THE ECOLOGY AND MANAGEMENT OF SOUTHLAND'S BLACK-BILLED GULLS

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The Ecology and Management of Southland's Black-billed Gulls

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ABSTRACT

The black-billed gull (*Larus bulleri*) is a small gull that nests in dense colonies on gravel-bedded rivers in southern New Zealand. This dissertation describes research undertaken in Southland in 2004-2006 that investigates black-billed gull population decline and its causes.

Historical ground counts of nests were calibrated with aerial photography of colonies and population trends analysed. The decline in breeding birds on Southland's four main rivers was equivalent to 6.0%/year (SE 1.8) or 83.6% in 30 years justifying the species' present listing as Endangered. Aerial monitoring is a poor index of the breeding population and major temporal variation was identified in counts.

All re-sighted second-year birds exhibited natal dispersal and ~70% left the natal catchment. Forty one percent of birds banded as adults also dispersed to other catchments. Breeding dispersal is apparently unrelated to previous breeding success and the availability of the previous year's colony site, and dispersing birds did not move as groups. Southland's black-billed gulls constitute a single inter-mixing population.

Black-billed gulls selected sites on islands and banks according to availability, and selected rivers consistent with the number of gravel patches. Site vulnerability to floods varied significantly. Re-use of colony sites was positively influenced by use in previous years, the extraction of gravel, site stability and low weed cover. Widespread introduced weeds on colony sites preventing nesting and may have increased flooding risk. Colony size was related to colony area, which was related to gravel patch size.

Investigation of historical changes in breeding habitat availability in Southland indicated a major reduction in gravel habitat on the Lower Oreti River between 1976 and 2002 due to river works including gravel extraction. On the Waiau River, Manapouri Dam construction in 1970 initially increased gravel areas, since reversed in the mid Waiau, and caused a 75% decline in the number of islands. Gravel patch sizes are still declining on the Lower Oreti and possibly the Mid Waiau. Hundreds of gravel patches remain on Southland rivers.

Over 5000 nests in 21 colonies were monitored during incubation. Colony nest success was most influenced by colony location, averaging 90.1% (SE 2.1) on islands within rivers, and 66.8% (SE 2.2) on riverbanks, indicating that terrestrial predators exert the greatest influence on productivity. Breeding success, the mean number of fledglings produced per nest by colony, varied between 0 and 0.88 fledglings (mean 0.32, SE 0.08). Both parameters were positively related to colony size. The three smallest colonies failed to breed successfully, suggesting the presence of an Allee effect.

Deterministic matrix models were used to investigate population trends using survival and productivity estimates for the closely related Kaikoura red-billed gull (*L. novaehollandiae scopulinus*). Adult survival, followed by breeding success and survival of first year birds, had the greatest influence on population projections. Improvements in most parameters are probably required to reverse the decline of Southland's black-billed gulls.

Predation and disturbance by introduced mammals and the native black-backed gull (*L. dominicanus*) had the greatest impact on black-billed gull productivity. Most human disturbance is insignificant compared to predator disturbance, but illegal shooting of large numbers of adult gulls has major impacts in smaller sub-populations. Damming and excessive water abstraction reduces island habitat due to lowering of flows. Major climatic events such as droughts, and chemical ingestion through a diet dominated by agricultural invertebrates, are potential major threats about which little is known. Management actions including the collation and analysis of all unpublished black-billed gull count datasets, a thorough test of the accuracy of aerial monitoring, trialling of decoys to attract colonies to nest on islands, predator control at bank colonies, targeted weed control on high quality sites, advocacy and education and further research are recommended.

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CHAPTER 1

General Introduction

Mossburn Bridge colony, Oreti River, 2006 (C. Garden)

Management of threatened bird species in New Zealand

In 2005, 2788 species in New Zealand were listed as threatened (Hitchmough et al. 2007). The scale of the problem is extraordinary, and only a fraction of the species is able to be managed by the government's Department of Conservation due to funding constraints. Of the 155 bird species breeding in New Zealand (excluding vagrants, migrants and introduced species; Dowding and Murphy 2001), 87 (56.1%) are threatened (Hitchmough et al. 2007). Most of New Zealand's avifauna evolved in the absence of mammalian predators, and it is widely agreed that the introduction of animals such as cats (*Felis catus*), mustelids (*Mustela* spp.) and rats (*Rattus* spp.) has had the greatest impact (Dowding and Murphy 2001; Innes et al. in press).

Predator-free offshore islands have been used extensively as 'safe havens' for threatened bird species that are unable to survive in the face of mammalian predation (Atkinson 1990). Associated with this has been the development of eradication techniques for mice, rats, possums and stoats to create further predator-free island reserves (Veitch and Bell 1990). More recently, construction of predator-proof fenced enclosures has allowed some of these species to return to the New Zealand mainland (e.g. Campbell-Hunt 2002). Many bird species are now restricted to these offshore islands and predator-free sanctuaries, for example, kakapo (*Strigops habroptilus*), little spotted kiwi (*Apteryx owenii*), stitchbird (*Notiomystis cincta*) and saddleback (*Philesturnus carunculatus*).

In the 1990s, the Mainland Island concept was founded, and large areas of forest were successfully protected by extensive predator control networks (Saunders and Norton 2001). Beneficiaries of this technology such as kokako (*Callaeas cinerea*), mohua (*Mohoua ochrocephala*) and North Island brown kiwi (*A. mantelli*) are further safeguarded by the presence of 'security' populations on islands. However, a small number of species cannot be managed on islands or in predator-free sanctuaries and actions to address threats must be undertaken in the species' natural environment. These include the suite of endemic river-breeding bird species; black stilt or kaki (*Himantopus novaezelandieae*; Critically Endangered), black-fronted tern (*Sterna albostriata*; Endangered), wrybill (*Anarhynchus frontalis*; Vulnerable) and black-billed gull (*Larus bulleri*; Endangered), which are largely restricted to braided and other gravel-bedded rivers for breeding (O'Donnell 2004). Predation has been shown to be a key causal factor in the population decline of black stilt (Pierce 1986, 1996; Keedwell et al. 2002) and black-fronted tern (Keedwell 2005). Moreover, a variety of other inter-relating threats also affect these species including: weed invasion of riverbeds; river works such as gravel extraction, water abstraction for irrigation and hydroelectric dams; disturbance by recreational users of riverbeds and changing land use surrounding rivers (Taylor 2000; Keedwell 2004; O'Donnell 2004).

Of the threatened river specialists, the black stilt has been the focus of intensive species management for more than two decades (Keedwell et al. 2002). Project River Recovery (PRR), an intensive ecosystem management programme, was initiated in 1991 in the Upper Waitaki Basin, Otago, aimed at rehabilitating braided river systems that had been severely affected by hydroelectric developments. The programme has focused primarily on extensive weed control and predator ecology (Caruso 2006). More recently, a catchment-wide predator control regime has been initiated in one of the rivers (conceptually similar to Mainland Island programmes within forests) and its effectiveness is being tested through monitoring of black-fronted tern and wrybill breeding success (Department of Conservation 2008). PRR is also developing localised control methods to protect black-fronted tern colonies (Department of Conservation 2008). Elsewhere in the South Island, efforts to control predators around black-fronted tern colonies have also been undertaken (e.g. Cranwell 2006; Boffa Miskell Ltd. 2007). However, black-billed gulls have not yet benefitted from such programmes; the species is now very rare in the Upper Waitaki Basin (Maloney 1999) and, nationwide, receives no government funding for management save for annual monitoring in the Ashburton River, Canterbury.

The black-billed gull

The black-billed gull is a small gull endemic to New Zealand (length 35-38 cm, weight 230 g; Higgins and Davies 1996; Figure 1). The species is colonial and breeds predominantly on gravel-bedded rivers from the coast to the headwaters (Beer 1966; Higgins and Davies 1996). Breeding takes place from approximately September to January (Higgins and Davies 1996). The species is generally described as having high breeding synchrony, the majority of gulls in a colony often laying within a week, although laying between colonies can be asynchronous (Stead 1932, Beer 1966, Evans 1982). Nest densities may exceed those of any other gull species (nest centre to centre measurements, mean 49.0 cm, SD 11.5 cm, n=70; Beer 1966). Colony size varies from those with less than 100 breeding birds to colonies numbering several thousand (Boud and Cunningham 1959; R. Sutton and M. Barlow unpubl. data). Colony locations are generally devoid of vegetation (Stead 1932; Soper 1959; Beer 1966) and often change each season (Beer 1966; Soper 1972), thought to be a response to the site becoming unsuitable due to modification by floods or vegetation invasion (Beer 1966). Mean clutch size is two eggs (Beer 1965). Chicks leave the nesting area at only a few days old (Beer 1966) and often gather in crèches around the colony starting from about two weeks of age (Besnard et al. 2006). Most birds migrate to coastal areas at the end of the breeding season, although movements are poorly known (Higgins and Davies 1996). The diet of black-billed gulls has been shown to consist of pasture invertebrates, freshwater invertebrates, other insects, fish, crustaceans and molluscs (Dawson 1958; Boud and Cunningham 1959; Moeed 1976) and, in the South Island, it is commonly seen following the plough taking invertebrates that are brought to the surface (Heather and Robertson 1996). The species is rarely seen scavenging refuse.

Figure 1: *Black-billed gull at nest with chicks, Dunrobin South colony, Aparima River, 2006 (C. Garden)*

Black-billed gulls are found throughout New Zealand but are most common east of the southern divide in the South Island. The species has recently extended its breeding range in the North Island (Gleeson et al. 1972). Nationwide surveys during 1995, 1996 and 1997 for black-billed gulls indicated that approximately 70% of the species nested within Southland, approximately 25% in Otago, Canterbury and Marlborough, and the remaining population in the North Island (Powlesland 1998).

Studies of black-billed gulls have focused on reproductive behaviour (Beer 1965, 1966); diet (Dawson 1958; Boud and Cunningham 1959; Moeed 1976); colony desertion and reproductive synchrony (Evans 1982); foraging efficiency, roosts and behaviour (Evans 1982b, 1982c; 1982d); territorial behaviour (Burger and Gochfield 1996); crèching behaviour (Besnard et al. 2002; Besnard et al. 2006) and a number of descriptive studies of an unusual colony nesting in a thermal area (Daniel 1963; Reid and Reid 1965). Only Boud and Cunningham (1959) and Besnard et al. (2002, 2006) undertook research in Southland. No studies addressed productivity or threats facing the species, although the potential for conflict with introduced predators was noted many years ago; Stead (1932) remarking that the species' "worst enemies" were probably stoats (*M. erminea*) and weasels (*M. nivalis*), and hedgehogs (*Erinaceus europaeus*) "if the nesting site is accessible to them".

Figure 2: *Mararoa Weir colony, Waiau River (above the Manapouri Dam), 2006 (C. Garden)*

The black-billed gull is one of three species of gull found in New Zealand. The red-billed gull (*L. scopulinus novaehollandiae*) is widespread throughout New Zealand and much of the Pacific. It is the closest relative of the black-billed gull (Chu 1998) but its breeding colonies are almost exclusively coastal (Heather and Robertson 1996). The red-billed gull population increased significantly with European colonisation in the 18th century, but is now considered to be in decline due to changes in marine productivity, possibly associated with global warming (Miskelly 2008). The third species is the native black-backed gull (Dominican gull, kelp gull; *L. dominicanus*). Rare prior to human habitation (Worthy and Holdaway 2002; Biswell 2005), major increases in numbers have occurred in tandem with human settlement, and the New Zealand population is now estimated at more than one million (Biswell 2005). The species is an opportunistic feeder and will take offal, refuse and carrion (Heather and

Robertson 1996). It is a known predator of eggs and chicks of other bird species and is sometimes culled (Biswell 2005). All three species breed in Southland.

The black-billed gull was upgraded to 'Endangered' in 2005 (BirdLife International 2006) based on observed declines in the core Southland population (Powlesland 1998; Taylor 2000) and declines in Otago combined with complete losses reported from some rivers (Maloney 1999; R. Hitchmough in BirdLife International 2006).

Study area

Southland is the southern-most region of New Zealand. It has the lowest average annual summer and winter temperatures in the country. Annual rainfall varies from over 10,000 mm in parts of western Southland (Fiordland National Park) to approximately 700-1500 mm in the lowlands and hill country to the east (Environment Southland 2000). The study area encompasses the lowland areas of the Waiau, Aparima, Oreti and Mataura river catchments which together comprise 18,305 km^2 and drain approximately 54% of Southland (Environment Southland 2000). Most of lowland Southland was covered with closed forest prior to human arrival in New Zealand in c.800 BP (McGlone 2001). Since European colonisation in the mid 19^{th} century, virtually all of lowland Southland has been converted to agriculture. The majority of lowland waterways are now bordered by farmland. Figures 3 and 4 show the location of Southland and the waterways referred to within this paper.

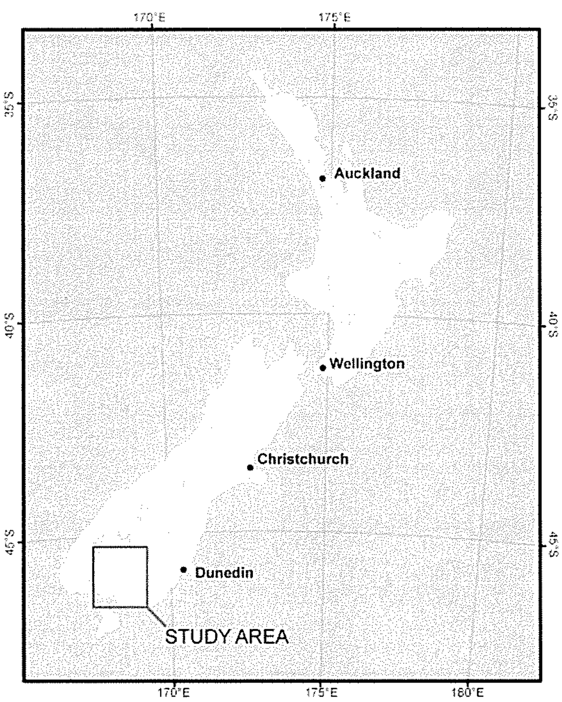

Figure 3: *Map of New Zealand showing the general location of the study area.*

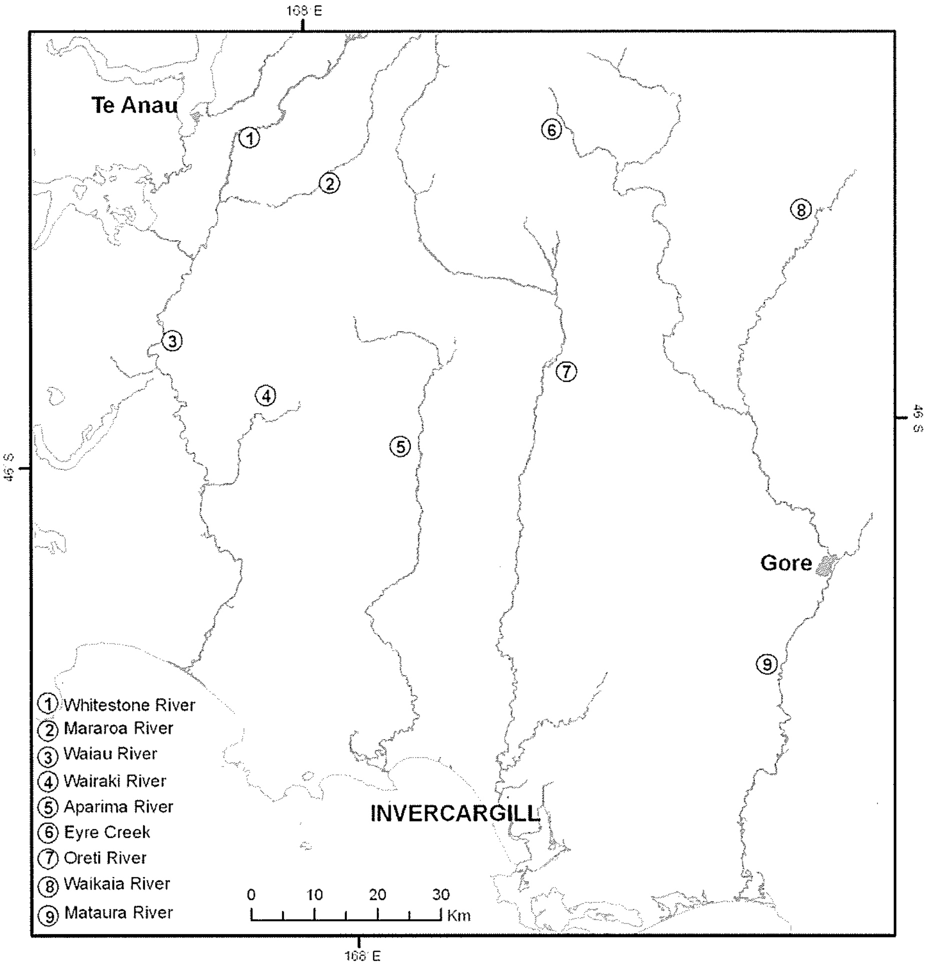

Figure 4: *Diagram of the Southland lowlands showing main urban centres and key waterways referred to in this thesis.*

The four study rivers are gravel-bedded (Figure 5) but have limited gravel-supply rates (Kelly et al. 2005). All rivers are single-channelled along parts of their lengths but contain braided sections, often splitting into two channels around a centre island. However, all contain sections with multiple braids, particularly the Oreti River. Mean annual flows are: Waiau 162 cumecs; Aparima 8 cumecs; Oreti 43 cumecs; and Mataura 96 cumecs (Environment Southland 2000). The Waiau was affected by the commissioning of the Manapouri hydropower station in 1970 which reduced its mean annual flow from 501 cumecs. The flow in the remaining three rivers is unmanaged. However, the rivers are affected to varying degrees by water abstraction for pasture irrigation and gravel extraction. In the past, gravel extraction rates for the Oreti and Mataura rivers have far exceed supply rates (Kelly et al. 2005). All four rivers are severely affected by invasion of exotic vegetation. Annual weed control (primarily of willow *Salix* spp., gorse *Ulex europaeus* and broom *Cytisus scoparius*) is carried out by Southland's regional council, Environment Southland.

Figure 5: *Examples of rivers and colonies. Top: Dunrobin South colony at the headwaters of the Aparima River, river flow is right to left. Middle, Otama South colony in the mid reaches of the Mataura River, river flow is right to left. Bottom, site of Lumsden Bridge colony (after desertion) in the mid reaches on the Oreti River, river flow is right to left.*

Study objectives

The overall aim of this research is to investigate the importance of factors potentially driving or contributing to black-billed gull population declines, both historically and currently, and thereby to identify information and actions necessary for effective management of the species within Southland. The primary objectives of the study are:

1. To quantify black-billed gull population trends within Southland and evaluate the species' present IUCN listing of Endangered
2. To investigate black-billed gull dispersal within Southland
3. To investigate colony site selection of black-billed gulls
4. To determine the impact of weeds on habitat availability for breeding
5. To determine the impact of predation on black-billed gull productivity
6. To examine population trends of Southland black-billed gulls using matrix models
7. To summarise all available evidence regarding the relative importance of threats to black-billed gull populations and provide management recommendations.

Thesis outline

This thesis has been written as three stand-alone papers intended for publication (Chapters 2, 3 and 7) and two chapters which will be split for publication (Chapters 4 and 5). This has resulted in some overlap in content. A combined reference list is given at the end of the thesis. Appendices are found at the end of the thesis. For simplicity, breeding seasons are referred to as a single year throughout this document, for example, the 2005-2006 breeding season is referred to as 2005.

Population data from Southland are the primary basis for the species' present IUCN classification. Estimates of decline have been published (BirdLife International 2000; Taylor 2000; Innes 2003; BirdLife International 2006) but have not taken into account the variation in survey methods over time. Chapter 2 collates, calibrates and analyses Southland population data, evaluating the methods employed for surveys and monitoring and recommends an appropriate IUCN classification. It also discusses likely historical population levels.

Dispersal studies on Laridae that habitually change breeding locations are almost non-existent. Chapter 3 addresses natal and breeding dispersal of black-billed gulls within Southland to determine the level of philopatry and group adherence (McNicholl 1975) in a highly mobile species. The overlap of dispersal ranges of different cohorts illustrates the extent to which Southland's black-billed gulls comprise one intermixing population. Patterns of dispersal may be an important indicator of the degree to which the species could cope with localised loss or degradation of breeding habitat and will provide a basis for future prioritisation of rivers or areas within rivers for weed or predator control.

Colony site selection studies on species that regularly change colony location are uncommon. Chapter 4 describes characteristics of Southland colonies, examines colony site selection by black-billed gulls and determines what factors affect colony site re-use in order to support decisions concerning which areas to focus management actions, particularly weed control. The relationship between colony size, productivity and available gravel habitat is also investigated to determine whether productivity could be affected by declining gravel patch sizes due to the spread of introduced plants. Actual loss of breeding habitat due to weed invasion in Southland is addressed in the second part of the chapter. Remote sensing is used in a GIS to determine changes in weed invasion in two key Southland rivers over several decades and, for the first time in a New Zealand context at least, changes in habitat availability.

Chapter 5 presents the first comprehensive study of nest success and breeding success of black-billed gulls; its primary purpose is to determine the impact of predators. The chapter addresses the possible benefits of extreme coloniality in the face of a suite of introduced predators. Factors influencing nest success are also examined, including whether nest success on islands is higher than on banks, suggesting reduced access by terrestrial predators (Pierce 1987; Rebergen et al. 1998; Boffa Miskell Ltd. 2007). The extent of disturbance by predators and the behaviour of gulls when disturbed are documented in a bank colony.

Chapter 6 uses matrix models to investigate the relative influence of survivorship and reproductive parameters on population trends of black-billed gulls and the closely related and intensively studied red-billed gull (*L. scopulinus novaehollandiae*) population at Kaikoura, New Zealand. This demonstrates which parameters will have most impact on population trends given improvements.

Chapter 7 summarises work from the Southland study and other research pertaining to management, in particular, aspects regarding the impact of threats facing black-billed gulls.

The threats are ranked in order of severity and recommendations given for management and further research.

CHAPTER 2

The status of populations of black-billed gulls in Southland, New Zealand

Vertical aerial photograph of Dunrobin South colony, Aparima River, 2006, and an enlargement showing individual gulls (R. Mathieu)

ABSTRACT

The status of black-billed gulls (*Larus bulleri*) in Southland, New Zealand, was assessed by collating, calibrating and analysing counts made between 1974 and 2006 from four major river systems. Two index count methods were evaluated and compared (ground estimates of nest density and aerial photography of colonies). The black-billed gull population appears to have undergone a substantial, rapid decline within its core breeding range between 1977 and 2006. Surveys in the 1970s indicated a population of about 140,000 breeding birds, whereas recent counts gave estimates of only 15-40,000 breeding birds. The overall decline in numbers of breeding birds on Southland's four main rivers is equivalent to 6.0%/year (SE 1.8) or 83.6% in 30 years. The decline has been greatest on the Oreti River which once supported the largest colonies recorded in New Zealand (96.7±2.1% in 33 years). The number of breeding colonies on the four rivers has also declined by almost 70% and the trend appears to be continuing. However, the two survey methods that have been used to estimate the size of the population cannot be compared with certainty. As well, infrequent historical surveys, possible bias in historical estimates of nest density and issues regarding the accuracy of aerial monitoring as an index of population size means estimates must be treated with caution. Nevertheless, the extent of the decline justifies the species' present IUCN listing as Endangered. The aerial monitoring and photography method is a poor index of the breeding population. The method is able to be a relatively precise measure of the number of individuals in a colony at the time of photography, but its accuracy as an index of total population is questionable as a pilot test demonstrated major changes in numbers over two-week intervals. This issue needs to be resolved with a robust and extensive test of the method. Historical records and observations of black-billed gull abundance are very difficult to interpret; it is possible that numbers were even higher in the 1950s and 1960s, and it seems likely that populations increased due to agricultural activities, however, the data are too poor to make a confident assessment.

INTRODUCTION

New Zealand's endemic black-billed gull (*Larus bulleri*) is regarded as the world's most threatened gull species (BirdLife International 2006). The gull was listed by the World Conservation Union (IUCN) as a species of 'Least Concern' in 1988 and again in 1994, but this classification was upgraded in 2000 to 'Vulnerable' and to 'Endangered' in 2005 (BirdLife International 2006). The justification for the latest classification was an observed "very rapid decline throughout its breeding range, equivalent to an overall decline of more than 50% in 32 years (three generations)" (BirdLife International 2006). Using the New Zealand Threat Classification System (Molloy *et al.* 2002), black-billed gulls were listed as a threatened species in 'Serious Decline' (Hitchmough *et al.* 2007). The system has since been revised and classifications and criteria have changed markedly (Townsend *et al.* 2008). The species is now listed as Nationally Endangered (Miskelly et al. 2008).

The region of Southland supports the majority of the New Zealand black-billed gull population (Powlesland 1998). National surveys by the New Zealand Ornithological Society during 1995, 1996 and 1997 found, respectively, 69%, 70% and 77% of the population breeding in the region's riverbeds (Powlesland 1998). A comparison of these and historical counts suggest the black-billed gull population declined markedly between the early 1970s and late 1990s. Based on these results, for example, a decline in the Oreti River, Southland, was reported as 80% in two decades (Taylor 2000) and an overall decline in Southland as 56-74% between 1977 and the late 1990s (Innes 2003). Given that black-billed gulls may be able to live to a maximum of 20 or more years[1] this decline is extreme, and could have major implications for the security of the species.

However, interpretation of these population data is not straightforward for several reasons. Firstly, surveys have employed two sampling methods which provide fundamentally different data (i.e. number of breeding birds, obtained from ground-based nest estimates, versus total number of birds present in a colony on a particular occasion, obtained from aerial photography). Secondly, historical survey and monitoring methods are poorly documented and unpublished making it difficult to compare different counts. Thirdly, the monitoring programme is unfunded and relies on volunteers. This has resulted in infrequent and sporadic surveys over the years and an inconsistent time series of counts. Fourth, the accuracy and precision of the methods are unknown. And lastly, the annual fluctuations of numbers of gulls within rivers characteristic of this species (O' Donnell and Moore 1983; O'Donnell 1992) are

[1] This is based partly on comparison with the closely related, well-studied red-billed gull (*L. scopulinus novaehollandiae*) and on the re-sighting of two black-billed gulls aged 22-23 years (R. Hitchmough and G. Taylor in litt. 2006).

poorly understood, in particular, whether numbers increase elsewhere when short-term, within-river declines are observed.

The size of the black-billed gull population in Southland prior to surveys commencing in the 1970s is unknown. Yet in the last 150 years, a suite of predators has been introduced, many of which are known to affect other river-breeding birds (Taylor 2000; Sanders and Maloney 2002; Murphy *et al.* 2004; Keedwell 2005). As well, agriculture has extended across the Southland lowlands, resulting in the almost complete loss of native vegetation, and causing potentially major changes in food supply. However, there appear to be few historical data with which to evaluate possible changes in abundance earlier in the 20th century in the context of the present decline.

This chapter evaluates the extent of the decline of the black-billed gull population within Southland and considers whether classification as an Endangered species is warranted. To do so, surveying methods used to undertake historic counts and the precision, accuracy and possible biases of the current monitoring method are evaluated. Evidence for population declines is examined and the relationship between the counting methods is determined. This relationship is used to revise and analyse data from all available historical surveys from 1973-2006 to derive estimates of regional and within-river population changes. In addition, pre-1970 records of abundance are assessed to determine whether inferences can be made regarding earlier population trends.

METHODS

Historical distribution and abundance 1870-1970

Information on general abundance and the locations and sizes of black-billed gull colonies in Southland was collated by reviewing scientific journals, books, other documents such as private journals and newspaper columns written between 1870 and 1970. In addition, anecdotal recollections of Southlanders were obtained during informal conversations. These occurred in a variety of ways: people attending research presentations; meeting farmers when accessing colonies; people making contact in response to media asking for band re-sightings and other information; and people approaching during field work. All recollections were from farmers, retired farmers or people who were raised on farms.

Ground surveys (1974-1986) and aerial surveys (1995-2006)

Ground survey methods and aerial survey methods have never been fully described in literature, published or unpublished. An objective of this research was to detail all methods used by compilation of unpublished data and conversations with those involved. The outcomes of this research have therefore been placed in the Results section.

Recounting photographic images of gull colonies 1995-2003

I scanned historical aerial photographs (1995-2003) at 600-1000 dpi in order to recheck previous counts. I counted gulls on a computer screen by placing dots on each bird within a grid square and recording the number counted within that square using the grid facility in Adobe Photoshop Elements 4.0™. The size of grid squares was not related to the image, but was set so no more than 100 gulls were present in a square. Of 100 photographs, 19 could not be counted as the quality was too poor. However, estimates were originally derived for these few original photographs and it is likely that the majority of these colonies were visited in order to obtain a ground estimate (L. Esler pers. comm. 2006). Remaining photographs were classified according to quality (poor, average or good).

Precision of aerial photograph counts

Three people independently counted gulls in the same sample of five good quality aerial colony photographs using Adobe Photoshop Elements 4.0™ (described previously) to assess the amount of variation between 'observers'. In addition, three independent observers visually estimated the number of gulls in a sample of photographs. Observers all had experience with black-billed gull field work, but only two had experience with the visual estimation method.

Accuracy of aerial photograph counts

In 2006, I undertook a pilot study to investigate the extent of temporal variation in numbers of gulls present in aerial photographs. Six colonies were chosen for the study; four on the Mataura River (Waipounamu, Otama North, Otama South and Wyndham), one on the Waikaia River (Waikaia), and one on Eyre Creek (Eyre Creek; i.e. all colonies present on these rivers; see Figure 2, Chapter 3 for colony locations). Oblique photographs of the colonies were taken from helicopter or plane flying at 80-100 m on three occasions at two-week intervals. A Canon EOS 50 with a 28-80mm lens was used. The second flight was part of the main Southland survey. Flights were undertaken in similar weather conditions in the morning (photographs of a colony were taken at a maximum of an hour's difference over all three flights). Gulls in photographs were manually counted by the same observer (as per methods for historic photographs).

Calibration of ground and aerial photograph counts

In order to compare ground and aerial survey methods, the number of nests was estimated at 13 of the 21 colonies monitored from 2004-2006. The resulting nest counts and aerial counts (see Results: Aerial surveys) were compared to give an estimate of the number of nests in each colony per gull present at the time of aerial photography. This factor was used to transform aerial count data from 1995-2006 into numbers of breeding birds. Nest counts were obtained by two methods.

In the first of these methods, complete ground counts of nests were completed at four smaller colonies (under approximately 1000 nests) at 'peak laying' in 2004 and 2005, defined as when the number of new nests on monitoring transects increased by less than 5% on two consecutive visits (typically 3-4 days apart; methods in Chapter 5). The nest count was completed on the following visit (adapted from Wanless and Harris 1984). These counts did not coincide well with aerial photography dates. In 2006, a further three ground counts of nests were undertaken at colonies specifically to coincide with aerial photography. Ground counts involved systematically walking the colony and marking every nest with florescent paint. Nest contents were recorded on a tape recorder. Accurately assessing the number of nests of gull species that nest on bare ground is straightforward and detection is generally 100% (Barbraud and Gélinaud 2005). At a test colony, a sub-colony with over 500 nests was counted. When completed, a second observer followed a zigzag route through the counted section and noted nests that were not marked. Only one was found. Counts included nests that were empty but which clearly had hatched chicks (determined by large amounts of faeces in the nest and a flattened nest bowl; chicks and parents leave the nest and territory approximately 4-8 days after hatching; R.K. McClellan unpubl. data).

In the second method, the number of nests was estimated using a combination of vertical aerial photographs of colonies and nest density estimates from transects in eight larger colonies where nest counts had the potential for significant disturbance (2005 and 2006 only). Colony areas were estimated from the vertical photographs, and nest density estimates were then used to calculate the number of nests in colonies.

To estimate areas, 5-6 ground control point markers (GCPs) were placed around each colony sufficiently close to be visible in lower altitude images. GCPs were painted florescent pink or green and were a minimum of 0.3 x 0.3 m in size. A GPS was used to take a series of 40 points every five seconds to reference each GCP. The locations given by GCPs were later corrected using a differential beacon located in Dunedin, New Zealand (approximately 300 km northeast of the colonies). Vertical photographs of colonies were taken, and the photographs geo-referenced using the GCPs in ERDAS IMAGINE 9. However, in 2006, a loss of GPS data required colony areas to be calculated differently. Instead, a sample of 10-15 sitting gulls in each vertical photograph was selected and their outline digitised using GIS software ArcMAP 9. The actual area of a sitting gull likely to be visible in the photographs was calculated by measuring three freshly dead adult carcasses. The resulting mean area of a gull was used to estimate colony areas.

To estimate nest density, firstly, areas of 'High', 'Medium' and 'Low' nest densities in the vertical aerial photographs were digitised using ArcMAP 9 (see Appendix A for examples). On the ground, nests on existing monitoring transects were first mapped, then nest density was calculated within blocks of 4 m^2 (i.e. the two-metre wide strip transects were divided into two-metre intervals), and thirdly, nest density was also grouped into areas of 'High', 'Medium' and 'Low' nest densities in similar proportions to areas calculated by GIS. Finally, the resulting mean nest density for each density category was extrapolated across the associated colony area.

When estimating nest density from aerial photographs, some photographs were of sufficiently high quality that individual nests were visible. In other photos, assessment of different density areas relied more on the location of birds, the change in the colour of the substrate (light brown due to faecal deposition in areas of high use/nests) and observer knowledge of the layout of each colony. These latter two factors were particularly important when colonies had distinct areas where gulls roosted but did not nest. Nest mapping was completed after colony desertion to avoid excessive disturbance. The number of colonies mapped was limited by post-breeding floods which modified many colony areas in 2004 and 2006.

Analysis of population trends

Many methods are used for statistical analysis of long term monitoring data sets. Some key methods include route regression (typical of North American Breeding Bird Survey analysis e.g. Kirsch and Sidle 1999; Thomas and Martin 1996), generalised linear models (e.g. Betts et al. 2007), generalised additive models (now typical of British Breeding Bird Survey analysis e.g. Fewster et al. 2000; Crick et al. 2004) and linear regression (e.g. Michol and Jouventin 2001; Ballard et al. 2003).

Southland population trends were analysed using all survey data available; ground survey data from the 1970s and 1980s and aerial monitoring data from 1995 onwards. Ground survey data were sparse and the use of two differing monitoring methods called for some caution in analysis. As a consequence, linear regression of the natural log of counts was used to test for population trends, where the slope of the regression is the rate of increase or decrease.

RESULTS

Historical distribution and abundance 1870-1970

The earliest records of black-billed gull distribution are from regions other than Southland, but indicate that the species has nested inland in the South Island in sizeable numbers since written records began. For example, Buller noted in 1888 that the species "is not confined to the inland lakes, as was hitherto supposed" (Turbott 1967) and gulls were recorded breeding in inland Marlborough in the 1860s (Travers 1871) and inland Otago at the turn of the 20^{th} century (Child 1983).

Likewise, the historical abundance of black-billed gulls in Southland is unclear. Oliver (1955), in a general summary of the species, noted that the gull had increased in numbers "considerably" during the previous 30-40 years, and that this had "clearly been due to the extra food available through the operations of man". However, the only specific change he reported was that the birds became "quite a feature of towns and villages". He wrote of "very large" breeding colonies present in Canterbury (in the central South Island) that numbered "several hundreds" of nests and noted, rather puzzlingly, that breeding colonies were smaller further south. Another general species summary noted that the species had increased in "European times" as native vegetation was cleared for agriculture, creating a new and plentiful invertebrate food source (L. Gurr in Robertson 1985).

Specific Southland records of numbers and locations of gulls and colonies in literature make no reference to changes in abundance and it is difficult to deduce any changes in abundance from them. Those located were dated from the 1930s to 1961 (see Appendix B for details). Records tend to refer to colonies of approximately 1000 or less gulls including several very small colonies of less than 100, but colonies numbering several thousand birds were also recorded in the 1940s and 1950s and were evidently common in the 1950s. Of particular interest are two, possibly three, references to "thousands" and "scores" of gulls present inland out of the breeding season (Anon 1940; Stidolph 1955; Sibson 1956).

Gull observations were obtained from several people who had lived on Southland farms during the 1950s-1970s. Three farmers had memories of c.40-50 years of gulls using the same banks to nest, but did not comment on any changes in abundance (J. MacDonald pers. comm. 2005; N. Gorrie pers. comm. 2005; B. Drummond pers. comm. 2005). One person had memories from the 1960s at Curio Bay, Southland, of often seeing "clouds of gulls...the sky was full of them" which he believed were migrating inland, but could not place the time of year (A. McDowall pers. comm. 2005). One retired farmer remembered the gulls being so numerous when he was growing up in the 1950s and 1960s that they were considered pests (C. Beer pers. comm. 2006). Another retired farmer believed he had seen a dramatic decrease in the numbers of gulls following his tractor, noting that the scene was one of chaos in the 1970s, with gulls getting stuck inside the cab of the tractor, and many getting caught and killed by the plough (M. McKenzie pers. comm. 2004).

Two farmers made comments regarding "thousands" of gulls travelling up and down the rivers at dusk and dawn during April/May, described by one as moving "in waves" (R. Smith pers. comm. 2005; name of second farmer not recorded in 2004). General references regarding the species' migration patterns to the coast (e.g. Higgins and Davies 1996) suggest that gulls would not be expected to be inland at this time of year, but both farmers were certain when questioned regarding the date (and see references listed previously). This behaviour was later described in detail by one retired farmer who told of how gulls remained inland throughout the year on the Aparima River in the 1950s and 1960s. He believed this was due to ploughing continuing up to the winter months and fields being left fallow over winter subsequently providing a stable year-round food source. The return to coastal migrations was associated with further major changes in land use, in particular, a significant reduction in the frequency of ploughing and the maintenance of grassed paddocks throughout winter (C. Beer pers. comm. 2006). These changes in the frequency and timing of ploughing are well-known in farming circles but appear to be undocumented in literature.

Monitoring methods

Early surveys of the rivers (1974-1986) were conducted on the ground. Surveys from 1995-2006 used a fixed wing plane and helicopter and aerial photography (summary in Table 1; no surveys were undertaken in intervening years).

Table 1: *Summary of black-billed gull survey and counting methods, 1974-2006, Waiau, Aparima, Oreti and Mataura rivers, Southland.*

Year and river	Survey method	Counting method
1974 Oreti*	Complete survey by foot	Exact method unknown, counts were of nests
1977 all rivers*	Incomplete survey of all rivers by foot	Estimate of nest density obtained from a sample of three colonies using grids. Area of all colonies measured; density estimate used to calculate nests in all colonies. Complete count of nests in a few small colonies.
1983 Mataura# 1985 Aparima* 1986 Oreti*	Complete survey by foot and boat	Area of all colonies measured; 1977 density estimate used to calculate nests in all colonies. Complete count of nests in a few small colonies.
1993 Waiau	Three reaches surveyed by foot (approximately a third of the Waiau)	Number of birds counted on the ground from a distance (Sagar 1994)
1995-1998 Waiau	Incomplete survey by foot following similar sections to Sagar (1994)	Following Sagar (1994) (McClelland 1996; 1997 and 1999)
2000, 2001 Waiau	Incomplete survey by foot following similar sections to Sagar (1994)	Complete nest counts (McClelland 2001, 2002)
1995-2003 all rivers (Waiau irregularly)*	Complete aerial survey, end points at headwaters vary. Photographs taken of all colonies.	Gulls originally counted on 6x4 inch photographs. Photographs later scanned at 600-1000 dpi and gulls counted on a computer screen (this study)
2004-2006 all rivers	Complete aerial survey. Photographs taken of all colonies.	Photographs scanned at 600-1000 dpi or digital photographs taken and gulls counted on a computer screen (this study)

*Ornithological Society of New Zealand, Southland Branch, unpubl. data (except 2003; Department of Conservation, unpubl. data).

#J. Riddell, Southland Acclimatisation Society (1984) unpubl. data.

Ground surveys 1974-1986

Ground surveys were carried out towards the end of October, which was thought to coincide with when the majority of birds were on nests (R. Sutton pers. comm. 2005). Rivers were split into sections and walked by teams of people who recorded the abundance of all observed bird species. Only the general location of colonies was recorded. All surveys were supervised by Mr Roger Sutton.

In 1977, Southland's four main rivers were surveyed, and nest density estimated in a sample of colonies. The method of estimating density, and thereby the size of the breeding population, was discussed with Peter Bull of the then Department of Scientific and Industrial Research and Sir Robert Falla (R. Sutton pers. comm. 2006). Approximately three colonies were used to estimate density. Grids were placed throughout the colony in order to sample different areas of density and nests were counted. The resulting density estimate of 1.79 nests/m^2 (R. Sutton, M. Barlow unpubl. data) was used to estimate the number of breeding pairs in the majority of colonies until 1986. However, the exact details of the method were not recorded and are not clearly remembered, in particular, the exact number of colonies, the number of grids and the method of grid placement. In 1984, one very large colony appeared to have a much higher density than colonies observed in previous surveys. Using Sutton's method, grids were placed in areas of visibly different densities (W. Cooper pers. comm. 2006) and nest density was estimated as 4.5 nests/m^2 (M. Barlow unpubl. data).

Two other ground methods have been used to estimate gull numbers. Sutton carried out complete counts of nests in the smallest colonies instead of measuring areas. Nest counts were also used on the Waiau River in 2000 and 2001 and were employed in this study (see previous section regarding precision of nest count estimates).

Waiau River counts from 1995-1998 were simple visual estimates of number of gulls present made by an observer standing at a distance. In 1998, the river was also aerially surveyed and the visual estimates were not used. Visual estimates made during 1995-1997 are included in the analysis, but the accuracy and precision of this method was not evaluated.

Aerial surveys 1995-2003

Members of the Southland branch of the Ornithological Society of New Zealand (OSNZ) carried out the first aerial black-billed gull survey using a fixed wing plane in 1995, covering the Oreti and Aparima rivers. Surveys continued on an irregular basis, and covered 2-7 rivers per annum depending on funding. Two to three observers were present during each flight. The pilot's door was removed to allow photographs to be taken as the plane banked around each colony at altitudes between approximately 80-150 m and at varying angles. A variety of basic cameras was used. The location of the colony was noted by an observer who had a thorough knowledge of Southland's rivers, and this was later given a map reference. The route taken on surveys was not recorded until 2003 and, consequently, it is not known if more rivers were surveyed but no colonies found. Likewise, it is possible that colonies were not seen on rivers that were known to have been surveyed (L. Esler and G. Morgan pers. comm. 2005). The timing of surveys varied between the last week of October and the second week of December. Time of day was not recorded.

Negatives were developed as standard 6x4 inch photographs. Gulls are visible as tiny white dots and were counted by hand using various means including dotting each gull with pen directly on to the photograph, dotting gulls using tracing paper and estimating numbers by counting gulls in squares and extrapolating across the photograph. The quality of photographs was highly variable ranging from those in which individual birds were clearly visible to those that were over-exposed, under-exposed or very blurry.

Aerial surveys 2004-2006

In 2004-2006, methods were similar to OSNZ surveys. In 2005, most photographs were taken from a helicopter that hovered briefly near colonies at approximately 80 m. A handheld GPS was used to record the general colony location. Accurate colony positions were later obtained when colonies were visited on the ground. A Canon EOS 50 with a 28-80mm lens, and later, a Canon 30D (a digital camera) and Canon EFS 17-85mm lens were used to take photographs. Surveys were carried out between October 3 and November 1. One colony was photographed in early December. In addition, vertical (nadir) photographs were taken of some colonies in 2005 and 2006 as part of a separate study.

Precision of aerial photograph counts

All photographs taken from 1995 to 2003 were scanned, classified for quality and re-counted. Quality varied considerably from those that were impossible to count (22%) through to photographs of 'good' quality (36%; Table 2). The recounts done as part of this study varied from original counts; recounts were lower than original estimates for photographs that were classified as poor or average quality (paired two-sided t-tests, both $t=2.13$, $df=15$, $P<0.05$) but were not different if photographs had been classified as good quality ($t=2.07$, $df=22$, $P>0.10$; Table 3). Total numbers of 'good' and 'average' photographs differ between Tables 2 and 3 because original counts from 2001 photographs were not made but the quality of the eight photographs was able to be classified (Table 2).

Table 2: *Quality of historical aerial photographs of black-billed gull colonies by year.*

Quality	1995	1996	1997	1998	1999	2001	2003	No. of photographs
Good	4	1	4	10	3	6	1	29
Average	4	2	4	2	2	2	2	18
Poor	6	4		2	2		2	16
Impossible		9	2	2	3		2	18
No. of photographs	14	16	10	16	10	8	7	81

Table 3: *Differences between original estimates and recounts of black-billed gulls in aerial photographs of colonies.*

Quality	Mean % difference (recount compared to original)	SE	No. of photographs	Paired estimates significantly different	P value
Good	25.2	9.8	23	No	>0.10
Average	-15.7	15.7	16	Yes	<0.05
Poor	-16.1	10.3	16	Yes	<0.05

Table 4: *Results of observer counts of black-billed gulls in aerial photographs of colonies.*

Colony/photograph	Obs. 1	Obs. 2	Obs. 3	Mean (SE)	Max. diff.	% of mean	Photograph quality
Mossburn 2005	2006	2129	2014	2049.7 (39.7)	123	6.0	Good
Mararoa 2005	536	468	536	513.3 (22.7)	68	13.2	Average
Avondale 2005	2209	2300	1966	2158.2 (99.7)	334	15.5	Average
Mararoa 2006	1581	1578	1637	1598.7 (19.2)	59	3.7	Good
Mararoa 2006 (obl.)	1819	1828	1465	1704.0 (119.5)	363	21.3	Good
Total	8151	8501	7618	8024.0 (207.7)	685	8.5	

One oblique and four vertical digital images that varied in quality were analysed by three observers. Counts varied by 3.7% to 21.3% of the mean counts of each photograph (Table 4). Good quality photographs where gulls were clearly visible tended to have very low variation between observers, although one observer missed many gulls in the oblique photograph. Individual observers did not show tendencies to under or over count. Overall, results varied by 8.5%. Visual estimates of gulls in aerial photographs were highly variable and occasionally extremely imprecise (Table 5). Interestingly, mean observer counts and mean observer visual estimates were relatively close, differing by 8-12%.

Table 5: *Results of observer visual estimates of black-billed gulls in aerial photographs of colonies.*

Colony/ photograph	Obs. 1	Obs. 2	Obs. 3	Mean (SE)	Max. diff.	% of mean	Photograph quality	Mean observer count (from Table 4)
Mossburn 2005	2000	2500	2200	2233.3 (145.3)	500	22.4	Good	2049.7 (39.7)
Mararoa 2005	400	600	350	450.0 (76.4)	250	55.6	Average	513.3 (22.7)
Avondale 2005	1600	4500	1200	2433.3 (1039.8)	3300	135.6	Average	2158.2 (99.7)

Accuracy of aerial photograph counts

The results from the aerial monitoring pilot study showed a substantial amount of variation in the numbers of gulls photographed in colonies at different times of the breeding season (Table 6). The first four colonies listed are on the Mataura River. Overall, colonies decreased by more than a quarter over the course of a month. Trends were also all negative over the two weeks following the main survey. However, between the first survey and the main survey, trends were variable. Some colonies decreased by almost 50% within two weeks and one colony increased by over a third.

