat at tern breeding and non-breeding locations were found at 2-3 out of 6 sites across the variables measured ($P < 0.05$) (Figure 15). These differences were not consistent across sites for any of the habitat variables. The majority of the differences were explained by two sites, Lower Ohau and Ashley, which both differed significantly in 4 out of 5 habitat variables measured.

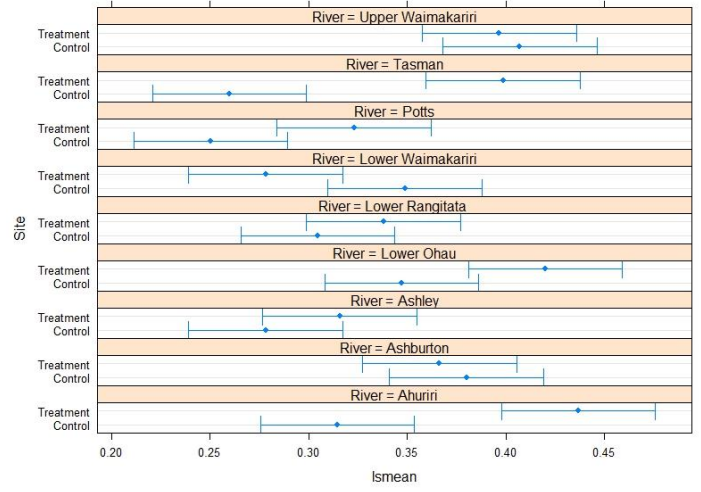
Table 11: Model fitting for the different substrate cover measures. Arcsine transformation with an interaction has the following structure: habitat cover ~ plot (or breeding) * river. All other models follow the same structure, with river as a random effect (habitat cover ~ breeding + (1 | River)) but the data was put through different transformations.

Substrate	Model	Plot		Breeding	
		AIC	ΔAIC	AIC	ΔAIC
Boulder	Arcsine transformation with interaction	-271.2	0.0	-147.8	0.0
	Arcsine transformation	-157.8	113.4	-115.8	32.0
	Log transformation	2248.9	2520.1	1957.4	2105.2
	Logit transformation	2442.6	2713.8	2153.9	2301.7
	Linear	5866.8	6138.0	5297.2	5445.0
	Binomial	12820.	13091.	12134.	12282.
Cobble	Arcsine transformation with interaction	-922.2	0.0	-757.4	0.0
	Arcsine transformation	-879.6	42.6	-732.4	25.0
	Log transformation	1643.4	2565.6	1510.0	2267.4
	Logit transformation	1791.2	2713.4	1641.6	2399.0
	Linear	5003.7	5925.9	4494.2	5251.6
	Binomial	6729.6	7651.8	6224.2	6981.6
Gravel	Arcsine transformation with interaction	-261.3	0.0	-208.7	0.0
	Arcsine transformation	-231.6	29.7	-140.6	68.1
	Log transformation	1869.4	2130.7	1732.1	1940.8
	Logit transformation	2173.0	2434.3	2011.5	2220.2
	Linear	6034.0	6295.3	5420.6	5629.3
	Binomial	13207.	13469.	12526.	12735.
Sand	Arcsine transformation with interaction	-7.7	0.0	67.2	0.0
	Arcsine transformation	72.4	80.1	131.7	64.5
	Log transformation	1366.2	1373.9	1369.8	1302.6
	Linear	6456.3	6464.0	5791.6	5724.4
	Binomial	17988.	17996.	17312.	17245.
Vegetation	Linear with interaction	1109.1	0.0	1110.1	0.0
	Linear	1175.0	65.9	1220.9	110.8
	Poisson	1531.0	421.9	1442.8	332.7

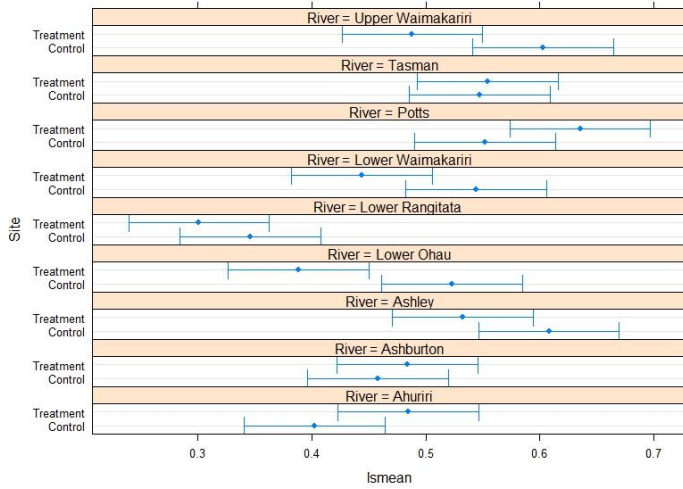
Boulder



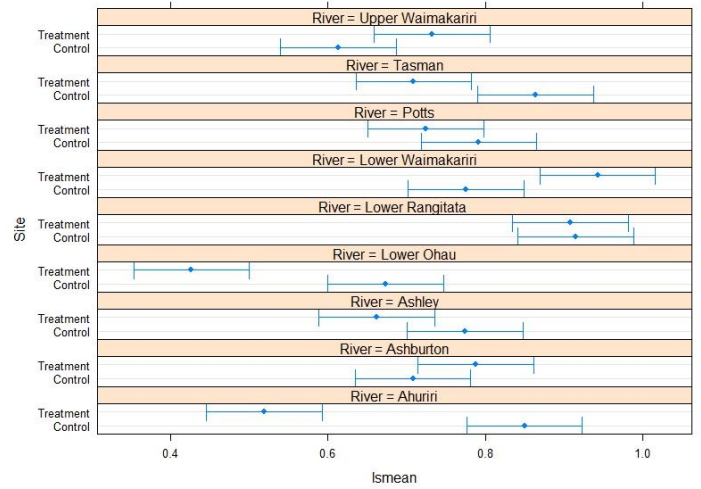
Cobble



Gravel



Sand



Vegetation

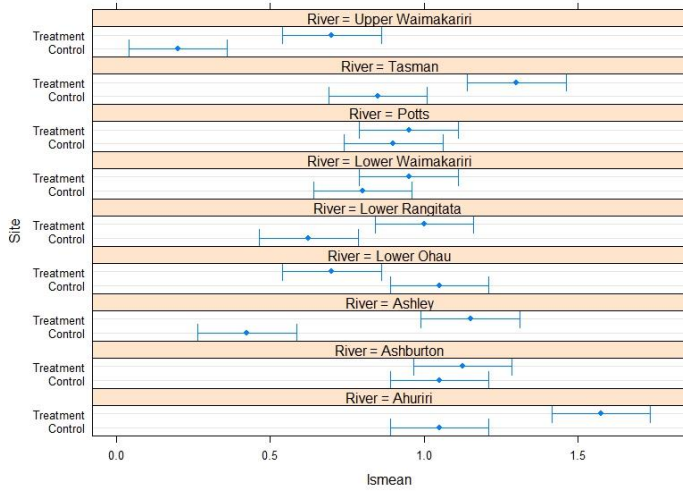
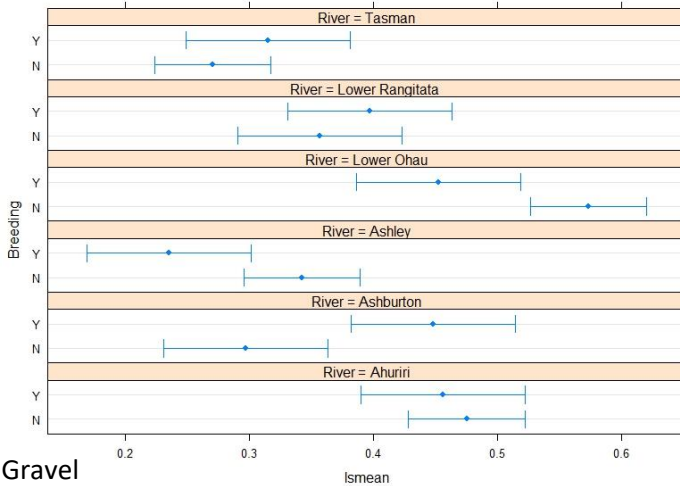
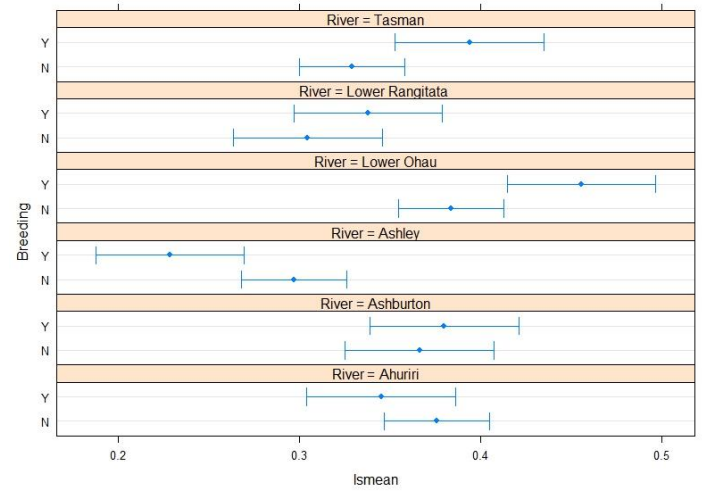


Figure 14: Model predictions by habitat class at treatment and control plots across sites. Error bars represent a 95% confidence interval.

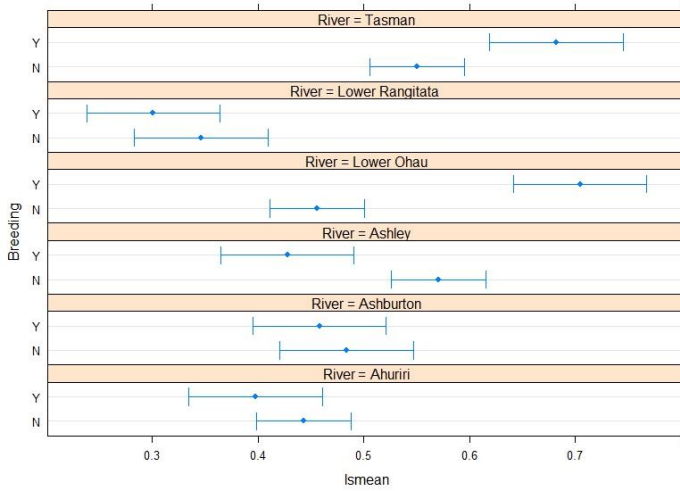
Boulder



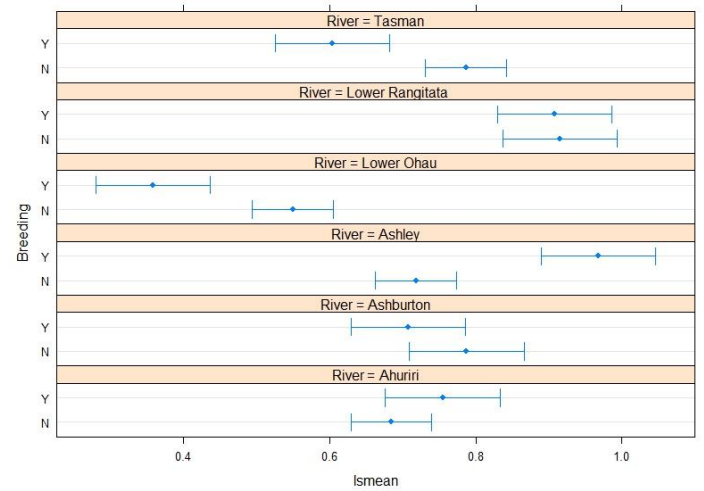
Cobble



Gravel



Sand



Vege

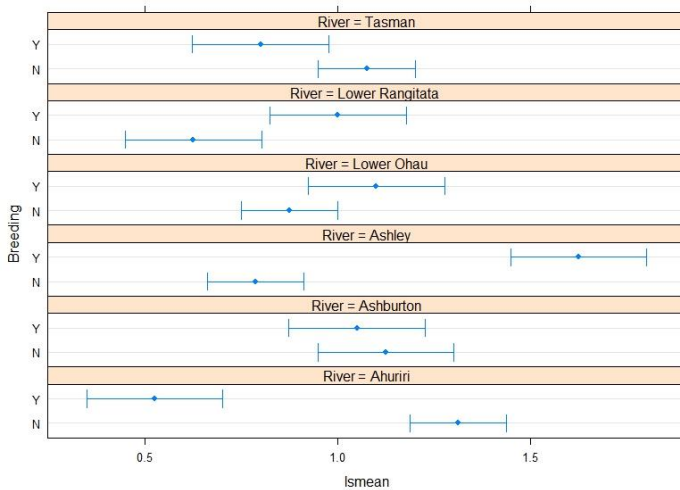


Figure 15: Model predictions by habitat class at breeding (Y) and nonbreeding (N) locations across sites. Error bars represent a 95% confidence interval.

3.4 Discussion

Black-fronted terns appear to be influenced by social attractants. Significantly greater central plot interactions were observed at the treatment plots compared to the control plots. This finding is supported by other social attractant literature which have reported successful outcomes in other tern species, such as, fairy terns (Jeffries and Brunton 2001), common terns (Arnold et al. 2011), Forster's and least terns (Kotliar and Burger 1984, Ward et al. 2011). The difference in the number of interactions between the control and treatment plots was consistent across all sites. In general, a greater number of interactions corresponded with a greater number of terns in the area. There were some exceptions to this generalisation. For example, significantly more tern interactions occurred at the Ashburton site compared to the Ahuriri, although a maximum of 40 terns were observed at each of these sites. This may suggest that terns in the vicinity of an attractant will not necessarily interact with the social attractants. One possible explanation is that terns which have already selected a breeding site may be less attracted to conspecifics. This is supported by observations in the Ahuriri River. In the Ahuriri a tern colony settled on an island across the river from the social attractant set up early in the season, and fewer interactions than expected based on the number of terns observed in the area. In contrast, the terns observed in the Ashburton River were relatively unsettled; several colony locations were abandoned in the early stages of initiation in the area around the experimental plots. Many terns in the Ashburton River would have been searching for potential re-nesting sites therefore making them more attracted to conspecifics.

The difference in interactions between the plots is not confounded by different habitat characteristics. Some individual habitat classes showed significant differences between treatment and control plots, although these were not consistent across all sites and were likely due to variability in the general braided river habitat. The lack of consistent, or significant differences in habitat characteristics support the prediction that differences in behaviour are due to the presence of social attractants.

Contrasting with central plot interactions, plot was not significant to the number of land-out events observed. One possible explanation was the influence of the Ashburton site. The Ashburton site had significantly more land-out events than other sites, the majority of which occurred at the control plot (326 at control and 29 at treatment), where a colony was established halfway through the season. Yet, when the Ashburton site was removed from the model, plot remained insignificant to the model and site remained significant. Alternatively, it is possible that the area in which land-out events were recorded, $\sim 31,415 \text{ m}^2$ compared with $\sim 25 \text{ m}^2$ for land-in events, was too large. Terns landing within this area, particularly in the outer reaches, were unlikely to be doing so due to the influence of the attractants. Across observations at the treatment plots across the sites an average of 20.45

interactions/m² were observed in the central plot area, more than one thousand times the average number of land out interactions/m² observed, 0.011 interactions/m². Compared to the central plot interactions, the number of land-out events may be of little use in determining the efficacy of social attractants.

The greatest number of interactions occurred in the second half of October (two weeks starting 17 October). However, almost half of those interactions (49%) occurred at a single site, the Lower Rangitata. The dramatic increase in tern interaction at the Lower Rangitata site during this period may be explained by prospecting terns which had been displaced by recent flooding events. The observation session with the highest recorded number of tern interactions occurred 10 days after a 150 m³/s flood, which was preceded by a 255 m³/s flood a month earlier (Environment Canterbury 2017). Normal flow rates in the Rangitata are ~50 m³/s. Increases in the river flow by 100-200 m³/s would likely have resulted in nest failure or breeding habitat loss for a large number of terns in this river system. High habitat turnover and generally low colony site reuse may make it more difficult for displaced terns to locate a new colony or suitable breeding habitat. Cueing off conspecifics may drastically reduce the search effort required, therefore it is likely that they will demonstrate strong conspecific attraction and interact with social attractants (Ward et al. 2011). The sudden increase in tern interaction supports strong conspecific attraction in black-fronted terns.

On average, 75% of the interactions occurred in September and October, after which the number of interactions generally plateaued. Two sites, the Ahuriri and the Tasman, differed substantially from the average. In the Ahuriri, there was a relative lack of interaction with the attractants earlier in the season which could be explained by the establishment of a tern colony at the site before the social attractants were deployed. Interestingly, the increased interaction toward the end of the season occurred primarily due to the movement of the adult terns and fledglings from their colony site to the treatment island. In contrast, 97% of the interactions in the Tasman occurred by early October. The early decline in interaction at this site could indicate that the terns in this system became habituated to the presence of the social attractants. Interactions were observed throughout the season at all of the other sites with no indication of habituation. It seems unlikely that habituation would occur in only one population of terns. The majority of the terns observed around the Tasman experimental sites were foraging over a near braid and demonstrated no interest in the nearby attractants. Rather than habituation, perhaps it is more likely that the terns observed near the experimental sites were not interacting as they had already selected a breeding site. Terns often spend several weeks in the vicinity a colony site before settling down to breed (Steele et al. 2009). Terns from the nearest recorded colony, less than 2 km away, could easily have been foraging around the experimental sites. Alternatively, a solitary tern pair or two that went undetected may have nested in closer proximity to the sites and used the braid near the sites to forage. The Tasman is a

very large river with an abundance of suitable tern breeding habitat and it would be easy for a couple of nesting pairs to be missed. A couple of tern pairs in the area would also correspond with the tern numbers (2-5) generally observed at the Tasman site. Observation of a fledgling being fed by two adults <50 m from the treatment plot during the last observation session in December may further support the theory that terns may have nested closer than recorded.