Table 6: *Numbers of black-billed gulls counted in aerial photographs of colonies taken at two-week intervals during the 2006 breeding season.*

Colony	Pre-survey 17/10/2006	Main Survey 1/11/2006	Post-survey 13/11/2006	% change Pre-Main	% change Main-Post	% overall change Pre-Post
Wyndham	3538	3729	2661	5.4	-28.6	-24.8
Otama South	5086	4266	3687	-16.1	-13.6	-27.5
Otama North	2311	3169	1606	37.1	-49.3	-30.5
Waipounamu	3464	3592	3285	3.7	-8.5	-5.2
Waikaia River	3049	1694	1161	-44.4	-31.5	-61.9
Eyre Creek	7235	7888	5400	9.0	-31.5	-25.4
Totals	24683	24338	17800			
Means (SE)	4114	4056	2967	-0.9 (11.1)	-27.2 (5.9)	-29.2 (7.5)

Calibration of ground and aerial photograph counts

The ratio of the number of black-billed gulls counted from aerial photographs versus the number of nests counted on the ground within the same colony varied from 0.90 gulls per nest to 3.95 gulls per nest with a mean of 2.14 ± 0.23 gulls (Table 7). Transect/GIS estimation tended to give lower ratios of gulls to nests than complete counts, despite estimates including all nests laid on the transects over the course of the season. However, where both methods were employed, transect/GIS estimation gave nest counts 2.4% and 13.7% higher than complete counts. The Papatotara colony was highly synchronous, and the nest count included all nests laid in the colony. Using all data in Table 7, the mean number of nests per gull was 0.56 (SE 0.07). This factor, multiplied by two, has been used to transform all aerial photographic counts to counts of breeding birds in the following section.

Table 7: *Numbers of black-billed gulls counted in aerial photographs and numbers of nests estimated from two count methods (complete ground counts and estimation from nest density on transects), Southland colonies 2004-2006.*

Colony	River	Date of aerial photograph	Number of gulls in aerial photograph	Date of nest count	Type of nest count	No. of nests	Ratio gull/nest
Dipton	Oreti	1 Nov. 2006	1884	30 Oct. 2006	Complete	477	3.95:1
Bayswater	Aparima	3 Oct. 2004	2927	31 Oct. 2004	Complete	794	3.69:1
Papatotara	Waiau	3 Oct. 2004	1217	23 Oct. 2004	Complete	395	3.08:1
Mossburn	Oreti	26 Oct. 2005	2006	27 Oct. 2005	Transect	771	2.60:1
Benmore	Oreti	3 Oct. 2004	721	22 Oct. 2004	Complete	321	2.25:1
Thornbury	Aparima	1 Nov. 2006	909	28 Oct. 2006	Complete	411	2.21:1
Otama South	Mataura	1 Nov. 2006	4266	31 Oct. 2006	Transect	2015	2.12:1
Etal Creek	Aparima	1 Nov. 2006	882	29 Oct. 2006	Complete	421	2.10:1
				2 Nov. 2006	Transect	431	2.05:1
Mararoa Weir	Waiau	26 Oct. 2005	536	14 Nov. 2005	Complete	277	1.94:1
					Transect	315	1.70:1
Avondale	Aparima	26 Oct. 2005	2709	27 Oct. 2005	Transect	2115	1.28:1
Otama North	Mataura	1 Nov. 2006	3169	31 Oct. 2006	Transect	2576	1.23:1
Mararoa Weir	Waiau	1 Nov. 2006	1828	31 Oct. 2006	Transect	1813	1.01:1
Dunrobin S	Aparima	1 Nov. 2006	3453	31 Oct. 2006	Transect	3819	0.90:1
Mean (SE)							2.14:1 (0.23)

Population trends 1974-2006

Regression analysis of log counts of breeding birds (corrected data for 1995-2006) indicate that numbers of black-billed gulls have declined significantly on three of four of key breeding rivers in Southland since the 1970s (Table 8, Figure 1). Overall, the decline on all four rivers is equivalent to 6.0% ± 4.4%/year or 83.6% in 30 years (fitted exponential trend, 95% CI, $P<0.05$; Figure 2). Data from the Waiau for 2003 have been excluded from all analyses as the survey was carried out on 10 December and two large colonies were known to have left their breeding locations (L. Esler pers. comm. 2004). All rivers were surveyed on this day (6-7 weeks later than recommended by Sutton) but prior knowledge of colony locations on the other rivers was not available and those rivers have been included (see Appendix C for survey dates and further information).

Table 8: *Estimated rate of decline of breeding black-billed gulls on Southland's four main rivers; 1974/1977-2006.*

River	Rate of decline per year	Overall decline	Significance
Waiau	3.9% ± 11.0%	68.0% in 30 years	P>0.10
Aparima	7.9% ± 6.5%	90.7% in 30 years	P<0.05
Oreti	10.0% ± 4.5%	96.5% in 33 years	P<0.01
Mataura	6.8% ± 4.5%	87.1% in 30 years	P<0.01
All rivers	6.0% ± 4.4%	83.6% in 30 years	P<0.05

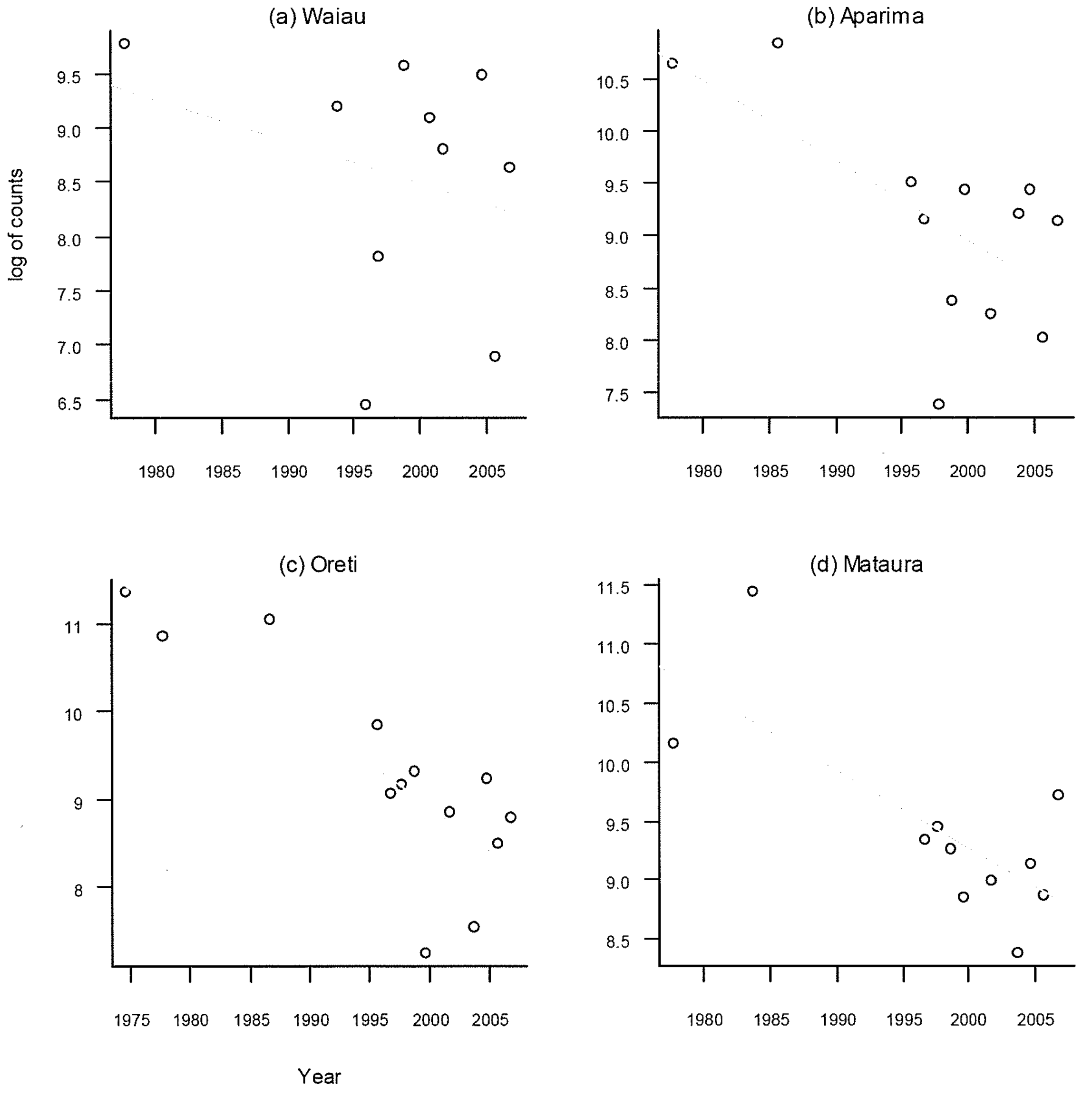

Figure 1: *Declines in the numbers of breeding black-billed gulls on four rivers, Southland, 1974-2006 (corrected counts).*

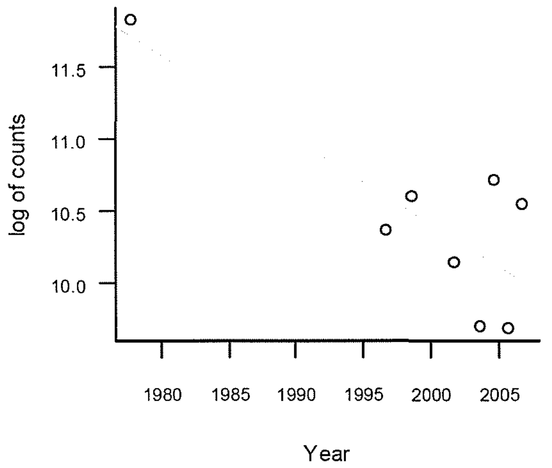

Figure 2: *Change in the numbers of breeding black-billed gulls, Waiau, Aparima, Oreti and Mataura rivers combined, Southland, 1974-2006 (corrected counts).*

Trends in the number of breeding birds since 1995 (aerial photography method except for three Waiau counts; see section on monitoring methods) are more variable and none are statistically significant. Positive trends are apparent on the Waiau (7.2%/year) and Aparima (0.6%) while negative trends continue on the Oreti (-7.3%) and Mataura (-1.6%). Overall, the trend is a decline equating to 2.6%/year. The mean number of breeding birds in a colony has been consistently smaller from 1995-2006 than previous years, but was considerably higher during the 1980 surveys (each of these surveys only covered one river; Table 9, Figure 3). A similar pattern is visible for the largest colony found in any one year.

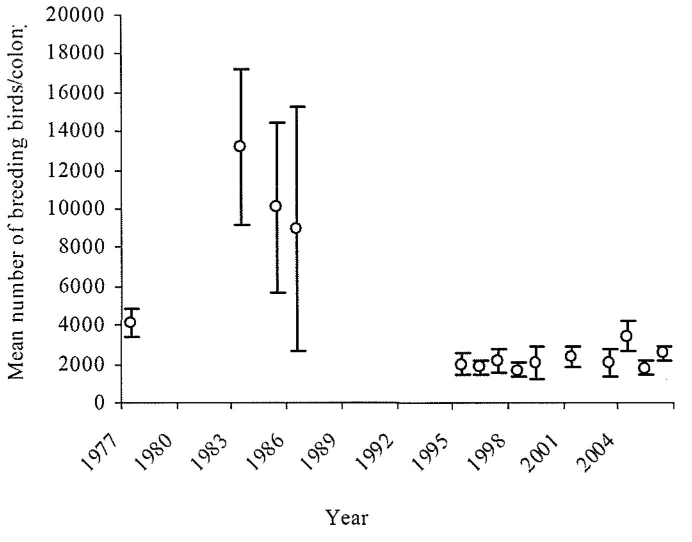

Figure 3: *Mean number of breeding black-billed gulls per colony (and standard errors), Waiau, Aparima, Oreti and Mataura rivers, 1977-2006 (corrected counts).*

Table 9: *Variation in the size of black-billed gull colonies on the Waiau, Aparima, Oreti and Mataura rivers, 1977-2006 (corrected counts).*

Year	No. of rivers surveyed	Number of colonies	Mean colony size (breeding birds)	SE	Median	Minimum	Maximum
1977	Four	33	4139.8	740.9	2492.0	210	16238
1983	One	7	13237.3	4021.2	10800.0	3525	35100
1985	One	5	10061.6	4401.2	8000.0	62	24516
1986	One	7	8976.4	6312.8	1000.0	90	44830
1995	Three	16	1997.5	592.4	1473.9	187	10211
1996	Four	18	1825.0	361.1	1473.9	110	5211
1997	Three	10	2160.1	647.6	1613.9	112	6497
1998	Four	18	1666.8	354.7	1523.2	63	4736
1999	Three	10	2098.8	837.9	1214.6	285	9287
2001	Four	14	2347.2	512.1	2311.1	766	4462
2003	Four	10	2025.9	719.7	1370.3	112	5600
2004	Four	13	3445.0	739.4	2858.2	570	9202
2005	Four	9	1770.1	365.1	2246.7	383	3034
2006	Four	15	2526.6	362.4	2110.1	48	4778

The number of colonies present on Southland's main rivers has also declined since 1977 (Table 10, Figure 4). Trends are not statistically significant for the Waiau and Aparima rivers, but declines have occurred on the Oreti ($P<0.01$), Mataura ($P<0.05$) and over all four rivers ($P<0.01$). An overall decline in colony numbers appears to be continuing; since 1996, colony numbers have decreased at a rate of 4.9%/year, a trend that is significant at $P<0.10$.

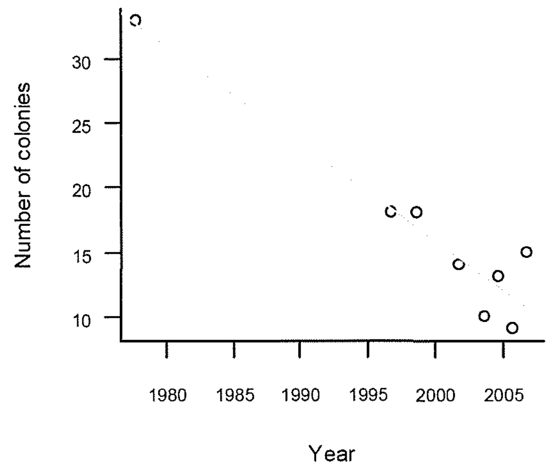

Figure 4: *Decline in the total number of black-billed gull colonies on the Waiau, Aparima, Oreti and Mataura rivers, 1977-2006.*

Table 10: *Number of black-billed gull colonies on the Waiau, Aparima, Oreti and Mataura rivers, 1977-2006.*

Year	Waiau	Aparima	Oreti	Mataura	All rivers
1977	7	6	11	9	33
1983				7	
1985		5			
1986			7		
1993	4				
1995	1	11	4		
1996	2	3	5	8	18
1997		1	3	6	
1998	3	4	6	5	18
1999		3	3	4	
2000	2				
2001	4	4	3	3	14
2003	3	2	1	4	10
2004	4	3	5	1	13
2005	2	1	2	4	9
2006	2	6	3	4	15

Correlation coefficients were used to assess the possible presence of a relationship between colony numbers and total breeding bird numbers (corrected counts) on each river and over all four rivers (Table 11). Individually, rivers varied from those with low coefficients, suggesting little relationship, to those with coefficients that suggested a strong relationship. Over all rivers, the correlation coefficient was 0.95.

Table 11: *Correlation coefficients for total number of black-billed gull colonies versus total number of breeding birds, Waiau, Aparima, Oreti and Mataura rivers, 1977-2006 (corrected counts).*

River	Waiau	Aparima	Oreti	Mataura	All rivers
Correlation coefficient	0.80 (P<0.01)	0.35 (P>0.10)	0.80 (P<0.01)	0.42 (P>0.10)	0.95 (P<0.01)

DISCUSSION

Historical abundance 1870-1970

There are no comprehensive counts of black-billed gulls available prior to 1974 with which to assess the historical abundance of the species. Located references were mostly of colonies of less than 1000 birds (noting the difficulty in ascertaining whether records refer to number of gulls observed, number of nests or number of breeding birds). However, colonies in the 1940s and 1950s evidently often numbered several thousand birds, and non-breeding season references and farmers' anecdotal observations are also of 'thousands' of birds. In 1957, five colonies were reported on the Aparima River over a stretch of 36 km (Boyd and Cunningham 1957). This equates to 12-13 colonies when extrapolated across the entire river compared to the six that were found as part of the 1977 surveys. A retired farmer likewise reported the presence of colonies every 2-3 miles on the Aparima in the 1960s (C. Beer pers. comm. 2006). This is equivalent to 18-28 colonies on the Aparima. These figures suggest colony numbers may have been even higher during these decades than in 1977.

Published references and comments from farmers suggest that "thousands", possibly the majority, of gulls were not migrating to the coast from at least 1939 through to the 1960s, presumably due to a predictable and consistent food supply from agricultural activities. A regular, guaranteed food source could have resulted in greater reproductive success, or even two broods being raised in a year, as can occur in red-billed Gull *L. novaehollandiae* populations in Australia (Pringle 1987) and may occur in Hartlaub's Gull *L. hartlaubii* in South Africa (Crawford and Underhill 2003). Higher productivity is one potential explanation for an inferred population increase, as is increased survival resulting from the cessation of migration.

It seems likely that Southland's black-billed gull population did indeed increase due to large scale land conversion to agriculture (as per suggestions from ornithologists) but just when this increase began, from what initial levels and when it peaked is very unclear, and it is therefore largely impossible to accurately infer 1870-1970 population trends (see Chapter 7 for further discussion on the impacts of land use).

Ground surveys 1974-1986

The accuracy and precision of historical ground surveys cannot be determined because the principle method of estimating nest density and extrapolating across colony areas was not fully described. Possible issues with the method are associated mostly with the estimation of density and include small sample size and subjective placement of grids or choice of colonies. In contrast, complete nest counts, used sparingly during the historical surveys (and used in addition to aerial photography in this study) are an extremely precise estimate of the breeding population at that point in time.

Results from this research indicate overall nest density is substantially lower than that found in 1977 of 1.75 nests/m^2. From 2002-2006, mean density was 1.2 nests/m^2 (eight colonies), reaching 3.8 nests/m^2 in the most dense colony. The highest density found on any 2x2 m section of transect was 19 nests or 4.8 nests/m^2 (R.K. McClellan, unpubl. data). These results suggest that density may have been overestimated in historic ground surveys. However, it could also be an effect of a much larger population or variation over time in weed or debris cover in the breeding location.

In comparison, the number of colonies present during the 1970s and 1980s seems relatively unambiguous; one issue being that rivers were not covered in their entirety during the large-scale 1977 survey and colonies may have been missed (R. Sutton pers. comm. 2006). This would simply mean that the calculated rate and extent of decline are underestimates. However, correlation coefficients between the number of colonies and the number of breeding birds indicates that the relationship is complicated by other factors, particularly the characteristic annual population fluctuations within rivers. The occasional occurrence of many small colonies or one or a few very large colonies on a river can clearly cause deviation from a linear relationship. The existence of a very strong, overall correlation between breeding bird numbers and colony numbers on all four rivers (therefore partly taking account of annual fluctuations within rivers/between river movements; see Chapter 3) suggests that the number of colonies is a good indicator of population trends.

The large gaps in the time series of surveys from the 1970s and 1980s and the issues with representativeness, accuracy and precision of those counts mean caution must be exercised when determining the extent of the decline. However, despite limitations, the data are invaluable, and clearly demonstrate the existence of a major population decline.

Aerial monitoring accuracy and precision

An unusual feature of aerial monitoring for black-billed gulls is that a complete census of all colonies on any number of waterways within Southland is easily achievable. All rivers and several key streams could be surveyed within a day at a cost of approximately $2000(NZ$). Manual counting of approximately 20 colonies may take a further 40 hours or more. Manual counting has the potential to be relatively precise (as measured by counts by a number of observers) i.e. less than 5% of mean counts, but observer variation becomes problematic if photographs are not of good quality. Precision in these trials was greater than was found in trials by Frederick *et al.* (2003). Automated counting may reduce the effort required to manually count aerial photographs, but its precision is not yet known (R. Mathieu and R.K. McClellan, unpubl. data). In contrast, ground counts of nests still require an aerial survey in the first instance to locate colonies; generally require permission for access across private land; cause major disturbance to colonies during counts; and fall victim to asynchrony of nesting (see following discussion).

In addition, aerial photography of black-billed gull colonies avoids many of the difficulties inherent with monitoring of other species of colonial birds. Many monitoring programmes rely on flight transects and resulting extrapolations (e.g. Bromley *et al.* 1995; Bryan *et al.* 2003; Rodgers *et al.* 2005; Noel *et al.* 2006); many, perhaps the majority, deal with issues of detectability where birds can be hidden by vegetation or blend in with the surrounds (e.g. Pollock and Kendall 1987; Dodd and Murphy 1995; Rodgers *et al.* 1995; Frederick *et al.* 1996; R. Shauffler pers. comm. 2007); photographs generally overlap and must be matched (e.g. Dolbeer *et al.* 1997; Steinkamp *et al.* 2003; R. Shauffler pers. comm. 2007); and often, colonies are mixed making it difficult, sometimes impossible, to distinguish between species (e.g. Rodgers *et al.* 1995; Bryan *et al.* 2003). Some aerial monitoring programmes rely on visual estimates made by observers while in flight (e.g. Frederick *et al.* 1996; Rodgers *et al.* 1995; Bryan *et al.* 2003). The majority of comparisons between aerial estimates and ground counts are of this nature; unsurprisingly, most find major discrepancies between methods (Kadlec and Drury 1968; Hutchinson 1979; Rodgers *et al.* 1995; Frederick *et al.* 1996).

However, there are a number of issues regarding the accuracy of aerial photography of black-billed gull colonies as an index of population abundance. Unlike many other species of gulls where counts from photographs are often of nests (e.g. Dolbeer *et al.* 1997; Johnson and Krohn 2001; Steinkamp *et al.* 2003) it is extremely difficult to discern black-billed gull nests from aerial photographs. The increasing resolution of digital cameras may allow higher quality photographs in which nests are clearer. However, if this is indeed possible, in addition to issues and assumptions already noted, counting black-billed gull nests raises still further problems (all pers. obs.):

- Nests are often poorly formed, becoming more developed throughout the breeding season. An unknown but significant proportion would not be visible in photographs. At the extreme, eggs are laid on to bare gravel
- Nest density can be such that nesting material can form a thick mat of several square metres; from a photograph, the number of nests represented would be impossible to estimate
- Nests are deserted once a chick is approximately 4-8 days old. These nests would be visible in photographs (if nesting material was not stolen; also commonplace) but could not be distinguished from inactive or failed nests
- Non-breeding birds are often in incubation position in and around the colony.

A further issue is the large variation between colonies in the ratio of nests on the ground to gulls in photographs (Table 7). The nest counts that were completed in order to carry out data transformation for this study raised a previously unknown aspect of black-billed gull breeding ecology, that of the variation in the proportion of gulls breeding in different colonies. Shauffler (1998) also found a similar level of variation in two species of North American gulls living on islands. Shauffler's ground counts of active nests were complete and synchronous with aerial photography. Over 14 islands (or colonies) the gulls/nest ratio for Herring Gulls (*L. argentatus*) had a mean of 0.86, with a range of 0.46 to 3.45. For Great Black-backed Gulls (*L. marinus*; 13 islands), the mean was 1.33 with a range of 0.89 to 2.44. For black-billed gulls, this same mean was 2.14 with a range of 0.9 to 3.95. Results from this study and from Shauffler's study clearly demonstrate that large numbers of gulls present within colonies are not breeding at the time of photography, and that this proportion of non-breeders varies significantly between colonies.

In addition, the timing of surveys is an issue common to all bird monitoring programmes (e.g. Wanless and Harris 1984; Johnson and Krohn 2001; Frederick *et al.* 2006). This study has illustrated the large amount of variation in numbers of gulls present in colonies within relatively short spaces of time for reasons that are not at all clear. Research has also shown significant variability in breeding synchrony between black-billed gull colonies; from all nests becoming active within two weeks, to nesting taking place over 5-6 months (R.K. McClellan, unpubl.data).

As well as lack of nesting synchrony, nest failure, re-nesting and double-brooding can all confound estimates of the breeding population (Wanless and Harris 1984; Green and Hirons 1988; Johnson and Krohn 2001: Frederick *et al.* 2006). Research has demonstrated another major source of inter-colony variability; that of the amount of re-nesting (e.g. between 0-25% of successful nests re-used; R.K. McClellan, unpubl. data). Variation can also come from unexpected sources, e.g. Bromley *et al.* (1995) found population estimates to be negatively correlated with nesting success; members of a failed pair remained together and were more easily flushed during aerial survey.

The overall consequence is that aerial photography of black-billed gull colonies is potentially a poor indicator of the breeding population. Possible scenarios where this could be a major problem include, for example, excessive disturbance (human or predator) or poor food supply causing adults to defer breeding but remain associated with a breeding colony. Aerial photography has the potential, however, to be an accurate index of the total population, but the variation in numbers of birds present at a colony over time needs to be examined with a full investigation of the methodology.

Overall trends and status

The exact magnitude of the decline of the black-billed gull population in Southland over the last three decades is debatable. In the last 10 years, numbers of breeding birds have varied within Southland rivers by as much as an order of magnitude, presumably due to birds shifting between rivers between seasons; a characteristic of black-billed gull behaviour that has long been known (O'Donnell and Moore 1983; O'Donnell 1992; but see Chapter 6 for further discussion). Applying linear regression models can mask long-term trends that are not necessarily linear (Fewster *et al.* 2000). Consequently, the analyses in this paper must be regarded as a simplified view of population trends. However, declines appear to be well in excess of 50% in 32 years (three generations); the threshold for the Endangered category as determined by IUCN red list criteria (BirdLife International 2007; see Chapter 6 for confirmation of generation length).

The extent of population decline in other regions in the South Island is unclear but may be of a similar degree. A robust, long term dataset from the Ashburton River, Canterbury, gives a significant decline ($P<0.10$), equivalent to a decline of 3.6%/year or 58.6% in 25 years (C. O'Donnell unpubl. data). Sparse data from the lower Waitaki River, Otago, indicates a decline of approximately 4.5% per year or 76% in 32 years (linear regression, df=5, adj. R^2=0.49, $P<0.05$). Densities of black-billed gulls in inland Canterbury and Otago decreased in six of nine rivers examined between counts in the 1960s (three counts) and 1990s (2-4 counts, variable between rivers), changes were significant in two rivers and black-billed gull colonies were not found in six of the rivers during the counts in the early 1990s (Maloney 1999). Counts from a number of other Canterbury and Otago rivers have apparently been undertaken but information is unpublished.

To list the species as Critically Endangered requires an observed or estimated decline of over 90% to have occurred within the same period of time. A decline of this magnitude may have occurred within Southland but data are not sufficiently robust to support this assertion. The potential biases of both ground and aerial methods, the possibility that the decline rate may have slowed in the last 10 years, and the lack of information regarding trends elsewhere in the country, suggest a more conservative view should be taken. Using the national classification system, the listing of Nationally Critical is warranted if the species is believed to be undergoing a decline in excess of 70% in three generations (Townsend et al. 2008). This criterion may well be met if the Southland population was shown to be continuing to decline at a similar rate, and if populations elsewhere were likewise rapidly declining.

The collation and, where possible, analysis of all existing datasets is urgently required in order to determine the correct threat listing of this species. Determining the pressures impacting productivity and survival are necessary in order to explain the population decline, and critical for the formulation of management actions to address the rapid demise of this species.

CHAPTER 3

Natal and breeding dispersal of the Endangered black-billed gull within Southland, New Zealand

Black-billed gull banded as a chick at Centre Bush colony, Oreti River, 2000. Photographed at Dunrobin South colony, Aparima River, 2006 (C. Garden)

ABSTRACT

The black-billed gull (*Larus bulleri*) is a colonial inland river-breeding specialist endemic to New Zealand. Natal dispersal (dispersal from the site of hatching to the site of first or potential reproduction) and breeding dispersal (change of breeding site between two successive breeding attempts) was examined within the core range of the species in Southland, New Zealand, during the 2005 and 2006 breeding seasons. Study birds consisted of seven years of cohort banded chicks and one year of individually banded adults. A minimum of 85 second-year birds (year of potential reproduction; 12.6% of the cohort) was re-sighted at 20 breeding colonies during 2006. No colonies re-formed at the six natal sites in 2006; natal dispersal was 100%. Mean dispersal of second-year birds was 35.7 km (SE 5.7) and the likelihood of dispersal decreased with distance from the natal location. Approximately 70% of dispersal was out of the natal catchment. Overlap analysis of dispersal ranges demonstrate that Southland black-billed gulls constitute a single intermixing population. Of 67 adults individually banded during 2005, 39 (58.2%) were re-sighted during the 2006 breeding season, 29 within breeding colonies. The remaining 10 birds were seen in colonies prior to breeding commencing or were seen foraging only. In 2006, colonies re-formed at one of the three adult banding locations. Of the 12 gulls banded at this colony that were re-sighted in colonies during the following season, nine were seen in the same location despite the previous colony's complete failure. The remaining 20 gulls (69.0%) dispersed to different colonies; 15 (51.7%) individuals in different catchments. Four adults were observed in 2-3 colonies. Mean breeding dispersal was 23.5 km (SE 4.3) and was significantly lower than natal dispersal. Breeding dispersal appeared to be unrelated to previous breeding success, the availability of the previous year's colony site and dispersing birds did not move as groups. The percentage of individuals exhibiting natal and breeding dispersal is very high compared to other colonial seabirds, and is likely due in part to the species' unstable breeding habitat. Further research to establish the risk of regional extinctions is warranted given the species' listing as Endangered.

INTRODUCTION

Understanding the dispersal of avian populations is fundamental to the development of effective conservation management strategies for many species (Clark et al. 2004). For example, species with limited dispersal capabilities may face long-term risks from major or large-scale habitat alterations (Sutherland et al. 2000). In this study, natal dispersal is defined as dispersal from the site of hatching to the site of first or potential reproduction (Greenwood and Harvey 1982) and breeding dispersal as the change of breeding site between two successive breeding attempts (Greenwood and Harvey 1982). Natal dispersal is particularly well known in seabirds (Bradley and Wooler 1991; Steiner and Gaston 2005). The juvenile bird is thought to make a decision regarding where it will breed for the first time; either within its natal colony, or to disperse to another (Dittman et al. 2005). The extent of natal dispersal among colonial seabirds is variable, from virtually no dispersal (e.g. Spear et al. 1998, Steiner and Gaston 2005) to more than half of the population of young birds (Paradis et al 1998; Crawford et al. 2002). The likelihood of natal dispersal among seabirds has been found to decrease with distance from the natal location (Oro and Pradel 1999) and to be related to biological aspects such as breeding population size (Crespin et al 2006), sex and time of hatching within the season (Spear et al. 1998). In general, natal dispersal occurs more than breeding dispersal (Gabrey 1996; Paradis et al. 1998; Dittman et al. 2005; Matthiopoulos et al. 2005; but see Hénaux et al. 2007).

Breeding dispersal may involve two decisions: whether to remain faithful to the previous breeding site and, if the decision is to disperse, where to breed (Cam et al. 2004). Such dispersal is influenced by many factors including the product of the average reproductive success of con-specifics within a habitat patch (Boulinier and Danchin 1997), mate fidelity, age, timing of breeding within the season, colony density (Kim et al. 2007) and previous individual breeding success (e.g. Switzer 1997; Kokko et al. 2004). Site fidelity (i.e. the return to and reuse of previously occupied breeding locations; Switzer 1993) tends to be very high among colonial seabirds (e.g. Spendelow et al. 1995, roseate tern (*Sterna dougallii*); Inchausti and Weimerskirch 2002, wandering albatross (*Diomedea exulans chionoptera*); Stenhouse and Robertson 2005, Sabine's gull (*Xema sabini*); Hénaux et al. 2007, great cormorant (*Phalacrocorax carbo sinensis*)) with often much fewer than 10% of a breeding population shifting colonies between years. However, for some colonial seabirds, breeding dispersal is high and appears associated with species nesting in comparatively unstable habitats; such species are largely from Laridae and often nest on riverbeds (e.g. McNicholl 1975, a wide range of Laridae including large-billed terns (*Phaetusa simplex*), royal terns (*Thalasseus maximus*) and black-billed gulls; Burger 1982, black skimmer (*Rynchops niger*); Burger 1984, Renken and Smith 1995, least tern (*Sternula antillarum*); Erwin et al. 1998, gull-billed tern (*Sterna nilotica*); Keedwell 2005, black-fronted tern (*Sterna albostriata*)).

Empirical data on avian dispersal are sparse, generally due to methodological and logistical problems (Paradis et al. 1998; Walters 2000; Grosbois and Tavecchia 2003; Cam et al. 2004). In many studies, dispersal is likely underestimated due to the inclusion of only small numbers of colonies or patches; sometimes only one (e.g. Paradis et al. 1998; Stenhouse and Robertson 2005). The literature is very limited in regard to the dispersal of colonial seabirds that breed in relatively unstable habitats, and almost non-existent on the topic of dispersal of colonial seabirds (and other colonial avifauna) breeding on inland rivers.

The black-billed gull (*Larus bulleri*) nests in large, dense colonies on gravel-bedded rivers in New Zealand, most migrating to the coast after breeding (Higgins and Davies 1996). Approximately 70% of the population breeds in Southland (Powlesland 1998). Unlike the majority of the world's colonial seabirds, the colony sites of black-billed gulls generally change from year to year, and annual numbers nesting on any one river can fluctuate dramatically, often by an order of magnitude (O'Donnell and Moore 1983; O'Donnell 1992; Chapter 2). New Zealand's gravel-bedded rivers, particularly braided rivers, support habitats that are physically unstable and have high turnover rates (Gray and Harding 2007). Colony sites on such rivers are often significantly modified by floods and the spread of vegetation between breeding seasons and become unsuitable for nesting (Soper 1959; Beer 1966; Chapter 4). Colony site desertion by black-billed gulls (i.e. a colony does not re-form in the same location in the following season) has been compared to other colonial seabirds that also nest in unstable habitats (Beer 1966; McNicholl 1975; Burger 1982). Associated hypotheses include reduced site tenacity and enhanced group adherence in unstable habitats allowing for rapid colonisation of new habitat (McNicholl 1975), and colony desertion at previously unsuccessful sites and colony reoccupation at successful sites (Burger 1982). Swizter (1993) however, hypothesised that species living in unstable habitats would reoccupy sites independently of previous reproductive outcomes, and would be 'site-faithful'.

Early observations of black-billed gulls suggested breeding groups of birds returned to the previous year's colony site and, if found unsuitable, moved somewhere else within that river until a suitable location was found (Beer 1966; Soper 1972). Such descriptions in literature give an impression of colonies moving as groups. However, empirical data on breeding dispersal and the extent to which black-billed gulls maintain similar group assemblages from year to year are lacking.

Natal dispersal is likewise poorly known. The age of first potential reproduction is thought to be two years of age for black-billed gull (Stead 1932; Dawson 1954). The single published account of natal dispersal (i.e. of a two-year old bird) is from Canterbury; where a chick banded on the Ashley River was seen breeding on the Waipara River two years later (Bull 1953; equating to approximately 20 km).

This chapter represents the first investigation of region-wide dispersal of the black-billed gull using seven years of cohort banded chicks re-sighted during two seasons, and individually banded adults re-sighted during one season. Based on the studies and observations reviewed above, I expected:

- The likelihood of natal dispersal to decrease with distance from the natal colony.
- The majority of natal and breeding dispersal in black-billed gulls to be restricted to within the catchment.
- The likelihood of natal dispersal and breeding dispersal in black-billed gulls to be higher than for other species nesting in more stable habitats.
- Desertion of the previous year's colony site to be related to the unsuitability of the site (e.g. subsequent modification by floods, weeds) and/or predation pressure in the previous year.
- Group assemblages to be maintained, both when colonies re-establish on the previous year's site, and when the site is abandoned.

METHODS

During August and September 2005 and 2006, newly-forming colonies were located around the Southland region by driving roads in closest proximity to rivers and observing flocks of foraging gulls in neighbouring paddocks. Aerial surveys in October and November located further colonies (full survey and aerial photograph methods are given in Chapter 2).

Banding and re-sighting

A total of 1611 black-billed gull chicks was banded in Southland between 1997 and 2005 at 14 different colonies on the Waiau, Aparima and Oreti rivers. Prior to this research starting in 2004, banding was organised and overseen by Mr Lloyd Esler. An average of 115 chicks was banded at each colony (range 39-182). Banding colonies only represented a small proportion of colonies within Southland in each year, but over all years, covered the majority of lowland Southland. Chicks were captured by three or more people herding them into a group and toward a temporary pen where they were immediately removed and placed into boxes to await banding. Approximately 100 to a maximum of 200 of the group were penned for banding to ensure the safety of the chicks. Coloured darvic bands were chosen as the most appropriate marking method in order to allow members of the public, particularly farmers, to identify birds without visual aids. Birds from each colony were banded with a colony-unique colour band combination (cohort banding). Three-colour combinations were used from 1997-2000 and two colours in 2004 and 2005. In 2004 and 2005, tetrahydrafuran (THF), a plastic bonding solvent, was used to weld colour bands to reduce band loss. All birds were also banded with a single, uniquely-numbered stainless steel rings.

In 2005, 67 adults were banded with unique three-colour band combinations at three colony sites on the Waiau, Aparima and Oreti rivers. Colour bands were bonded with THF. Adults were caught on the nest during incubation using a drop-trap (Mills and Ryder 1979). Figure 1 shows the location of all colonies where banding occurred.

Searches for banded birds were undertaken in the 2005 and 2006 breeding seasons using telescopes, primarily in breeding colonies, but also in a small number of pre-breeding congregations of birds on rivers, and other flocks of birds foraging or roosting in rivers or on paddocks. The same two observers carried out the majority of searches in both years. Colonies were visited for nest monitoring (i.e. study colonies; every 3-6 days) or specifically for searching for banded birds.

In addition, advocacy work via the media was initiated prior to the start of both seasons. Media releases encouraged members of the public to report sightings of banded gulls. Articles were carried by rural bulletins and newsletters, local and regional newspapers, national radio stations, national anglers, ornithological and conservation magazines, the Southland regional council's ratepayers' magazine, and regional and national television. Most media carried contact details for reports of banded bird sightings (see Appendix E for examples of newspaper articles). Though national coverage of the plight of the species and the need for banded bird sightings was achieved, the amount of re-sighting effort in other regions was probably very low and cannot be calculated. Consequently, this chapter is restricted to describing regional dispersal only.

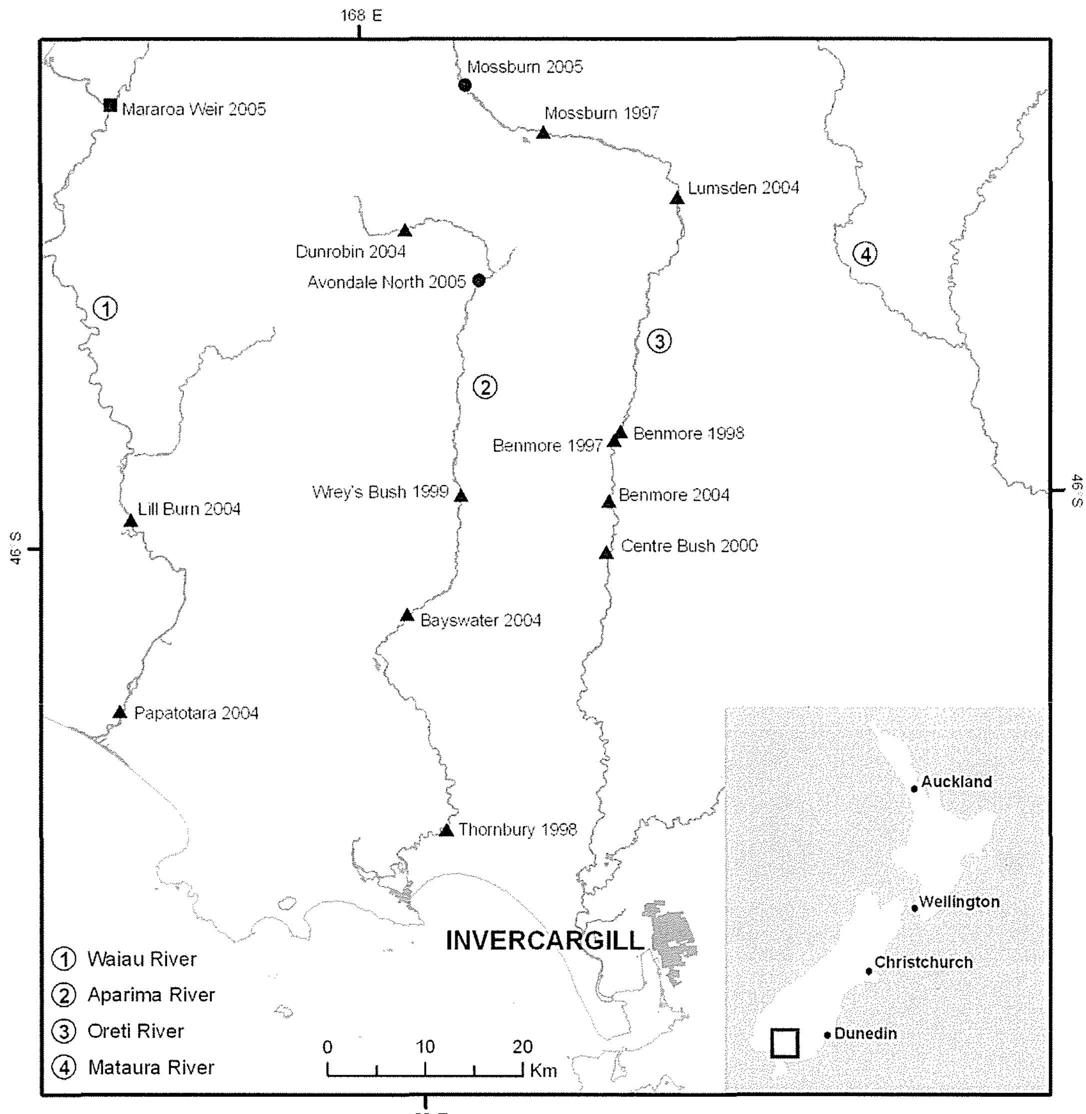

Figure 1: *Banding locations (colonies), 1997-2005, of black-billed gull chicks and adults. Closed triangles represent chick banding localities; the closed circle represents an adult banding locality and the closed square represents a colony where adults and chicks were banded. Insert shows a map of New Zealand and the general location of the study area.*

Data analysis

Estimating re-sighting rates for birds banded as chicks

The analysis of dispersal is limited by cohort-banding: gulls that had been banded as chicks could be seen on more than one visit to a colony, but could not be individually identified as they were banded according to natal colony. In order to avoid over-reporting re-sighting rates, the minimum number of individuals of a particular cohort seen in a colony was used. More than one individual of a cohort was sighted at many colonies; in these cases, some individuals were able to be differentiated by different eye colour (black or white), missing bands, or all individuals being clearly observed at the same time. This chapter distinguishes between general dispersal of birds banded as chicks and natal dispersal; i.e. that of two-year old birds in the 2006 season.

In addition, many birds banded as chicks were seen away from colonies, mostly on farms by members of the public. These reports were not used in the analysis of re-sighting rates of birds banded as chicks as they may have been the same individuals as those observed in colonies by researchers. Also, it could not be ascertained whether the birds were part of a breeding colony.

Two colonies fully deserted and one colony partially deserted very early in the 2006 breeding season. A small number of banded birds were re-sighted in these colonies, and may have integrated with existing colonies and been counted twice.

Band loss

Band loss can be a significant source of bias leading to underestimation of parameters such as dispersal. Band loss among black-billed gulls banded in Southland since 1997 was estimated using re-sightings of banded birds in colonies in 2006 by researchers only. Band loss was recognised by a gull with one or more missing coloured bands or a gull with colour bands but no metal band. Analysis was restricted to 2006 to avoid re-sighting individuals in more than one year and potentially over-estimating the rate of band loss. The cohort and year of banding could not be ascertained for several individuals. However, all individuals were able to be identified to 'old' (1997-2000) cohorts or 'new' (2004-2005) cohorts from remaining band colours.

Calculating ranges

Ranges6 v1.2208 (Kenward et al. 2003; software for the analysis of tracking and location data) was used to create 100% minimum convex polygons (MCPs) delineating the extent of dispersal of all re-sighted individuals for each natal colony. Analysis only included natal colonies from 2000 onwards as samples of older birds were very small. Ranges were then assessed using the overlap function in Ranges6. This produces a matrix of the percentage overlap for each pair of ranges, for example, of range A on B, and of range B on A. In this manner, the extent of overlap of dispersal for each colony can be easily examined, indicating whether the Southland black-billed gulls comprise a single, inter-mixing population.

RESULTS

Re-sighting effort and summary

Aerial and ground searches throughout Southland resulted in the location of 20 colonies in 2005 and 24 colonies in 2006 (Table 1). In 2005, the majority of observations were made by members of the public (73.3%); nine gulls were seen at the mouth of the Waiau River, 23 were seen by people cultivating paddocks on Southland farms and one gull was seen in a colony on the Waitaki River, Otago region. In 2006, the two researchers obtained 79.0% of re-sightings; 332 observations were within Southland colonies, two were from congregations on rivers and one was seen in a city park. Members of the public reported the remainder of observations; three were seen in breeding colonies, 82 were seen following cultivators or other machinery on Southland farms and one was seen on the coast close to a breeding colony. Three were seen out of the breeding season on the coast in other regions of the South Island (Otago and Marlborough).

Overall, researchers' searching effort was concentrated in colonies which is reflected in the results. Public observations were almost wholly obtained away from colonies. Unexpectedly, a greater percentage of banded birds were re-sighted out of colonies in 2005 than in colonies despite active searching by researchers.