Interactions recorded were not limited to adult black-fronted terns, interestingly juvenile, non-breeding black-fronted terns, were noted to interact with the social attractants. Juvenile interactions were not formally recorded; however the interactions were recorded as points of interest where possible. Juvenile terns were observed at all ten sites at some point throughout the breeding season, with a maximum of three individuals observed, in the Ashley River. Central plot interactions by juveniles were observed at the treatment plots of seven sites and the control plot of one site. In contrast, observation sessions in which only juveniles were observed to simply pass the experimental plot occurred only at the control plots of six sites. These limited records suggest that juvenile black-fronted terns may be substantially attracted to the social attractants. Most interesting, was the prolonged interaction with the attractants that non-breeding birds were observed to demonstrate. For example, there were multiple occasions when the juvenile tern would hover over the audio playback for the duration of the audio track; this behaviour appeared to be less common in the adults. Other studies have also found young or non-breeding birds to be particularly susceptible to artificial cues (Schlossberg and Ward 2004, Friesen et al. 2016). This trend is often explained by young birds prospecting for their first breeding site. Natal-site fidelity is generally low in tern species, therefore dispersing juvenile terns need to locate a new colony location and are likely to cue off conspecifics (Devlin et al. 2008, Jones and Kress 2012).

Ultimately the goal of social attraction is to establish a breeding colony at the chosen location (Jones and Kress 2012). Five of the eight sites at which tern breeding was recorded were less than 300 m from both the treatment and control plots. Of these five sites, three breeding sites were closer to the treatment than the control plot. This is encouraging, particularly the Lower Rangitata and Lower Ohau sites where tern breeding occurred <70 m from the treatment plots and was in closer proximity to the treatment plot compared to the control plot. The Lower Rangitata nest was perhaps the most promising indication that social attractants could facilitate nesting in black-fronted terns as it was located just 26 m from the closest decoy. The most recent recorded nesting in the general area was in 2014, making it unlikely that site fidelity played a role in this site selection. The close proximity of nesting to the attractants combined with the lack of recent breeding in the area, strongly suggests that in this case the presence of the attractants impacted the terns' breeding site selection.

The motivation for site selection was not as clear cut at other sites. For example, in the Upper Ashburton, a tern colony established 67 m from the treatment plot and another colony established 14 m from the control plot (285 m from the treatment plot). Again, it is unlikely that past breeding in this area played a role in selecting this site as the closest historical colony to the experimental plots was in 2007 when a 40 tern colony established 147 m and 186 m from the treatment and control plots respectively (Department of Conservation data DOCDM-443900). The close proximity of tern breeding to both the treatment and control plots makes it difficult to discern the influence that the social attractants had. It is possible that the experimental plots were too close together and the terns nesting at the control plot were also influenced by the social attractants (186 m away). This seems unlikely as there was plenty of suitable habitat closer to the attractants where they could have nested if their site selection was influenced by conspecific attraction. The inter-plot distance used in this study was greater than the general range used in other tern social attractant studies, from 0 to ~100 m (Jeffries and Brunton 2001, Arnold et al. 2011), further supporting the case that the control colony selection was not influenced by the attractants. However, the inter-plot distance in the current study may not have sufficiently accounted for the dispersed nature of black-fronted tern colonies. Black-fronted tern colonies will often cover several hundreds of meters, future social attractant studies on black-fronted terns may benefit from greater inter-plot distances.

Camera traps did not effectively capture the interactions of terns at the experimental plots. A substantially greater number of tern interactions were captured at the treatment compared with control plot, 0.26 and 0.06 photos/trap day, respectively. Although this trend was consistent with the behavioural data the difference between plots was not significant. While cameras may be a good tool to monitor larger tern activity events, such as colony formation, and may be useful to aid in the determination of efficacy of social attractants if direct observations sessions are limited. The cameras were relatively restricted in the individual tern behaviours they captured. Photos of terns flying past the plot, over a nearby braid or in the background, were most commonly recorded, whereas very few aerial interactions, hovering or circling, or ground behaviours were captured. Photos of terns passing by the plots may provide an indication that there are more terns in the vicinity of the plot. However, it does not necessarily suggest attraction to the plot itself, for example they may be attracted to the good foraging habitat provided by the nearby braid. Aerial interactions accounted for 81.3% of the central plot interactions recorded through behavioural observation indicating that the cameras missed a substantial proportion of the interaction behaviours. Many instances were also noted when ground behaviours were recorded during observation sessions yet were not captured on the camera trap photos. Many reasons may explain this disparity, such as a misplaced field of view or obstacles between the camera and where the behaviour occurred. Using multiple cameras per plot would increase the coverage area, potentially reducing the number of behaviours missed.

Video recording of time-lapse photos may be useful alternatives to still photos. Video recording may increase the chance of capturing rapid tern behaviours. Nest predators, have been monitored successfully in braided rivers using video cameras (Sanders and Maloney 2002, Keedwell 2005). Nest predation studies have used video cameras for close and specific targets (eggs, chicks, incubating terns and predation events) likely making it easier to get clear footage which can be slowed down to accurately record rapid events. Getting clear film of a broader target, such as a social attractant set up, is more difficult. Steffens (2008) used a video recorder to monitor black-fronted tern behaviour in the Wairau river social attractant trial. They found their video set up to be inadequate for accurate identification of tern behaviour. Advances in technology since the Steffens (2008) trial may have increased the accessibility of higher quality the video recorders required for accurate video observation of terns. The trade-off of video recording verses still photos is that there is much greater analysis time required to sort through all footage captured. Sanders and Maloney (2002) found that 24 hours of recording could take up to 90 minutes to review, as each event of interest was viewed in slow motion, to ensure accurate recording.

Time-lapse image recording, unlike motion activated still photos, is an event independent recording system (Reif and Tornberg 2006). Time-lapse recording is commonly used for studies in which the target animal are either frequently within the cameras field of view or their activity is frequently repeated (Cutler and Swann 1999). In the context of this study, time-lapse image recording may prove useful as an indication of colony formation, as this kind of activity would result in both an increase in the terns' presence and repetition of activity. Time-lapse recording has been used successfully for monitoring of other colonial bird species, for example, Huffeldt and Merkel (2013) used time-lapse image recording to determine diurnal variation in colony attendance for thick-billed murrets (*Uria lomvia*). Although, time-lapse may be effective at detecting when a colony forms, it is unlikely to be more effective than motion activated still photos as detecting the terns interactions with the social attractants. Early interactions with the social attractants were sporadic and would therefore have a low probability of being captured on the time-lapse frames. Overall, the camera traps, as they were used in this study, were not comparable to the data collected through behavioural observations. Although there are further avenues to be investigated to improve the data they collect, they are not recommended as a substitution for physical observation of behaviours.

While camera traps did not effectively replicate the information gathered through direct behavioural observation they did offer an insight into occurrence of other events and animal interactions at the plots. Overall, at three of the five sites, more photos with objects of interest were captured at the treatment plots and this was significant for tern and avian predator records. These results suggest that both conspecifics and avian predators may be attracted to the social attraction set up. Avian predators primarily use visual cues to search for prey (Dowding and Murphy 2001) and active

colonies with terns moving around are likely to make much more attractive targets than a stationary social attractant set up. If avian predators were attracted to approach social attractants they could investigate the area freely, as there would not be any real terns to actively deter them as there would be in an active colony. The predators may become habituated to the attractants, as they would receive no reward for their investigation, reducing the likelihood that they would investigate further. Alternatively, the presence of the attractants may cause them to link the decoys, a potential food source, to that particular location, potentially endangering any terns which do nest there. Black-fronted terns are well adapted to defend against diurnal avian predation and they are likely able to defend themselves against any slight increases in avian predator interest.

There were no significant differences between plots with respect to the number of mammalian predators recorded, although there was a very small sample size (11 photos, 2.5% of all camera photos). This suggests that mammalian predators were not influenced by the presence of the social attractants. The lack of interest from mammalian predators is supported because they primarily hunt using olfactory cues, which would differ substantially between an active tern colony and the attractants. This finding is in line with the commonly held belief that predators do not respond to social attraction techniques (Ward et al. 2011), although I am unaware of any studies which have formally investigated this.

The habitat analysis results demonstrate that there was very little difference between the habitat characteristics measured at the experimental plots and sites where terns nested (Figure 5). Some habitat classes differed significantly, most of which is explained by two sites. First, the Lower Ohau, in which treatment and control plots were primarily boulder and sand respectively, terns nested in primarily gravel and cobble which was located between the two plots. Second, the Ashley, in which two plots were both artificially created/modified islands, differed significantly in 4 out of 5 habitat classes from the tern nesting island. Despite these differences in habitat there were a substantial number of tern interactions at both of these sites.

One of the dangers of social attraction techniques is that without extensive knowledge of target species, you may be lure birds into potentially unsuitable habitat. Ahlering et al. (2010) suggest that social attraction techniques may be too risky to use on endangered species as we often have an incomplete understanding of their habitat requirements. Currently, our understanding of the requirements for black-fronted tern breeding habitat is very broad, simply that clear gravel islands are preferred, but specific characteristics can differ substantially between rivers (Robertson et al. 1983). However, the terns do breed across a diverse range of river systems with very different geological histories. The site selection and breeding habitat requirements of a species goes beyond the substrate characteristics, the terns may be cueing off a range of other features, such as food

supply. Further investigation of the full range breeding habitat requirements of black-fronted terns, in particular what they are cueing off with respect to breeding habitat selection, would ensure that use of social attractants in the future has the greatest chance for success.

Black-fronted terns interacted significantly with social attractants supporting the hypothesis of strong conspecific attraction. The combination of significant interaction with the attractants, and the close proximity (< 300 m) of tern nesting to five of the experimental sites, suggest that social attractants have great potential for use in future black-fronted tern conservation. The next step would be to identify whether social attractants may be used to influence tern breeding colony locations. Future research would be required to identify the most attractive social attractant set up (audio playback tracks and schedule, decoy number and arrangement) for black-fronted terns to not only interact, but to stay and breed.

Chapter 4

General Discussion



Pair of black-fronted terns in the lower Ohau River (C. Hamblin)

Black-fronted terns are a globally endangered species and at the current decline rates their populations are expected to be 50% of what they are today within the next 30 years (O'Donnell and Hoare 2011). Black-fronted terns breed almost exclusively on the South Island braided riverbeds, forming colonies on bare gravel areas. The two major threats to black-fronted tern survival are predation, primarily due to introduced mammals, and habitat degradation, including weed invasion, low flow rates and human disturbance. Current management practises have proven effective in reducing or reversing the declines of some black-fronted tern populations, however many tern populations remain relatively unprotected. The current research aimed to facilitate more effective management of black-fronted terns through investigation into their colony dynamics and the use of social attraction.

4.1 Main findings

Historic GPS colony locations were used to investigate black-fronted tern colony location dynamics. Overall, black-fronted terns demonstrated high colony site turnover and low site-fidelity. For seven out of nine rivers analysed, the observed historical colony distributions did not differ significantly from random distributions. Changing colony locations frequently has been suggested as both an adaptation to the dynamic braided river environment (O'Donnell and Moore 1983) and as a predator avoidance strategy (Erwin 1978, Ward et al. 2011). Disturbance events have also resulted in frequent changes in breeding colony locations in many tern species, including arctic (*Sterna paradisaea*) (Devlin et al. 2008), black (*Chlidonias niger*) (Shuford 1999), Forster's (*S. forsteri*) and least terns (*Sternula antillarum*) (Ward et al. 2011).

Historic colony locations were also used to investigate clustering in black-fronted tern colony locations. The presence of a colony location within a river section was more likely to have colony locations in either or both of the neighbouring sections. The reverse was observed, for river sections where colonies were absent, the neighbouring sections to be more likely to lack colony locations, suggesting that black-fronted tern colony locations are likely to occur in clusters. Colony clustering may be an indication of a broader regional fidelity, in which black-fronted terns may favour certain regions of rivers in which to form their colonies.

Significant positive results for some rivers in both colony distributions and colony clustering suggest that under certain conditions, black-fronted tern site fidelity may be greater than generally expected. These observations contrast with the more generally accepted view of black-fronted terns as 'fickle' nesters in the braided river environment, frequently changing their colony locations (O'Donnell and Moore 1983, Robertson et al. 1983). However, the findings of Pierce (1983) and Keedwell (2002),

both of which observed tern colonies forming in more consistent locations, support some level of black-fronted tern site fidelity. Anecdotal observations by people who are frequently in these river systems also support that there are some colony locations which black-fronted terns will return to for multiple seasons. For example, the 'Shark's Tooth colony' in the Waiau River was formally recorded in each of the river surveys from 2008-2010 and again in 2015-2017 and is said to be present most years (BRaid). The reuse of black-fronted tern colony locations is often associated with limited availability or greater stability of suitable habitat within a river system.

The current study was the first to intensively monitor black-fronted tern behaviour in response to the presence of social attractants (audio playback and decoys). Black-fronted terns were observed to interact significantly more at the treatment plots where the social attractants were present compared to the control plots with no social attractants. Significant attraction of black-fronted terns to the social attractants suggests that social attractant techniques have the potential to be used in the management of this species. These results are in line with social attraction projects in other tern species around the world (Kress 1983, Blokpoel et al. 1997, Jeffries and Brunton 2001, Collis et al. 2002).

Camera traps were trialled as a possible replacement for human observation of tern behaviour. Data from camera traps were not comparable to the records collected by direct behavioural observation. Cameras sometimes missed interactions which were observed directly and failed to record a substantial number of the aerial (circling and hovering) and ground (landing events) behaviours. There are many different camera set ups that can be trialled to increase the effectiveness of camera traps. However, at this stage, cameras are not recommended as a substitution for physical observation of tern behaviour. The cameras did capture other species present at the experimental plots, the significant presence of avian predators at the treatment plots were of particular interest.

4.2 Future research

Breeding colony dynamics are highly complex and determined by a range of factors, including site fidelity, dispersal, habitat stability and conspecific attraction (Erwin et al. 1981, Roby et al. 2002, Serrano et al. 2004, Palestis 2014). Limited literature is available on black-fronted tern colony dynamics, with most studies focusing on population trends (O'Donnell and Hoare 2011, Spurr and Ledgard 2016), monitoring breeding success or causes of mortality (Keedwell 2002, Sanders and Maloney 2002, Anderson et al. 2007, Steffens et al. 2012). Aside from the current study, the banding project conducted by Keedwell (2002) is the only research that has attempted to explore site fidelity and colony site use in black-fronted terns. Both of these studies have found indications that there are

areas or sites in which black-fronted tern colonies will form with greater consistency as demonstrated through the suggestion of regional fidelity and main colony sites (sites that tended to be reused) in the current study and Keedwell (2002), respectively. Areas to which the terns are more likely to return to and breed are of upmost importance for black-fronted tern conservation. Past breeding success and habitat stability are two of the factors most commonly associated with increasing site fidelity (McNicholl 1975, Cuthbert 1988). These two factors could potentially be controlled or enhanced through management actions such as localised predator control and artificial island creation. Further research is required to determine the major factors influencing black-fronted tern colony site selection.

Information about black-fronted tern site fidelity and dispersal could be gained through banding studies. Black-fronted terns do not generally lend themselves to banding, as their short legs can only fit one band each. Their legs are also concealed during a lot of the breeding season as the terns are most commonly either flying or incubating. However, they do extend their legs when attacking intruders in a colony, therefore photos of terns attacking a person as they walk through a colony may enable the bands to be observed. The use of flagged leg bands, is currently being explored as a way to make individual marking of black-fronted terns easier (R. Maloney, personal communication, DOC, August 2016). The flags are essentially colour bands with a small extra piece of plastic attached which makes the marking more visible (Myers et al. 1983). Banding requires a huge investment of time, not only to band a large enough number of birds, but also in the re-sighting of banded birds. However, this is currently the one of the most effective ways we have of gathering data about the movements of individual birds.

Black-fronted terns were successfully attracted to interact with the social attractant set up in the current study. The terns' interacted significantly more with the attractants, suggesting that social attraction may be a viable tool for the management and protection of black-fronted terns. The next step is to demonstrate that terns can be attracted to breed at predetermined locations. The key to this will be to identify the most attractive social attractant set up for black-fronted terns, will also be important in determining the efficacy of this technique. For terns, audio playback has been identified as the primary proximate cue of a social attractant set up, with decoys acting as a secondary cue (Arnold et al. 2011). Personal observations throughout the current study support this with the vast majority of interactions occurring in response to the audio stimulus. Many recorded interactions occurred directly over the cage housing the audio playback device, and in two separate events an adult tern landed on top of the cage (Figure 15). I could not find anything in the literature which explored the impact of different calls or playback schedules on the success of social attractant projects. I hypothesise that tracks of longer duration and greater call variation are more likely to elicit

a positive response from black-fronted terns. Future social attractant research should include investigation of different audio tracks and the impact they have on the terns' response.