Table 1: *Re-sighting effort for banded black-billed gulls and general results (banded adults and chicks combined); by observer type (researcher and public) and location type (colony and elsewhere).*

General results	2005	2006
No. of colonies located in Southland	20	24
No. of colonies searched by researchers (% of colonies located)	16 (80.0%)	21 (87.5%)
Effort (hours spent searching for bands in breeding colonies)	16.9 hours	58.6 hours
Total sightings of identifiable banded birds (% of total banded*)	45 (3.2%)	424 (25.3%)
Total sightings: researchers (% of total sightings)	12 (26.7%)	335 (79.0%)
Total sightings: public (% of total sightings)	33 (73.3%)	89 (21.0%)
Sightings in colonies by researchers (% of researcher sightings)	9 (75.0%)	332 (99.1%)
Sightings out of colonies by researchers (% of researcher sightings)	3 (25.0%)	3 (0.9%)
Sightings in colonies by members of the public (% of public sightings)	1 (3.0%)	3 (3.4%)
Sightings out of colonies by members of the public (% of public sightings)	32 (97.0%)	86 (96.6%)

*Note that total sightings include re-sightings of the same individuals

Dispersal of birds banded as chicks

Searches by researchers in Southland colonies for gulls banded as chicks resulted in nine observations in 2005 and 274 in 2006 (Table 2), equating to a minimum number of individual birds of eight in 2005 and 139 in 2006 (two further birds were seen in pre-breeding congregations on rivers and are not included in analyses). Of 1407 birds banded as chicks prior to 2005, 0.6% were re-sighted in the 2005 season. Of 1611 birds banded as chicks prior to 2006, 8.6% were re-sighted in that season. Taking account of differences in re-sighting effort, the rate of re-sightings (number of banded birds re-sighted per hour of effort) of all birds banded as chicks was five times higher in 2006 than in 2005. The rate of re-sightings of older cohorts (1997-2000; combined due to small sample sizes) and one-year old birds was approximately twice as high in 2006 than 2005, and the rate of re-sightings of the 2004 cohort was eight times higher in 2006 than 2005 (Table 2). No cohorts were banded in 2001-2003.

Table 2: *Numbers and rates of re-sightings in colonies of black-billed gulls banded as chicks, 2005 and 2006 seasons (1997-2000 cohorts combined).*

Observations	2005				2006			
	No. of obs.	Bands seen/hour	% of total	% of cohort	No. of obs.	Bands seen/hour	% of total	% of cohort
Total observations of gulls banded as chicks	9	-	-	-	274	-	-	-
Minimum number of chicks observed	8	0.47	0.6	-	139	2.37	8.6	-
Minimum number of 2004 cohort observed	3	0.18	-	0.4	84	1.43	-	12.5
Minimum number of 1997-2000 cohorts observed	5	0.30	-	0.7	36	0.61	-	4.9
Minimum number of 2005 cohort observed	-	-	-	-	19	0.32	-	9.3

Given the paucity of re-sightings in 2005, the following analyses are based on 2006 data only. Twenty-one Southland colonies were searched in 2006 (Figure 2). Re-sighting rates in 2006 as a percentage of the total numbers banded in each cohort varied from 0.7% (1999 cohort) to 13.0% (2000 cohort; Table 3). All birds had dispersed; only one colony re-formed at one of the 14 natal/banding locations (a 1998 banding location), and no birds originating from that colony were re-sighted at the location in 2006. Dispersal from the catchment was also very high, varying from 55% to 100%. Mean dispersal distances did not vary between cohorts (single-factor ANOVA, F=2.28, df=138, P>0.10).

Table 3: *Numbers and rates of re-sightings in colonies of black-billed gulls banded as chicks by cohort, and rates of dispersal from natal location and catchments, 2006 season.*

Cohort	Total marked	Min. no. re-sighted in colonies	% of cohort re-sighted	% dispersed from natal location	% dispersed from natal catchment	Mean dispersal distance from natal colony (km) (SE)
1997	120	4	3.3	100	100	31.8 (7.9)
1998	314	10	3.2	100	60	42.3 (8.6)
1999	139	1	0.7	100	100	21.6
2000	162	21	13.0	100	86	41.7 (4.1)
2004	672	85	12.5	100	67	35.3 (2.3)
2005	204	19	9.3	100	55	33.3 (4.9)
Totals/means (SE)	1611	139	7.0 (2.2)	100	78.0 (8.2)	34.3 (3.1)

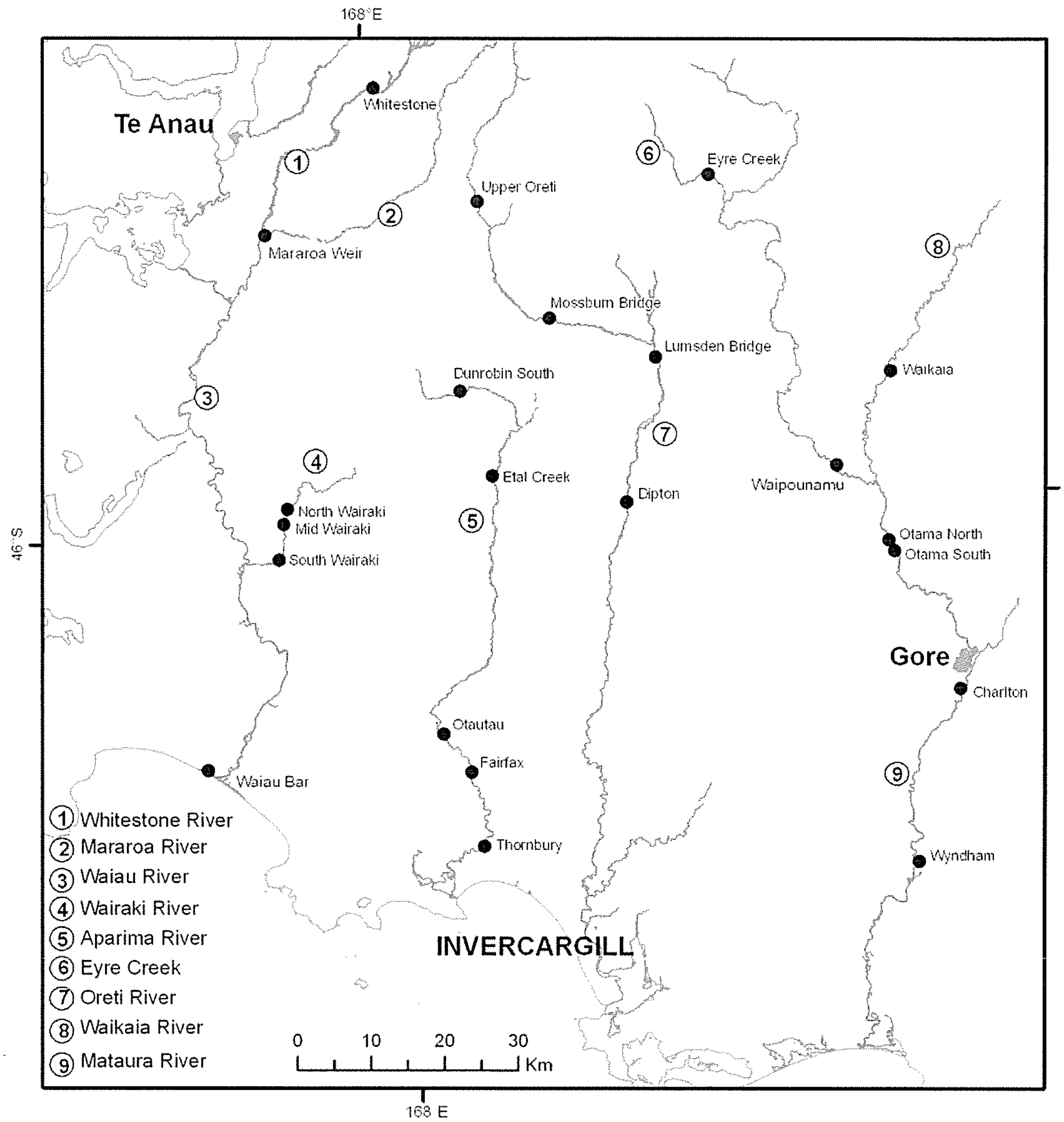

Figure 2: *Locations of black-billed gull breeding colonies searched for banded birds in 2006.*

Observations of birds from each banding colony were spread throughout the 21 breeding colonies and nine rivers/catchments regardless of the age of the cohort e.g. a minimum of 17 second-year birds banded at Benmore colony were seen in 15 colonies in six catchments in 2006 (Table 4). However, despite all gulls dispersing and dispersal being widespread, mean dispersal from the natal colony site was consistently less than the mean distance from that natal colony to all known 2006 colonies (i.e. mean random dispersal distance). Dispersal of second-year gulls was significantly lower than mean random dispersal distances for four of the six natal colonies (t-tests assuming unequal variances; Bayswater t=1.81, df=31; df=36; Lill Burn t=3.46, df=29; Lumsden t=2.14, df=32; Papatotara t=2.16, df=23; Table 4); the frequency of natal dispersal decreased with distance from the natal colony. Dispersal was also significantly lower for first-year gulls from one of the two natal colonies (Mossburn t=2.00, df=27). Six-year old birds exhibited dispersal distances similar to those expected from random dispersal. Small sample sizes may have affected older cohorts and those from Avondale North.

Table 4: *Numbers of re-sightings in colonies of black-billed gulls banded as chicks by natal colony, and mean and random dispersal distances, 2006 season.*

Cohort and colony	Minimum no. re-sighted	Total observations	No. colonies with re-sightings	No. catchments with re-sightings	Mean dispersal distance from natal colony (km) (SE)	Mean distance from natal colony to all 2006 colonies (km) (SE)[1]
1997 Mossburn	4	4	3	3	31.8 (7.9)	44.9 (5.1)
1998 Benmore	4	4	3	3	35.0 (11.0)	42.0 (3.4)
1998 Thornbury	6	9	6	4	47.2 (12.8)	60.4 (5.9)
1999 Wrey's Bush	1	1	1	1	21.6	43.9 (3.8)
2000 Centre Bush	21	39	13	8	41.7 (4.1)	45.5 (3.4)
2004 Bayswater	16	43	12	5	34.9 (6.1)	48.9 (4.8)*
2004 Benmore	17	46	15	6	38.7 (3.2)	43.7 (3.2)
2004 Dunrobin	14	24	11	8	37.1 (5.4)	44.1 (4.9)
2004 Lill Burn	10	18	9	5	31.7 (4.7)	58.8 (6.2)***
2004 Lumsden	14	25	10	4	30.6 (4.2)	44.0 (4.6)**
2004 Papatotara	13	32	9	6	39.9 (9.6)	70.5 (6.7)**
2005 Avondale North	6	6	6	5	32.8 (8.4)	41.8 (4.3)
2005 Mossburn	13	21	8	5	31.0 (6.4)	47.8 (5.4)*
Totals/means (SE)	139	272	8.2	4.8 (0.5)	34.9 (1.7)	48.9 (2.4)

[1]One tailed t-test; actual dispersal versus random dispersal; *** P<0.01, **P<0.05, *P<0.1

The minimum number of gulls banded as chicks seen in each breeding colony in 2006 varied from 1 to 17 (mean 6.6 gulls, SE 1.0; Table 5). Large numbers of banded birds were seen in some colonies, while other colonies had relatively few re-sightings; however effort varied substantially between colonies. Colonies also varied greatly in their mean distances from all natal colonies (mean 51.7 km, SE 3.5, range 29.1-74.1 km). When corrected for re-sighting effort between colonies, larger colonies had less re-sightings than smaller colonies (Figure 3a) and colonies further from natal locations had less re-sightings than closer colonies (Figure 3b).

Table 5: *Numbers and rates of re-sightings of all black-billed gulls banded as chicks by 2006 colony, and mean distance to that colony from natal colonies, 2006 season.*

Breeding colony 2006	Number of gulls in colony	Total obs. of banded birds	Minimum no. of indiv. seen	Minimum no. indiv./ 1000 gulls	Time searched (mins)	Minimum no. of indiv./hour	Mean distance from all natal colonies (km) (SE)
Eyre Creek	7888	16	13	1.65	415	0.03	60.1 (7.1)
Whitestone	5000[1]	5	5	1.00	190	0.03	67.0 (6.1)
Otama South	4266	5	4	0.94	130	0.03	59.3 (5.1)
Wyndham	3729	1	1	0.27	85	0.01	76.4 (4.7)
South Wairaki	3728	6	5	1.34	110	0.05	39.0 (3.6)
Waipounamu	3592	4	4	1.11	105	0.04	56.3 (5.7)
Dunrobin South	3453	26	12	3.48	335	0.04	31.3 (5.1)
Waiau mouth	3172	31	12	3.78	135	0.09	52.8 (6.3)
Otama North	3169	15	7	2.21	245	0.03	58.5 (5.2)
Mossburn Bridge	2517	19	8	3.18	190	0.04	36.2 (6.6)
Dipton	1884	38	17	9.02	260	0.07	30.1 (5.0)
Mararoa Weir 06	1828	8	5	2.74	295	0.02	54.6 (4.0)
Waikaia	1694	1	1	0.59	115	0.01	62.3 (6.0)
Otautau	1526[2]	46	16	10.48	220	0.07	35.5 (4.7)
Upper Oreti	1369	3	3	2.19	45	0.07	49.8 (6.7)
Mid Wairaki	1139	5	4	3.51	105	0.04	38.9 (3.2)
Thornbury	909	21	7	7.70	94	0.07	45.5 (6.0)
Etal creek	882[2]	12	7	7.94	90	0.08	27.1 (3.9)
Charlton	800[3]	3	2	2.50	65	0.03	70.5 (4.7)
Lumsden	600[3]	1	1	1.67	20	0.05	38.0 (6.5)
Fairfax	120[2]	6	5	41.67	66	0.08	38.5 (5.1)
Means (SE)	2536 (400)	13.0 (2.8)	6.6 (1.0)	5.2 (1.9)	159 (23)	0.05 (0.01)	48.9 (3.1)
Totals	53265	272	139				

[1]Estimated on the ground

[2]Colonies initially larger; significant proportions deserted due to floods and disturbance. The number given is an aerial count of remaining birds

[3]Estimated on the ground, colony abandoned shortly after commencement of nesting

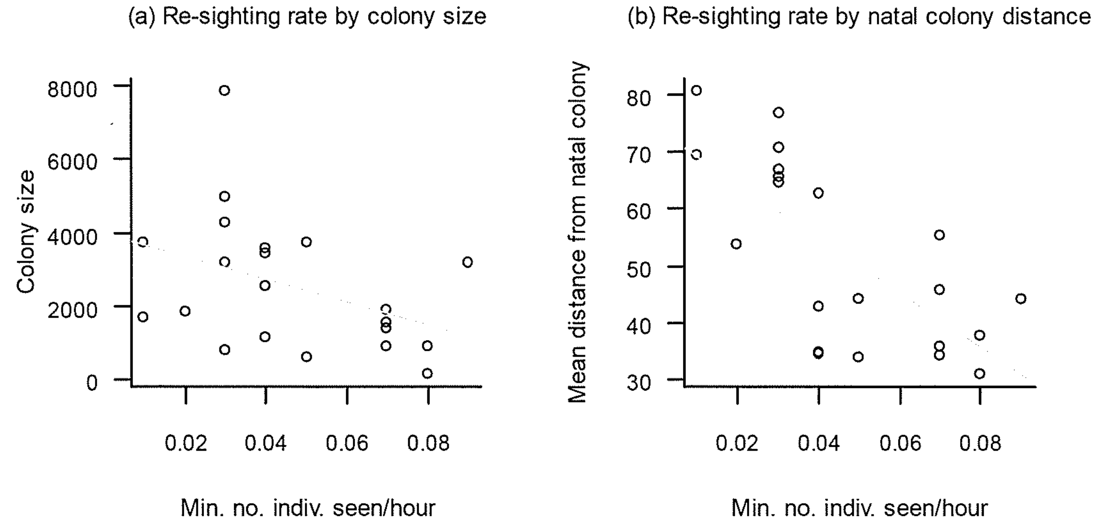

Figure 3: *Plots of the minimum number of black-billed gulls banded as chicks in colonies against colony size and the mean distance from natal colonies, 2006 season. Lines represent linear best fits.*

Table 6: *Overlap matrix of dispersal ranges of black-billed gulls banded as chicks by natal colony; 2006 season.*

Colony / Range B	Range A / Year	Centre Bush (n=21) 2000	Lill Burn (n=10) 2004	Lumsden (n=14) 2004	Dunrobin (n=14) 2004	Bayswater (n=16) 2004	Benmore (n=17) 2004	Papatotara (n=13) 2004	Mossburn (n=13) 2005	Avondale (n=6) 2005
Centre Bush	2000	100.0	42.3	43.4	72.5	69.2	81.0	86.5	56.4	45.7
Lill Burn	2004	100.0	100.0	28.1	72.6	100.0	63.1	100.0	68.5	76.3
Lumsden	2004	100.0	27.3	100.0	76.9	72.6	100.0	99.8	40.7	31.7
Dunrobin	2004	96.4	40.7	44.0	100.0	60.5	86.9	83.2	74.8	57.8
Bayswater	2004	76.7	46.8	34.9	50.7	100.0	70.6	75.9	41.5	42.8
Benmore	2004	88.2	29.1	47.2	71.2	69.3	100.0	76.4	53.5	40.7
Papatotara	2004	100.0	48.7	49.6	72.5	79.0	81.1	100.0	54.5	48.1
Mossburn	2005	100.0	51.2	31.4	100.0	66.2	87.2	83.7	100.0	75.3
Avondale	2005	100.0	70.3	30.4	95.6	84.6	82.0	91.5	93.0	100.0
Mean % overlap of range A on B		95.7	50.7	45.4	79.1	77.9	83.5	88.5	64.7	57.6

Overlap analysis of MCPs of dispersal (delineating the dispersal range of all individuals re-sighted from each natal colony) indicates a high amount of overlap between all colonies, regardless of year (Table 6). First and second-year gulls from some natal colonies, particularly

Lill Burn and Lumsden, dispersed less than others, their ranges often not extending into a particular major catchment (see Appendix F for examples of dispersal of a selection of natal colonies). The range of the oldest cohort, the Centre Bush gulls, encompassed much of lowland Southland and overlapped the majority of other ranges.

In addition to birds banded as chicks seen in Southland colonies, two were seen in colonies in other regions. A one year-old bird was seen in a colony on the Waitaki River in Otago in 2005, approximately 250 km from the site of its natal colony. A second bird was seen in a Canterbury colony in 2006, approximately 460 km from the site of its natal colony. The colour bands were sighted on this bird, but not their position; the gull was either seven or nine years of age.

Adult dispersal

Thirty nine of the 67 adults (58.2%) banded in 2005 were re-sighted during the 2006 breeding season. Ten were seen in more than one location; three were sighted in two colonies, one was sighted in three colonies, five were sighted in a colony and foraging on a farm and one was seen on two farms.

Twenty-nine individuals were seen in breeding colonies. Mean dispersal from the banding colony site was less than the mean distance from that colony to all known 2006 colonies (i.e. mean random dispersal distance; Table 7). Differences were significant for Mararoa and Mossburn adults (t-test assuming unequal variances; Mararoa $t=4.68$, $df=24$; Mossburn $t=2.50$, $df=11$). Dispersal distances for adults were significantly lower than the overall dispersal distances for chicks (t-test assuming unequal variances, $t=2.92$, $df=46$, $P<0.01$). Colonies did not re-form at either Avondale North or Mossburn; breeding dispersal of birds from these colonies was 100%. A colony re-formed at the Mararoa banding site, and the majority (75%) of re-sighted gulls were seen again at this location in 2006. The remainder that dispersed all left the catchment. The majority of Mossburn birds left the catchment, while most Avondale North birds remained.

Table 7: *Numbers of re-sightings in colonies of black-billed gulls banded as adults by banding colony, and mean and random dispersal distances, 2006 season.*

Colony	No. re-sighted in a colony	% of cohort re-sighted	No. colonies with re-sightings	No. catchments with re-sightings	% dispersed from banding location	% dispersed from banding catchment	Mean dispersal distance from banding colony (SE)	Mean distance from banding colony to all 2006 colonies (SE) [1]
Mararoa	12	42.9	3	3	25%	25%	13.9 (7.0)	59.3 (5.9)***
Avondale North	11	44.0	8	4	100%	36%	34.0 (5.8)	37.8 (4.2)
Mossburn	6	42.9	4	4	100%	75%	23.3 (5.6)	45.2 (4.8)**
Summaries	29	43.3					23.5 (4.3)	47.4 (3.0)

[1]One tailed t-test; actual dispersal versus random dispersal; *** P<0.01, **P<0.05, *P<0.1

Dispersing birds showed minimal evidence of group adherence. Of the three Mararoa birds that dispersed, two were in a colony in another catchment, and one was in a third catchment. The six Mossburn birds dispersed to four colonies in four catchments; two to the Mararoa colony. The six Avondale North adults that remained in the Aparima catchment were split between five colonies; the five that dispersed from the catchment were in three different colonies in two different catchments.

Table 8: *Size and productivity (2005 breeding season) of black-billed gull colonies where adults were banded, and activity at those sites during the 2006 breeding season.*

Colony	Colony size 2005[1]	Overall productivity 2005 season	Activity 2006 season	Colony size 2006[1]
Mararoa	536	Completely failed (probable predation)	Colony re-formed within 100m of old site	1828
Mossburn	2006	Highly successful	Site destroyed by floods after 2005 season, closest colony 8 km downstream	2517[2]
Avondale	2709	Moderately successful, major predation	Site unchanged, pre-breeding group established, but abandoned one month later before breeding started	6000

[1] Counts from aerial photographs

[2] Count of Mossburn Bridge colony

Conflicting evidence was found as to whether the desertion of colony sites was related to predation in the previous year or sites becoming unsuitable. Adults dispersed from Avondale North despite the colony being successful in the previous year and the site remaining available (Table 8). Adults returned to Mararoa despite complete failure of the colony. The Mossburn site was destroyed by floods prior to 2006 and clearly forced birds to disperse; the nearest colony in 2006 was 8 km downstream and was of similar size (Mossburn Bridge). Two adults were re-sighted at this colony, both Mossburn birds.

Band loss

Thirty nine adults and a minimum of 139 gulls banded as chicks were re-sighted in 2006. Of these, 14 (8.0% of birds re-sighted) had lost one or more bands. Six could not be assigned to natal colony, but could all be identified as coming from either the 1997-2000 cohorts or 2005 cohort from remaining bands. Of birds banded as adults or chicks in 2005 and re-sighted in 2006, none had lost metal bands, and one had lost a coloured band (0.6% of coloured bands applied; Table 9). Of birds banded as chicks in 2004, none had lost metal or coloured bands. Of chicks banded from 1997-2000, 13 had lost bands: five had lost metal bands (13.9%); 10 had lost coloured bands (13.0%; four birds had lost two coloured bands each) and two birds had lost both a metal and a coloured band. Of the 13 birds banded in 1997-2000 that had lost bands, seven came from the single colony banded in 2000 and represent 31.8% of all sightings of that cohort in 2006. One bird had lost two coloured bands. A further four of the five unidentified 1997-2000 birds may also have been from this cohort.

Table 9: *Band loss among black-billed gulls re-sighted during the 2006 breeding season.*

Cohort	Minimum individuals re-sighted	Total bands	Missing colour bands	Percentage loss of colour bands	Missing metal bands	Percentage loss of metal bands
1997-2000 chicks	36	108	14	13.0%	5	13.9%
2004 chicks	84	164	0	0	0	0
2005 chicks	19	38	1	0.6%	0	0
2005 adults	39	117	0	0	0	0
Total observations	178	427	15		5	
Means				3.5%		2.8%

Recoveries and re-sightings during the non-breeding season

A small number of re-sightings and recoveries have been made of Southland banded birds during the non-breeding season since 1998 (Table 10). Results indicate that birds migrate to southern, eastern and northern coasts of the South Island, and some birds may remain inland in Southland year round.

Table 10: *Recoveries of Southland-banded black-billed gulls in Southland and recoveries and re-sightings from other regions during the non-breeding season.*

Location	Region	Date	Status
Waiau River mouth	Southland	Jul 1998	Dead
Paddock in Menzies Ferry	Southland	May 1999	Dead
Invercargill airport	Southland	May 2007	Dead
Victory Beach, Otago Peninsula	Otago	Mar 1998	Dead
State Highway 1, Hampden	Otago	Feb 1998	Dead
Papanui Inlet, Otago Peninsula (two birds)	Otago	Feb 1999	Sighted
Waitaki River mouth	Otago	Feb 1999	Dead
Blue Skin Bay, north of Dunedin	Otago	Apr 2006	Sighted
Goose Bay, Kaikoura	Marlborough	Mar 2006	Sighted
Ngakuta Bay, Picton	Marlborough	Mar 2006	Sighted

DISCUSSION

Limitations of study

In this study, second-year birds dispersed up to 102 km, the maximum distance between colonies in 2006 being 106 km. Coupled with observations of Southland-banded gulls in colonies in Otago (c.250 km; first-year bird) and Canterbury (c.460 km; seven or nine-year old bird) indicates the study area was too restricted to examine the true dispersal capabilities of this highly mobile species. However, location of possibly all Southland colonies and thorough searching ensures results accurately represent local dispersal patterns.

The frequency of dispersal will have been underestimated to an unknown degree due to difficulty in distinguishing cohort-banded individuals, differing searching effort between colonies, and difficulty in sighting banded birds in large, dense colonies (Figure 3a). Dispersal frequency may also have been underestimated in 2005 due to lower searching effort compared to 2006. In contrast, band loss is unlikely to have resulted in underestimation as very few birds were unable to be assigned to natal colony, and band loss was concentrated in the 2000 cohort (a single colony).

Frequency of natal dispersal

In this chapter, dispersal of second-year gulls was considered to represent natal dispersal. Second-year gulls exhibited a similar pattern of attendance in colonies throughout the 2006 breeding season as six to nine year-old birds (R.K. McClellan unpubl. data). In addition, the frequency of observations of the 2004 cohort attending nests undoubtedly underestimates actual breeding activity given banded birds are less likely to be sighted when incubating or brooding. Subsequently, it seems likely that many second-year gulls were breeding in 2006 and that colonies were therefore sites of 'first or potential reproduction' (Greenwood and Harvey 1982).

All gulls banded in 2004 were in new locations in 2006, due at least in part to no colonies re-forming at natal colony sites. As originally hypothesised, the likelihood of natal dispersal decreased with distance from the natal colony in five of the six cases examined as has been found in other studies (e.g. summary in Paradis et al. 1998; Oro and Pradel 1999). Natal dispersal was significantly higher than breeding dispersal, as reported for many colonial seabird species (Greenwood and Harvey 1982; Gabrey 1996; Paradis et al. 1998; Dittman et al. 2005; Matthiopoulos et al. 2005; but see Hénaux et al. 2007).

Extending the study area to include other regions within the South Island of New Zealand may have resulted in higher mean natal dispersal distances. Though the results clearly show the majority of young birds are likely to remain close to the natal site, infrequent long distance natal dispersal events are well known among avian populations (Paradis et al. 1998; Sutherland et al 2000). The one-year old bird observed in a colony in Otago and the older bird in a Canterbury colony may have represented 'future' and historical natal dispersal events. Natal dispersal is critical for gene flow between populations and colonisation (Clobert et al. 2001). Expanding the study to encompass the Otago and Canterbury regions would allow estimation of the frequency and distances of long distance natal dispersal which would clarify the extent to which populations in the three regions mix.

Dispersal from the catchment

The study hypothesis predicted natal and adult dispersal to be largely restricted to movements within the catchment, and was strongly disproven. The majority of natal dispersal was out of the natal catchment (67%). Dispersing adults also showed no particular tendency to remain within the same river or catchment. In fact, breeding adults returning at the start of the season appeared to be prospecting among forming colonies on different rivers/catchments, a behaviour usually associated with pre-breeders (e.g. Dittman et al. 2005). Given the difficulty in observing banded birds in dense colonies, and the logistics associated with re-sighting birds, the frequency of birds moving among colonies during this early period is likely to have been higher than was recorded. Danchin and Cam (2002) suggest such breeding dispersal among colonial seabirds will often coincide with missed breeding attempts. It is not surprising, perhaps, that for a species where breeding dispersal is the norm, dispersing black-billed gull adults were able to successfully breed (pers. obs.).

The distances between Southland colonies relative to migration distances and even foraging distances observed during this study were small (one adult was recorded foraging 50 km from the breeding colony). High mobility among both adults and young birds illustrates the species' ability to disperse throughout the study area within a short time frame to either take advantage of better quality habitat or abandon areas that are no longer suitable. Results suggest there is no physical barrier to dispersal throughout the region.

Comparison with colonial seabirds breeding in stable habitats

Few *Larus* species breed in unstable habitats. Burger (1982) lists four; Franklin's gull (*L. pipixcan*) and brown-hooded gulls (*L. maculipennis*; which nest in prairie marshes), laughing gulls (*L. atricilla*; which can disperse during flood conditions), and black-billed gulls. Dispersal in the former three species has not been studied. Accordingly, the percentage of black-billed gulls exhibiting natal dispersal may be the highest recorded among gull species. Fidelity of other *Larus* species to natal colonies varies substantially, from virtually no dispersal (Prévot-Julliard et al. 1998; Spear et al. 1998) to approximately 40-80% of individuals returning to breed (summary in Gabrey 1996). However, in regard to dispersal distances, black-billed gull shows little difference to species nesting in stable environments. Three British *Larus* species had natal dispersal distances of 21.1-47.0km (Paradis et al. 1998; analysis methods may have resulted in inclusion of some amount of breeding dispersal) and two Great Lakes species dispersed mean distances of 98-264km (Gabrey 1996).

Like natal dispersal, breeding dispersal by black-billed gulls is also extensive, and would be almost 100% in some years when few colonies re-form in the previous year's locations. This is unusual among colonial seabirds, most of which exhibit minimal breeding dispersal (e.g. Spendelow et al. 1995; Inchausti and Weimerskirch 2002; see summary in Crawford et al. 1994). However, similar cases exist among colonial Laridae, usually, though not always nesting in unstable habitats; these species are primarily terns. Least terns (*Sterna antillarum*) nesting on inland rivers in North America show lowered fidelity to breeding sites; 42% of adults returned to the banding colony in a subsequent year (Renken and Smith 1995). Gull-billed terns (*S. nilotica*) nesting on sandy beaches and storm-deposited shell piles showed low site fidelity; of 25 sites used over four years, only three were used in all four years (Erwin et al. 1998). Black skimmers (*Rynchops niger*) nesting in salt marshes displayed identical habits (Burger 1982). Only 19% of black-fronted terns (*S. albostriata*; which nest in the same rivers as black-billed gulls) were re-sighted in their banding colony (Keedwell 2005). One other highly mobile gull species, Hartlaub's gull (L. hartlaubii), does not appear to nest in unstable habitat, but yet shows very high rates of breeding dispersal. For example, nesting locations on Schaapen Island, South Africa, were recorded in five years between 1987 and 1993. Sixteen locations were used for breeding, none were used more than once and there was no obvious pattern of movement around the island (Crawford et al. 1994). Dispersal in this species, however, does not yet appear to have been studied.

Maintenance of group assemblages

McNicholl (1975) referred to the black-billed gull and a small number of other larids as sharing an attribute termed group adherence, a characteristic that would enable species inhabiting unstable environments to rapidly colonise new habitat. Group adherence was indicated by a species with a tendency to regularly nest among the same individuals year after year. These species would also exhibit lowered or non-existent site tenacity. Burger and Shisler (1980) suggested all larids exhibited site tenacity, returning to previous colony locations, and then shifting if the location was no longer suitable. However, little banding work has been completed to examine whether (1) returning individuals are the same as those that previously nested at the site, and (2) colonies have in fact shifted, i.e. comprise the same individuals.

Many observations of pre-breeding flocks returning to a previous year's colony location were made during this study (e.g. Avondale North colony). Historical accounts report the same behaviour (Beer 1966; Soper 1972). This indeed suggested adults (colonies) were moving, to some extent, as units. However, the picture portrayed by the re-sightings of banded adults in 2006 is more complex. Despite the small sample, the results give strong indication that once the decision is made to disperse, adult birds move as individuals, for example, the 11 North Avondale birds were re-sighted in eight colonies. Group adherence also appeared to be absent among dispersing second-year and first year birds (e.g. a minimum of 17 Benmore birds re-sighted in 15 colonies). These findings disprove the study hypothesis.

Colony site desertion

Complete desertion of colony locations has been described for other larid species, and is thought to be the result of instability of breeding habitat and breeding failure (e.g. McNicholl 1975; Burger 1982; Gabrey 1996; Grosbois and Tavecchia 2003). Though the results are based on a single year's re-sightings, they give persuasive indications of the factors which *do not* influence the breeding dispersal of black-billed gulls. While the destruction of the Mossburn site by floods forced birds to move location, site availability at North Avondale did not result in re-use. This low site fidelity/tenacity despite availability (c.f. McNicholl 1975) has been described for least terns on the lower Mississippi River (Renken and Smith 1995; c.f. coastal nesting California least terns which exhibit high site fidelity, Akçakaya et al. 2003) and for gull-billed terns (Erwin et al. 1998). Likewise, individual reproductive success (Switzer 1997; Danchin and Cam 2002) does not appear to affect breeding dispersal of black-billed gulls. Gulls returned to sites despite intense predation and/or disturbance and previous failure (e.g. Mararoa and North Avondale; c.f. Burger 1982). In the studies mentioned previously, both least terns and gull-billed terns were also not influenced by previous breeding success (Renken and Smith 1995; Erwin et al. 1998).

Conservation management

Complete loss of black-billed gull colonies from rivers has been reported, particularly in the neighbouring Otago region (Maloney 1999; BirdLife International 2006). The apparent lack of re-colonisation of these areas suggests a number of possibilities: (1) long-distance dispersal from other regions is infrequent; (2) a source-sink scenario (Peery et al. 2005) is not operating (e.g. larger Southland colonies produce 'excess' juveniles which disperse and help maintain the smaller Otago colonies); (3) the Otago population does not disperse widely; or (4) breeding and/or foraging habitat is no longer suitable (e.g. weed infestation of riverbeds; land-use changes).

It is doubtful the generally larger Southland colonies produce excess juveniles; breeding success can be poor, often as low as one fledgling per three nests (Chapter 5). There are unlikely to be barriers to dispersal in Otago; the region has more braided rivers and almost twice as much suitable habitat as Southland (Caruso 2006). It is perhaps more likely that colony loss from rivers is due to a combination of infrequent long-distance dispersal (given the tendency of second-year birds to remain close to their natal colony) and habitat degradation. However, loss of populations from rivers has not been proven in Southland, despite the extraordinary population decline within the region. Colonies are often absent from smaller rivers for one or more years (see Chapter 2) but eventually return. In Otago, where the population may be 10% of Southland numbers, absences from rivers may be more frequent and of longer duration. In this scenario, continued use of rivers would only be detectable by thorough annual surveys.

Defining the spatial extent of the population that encompasses Southland's black-billed gulls provides a context for viewing the management of the species in the South Island. Given large scale surveys in these two regions do not occur, and searches for banded gulls are rare and sightings essentially fortuitous, it is plausible that actual dispersal rates of Southland birds into northern regions may be significantly higher than the chance sightings suggest. Given the high threat classification of the species, further research is warranted into the frequency and extent of natal and breeding dispersal within the South Island. Coupled with regional studies of productivity and survival, this will help clarify the extent to which South Island populations are vulnerable to regional extinctions.

CHAPTER 4

Changes in availability of breeding habitat, 1949-2002, and selection of breeding colony sites of the black-billed gull in Southland, New Zealand

Oreti River from the air, 2006 (R. McClellan)

ABSTRACT

The black-billed gull (*Larus bulleri*) nests in dense colonies on bare, exposed gravel on inland riverbeds in New Zealand. Colony locations often change from season to season. Twenty characteristics at up to 48 Southland colonies were recorded from 2004-2006. Colonies established on island and bank sites within rivers in accordance with availability, and on rivers in accordance with the number of gravel patches available. Over 60% of Southland colonies established on banks on single channel sections of river. Cross-sections and flow modelling at 10 colony sites indicated that most sites could expect to be flooded at least once during the breeding season. Vulnerability to flooding varied significantly between sites. Introduced plants were present at all colony sites except one, but weed cover tended to be very low (<5%) within the colony area. Weeds were present at the highest point available at 62.5% of colony sites, but gulls did not necessarily nest at the highest point when it was free of vegetation. The presence of dairy farms did not affect selection of colony sites. Colony size and colony area were related as were colony area and the available gravel area (or patch size). The smallest gravel patch used by a colony was 0.09 ha. Gulls were more likely to re-use colony sites in the following season if the site: had been recently used (in 2003); was a gravel extraction site; had been morphologically stable for several years; and had low vegetation coverage within the colony area. River works including gravel extraction caused a major loss of gravel habitat on the Lower Oreti River between 1976 and 2002 and a decline in gravel patch sizes. On the Waiau River, Manapouri Dam construction in 1972 caused significant increases in the amount of available gravel habitat from a lowering of the water level, but also resulted in a c.75% decline in the number of islands (potentially predator-free breeding habitat). Since initial increases, gravel-dominated habitats have declined on the Mid Waiau and fluctuated on the Lower Waiau. No trends in the availability of breeding habitat were observable on the Mid Oreti. Gravel patch sizes on the Waiau and Mid Oreti remain stable. Hundreds of gravel patches remain on Southland rivers.

INTRODUCTION

The black-billed gull (*Larus bulleri*) is a small, highly colonial endemic gull that nests predominantly on bare, exposed gravel on inland riverbeds and migrates to coastal areas after breeding. Southland colonies number from a few hundred to several thousand nests (Chapter 2) and cover relatively small areas within which there is minimal or no vegetation and little discernable difference in substrate or any other variable. The species' nesting density may be higher than any other gull (Beer 1966). Colony sites often change each season, a characteristic thought to be a response to sites becoming unsuitable during the non-breeding season due to floods (Beer 1966; Soper 1972) or the spread of vegetation (O'Donnell and Moore 1983; O'Donnell 1992; Maloney et al. 1999).

The majority of Southland was covered with closed canopy forest prior to the arrival of humans in New Zealand in c.800 BP (McGlone 2001). Starting in the mid 19th century (Critchfield 1951) virtually all of lowland Southland was converted to agriculture. The majority of lowland waterways are now bordered by farmland. The original vegetation on braided rivers was highly specialised, consisting primarily of ground cover plants and was largely devoid of tall vegetation (Parkinson and Cox 1990). The naturalisation of more than 2,500 species of flora in New Zealand (NZPC 2008) since European colonisation combined with land clearance and river modification works (which included widespread planting of willow (*Salix* spp.) for bank stabilisation in Southland; Poole 1990) has markedly changed the face of New Zealand's gravel-bedded rivers. These rivers now support one of the most invaded riparian plant communities in the world (Williams and Wiser 2004). Encroachment by trees, shrubs and herbaceous flora acts to stabilise banks and gravel islands (Maloney et al. 1999; see European review in Gurnell and Petts 2002: Rinaldi 2003; Moseley 2004), increase river incision (Maloney et al. 1999; Rinaldi 2003), increase predation risks for nesting birds by providing cover for predators (Pascoe 1995; Rebergen et al. 1998) and may force birds to nest closer to water levels making colonies more susceptible to flooding (Innes 2003; O'Donnell 2004; Caruso 2006).

That Southland's riverbeds are heavily invaded by exotic vegetation is uncontested. Environment Southland (Southland's regional council) spends several million dollars every year controlling willow, broom (*Cytisus scoparius*) and gorse (*Ulex europaeus*) on the region's main riverbeds to maintain open floodways (Environment Southland 2007).

However, observations of historical changes are largely anecdotal (Poole 1990). Likewise, the extent of weed spread as it relates to the availability of black-billed gull breeding habitat is unknown, though it is postulated that available habitat has declined in Southland (Innes 2003) and nationally (Taylor 2000: Dowding and Murphy 2001). A GIS-based approach using repeat aerial photographs is commonly used to assess changes in river planform (i.e. the shape and layout of a river as viewed from above; e.g. Gurnell 1997; Tiegs and Pohl 2005; Hughs et al. 2006) and changes in vegetation on rivers (e.g. Gurnell 1997; Apan et al. 2002; Higinbotham et al. 2004; Tiegs and Pohl 2005; Biondini and Kandus 2006). Remote sensing provides a tool with which to examine the extent of invasion by weeds on Southland's waterways over decades, which would otherwise be impossible without instigating major, long-term monitoring programmes.

A wealth of studies examine site selection by larids. Research tends to focus on the nest and the influence of variables including surrounding nest structure, substrate and slope on breeding success (e.g. Burger and Gochfeld 1981; Spear and Anderson 1989; García-Borboroglu and Yorio 2004) and/or the vegetation type (e.g. Ewald et al. 1980; Pierotti 1982; Saliva and Burger 1989; Rodway and Regehr 1999; Good 2002). Fewer studies investigate selection at other spatial scales, such as of the colony site, particularly in regard to physical characteristics (e.g. Burger and Shisler 1980; Thompson and Slack 1982; Erwin et al. 1998; Forys and Borboen-Abrams 2006). These studies are often on colonial tern species which, like black-billed gull, frequently shift breeding locations between seasons.

A small number of features have been cited as characteristic of black-billed gull colony sites. The gull is often described as a species of braided riverbeds (Evans 1982; Higgins and Davies 1996; Taylor 2000). Preference for islands within rivers (Stead 1932; Soper 1972) and higher areas (Stead 1932) has been suggested. The species has been noted as preferring the presence of driftwood (Soper 1972); Stead (1932) reporting that any log would be covered with nests. Preferred stone size was referred to as "not-too-large" by Soper (1972). Evans (1982) reported colony establishment occurring within 1-2 km of major nearby food sources (though he did not specify exactly what these food sources were). However, no quantitative studies of site selection by black-billed gulls have been undertaken.

In this chapter, I describe a number of characteristics of black-billed gull colony sites, and assess whether any predict their re-use. I examine the extent of modification of black-billed gull breeding habitat by the spread of weeds within two Southland rivers over 3-5 decades, and determine whether available habitat and patch sizes have reduced, and investigate the possible impact on the productivity of colonies. I expected:

- Black-billed gulls to exhibit preferences for establishing colonies on islands with low susceptibility to flooding.
- Re-use of colony sites to be related to the stability of the site over time, availability of food sources, and absence of vegetation.
- Available breeding habitat and gravel patch sizes on riverbeds to have decreased over time.

METHODS

Location of colonies and aerial photography (2004-2006)

Black-billed gull colonies were located in July and August of 2004-2006 when colonies were beginning to form. Most locations were found by driving roads adjacent to the rivers and either observing the colonies themselves or foraging flocks in farmland indicating that a colony was close. Some colonies were located by aerial surveys which were carried out two or more times within a season. A small number were located by members of the public and staff from interested agencies (survey and aerial photography methods in Chapter 2).

Colony site selection (2004-2006)

Up to 20 characteristics were measured at 48 colonies throughout Southland (all colonies for which clear aerial photographs were obtained). A small number of colonies were not visited (measurements were determined from aerial photography only) and some characteristics were not recorded as a result. Sample sizes that differ from 48 are noted below.

1. Colony location (island, bank or partial bank). Islands were surrounded by a stable water flow of >1m^3 sec^{-1} (Rebergen et al. 1998). Partial banks were colony sites surrounded by flows that varied from above to below 1m^3 sec^{-1} during the breeding season (limited to colonies monitored as part of the concurrent breeding study).

2. Colony size. Oblique and/or vertical photographs were taken of all observed colonies during aerial surveys and counts made of gulls in photographs (methods in Chapter 2).
3. Colony success. Colonies were recorded as producing fledglings or failing to breed.
4. Number of channels. Measured at a cross-section through the colony centre at normal flow. Some colonies were not visited and aerial photographs were not at a sufficient height to determine number of channels (n=46).
5. Bank to bank width. Measured by a cross-section taken through the colony centre using a level and staff.
6. Presence of standing water at colony site. Standing water/backwaters had no or minimal flow. Bank colonies only.
7. Colony substrate. Substrate composition was measured along transect lines used for monitoring nests (monitoring methods in Chapter 5). A string line marked with metre intervals was laid along the transect and the particle touched by the mark was recorded (Wolman 1954). The particle was measured and classified as sand (<2mm), fine gravel (2-10mm), gravel (10-64mm), cobble (64-264mm) and boulder (>264mm) according to a modified Wentworth particle size scale (Jowett et al. 1991). At least 100 points were obtained within each colony. Measurements of substrate were collected after desertion of sites at the end of the season to avoid excessive disturbance to birds. However, most sites were affected by floods which occurred soon after abandonment, and sample size was accordingly affected (n=8).
8. Presence of gravel extraction activities within 50m of colony location. Remnants of workings were obvious at sites (e.g. holes, gravel piles, vehicle paths etc.).
9. Colony area (m^2). Minimum convex polygon representing the area covered by nests. If colonies were separated into discrete clusters, the area of each cluster was measured separately. The GIS ArcMap 9 was used to estimate areas on vertical aerial photographs of colonies which had been geo-referenced using ERDAS IMAGINE 9 (refer Chapter 2 for geo-rectification methods).
10. Available area (m^2). Available area (or gravel patch size) for breeding was defined as contiguous gravel areas i.e. it did not include adjacent islands of gravel or areas of gravel separated from the colony by significant weed patches. It did include areas with sporadic weed cover as gulls will nest among sparse weeds, but did not include substantial patches of weeds. Estimated using ArcMap 9.
11. Vegetation coverage within colony area. In order to avoid excessive disturbance to birds, vegetation cover was estimated visually using vertical photographs when available, or

oblique aerial photographs. A simple classification of coverage was used: (1) no weeds; (2) <5% weeds; and (3) 5-30%.

12. Vegetation coverage within potential habitat. Potential habitat was defined as all exposed habitat contiguous with the colony area and available area (e.g. an entire island site). Coverage classifications were: (1) no weeds; (2) <5% weeds; (3) 5-20% weeds; (4) 20-50% weeds; and (5) 50+% weeds.
13. Willows within 20m of colony edge. Bank and Partial Bank colony sites only (n=40).
14. Weed patches within 20m of colony edge. Patches were those exceeding $4m^2$.
15. Dominant weeds within available area. Classified into three groups; grasses (e.g. pasture and native grasses); herbs and other low growing flora (e.g. lupins, thistles, small gorse and broom plants); and shrubs (mature gorse and broom plants).
16. Vegetation present at highest point within available area. Estimated from cross-sections where completed, otherwise visually observed. Not recorded where differing heights were not clearly discernable (n=46).
17. Colony at highest point. As previously (n=46).
18. Stable site. Land Information New Zealand photographs taken in 1999-2001 were used to assess whether sites used in 2004-2006 were present 3-7 years earlier. Sites were classified as: (1) largely unchanged; (2) changed, but sufficient habitat still available (e.g. an island site was a bank site, or a site was much smaller or larger); and (3) changed and insufficient/no habitat available (i.e. major modification of channels). Early photographs could not be located for some colonies (n=44).
19. Site used in 2003. Assessed from aerial photographs and grid references.
20. Presence of dairy farms adjacent to colony. Dairy farms are thought to lower the availability of pasture invertebrates through compaction of soils and because high grass lengths are maintained year round (Innes 2003). Location and number of dairy farms within Southland was calculated by using annual data associated with resource consents for waste discharge lodged with Southland's regional council. ArcGis 9 was used to summarise the data and determine the number of dairy farms and the percentage area of dairy farms within a 2 km radius of colony sites (distance chosen from researcher's observations early in the breeding season and from observations from Evans (1982)).