Figure 16: Adult black-fronted tern resting on top of the cage housing the audio playback equipment (C. Hamblin).

The decoys may have been a secondary cue to the audio playback. Very few tern interactions were observed with the decoys alone, when the audio was not playing. However, the combination of both audio playback and decoys has been found to be the most attractive combination of social attractants for many tern spp. (Arnold et al. 2011, Feare et al. 2015). Investigation of different decoys and decoy arrangements may generate greater interest from the terns. I suggest that using more decoys in a more dispersed decoy arrangement and over a wider area, may be a more realistic approximation of a black-fronted tern colony and more attractive to prospecting birds.

Alternatively, when it comes to establishing tern breeding colonies at predetermined locations, the targets may not be the breeding adults, rather the juvenile terns. Juvenile birds will often prospect for potential future breeding sites during their non-breeding seasons. The inexperience of young birds is likely to increase their reliance on conspecifics cues as indications of habitat quality; this tendency can make them highly responsive to social attractants (Schlossberg and Ward 2004, Nocera et al. 2009, Friesen et al. 2016). This was supported by the strong response suggested by observations of juvenile black-fronted tern behaviour during the current study. However, the role that juvenile interactions play in their breeding site selection in later breeding seasons has not been explored.

4.3 Broader applications

Social attraction techniques may have broader applications within the braided river environment. Black-billed gulls (*Larus bulleri*) are another braided river species whose rapidly declining population has resulted in them being listed as critically endangered. Like black-fronted terns, black-billed gulls will frequently change their breeding colony locations and the facilitation of more consistent breeding colony locations would aid more efficient management (Beer 1966, McClellan 2009). Social attraction has been trialled on black-billed gulls in the lower Waimakariri River (Popenhagen 2017) and the Tongariro Delta, Lake Taupo (Scrimgeour 2016) in the 2016-2017 season. Although both of these small scale trials were unsuccessful, there were some indications of interest from the gulls and further trials, with modifications, will be conducted next season.

Use of conspecific attraction may also facilitate the protection of colonial species from anthropogenic disturbances. Most commonly, social attraction techniques are used to restore seabird colonies to historic locations. However, there have been instances in which the technique has been used to achieve other goals. For example, a Caspian tern (*Hydroprogne caspia*) colony in the Columbia River estuary was relocated to a temporary nesting site on a barge in order to reduce predation on threatened salmonid stocks (Collis et al. 2002). Social attractant trials on both Caspian terns, Port Waikato (K. Opie, Personal communication, February 2, 2016) and black-billed gulls, Lake Taupo, (Scrimgeour 2016) aimed to reduce conflict with human activities by moving the birds away from a mining site and power station respectively. The ability to move colonies away from areas of conflict with human activities would both protect the birds and enable the anthropogenic projects to continue.

4.4 Conclusions

Black-fronted terns' small declining population has resulted in their classification as a globally endangered species. Current black-fronted tern management has reduced or reversed some local population declines; however the reversal of their global population declines will likely require a much larger scale management approach. Management strategies have been at either the landscape scale, covering a large area within which terns are likely to nest, or colony scale, in areas where either the terns have nested in the past or around habitat managed specifically for the terns. Landscape management has proven effective for improving black-fronted tern success when all predatory species, not only introduced mammals, are controlled. For example, black-fronted tern breeding success increased following the incorporation of black-backed gull control into the

landscape management in the Tasman catchment. Landscape scale management appears to be good approach for braided river systems with large tern populations or many colonies; however this approach may not be economically viable in systems with smaller populations or few breeding colonies. These river systems may be better suited to the colony scale approach.

Colony scale, intensive management has been effective when colonies have reliably returned to breed in the managed area, as occurred with 'Tern Island'. However, this management strategy is at the mercy of the terns' colony site selection. Developing further understanding of black-fronted tern colony dynamics may facilitate more reliable management at the colony scale. This is particularly true in the light of the regional fidelity indicated by the results of the current study. Regional fidelity may be able to be further consolidated with the additional use of social attractants. This study found that black-fronted terns can be attracted to interact with social attractants. Future research may be able to determine the attractant set up to facilitate breeding colony formation in those areas. Greater understanding of black-fronted tern colony dynamics combined with the use social attraction techniques have the potential to drastically increase the effectiveness of black-fronted tern management.

Appendix A

Historical black-fronted tern breeding colony locations 2004-2015

River	Season	Number of terns	NZTM Easting	NZTM Northing	Formally surveyed (Y/N/Unknown)	Sections surveyed (if known)	Reference
Ahuriri	2004	30	1331724	5083476	N		Unpublished data, Simone Cleland, Department of Conservation, June 2016
	2006	-	1364235	5071334	N		Unpublished data, Simone Cleland, Department of Conservation, June 2016
		-	1362258	5071501			
		-	1361552	5071478			
		-	1361543	5071604			
		-	1361419	5071400			
		-	1353340	5069630			
		-	1353106	5069509			
		46	1352108	5069124			
		-	1346341	5066230			
		-	1344539	5067229			
		-	1342415	5068495			
		-	1338523	5072062			
	-	1337654	5073061				
	-	1337184	5074662				
	-	1337121	5075037				
2007	60	1349999	5067430	N		Unpublished data, Simone Cleland, Department of Conservation, June 2016	
	30	1349564	5067000				
2009	25	1361227	5071421	N		Unpublished data, Simone Cleland, Department of Conservation, June 2016	
	30	1330737	5085107				

	2012	10	1365104	5070933	N		Unpublished data, Simone Cleland, Department of Conservation, June 2016
		35	1363754	5071478			
	2013	50	1365709	5070012	N		Unpublished data, Simone Cleland, Department of Conservation, June 2016
		14	1365285	5070601			
		25	1364721	5071117			
	2014	80	1361023	5071445	N		Schlesselmann and Maloney (2017)
50		1331208	5084059				
Aparima	2009	80	1221949	4907323	Y	All sections (8)	DOCDM-514978, Neil Robertson, June 2016
		60	1221903	4911120			
	2014	20	1221309	4886514	N		Schlesselmann and Maloney (2017)
Ashburton	2007	8	1501787	5130289	Y	South branch - all sections (7), Buicks bridge to river mouth	DOCDM-443900 - DOC-2580500, Richard Maloney, May 2016
		15	1502800	5132115			
		40	1452179	5172000			
	2010	50	1502051	5128523	Y	South branch - all sections (7), Buicks bridge to river mouth	DOCDM-95401, Richard Maloney, May 2016
		2	1501850	5128854			
		16	1501740	5128853			
		2	1500153	5135353			
		20	1499526	5135914			
		70	1495147	5142340			
		29	1472347	5157212			
	90	1453241	5169493				
	2012	40	1502121	5130887	Y	South branch - all sections (7), Buicks bridge to river mouth	DOCDM-95401, Richard Maloney, May 2016
		26	1500041	5135141			
		65	1499586	5135798			
		12	1484218	5154795			
8		1453130	5170133				
15		1452668	5171526				
10		1452359	5171598				

	2013	22	1503951	5122101		South branch - 6/7 sections surveyed, section 2 not done (RDR - Valetta)	DOCDM-443900 - DOC-2580500, Richard Maloney, May 2016	
		50	1502469	5127571				
	2014		8	1503970	5122130	Y	South branch - 6/7 sections surveyed, section 2 not done (RDR - Valetta)	DOCDM-443900 - DOC-2580500, Richard Maloney, May 2016
			60	1502480	5127700			
			10	1502563	5132983			
			100	1452941	5170215			
			11	1452648	5171640	N		Schlesselmann and Maloney (2017)
			70	1502344	5128049			
			14	1452244	5171919			
			60	1452858	5170319			
	2015		26	1490481	5149082	Y	South branch - 6/7 sections surveyed, section 2 not done (RDR - Valetta)	DOCDM-443900 - DOC-2580500, Richard Maloney, May 2016
			4	1453106	5170102	N		Unpublished data, Brad Edwards, Department of Conservation, June 2016
6			1451941	5172410				
Ashley	2004	16	1574529	5208333	Y	ARRG managed area - Okuku junction to SH1 bridge	C. Hamblin and N. Ledgard (2016), GPS locations digitised from AARG annual reports Ledgard (2016)	
		18	1564797	5207563				
		14	1561360	5207522				
	2005	75	1577969	5209685				
		10	1565100	5207651				
		2	1561501	5207522				
		4	1560663	5207526				
	2006	42	1569557	5207780				
		52	1564746	5207509				
		2	1563031	5207443				
		2	1560458	5207509				
		50	1559200	5207843				
	2007	30	1569543	5207765				
		2	1568571	5207653				
		2	1567706	5207774				

		18	1564805	5207514			
		24	1564249	5207462			
	2008	24	1573484	5208484			
		4	1567699	5207770			
		24	1565216	5207612			
		28	1565067	5207582			
		24	1567820	5207805			
	2009	16	1564646	5207551			
		16	1563204	5207556			
		40	1569863	5207956			
	2010	50	1565052	5207603			
		2	1564604	5207499			
		50	1556651	5209839			
		40	1571088	5208217			
	2011	12	1570289	5207954			
		30	1567839	5207821			
		30	1562719	5207487			
		9	1535599	5222744			
		8	1535277	5221893			
		22	1574426	5208342			
	2012	15	1565739	5207801			
		40	1564516	5207537			
		25	1563103	5207536			
		50	1566020	5207855			
	2013	40	1564704	5207666			
		10	1559651	5207796			
		40	1571708	5208455			
	2014	6	1570433	5208023			
		10	1566424	5207833			

		50	1566029	5207824			
		4	1564676	5207581			
		2	1563747	5207487			
		25	1560029	5207745			
		25	1559226	5208171			
	2015	20	1565463	5207653			
		6	1559458	5207963			
		20	1558905	5208154			
		6	1558450	5208199			
	prior to 04	16	1563143	5207489			
Buller	2014	30	1573231	5381865	N		Schlesselmann and Maloney (2017)
Cass	2014	40	1399753	5138227	N		Schlesselmann and Maloney (2017)
	2012	6	1386777	5096647	N		Unpublished data, Simone Cleland, Department of Conservation, June 2016
Charwell	2013	10	1630064	5301941	N	Inland Kaikoura bridge to Conway River	DOCDM-95401, Richard Maloney, May 2016
Clarence	2015				Y	Full river	GPS locations available from Mike Bell, Wildlife Management International, June 2016
Clutha	2014	100	1313064	4948963	N		Schlesselmann and Maloney (2017)
Conway	2008	26	1627895	5279871	Y	SH1 inland Kaikoura to river mouth	DOCDM-95401, Richard Maloney, May 2016
		-	1627678	5280021			
		5	1626891	5289840			
		11	1626378	5290146			
Dart	2007	38	1233342	5028150	Y	River mouth to Paradise flat	Unpublished data, Ray Molloy, Department of Conservation, June 2016
		6	1232424	5027834			
	2008	2	1231003	5030971	Y	River mouth to Paradise flat	Unpublished data, Ray Molloy, Department of Conservation, June 2016
		74	1231387	5039148			
	2009	2	1231945	5028258	Y	River mouth to Paradise flat	Unpublished data, Ray Molloy, Department of Conservation, June 2016
2		1230469	5034780				

		2	1230230	5037320			
		2	1230365	5037655			
		4	1231676	5038567			
		2	1231865	5039118			
		100	1231437	5039143			
		6	1231121	5039117			
	2010	38	1229699	5033591	Y	River mouth to Paradise flat	DOCDM-726225, Ray Molloy, June 2016
		20	1231679	5038657			
	2014	20	1230719	5032945	N		Schlesselmann and Maloney (2017)
Eglington	2013	6	1207189	5012091	Y	Upper river to Mackay Creek	DOCDM-314150, Ann Schlessleman, June 2016
		15	1206437	5009765			
		20	1203607	4993220			
2014	40	1204315	4994033	N		Schlesselmann and Maloney (2017)	
Eyre creek	2009	16	1246246	4954826	Y	All sections (2)	DOCDM-514978, Neil Robertson, June 2016
		20	1243853	4958894			
		2	1242504	4961992			
Fraser Stream	2006	-	1363249	5100562	Unknown		Unpublished data, Ray Molloy, Department of Conservation, June 2016
Grey	2014	30	1483684	5315493	N		Schlesselmann and Maloney (2017)
Hae Hae Te Moana	2012	223	1452619	5118936	Y	All sections gorge to wetland	DOCDM-95401, Richard Maloney, May 2016
Hunter	2014	4	1320866	5100218	N		Schlesselmann and Maloney (2017)
		16	1317534	5090686			
Hurunui	2006	120	1596608	5254174	Y	South Branch - sections 1-2 and 5-10	DOCDM-95401, Richard Maloney, May 2016
		30	1581055	5253270			
		10	1564769	5260631			
		10	1533550	5262500			
	2007	265	1587425	5256680			
	2007	30	1609041	5250443	Y	South branch- sections 1-2, 5, 7-10	DOCDM-95401, Richard Maloney, May 2016

		12	1608732	5250394			
	2008	-	1609302	5250580	Y	South branch - sections 1-2 and 7-10	DOCDM-95401, Richard Maloney, May 2016
		26	1584000	5254773			
		20	1579139	5253465			
		9	1532674	5264530			
		16	1604114	5252329			
		18	1593329	5256624			
	2009	40	1612994	5251095	Y	South branch - sections 7-10	DOCDM-95401, Richard Maloney, May 2016
		50	1609005	5250411			
		30	1608684	5250436			
		151	1608567	5250399			
		52	1620055	5251486			
		46	1613060	5251301			
		40	1564629	5260856			
		5	1579621	5253594			
	2010	28	1564781	5260863	Y	South branch - sections 7-10	DOCDM-95401, Richard Maloney, May 2016
		12	1616083	5252124			
		2	1574327	5256090			
	2014	9	1564630	5260834	N		Schlesselmann and Maloney (2017)
		70	1608784	5250610			
		50	1580968	5253451			
Kuhatara	2008	6	1646210	5304012	Unknown		DOCDM-95401, Richard Maloney, May 2016
Makarora	2014	40	1295935	5092229	N		Schlesselmann and Maloney (2017)
Manuherikia	2014	30	1356375	5028943	N		Schlesselmann and Maloney (2017)
Mararoa	2014	4	1209785	4949984	N		Schlesselmann and Maloney (2017)
		12	1214440	4957833			
Maruia	2014	8	1534697	5320082	N		Schlesselmann and Maloney (2017)
Matakitaki	2014	16	1552755	5349993	N		Schlesselmann and Maloney (2017)

Mataura	2009	4	1254069	4963746	Y	All sections (15)	DOCDM-514978, Neil Robertson, 2016
		150	1277182	4898249			
Ohau	2006	66	1374980	5088016			Unpublished data, Simone Cleland Department of Conservation, June 2016
		38	1360780	5094104			
		20	1372872	5089577			
		-	1372552	5089816			
		15	1369906	5091138			
	2007	2	1374985	5087964			Unpublished data, Simone Cleland Department of Conservation, June 2016
		106	1360772	5094261			
	2008	240	1360772	5094261			DOCDM-993031, Sue Anderson, June 2016
		14	1368964	5091749			
	2009	-	1376323	5086414			Unpublished data, Simone Cleland Department of Conservation, June 2016
		30	1376207	5086535			
		6	1375002	5087817			
		360	1360772	5094261			
		12	1374259	5088588			Unpublished data, Simone Cleland Department of Conservation, June 2016
	2010	220	1360772	5094261	N		Woolmore et al. (2012a)
	2011	418	1360772	5094261	N		DOCDM-2516040, Sue Anderson, June 2016
	2012	494	1360772	5094261	N		DOCDM-2516043, Sue Anderson, June 2016
2013	672	1360772	5094261	N		DOCDM-2824017, Sue Anderson, June 2016	
2014	696	1360772	5094261	N		Sue Anderson, personal communication, June 2016	
Opihi	2011	7	1454359	5097670	Y	Upper Opihi - Stoneleigh Rd ford to lagoon	DOCDM-95401, Richard Maloney, May 2016
		55	1440200	5105981			
	2013	8	1464815	5097465	Unknown		DOCDM-95401, Richard Maloney, May 2016
		20	1449013	5101482			
	2014	40	1451796	5098569	Unknown		DOCDM-95401, Richard Maloney, May 2016

		50	1447051	5103818			
Orari	2008	14	1469264	5103566	Y	All sections - gorge to wetland	DOCDM-95401, Richard Maloney, May 2016
		8	1461415	5121639			
		26	1460844	5122757			
	2009	44	1460808	5122837	Y	All sections - gorge to wetland	DOCDM-95401, Richard Maloney, May 2016
	2011	30	1456976	5130062	Y	All sections - gorge to wetland	Orari Rivercare Group (2011)
	2012	5	1468248	5104771	Y	All sections - gorge to wetland	DOCDM-95401, Richard Maloney, May 2016
		70	1458337	5127559			
		53	1458555	5128002			
		105	1462682	5134182			
	2013	100	1464139	5112729	Y	All sections - gorge to wetland	DOCDM-95401, Richard Maloney, May 2016
		100	1464272	5112604	Y	All sections - gorge to wetland	Orari Rivercare Group (2013)
		500	1463169	5115788			
		100	1460981	5122634			
		8	1460719	5123064			
2014	70	1455574	5132112	N		Schlesselmann and Maloney (2017)	
Oreti	2009	50	1234763	4876527	Y	All sections (11)	DOCDM-514978, Neil Robertson, June 2016
		15	1235116	4877470			
		6	1237535	4889598			
		8	1237672	4889786			
		30	1237638	4894530			
		20	1237564	4894709			
		20	1240097	4906002			
		45	1240429	4912545			
		13	1241490	4917501			
		25	1243371	4919066			
		20	1241015	4930311			
		30	1238092	4930932			
		50	1237481	4931139			