Aerial photographs from 2002 were used to visually estimate the number of gravel patches of sufficient size for colony establishment on the Aparima, Oreti and Mataura rivers. The number of patches on the Waiau River was calculated using remote sensing in a GIS (see GIS methods).

Trapping of potential predators by habitat type

Southland's regional council (Environment Southland) has been undertaking ferret control throughout much of lowland Southland since 1993 as part of a national programme to eradicate tuberculosis (Tb) from domestic livestock in New Zealand. A key part of the programme is to control and monitor vectors of Tb in Risk Areas, primarily introduced Australian brushtail possums (*Trichosaurus vulpecula*) and ferrets. Other non-target animals also considered pests such as stoats and hedgehogs are occasionally killed, and traps are often specifically set for stoats and feral cats. Ferrets are likely predators of black-billed gulls as are cats, stoats and hedgehogs (Taylor 2000, Sanders and Maloney 2002).

Environment Southland manages a database of trapping results from 2003 to the present. It contains the location and species of each animal caught, the location of all trap sites and the number of nights that each trap was used. It sometimes classifies the habitat type where the trap was situated. The dataset was reduced to include only those trap sites located within 2 km of one of the four main Southland rivers (Waiau, Aparima, Oreti and Mataura). This dataset was used to summarise and analyse trapping data in relation to habitat types (n=18,021).

Site specific flood vulnerability

Elevations were taken along a single cross-section using a staff and level at a selection of colony sites after colony abandonment. The cross-section was located through the highest point of the colony. Sites were selected on the basis that they had not been modified by floods post-breeding and could be surveyed on foot without requiring boats or vegetation removal. The location of channel edges, colony position and the time of surveying were recorded.

Hydraulic calculations using Hydro (Hilltop Software) were made from the resulting cross sections to identify the increase in the depth of water required to reach the lowest edge of the colony. The river flow at the time of surveying was assumed to be that measured by the nearest river gauge (a network of river gauges is maintained throughout Southland by Environment Southland). Flows were calculated by comparing cross-sectional data at the nesting site with nearby gauged and rated sites on the network. From this, a simulation of flow based on the nearest rated site was made. In some cases, two rated sites were used and the flows combined. Though the method was simplistic (i.e. reliant on a single cross-section and based on flow readings from gauges distant from the site) results were able to be confirmed against actual flood events that were observed at eight of the 11 colony sites, ensuring greater accuracy of estimates.

Using data from the nearest river gauge, a programme was written using VIMSIM (Hydro) which calculated for each cross section the number of times floods of the size identified as reaching the colony had occurred between the start of September and the end of December (approximate length of the breeding season) since installation of the gauge (between 23 and 52 years).

Statistical analysis

Availability of island and bank gravel patches versus use by colonies and the availability of gravel patches on Southland's four main rivers versus use was analysed using Fisher's exact tests. Linear regression was used to examine a number of potential relationships between height above sea level and river width, colony size and nest density; and relationships between colony area, available area and colony size. Single factor ANOVA was used to assess whether colony sites on the Aparima and Mataura rivers differed in their vulnerability to flooding (insufficient cross-sections were completed on other rivers to allow analysis). Possible differences between the mean percentage area of dairy farms within a 2 km radius of each colony and the area of dairy farms within a 2 km strip either side of the same river was examined using student's t-tests assuming unequal variances.

The most common method of determining which characteristics birds use to select nest sites is to assess both nest sites and a sample of randomly selected 'non-nest' sites (e.g. Quintana and Travaini 2000; Borboroglu and Yorio 2004; Jia et al. 2005; Bailey and Thompson 2007; Giancarlo 2008). Nest site selection is also examined by monitoring nest success (e.g. Lee et al. 2006; Rader et al. 2007). Colony site selection analyses are few but also tend to determine selection by presence/absence; typical measures include vegetation present at colony site or vegetation cover, substrate, the height of the colony above water level and slope (e.g. Thompson and Slack 1982; Boe 1993; Rayner et al. 2007). Erwin et al. (1998) modelled colony site selection by investigating re-use or presence-absence of colonies at sites over time, similar to a mark-recapture approach.

This study also examines site selection by assessing re-use, but uses logistic regression modelling where the variable under investigation is the re-use of colony sites. Only two years of data were available and only re-use in the following year was considered; specifically, colony sites used in 2004 could be re-used in 2005, and colony sites used in 2005 could be re-used in 2006. A set of eight candidate models was contrasted using AICc (adjusted for small sample size; Akaike 1973, Burnham and Anderson 2002). Potential explanatory variables assessed were colony location (island, bank or partial bank), colony size, colony success, gravel extraction, weed cover within the colony, weed cover within the potential area, site stability, use in 2003 and the percentage area of farms around colony sites. All covariates were categorical except for one. The le Cessie-van Houwelingen global goodness of fit statistic was used to verify the fit of the global model selected model. All statistical analyses were implemented in R (R Development Core Team 2008).

Habitat availability (1949-2002)

Selection of sites and aerial photographs

Sections of the Waiau and Oreti rivers were selected for GIS analysis (Figure 1). The Oreti River is the third largest river in Southland; mean annual flow is 43.4 cumecs. The middle and lower reaches drain agricultural land, much of which was originally wetlands prior to European colonisation. Major drainage and flood control works have been undertaken to convert the region to farmland (Environment Southland 2000). The Waiau is the largest river in Southland. Prior to the construction of the Manapouri Dam in 1972, the river was the second largest in New Zealand, flowing at c.450 cumecs from Lake Manapouri. The diversion of water from the river reduced flow to 0.3 cumecs from the lake, and reduced the magnitude and duration of flood events. In 1996, the flow was increased to 12-16 cumecs with 'flushing' flows to 35 cumecs to improve biodiversity and recreation values (Innes 2003). The mean annual flow of the Waiau is 162 cumecs (Environment Southland 2000). The middle and lower sections of the Waiau are also largely surrounded by agricultural land; however, 40% of the catchment remains in native forest (Environment Southland 2000).

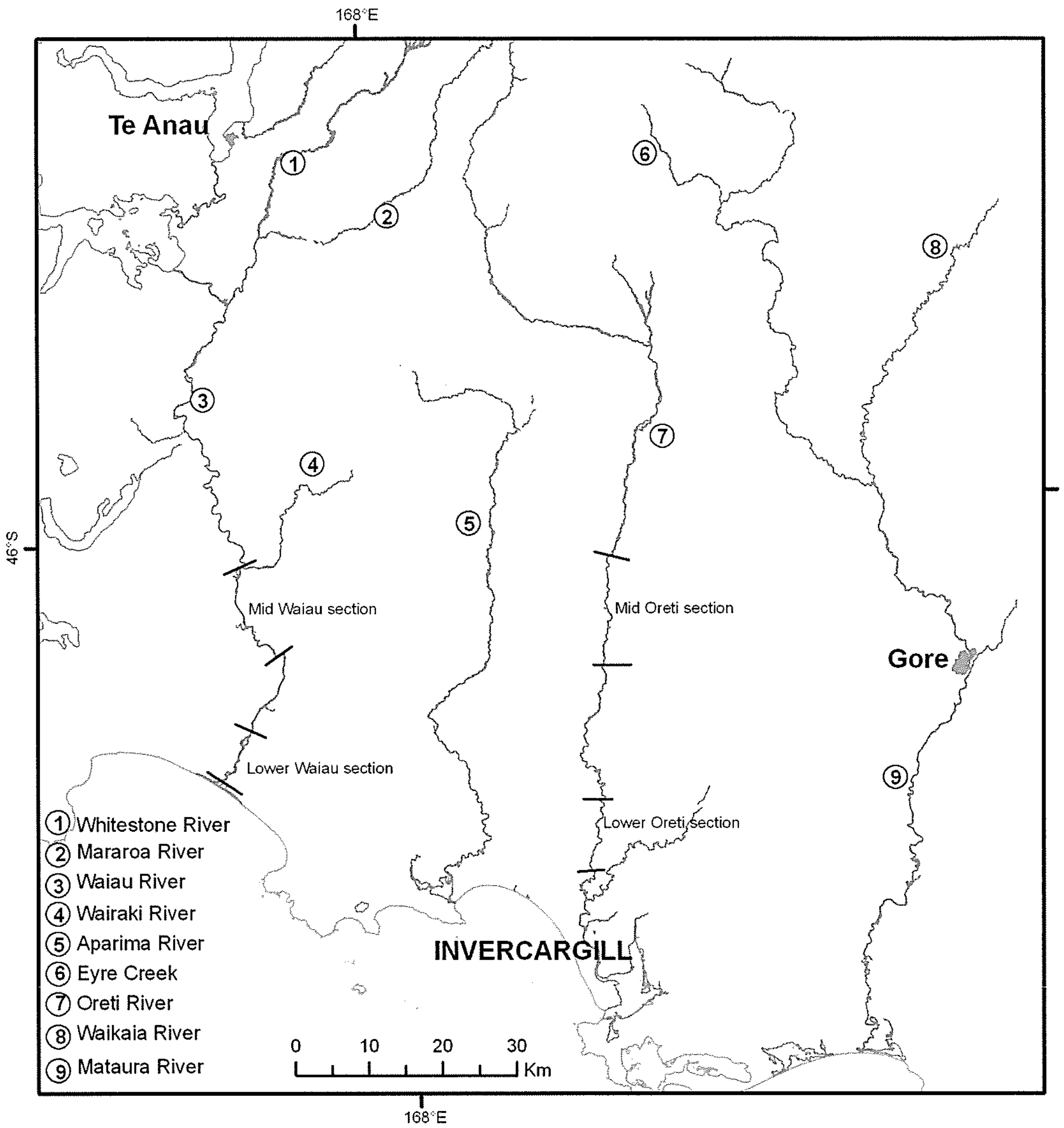

Figure 1: *Study area showing location of major waterways in lowland Southland and the location of river sections used in GIS analysis of weed spread.*

A lower section of the Oreti (Lochiel Bridge to the 'Iron Bridge') was chosen as several major colonies were located in this reach in the 1970s and 1980s, including the largest ever recorded in New Zealand (40,000 nests), however, no colonies have been found during aerial surveys (initiated in 1995). A mid section of the Oreti was selected between the Benmore and Centre Bush bridges which had substantially different morphology, and has been consistently used for breeding during 30 years of surveys. Analogous sections of the Waiau (Tuatapere Bridge to the mouth, and Wairaki confluence to Clifden Bridge) were selected. These sections were also significantly different from one another; the lower reach being typically braided, and the upper section being largely single-channelled.

Table 1: *Aerial photography series of the Oreti and Waiau rivers used to investigate habitat change, and the availability of river gauge and rainfall data for those particular river sections.*

River and section	Date	Scale	Gauge data available	Rainfall data available
Oreti, mid	5 Mar 1949	1:16000		Yes
Oreti, mid	11 Oct 1975	1:25000		Yes
Oreti, lower	15 Mar 1956	1:16000		Yes
Oreti, lower	27 Feb 1976	1:25000		Yes
Oreti, lower/mid	18 Mar 1987	1:8000	Yes	
Oreti, lower/mid	12 Mar 1997	1:10000	Yes	
Oreti, lower/mid	22 Jul 2002	1:16000	Yes	
Waiau, lower/mid	10 Mar 1963	1:14000		Yes
Waiau, lower/mid	11 Feb 1978	1:25000	Yes	Yes
Waiau, lower/mid	7 Feb 1984	1:25000	Yes	
Waiau, lower/mid	5 Feb 1998	1:10000	Yes	
Waiau, lower/mid	11 Apr 2002	1:16000	Yes	

Aerial photographs were sourced that covered these sections. Photographs were of differing altitudes and quality and most were black and white (Table 1). Later photographs (1980s onwards) were taken by Environment Southland staff specifically for river management purposes. Choice of photographic series was restricted, but approximately one series was able to be obtained per decade. Photographs were scanned at 600-1000 dpi. For later photographs, river flow data were sourced from Environment Southland river gauges (http://map.es.govt.nz/RiverRainfall/index.aspx). For earlier photographic series, unpublished raw data from Southland weather stations were examined (dating from the early 1900s through to 1984). Daily rainfall data were obtained for Invercargill city, but data from all other weather stations were in monthly summaries only (details in Appendix G). These data were used to indicate possible river flows at the time of photography.

Section analysis and river levels

River levels were variable between series for both rivers (Table 2). Photographs were taken during normal conditions for three of the five mid Oreti series, but river levels were high in 1987 and 2002; this is clear from simple visual assessment of the photographs (e.g. Figure 5). Lower Oreti series photographs may have been taken during low flows in 1956 and 1976; rainfall during both months was lower than mean monthly rainfall (Appendix G) and visual assessment indicates a lower flow than 1997 (Figure 6). The 1984 Waiau series was affected by a flood that occurred on January 27 that measured over 2000 cumecs at the 'Sunnyside' gauge station. The river took a month to resume normal flow. Despite the 1984 flow being approximately 20 times normal, the difference is not obvious in a visual assessment (e.g. Figures 9). The 1975, 1978, 1998 and 2002 series were taken during comparable river levels. The 1963 series was taken prior to the installation of the dam.

Table 2: *River flow at time of aerial photography determined by river gauge and/or rainfall data, Oreti and Waiau rivers.*

River and section	Date	Gauge data [1]	Possible flow determined from rainfall data and photograph comparison[2]
Oreti, mid	5 Mar 1949		Normal flow
Oreti, mid	11 Oct 1975		Normal flow
Oreti, lower	15 Mar 1956		Low flow
Oreti, lower	27 Feb 1976		Low flow
Oreti, lower/mid	18 Mar 1987	~20 cumecs	
Oreti, lower/mid	12 Mar 1997	~8 cumecs	
Oreti, lower/mid	22 Jul 2002	~29-35 cumecs	
Waiau, lower/mid	10 Mar 1963		Low flow (prior to dam construction)
Waiau, lower	3 Mar 1975	~22 cumecs	Normal flow
Waiau, mid	11 Feb 1978	~14 cumecs	Low to normal flow
Waiau, lower/mid	7 Feb 1984	~250-350 cumecs	
Waiau, lower/mid	5 Feb 1998	~15 cumecs	
Waiau, lower/mid	11 Apr 2002	~38 cumecs	

[1]For Oreti River, 'Lumsden' river gauge; for Waiau River, 'Sunnyside' river gauge

[2]Details of analysis in Appendix A

GIS methods

Initially, 6-7 ground control points (GCPs) were obtained for each of the 2002 Waiau photographs. GCPs were selected from the photographs and located on the ground (typically fence posts and small trees were used). Forty-five readings were taken at five second intervals at each point using a GPS and later differentiated giving GCPs with 1-2 m accuracy. However, polynomial georectification of the photographs using Erdas Imagine 9.1 resulted in unacceptable errors in overlaps between adjacent photographs of up to 50 m. It was postulated that this may have been due to differences in the angle and altitude of the plane during photography (A. Chong pers. comm. 2006).

Instead, aerotriangulation (or rubbersheeting) was used to match photographs to one another which omitted the requirement for field-based GCPs. Aerotriangulation is considered acceptable when study areas have topographical relief of less than 25 m (Evans et al. 2007). GCPs are instead chosen on actual photographs. This process forces GCPs to have identical coordinates on the target (unregistered) layer and (georeferenced) base layer which causes the image to be warped along triangulated edges rather than at point locations as for georectification. In order to obtain high accuracy, large numbers of GCPs are required. This can be an issue in river-based studies as the number and distribution of GCPs are often limited (Hughes et al. 2006). In such studies, error can vary in a non-systematic fashion, complicating error analysis (Hughes et al. 2006).

Firstly, 2002 photographs were matched to web-based Land Information New Zealand (LINZ) orthophotos. LINZ orthophotos of the Waiau were taken in 2002-2003, of the lower Oreti in 1998-1999 and of the mid Oreti in 2001-2002. All orthophotos had a pixel resolution of 2.5 m and positional accuracy of ±12.5 m (LINZ 2007). Aerotriangulation was accomplished by selecting 20-40 GCPs on each 2002 photograph and matching them with the same point on the LINZ orthophotos. GCPs were typically fence posts, trees and shrubs, and corners of sheds and houses. Hughes et al. (2006) found the choice of 'soft' GCPs, such as trees and shrubs, versus 'hard' GCPs had little effect on error production. As many as possible were located close to the river to ensure registering was as accurate as possible within the area of interest (Hughes et al. 2006). Each photograph from previous series was matched to the corresponding 2002 photograph(s) in order to further minimise error production. Sufficient usable GCPs were still able to be found on the oldest series despite complete land-use changes in some photographs.

Few GIS studies address the impact of geospatial error on the results of analyses (Mount and Louis 2005; Hughes et al. 2006). With comparisons of aerial photographic series in regard to river planform movements, it has been suggested that change is only demonstrated when the amount of change in measured parameters exceeds measurement errors (Mount and Louis 2005). Root mean square errors (RMSE) are obtained from commonly applied methods of polynomial georectification. However, aerotriangulation does not produce automated error calculations. Instead, errors between each photographic series were measured by selecting 15 points evenly spread throughout the series and measuring the distance between the point on the 2002 photograph and the corresponding point in each series (Table 3). Mean errors were low, although individual errors reached 10 m. The errors between the 2002 series and the LINZ orthophotos were likewise low, but were largely irrelevant to the study as positional accuracy and precision was not as important as the geospatial error between photographic series.

Table 3: *Error measurement between series of registered aerial photographs used to investigate habitat change in the Oreti River.*

Location	Years	Mean (m)	SE
Mid Oreti	2002-1949	2.24	1.76
Mid Oreti	2002-1975	3.39	2.31
Mid Oreti	2002-1987	2.55	2.63
Mid Oreti	2002-1997	3.60	3.11
Lower Oreti	2002-1956	3.71	2.68
Lower Oreti	2002-1976	3.07	2.24
Lower Oreti	2002-1987	3.17	2.33
Lower Oreti	2002-1997	2.20	1.23

Table 4: *Habitat classification types for investigation of habitat change, Waiau and Oreti rivers.*

Habitat type	Description	Breeding habitat quality	Habitat stability
Gravel	<5% vegetation	Excellent	Highly mobile
Gravel and grass/herbs	5-15% vegetation	Good	Highly mobile
Grass/herbs and gravel	>15% vegetation and with gravel	Poor	Moderately mobile
Grass/herbs	Patches dominated by low growing vegetation	Not usable	Requires a major flood to mobilise
Shrubs/trees	Patches dominated by higher vegetation	Not usable	Requires a major flood to mobilise

Habitat classification was done manually with ArcGIS 9. A number of GIS programmes exist which can automatically assign habitat types within aerial photographs, however, the differing qualities and types of photographs available for this study would have likely resulted in errors of assignment. After examination of all photographic series, a polyline was drawn to represent the boundary for the study which encompassed all major morphological changes within the river during the period of investigation. Different broad-scale habitat types were defined which were easily identified within the study boundary and related to both the quality of the habitat for breeding by black-billed gulls and the relative stability of the habitat (Table 4). The 'grass/herbs and gravel' category generally had less than 50% vegetation as substantial vegetation patches were classified as either 'shrubs/trees' or, more often, 'grass/herbs'. Polygons were drawn around each habitat type and, in addition to the habitat classification, the polygon was classified as either being island or bank habitat. Categories were summed for each year and graphed.

The manual creation of polygons produces errors as it relies on 'observer' knowledge (of vegetation types in the area of question), skill and patience when creating polygons; such error is difficult to manage or measure. It should be noted that automated assignment of habitat classifications also produces error, both geospatial and in assignment of classifications).

Error is also relative to the size and shape of the polygon, which can be modelled from simple calculations (e.g. Table 5). The area of a square 0.35 ha in size will have a mean error of approximately 10% given a mean error of 3 m (as found in this study between series). This error drops to below 4% when areas increase to approximately 2.0 ha. Likewise, long, thin polygons have much greater potential error than square polygons. In addition, given polygons abut one another, if the area of one is underestimated, the common boundaries of adjacent polygons will be overestimated. The complexity of resulting error calculations is clearly apparent when the areas of polygons are added; such addition unavoidably increases error production. This issue appears to not have yet been assessed in such studies (e.g. Higinbotham et al. 2004; P. Sirguey pers. comm. 2008). For this reason, no statistical analysis has been undertaken on this work.

Table 5: *Calculations of mean percent error of different sized square polygons based on a mean geospatial error of 3 m.*

Area (m^2)	Length of side of square (m)	Mean % error if side 3 m longer than measured
3500	59.16	10.40
8500	92.20	6.61
13500	116.19	5.23
18500	136.01	4.46
23500	153.30	3.95
28500	168.82	3.59
33500	183.03	3.31
38500	196.21	3.08

RESULTS

Factors influencing colony site selection (2004-2006)

River morphology

The Waiau, Aparima and Oreti rivers had similar numbers of patches of available breeding habitat per kilometre of river; the Mataura River had half as many patches (Table 6). The proportions of patches on islands versus banks were similar between rivers. Black-billed gulls selected island and bank sites within the rivers in accordance with their availability, (Fisher's exact tests, P>0.10, odds ratios Waiau=0.62, Aparima=1.05, Oreti=1.04, Mataura=1.05) however, there was some indication that gulls were preferentially selecting colony sites on islands in the Waiau. Note that the number of colonies on the Waiau does not include a colony that established on the gravel bar at the mouth of the river in two consecutive years as it was not easily classifiable as either island or bank (and was not included in the analysis). Single colonies that nested on an island and a bank were classified as both an island and bank colony (and classified as a single colony in Table 7).

Colonies established on the Aparima and Oreti in similar numbers to what would be expected given occurrence of gravel patches in those rivers (Table 7). Fewer colonies were found in the Waiau than expected and presence of colonies in the Mataura was higher than expected although differences were not significant (Fisher's exact tests, P>0.10, odds ratios Waiau=1.26, Aparima=1.08, Oreti=1.07, Mataura=0.57).

Table 6: *Use of banks and islands for black-billed gull colony sites versus availability by river*

River	Length of river analysed (km)	Total gravel patches	No. of gravel patches per km	% of patches on banks	% of patches on islands	No. of colonies 2004-2006	% of colonies on banks	% of colonies on islands
Waiau	21	84	4.0	56.0	44.0	7	28.6	71.4
Aparima	81	341	4.2	69.8	30.2	12	75.0	25.0
Oreti	91	343	3.8	62.4	37.6	10	60.0	40.0
Mataura	120	213	1.8	76.1	23.9	11	72.7	27.3
Means (SE)	78.3 (20.8)	245.3 (61.8)	3.5 (0.6)	66.1 (4.4)	33.9 (4.4)	10.8 (1.3)	61.0 (11.2)	39.0 (11.2)

Table 7: *Use of rivers for black-billed gull colony sites versus availability of gravel patches by river.*

River	No. of gravel patches per km	Expected number of gravel patches in 50 km of river	% occurrence of gravel patches by river	No. of colonies 2004-2006	% occurrence of colonies by river
Waiau	4.0	200	29.0	9	23.1
Aparima	4.2	210	30.4	11	28.2
Oreti	3.8	190	27.5	10	25.6
Mataura	1.8	90	13.0	9	23.1
Totals		690		39	

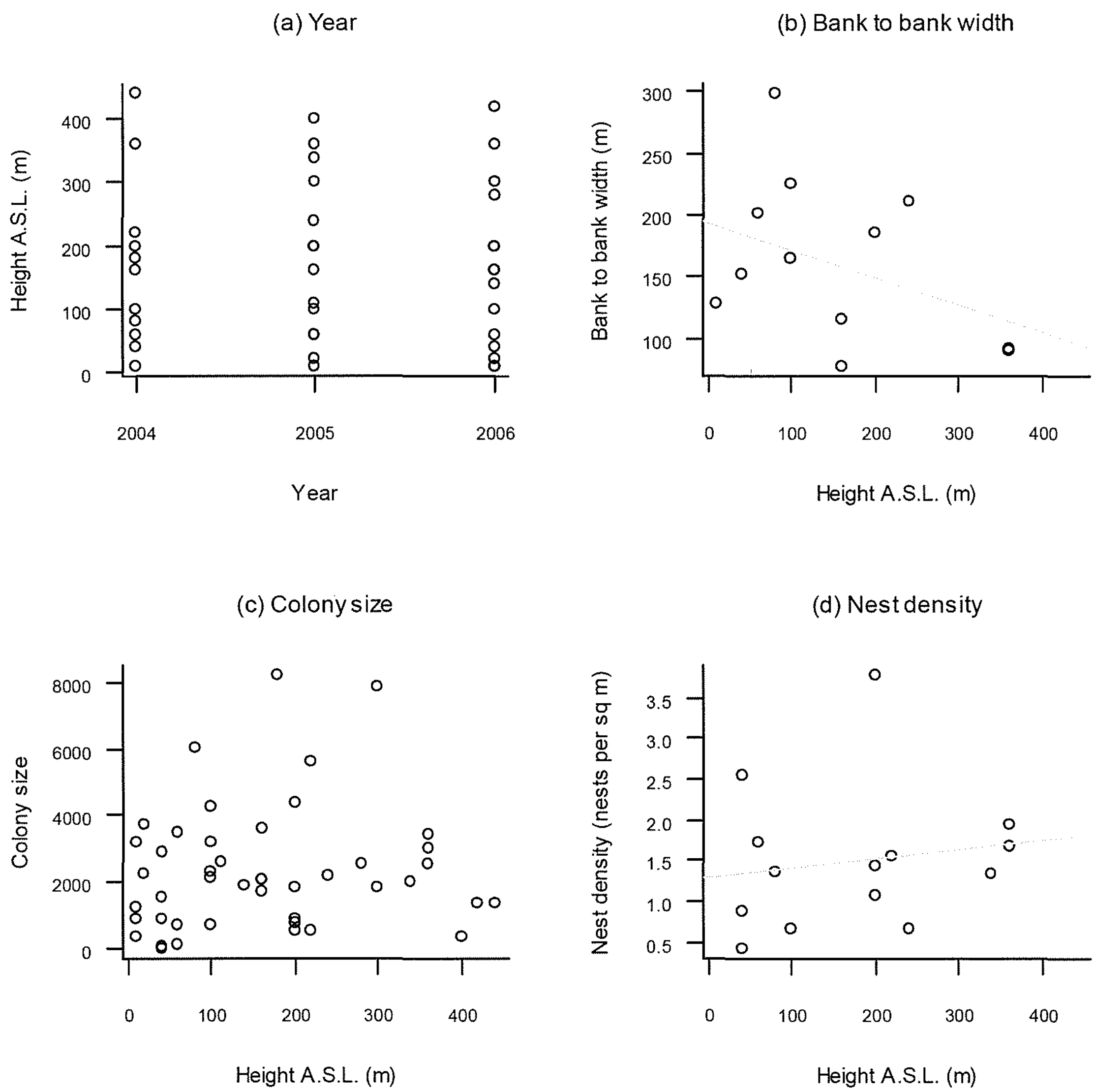

Figure 2: *Height above sea level of black-billed gull colony sites by year and height above sea level versus river width, colony size and nest density. Lines are linear best fits.*

Colonies established throughout rivers from headwaters to the mouths (Figure 2a). Though there was a slight tendency for river widths to become narrower towards headwaters (Figure 2b; linear regression, adj. R^2=0.08, df=11, P>0.10), no patterns were visible in regard to colony size and nest density (Figures 2c and d).

The majority of colonies (60.9% of 46; three colonies excluded due to aerial photographs not clearly indicating channel numbers) were located on banks on sections of river that comprised a single channel (Table 8). Only five colonies (10.9%) were located on sections of rivers that could be considered truly braided (i.e. comprising multiple, mobile channels; Gray and Harding 2007). One colony was located on an island in a small lake formed by a hydroelectric dam at the confluence of two rivers, and was classified as two channels. All 'Partial Bank' sites were considered islands.

Table 8: *Number of channels at black-billed gull colony locations.*

Waterway	One	Two	Three	Four	Totals
Waiau River	3	5	1		9
Aparima River	9	2			11
Oreti River	6	2		2	10
Mataura River	6	3			9
Waikaia River	3				3
Princhester Creek	1				1
Robert Creek		1			1
Eyre Creek			1	1	2
Totals	28	13	2	3	46

Substrate analysis indicated colonies established at sites dominated by gravels or cobbles with varying proportions of sand, fines and boulders (Table 9). Both Dunrobin colonies were located the closest to river headwaters and contained relatively high proportions of boulders. Of 34 colony sites on banks, 20 (58.8%) were adjacent to standing water. Four colonies established on gravel extraction sites (two colonies on the same site in subsequent years).

The frequency of flooding at colony sites determined by cross-sections and modelling indicates virtually every site could be expected to flood at least once during a breeding season and some several times (mean 2.1 floods, SE 0.3; Table 10). During the breeding season of 1988, floods reached the height of the Dunrobin South colony on 18 occasions. The vulnerability of sites to flooding within the Aparima and Mataura each varied significantly (ANOVA: Aparima, $F=2.45$, $df=120$, $P<0.01$; Mataura, $F=2.65$, $df=203$, $P<0.01$).

Table 9: *Substrate analysis at black-billed gull colonies.*

Colony and year	% sand	% fine	% gravel	% cobble	% boulder
Dunrobin 2004	13.5	8.9	14.7	51.4	11.6
Mararoa Weir 2006	11.0	11.8	57.4	19.9	0.0
Dunrobin South 2006	8.7	1.4	23.2	50.7	15.9
Etal Creek 2006	8.5	3.9	34.1	51.9	1.6
Fairfax Bank 2006	6.2	11.3	74.2	8.2	0.0
Fairfax Island 2006	33.3	1.2	51.2	14.3	0.0
Otama North 2006	16.5	18.9	52.0	11.8	0.8
Means (SE)	14.0 (14.0)	8.2 (2.4)	43.8 (7.9)	29.7 (7.7)	4.3 (2.5)

Table 10: *Frequency of flooding of black-billed gull colony sites.*

Colony	River	Flow required to reach colony (cumecs)	No. years of data	Frequency of flood flow: Sept. to Dec.	Rate of flood occurrence in season (SE)	Range
Motu Bush	Waiau	~315	36	134	3.7 (0.6)	0-14
Dunrobin South	Aparima	~60	29	98	3.3 (0.7)	0-18
Avondale North	Aparima	~120	24	45	1.9 (0.4)	0-9
Etal Creek	Aparima	-95	24	59	2.5 (0.6)	0-14
Fairfax Island	Aparima	~177	23	21	0.9 (0.1)	0-2
Thornbury (low)	Aparima	~225	23	14	0.6 (0.2)	0-2
Thornbury (high)	Aparima	~155	23	29	1.3 (0.3)	0-5
Cattleflat	Mataura	~80	52	99	1.9 (0.3)	0-11
Waipounamu	Mataura	~55	52	200	3.8 (0.4)	0-14
Otama North	Mataura	~200	50	98	2.0 (0.3)	0-11
Otama South	Mataura	~240	50	69	1.4 (0.2)	0-5
Means (SE)		156.5 (25.2)	35.1 (4.0)	78.7 (16.7)	2.1 (0.3)	

Weeds

Introduced plants were present in almost all gravel areas where colonies established from 2004-2006 and made up the vast majority of flora present; only one colony established in an area completely free of weeds (2.1%; Table 11). Weed cover within the colony boundary tended to be very low (75.0% of colonies established in areas with <5% weed cover). Surrounding potential habitat tended to have greater weed cover.

Table 11: *Weed cover in colony area and potential area at black-billed gull colony sites*

		Weed cover in potential area (%)					
		0	<5	5-20	20-50	50+	Totals
Weed	0	1	7	3	3	2	16
cover in	<5	0	4	6	6	4	20
colony	5-30	0	1	3	1	7	12
area (%)	Totals	1	12	12	10	13	48

At most colony sites (65.2%; Table 12), weeds were present at the highest point available and gulls rarely nested among the weeds in this situation. However, gulls did not nest at the highest point on a quarter of occasions when weeds were absent.

Table 12: *Presence of weeds at the highest available point within potential area versus the presence of black-billed gull colonies at the highest available point*

		Colony present at highest point in potential area		
		No	Yes	Totals
Weeds present at	No	4	12	16
highest point in	Yes	27	3	30
potential area	Totals	31	15	46

Eleven of 40 (27.5%) colonies (bank and partial bank colonies only) had willows present within 20 m of the colony edge. These colonies tended to be those at lower altitudes. Thirty-seven of 48 (77.1%) colonies had significant weed patches within 20 m of the colony edge. Main weed groups within colony and available areas were grasses (60.9%), herbs (such as lupins, thistles, small gorse and broom; 32.6%) and shrubs (such as larger gorse and broom plants, generally dead from previous weed control work; 6.5%).

Analysis of Environment Southland trapping data indicates that of c.18,000 trap sites placed within 2 km of a major Southland river, 38% were in or around patches of 'scrub' (Table 13; the term scrub is loosely used to describe both exotic and native low-growing vegetation, generally with an absence of mature trees). Ferrets were most likely to be caught in this habitat type, and in relatively higher numbers than other introduced predators. All other predators were less likely to be caught in scrub than would be expected given control intensity. 'Exotic trees' habitat/site type included willow species, and caught all four predators in similar proportions. Habitat/site type 'water' (which includes the main rivers as well as streams, drains etc.) caught all predators in considerably greater proportions than would be expected given control intensity.

Table 13: *Captures of cats, ferrets, hedgehogs and stoats by habitat type within 2 km of major Southland rivers.*

Habitat/site type	% of traps/poison placed in habitat type (n=18,021 trap sites)	Percentage of animal captures/kills by habitat type			
		Cat (n=246)	Ferret (n=499)	Hedgehog (n=682)	Stoat (n=149)
Native trees	14.14	3.25	21.24	2.79	2.68
Exotic trees	10.00	11.79	10.42	17.45	13.42
Scrub	37.81	14.63	36.87	16.13	13.42
Water	4.72	18.29	13.03	9.97	19.46
Fence line	27.63	31.71	14.43	41.50	39.60
Tracks	4.55	9.76	3.01	10.12	8.05
Other	1.15	10.57	1.00	2.05	3.36

Colonies established on sites that varied from 0.09-4.13 ha of available bare gravel and numbered from c.50-6000 gulls. A significant relationship was found between the number of gulls in a colony and the size of the immediate area used for nesting, suggesting a relatively constant nest density between colonies (Figure 3a; linear regression, $P<0.05$, df=12, adj. $R^2=0.33$). The relationship between the area available for nesting and the colony area was also significant (Figure 3b; $P<0.05$, df=11, adj. $R^2=0.34$). The relationship between available area and colony size was not significant (Figure 3c; $P>0.1$, df=17, adj. $R^2=0.08$), but was significant for available areas smaller than 1 ha ($P<0.05$, df=10, adj. $R^2=0.37$).

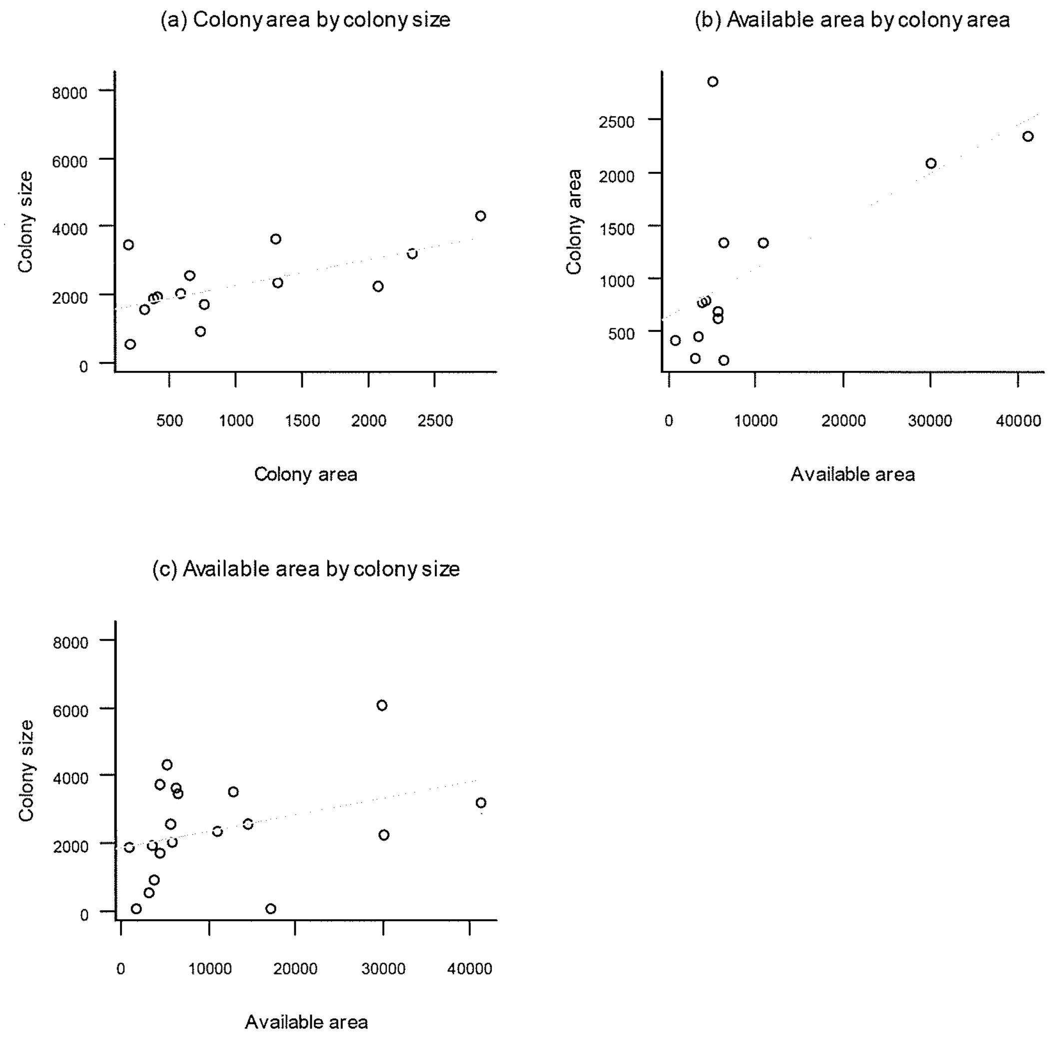

Figure 3: *Plots of relationships between black-billed gull colony area, available area and size of colony. Lines shown are linear best fits.*

Land use

From 2004-2006, the area of dairy farms increased marginally within Southland. Dairy farming was less prevalent on land adjacent to the Waiau than on the other three main rivers, being highest on the Aparima (Table 14). The mean percentage area of dairy farms within a 2 km radius of colony sites on the four main rivers was not significantly different from the area along a 2 km strip either side of the same river (t-tests assuming unequal variances: Waiau, t=-1.46, df=8, P>0.10; Aparima, t=-0.06, df=10, P>0.10; Oreti, t=0.20, df=9, P>0.10; Mataura, t=-0.81, df=8, P>0.10).

Table 14: *Mean percentage area of dairy farms (farms over 2 ha) within 2 km of river and 2 km radius of black-billed gull colonies*

River	Mean % area of dairy farms within 2 km of river (2004-2006) (ha)	Mean % area of dairy farms within 2 km radius of colonies (ha)
Waiau	2.9 (0.4)	13.0 (6.9)
Aparima	20.5 (1.4)	20.9 (6.7)
Oreti	11.6 (0.0)	10.5 (5.4)
Mataura	14.4 (0.5)	16.7 (2.8)

Re-use of colony sites

Of 44 sites assessed from 2004-2006, the majority (68.2%) used during 2004-2006 were largely unchanged since aerial photographs were taken in 1998-2001 (Table 15; four sites could not be assessed). Of eight sites that did not exist in earlier photographs, seven were on the Oreti River.

Table 15: *Stability of black-billed gull colony sites over 4-9 years*

Stability	Frequency (%)
Largely unchanged	30 (68.2)
Changed, sufficient habitat available	6 (13.6)
Changed, habitat insufficient/unavailable	8 (18.2)

Of 29 colony sites used during 2004 and 2005, eight were re-used the following season (27.6%) and one was used in all three seasons. Logistic regression modelling indicates that the probability of site re-use is best explained by site use in 2003 ($P<0.01$) and the presence of gravel extraction activities ($P<0.01$; Table 16). Gulls were more likely to return to a colony site if it had been used in 2003 and it was used for gravel extraction. The confidence set of candidate models included models with Akaike weights within 10% of the best model i.e. models which included 3-5 parameters: site stability, low weed cover within the colony area, and the location of the colony (bank sites were more likely to be re-used). The chosen model was only 1.5 times more likely to be the best explanation for site re-use than the 3-parameter model containing stability of site (i.e. 0.4575/0.3052) and 2.8 times more likely than the 4-parameter model containing low weed cover. The global model was found to be a good fit for the data (le Cessie-van Houwelingen global goodness of fit statistic = 0.2419, $P=0.81$).

Table 16: *Modelling results assessing the effects of black-billed gull colony and colony site characteristics on the likelihood of re-use of the colony site (K=number of parameters,* Δ_i *=* AIC_c *differences,* w_i *= Akaike weights).*

Model	K	AIC_c	Δ_i	W_i
2003+gravel	2	28.99	0	0.4575
2003+gravel+stable	3	29.80	0.81	0.3052
2003+gravel+stable+weeds colony	4	31.05	2.06	0.1633
2003+gravel+stable+weeds colony+location	5	33.17	4.18	0.0566
2003+gravel+stable+weeds colony+location+weeds area	6	35.91	6.92	0.0144
2003+gravel+stable+weeds colony+location+weeds area+fledged	7	39.32	10.33	0.0026
2003+gravel+stable+weeds colony+location+weeds area+fledged+farms	8	43.13	14.14	0.0004
2003+gravel+stable+weeds colony+location+weeds area+fledged+farms+size	9	47.28	18.29	0.0000

Habitat availability (1949-2002); influence of weeds and water flows

Mid section length of each river analysed was approximately 12 km; lower sections were approximately 9 km (Table 17). The number of habitat patches (or polygons) remained relatively stable over time in the lower river sections, whereas the number of polygons for both mid river sections almost halved between the earliest and latest series.

Table 17: *Length of river sections used in GIS analysis of habitat change, and mean number of habitat patches (or polygons) in each.*

River section	No. of photographic series analysed	Approximate length of section (km)	Mean no. habitat patches (or polygons) per series	SE
Lower Oreti	5	9.5	101.6	6.7
Mid Oreti	5	12.3	234.4	28.6
Lower Waiau	5	8.5	63.2	3.4
Mid Waiau	5	12.8	124	12.3

Changes in the area of gravel habitat

Habitat types within both the Lower Oreti and Mid Oreti River sections showed substantial changes in area over five decades (Figure 4, Tables 18 and 19). 'Mobile' and 'stable' substrates have fluctuated within the Mid Oreti since 1949, with no apparent overall trend (Figure 4a and b). Gravel-dominated substrate was more common in 1997 (low flow) than in 1949 and 1975 (normal flows). However, this may be partly due to the difficulty in distinguishing gravel habitat versus areas of $\geq$15% vegetation and gravel in the two earlier series (see Discussion); for this reason, the combined category 'all mobile habitat types' gives a more accurate comparison. The greatest change in the Mid Oreti section was the eight-fold increase in shrub/tree-dominated habitat between 1949 and 1975. Since 1975, gradual conversion to pasture has seen a major increase in grass/herb-dominated habitat (clearly visible in aerial photography; Figure 5).

Table 18: *Areas (ha) of habitat types by year as determined by GIS analysis; Mid Oreti.*

Habitat type	1949	1975	1987	1997	2002
Gravel dominated	51.0	30.8	80.0	96.0	47.4
≥15% vegetation and gravel	121.4	88.6	60.1	61.0	65.3
All 'mobile' habitat types	*172.3*	*119.5*	*140.1*	*157.0*	*112.7*
Grass/herb dominated	199.6	116.0	100.6	167.1	179.2
Tree/shrub dominated	22.4	179.8	132.9	96.5	99.2
All 'stable' habitat types	*222.0*	*295.7*	*233.4*	*263.6*	*278.4*
Total habitat (ha)	394.4	415.2	373.5	420.6	391.1

Table 19: *Areas (ha) of habitat types by year as determined by GIS analysis; Lower Oreti.*

Habitat type	1956	1976	1987	1997	2002
Gravel dominated	39.0	33.6	37.2	33.4	12.2
≥15% vegetation and gravel	84.0	110.7	66.7	45.0	14.2
All 'mobile' habitat types	*123.0*	*144.3*	*103.8*	*78.4*	*26.3*
Grass/herb dominated	99.9	73.1	66.6	119.9	132.2
Tree/shrub dominated	17.9	30.8	31.2	38.1	67.4
All 'stable' habitat types	*117.8*	*104.0*	*97.8*	*158.0*	*199.7*
Total habitat	240.8	248.2	201.7	236.4	226.0

As for the Mid Oreti analysis, 'all mobile habitat types' gives a more accurate picture of changes in the Lower Oreti section. Results may have been affected by possible low flows in 1956 and 1976 and high flows in 1987 and 2002. Despite this, results show a downward trend from 1976 (Figure 4c), supported by a doubling in stable habitat types between 1987 and 2002 (these habitat types are likely to remain visible during minor floods). Results are supported further by striking visual changes in the planform of the river which has become channelised (e.g. Figure 6 and 13).