		30	1235811	4931958			
		25	1234981	4932070			
		30	1229071	4932794			
		100	1228625	4932863			
		5	1225353	4934395			
		50	1225178	4934575			
		5	1224506	4935135			
		5	1224355	4935380			
		25	1219514	4948841			
	2010	12	1236530	4880026	Y	All sections (11)	DOCDM-514978, Neil Robertson, June 2016
		40	1237817	4891052			
		100	1239517	4903943			
		6	1240392	4910123			
		10	1241341	4914026			
		6	1241461	4917465			
		4	1241521	4917709			
		4	1241705	4918154			
		65	1242789	4929706			
		40	1239721	4930801			
		9	1234160	4932197			
		20	1233895	4932244			
		50	1233337	4932297			
		25	1230251	4932671			
		30	1219752	4948251			
		70	1219513	4948828			
		2014	20	1229908			
	60		1228150	4933054			
	Pukaki	2007	40	1378978	5090429	Unknown	Unpublished data, Simone Cleland Department of Conservation, June 2016
50			1378025	5091684			

	2008	20	1378025	5091684	Unknown		Unpublished data, Simone Cleland Department of Conservation, June 2016
Rakaia	2009	6	1526956	5149920	Y	Lower river - Barhill-mouth	DOCDM-95401, Richard Maloney, May 2016
		14	1526984	5151146			
		4	1526419	5150959			
		7	1526438	5151283			
		1	1511524	5163018			
	2011	6	1508105	5164566	Y	Upper and Mid river sections - upper gorge to Doublehill and mid gorge to Barhill	DOCDM-95401, Richard Maloney, May 2016
		15	1507948	5164743			
		20	1506825	5166198			
		1	1501720	5172271			
		4	1487050	5189416			
		7	1484161	5193957			
		17	1483859	5194489			
	2012	7	1470266	5202373	Y	Upper and Mid river sections - upper gorge to Doublehill and mid gorge to Barhill	DOCDM-95401, Richard Maloney, May 2016
		21	1484221	5194026			
	2013	16	1482793	5194460	Y	Upper and Mid river sections - upper gorge to Doublehill and mid gorge to Barhill	DOCDM-95401, Richard Maloney, May 2016
		3	1507695	5164802			
		3	1486394	5189989			
8		1476845	5197615				
7		1469967	5204305				
12		1467334	5205918				
15		1466722	5205877				
-	1504335	1504335					
2014	50	1532332	5142881	N		Schlesselmann and Maloney (2017)	
Rangitata	2006	271	1463552	5130932	N		Unpublished data, Andrew Grant, Department of Conservation, April 2016
	2007	50	1479144	5113573	Y	Lower river - Lynn Stream to river	DOCDM-95401, Richard Maloney, May 2016

		18	1478288	5115685		mouth	
		16	1473110	5120774			
		48	1470625	5123157			
		100	1463604	5129929			
		30	1462312	5134420			
		77	1461348	5136166			
		18	1461314	5137087			
		6	1461320	5138647			
		23	1460392	5141915			
		15	1470625	5123157			
	2009	Y	15	1479483	5111766	Lower river - Lynn Stream to river mouth	DOCDM-95401, Richard Maloney, May 2016
			106	1479443	5112686		
			100	1467316	5124178		
			80	1464178	5128716		
			88	1463989	5128795		
			30	1463901	5129178		
			16	1464073	5129522		
			84	1461307	5138803		
			5	1460625	5141616		
	2010	Y	4	1449038	5156251	Upper river - Havelock to gorge (sections 1-4)	DOCDM-95401, Richard Maloney, May 2016
			6	1448684	5156551		
			41	1443774	5159079		
			2	1443493	5159140		
			2	1443421	5159142		
			11	1443263	5159375		
			24	1443148	5159415		
			12	1442565	5159767		
			2	1439717	5160664		
			2	1437538	5162096		

		14	1437593	5162421			
		2	1428594	5171530			
	2012	20	1433588	5166904	Y	Upper river - Havelock to forest creek (sections 1-2)	DOCDM-95401, Richard Maloney, May 2016
		6	1428189	5172594			
	2014	10	1434135	5173280	y	Full river	DOCDM-95401, Richard Maloney, May 2016
		6	1434567	5173170			
		8	1477799	5115852			
		44	1477472	5116099			
		2	1476489	5116720			
		160	1474213	5119834			
		8	1461365	5136689			
		2	1439328	5160365			
		2	1438175	5160676			
		70	1438175	5161221			
		16	1437877	5161558			
		20	1477349	5116346	N		Schlesselmann and Maloney (2017)
		18	1431512	5170777			
		86	1438275	5161133			
	2015	12	1480834	5106408	Y	Lower river - gorge to river mouth	Unpublished data, Brad Edwards, Department of Conservation, June 2016
		40	1480575	5106615			
		10	1480366	5106755			
		48	1480216	5107001			
		16	1480366	5108896			
		4	1479539	5108896			
		22	1475493	5117832			
		30	1475493	5118148			
		2	1473179	5120718			
		6	1433443	5167989			
		168	1438997	5160722		Upper river - above gorge	

		60	1462457	5132885	N		Unpublished data, Andrew Grant, Department of Conservation, April 2016
Rees	2009	12	1236868	5031934	Y	Muddy creek to 25mile creek	Unpublished data, Ray Molloy, Department of Conservation, June 2016
		14	1236822	5032214			
		14	1236992	5032376			
Ruataniwha Wetlands	2005	32	1369780	5091655	Y	Full wetland	Unpublished data, Simone Cleland Department of Conservation, June 2016
		6	1369379	5091933			
		16	1368767	5092344			
	2006	214	1369222	5092109	Y	Full wetland	
	2007	118	1368742	5092359	Y	Full wetland	
	2008	24	1368742	5092359	Y	Full wetland	
Sawdon Stream	2004	24	1401954	5112374	Unknown	Unknown	Unpublished data, Simone Cleland Department of Conservation, June 2016
Tasman	2004	6	1369773	5134638	Y	Full river	Unpublished data, Simone Cleland, Project River Recovery, Department of Conservation, June 2016.
		8	1370192	5135199			
		2	1369630	5136041			
		2	1369576	5136370			
		2	1368964	5140042			
		2	1368531	5140353			
		6	1368160	5140825			
		2	1368325	5143694			
		22	1368563	5146329			
		6	1371896	5138964			
	2	1378496	5138496				
	2005	14	1370082	5134903	Y	Full river	
		14	1369150	5136399			
		38	1368160	5140755			
		22	1368096	5141594			
10		1368325	5141861				

		22	1368706	5144257		
	2006	24	1370421	5134095	Y	Full river
		10	1369317	5136209		
		16	1369285	5136740		
		2	1368343	5141905		
		38	1368713	5143119		
		54	1371705	5137928		
		4	1370657	5142870		
		6	1360635	5143092		
		2007	2	1369179		
	16		1369399	5138068		
	2		1368984	5138133		
	18		1368160	5141702		
	14		1368350	5141969		
	2		1372225	5138125		
	2		1371927	5138942		
	2		1371693	5139161		
	2008	2	1371007	5134822	Y	Full river
		18	1369182	5136463		
		12	1369364	5136717		
		24	1371420	5136486		
		6	1370028	5143729		
	2009	10	1369166	5136320	Y	Full river
		22	1370142	5140254		
		8	1368071	5141601		
		12	1368408	5143157		
	2012	62	1370235	5134545	Y	Full river
		82	1369560	5137522		
		12	1368149	5140849		

		24	1368389	5144101				
		2	1368464	5144729				
		10	1371299	5137540				
		12	1371512	5137991				
		40	1370810	5138145				
		2	1372262	5138771				
		74	1371452	5139933				
		16	1370383	5140755				
		46	1370211	5141148				
		12	1371195	5141465				
	2013		24	1371132	5135424	Y	Full river	
			4	1370941	5135620			
			6	1370948	5135951			
			2	1371121	5136133			
			8	1370442	5139121			
			22	1370263	5139685			
			8	1369689	5141302			
			26	1369630	5148088			
			2	1370738	5138040			
	2014		10	1369435	5138204	Y	Full river	
			12	1368474	5140378			
			2	1369669	5141293			
			54	1369595	5148049			
	2015		2	1370345	5134490	Y	Full river	
			8	1369436	5138116			
			2	1370054	5141025			
			18	1368149	5141003			
			92	1369664	5147968			
			2	1371049	5139460			

		2	1370274	5140864			
		2	1370302	5141032			
Tekapo	2006	-	1378034	5087272	N		Unpublished data, Simone Cleland Department of Conservation, June 2016
		94	1378510	5088513	Unknown		
		42	1378510	5088513			
		39	1378510	5088513			
		5	1380210	5090904			
		12	1381928	5091841			
	2007	100	1378510	5088513	Unknown		Unpublished data, Simone Cleland Department of Conservation, June 2016
		20	1376184	5096864			
	2008	70	1378510	5088513	Unknown		Unpublished data, Simone Cleland Department of Conservation, June 2016
	2009	4	1377624	5086804	Unknown		Unpublished data, Simone Cleland Department of Conservation, June 2016
		8	1377730	5086871			
		12	1378800	5088951			
		20	1380768	5090775			
		16	1381025	5090826			
		40	1386294	5093537			
		12	1385921	5096019			
		8	1391514	5105162			
		17	1393114	5106864			
	2012	2	1394423	5109297	Unknown		Unpublished data, Simone Cleland Department of Conservation, June 2016
		100	1378060	5087544			
		40	1378475	5087940			
30		1383319	5090510				
2014	6	1386226	5093454	Unknown		Unpublished data, Simone Cleland Department of Conservation, June 2016	
	70	1385582	5091732				
	40	1395043	5112669				N
100	1386288	5092953					

Twizel	2006	-	1368371	5101935	Unknown		Unpublished data, Simone Cleland Department of Conservation, June 2016
		-	1368085	5102555			
Waiau	2008	17	1630717	5264000	Y	13/14 sections surveyed - section 9 not done, Sandersons Rd to Bourne Rd (E251298, N5837772)	DOCDM-95401, Richard Maloney, May 2016
		5	1618490	5269800			
		30	1606076	5273859			
		10	1598908	5278324			
		32	1596227	5276364			
		10	1596056	5276221			
		40	1584740	5273049			
		75	1581911	5275856			
		20	1581911	5275698			
		24	1580962	5286396			
		40	1576050	5287367			
	8	1575693	5287183				
	2009	40	1622467	5269621	Y	All sections (14)- Waterfall stream to river mouth	DOCDM-95401, Richard Maloney, May 2016
		10	1622390	5269799			
		28	1622256	5269775			
		50	1621866	5269680			
		25	1609316	5276338			
		120	1597267	5277732			
		28	1587470	5271976			
		80	1581861	5275674			
		20	1580970	5286391			
30		1579279	5286601				
2010	23	1629991	5263899	Y	All sections (14)- Waterfall stream to river mouth	DOCDM-95401, Richard Maloney, May 2016	
	10	1612351	5274179				
	60	1608580	5275305				
	55	1602872	5276646				

		15	1597554	5276640			
		8	1596093	5276270			
		46	1588507	5272445			
		18	1585721	5272140			
		100	1581959	5275666			
		16	1575408	5287536			
		12	1575293	5287298			
	2014	30	1582010	5275823	N		Schlesselmann and Maloney (2017)
Waimakariri	2008	13	1569198	5191950	Y	Lower river - Gorge to SH1	DOCDM-95401, Richard Maloney, May 2016
		13	1569198	5191950			
		6	1569088	5191940			
		6	1569088	5191940			
		5	1567676	5191478			
		5	1567676	5191478			
		10	1565643	5191148			
		10	1565643	5191148			
		3	1563972	5190932			
		3	1563972	5190932			
		15	1562472	5190259			
		15	1562472	5189825			
		12	1560764	5189865			
		12	1560764	5189865			
		10	1560658	5189825			
		10	1560658	5189825			
		15	1560491	5189761			
		15	1560491	5189761			
10	1559602	5189759					
10	1559602	5189757					
14	1554913	5189159					

		16	1554218	5189030					
		8	1554195	5188896					
		29	1524128	5198644					
	2009		85	1554974	5189144	Y	Lower river - Gorge to SH1	DOCDM-95401, Richard Maloney, May 2016	
			6	1547214	5188381				
			20	1545143	5187651				
			2	1539580	5188874				
			40	1529348	5192169				
			8	1526051	5195710				
			2012		10				1505896
	4	1501394			5237198				
	7	1500029			5231743				
	2013		50	1562852	5190253	N		Unpublished data, Andrew Grant, Department of Conservation, April 2016	
			50	1562852	5190082				
	2014		5	1503705	5234033	Y	Upper river - Bealey bridge to Esk confluence	Unpublished data, James Jolly, June 2016	
			5	1503701	5234072				
			15	1503668	5234076				
			20	1504194	5232560				
			9	1502187	5236620				
			15	1512194	5229290				
7			1512488	5229199					
5			1514197	5227863					
2014				2	1537639	5188667	N		Schlesselmann and Maloney (2017)
				2	1560230	5189738			
	70	1560039		5190133					
2014		30	1502185	5236530					
Wairaki	2009	16	1193552	4903094	Y	All sections (5)	DOCDM-514978, Kate Steffens, June 2016		
		50	1194775	4907715					
		22	1201550	4911219					

Wairau	2009	18	1680068	5412238	Y	Full river - Bull Paddock Stream to SH1	DOCDM-494358, Kate Steffens, June 2016
		67	1669833	5408538			
		15	1663468	5406615			
		7	1660912	5404985			
		29	1642946	5400024			
		59	1630573	5393810			
		97	1623630	5390656			
		194	1619814	5389960			
		18	1613977	5385622			
		7	1611376	5384419			
		17	1609841	5383217			
		55	1598220	5375717			
	2010	73	1680156	5412214	Y	Full river - Bull Paddock Stream to SH1	DOCDM-494358, Kate Steffens, June 2016
		13	1657939	5403441			
		11	1639201	5397626			
		10	1633708	5395100			
		6	1623516	5390455			
		33	1623051	5390292			
		33	1620469	5389990			
		18	1617720	5388922			
		21	1613676	5385501			
		14	1609801	5383173			
		8	1608956	5382066			
	2011	22	1675373	5411221	Y	Full river - Bull Paddock Stream to SH1	DOCDM-494358, Kate Steffens, June 2016
		53	1659851	5403847			
		54	1623339	5390279			
		53	1621482	5390042			
		171	1620641	5389992			
		22	1611816	5384585			

		103	1610504	5383718				
		70	1603862	5380235				
		25	1598174	5375705				
	2012		39	1680145	5412165	Y	Full river - Bull Paddock Stream to SH1	DOCDM-494358, Kate Steffens, June 2016
			36	1676886	5411829			
			6	1658551	5403520			
			13	1641983	5398989			
			12	1639754	5397894			
			8	1634610	5395595			
			31	1623885	5390719			
			33	1617061	5388545			
			29	1615940	5388173			
			16	1610383	5383652			
			30	1598189	5375735			
			50	1597000	5374168			
			2013		248			
	61	1654080			5402263			
	15	1618635			5389606			
	18	1616123			5388281			
	3	1611561			5384484			
2014		200	1675937	5411501	N		Schlesselmann and Maloney (2017)	
Waitaki	2014	30	1399867	5044787	N		Schlesselmann and Maloney (2017)	
		100	1405582	5038226				
	2015		-	1399867	5044787	N		Unpublished data, A. Schlessleman, June 2016
			-	1405882	5037721			
			-	1399874	5044802			
			-	1403797	5040090			
			-	1404989	5039078			
-	1425062	5028898						

		-	1425116	5028807			
Whitestone	2009	20	1200170	4959889	Y	All sections, 1-4	DOCDM-514978, Neil Robertson, June 2016

Appendix B

Camera trap groups

Table A 1: Camera trap group categories and the species, or objects, of interest they each contain.

Group	Species/object of interest
Native birds	Black-fronted tern (<i>Chlidonias albostratus</i>) Banded dotterel (<i>Charadrius bicinctus</i>) Black-billed gull (<i>Larus bulleri</i>) Caspian tern (<i>Hydroprogne caspia</i>) Paradise shelduck (<i>Tadorna variegata</i>) Pied stilt (<i>Himantopus himantopus</i>) South Island pied oystercatcher (<i>Haematopus finschi</i>) Spur-winged plover (<i>Vanellus miles</i>) Wrybill (<i>Anarhynchus frontalis</i>)
Introduced birds	Skylark (<i>Alauda arvensis</i>) Chaffinch (<i>Fringilla coelebs</i>) Canada goose (<i>Branta canadensis</i>)
Mammalian predator	Cat (<i>Felis catus</i>) Dog (<i>Canis lupus familiaris</i>) Rat (<i>Rattus sp.</i>) Possum (<i>Trichosurus vulpecula</i>) Ferret (<i>Mustela putorius furo</i>)
Avian predator	Harrier hawk (<i>Circus approximans</i>) Black-backed gull (<i>Larus dominicanus</i>)
Disturbance	Four wheel drive vehicle Helicopter Human Jet boat Motorbike Flooding
Unknown	Any unidentified object of interest

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