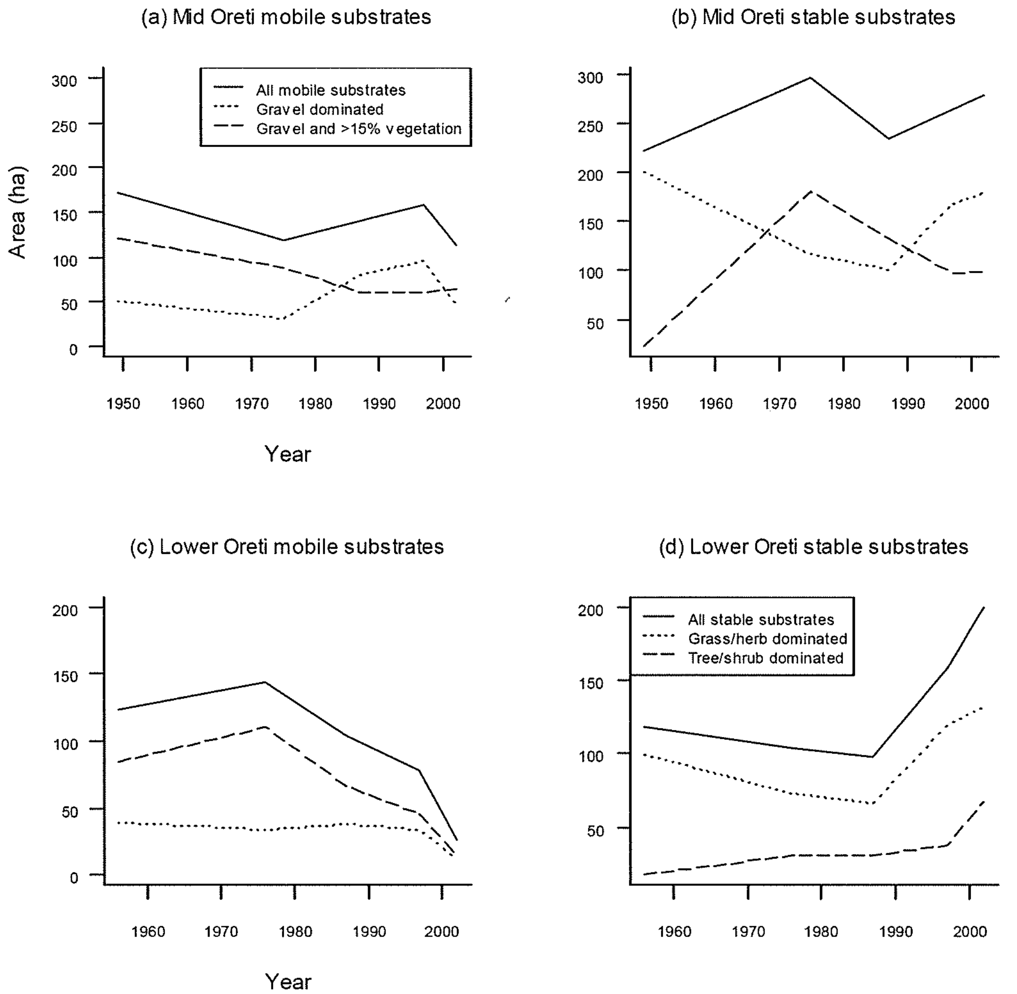

Figure 4: *Vegetation changes within the Oreti River; 1949-2002.*

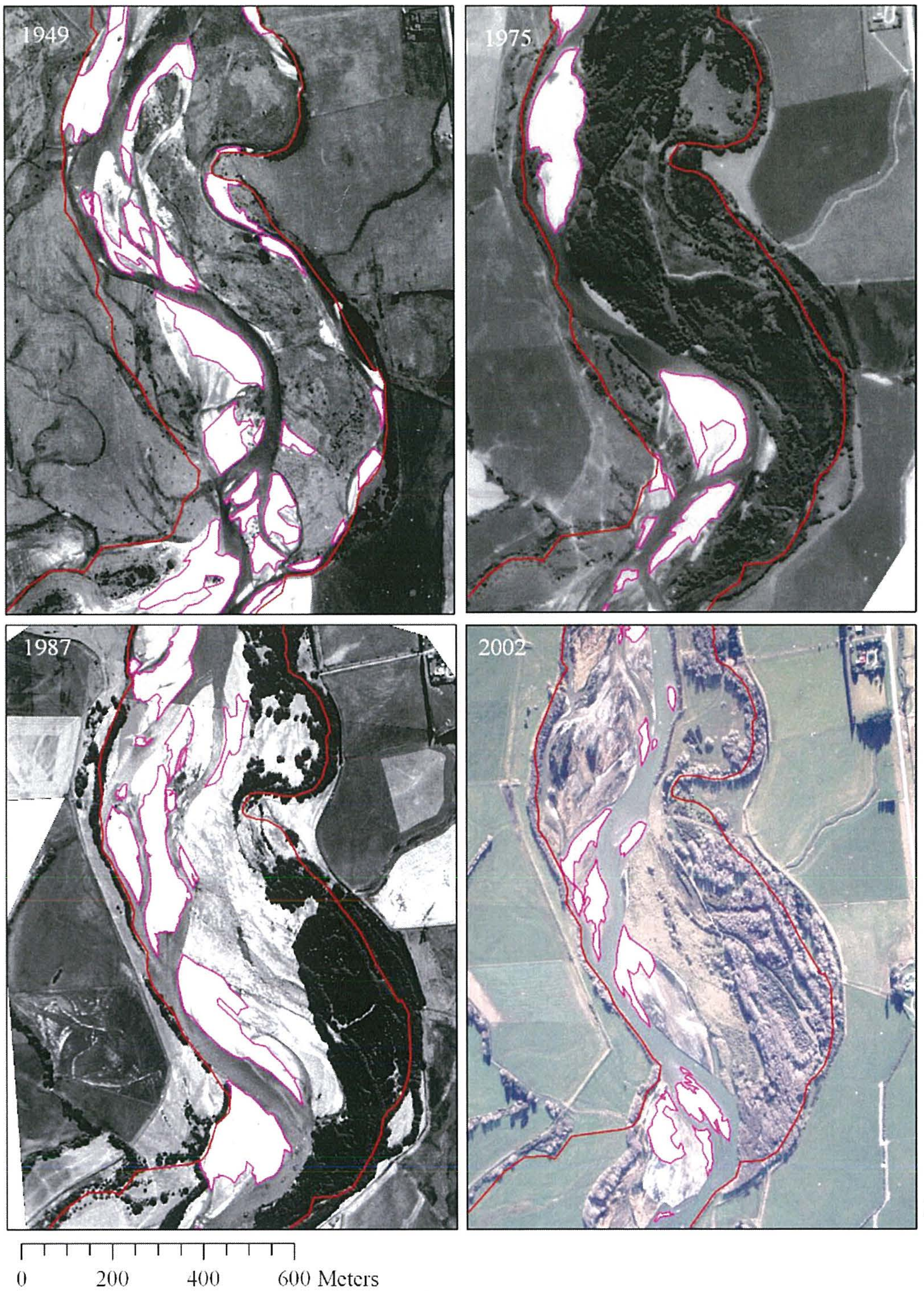

Figure 5: *Example of changes in vegetation in the mid Oreti section (series 1998 omitted). Red line denotes boundary of GIS analysis, pink delineates gravel habitat.*

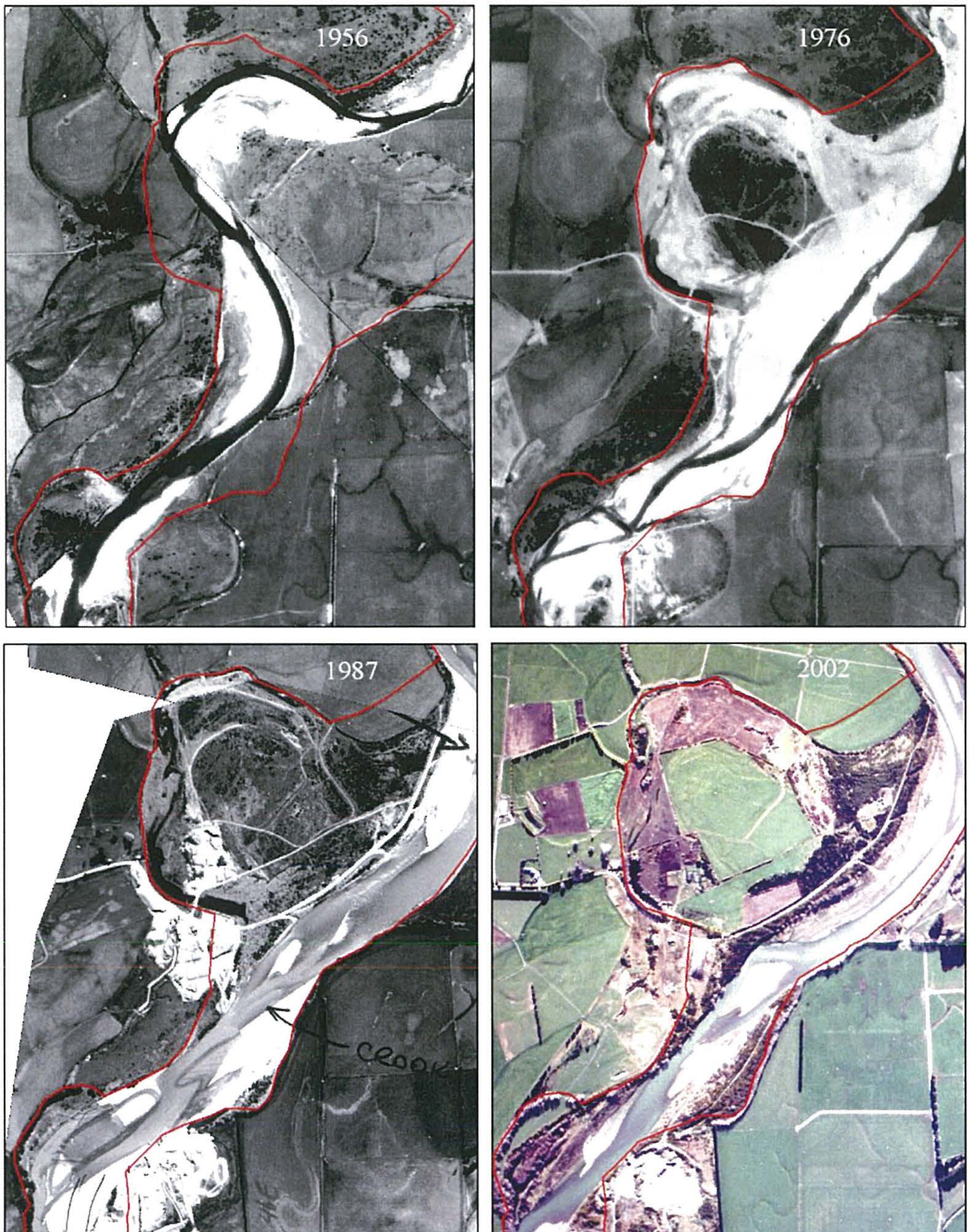

Figure 6: *Example of changes in vegetation in the lower Oreti section (series 1998 omitted). Red line denotes boundary of GIS analysis.*

Gravel-dominated habitat increased substantially in the Mid Waiau section between 1963 and 1978, coinciding with dam construction in 1972 (Figure 7a, Table 20), after which it immediately declined. In the Lower Waiau section, gravel-dominated habitat also increased after dam construction, but has since fluctuated (Figure 7c, Table 21). Both sections show a loss of mobile habitat over the short period from 1998 to 2002. While the latter photographs may be affected by slightly higher water levels, stable habitats also increased rapidly during this time. This amounts to a 50% decline in mobile habitat types on the Mid Waiau since 1978. The greatest change on the Lower Waiau has been in the replacement of tree/shrub-dominated habitat with grass/herb-dominated habitat.

Table 20: *Areas (ha) of habitat types by year as determined by GIS analysis; Mid Waiau.*

Habitat type	1963	1978	1984	1998	2002
Gravel dominated	31.7	122.9	83.1	97.8	72.2
≥15% vegetation and gravel	55.2	121.4	88.5	92.1	47.7
All 'mobile' habitat types	86.9	244.3	171.5	189.9	119.9
Grass/herb dominated	24.7	29.9	77.4	86.9	140.6
Tree/shrub dominated	140.3	112.1	114.3	96.9	108.0
All 'stable' habitat types	165.0	142.0	191.6	183.7	248.6
Total habitat	251.9	386.3	363.1	373.6	368.5

Table 21: *Areas (ha) of habitat types by year as determined by GIS analysis; Lower Waiau.*

Habitat type	1963	1975	1984	1998	2002
Gravel dominated	10.4	26.6	33.8	49.0	37.8
≥15% vegetation and gravel	8.0	46.8	30.3	55.2	19.6
All 'mobile' habitat types	18.4	73.4	64.0	104.2	57.4
Grass/herb dominated	29.5	24.8	25.6	98.7	128.8
Tree/shrub dominated	143.5	151.8	149.9	61.1	64.8
All 'stable' habitat types	173.0	176.6	175.4	159.9	193.6
Total habitat	191.4	250.0	239.4	264.0	251.0

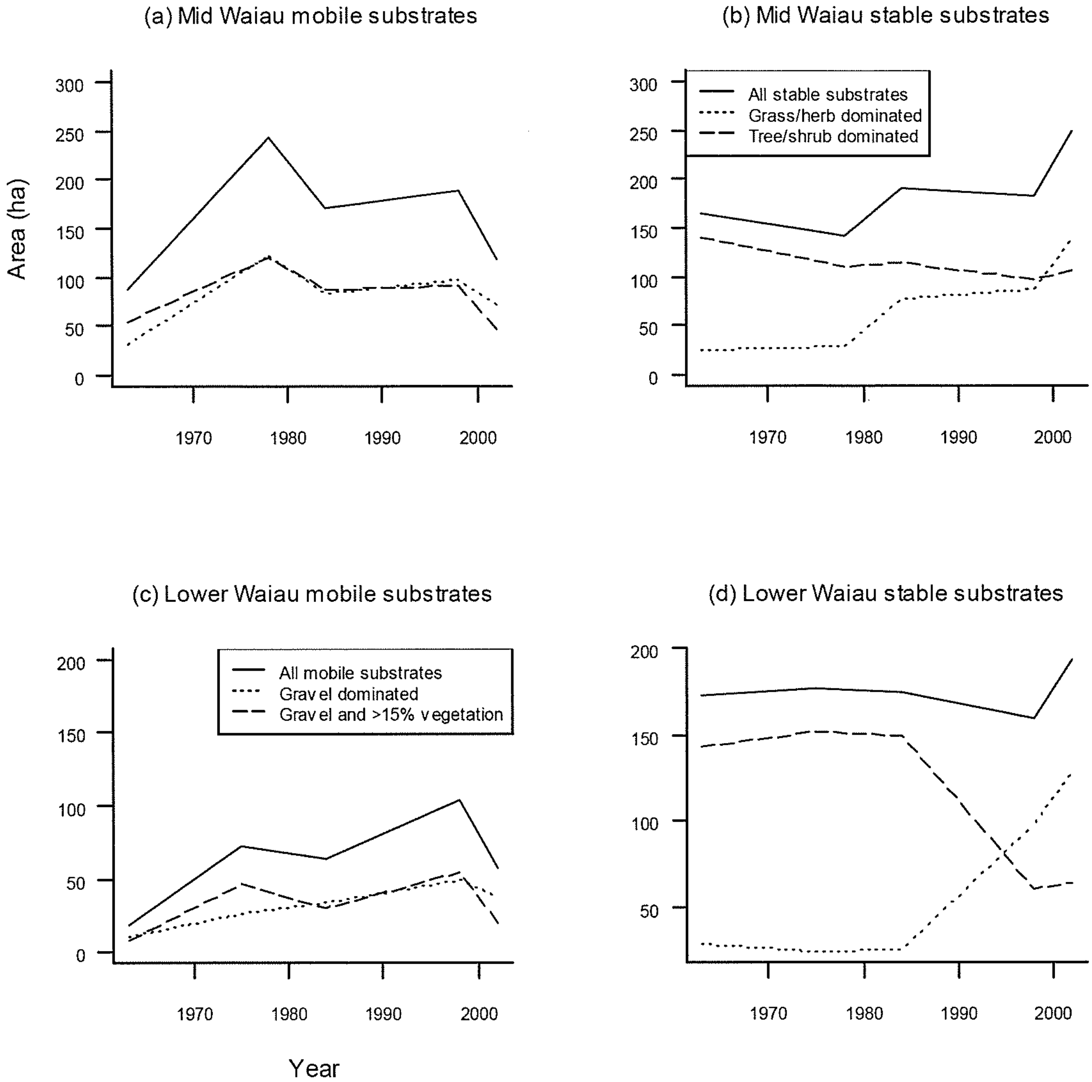

Figure 7: *Vegetation changes within the Waiau River; 1963-2002.*

Figure 8 illustrates the gradual infilling of mobile habitats since 1978 with more stable vegetation types (the triangular island of gravel in the centre of the 2002 photograph is used irregularly as a colony site, and in 2004, supported a colony of 3,500 birds). The photographs are typical of the relative morphological stability of the Mid Waiau section. Figure 9 shows the relatively pristine state of the lower Waiau River in 1963 with large amounts of forest within the river boundaries and little gravel habitat. Dewatering of the river exposed large amounts of gravel which remained relatively constant in the following three series. The photographs also illustrate the almost complete loss of forest and shrub vegetation between 1984 and 1998.

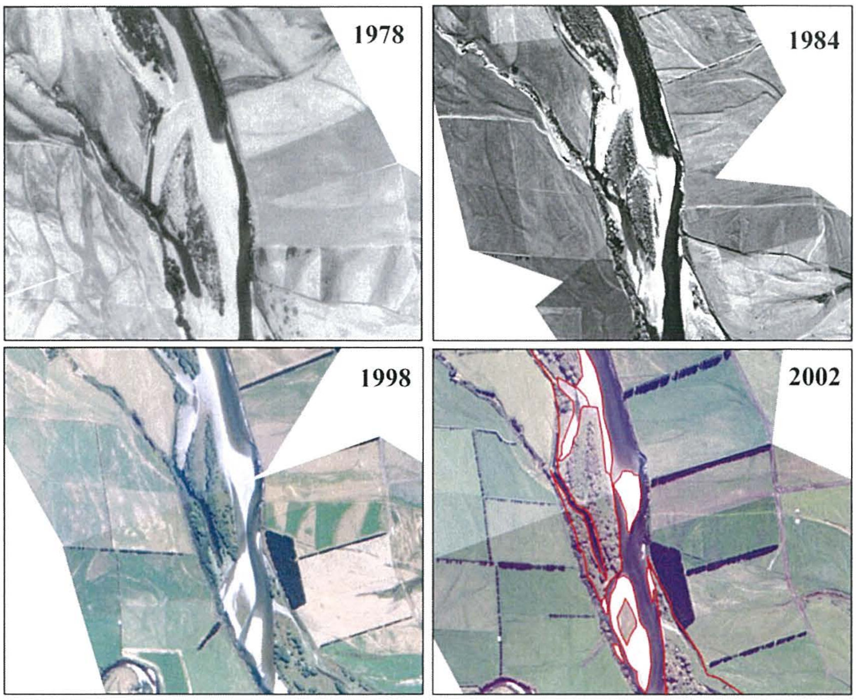

Figure 8: *Example of changes in vegetation in the mid Waiau section (series 1963 omitted). Red lines in 2002 photograph show vegetation polygons.*

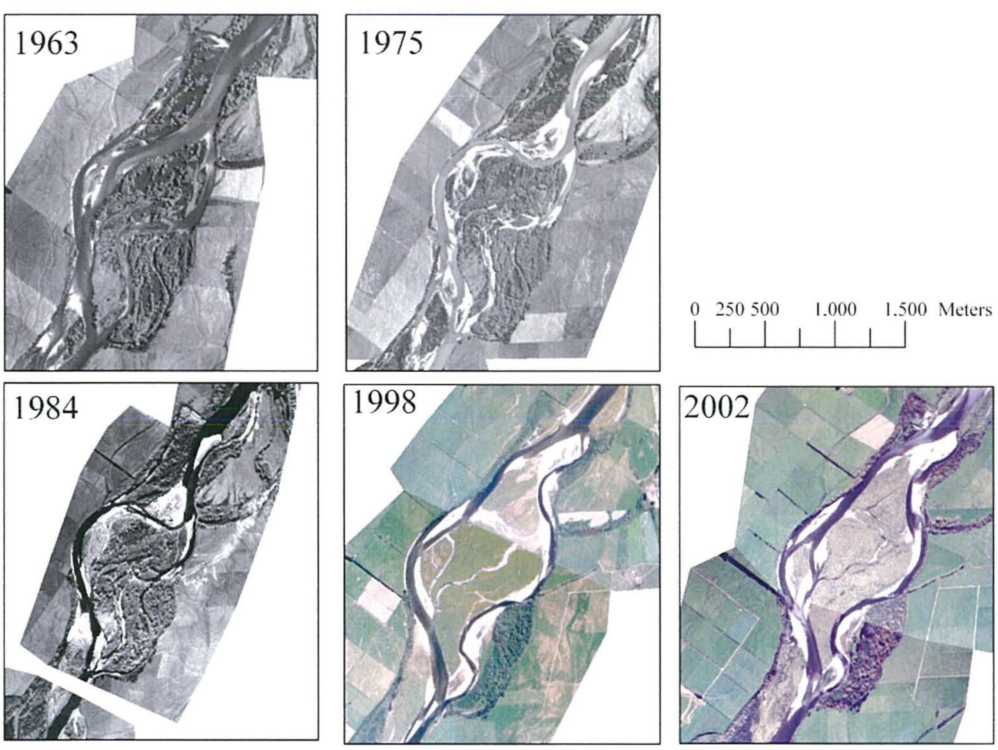

Figure 9: *Example of changes in vegetation in the lower Waiau section, 1963-2002.*

Changes in numbers and areas of gravel patches

The number of gravel patches within the Waiau sections and the Lower Oreti section showed little variation over time (Table 22, Figure 10). Substantial variation occurred within the Mid Oreti section (Figure 10a). Black-billed gulls breed in gravel patches as small as 0.09 ha. Mean patch size was substantially larger than this in all sections in all years (Table 22, Figure 11). The percentage of patches smaller than 0.09 ha was variable in both Oreti sections; sizes in 1987 and 2002 may have been influenced by water levels. The occurrence of small patches on the Waiau was consistently low. Patches of gravel-dominated substrate were larger overall on the Waiau, and greatest in the Mid Waiau, reaching a mean of 3 ha in 1978.

Table 22: *Number and mean size of gravel patches and percentage of gravel patches less than 900m^2 by year and river section.*

Section	Year	No. patches	Mean (ha)	SE (ha)	% of patches less than 0.09 ha
Lower Oreti	1956	27	1.44	0.32	18.5
	1976	23	1.46	0.27	0.0
	1987	37	1.00	0.19	8.1
	1997	35	0.96	0.15	14.3
	2002	35	0.35	0.06	40.0
Mid Oreti	1949	76	0.67	0.09	11.8
	1975	44	0.70	0.10	4.5
	1987	115	0.70	0.09	24.3
	1997	85	1.13	0.17	21.2
	2002	92	0.51	0.07	26.1
Lower Waiau	1963	20	0.52	0.11	5.0
	1975	29	0.92	0.12	0.0
	1984	28	1.21	0.25	7.1
	1998	21	2.33	0.83	0.0
	2002	28	1.35	0.25	3.6
Mid Waiau	1963	55	0.58	0.11	9.1
	1978	38	3.23	0.76	2.6
	1984	53	1.57	0.32	3.8
	1998	48	2.04	0.53	2.1
	2002	49	1.47	0.30	4.1

Data from the Lower Oreti section are indicative of a gradual decline in gravel patch size since 1976 (Figure 11a). Patch size on the Mid Waiau increased substantially post-dam, dropping to lower levels from 1987 onwards (Figure 11b). Patch size on the Lower Waiau increased slightly until 1984 and then fluctuated. Overall, between the 1980s and 2002, no trends are observable within the Waiau, but a decline in patch size may still be occurring on the Lower Oreti, though Oreti results are affected by floods. Only the Mid Oreti section showed little change in patch size over time.

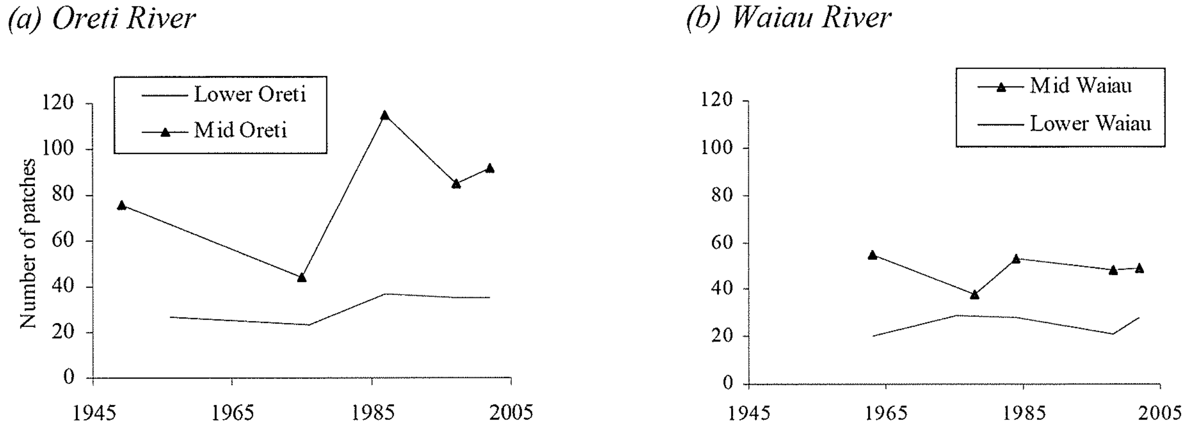

Figure 10: *Changes in the numbers of gravel patches on the Oreti and Waiau river sections, 1949-2002.*

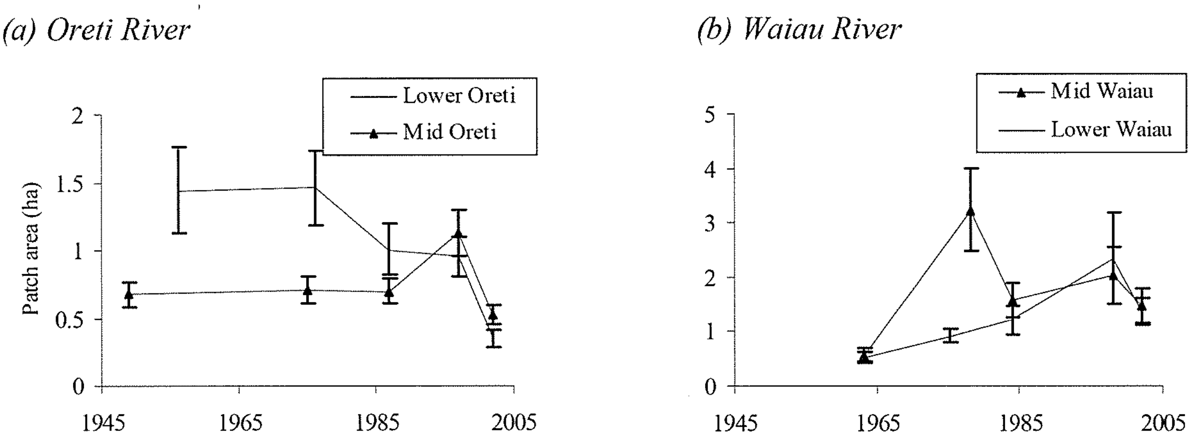

Figure 11: *Changes in the size of gravel patches on the Oreti and Waiau river sections, 1949-2002. Error bars indicate standard error.*

Changes in the number of islands and gravel on islands

The number of islands in the Lower Oreti section fluctuated between eight and 17, and in the Mid Oreti, between 29 and 53; highest numbers were recorded when water levels were high (1987 and 2002; Figure 12). The percentage of gravel patches on islands follows a similar pattern. Despite similar lengths, the Mid Oreti section contains many more islands than the lower section.

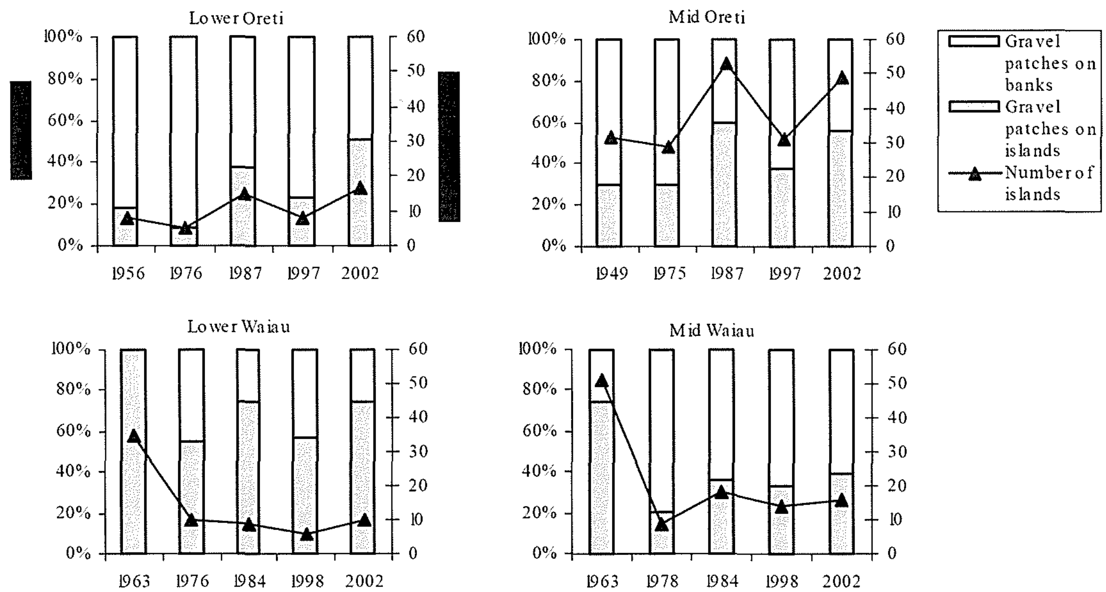

Figure 12: *Changes in the number of islands and the percentage of gravel habitat patches on islands versus banks; Waiau and Oreti river sections, 1949-2002.*

The Waiau sections both show a major decline in the number of islands between 1963 and 1975/1978, coinciding with the construction of the dam and associated lowering of water levels. Prior to dam construction, the majority of gravel patches were on islands. Post-dam, the Lower Waiau still supports the majority of gravel patches on islands, whereas in the Mid Waiau, most gravel patches are now on banks. No trends are apparent.

DISCUSSION

Factors affecting colony site selection (2004-2006)

Limitations of study

A small number of studies have addressed colony site selection by highly mobile species (e.g. Thompson and Slack 1982; Boe 1993; Erwin et al. 1998; Sanchéz et al. 2004; Forys and Borboen-Abrams 2006), most commonly using presence-absence data. This study employed a much more simple methodology as very little was known about the species' colony site preferences and it was unclear whether any of the variables measured would, in fact, drive site selection. One possibly critical variable, food availability, was only able to be measured simplistically. Despite this, and limited data, modelling detected the significant influence of a number of covariates. Colony site selection should be re-examined in the more classical manner using a similar set of explanatory variables but in conjunction with a number of measures of food availability.

River morphology

Colonies established on Southland's four main rivers in accordance with habitat availability (number of patches). The rivers differ in a number of aspects including presence of hydroelectric dams, amount of adjacent land and catchment area remaining in native vegetation, water quality (Environment Southland 2000), extent of infestation by the newly established water weed *Didymosphenia geminata* (pers. obs.), and percentage of adjacent land in dairying (this study). This indicates that any differences in habitat quality as may be perceived by conservation managers do not appear to affect site choice. Colonies also establish on islands and banks within rivers in accordance with availability (c.f. Stead 1932; Soper 1972). Given two thirds of gravel patches are on banks, it can be expected that a similar proportion of colonies will be accessible to terrestrial predators (see Chapter 5 for further results and discussion).

The availability of habitat found by this study is very different from that found by Wilson (2001) who used a combination of the New Zealand Land Resource Inventory, New Zealand Land Cover Database and topographical maps to determine the presence of 'open' (i.e. non-vegetated) patch numbers and sizes on braided rivers in New Zealand. For example, Wilson found 292 open patches on the Mataura with a mean size of 3.3 ha and 178 patches with a mean size of 10.1 ha on the Oreti. This study found 90 gravel patches in 50 km on the Mataura and 190 on the Oreti with a mean patch size of 0.3-1.5 ha over all photographic series from 1949-2002 on the Oreti (this study). Wilson reported the Aparima as having a mean open patch size of 19.0 ha with only 48 open patches, whereas in this study, the Aparima had a similar frequency of gravel patches to the Oreti, and patch size is likely to be 2 ha or less (pers. obs.). The use of low altitude aerial photography employed by this study will have greater accuracy.

Gray and Harding (2007) define a braided river as one that flows in multiple, mobile channels at some point along its length across a gravel floodplain and which has evidence of recent channel migration within the active bed of the river. The majority of colonies (61%) were situated on banks on single channel sections of river and only 11% were sections with multiple channels (three or more). On this basis, Southland black-billed gull colonies tend to be more characteristic of gravel-bedded rivers rather than braided rivers in particular. These results indicate that single channel, gravel-bedded streams and rivers should be included in surveys in other South Island regions.

Vulnerability to flooding

Cross-sections and modelling of river flow indicated that all sites were likely to be flooded during the season on at least one occasion, and up to 18 occasions. Colony sites differed significantly from one another in regard to their vulnerability to flooding. In addition, weeds, particularly grasses, were immediately adjacent to most colony sites and were present at the highest available point at the colony site in 65.2% of cases, most likely forcing colonies to establish closer to the water line (although some colonies did not necessarily establish at the highest point when available). Given that gulls do not necessarily choose sites that are relatively safe from floods, a combination of management actions targeted at clearing sites with low flooding probability of weeds and trialling the use of decoys to attract gulls to those sites may improve productivity. Decoys have been used with success for a variety of species in an attempt to attract birds to safer breeding sites (e.g. Kotliar and Burger 1984; Dunlop et al. 1991; Collis et al. 2002; see Chapter 7 for further discussion).

Weeds

Weedy vegetation also provides cover for terrestrial predators which can allow greater access to prey such as black-billed gulls (Pascoe 1995; Rebergen et al. 1998; Dowding and Murphy 2001) and can also support den sites (Rebergen et al. 1998; a ferret den was found beneath gorse bushes within 40 m of a monitored colony, pers. obs.). Trapping results from Southland rivers clearly indicate that predators are preferentially caught in traps set next to waterways; water was the single habitat type that gave a higher capture rate for all four predator species (2-4 times higher than expected). These results should be used to locate trap sites in any trapping programme aimed at protecting black-billed gull colonies.

Relationships between colony size and colony area and colony area and the available area (or gravel patch size) were identified, suggesting that if vegetation were to spread and patch sizes decrease, colony sizes may likewise decrease. This could have major implications if black-billed gull colony productivity showed a positive relationship to colony size (see Chapter 5 for further results and discussion).

Influence of dairying

The amount of area in dairying did not influence colony site placement; however, as previously mentioned this may be a poor indicator of food availability. A full investigation of both colony site selection and site re-use will need to take account of food availability, particularly at the beginning of the breeding season, and require investigation of food sources, foraging distances and locations and diet. The complicated nature of such a project may be an underlying reason for the apparent lack of colony site selection studies on highly mobile species, and a possible reason for some studies (e.g. Erwin et al. 1998) not being able to identify causal factors for site re-use.

Factors affecting re-use of colony sites

Past use of a colony site and to a lesser extent, morphological stability, are important determinants of a site's re-use in following seasons. This is not surprising given the propensity of seabird species, once breeding adults, to display high site fidelity (Coulson 2002). Comments from neighbouring farmers indicated gull colonies could establish irregularly in the same exact locations for decades (J. MacDonald pers. comm. 2005; N. Gorrie pers. comm. 2005; B. Drummond pers. comm. 2005). One farmer recorded a gull colony establishing in the same site for seven of eight consecutive years (B. McMillan pers. comm. 2006). Oreti River sites were generally modified substantially by the following year, and no sites were re-used. In comparison, several key island sites on the Waiau have been present for over 30 years, suggesting there are major differences in relative stability between Southland rivers.

The presence of gravel extraction activities was also found to be an important explanatory variable for site re-use based on two gravel extraction sites that were re-used the following year. Both sites were regularly used by gulls, and may be attracted to the location in part because the regular movement of machinery over the gravels maintains a relatively weed-free area (and because the sites have a history of occupation). However, gravel extraction rates that are in excess of natural accumulation rates will lower the site, making it more vulnerable to flooding and, at extreme levels will remove the available habitat altogether. In addition, the presence of breeding birds can cause major inconveniences to persons and companies involved in gravel extraction as it is illegal to disturb black-billed gulls that are breeding.

Low weed coverage within the colony area was an important factor determining the re-use of colony sites (a parameter in the third best model). At some sites, major weed irruptions occurred post-season in the immediate colony area, presumably encouraged by thick deposits of guano, and were not re-used. However, other sites did not suffer similarly, perhaps due to flood frequency and size in the intervening months clearing the deposits.

Insufficient cross-sections were able to be carried out in order to examine whether flood frequency affected the probability of re-use. However, among other mobile colonial seabirds, Erwin et al. (1998) found that gull-billed terns re-nested at colony sites within the same year despite flooding events, and Burger (1982) found black skimmers shifted colony site the following season when predators caused low productivity but not flooding, hypothesised to be due to the relative predictability of the two events.

Habitat availability (1949-2002)

Limitations of GIS methodology

River levels varied between photographic series resulting in changes in the amount of habitat visible that could not be measured. The proportion of habitat exposed at different flows could be assessed via remote sensing and GIS analysis, but would require photographs to be taken at a variety of flows over a short term period to ensure minimal vegetation change (see Duncan et al. 2008). In this study, flows in those series affected by higher water levels were unlikely to have influenced the amount of stable substrate habitats visible (i.e. grass/herbs and trees/shrubs).

The two earliest black and white series of the Oreti River (Lower and Mid sections) both had an unusual colouration within sparsely vegetated habitat types which appeared unpredictably throughout many of the photographs, possibly due to diffraction of light. This caused difficulty in differentiating ≥15% vegetation and gravel habitat from gravel habitat. All habitat affected by this colouration was classified conservatively as ≥15% vegetation and gravel habitat, though much of it was likely to have been gravel. Because of this, the actual amount of gravel habitat in early Oreti photographs may have been underestimated.

The limitation of the GIS analysis to five series of photographs per section means results are a series of snapshots of habitat composition, and cannot give a detailed picture of trends, particularly the extent of short-term (i.e. 2-4 year) fluctuations. As a consequence of the inability to obtain estimates of error associated with summing habitat polygons, it is not possible to determine whether observed changes in habitat types are statistically significant. However, graphs closely align with visual examination of photographs. Despite these issues, remote sensing remains only method to examine changes over time in the absence of a large-scale monitoring programme. Determining the amount of available habitat from aerial photographs and the number and area of islands via remote sensing and GIS is also recommended by Duncan et al. (2008) as a tool in the conservation management of New Zealand endemic riverbed nesting birds.

Trends in available breeding habitat and gravel patch sizes over time

Mobile habitat types noticeably diminished on the Lower Oreti between 1976 and 2002, associated with major changes in river planform. The habitat loss is most likely explained by human-induced changes in and around the river. In 1974, 250,000 cubic yards of gravel per annum was being extracted from a 12 km section of the Oreti River (including the Lower Oreti section covered in this analysis; Ledington 2007). Historical extraction rates on this and other Southland rivers were considered to be far in excess of supply rates (Hicks et al. 2005 in Ledington 2007). Large-scale extraction can result in river incision and changes in channel width and morphology (Rindaldi et al. 2005); the lower Oreti was recently found to have lowered by over one metre, thought to be a result of high extraction rates (Hudson 1997 in Ledington 2007).

In addition to gravel extraction, extensive plantings of willow (*Salix* spp.) on riverbanks throughout Southland were initiated during the 1940s and 1950s to reduce erosion and stabilise banks to secure land for farming (Poole 1990; visible as increased areas of trees between earliest photographs and those taken during the 1970s e.g. Figure 5). Stop banks and groynes were built. These works have largely changed the lower Oreti from a meandering river to a narrower, straighter river (Figure 13).

The largest and third largest black-billed gull colonies reported in New Zealand were found on the Lower Oreti in 1977 and 1986. Examination of the general area where the colonies established in photographs indicates that substantial gravel habitat still remained in 1987 (though markedly less than in 1956 and 1976). However, by 2002, all gravel areas were largely vegetated. The situation is similar if not worse in recent digital photography taken in 2007. No colonies have been observed on the lower 30 km of the Oreti since the initiation of aerial surveys in 1995. This suggests the lower Oreti may no longer suitable for breeding due to lack of habitat.

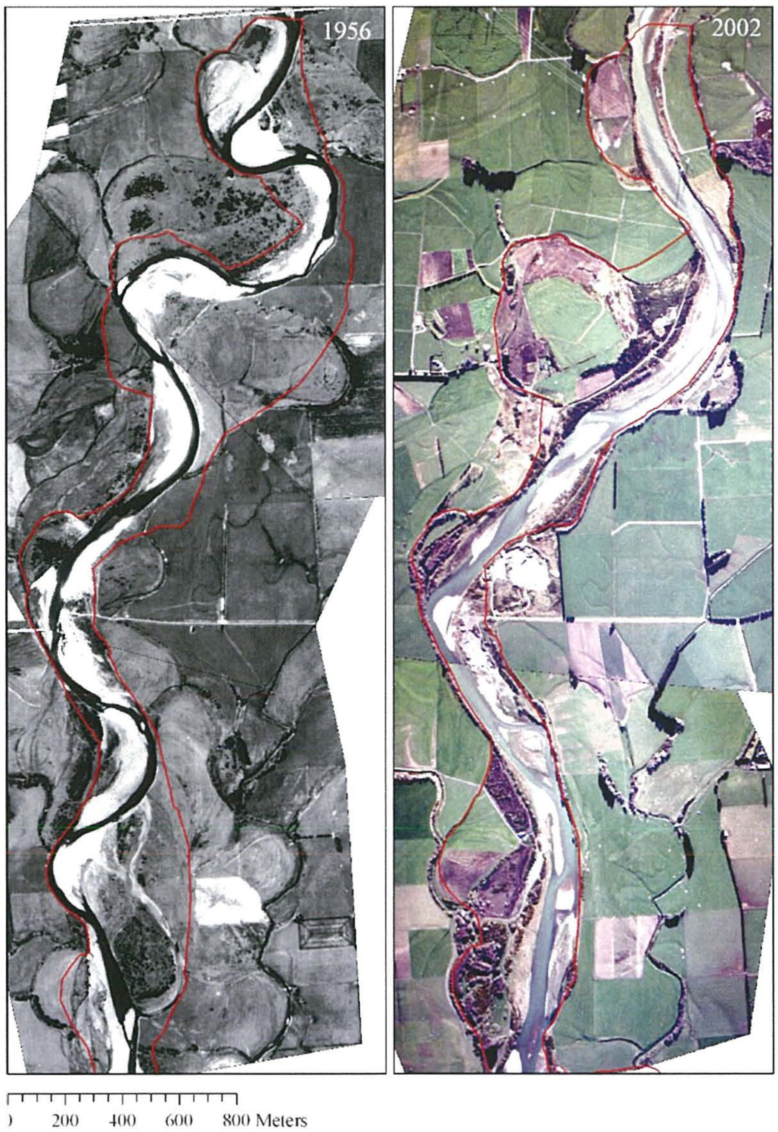

Figure 13: *Changes in river planform on a section of the lower Oreti River between 1956 and 2002.*

The damming of the Waiau in 1972 and the associated reduction in flow created large amounts of new breeding habitat in both the Mid and Lower Waiau sections. The initial subsequent decrease in mobile habitats as more stable habitats evolved in the Mid Waiau is not unexpected given the major change to the river's flow and flood regime. The amount of gravel habitat available in the Mid Waiau in 2002 may be more than was available prior to damming. On the Lower Waiau, available gravel habitat may have continued to increase. The major loss of forest vegetation visible in the early Lower Waiau photographs (and replacement with grass/herb dominated vegetation) occurred as a result of widespread spraying programmes during the 1970s and 1980s which aimed to clear floodplains of woody vegetation along 10 chain widths (200 m; C. Young pers. comm. 2008). This occurred throughout Southland (e.g. in the Oreti River, Figure 6, and the Waiau River, Figure 10) and targeted willow, which had begun to choke many waterways (Poole 1990).

The relationship between colony size and available area (or gravel patch size), particularly for smaller areas, could be of concern if a subsequent relationship was shown between colony size and productivity (see Chapter 5) and a decreasing trend was evident in the size of gravel patches. However, mean patch sizes on the Waiau sections have fluctuated over the last 20 years, and are larger than mean patch sizes prior to dam construction and, on the Mid Oreti, patch sizes have remained largely stable. Patch sizes have only noticeably declined on the Lower Oreti.

Despite losses in the Lower Oreti and, to a lesser extent, the Mid Waiau, substantial breeding habitat remains within the four sections (approximately 200 patches in 2002). It is plausible that well over 1000 patches greater than 900 m^2 in size would be available in any year in Southland's gravel-bedded rivers and streams. Given less than 25 colonies established annually within Southland in 2004-2006, ample habitat appears to remain to allow gulls to select quality colony sites. However, detection of gravel patches in aerial photographs does not necessarily equate to a quality site: for example, patches may be too close to the water line or they may be too distant from food sources. Ground-truthing immediately after photography could enable a simple verification of height above water lines. Extensive weed control work is undertaken by Environment Southland on the region's main rivers for flood control management. This programme is mostly likely largely responsible for the relative stability of gravel breeding habitat on the Waiau and Oreti rivers.

Changes in the numbers of islands

Islands are potentially higher quality nesting sites than those on banks as terrestrial predator access may be reduced (Pierce 1987; Rebergen et al. 1998; Nuechterlein et al. 2003; Boffa Miskell Ltd. 2007; Chapter 5). On the Oreti sections, numbers of islands were largely stable over the period of analysis, higher numbers being present in times of moderate flood. However, post-dam construction, numbers of islands in each of the Waiau sections dropped by approximately 75%, presumably due to lowered flows. Lowering of flows due to dam construction or water abstraction can lead to loss of island habitat (Johnson et al. 1995; Duncan et al. 2008) and is a major threat to river-breeding birds.

CHAPTER 5

The influence of coloniality on the productivity of black-billed gulls in Southland, New Zealand

Monitoring black-billed gull nests, Dunrobin South colony, Aparima River, 2006 (C. Garden)

ABSTRACT

The productivity of the Endangered black-billed gull (*Larus bulleri*) in Southland was assessed during three breeding seasons from 2004 to 2006. Over 5000 nests in 21 colonies were monitored during incubation. Nest success (percentage of nests hatching at least one egg) by colony varied between 18.7% (SE 1.1) and 94.0% (SE 0.1) and averaged 90.1% (SE 2.1) on islands within rivers and 66.8% (SE 2.2) on riverbanks. Using a photographic method to estimate the number of fledglings, breeding success was found to vary between 0 and 0.88 fledglings per nest (mean 0.32, SE 0.08). Nest success and breeding success showed a strong, positive relationship with colony size. The level of colony disturbance by predatory black-backed gulls (*L. dominicanus*) displayed a negative relationship with colony size. The three smallest colonies largely failed to produce fledglings suggesting the presence of an Allee effect whereby colony productivity decreases at an increasing rate below a certain colony size threshold. Modelling indicated that the position of the colony (i.e. on a bank or island) best explained variation in nest success; nest success on islands was significantly higher, presumably because terrestrial predators are less likely to cross water barriers. The use of infra-red cameras in a bank colony indicated that a small number of predators caused in excess of 100 and possibly several hundred disturbances over two months of the breeding season. Such disturbances indirectly resulted in half of all observed egg mortality. Direct predation caused 80% of observed chick mortality (between hatching and eight days of age). The existence of a relationship between productivity and colony size as well as an Allee effect has major implications for this rapidly declining species as the size of colonies will gradually decrease leading to lower overall productivity.

INTRODUCTION

New Zealand's endemic Endangered black-billed gull (*Larus bulleri*) breeds in dense colonies, primarily on inland riverbeds. Approximately 70% of the population breeds in Southland rivers, where it has undergone a rapid decline well in excess of 50% since 1977 (Chapter 2). Predators are thought to be a primary cause of black-billed gull mortality (Taylor 2000; Murphy et al. 2004); however, there is minimal empirical evidence. Several studies have investigated the identity and impact of predators on other, likewise threatened, endemic species of braided river birds. Key predators are largely introduced terrestrial mammals:

ferrets (*Mustela furo*); stoats (*M. erminea*); cats (*Felis catus*); hedgehogs (*Erinaceus europaeus*) and Norway rats (*Rattus norvegicus*) (Pierce 1986; Sanders and Maloney 2002; Keedwell 2003; Murphy et al. 2004).

Protection from predators has often been given as a key explanation for the evolution of avian coloniality (reviews in Wittenberger and Hunt 1985; Siegel-Causey and Kharitonov 1990; Danchin and Wagner 1997; Brown and Brown 2001; Coulson 2002). In theory, colonial breeding can reduce predation by (1) allowing earlier detection of a predator; (2) increasing the chances of successfully deterring that predator (by mobbing, confusing etc.); and (3) diluting the impact of the predator (Burger 1979; Hernández-Matías et al. 2003; Serrano et al. 2005; reviews in Wittenberger and Hunt 1985; Brown and Brown 2001). However, studies are frequently contradictory, to the extent where some authors have observed that coloniality increases predation (Burger 1984; Clode 1993; Brown and Brown 1996; Stokes and Boersma 2000; Brown and Brown 2001: Varela et al. 2007).

Studies of colonial breeding birds, particularly in regard to predation, often focus on relationships between productivity and colony size, nest density and breeding synchrony. Among 20 such studies of Laridae, results have shown positive and negative relationships between colony size and reproductive success, or no relationship (summary in Brown and Brown 2001). Nesting at higher densities has been shown to afford greater protection from predators (Götmark and Andersson 1984; Phillips et al. 1998; Hernández-Matías et al. 2003) but again, studies have produced mixed results (Parsons 1976; Butler and Trivelpiece 1981; Pienkowski and Evans 1982; Becker 1995; Brunton 1999; Stokes and Boersma 2000; see summary in Burger 1979). Breeding synchrony is common among colonial seabirds (Wittenburger and Hunt 1985). According to the predation hypothesis, breeding synchrony acts to swamp predators with prey, subsequently increasing productivity (Darling 1938). However, synchrony is extremely variable among colonial bird species, and is common among non-colonial species (Coulson 2002).

Black-billed gulls may nest more densely than any other gull species (Beer 1966) and appear to nest exclusively in colonies (i.e. obligate coloniality). Marked breeding synchrony has been recorded, most gulls within a colony laying within a week (Stead 1932; Beer 1966; Evans 1982, but see Burger and Gochfield 1996). Such extreme coloniality may be a response to predator pressure; black-billed gulls co-evolved with a variety of potential avian predators, many of which are now extinct. Limitation of breeding habitat, another theory explaining the adoption of colonial breeding (reviews in Brown and Brown 2001; Coulson 2002) is very unlikely to apply to black-billed gulls as nesting habitat is plentiful (Chapter 4). Improved foraging efficiency is a further hypothesis that could explain black-billed gull coloniality (Evans 1982b; Evans 1982c) as the species is opportunistic, primarily feeding on a wide variety of invertebrates (Stead 1932; Dawson 1958; Boud and Cunningham 1959; Moeed 1976; R.K. McClellan unpubl. data) for which availability may be unpredictable (e.g. moth population explosions, mayfly hatches, ploughing of pasture exposing earthworms). Overall, the evolutionary significance of 'extreme' coloniality in the species is unclear, as is its importance in enabling the gulls to withstand the presence of an array of introduced predators in the modern environment; the key threat facing the majority of New Zealand's endemic bird species (Saunders and Norton 2001; Innes et al. in press).

A focus of recent research on New Zealand endemic river-breeding birds is the relative impacts of introduced predators on birds nesting on islands within rivers compared to those nesting on riverbanks (Pierce 1987; Rebergen et al. 1998; Boffa Miskell Ltd. 2007). Studies have shown nesting on islands to be more successful than nesting on riverbanks, presumably because terrestrial predators are deterred by the presence of water (Pierce 1987; Pascoe 1995; Boffa Miskell Ltd. 2007). Productivity of black-billed gulls has not been studied in this way.

Based on the studies reviewed above, I expected:

1. Productivity (e.g. nest success, breeding success) to be positively correlated with the size of the colony, breeding synchrony and nest density; and
2. Nest success to be related to colony location i.e. on banks or on islands within rivers.
3. Predation to be the primary cause of mortality of eggs and chicks in colonies on banks

In this chapter, I examine the relationship between nest success and other factors such as synchrony, nest density and colony size to investigate avian coloniality theory as it relates to black-billed gulls. I also investigate the possible impacts of predation by assessing nest success on islands versus banks, examining patterns of nest failure within colonies, and the use of infra-red camera technology to give insight into predator behaviour and impacts.

METHODS

Colony location and size estimation

Colonies were located each year by vehicle and plane and gulls in aerial photographs of colonies were counted (survey and aerial photography methods in Chapter 2.

Colony productivity

Four measures of productivity were assessed: clutch size (greatest number of eggs observed in a nest); hatching success (percentage of eggs hatching chicks); nest success (percentage of nests hatching at least one egg) and breeding success (number of fledglings per nest; full results in Appendix H).

Monitoring nest success

Too few colonies were present in study rivers in all years to allow the selection of a sample stratified for islands and banks. As a consequence, all colonies that were found sufficiently early in the season and could be accessed safely were monitored (channels were too deep or swift to access some island colonies). In 2004 and 2005, study rivers were the Waiau, Aparima and Oreti rivers. In 2006, the Mataura River was included to ensure a large sample size. In total, 21 colonies were monitored (Figure 1). A colony at Fairfax nested both on an island and a bank approximately 50 m distant from each other; these sites were treated as two separate colonies for the purposes of all analyses.

Nests were sampled in large colonies (>150 nests) because it was not practical to monitor all nests. At each colony, strip transects separated by 8-10 m were established parallel to river flow starting from a random point from the river (8 m was sufficient to avoid disturbing birds on the adjacent transect once the majority of the colony was incubating). Fluorescent spray paint was used to mark transects as it was a quick method that kept disturbance to a minimum. Transects were re-marked as required throughout the season. Every nest with eggs within 1 m of the transect line was marked. Nests were marked with a number by writing with permanent pen on an adjacent rock with an arrow pointing to the appropriate nest. Marker rocks were preferably embedded within the substrate to reduce the chance of being moved by gulls or small floods. Infrequently, appropriate rocks were not available and needed to be placed by nests; these rocks were often knocked or found inside nests causing problems for analysis. All nests were monitored in two small colonies.

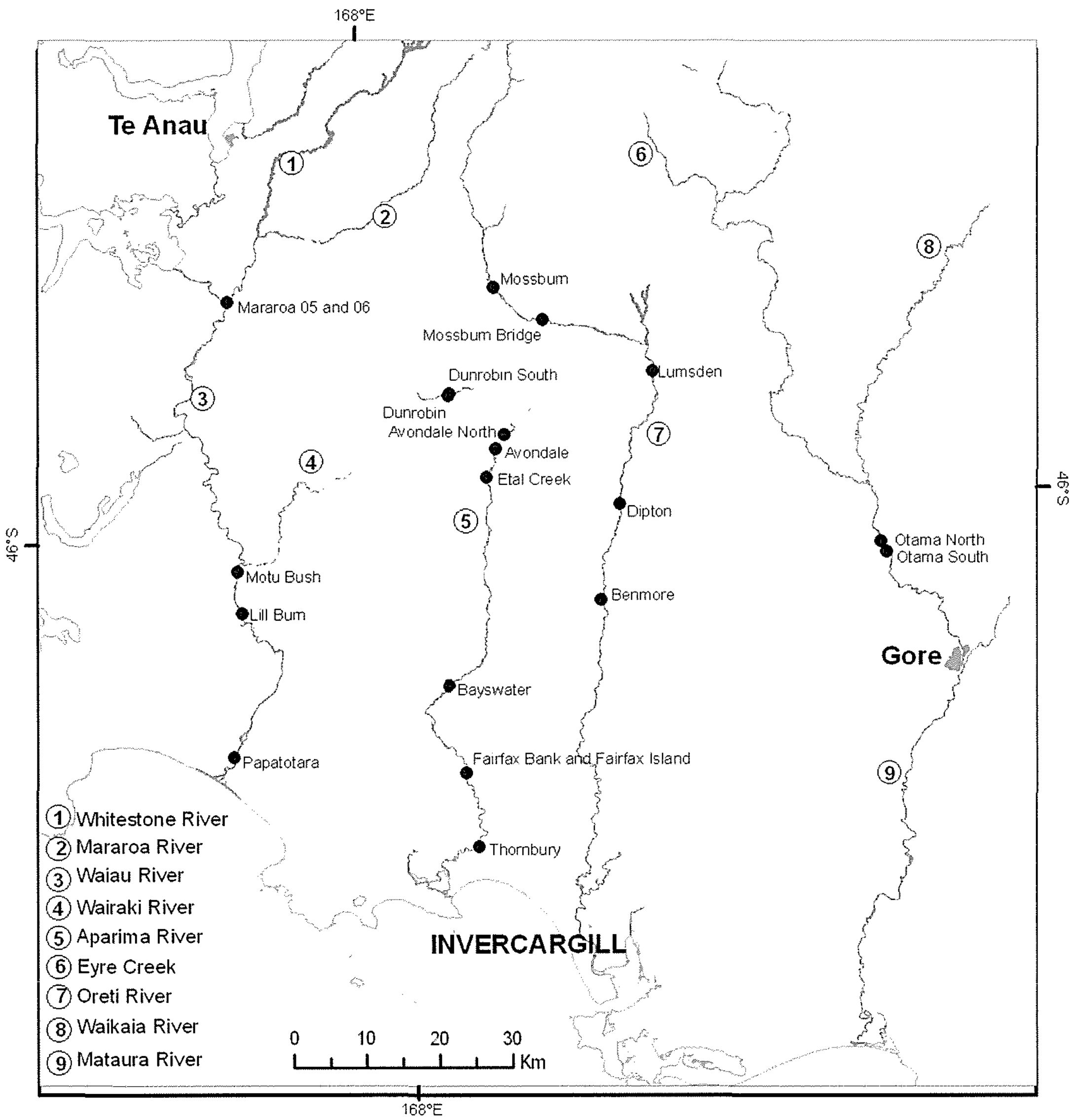

Figure 1: *Location of black-billed gull colonies monitored from 2004-2006 in Southland.*

Colonies were visited every 3-6 days to check nest contents, but on a small number of occasions, at considerably longer intervals when river levels restricted access to island colonies. At each visit, nest contents in monitored nests were recorded and new nests with eggs were marked. Nest monitoring ceased when the majority of incubation attempts had been completed and nests were largely deserted (chicks and parents desert the immediate nesting area at 4-8 days after hatching; R.K. McClellan unpubl. data). Varying numbers of nests usually remained active at this time (generally less than 10%) but the continued disturbance to the colony caused by monitoring small numbers of nests was considered unwarranted.

Nest counts

I estimated the number of nests at 13 of the 21 colonies monitored from 2004-2006 by two methods. Nest counts were used in 2004 and 2005 at four colonies at 'peak laying', defined as when the number of new nests on monitoring transects increased by less than 5% on two consecutive visits. The nest count was completed on the following visit (adapted from Wanless and Harris 1984). In 2006, a further three nest counts were undertaken at colonies specifically to coincide with aerial monitoring of black-billed gull colonies. In eight larger colonies where nest counts had the potential for significant disturbance, the number of nests was estimated using geo-referenced vertical aerial photographs of the colonies (nest count and GIS/transect count methods in Chapter 2).

Breeding success

The number of fledglings and nests in the colony was estimated in order to calculate breeding success, defined as the number of fledglings per nest. Initially, the number of fledglings produced in the colony was estimated by mark-recapture. Timing was determined using 'peak laying' as a guide; in 2004, mark-recapture was carried out four weeks following peak laying and five weeks after peak laying in 2005. Chicks varied from approximately 2-6 weeks of age. Chicks were captured by using three or more people to 'herd' the entire chick population within the colony into a group. Virtually all mobile chicks (well over one thousand on occasions) could be gathered quickly in this way with 0-5% escaping. The chicks were encouraged to move toward a temporary pen where approximately 200 were split from the group and penned. This number ensured the safety of the chicks. They were immediately removed and placed into cardboard boxes which held up to 10 chicks each to await either banding with metal and plastic coloured bands (for dispersal and survival research), or marked with raddle on the wing, a form of paint used to mark livestock. The following day, chicks were captured as before, and quickly checked for bands or marks and released. The Lincoln-Petersen method was used to obtain an estimate of the size of the fledgling population:

$$\frac{\hat{N}}{M} = \frac{C}{m}$$

where $\hat{N}$ is the population size estimate at the time of the original sample, M is the number of individuals released on the first occasion, C is the size of the second sample captured and m is the number of marked animals in the second sample.

The suitability and accuracy of mark-recapture was questionable (see Results for details) and, in 2006, four weeks after 'peak laying', a second, very straightforward method was trialled. It relied on the relative ease with which all fledglings within a colony could be herded into a group. A photographer stood at the top of a 2.5 m ladder approximately 30m away from the colony (a sufficient distance to avoid disturbance). The 'herders' worked as usual to gather fledglings together (Figure 2), and counted any chicks they saw escaping the herd which were later tallied. The herders encouraged the flock to move towards the photographer and when the chicks were sufficiently close and relatively still, several high resolution digital photographs were taken (Figure 3). Using the grid facility in Adobe Photoshop Elements 4.0™, photographs were enlarged on screen and the chicks were counted by placing dots on each bird within a grid square and recording the number counted within that square.

For a small number of colonies, actual counts of the numbers of fledglings were possible (either all could be caught, or so few survived that they could be counted easily).

Figure 2: *Photograph taken from a ladder for the purpose of estimating fledgling numbers at a black-billed gull colony. Photograph shows a herd of black-billed gull chicks and three of five 'herders'. The colony is visible in the background. Otama North colony, Mataura River, Southland, 2006 season.*

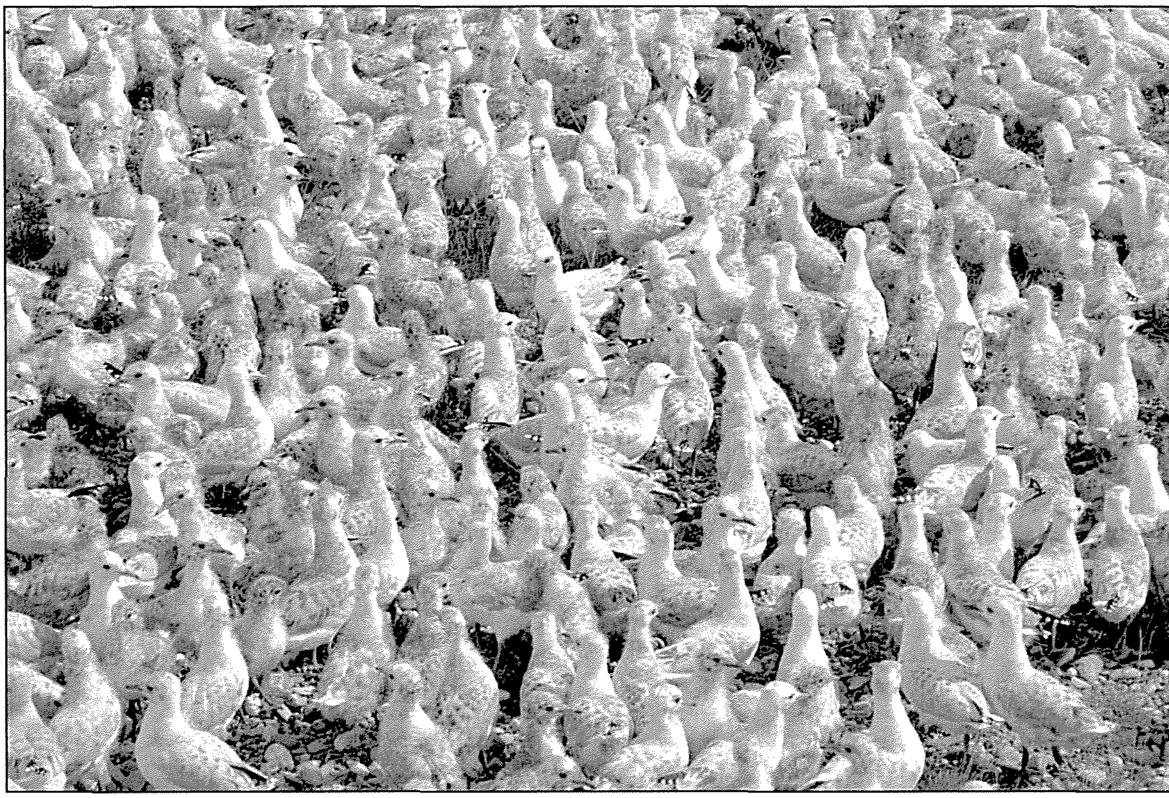

Figure 3: *Example of a section of a black-billed gull fledgling photograph used for counting. Taken of Otama North colony, Mataura River, Southland, 2006 season (see Figure 2); 27% actual size.*

Colony mapping

Marked nests were mapped after colonies had left the breeding sites to reduce disturbance. However, this limited mapping to a small number of colonies as all three breeding seasons were affected by post-breeding floods in December and/or January which affected the topology of many colony sites and markers were moved or washed away. The position of each nest was measured to the nearest centimetre along an x and y axis for each transect. Nest material was often gone from the site, and only the markers remained. In these cases, actual centre positions of the nests were approximated to be 15 cm from the marker rock.

Disturbance by gulls

As part of visits to study colonies, observations of the presence of black-backed gulls (*L. dominicanus*) were recorded. Observations for each colony were collated and classified into three levels of disturbance: 'high', 'low to moderate', and 'never observed' (Table 1). Examples of observed behaviours included: one or two gulls 'dive-bombing' a colony (low to moderate); many gulls standing around the edge of a colony, or sitting in the river adjacent to a colony, but not interacting with the colony (low to moderate); and gulls carrying off black-billed gull chicks (high).

Table 1: *Classification of black-backed gull disturbance of black-billed gull colonies.*

Disturbance category	Possible criteria
High	Many gulls harassing colony on few to many occasions
	Successful predation observed
Low to Moderate	Gulls present but not seen disturbing colony
	Infrequent harassing of colony by small numbers of gulls
Never observed	Gulls never observed at colony

Adult weights

During adult banding work, individuals were weighed in a cloth bag using a 500 g pesola scale. Bags were re-weighed after approximately every five birds, and birds were weighed to the nearest gram. Tarsus and bill measurements were taken (to two decimal places), and the wing was measured (to one decimal place).

Predator abundance in colony regions

Environment Southland undertook trapping of ferrets, stoats, feral cats and hedgehogs (the latter three as by-catch) at various times in the vicinity of several of the black-billed gull colonies that were monitored in this study (see Chapter 4 Methods for background). The council maintains a database of trapping results from 2003 to the present. It contains the location and species of each animal caught, the location of all trap sites and the number of nights that each trap was used. This dataset was used to summarise and analyse trapping data in relation to colony locations as it was hypothesised that captures may have had some impact on predator pressure at monitored colonies. The dataset was reduced to traps and captures located within a 2 km radius of each colony within the calendar year of that particular breeding season using ArcMap 9. A second database was summarised which contains only ferrets that have been autopsied to check for Tb and their capture location. Crossover between the trapping and autopsy database exists where ferrets have been captured as part of the trapping programme and autopsied. However, many ferrets have been caught as part of the Tb monitoring programme only, and data recording trap locations and number of nights of use have not been recorded. This means that trapping effort surrounding each colony cannot be accurately calculated and the simple summary that is given can only be used as an approximate guide to trapping effort and predator abundance.

Camera study of nest survival

In 2005, three video camera systems were used to examine the impact and behaviour of predators and the behaviour of gulls in a bank colony on the Aparima River. The colony covered an area of approximately 150x40 m and contained approximately 2000 nests. Camera systems comprise a black and white, infra-red sensitive video camera mounted on a 0.5-1 m tripod linked to a time-lapse video tape recorder (VCR) by a 60-100 m cable. Nests were illuminated at night by an infra-red light mounted on the camera or tripod. The system was powered by one or more 12 V batteries. VCRs were set to operate on 24 h time lapse mode which recorded 5.6 frames per second (as per Sanders and Maloney 2002). Date and Standard Time were recorded on footage and synchronised between all operating VCRs. Tapes and batteries were changed every morning. Recorded footage (approximately 2.25 hours of tape) was viewed each day in 'fast forward' mode, taking approximately 20 minutes.

Two cameras began operation on October 5; the third camera was installed on October 10. VCRs and batteries were placed a sufficient distance from birds to ensure no disturbance occurred during daily cassette and battery changes. The first three camera positions were randomly selected. Cameras were moved when all nests had either failed or eggs had hatched (on one occasion, eggs remained in a single nest). Subsequent locations were chosen subjectively keeping VCR and battery locations the same. Cameras filmed multiple nests at each location (3-13 nests in view at night).

Any recorded disturbance to nesting gulls was watched at slower speeds, documented and classified (Table 2). For the purposes of this study, a disturbance was defined as any event causing at least half of the incubating birds in view to leave their nests. The disturbance started when the last of the birds to leave their nest had gone, and finished when all incubating birds had returned and were sitting. Occasionally, a single bird took significantly longer to return than other incubating birds (often several hours). These birds were apparently in the process of nest desertion and were not included when calculating the finish time of a disturbance.

Table 2: *Causes of disturbances of nesting black-billed gulls, Avondale colony, 2005.*

Disturbance type	Description/explanation
Nest checks	Filmed nests were checked every three days to ascertain contents to ensure no losses of eggs or chicks had been overlooked when reviewing daily footage
Camera/IR lights	The camera and light equipment often needed to be adjusted due to wind or gulls knocking or landing on the camera, or changed due to failure
Transect monitoring	310 permanently marked nests on transects were checked every 3-6 days. Start and finish times were noted. Any disturbances occurring within this time frame were considered to be a result of monitoring unless otherwise observed
Researcher disturbance	Other activities carried out by researchers such as banding adults, measurements of camera locations, establishing and dismantling quadrats (for an aerial photography experiment)
People	Disturbances by people other than researchers
Predator	Any mammal or avian predator seen in camera footage
Possible predator	Any disturbance occurring simultaneously or within 15 minutes of the start or finish of any predator disturbance
Other	
Unknown	

Statistical analyses

Determining outcomes for nest success

Nest marks were sometimes not visible due to faeces. In these circumstances, if the nest had failed (i.e. did not contain eggs) it could be overlooked. These nests were found at a later date once faeces had been removed by bird movements or rain. This was the most common reason for not finding nests. Additionally, nests that had failed often completely disappeared, presumably because other gulls took nesting material. These nests were easily overlooked. Occasionally, particularly when a marked nest had failed and disappeared, another nest was built over the mark. 'Missing' nests were either found during following visits, or more rarely, not found again until the colony had deserted and nest material had mostly gone. These factors had implications for the analysis of nest success and were assessed as follows:

- If nests contained eggs on at least two consecutive occasions then were not found again, these nests were considered failures
- If a nest contained eggs once only then was not found again, these nests were classified as an unknown outcome

- If nests contained eggs for one or more consecutive visits, then were not found for any number of occasions, then found at a later visit with no eggs, they were considered to have failed by the first 'not found' event.

A second issue was a small number of clutches that were incubated for well over 25 days and did not hatch. If a clutch was present for 28 days or more (from the date of laying of the last egg) it was considered to have failed. The number of nest days for these nests was set at 27, so as to avoid small samples of lengthy incubation periods of failures only in Kaplan-Meier (KM) survival time analyses (see following section).

Nest success measures and statistical modelling procedures

I used four methods to estimate nest success: apparent nest success, Mayfield, Kaplan-Meier and Program MARK. In this study, apparent nest success was estimated by determining nest outcome, and for those with known outcomes, dividing the number of successful nests by the total number of nests. The use of this method was justified by the ability to find the majority of nests at initiation of incubation (Klett and Johnson 1982). The Mayfield method was employed for a similar reason and also allowed the analysis of nests that were not monitored to conclusion toward the end of the breeding season. The Mayfield method (Mayfield 1975) is the mostly commonly used method to estimate nest success, and was devised to manage the bias associated with finding nests at different stages. Johnson (1979) illustrated how to calculate standard errors and provided examples of simple tests. The assumptions of the Mayfield method are: (1) probability of nest failure is constant through time; (2) all nests have the same probability of failure; and (3) nest outcome is independent (Mayfield 1975). These assumptions have a high likelihood of failure in nature (Nur et al. 2004; Jehle et al. 2004).

A suite of analytical methods, old and new, can overcome some or all of the three Mayfield assumptions. These include KM survival time analysis (Nur et al. 2004), the nest survival model available in programme MARK (Dinsmore et al. 2002; Jehle et al. 2004; see Rotella et al. 2004 for a comparison of the model using programmes MARK and SAS), the Stanley method (Stanley 2000; reviewed in Jehle et al. 2004), a logistic-exposure model (based on a generalised linear model; Shaffer 2004) and Mayfield logistic regression (Aebischer 1999; Hazler 2004). For this study, a key issue with KM survival time analysis and the Stanley method (but see Stanley 2004) is that the age of the nest is known (Jehle et al. 2004; Nur et al. 2004). Dinsmore et al. (2002) recommends that nest age is known in order to optimise the use of Program MARK, however, it is not a requirement (Rotella et al. 2004). For black-billed gull, a highly threatened species nesting in very dense colonies, the increased disturbance caused by the extra time required to age often more than 100 eggs in a single visit by "floating" was considered unacceptable (the orientation of an egg floating in water enables the age of a nest to be estimated; Westerkov 1950). A second issue involves the lack of independence of nest fate within black-billed gull colonies, independence being an assumption of all methods. However, Nur et al. (2004) indicate that this can be dealt with by taking account of the influence of covariates, and Jehle et al. (2004) suggest that this is not a critical assumption but will result in underestimated variance.

Daily survival estimates were also calculated using the Program Mark nest survival model but were implemented in R (R Development Core Team 2008) using RMark (Laake and Rexstad 2008). Mayfield and RMark methods compute a daily survival rate (DSR) for nests which, in order to obtain a nest success estimate, is raised to the power of the number of days in a typical incubation period. For black-billed gull, this is between 20-24 days (Higgins and Davies 1996). In this study, 24 days was used as the incubation periods for many gulls were found to exceed this.

Linear regression was used to explore potential relationships between nest success and colony size, nest density and synchrony. Generalised linear modelling was used to investigate potential explanatory variables for nest success. Colonies were treated as sample units and Mayfield estimates of nest success were used. A set of eight candidate models was contrasted using AICc (Akaike 1973, Burnham and Anderson 2002) based on *a priori* hypotheses. Factors assessed by stepwise deletion of insignificant terms from the global model were river, year, site (bank, partial bank or island), size of colony, nest density and synchrony of laying. Extra-binomial variation (overdispersion) was high; F-tests were used instead of chi-square and model results were scaled by the dispersion parameter calculated from the model that contained the greatest number of covariates but no missing values (i.e. river + year + site + size). Regressions were weighted by the number of nest successes and failures for each colony (Crawley 2002).

A comparable set of analyses on nest success was carried out using KM survival time analysis. Fewer explanatory variables were examined, with the addition of a variable describing the time of laying during the season (early, peak or late). However, to better meet the requirement of known nest age, nests initiated during visitation intervals longer than four days were removed from the analyses; i.e. nests analysed were 0-4 days of age. Data from only nine of the 21 colonies were analysed due to resulting reductions in sample size; no island colonies or 2005 colonies were suitable for analysis. Of the nine colonies analysed, nests initiated by the first visit were not analysed for five colonies as these did not meet interval criteria; nests initiated by the second visit were also removed from analysis for two of these for the same reason. Survival time distribution functions were compared using log-rank tests.

Breeding synchrony

Measures of breeding synchrony generally take into account the spread of laying dates by either the standard deviation of date of first egg laying (e.g. Burger 1979; Brunton 1999), quartile distributions of the same (e.g. Hernández-Matías et al. 2003), medians (Wilhelm and Storey 2002) and means (Phillips et al. 1998). These are all affected to some extent by the range of laying dates. In this study, many colonies were not monitored intensively towards the end of the season as the disturbance was considered unjustified given the small number of nests still being incubated, however, the colonies were observed periodically. This made a true estimate of the length of the nesting season for some colonies less accurate. In addition, it was suspected that nest failures were resulting in re-nests which would then affect the range of laying dates and any of the aforementioned parameter estimates of synchrony. For this reason, mode laying dates were used (in addition to standard deviations and means) which were unaffected by the range of dates and possibly a better indication of synchrony. Mode laying dates in this case represented a form of 'peak laying'.

In order to test whether selection for breeding synchrony existed (i.e. whether early or late clutches experience reduced breeding success; Smith 2004) laying dates were grouped into 'early', 'peak' and 'late' dates and analysed using KM survival time analysis.

Distribution of nest failure

Position coordinates of nests on mapped transects (see previous section on colony mapping) were transformed into grid references and loaded into ArcMap. Using the nearest neighbour facility in ArcMap9, nearest neighbour ratios were calculated (indicating a continuum from dispersed nests through to clustered nests) for all nests on transects and those that had failed.

RESULTS

Twenty one breeding colonies were intensively monitored during the 2004, 2005 and 2006 seasons (Table 3). The Mataura River was included in the study area in 2006 only. Only one colony re-established in the following year at the same site and was monitored during two seasons (Mararoa Weir, Waiau River, 2005 and 2006).

Table 3: *Number of black-billed gull colonies by year and river.*

River	2004	2005	2006	Total
Waiau	3	1	1	5
Aparima	3	1	5	9
Oreti	2	1	2	5
Mataura	0	0	2	2
Total	8	3	10	21

The sample of island sites was limited as several were not accessible due to deep and/or fast water. During the 2006 season, river levels were highly changeable. Four sites had narrow, relatively shallow channels separating them from the 'mainland' and varied between islands and banks depending on the river level. In order to simplify analyses, these sites were classified as 'partial banks'. Monitored colonies established on five island, four partial bank and 12 bank sites (Table 4).

Table 4: *Number of black-billed gull colonies by site type and river.*

River	Island	Partial bank	Bank	Total
Waiau	3	1	1	5
Aparima	1	1	7	9
Oreti	1	1	3	5
Mataura	0	1	1	2
Total	5	4	12	21

Measures of nest success

Mayfield nest success estimates varied from 18.7% to 94.0% (mean 69.0%, SE 3.9%; Table 5). Mean apparent nest success estimates (mean 64.2%, SE 4.2%) were consistently lower than Mayfield estimates and were calculated using smaller sample sizes as nests with unknown outcomes were not included in the analysis (primarily late nests that were not followed to conclusion). RMark estimates used the same sample and produced similar results to apparent nest success but were substantially different for some colonies, particularly those with very high nest success (mean 61.9%, SE 4.1%). Overall, mean KM nest success was marginally higher than Mayfield nest success (mean 71.1%, SE 2.3%). KM sample sizes were generally less than half of those used for Mayfield calculations, and varied unpredictably from Mayfield nesting success estimates.

Table 5: *Comparison of measures of nest success of black-billed gull colonies in Southland (apparent nest success, Program MARK, Mayfield and Kaplan Meier).*

Colony	River	Site	Apparent nest success	MARK	n	Mayfield (SE)	n	Kaplan-Meier	n
Papatotara	Waiau	Island	93.3	84.8	150	94.0 (0.1)	170		
Mossburn	Oreti	Island	88.5	84.5	174	89.7 (0.1)	215		
Motu Bush	Waiau	Island	88.0	83.0	277	92.2 (0.1)	345		
Lill Burn	Waiau	Island	82.1	77.9	279	84.3 (0.1)	330		
Dunrobin	Aparima	Bank	78.9	76.9	469	80.3 (0.1)	520	82.1	257
Otama South	Mataura	Partial bank	75.3	75.8	174	78.5 (0.2)	213	75.6	127
Dipton	Oreti	Bank	71.4	71.9	35	77.6 (0.3)	48		
Bayswater	Aparima	Bank	71.0	68.9	221	75.3 (0.1)	311	74.6	67
Mararoa 06	Waiau	Partial bank	71.0	70.9	279	74.1 (0.1)	339		
Avondale	Aparima	Bank	65.4	61.4	294	70.6 (0.2)	322	65.4	127
Dunrobin South	Aparima	Partial bank	64.8	61.5	395	69.5 (0.1)	477	66.8	193
Otama North	Mataura	Bank	62.5	64.1	229	68.8 (0.2)	255	61.9	97
Benmore	Oreti	Bank	60.0	55.4	85	63.8 (0.3)	103		
Mossburn Bridge	Oreti	Partial bank	59.7	57.3	191	70.2 (0.2)	310	78.7	136
Avondale North	Aparima	Bank	59.5	56.9	237	62.0 (0.2)	297		
Mararoa 05	Waiau	Bank	58.9	53.2	158	63.1 (0.2)	205		
Lumsden	Oreti	Bank	57.7	58.0	239	61.4 (0.2)	297	68.2	129
Thornbury	Aparima	Bank	56.6	56.1	136	63.6 (0.2)	182		
Etal Creek	Aparima	Bank	46.3	47.7	95	58.9 (0.3)	133	66.4	122
Fairfax island	Aparima	Island	25.5	23.3	51	31.5 (0.8)	53		
Fairfax bank	Aparima	Bank	11.6	9.9	43	18.7 (1.1)	51		
Mean (SE)			64.2 (4.2)	61.9 (4.1)		69.0 (3.9)		71.1 (2.3)	
Total					4211		5176		1255

For a small number of colonies, actual counts of the numbers of fledglings were possible (either all could be caught, or so few survived that they could be counted easily).

Breeding success

Breeding success was estimated at 14 of the 21 colonies and varied from 0 to 1.01 fledglings per nest (Table 6). Mark-recapture of chicks resulted in high estimates of breeding success; approximately one fledgling per nest. However, results from the Benmore colony of 1.01 fledglings per nest clearly indicated that mark-recapture over-estimated the number of fledglings in this instance: clutch size of 1.82 and hatching success of 41.4% indicate that only 0.75 chicks hatched per nest. The photographic method and actual counts (where all fledglings were captured or easily identified and counted) were consistently lower than mark-recapture results (combined mean 0.33, SE 0.08).

Table 6: *Black-billed gull breeding success estimates using three different methods: mark-recapture, actual estimates (where all chicks were caught or sighted) and photographic counts.*

Colony	Year	Site	Nesting success (%)	Breeding success		
				Mark-recapture	Actual counts	Photograph count
Papatotara	2004	Island	94.0		0.44	
Lill Burn	2004	Island	84.3	0.93		
Otama South	2006	Partial bank	78.5			0.88
Dipton	2006	Bank	77.6			0.55
Bayswater	2004	Bank	75.3	1.00		
Mararoa 06	2006	Partial bank	74.1			0.37
Dunrobin South	2006	Partial bank	69.5			0.34
Otama North	2006	Bank	68.8			0.31
Benmore	2004	Bank	63.8	1.01		
Thornbury	2006	Bank	63.6			0.45
Mararoa 05	2005	Bank	63.1		0.01	
Etal Creek	2006	Bank	58.9			0.21
Fairfax Island	2006	Island	31.5		0.02	
Fairfax bank	2006	Bank	18.7		0	
Means (SE)				0.98 (0.03)	0.33 (0.08)	

Influence of season and synchrony

Survival distribution curves for the 2004 and 2006 seasons were significantly different with nests in 2004 doing substantially better later in incubation than those in 2006 (log-rank test, chi-square statistic = 3.3, df = 1, $P<0.10$; Figure 4). Insufficient data from 2005 were available to analyse. Survival distribution curves in all KM analyses stop at 27 days at which point survival is very low (Figures 4, 9 and 14). This is because lengthy incubation periods (some of over 40 days) of eggs that failed to hatch were shortened to an arbitrary period of 27 days for the purposes of analysis. Expected incubation times for black-billed gulls are 20-24 days (Higgins and Davies 1996). Observing the survival curves at these dates gives a better appreciation of the differential survival of nests.

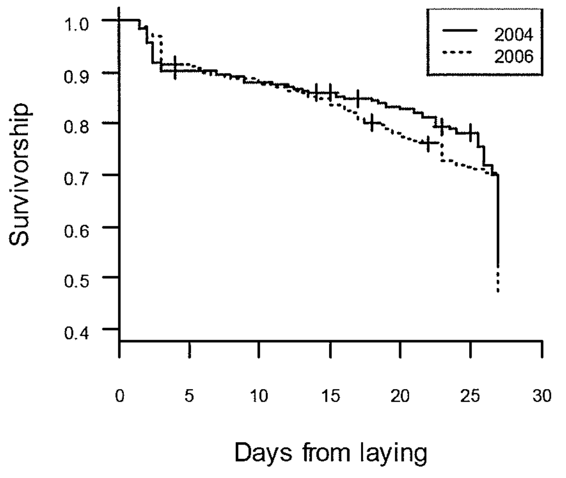

Figure 4: *Kaplan-Meier survival distribution curves for black-billed gull nests by season (n=1244); all colonies.*

Differences between seasons were also visible in clutch sizes as well as within season trends. Clutch sizes increased in a linear fashion through much of the 2004 season from approximately 1.4 eggs per nest in mid September to well over two eggs in early November (linear regression, $P<0.01$; adj. $R^2=0.30$, Figure 5). Clutches laid after this date, however, were substantially smaller. A slightly increasing trend was observable in 2005 but was not significant (adj. $R^2=0.07$, $P=0.12$); whereas during 2006, clutch sizes remained stable throughout. Overall, clutch sizes increased through the season (adj. $R^2=0.19$, $P<0.01$) but again, late season clutches had greater variability and tended to be smaller.

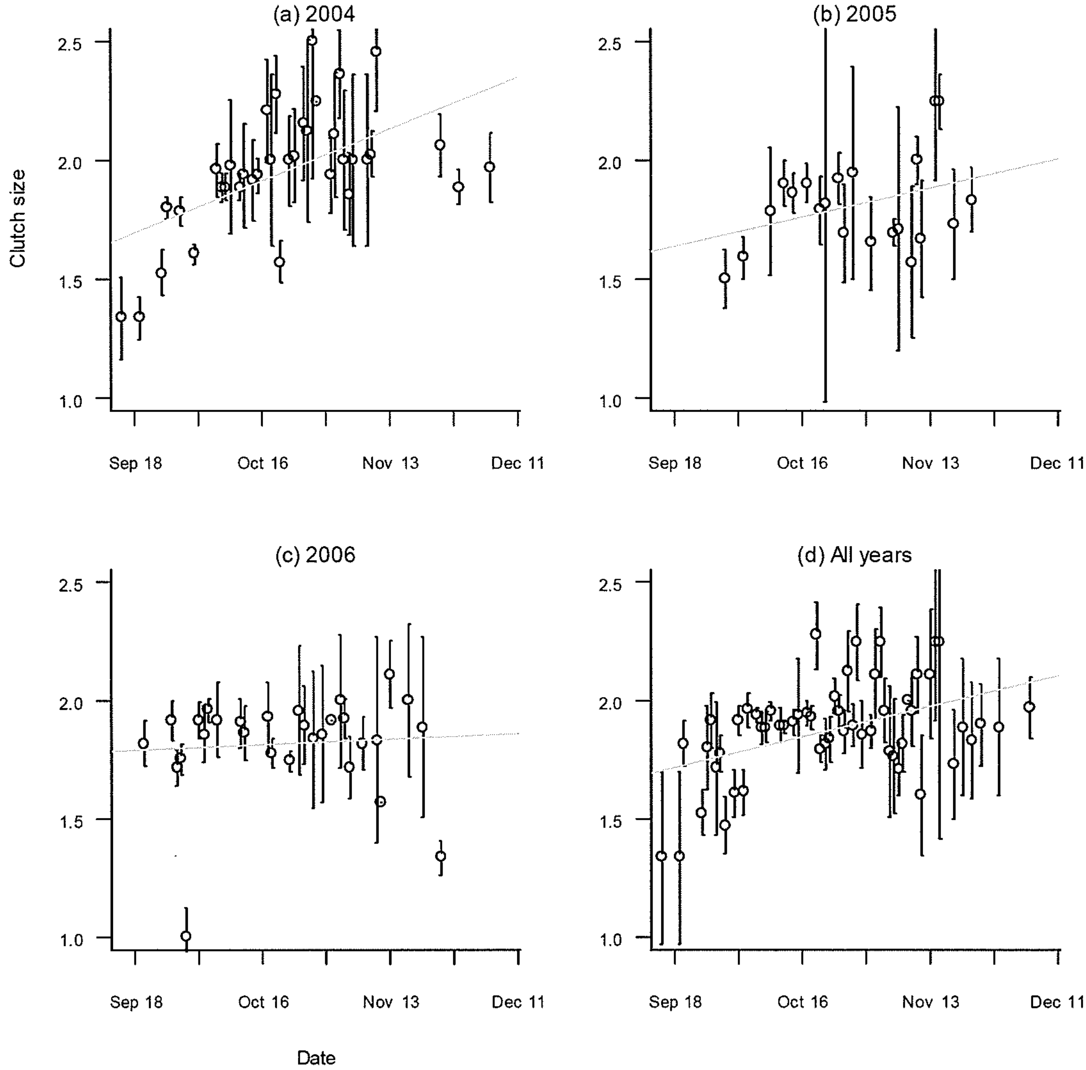

Figure 5: *Plots of changes in black-billed gull clutch sizes by season (n=5226); all colonies. Error bars are 2*standard error. Line is linear best fit.*

Little difference in breeding synchrony was observable between seasons. The mode (or peak) date of first egg laying differed by six days between 2004 and 2006 (Table 7). The mean date also varied by six days and its standard deviation, a measure of breeding synchrony, was similar between years. Differences were more marked between colonies (Table 8). The mode varied from September 20 to October 20, and the mean from October 8 to October 29. The standard deviation of the mean varied from 0.8 in a colony where almost all nests were laid within a few days, to 25.8 in the single colony that had two marked peaks of nest establishment. The most synchronous colony laid all eggs within 11 days; the most prolonged nesting season was recorded for the Otama North colony which started two weeks earlier than any other colony and completed laying in three months. Patterns of breeding synchrony are illustrated in Figure 6, from the least synchronous (Bayswater and Otama North) to colonies with typically greater synchrony (Motu Bush and Dunrobin). Note that peak laying in 2004 occurred when clutch sizes were only two eggs or less (refer Figure 5).

Table 7: *Black-billed gull breeding synchrony by season; all colonies.*

Year	Colonies	Nests	Mean	SD (days)	Mode	First eggs	Last eggs
2004	8	2504	14-Oct	15.7	9-Oct	15-Sep	5-Jan
2005	3	712	16-Oct	11.8	12-Oct	20-Sep	29-Nov
2006	4	1396	10-Oct	13.9	6-Oct	3-Sep	6-Dec

Table 8: *Black-billed gull breeding synchrony by colony; all seasons.*

Colony	Site	Nests	Mean laying date	SD	Mode laying date	First eggs	Last eggs
Papatotara	Island	175	8-Oct	0.8	9-Oct	29-Sep	9-Oct
Mossburn	Island	216	14-Oct	5.0	12-Oct	2-Oct	11-Nov
Dunrobin	Bank	539	12-Oct	6.1	12-Oct	28-Sep	8-Nov
Dunrobin South	Partial Island	502	10-Oct	7.4	6-Oct	27-Sep	4-Nov
Mararoa 06	Partial Island	341	10-Oct	8.5	4-Oct	23-Sep	5-Dec
Avondale	Bank	306	8-Oct	9.1	6-Oct	25-Sep	14-Dec
Lill Burn	Island	345	19-Oct	10.0	14-Oct	20-Sep	20-Dec
Mararoa 05	Bank	177	29-Oct	10.6	20-Oct	6-Oct	29-Nov
Avondale North	Bank	319	11-Oct	10.9	3-Oct	20-Sep	15-Nov
Benmore	Bank	114	13-Oct	13.0	7-Oct	21-Sep	18-Nov
Motu Bush	Island	342	15-Oct	13.5	9-Oct	30-Sep	20-Dec
Otama South	Partial Island	235	12-Oct	14.5	6-Oct	24-Sep	6-Dec
Lumsden	Bank	351	10-Oct	21.9	24-Sep	15-Sep	5-Jan
Otama North	Bank	318	10-Oct	22.9	20-Sep	3-Sep	6-Dec
Bayswater	Bank	332	25-Oct	25.8	6-Oct	1-Oct	15-Dec
Means		307.5	14-Oct	12.0	6-Oct	24-Sep	3-Nov

Over all years, colony nest success tended to improve with later mean laying dates until a point after which nest success declined (Figure 7). Nest success showed slightly less association with mode laying dates, although again, earlier and later peak laying appeared to result in lower nest success and an increasing linear trend was evident among intermediate modal dates. Breeding synchrony and nest success showed some suggestion of a linear relationship, but was not significant (linear regression, $P>0.10$; adj. $R^2= 0.11$, Figure 8).

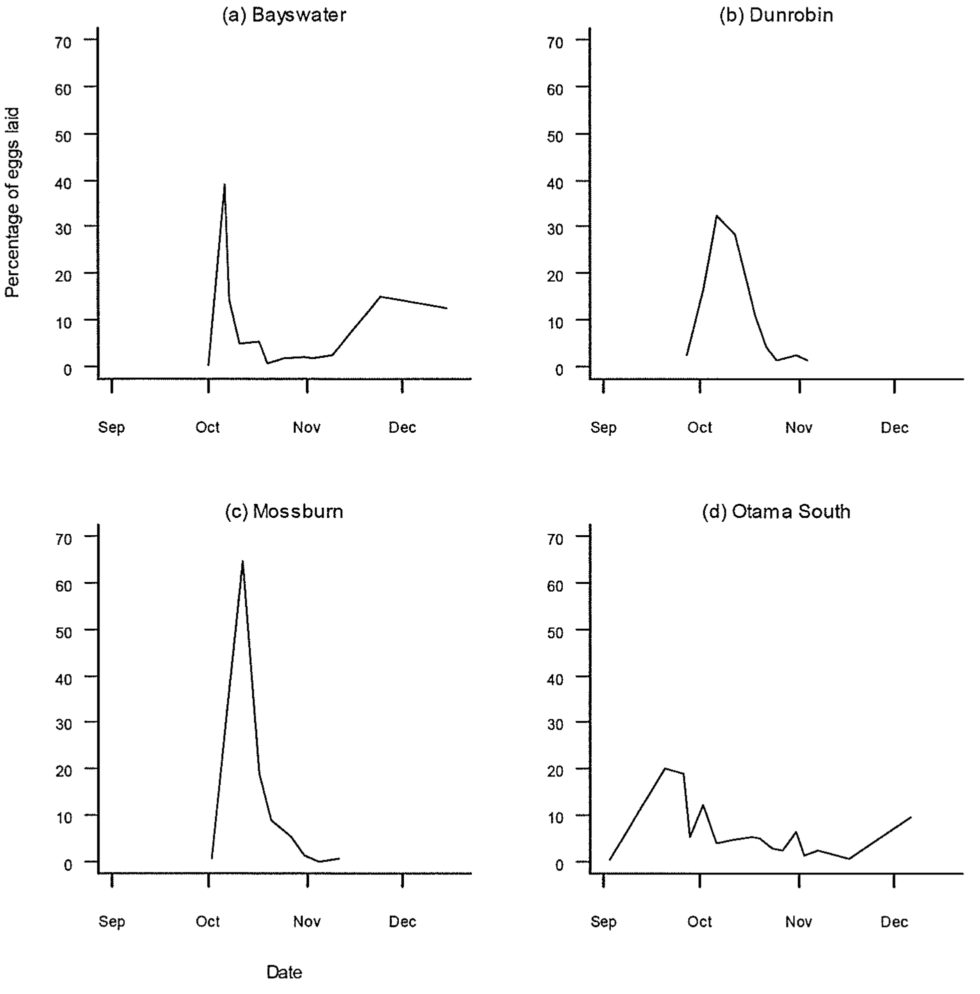

Figure 6: *Examples of breeding synchrony among Southland black-billed gull colonies*

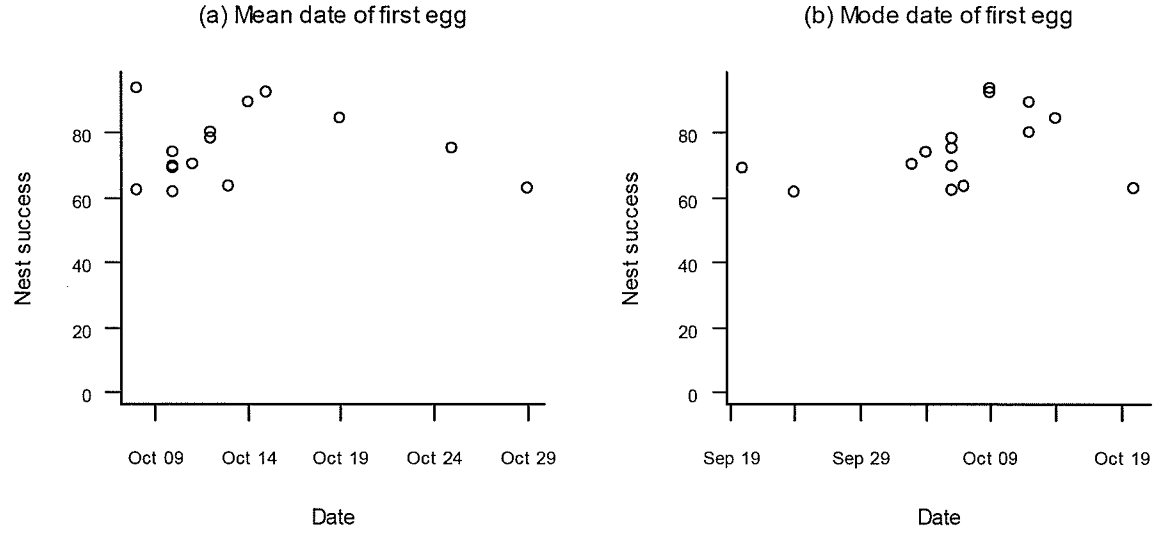

Figure 7: *Plots of the mean and mode date of first egg laying of black-billed gull colonies against mean nest success.*

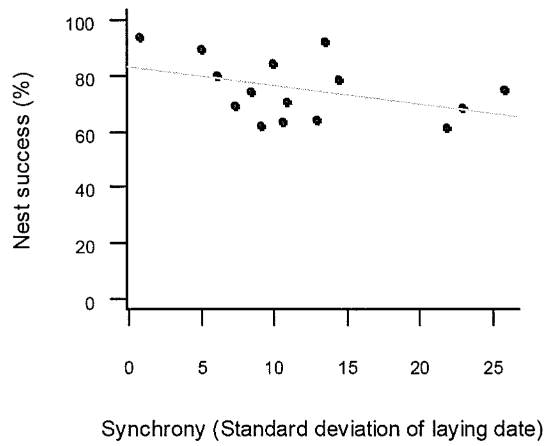

Figure 8: *Plot of mean nest success against breeding synchrony of black-billed gull colonies. Line is linear best fit.*

Nests from 2004 and 2006 were divided into early (pre-Oct 4), peak (Oct 4-14 i.e. two days either side of mode laying dates for 2004-2006) and late (post-Oct 14) laying dates. Nest survival time differed between the three laying periods (log-rank test for survival data, chi-square statistic = 18, df = 2, P<0.01). Nests laid after peak laying had the highest survival with nests laid during the peak initially surviving significantly better than those laid early in the season but final survival was lower (Figure 9).

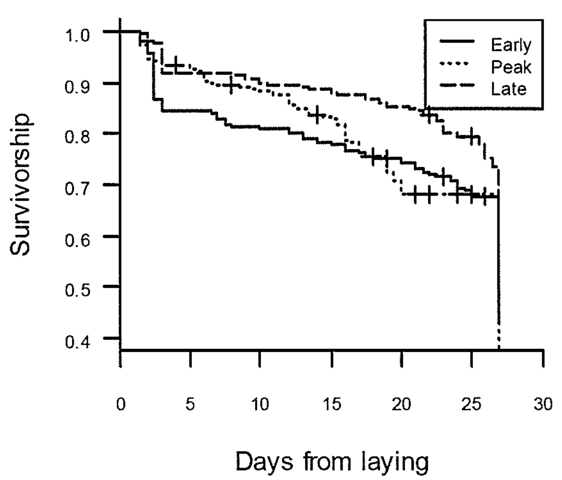

Figure 9: *Kaplan-Meier survival distribution curves for black-billed gull nests by time of laying within season (n=1244); all colonies.*

Influence of colony size

A strong relationship between colony size and nest success was found, with nests in larger colonies tending to be more successful (linear regression, P<0.01, adj. R^2=0.55, Figure 10). However, the model did not fit the data particularly well. Importantly, the relationship was largely influenced by nest success estimates from colonies on banks, although two of the largest bank colonies did substantially worse than the model predicted (Avondale and Lumsden). A relationship was also found between breeding success and colony size using only actual and photographic methods (Figure 11; linear regression, P<0.01, adj. R^2=0.51). Of the 21 colonies monitored, the three smallest largely failed to produce fledglings (Mararoa 05 produced two, and Fairfax Island produced one).

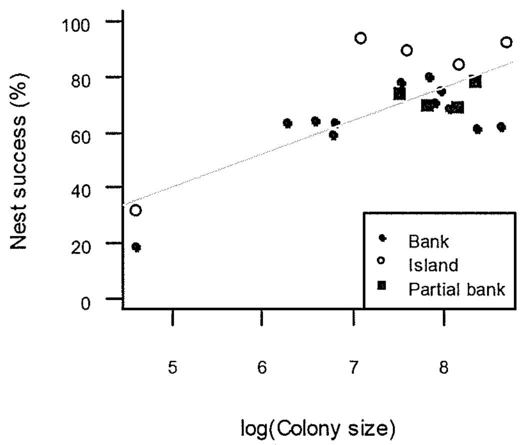

Figure 10: *Plot of mean nest success against black-billed gull colony size. Line represents linear best fit.*

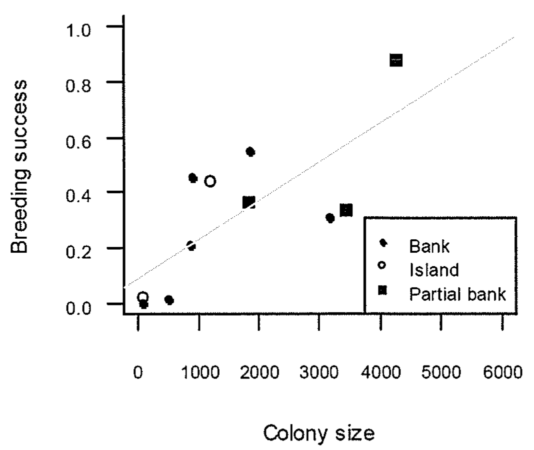

Figure 11: *Plot of black-billed gull colony size against breeding success. Line represents linear best fit.*

Disturbance of black-billed gull colonies by black-backed gulls (*Larus dominicanus*) was classified into three categories (Table 8). Any one of the criteria was required for classification. Black-backed gulls were never seen disturbing colonies of approximately 3000 gulls and over, but caused significant disturbance for colonies that were less than approximately 1500 gulls (Figure 12). Extreme cases of disturbance were limited to colonies of 600 or less.

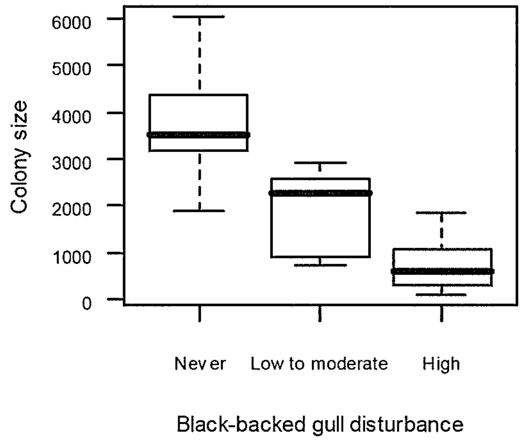

Figure 12: *Box and whisker plots of black-backed gull disturbance of black-billed gull colonies by colony size (n=22). The marker in the box shows the median, the ends of the box show the 25 and 75 percentiles, the dashed line shows the minimum and maximum.*

Influence of nest density

Nest density in colonies varied from 0.43 to 3.77 nests/m^2 with a mean of 1.5 nests/m^2. The two colonies with the lowest nest success had very low nest density but were also the two smallest colonies monitored suggesting it may have been the size of the colonies that influenced nest success rather than nest density.

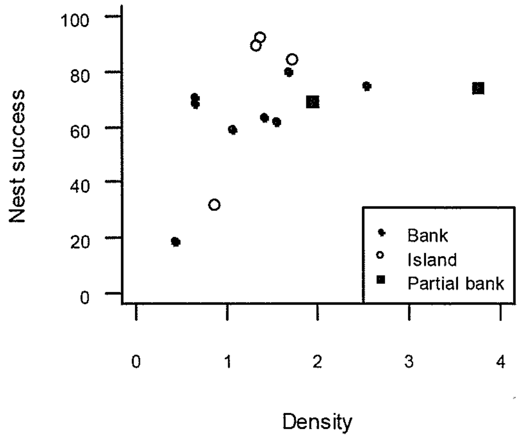

Figure 13: *Plot of mean nest success against nest density in black-billed gull colonies.*

Influence of colony site

Islands within rivers had greater clutch sizes, greater nest success and higher hatching success than colonies on partial banks or banks (Table 9, Figure 14). Colonies on banks had the lowest productivity and colonies nesting on partial banks had an intermediate level of productivity. Nesting on banks resulted in only half of eggs producing nestlings. Two significant outliers are visible in Figures 14b and c; Fairfax Island and Fairfax bank, which were the smallest colonies monitored (both numbered only c.50 nests; the next smallest colony was six times the size). Both colonies had originally numbered several hundred birds but had been severely disturbed by vehicles and were largely abandoned. The colonies continued to desert and were completely abandoned early in the season.

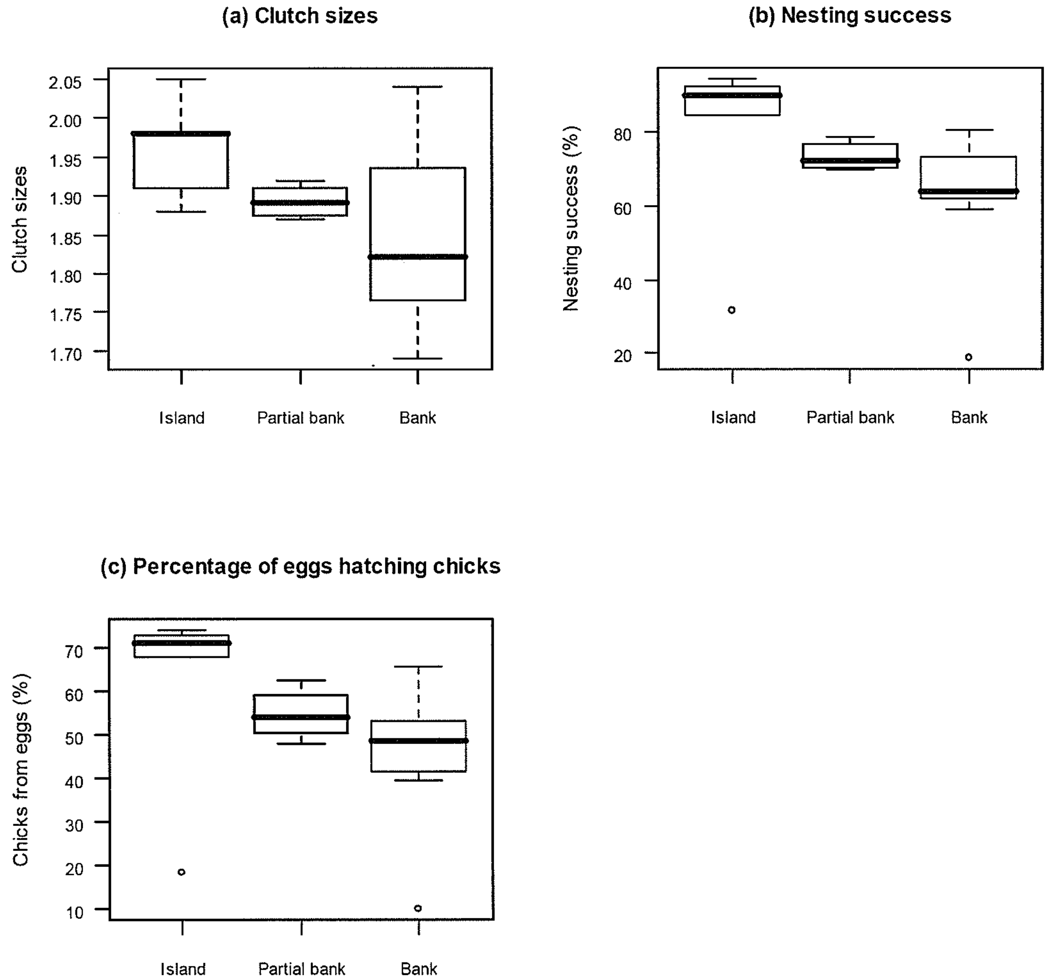

Figure 14: *Box and whisker plots of black-billed gull clutch size, nest success and percentage of chicks hatching from eggs by colony site; study colonies (n=21). The marker in the box shows the median, the ends of the box show the 25 and 75 percentiles, the dashed line shows the minimum and maximum. Dots are outliers. Where outliers exist, the lines show 1.5 times the interquartile range of the data.*

Table 9: *Black-billed gull clutch size, nest success and percentage of chicks hatching from eggs by colony site (island, partial bank or bank).*

Colony site	Colonies	Nests	Clutch size (SE)	Nest success (SE)	Hatching success (SE)
Island	5	1430	1.94 (0.02)	90.1% (2.1)	71.8% (1.4)
Partial bank	4	1080	1.90 (0.01)	73.1% (2.1)	54.9% (3.0)
Bank	11	2758	1.87 (0.02)	66.8% (2.2)	49.7% (2.6)

Significant differences were detected in nest success, hatching success and clutch size between islands and banks, and islands and partial banks (Table 10). Limited differences were found between partial banks and banks. These analyses exclude the major outliers of Fairfax Island and Fairfax Bank observed in Figure 14 as their extremely low nest success was considered to be due to the overriding influence of unusually small colony size (see Discussion on the possible presence of an Allee effect) and not colony location (i.e. island or bank). Survival curves for nests on banks and partial banks showed little discernable difference and were not significantly different (Figure 15).

Table 10: *Comparisons of black-billed gull productivity estimates between colony sites; results of two-sided two sample t-tests assuming unequal variances (with Bonferroni correction set at α=0.05).*

Site comparison	t-statistic, S (significant) or NS (not significant), df		
	Nest success	Hatching success	Clutch size
Island vs. bank	7.70, S, 9	7.56, S, 12	2.22, NS, 9
Island vs. partial bank	5.74, S, 6	5.07, NS, 4	2.18, NS, 4
Partial bank vs. bank	2.10, NS, 9	1.31, NS, 8	0.81, NS, 11

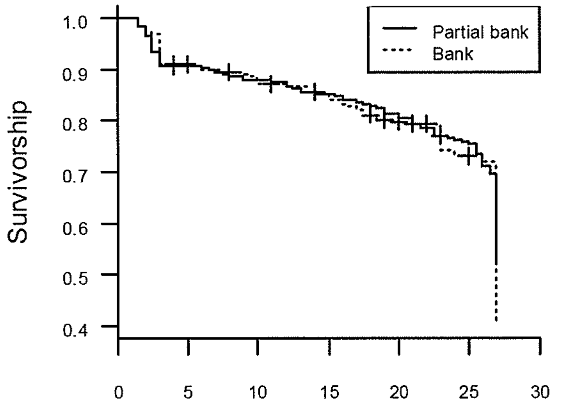

Figure 15: *Kaplan-Meier survival distribution curves for black-billed gull nests by colony site (n=1244); all colonies.*

Weights of adults banded at three colonies in 2005 were significantly different (single factor ANOVA, $P<0.05$; Table 11). When combined, weights of adults nesting in two bank colonies were significantly lower than for the 14 adults banded in an island colony (two-sided t-test assuming unequal variances, $t=-2.08$, $df=14$, $P<0.10$). Adults from Mararoa 05 colony had the lowest weights, condition index and nest success; the colony eventually failed (only two fledglings survived).

Table 11: *Weight and condition of black-billed gull adults banded at colonies on islands and banks and the associated nest success of that colony.*

Colony	Site	Sample	Weight (SE)	Condition index (weight/wing length)	Nest success (%)
Avondale North	Bank	25	263.3 (3.9)	8.95	70.6
Mararoa 05	Bank	28	249.4 (3.0)	8.59	63.1
Mossburn	Island	14	270.8 (7.7)	9.36	89.7

Modelling nest success

Nest success was modelled as a function of year, river, colony size, synchrony, density and colony site. Inclusion of the two Fairfax colonies significantly affected analysis and no factor was found to influence nest success. Figure 16 clearly illustrates the extent to which the very small Fairfax colonies did not fit a linear model (linear regression, $P<0.05$, adj. $R^2=0.18$) and suggests the existence of a colony size threshold below which colonies are unlikely to succeed.

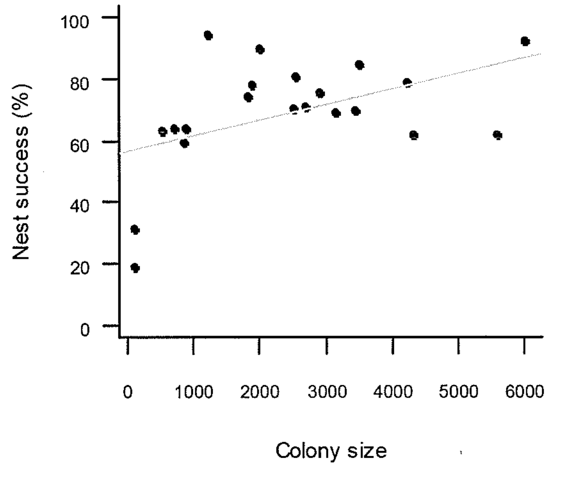

Figure 16: *Plot of black-billed gull colony size (actual numbers) against nest success. Line represents linear best fit.*

A second analysis was completed which excluded these colonies. In this analysis, the best model for the dataset as determined by F-tests included only site ($P<0.01$); the next most significant covariate was density ($P=0.36$). In other words, nest success was most influenced by the location of the colony site on the river. However, AIC_c selection of models gave a completely different result (Table 12) and supported a substantially more complex model which included all covariates except year. All other models had negligible support. The overdispersion present in the model that included only site was the lowest of all competing models but was high at 5.8, indicating that the chosen variables do not fully explain the differences in nest success between black-billed gull colonies. The disagreement between the two model selection methods illustrates the complexity of the relationships between the covariates and nest success. In this situation, it is recommended to use F-tests instead of AIC (Crawley 2002).

Table 12: *Modelling results assessing effects of river, site and colony size on black-billed gull nest success (K=number of parameters, AIC_c = AIC corrected for sample size, Δ_i = AIC differences, w_i = Akaike weights).*

Model	K	AIC_c	Δ_i	W_i
Site + density + size + synchrony + river	5	122.72	0	0.8783
Site + density + size + synchrony + river + year	6	127.16	4.44	0.0954
Site + density + size + synchrony	4	129.78	7.06	0.0257
Site + density	2	138.03	15.31	0.0004
Site + density + size	3	140.77	18.05	0.0000
Site	1	204.68	81.96	0.0000

Influence of predators: camera study

Three infra-red video camera sets were used to record predator and gull behaviour in the Avondale North colony which was located on a bank. Cameras operated for 56 consecutive days. Two cameras ran concurrently for the total period. Three cameras ran concurrently for 46 days. Each camera was moved three times during filming. At initial locations, cameras filmed most nests from early stages of incubation including several instances of laying. At the second and third camera locations, nests were further advanced, and cameras were *in situ* for shorter periods of time. Each camera filmed between 3-13 nests night (and more during the day). In total, 67 nests were able to be monitored for 24 hours per day.

Causes of disturbances

Gulls reacted to disturbances in a consistent manner; becoming alert, craning their necks to see what was happening, non-incubating birds usually leaving the field of view first, followed by incubating birds. On most occasions, no gulls remained visible to the camera. The state of alertness lasted for a few seconds to half an hour or more. Infrequently, birds would leave with no warning.

A total of 628 disturbances was recorded on video footage (Table 13). Researchers accounted for 29.9% of the disturbances. Most researcher disturbance resulted from work associated with the camera study; either nest checks, adjustments to the camera and IR lights or measurements of camera positions. A third of researcher disturbances were due to other concurrent studies (e.g. adult banding) which occurred over two days. Only 11 disturbances occurred as part of monitoring transect nests. Farmers visited the river to fish, to look at the nests in the colony, and as part of work on the adjacent paddock. The cause of 39.3% of the disturbances was unknown.

Table 13: *Number and type of disturbances recorded by infra-red video cameras in a black-billed gull colony sited on a bank.*

Disturbance type (general)	No. of disturbances (general) (%)	Disturbance type (specific)	No. of disturbances (specific) (%)
Predator	179 (28.5)	Predator	90 (14.3)
		Possible predator	88 (14.0)
Researcher	188 (29.9)	Nest checks	61 (9.7)
		Transects	11 (1.8)
		Camera/IR lights	50 (8.0)
		Other	66 (10.5)
Other	14 (2.2)	Harrier	3 (0.5)
		People	11 (1.8)
Unknown	247 (39.3)	Unknown	247 (39.3)
Totals	628 (100)		628 (100)

Predators accounted for 28.5% of disturbances; mammals (excluding humans) were seen on camera footage a total of 90 times on 23 days and a further 88 disturbances were classified as 'possible predator'. A cat was recorded on footage 77 times on 21 days, and a ferret was recorded on 12 occasions on eight days. A rat was seen once. Multiple sightings of the same animal on the same camera and on more than one camera occurred within the same 24 hour period, for example, on November 24 2005, a cat was seen eight times and a ferret was seen four times. Of the 77 cat sightings, a black cat was seen five times and a tabby cat 72 times. The latter animal could not be confidently identified as the same individual.

Timing and length of disturbances

First eggs were laid during the last week of September, approximately a week before the cameras were installed. The first chicks hatched around October 4; approximately half of transect nests contained chicks by November 10. The frequency of predator sightings over the 56 days of filming began to increase dramatically at this stage and predators were seen during virtually every 24 hour period (Figure 17).

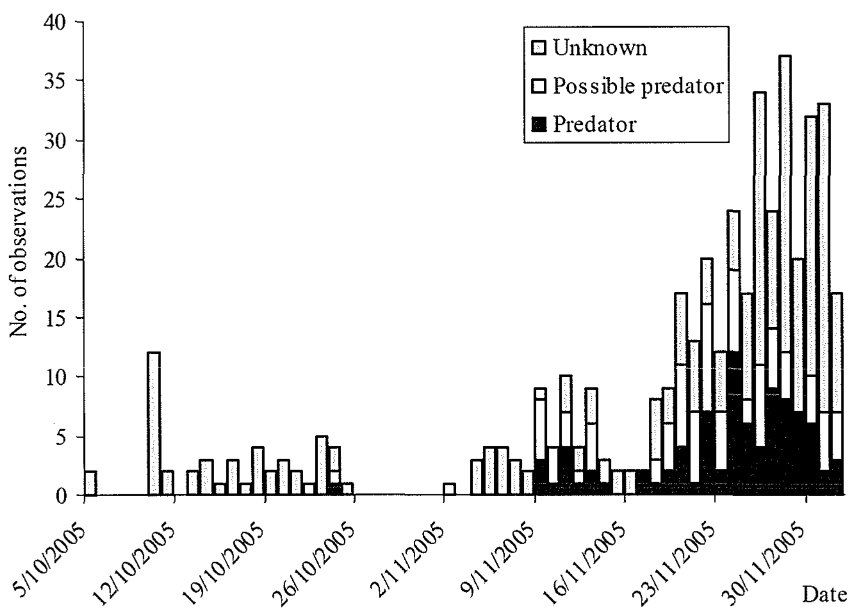

Figure 17: *Number of predator, 'possible predator' and unknown disturbances by 24-hour period in a black-billed gull colony sited on a bank; all cameras.*

Cat visitations caused the longest disturbances (mean 24.4 minutes; Table 14). Cats remained in the colony for long periods of time. A cat was seen on multiple cameras on 16 occasions, these series of observations often lasting for one hour or more. Birds remained off their nests for 4:40 hours at one camera during a cat disturbance. In comparison, ferret disturbances were shorter (mean 3.83 minutes, t-test assuming unequal variances, t-stat=-3.89, P<0.01, df=87). Researchers kept gulls off nests for the least amount of time but this was not statistically different from ferret disturbances. Of the 247 disturbances for which the cause was unknown, 205 were less than four minutes in duration (the mean disturbance time of a ferret).

Table 14: *Average length of predator disturbances as recorded by infra-red video cameras in a black-billed gull colony sited on bank.*

	Number of disturbances	Mean (minutes)	95% CI	Range (minutes)
Cat	77	24.38	9.96	1-280
Possible cat	74	8.42	3.82	1-133
Ferret	12	3.83	3.71	1-22
Possible ferret	13	1.62	0.63	1-4
Researcher (all disturbances)	188	2.47	0.34	1-17

Over the period of camera operations, sunrise times varied between 6:07 and 4:49 and sunset times varied from 19:03 to 20:27 (New Zealand Standard Time at Invercargill). All cat observations were during the hours of darkness. Eleven of the 12 ferret observations were during daylight hours (Figure 18). The majority of unknown disturbances of four minutes or longer occurred during darkness. Most short disturbances of less than four minutes were during daylight hours (Figure 19).

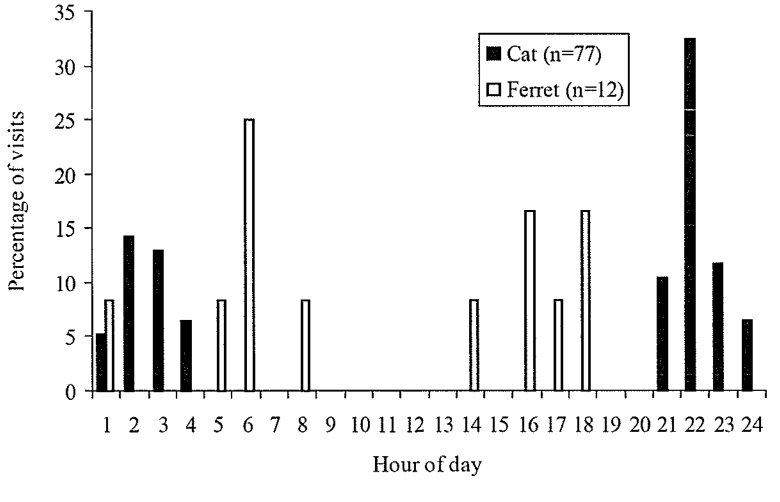

Figure 18: *Timing of predator disturbances (24 hour clock) as recorded by infra-red video cameras in a black-billed gull colony sited on bank.*

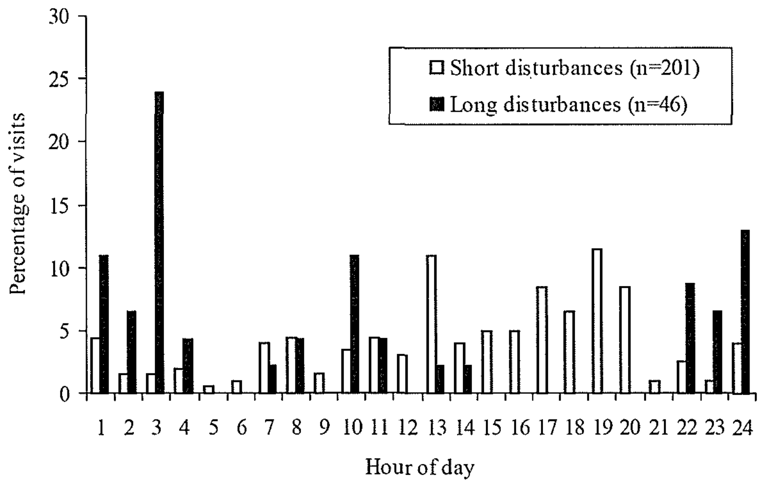

Figure 19: *Timing of unknown disturbances as recorded by infra-red video cameras in a black-billed gull colony sited on bank; short disturbances (<4 minutes) and long disturbances (≥4 minutes).*

Causes of egg and chick mortality

Sixty-seven nests were filmed that could be clearly observed during day and night. Nest success was 62.7% (nest success on transects was 62.0%; n=237). Half of egg mortality was indirectly caused by cats or ferrets disturbing incubating gulls, resulting in eggs being accidentally knocked out of nests, desertion of nests or predation by other black-billed gulls (13 of 26 known or presumed outcomes; 13 eggs from 13 nests; Table 15; see Appendix I for details).

Table 15: *Causes of mortality of eggs and brooded chicks in nests monitored by infra-red video cameras in a black-billed gull colony sited on bank.*

Reason for loss	Eggs	Chicks	Definition of event
Cat predation	0	10	Observed and presumed predation
Predator disturbance	13	0	Loss of eggs during disturbances either by known or 'possible' predator, and gull predation after desertion due to known or 'possible' predators
Natural	11	2	Accidental and purposeful removal of eggs, gull predation, and chick deaths
Researchers	2	0	Desertion resulting in gull predation
Unknown	3	0	Egg/chick loss not observed
Equipment failure	6	0	Footage missing
Total	35	12	

Chicks remained in the nest for an average of 6.5 days before the family group left the immediate nesting area (n=13). Of 63 chicks that hatched, 16 were still in nests when cameras were moved. Of the remaining 47 chicks, 35 (74.5%) left the nest. Overall, 0.52 mobile young were produced per nest. Of 12 chicks that died, cats caused 83% of the mortality (10 chicks from seven nests; Table 13). One mortality event was assumed to be a cat as it was seen briefly pausing at the nest though the footage was poor and no details could be ascertained. The chick disappeared in this period. Cats killed and ate all chicks in situ and only remained in field of view for less than two minutes. No nests with chicks were deserted. Ferrets were not observed preying on any study nests, though a ferret raced past a camera with a small chick in its mouth on one occasion and a ferret was seen killing two chicks and taking another out of the colony during a video and battery changeover (pers. obs.).

Influence of predators: nest location vs. likelihood of failure

The hypothesis that failed nests in colonies would show a clustered distribution owing to the influence of predator disturbance was shown to be incorrect. Nearest neighbour ratios demonstrated that the dispersion pattern of transect nests and nests that had failed on transects (a subset of all nests) was highly variable between colonies and within colonies (Table 16). Colony nests tended to show dispersed patterns, although nests on some transects were strongly clustered (Table 17). In contrast, failed nests were never clustered, most either being dispersed or randomly spaced.

Table 16: *Pattern of black-billed gull nest dispersion on transects; all nests versus failed nests.*

Colony (site)	Transect	Number of nests	Nests	Observed mean distance (m)	Expected mean distance (m)	Nearest neighbour ratio	Pattern of dispersion	P
Avondale N.	1	17	All nests	0.76	1.59	0.48	Clustered	<0.01
(Bank)		13	Failed nests	0.74	0.42	1.77	Dispersed	<0.01
	2	254	All nests	0.58	0.64	0.91	Clustered	<0.01
		75	Failed nests	1.10	1.12	0.98	Random	NS
	3	35	All nests	1.57	1.01	1.55	Dispersed	<0.01
		25	Failed nests	2.11	1.14	1.84	Dispersed	<0.01
Dunrobin S.	1	185	All nests	0.44	0.42	1.07	Partially dispersed	<0.05
(Partial bank)		59	Failed nests	0.75	0.68	1.10	Partially dispersed	<0.10
	2	291	All nests	0.36	0.30	1.19	Dispersed	<0.01
		75	Failed nests	0.69	0.58	1.19	Dispersed	<0.01
Mararoa 05	1	62	All nests	0.57	0.50	1.14	Partially dispersed	<0.05
(Bank)		25	Failed nests	0.93	0.73	1.27	Dispersed	<0.01
	2	102	All nests	0.41	0.34	1.21	Dispersed	<0.01
		30	Failed nests	0.49	0.53	0.94	Random	NS
Mararoa 06	1	320	All nests	0.30	0.26	1.14	Dispersed	<0.01
(Partial bank)		77	Failed nests	0.66	0.53	1.25	Dispersed	<0.01
Mossburn N	1	38	All nests	0.61	0.72	0.84	Partially clustered	<0.05
(Island)		5	Failed nests	2.64	1.20	2.21	Dispersed	<0.01
	2	137	All nests	0.41	0.33	1.24	Dispersed	<0.01
		12	Failed nests	1.62	0.80	2.03	Dispersed	<0.01
Otama N	1	35	All nests	0.71	0.62	1.13	Partially dispersed	<0.10
(Bank)		6	Failed nests	2.58	0.70	3.69	Dispersed	<0.01
	2	136	All nests	0.40	0.53	0.76	Clustered	<0.01
		49	Failed nests	0.88	0.84	1.05	Random	NS
	3	37	All nests	1.04	0.90	1.15	Partially dispersed	<0.05
		10	Failed nests	5.27	1.45	3.62	Dispersed	<0.01

Table 17: *Summary of black-billed gull nest dispersion on transects; dispersed, random or clustered.*

Nest type	Number of transects showing dispersal pattern		
	Dispersed	Random	Clustered
All nests	9	0	4
Failed nests (subset of all nests)	10	3	0

Influence of predators: predator abundance in colony surrounds

Colonies established on banks or partial banks in five locations where control of introduced predators had been undertaken within the calendar year (Table 18). The Dunrobin colony was the most successful bank colony in three years of monitoring, and was situated in an area where significant effort had been spent on control, both within 2 km of the colony location, but also throughout the headwaters of the river. Trapping produced low capture rates at Dunrobin compared to Avondale North which suffered low nest success (approximately 15 km downstream). Low capture rates were also found around the vicinity of the Lumsden colony and trapping was better timed to benefit nesting. Despite this, nest success was comparatively low.

Given the absence of trapping effort data for the autopsy programme and evidence that trapping for the programme was occurring at several more of the colony sites, no analysis of trapping effort, capture rates and nest success has been undertaken.

Table 18: *Predator trapping intensity and captures during the calendar year within a 2 km radius of black-billed gull bank and partial bank colony sites. Animals captured: c=cat, h=hedgehog, s=stoat, f=ferret.*

Colony	Year	Nest success	No. of trap sites (% on colony side)	Total trap nights in calendar year	Timing of trapping effort	Animals caught	Capture rate (%)	Autopsy database (ferrets only)
Dunrobin	2004	80.3	109 (64)	1203	Jan, Dec	1c, 3h	0.3	3
Avondale	2004	70.6	0					12
Bayswater	2004	75.3	0					3
Lumsden	2004	61.4	30 (33)	310	Aug, Nov	1h, 2f	1.0	0
Benmore	2004	63.8	2 (100)	20	Aug	0	0	3
Mararoa	2005	63.1	25 (60)	250	Jun, Jul	0	0	0
Avondale N.	2005	62.0	43 (42)	405	Jan, Jun	4s, 1h, 9f, 1c	3.7	9*
Dunrobin S.	2006	69.5	0					7
Etal Creek	2006	58.9	0					18
Fairfax Bank	2006	18.7	0					0
Thornbury	2006	63.6	0					0
Mossburn B.	2006	70.2	0					7
Dipton	2006	77.6	0					4
Otama North	2006	68.8	0					0
Otama South	2006	78.5	0					0

*Ferrets for autopsy taken from trapping programme

DISCUSSION

Limitations of study

Monitoring method

Several assumptions were made in order to analyse nest success, necessitated by the difficulty in relocating marked nests, particularly those that had failed. Writing nest numbers on adjacent rocks often resulted in marks becoming obliterated by faeces. Other alternatives, however (such as painting rocks, inserting markers/flags into the ground etc.) were not feasible given sample sizes, nest density, disturbance by gulls, substrate type and the disturbance caused by extended periods spent in the colony. It is possible that the method resulted in nest success being overestimated, principally because large numbers of nests found only on one occasion were not analysed, many of which may have failed.

Categorisation of colony site

The simplification of colony sites into three categories (bank, partial bank and island) lost potential information on the extent of predator access to colony sites. Ideally, cross-sections would be undertaken between an island and the riverbank and changes in water flow would be measured continuously throughout the breeding season to allow the calculation of an overall index of 'predator access'. This would also allow nest failure during the season to be tracked against changes in predator access. This was beyond the logistical capabilities of this study. Despite the simplification, however, the results clearly indicate that islands with a stable flow of more than one cumec are able to provide high quality breeding habitat for black-billed gulls.

Estimation of breeding success

Complications in the estimation of breeding success arising from asynchronous breeding and the créching of chicks are extremely difficult to overcome in highly colonial species, particularly if a priority is to minimise disturbance. Banding chicks before nest desertion (i.e. at 3-4 days old) was considered unacceptable. Other studies have banded chicks at hatching with fibre-tape bands to minimise impacts (Yorio et al. 1996), however, re-sighting banded birds within dense black-billed gull colonies is difficult (see Chapter 3). Only a small proportion of the fledglings could be penned and marked (approximately 200); meeting the requirement that this was a random sample in order to satisfy the assumptions of mark-recapture was largely impossible. The author also observed banded chicks moving to the back of the flock and away from the pen where they were less likely to be split off for banding. If marked chicks were less likely than unmarked chicks to be penned the following day during recaptures, this would explain the unlikely result in the Benmore colony (1.01 fledglings per nest given a hatching success of 41.4%), and suggests mark-recapture resulted in the size of the fledgling populations being overestimated.

In comparison, the photography method of estimating the fledgling population caused minimal disturbance, and the subsequent photographic counts were generally precise (counts by three 'observers' varied by a mean of 4.0%, R.K. McClellan unpubl. data). In all cases where the method was used, few nests were still active (c.1-5%) and fewer than 5% of fledglings were observed escaping the flock (generally less than 1%). However, it is unknown how many chicks had already fledged in colonies that had begun nesting much earlier. The photography method had the added advantage of being less likely to put fledglings that could fly to air as it caused less disturbance.

Breeding success for black-billed gull chicks was estimated before most birds were able to fly and will have been underestimated due to post-fledging mortality. Keedwell (2003) found a further 20% of black-fronted tern chicks died after fledging on New Zealand riverbeds, 75% by predation. Major mortality events of juveniles have been recorded at Southland black-billed gull colonies. Approximately 130 fledglings were found dead at the Dunrobin colony after abandonment at the end of the season, most would have been able to fly. Observations of c.100 (C. Sinclair pers. comm. 2004), 125 (T. Dodgshun pers. comm. 2004) and c.100 (S. Crawford pers. comm. 2005) dead juveniles have been reported to the author from other Southland colonies. These indiscriminate mass killings are thought to be due to stoats.

Modelling nest success

The best model that explained variation in nest success only included colony location. However, there were some issues with the fit of the model. Possible factors that were not measured that may have helped performance of the model were predator guilds and abundance at colony sites, the availability of food, and greater detail on predator access.

Nest success measures

A key assumption of the Mayfield method is that daily nest survival is constant in time (Mayfield 1975). However, Kaplan-Meier survival time analysis clearly showed that nests laid late in the breeding season had a higher rate of survival than those laid early in the season and during peak laying. Paradoxically, the use of Mayfield estimates was justified because of this fact; that is, at the end of the season, a small proportion of nests in almost every colony was not monitored through to hatching to avoid excessive disturbance when the colony was full of mobile chicks. These nests may have done significantly better than early and mid season nests and their exclusion from analysis would have resulted in the underestimation of nest success. Mayfield estimates were higher than Program MARK and apparent nest success estimates, possibly for this reason. In addition, Etterson and Bennett (2005) reviewed the Mayfield method and concluded that traditional Mayfield models were likely to provide 'adequate' estimates for studies that used visitation intervals of no more than three days. The majority of visitation intervals used in this study were of 3-4 days, sometimes 5-6 and rarely more.

The Mayfield method and the nest survival model in Program MARK both require the number of days of incubation for a particular species to be known in order to calculate nest success. The use of the methods was complicated by evidence that black-billed gull incubation periods are relatively poorly known and were not consistent, often progressing past 24 days. Footage from the camera study demonstrated that gulls were kept off their nests often and for extensive periods during the night when temperatures would have been close to or below 0°C, cooling the eggs and possibly extending incubation periods.

Influence of colony size, breeding synchrony and nest density

Colony size

Nest success and breeding success exhibited a positive density dependent relationship with the size of the colony, regardless of colony site (island or bank), and a negative relationship with black-backed gull disturbance. Clearly, however, the relationship cannot be strictly linear as nest success and breeding success cannot increase past 100% whereas colony sizes can be larger than those in this study. Further data may be likely to produce an asymptotic or logarithmic rather than a linear relationship where further increases in colony size are less likely to produce increases in productivity. Other examples of positive density dependence may also be occurring. Serrano et al. (2005) found that, as well as nest predation decreasing, adult survival increased with increasing colony size. Foraging efficiency may decrease as colony size decreases (Bucher 1992).

At the extreme, the three smallest colonies monitored largely failed to produce fledglings. This suggests that a threshold may exist below which colonies are likely to experience breeding failure. Observations of gull and predator behaviour in the large Avondale colony (c.2000 nests) clearly illustrate how a single predator making numerous visits to colonies of 50-200 nests could cause immense disruption and probable abandonment of breeding. Such a threshold is a possible manifestation of the Allee effect (i.e. inverse density dependence at low densities; Courchamp et al. 1999). Courchamp et al. (1999) suggest that the Allee effect could be generated by lower survival as a result of low densities of prey exhibiting inefficient anti-predator strategies. Empirical studies have illustrated the reduced performance of small colonies in the face of predation (Brunton 1999, Brown and Brown 2001; Cuthbert 2002) including a study of a predatory large gull species on a smaller gull species (Oro et al. 2006). Créching larid species such as black-billed gulls are thought to show low levels of aggression toward predators (Besnard et al. 2002). However, a second possible theory explaining the existence of an Allee effect is that small colonies (possibly comprising lower quality individuals) establish in poor quality habitat whereas larger colonies form in higher quality habitat. The small colonies then suffer accordingly.

The presence of an Allee effect significantly increases the likelihood of extinctions (Stephens and Sutherland 1999). The effect has been suggested to have been partly responsible for the extinction of the highly colonial passenger pigeon *Ectopistes migratorius*, once the most abundant bird in North America (Stephens and Sutherland 1999), and may yet cause the extinction of the tricolored blackbird *Agelaius tricolour*, which forms the largest breeding colonies of any North American landbird since the demise of the passenger pigeon (Cook and Toft 2005). Evidence of Allee effects in the colony size of black-billed gulls poses a very real problem for conservation managers responsible for a species in continuing, rapid decline.

Synchrony

Beer (1966) suggested unstable breeding habitat and high risk of flooding favoured selection of breeding synchrony among black-billed gulls. Evans (1982) hypothesised that breeding synchrony was a key consequence of the species' characteristic desertion of colonies during breeding which he suggested was due to declining food supplies. Evans examined synchrony within 16 colonies and noted that nesting could be strongly asynchronous within and between years, but that nesting within a colony tended to be highly synchronous. Burger and Gochfield (1996) however, noted that breeding was not particularly synchronous among seven colonies with some colonies containing incubating adults and flying young. In this study, the mean and mode date of laying varied by only six days between all three years, and the mode date of laying varied by only 10 days for 12 of 15 colonies. However, though eggs tended to be laid over a five-week period (mean of first and last eggs), some colonies exhibited substantial asynchrony with egg laying continuing for up to three months.

Breeding synchrony is likely confounded by pairs re-laying after failing during incubation: the more failures within the colony, the more protracted the breeding season. Omitting second attempts in the same nest (e.g. Wilhelm and Storey 2002) is also problematic as nests were clearly used on occasion by different pairs; most obviously, nests with chicks could contain eggs on the following visit. Overall, 8.8% of nests were re-used and 3.6% of successful nests were re-used. Variation between colonies was considerable: up to 24% of all nests were re-used and up to 15.3% of successful nests were re-used in a colony.

Nest density

Though some evidence of a relationship between nest density and nest success was found, it was largely based on two very small colonies that nested at low density that experienced breeding failure. The low productivity is likely to have been more a result of colony size than nest density given the strong relationship observed between breeding and nest success and colony size, and the possible existence of an Allee effect. Studies of this relationship in *Larus* species have produced mixed results including: negative density dependent relationships (thought to be a response to increased aggression conspecifics at high nest densities; Butler and Trivelpiece 1981), highest breeding success at intermediate densities (Parsons 1976) and no relationship (Dexheimer and Southern 1974). Unlike Butler and Trivelpiece (1981) and Parsons (1976), the highest nest densities (2.54 and 3.77 nests/m^2) in this study both achieved relatively high nest success (approximately 75%). Excluding the two unusually small colonies from the analysis results in no relationship.

Influence of predation

Black-billed gulls evolved in a markedly different environment to the one that now exists as no terrestrial mammals were present prior to human colonisation of New Zealand. Potential avian predators included weka (a flightless rail; *Gallirallus australis*), Haast's eagle (*Harpagornis moorei*), Forbe's harrier (*Circus teauteensis*), Australasian harrier (*Circus approximans*), New Zealand falcon (*Falco novaeseelandiae*), South Island adzebill (a giant flightless rail; *Aptornis defossor*), laughing owl (*Sceloglaux albifacies*), morepork (a small owl; *Ninox novaeseelandiae*) and the native black-backed gull. Haast's eagle (the world's largest, and probably too large to prey on small birds), Forbe's harrier, the adzebill and the laughing owl are now extinct due to human impacts, and the weka is locally extinct from most black-billed gull habitat; these species' influence on extent of black-billed gull coloniality will remain unknown but may have been significant (possible prey types of extinct species determined from Tennyson and Martinson 2006).

Present day records of avian predation are largely of black-backed gulls. Fossils of these species are virtually restricted to coastal dune deposits and relatively rare for a large bird, and records suggest the species was also uncommon at the arrival of Europeans (Worthy and Holdaway 2002; Biswell 2005). It is possible that depredation by this species is now much more frequent due to population increases associated with human activities. There appears to be only one record of a harrier attacking a colony (this study) and none of the falcon. However, panic flights are only initiated by Accipitriformes (pers. obs.) suggesting an evolutionary cause and effect. It is plausible that avian predation was at least a partial reason for the development of extreme coloniality in the black-billed gull. The benefits afforded by nesting in larger colonies are clearly evident in this study, and are likely to be at least partly due to increased protection from predators (as evidenced by black-backed gull disturbances).

In the present environment, black-billed gull colonies almost certainly attract predators through their constant noise, smell and lack of camouflage. The extremely compact nature of a black-billed gull colony, however, may mean that where territorial predators are concerned (e.g. cats, mustelids) such predators may exclude others of the same species (Coulson 2002). Large numbers of prey, then, would swamp the effect of a few predators (Seigel-Causey and Kharitonov 1990; Danchin and Wagner 1997; Brown and Brown 2001) resulting in a relationship between colony size and productivity, such as has been shown here. Again, however, the high density of nesting means that a single predator such as a cat can indirectly bring about significant mortality simply through disturbance rather than just predation, as shown from the camera study.

Disturbance may also be the cause of lower body weights among adult gulls on banks, where there are no barriers to predator access. That predators are inhibited by bodies of water has been noted internationally (Craighead and Craighead 1949; Hammond and Mann 1956;

Drewien and Frederickson 1970; Duebbert 1982; Johnson et al. 1988; Knopf et al. 1988; Lokemoen and Woodward 1992; Boe 1993; Johnson et al. 1995; Kristiansen 1998; Barbraud et al. 2002; Nuechterlein et al. 2003; but see Moser and Ratti 2005) as well as in regard to New Zealand's endemic braided river birds (Pierce 1987; Rebergen et al. 1998; Boffa Miskell Ltd. 2007). Burger and Gochfield (1996) noted that species such as black-billed gulls were not only vulnerable to floods, but also during very low water levels when mammalian predators could gain access to their nests. On banks and partial banks, mean clutch size, nest success, hatching success and breeding success were all substantially lower than on islands, suggesting easier predator access. Modelling of nest success therefore indicates that introduced terrestrial predators are likely to be the primary cause of variation in black-billed gull productivity. Of 48 colonies found in 2004-2006, 34 (71%) were bank colonies, indicating the majority of Southland's black-billed gulls are subject to disturbance and depredation during breeding.

Influence of researcher disturbance

In order to investigate black-billed gull productivity, extensive disturbance of breeding colonies must be undertaken. Despite much literature documenting impacts of human disturbance, particularly researcher disturbance, on colonial birds (Burger 1981; summaries in Götmark 1992; Carney and Sydeman 1999) it is generally not built into studies of nesting success. In this study, analysis of observer effect using Program MARK and the method described by Rotella et al. 2000 gave inconclusive results, possibly because of the lack of power of the methods. Despite this, the relative impact of researchers compared to predators was clearly evident from the camera study work. Monitoring of transects resulted in 11 instances of disturbance of nesting birds compared to 90 predator disturbances, 88 possible predator disturbances and 247 disturbances of unknown origin but most likely also due to predators.

Coloniality and the black-billed gull

Strong relationships are evident between black-billed gull productivity and colony size and, to a lesser extent, synchrony and nest density, possibly the result of an evolutionary response to pressure from an avian predator guild that is now greatly changed. However, the existence of the relationship with productivity may instead be a response to unpredictable food sources, as suggested by Evans (1982) whereby foraging efficiency improves with larger colony sizes (Brown and Brown 1996). Whether coloniality in the black-billed gull evolved in response to pre-human guilds of avian predators or foraging efficiency or a combination of both (and even other possible factors) will remain a mystery.

Results indicate that the primary factor influencing productivity in the 21st century is predation by introduced mammals. It is likely that the impact of predators is lessened with increasing colony size as shown by variations in the level of black-backed gull disturbance. The existence of the relationship between colony size and productivity combined with the possible existence of an Allee effect, whatever their evolutionary causes, will ensure that as populations of black-billed gulls continue to decline, overall productivity will also decrease. The rapid decline of Southland's black-billed gull population indicates that the known and potential benefits provided by the species' extreme coloniality are insufficient for the population to maintain a stable population trajectory in the absence of management of human-induced threats.

CHAPTER 6

Modelling population dynamics of the Endangered black-billed gull in Southland, New Zealand

Black-billed gull chicks, Dunrobin South colony, Aparima River, 2006 (C. Garden)

ABSTRACT

Deterministic matrix models were used to investigate population trends of black-billed gulls (*Larus bulleri*) in Southland, New Zealand, where they have declined by well over 50% in the last 30 years. Survival parameters for the species are poorly known and substitute parameters were used from a population of the closely related red-billed gull (*L. novaehollandiae scopulinus*) at Kaikoura, New Zealand, which has been studied for over 40 years. The initial model based only on red-billed gull reproductive and survival rate estimates predicted a greater rate of decline than has been observed at Kaikoura. Introducing breeding success estimates from black-billed gulls in Southland into the matrix gave an annual rate of decrease of -0.092. This closely matched actual population estimates from Oreti River, Southland, where the decline has been estimated at 96.7% in 33 years. Further models increased the levels of individual parameters to obtain a stable population while keeping others constant. Almost 100% hatching and breeding success stabilised the population trajectory, whereas adult survival needed to reach 97%/annum. Breeding frequencies of all age groups set at 100% was insufficient to bring the annual rate of increase close to zero. Sensitivity and elasticity estimates indicated that adult survival had the greatest influence on population trends, followed by breeding success and then survival of gulls aged between 0 and 1. Tentative evidence suggests that survival of black-billed gulls to ages 6-9 is equal to or lower than that of Kaikoura red-billed gulls. The results demonstrate that, if the models are considered to be a reasonable representation of actual reproductive and survival rates of black-billed gulls in Southland, improvements need to be made in several rates to halt the population's rapid decline.

INTRODUCTION

The black-billed gull (*Larus bulleri*) is endemic to New Zealand, and breeds mostly on inland rivers and streams in dense colonies. Approximately 70% of the population breeds in Southland, the southern most region of New Zealand (Powlesland 1998). The species has undergone a decline well over 50% in 30 years in Southland, possibly more than 80%, and exceeding 90% in the Oreti River, a key breeding habitat. However, the decline may have slowed in the last decade, although aerial monitoring, initiated in 1995, is relatively insensitive to short term population changes (Chapter 2). The species was upgraded to

Endangered in 2005 due to the observed rapid decline and is recognised as the most threatened gull in the world (BirdLife International 2006).

Many potential factors may be driving the present decline in Southland. Introduced predators such as ferrets (*Mustela furo*) and cats (*Felis catus*) prey on chicks and adults (Chapter 5) and are likely to take eggs (Pierce 1986; Sanders and Maloney 2002; Keedwell 2003; Murphy et al. 2004). Introduced flora such as broom, gorse and pasture grasses have spread into braided river systems and stabilise islands within rivers (Maloney et al. 1999; see European review in Gurnell and Petts 2002: Rinaldi 2003; Moseley 2004), increase river incision (Maloney et al. 1999; Rinaldi 2003), increase predation risks for nesting birds by providing cover for predators (Pascoe 1995; Rebergen et al. 1998) and may force birds to nest closer to water levels making colonies more susceptible to flooding (Innes 2003; O'Donnell 2004; Caruso 2006; Chapter 4). Modification of waterways to control rivers combined with excessive levels of gravel extraction appears to have resulted in river incision and loss of habitat (Kelly et al. 2005; Chapter 4). Recreational users of rivers can cause disturbance which, at its worst, causes colony abandonment and mortality of eggs, chicks and adults (Chapter 5). Hydroelectric development can result in loss of island habitat (Chapter 4) which provides greater protection from mammalian predators than bank habitat (Chapter 5; Pierce 1987; Rebergen et al. 1998; Boffa Miskell Ltd. 2007). The reduction in water flows in dammed rivers encourages further invasion by exotic flora (Balneaves and Hughey 1989; Johnson et al. 1995; Tal et al. 2003). Flooding regularly disrupts nesting attempts (Chapter 4) and though the species has presumably evolved to cope with such events, potential increases in the number of floods due to climate warming (Fraser 2002; Appendix J) may have an impact on black-billed gull survival.

This chapter investigates population trends of Southland's black-billed gulls using matrix models; the simplest form of population viability analysis (PVA). PVA is the development of formal, qualitative and quantitative models representing the dynamics and ecology of species and the factors that affect them (Possingham et al. 1993). Demographic models such as Leslie matrix models are tools which allow the use of known or projected demographic parameters to predict past, present and future population trends. Models require explicit statements about key elements that make up the demographic structure of the species in question, quickly revealing the limits of understanding of that particular species (Beissinger et al. 2006). PVA has often been criticised as such analyses can be subject to considerable uncertainty (e.g.

Taylor 1995; McCarthy et al. 1996; Beissinger and Westphal 1998; Ludwig 1999; Coulson et al. 2001). Likewise, many authors are proponents of the potential strengths of PVA, particularly in regard to their ability to aid the direction of management of threatened species (e.g. Burgman 2000; Caswell 2001; Drechsler et al. 2003; Beissinger et al. 2006). Sensitivity analyses complement model predictions (Reed et al. 2002) allowing the identification of those parameters which have the most influence on population trends and, consequently, which require more accurate estimation (McCarthy and Burgman 1995; Caswell 2000).

By using the closely related and intensively studied Kaikoura red-billed gull (*L. novaehollandiae scopulinus*) population as a basis for matrix modelling, this paper aims to:

- Test a set of models which incorporate varying levels of reproductive and survival parameters to illustrate potential outcomes; and
- To calculate sensitivities and elasticities of reproductive and survival parameters in order to determine which have the greatest impact on population trends.

METHODS

Demographic data

Chicks marked from 1997-2000 were banded by Lloyd Esler and a number of volunteers. As part of present research, chicks were marked in 2004 and 2005, and adults in 2005. A total of 67 black-billed gull adults was individually colour banded in three colonies. Searches conducted in 22 colonies during the following season re-sighted 58.2% of individuals. This will be a significant underestimate of adult survivorship given the restriction to a single encounter event, and because the gulls were already adults when banded. Re-sighting in 2006 of black-billed gulls banded as chicks gave minimum survival estimates of different cohorts (Table 1) in part because chicks were banded with cohort band combinations and could not be individually identified (methods in Chapter 3). As for banded adults, restriction to a single encounter event (the 2006 season) means the data cannot be formally analysed using mark-recapture methods in order to give more robust survival estimates for different age groups.

Black-billed gulls are first able to breed at two years of age (Dawson 1958; Chapter 3). Mean age of first breeding, however, is unknown, and is likely to be considerably higher (G. Taylor and R. Hitchmough in BirdLife International 2006). The oldest black-billed gull recorded was 23, observed in 2008 (G. Taylor pers. comm. 2008).

Table 1: *The percentage of black-billed gulls banded as chicks re-sighted during the 2006 breeding season in 22 Southland colonies.*

Cohort (age)	Number of chicks banded	Min. no. re-sighted in colonies	% of cohort re-sighted
1997 (9th year)	120	4	3.3
1998 (8th year)	314	10	3.2
1999 (7th year)	139	1	0.7
2000 (6th year)	162	21	13.0
2004 (2nd year)	672	85	12.5
2005 (1st year)	204	19	9.3
Totals/means (SE)	1611	139	7.0 (2.2)

Annual variation in the proportion of black-billed gulls breeding within Southland is likely to be significant. An attempt to locate all Southland colonies from 2004-2006 resulted in a similar number of colonies, but widely fluctuating numbers of individuals between years over all waterways (Table 2). In addition, the proportion of non-breeding birds was found to vary significantly between colonies (counts of birds in aerial photographs of colonies compared to counts of nests; mean 2.14 gulls/nest, range 0.90-3.95 gulls/nest; methods in Chapter 2).

Table 2: *Number of black-billed gull colonies located in Southland and number of birds as estimated from aerial photographs of colonies.*

Year	2004	2005	2006
Date of photographs	3 Oct.[1]	26 Oct.	1 Nov.
Total colonies	22	20	24
No. of birds (nearest 1000)	50,000	27,000	57,000

[1]Mataura River survey carried out on 1 Dec.

Black-billed gull clutch size was estimated from 5268 nests in 21 colonies and was 1.90 (SE 0.01). Breeding success (the number of fledglings per nest) was estimated in eleven colonies and varied from 0-0.88 fledglings per nest (mean 0.32, SE 0.08; Chapter 5).

Black-billed gulls are most closely related to red-billed gulls (Chu 1998). The latter have been studied at Kaikoura, New Zealand, for over 40 years. In these coastal colonies, emigration of young and adults is considered to be low and re-sighting rates extremely high (Mills et al. 2008). From 1983-1993, the red-billed gull population remained relatively stable; however, since 1994, the population has been declining rapidly. The following survival and reproductive parameters have been published for female red-billed gulls:

- Age at first breeding: prior to the decline, age at first breeding varied from 2-18 years; 6% commenced breeding as two year olds, 27.6% as three year olds and 34.9% as four year olds. Post-decline, 24.0% began breeding at three, and 38.2% at four (Mills et al. 2008).
- Recruitment to breeding population: of 74,453 banded chicks, 14.57% were recruited to the population (Mills et al. 2008), and 23% of fledglings survived to breed (Mills 1989).
- Breeding frequency by age: in the 1983 season, 74% of 5-9 and 10-14 year old females were breeding, 55% of 15-19 year old females and 43% of 20-25 year old females (considered a 'typical' season; Mills 1989). During the same season, 51% of females bred compared to 86% of males (Mills 1989). From 1983-2004, an average of 62% of the Kaikoura population bred each season, varying from 28.2-98.4% (Mills et al. 2008).
- Adult survival: of 12,792 re-sighted females, 86% were re-sighted a second time (Mills et al. 2008). Previously, females had been found to have an annual survival rate of 89.4% (SE 2.6; Mills 1991).
- Adult longevity: 29 years (Mills 1991).
- Clutch size: mean 1.94 (SD 0.09) prior to the decline, decreasing to 1.88 (SD 0.08) after the decline (Mills et al. 2008).
- Breeding success: mean 0.61 (SD 0.26) prior to the decline, decreasing to 0.59 (SD 0.15) during the decline (Mills et al. 2008).

Modelling

A deterministic Leslie Matrix model was constructed to investigate population trends of black-billed gulls in Southland. This method was chosen as parameters of black-billed gull survival and age-specific reproductive performance are poorly known and excessive parameterisation of models has been criticised by some authors (e.g. Bessinger and Westphal, 1997; Starfield, 1997). The population model was a post-breeding, age-classified matrix for a female population (Caswell 2001). Given the poor quality of demographic data for black-billed gulls, the Kaikoura red-billed gull population was used as a basis for all modelling. The total population at Kaikoura numbered approximately 17,000 birds in 1983 but has since declined by almost 50% (Mills et al. 2008). This decline (possibly due to changes in the availability of the planktonic euphausid (*Nyctiphanes australis*); Mills et al. 2008) makes it a less than ideal template for modelling black-billed gull parameters. In addition, the red-billed gull females have considerably higher survival than males, leading to later recruitment to the breeding population and lower frequency of breeding than males (Mills 1989; Mills 1991; Mills et al. 2008), a situation that may not be replicated in the Southland black-billed gull population.

Long-lived seabirds such as red and black-billed gulls tend to have delayed reproductive maturity (Weimerskirch 2002) and pre-breeders are often absent from the colonies in early years making estimates of age-specific fecundities problematic. Authors have dealt with the issue of parameterising matrix models for these species using a number of methods. Jones (2002) based annual survival rates of pre-breeding birds (until age five) on non-breeder survival. Jenouvrier et al. (2005) and Jenouvrier et al. (2005b) assigned a survival rate during the species' first year which was calculated as the survival of fledglings to recruitment, and then used an adult survival rate for subsequent years. Frederiksen et al. (2004) identified a quadratic relationship between true age (from age 2) and survival and used this to model adult survival, extrapolating it to kittiwakes aged 1-2 years, and then tested various levels of first year survival in matrices. Peery et al. (2006) used the same survival rate for sub-adults and adults as individuals were not distinguishable in the field and parameterised the model with three estimates of juvenile survival. Cuthbert et al. (2004) used rates from a substitute species for which juvenile survival had been found to relate to adult survival over four separate time periods with a ratio of 0.819:1.

For the red-billed gull population, adult survival (Φ_a) was set as 0.894 (Mills 1991). Senescence was not included in the model. Age at first breeding is known to be 2, and the oldest age at which females were recruited has so far been found to be 18. However, for the purposes of this paper, all females were recruited by age five (almost 70% are breeding by age four; Mills et al. 2008). First year survival ($\Phi_{0\text{-}1}$) is not known as most one-year old birds do not return to the colony (Mills et al. 2008; similarly for black-billed gulls, pers. obs.; T. Harbraken pers. comm. 2005) nor is the survival of young adults aged 2-4 years ($\Phi_{2\text{-}4}$) which are in the process of being recruited to the breeding population. However, overall, 23% of fledglings are known to be recruited to the breeding population (in this model, assumed to have occurred prior to five years of age). Therefore, the survival of young adults was set at 10% less than adult survival and first year survival was set at 0.286, such that:

$$0.23 = \Phi_{0\text{-}1} * \Phi_{2\text{-}4}$$

The proportion of females breeding was set as per red-billed gull data from the 1983 season. Breeding frequency for the age group 26-29 was assumed to be the same as the previous age group. No estimates exist for ages 2-4 so this parameter was initially set as the cumulative proportion of birds breeding by age 4 (0.685) multiplied by the mean proportion of females breeding during the 1983 season (0.51). Breeding success was set as 0.30 for all age classes (half of the estimate for breeding success as the model included only females). As a consequence, the resulting matrix was largely built from parameters sourced during the relatively stable period prior to the beginning of the rapid population decline at Kaikoura (Table 3). The population trajectory predicted by the matrix was compared to actual annual population estimates made using mark-recapture methods (methods in Mills et al. 2008).

Table 3: *Input parameters for the initial population matrix model for red-billed gulls at Kaikoura, New Zealand.*

Age class	Female survival		Proportion of females breeding		Breeding success		Fecundity
0-1	$\Phi_{0\text{-}1}$	0.286	$P_{0\text{-}1}$	0	BS	0	$F_0 = \Phi_{0\text{-}1} P_{0\text{-}1} BS$
2-4	$\Phi_{2\text{-}4}$	0.805	$P_{2\text{-}4}$	0.35	BS	0.30	$F_{2\text{-}4} = \Phi_{2\text{-}4} P_{2\text{-}4} BS$
5-9	Φ_a	0.894	$P_{5\text{-}9}$	0.74	BS	0.30	$F_a = \Phi_a P_{5\text{-}9} BS$
10-14	Φ_a	0.894	$P_{10\text{-}14}$	0.74	BS	0.30	$F_a = \Phi_a P_{10\text{-}14} BS$
15-19	Φ_a	0.894	$P_{15\text{-}19}$	0.55	BS	0.30	$F_a = \Phi_a P_{15\text{-}19} BS$
20-25	Φ_a	0.894	$P_{20\text{-}25}$	0.43	BS	0.30	$F_a = \Phi_a P_{20\text{-}25} BS$
26-29	Φ_a	0.894	$P_{26\text{-}29}$	0.43	BS	0.30	$F_a = \Phi_a P_{26\text{-}29} BS$

Sensitivity and elasticity analyses were carried out by altering each parameter by 0.01 and estimating the change in λ (dominant eigenvalue or the finite rate of increase). An estimate of sensitivity refers to the change in λ caused by changes in θ, which represents the parameter of interest:

$$S_\theta = \frac{\partial \lambda}{\partial \theta}$$

Elasticity estimates are scaled, allowing comparison between changes in θ:

$$E_\theta = \frac{\partial \lambda / \partial \theta}{\lambda / \theta}$$

Arcsine-transformed elasticity values were also calculated (Link and Doherty 2002) as this method of scaling sensitivity values has been shown to be more appropriate for binomial parameters (i.e. those bounded by 0 and 1 such as all of the parameters used in this model except one). The notation for arcsine transformation is:

$$\frac{\partial \log \lambda}{\partial \left[2 \sin^{-1}\left(\sqrt{\theta}\right)\right]} = \left(\frac{\sqrt{\theta(1-\theta)}}{\lambda}\right)\frac{\partial \lambda}{\partial \theta}$$

RESULTS

The initial population model for red-billed gulls indicates a rapid rate of decrease (λ=-0.075) substantially greater than the actual decline rate found at Kaikoura (fitted exponential trend = -0.039; Figure 1; Table 4).

Using the initial matrix and changing the breeding success parameter to that of the black-billed gull (0.32 fledglings per nest or 0.16 female fledglings) caused the rate of increase to drop to λ=-0.092 (Table 4). The predicted trend closely mirrors actual population trends on the Oreti River (Figure 2; fitted exponential trend =-0.100; the Oreti River has greatest amount of historical survey data in Southland).

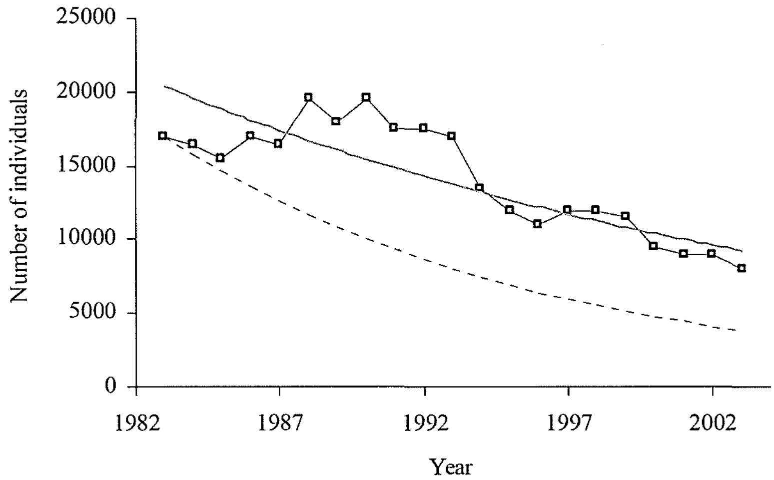

Figure 1: *Actual population trend observed at Kaikoura (open squares; from Mills et al. 2008; refer for estimation methods) and the fitted exponential trend for Kaikoura data (grey line). Trend predicted by initial matrix model (dashed line).*

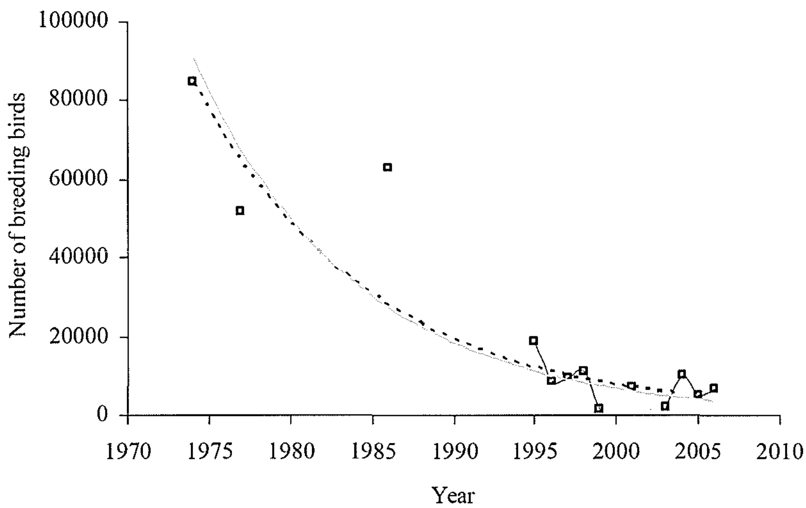

Figure 2: *Actual population trend observed the Oreti River, Southland (open squares) and the fitted exponential trend for Oreti River data (grey line). Trend predicted by initial matrix model altered by black-billed gull breeding success (dashed line).*

Black-billed gull data for adult survivorship was considered too poor to include in a model; the re-sighting of 58.2% of adults in 2006 is clearly a serious underestimate of adult survival and is so low that a resulting matrix would give a severe rate of decline. If, however, annual survivorship was assumed to be 90% (similar to that of red-billed gulls), then approximately 35% of banded adults were alive but not re-sighted in 2006 (either in colonies and missed, not in colonies, or in a region other than Southland, although breeding dispersal distances were short; Chapter 3). Mean rate of re-sighting of 6-9 year old birds was 5.1% and, adjusted for birds not seen, is 6.8%. This assumes that cohort-banded birds could be individually identified (more likely for the older 6-9 year old cohorts as particular band combinations were often recognisable due to wear, fading or missing bands), and also that rates of dispersal out of Southland were low (see section on Breeding frequency for a discussion of assumptions). If the figure of 6.8%, or survival to age 6-9, is taken to be equivalent to the figure for breeding recruitment in the red-billed gull population i.e. 23%, or survival to age 5-9, under this scenario, the rate of decline worsens (λ=-0.106; Table 4).

Table 4: *Reproductive parameters used in seven population matrix models and the predicted annual population growth rate over 20 years. Models 1-3 are based on actual parameters measured for red-billed gulls and black-billed gulls. Models 4-7 each alter one parameter in order to attain a stable population; for adult survival, survival for 2-4 year olds is 10% lower and survival of 0-1 year olds is equal to 0.23/survival of 2-4 year olds. Breeding success figures in brackets are estimates used in the models (i.e. half of observed levels of breeding success). Breeding frequencies for age classes are as per 1983 season data except for Model 7.*

	Black-billed gull models			Stable models			
Parameter	Model 1 RBG Initial model	Model 2 BBG Breeding success	Model 3 BBG Survival to age 5-9	Model 4 Breeding success	Model 5 Adult survival	Model 6 Juvenile survival	Model 7 Breeding frequency
Breeding success	0.60 (0.30)	0.32 (0.16)	0.32 (0.16)	1.80 (0.90)	0.60 (0.30)	0.60 (0.30)	0.60 (0.30)
Adult survival	0.894	0.894	0.894	0.894	0.970	0.894	0.894
Survival 0-1	0.286	0.286	0.186	0.286	0.263	0.800	0.286
Survival 2-4	0.805	0.805	0.366	0.805	0.873	0.894	0.805
Breeding frequency	Variable	Variable	Variable	Variable	Variable	Variable	All 100%
Growth rate (λ)	-0.075	-0.092	-0.106	-0.002	0.001	0.002	-0.035
Generation time	15.12	19.09	27.91	9.49	32.09	9.35	12.43
Mean age of parents	9.54	9.54	9.42	9.42	32.74	9.42	10.43

Four further models were examined which each varied one or more parameters in order to obtain a stable population (i.e. where λ is close to zero; Table 4). By itself, breeding success needed to be raised to 1.8 fledglings per nest (i.e. almost 100% hatching and breeding success) to stabilise the population, whereas adult survival needed to reach 97%/annum.

Together, young adult survival set at the same rate as adult survival, and juvenile survival (ages 0-1) set at 80% was sufficient to reach a stable population trajectory. In contrast, breeding frequencies of all age groups set at 100% was insufficient to stabilise the population.

The sensitivity of λ to adult survival was extremely high compared to all other sensitivities (Table 5), indicating that changes in adult survival will have a much greater impact on population trends than any other parameter. The elasticities (a scaled estimate of sensitivity) of breeding success and juvenile survival were also high, but have much less influence on population trends than does adult survival. Overall, the sensitivities and elasticities of breeding frequencies are very low.

Table 5: *Sensitivity, elasticity and arcsine-transformed elasticity values for parameters in Model 2 (black-billed gull breeding success).*

Parameter	Sensitivity	Elasticity	Arcsine elasticity
Adult survival	1.080	-10.481	-3.609
Breeding success	0.125	-0.217	-0.498
Survival 0-1	0.070	-0.217	-0.343
Survival 2-4	0.025	-0.217	-0.108
Breeding frequency 2-4	0.001	-0.006	-0.005
Breeding frequency 5-9	0.001	-0.008	-0.005
Breeding frequency 10-14	0.001	-0.008	-0.005
Breeding frequency 15-19	0.001	-0.006	-0.005
Breeding frequency 20-24	0.001	-0.005	-0.005
Breeding frequency 25-29	0.041	-0.191	-0.220

DISCUSSION

Limitations of method

The matrix models used in this study are deterministic and are simplified by a number of assumptions that are unlikely to be met in nature, such as rates of survival and breeding success remaining constant over time. Deterministic matrix models are able to include demographic stochasticity. Variation in demographic parameters almost certainly occurs within the black-billed gull population, for example, as a result of poor weather during either breeding or non-breeding seasons. Extreme weather events are known to have caused catastrophic mortality within Southland's black-billed gull population in the last 40 years (refer Chapter 7). It is recognised that the exclusion of such environmental variation and catastrophes can lead to overestimation of population growth rates (Beissinger and Westphal 1997). However, they were not included in order to avoid overcomplicating models that were already based on imperfect data (Beissinger and Westphal 1997; Starfield 1997). Modelling catastrophes or measures of environmental variation will both act to increase the rates of decline.

The initial red-billed gull population model appears to overestimate the extent of the decline at Kaikoura, presumably due to underestimation of one or more population parameters. The adult survival estimate used in this chapter was published in 1991 (Mills 1991), prior to the start of the decline in c.1993, and so was derived from data obtained during a period of relative population stability. More recent and robust methods of survival estimation have led to increases in survival estimates from the same datasets (Weimerskirch 2002) and it is likely that reanalysis of the red-billed gull data will result in higher adult survivorship estimates. Analysis of red-billed gull re-sighting data before and during the decline combined with further modelling will elucidate whether a decrease in adult survival is a primary cause of decline.

Modelling population trends

Breeding success

The complexity involved in measuring black-billed gull breeding success is such that the direction of bias is unknown. Black-billed gull chicks leave the nest area approximately 4-8 days after hatching (R.K. McClellan unpubl. data) and often attend crèches (Higgins and Davies 1996). Estimates of fledging success can be made by mark-recapture or, more reliably, via a photographic census of young birds that have been 'herded' into a group by people (methods in Chapter 5). This is done before the birds are able to fly, and will subsequently underestimate fledgling success. Depending on colony breeding synchrony, the timing of the fledgling population estimate often means a proportion of nests will still contain eggs and/or young chicks and the fledging population will also be underestimated. Additionally, post-fledging mortality can be significant (Chapter 5) and was found to exceed 20% in black-fronted terns, another New Zealand endemic river-breeding species, largely due to introduced predators (Keedwell 2003). However, in the other direction, breeding success could only be estimated at one true island colony which had been affected by black-backed gull disturbance.

Islands within rivers provide breeding habitat that is relatively safe from terrestrial predators (Chapter 5) and make up approximately one third of available gravel patches within the four main rivers in Southland (Chapter 4). Gulls use patches in accordance with availability (Chapter 4) so it could be expected that overall breeding success in Southland is higher than 0.33 fledglings per nest.

Productivity of black-billed gulls is most affected by introduced predators and the native black-backed gull (*L. dominicanus*; Chapter 5). Available productivity estimates of other gull species are higher than estimates found in Southland black-billed gulls (Table 6). This suggests that the extent of the impact of introduced predators on black-billed gull productivity is severe; albeit the population trends of the various species are more complex than simply observing the number of fledglings produced per egg (e.g. adult survivorship and longevity may differ between species).

Table 6: *Breeding parameters of a selection of* Larus *species and the associated trend of that particular population compared with results for black-billed gulls in Southland.*

Species	Clutch size	Breeding success	Fledglings per egg	Population trend	Reference
L. bulleri (islands)	1.94 (SE 0.02)	0.44	0.23	Declining	This study
L. bulleri (banks)	1.87 (SE 0.01)	0.31 (SE 0.09)	0.17	Declining	This study
L. novaehollandiae scopulinus	1.94 (SD 0.09)	0.61 (SD 0.26)	0.31	Declining	Mills et al. 2008
L. audouinii	2.74 (SE 0.02)	1.12 (SE 0.30)	0.41	Increasing	Genovart et al. 2003
L. ridibundus	2.6 (SD 0.07)	0.7 (SD 1.0)	0.27	Increasing	Thyen and Becker 2006
L. argentatus	2.8 (SE 0.1)	1.2 (SE 0.1)	0.43	Declining	Ellis and Good 2006
L. marinus	2.8 (SE 0.1)	0.9 (SE 0.1)	0.32	Increasing	Ellis and Good 2006
L. occidentalis x glaucescens	2.38 (SE 0.13)[1]	0.77 (SE 0.27)[1]	0.32	Unknown	Good 2002

[1]Figures do not include estimates made in sand habitat which was specifically sampled to investigate the extent of poor reproduction

Frequency of breeding

Major fluctuations in the numbers of birds breeding annually have been reported for at least two species of gulls, Hartlaub's gull (Crawford and Underhill 2003) and red-billed gull (Mills et al. 2008). In the case of Kaikoura red-billed gulls, the number of birds breeding as a percentage of those attending colonies ranged between 28.2-98.4% (Mills et al. 2008). The percentage of black-billed gulls breeding clearly varies between colonies, but there was no indication of a pattern between years (Chapter 2). However, there was good evidence that many non-breeding birds do not attend a colony. The number of gulls counted in Southland colonies in 2005 was approximately half that counted in 2004 and 2006 (equating to a 'loss' of approximately 30,000 gulls in 2005; Table 2). Birds banded between 1997 and 2000 were also re-sighted within colonies at half the rate in 2005 than in 2006 as were first-year birds (Chapter 3). The mean number of birds counted per colony was also lower. Given the precision with which photographs can be counted (Chapter 2), the ability to locate all colonies from aerial surveys, the relatively short breeding dispersal distances of black-billed gulls (Chapter 3) and the lack of a monitoring bias that could account for so many birds (Chapter 2), it is most likely that large numbers of gulls were absent from colonies, and presumably not breeding. Food availability seems the most likely reason explaining why much of the Southland population did not breed in 2005, as the season was largely unaffected by floods, but there is no evidence to support this.

Several observations support the idea that many black-billed gulls did not breed in 2005. Ground surveys carried out to locate colonies early in the 2005 season found similar numbers of colonies and birds establishing on Southland's four main rivers to the previous year. Rapidly, over a period of two weeks, many colonies 'vanished' prior to breeding and comparable numbers were not relocated elsewhere despite intensive efforts. A farmer reported a breeding colony on the Whitestone River that established in eight of the nine years since 1998, and returned in 2005, but also deserted prior to initiation of breeding (B. McMillan pers. comm. 2006).

The possibility that large numbers of breeding adults do not attend colonies in some years would have major implications for overall productivity and recovery from decline. However, if such breeding deferral does indeed occur, the frequency at which it occurs is unknown. Given the propensity for major, annual population fluctuations within rivers, deferral can only be investigated by region-wide monitoring (as opposed to monitoring key waterways as presently occurs). Likewise, the proportion of non-breeders in a colony cannot be measured by the current monitoring method (aerial photography; Chapter 2) which means that any trends in the frequency of non-breeding in colonies would not be observed.

Survival

Adult survivorship has the most influence on black-billed gull population trends of any demographic parameter. This has long been known to be a characteristic of long-lived bird species (Pfister 1998). Consequently, management actions focused on the improvement of the survival of adult black-billed gulls will have the most impact on population trends. However, it is also recognised that effecting such improvements can be extremely difficult, and that it may in fact be more cost-effective to direct efforts towards improving other parameters, such as breeding success (Baxter et al. 2006). However, in the breeding success model (Model 4), an increase to 1.8 fledglings per nest was required to stabilise the population. This is only slightly lower than the average clutch size (1.9, SE 0.01) and considerably higher than the most successful monitored colony (0.88 fledglings/nest) and, as such, will be unachievable in reality.

The extent to which the survival rates of Kaikoura red-billed gulls are a suitable approximation of the survival rates of Southland's black-billed gulls is unknown. Both populations are affected by introduced predators and black-backed gulls; predation levels reported at Kaikoura (25% of eggs and 17% of chicks succumb to predation; Mills 1989) are similar than those found at a bank colony on the Aparima River, Southland (12% of eggs and 21% of chicks; Chapter 5). However, overall, breeding success is considerably lower in Southland. Black-billed gulls are seen in their thousands at Kaikoura during the non-breeding season, often with a rose flush, possibly from feeding on euphausids at sea (P. Langlands pers. comm. 2005), the principle food item of Kaikoura's red-billed gulls (Mills et al. 2008). A Southland black-billed gull banded as an adult was seen in Kaikoura after breeding (J. Mills pers. comm. 2005) suggesting that at least some of the Southland population migrates to this region. Increases in the availability of the planktonic euphausid *Nyctiphanes australis* were shown to positively affect breeding frequency, age at recruitment, adult condition, clutch size and fledging success of red-billed gulls (Mills et al. 2008). The influence of the euphausid's availability on survivorship was not investigated. However, it seems plausible that the availability of euphausids and other marine food sources outside of the breeding season also affects red-billed gulls and black-billed gulls, possibly influencing survival. Additionally, migrating species such as black-billed gulls are likely to experience greater mortality than the more sedentary red-billed gulls (see discussion on evolution and long-distance migration in Alerstam et al. 2003).

Re-sighting rates of 7-9 year-old black-billed gulls were extremely low compared to a relatively high encounter rate for 6 year-old gulls. Differential survival of cohorts has been shown for Kaikoura red-billed gulls where survival to recruitment of cohorts ranged from 6-31% (Mills 1991) and for other species (e.g. Ratcliffe et al. 2002; Imber et al. 2003; Harris et al. 2007). The mean survival of Southland black-billed gulls to age 6-9 was 6.8% (adjusted for birds not sighted in colonies). The frequency of dispersal out of Southland of birds banded as chicks is unknown, though sightings of a Southland gull in an Otago colony and one in a Canterbury colony are evidence of its occurrence. The likelihood of natal dispersal in Southland, however, was found to decrease with distance from the natal colony, suggesting that long distance dispersal events are probably rare (Chapter 3). Nevertheless, the estimate of 6.8% survival to age 6-9 will be an underestimate due to emigration from the region and the probability that an unknown number of the 2000 cohort (age 6) will not have been counted as they could not be distinguished from other gulls of the same cohort sighted within the same colony. The 6.8% survival to ages 6-9 (which does not necessarily equate to recruitment) compares to the 23% survival of red-billed gulls to recruitment (where almost 70% are recruited by age 5). Taking account of possible emigration and under-reporting of actual presence of banded birds, it is plausible that this survival rate is similar or lower than for red-billed gulls. While these estimates of adult and juvenile survival are reliant on minimal data, there is clearly some indication that current survival and recruitment of black-billed gulls may be too low to sustain a stable population.

Density dependent effects

Nest success and breeding success are positively related to the size of black-billed gull colonies. Likewise, the larger, predatory black-backed gull is more likely to disturb smaller colonies (Chapter 5). This is strong evidence of density dependent effects; given that colony size is correlated with population size (Chapter 2), as the population declines, colony sizes decrease and productivity can be expected to decrease further. Some evidence was also found of an Allee effect, that is, below a certain size threshold, colonies have a high probability of complete failure (Chapter 5). Density dependent processes are often modelled using matrices (Caswell 2001). However, modelling an inverse density dependent relationship which acts at low densities, such as the one previously described, simply causes the population to decline to extinction once the threshold is reached (McCallum 2000).

CHAPTER 7

Conservation management of New Zealand's Endangered black-billed gull

Black-billed gulls following the plough, paddocks adjacent to Avondale North colony, Aparima River, 2005 (C. Garden)

ABSTRACT

The status of New Zealand's black-billed gull (*Larus bulleri*) was evaluated after analysis of population trends in Southland and Canterbury. The present classification of Endangered was supported. A conservative listing of Nationally Vulnerable was recommended under the New Zealand Threat Classification System, although if historical rates of decline are detected, the species should be upgraded to Nationally Critical. Predation and disturbance by introduced mammals and the native black-backed gull were found to be the most critical of known threats, significantly affecting productivity, and possibly lowering adult body condition. Weed invasion of river beds was not found to have significantly reduced habitat on key Southland rivers in the last 30-50 years, but could reduce productivity by forcing colonies to establish closer to the water line. The availability and quality of habitat in other regions is unknown. Human disturbance of breeding colonies is commonplace but impacts are probably insignificant compared to rates of predator disturbance. However, the occasional illegal shooting of adult birds in colonies is of great concern. River works such as damming and water abstraction that reduce flows to the point where the number of available islands is reduced should be avoided as islands provide habitat that is significantly safer from terrestrial predators. At least two extreme weather events have caused the death of several thousand adults in Southland in the last 50 years, but their probability of reoccurrence is not known. Ingestion of chemicals such as DDT, its metabolites and other insecticides has not been studied but could be an important threat given the species' diet during the breeding season. Key management actions are recommended and include a full investigation of the aerial monitoring methodology, raising awareness of the plight of the species to reduce disturbance and encourage support for conservation work, the trialling of decoys to attract gulls to nest on islands, annual weed control on island sites and other sites that have a recent history of use, predator control at bank sites. Further research is also recommended, and includes investigation of survival, diet and the vulnerability of small colonies to predation and disturbance.

INTRODUCTION

New Zealand's endemic black-billed gull (*Larus bulleri*) is listed as Endangered by the World Conservation Union (IUCN), the highest threat classification of any gull species (BirdLife

International 2006). The species was listed by the IUCN as 'Least Concern' in 1988 and again in 1994, but this classification was upgraded in 2000 to 'Vulnerable' (BirdLife International 2000) and to 'Endangered' in 2005 (BirdLife International 2006). National surveys for the species in 1995-1997 indicate that approximately 70% of the national population breeds in Southland (Powlesland 1998), the southern-most region of New Zealand. Here, the species is thought to have undergone a rapid decline well in excess of 50% since the 1970s (Taylor 2000, Innes 2003). Most of the remaining population breeds in the Otago, Canterbury and Marlborough regions of the South Island, approximately 5% in the North Island (Powlesland 1998). The species was first observed breeding in the North Island in 1932 and has gradually extended its breeding range and increased in abundance (summary in Southey 2007).

Black-billed gulls breed predominantly on gravel-bedded rivers (Higgins and Davies 1996). Colonies are dense (up to 3.8 nests/m^2; Chapter 5); the species may nest more densely than any other gull (Beer 1966). Colony sites often change from year to year (Beer 1966; Soper 1972; Chapter 4) and annual numbers fluctuate within rivers (O' Donnell and Moore 1983; O'Donnell 1992; Chapter 2) making population trends difficult to assess. Gulls migrate to the coast after breeding, although abundances and locations are poorly known (Higgins and Davies 1996). The species is thought to be affected by a complex array of threats including: introduced predators such as ferrets (*Mustela furo*), stoats (*M. erminea*), cats (*Felis catus*), hedgehogs (*Erinaceus europaeus*) and Norway rats *Rattus norvegicus* (Taylor 2000; Sanders and Maloney 2002; Murphy et al. 2004; the spread of weeds on riverbeds reducing the availability of breeding habitat (Taylor 2000: Dowding and Murphy 2001) and making colonies more vulnerable to flooding (Innes 2003; O'Donnell 2004; Caruso 2006); hydroelectric development, water abstraction, gravel extraction, flood protection and other river modification works reducing or otherwise altering habitat and increasing weeds through the stabilisation or lowering of water flows (Maloney et al. 1999; Taylor 2000; O'Donnell 2004); changes in agricultural practices including extensive conversion of sheep farms to dairying in Southland (Innes 2003) and recreational use of riverbeds causing disturbance to colonies (Taylor 2000). However, threats are only postulated, none have been studied until recently, and their relative impacts are unknown.

This chapter collates historical work and recent research undertaken in Southland that can assist in the formulation of management actions, and addresses the relative extent of known and potential threats. Research methods and results, both from Southland and elsewhere, are summarised briefly to give an overview of all pertinent information relating to management, resulting in some repetition of previous chapters. The severity of threats is ranked and recommendations for species management are given.

METHODS

Population trends

Survey and monitoring methods

Ground surveys appear to have been first undertaken specifically for black-billed gull colonies in 1974; the Oreti River in Southland (R. Sutton and M. Barlow, unpubl. data) and the lower Waitaki River in Otago (C. O'Donnell unpubl. data). In 1977, all main rivers in Southland were surveyed by foot, giving the first baseline population estimate for the region (R. Sutton and M. Barlow, unpubl. data; methods in Chapter 2). In Canterbury, annual ground monitoring was established on the Ashburton River in 1981 using a combination of nests counts and repeat counts of adults from a distance (data were not collected for four years from 1991 and five years from 2000; O'Donnell and Moore 1983; C. O'Donnell unpubl. data; C. O'Donnell pers. comm. 2008). In 1995, aerial monitoring/photography of black-billed gull colonies in Southland was initiated and was carried out by Ornithological Society of New Zealand (OSNZ) members on a more-or-less annual basis until 2003 (methods in Chapter 2). A nationwide survey was completed by OSNZ members over three consecutive seasons from 1995-1997 (Powlesland 1998). OSNZ members have been completing winter and summer counts of black-billed gulls in the Firth of Thames and greater Auckland region (part of the small northern population) for over 60 years (Southey 2007). In addition to these efforts, occasional surveys have been carried out in most regions since the 1980s.

The Southland study monitored numbers on the region's four main rivers from 2004-2006 following aerial monitoring methods employed by Southland OSNZ. In 2004, reports of other colony locations in Southland were sought, but in 2005 and 2006, the majority of all other key rivers and streams in the region were also aerially surveyed. Vertical photography of colonies was trialled, in part to test the efficacy of automated counting software (R. Mathieu and R.K. McClellan, unpubl. data). A pilot study to investigate the variation in counts made from aerial photography was undertaken in six colonies in 2006. Three counts separated by two-week intervals were completed (Chapter 2).

Population trends

In Southland, the two types of index counts (historical counts of nests using estimates of nest density and aerial photography) were evaluated and compared by calculating a ratio of gulls in photographs to nests on the ground in monitored colonies from 2004-2006. Counts from historical ground surveys and aerial photography were then calibrated. Linear regression was applied to the natural log of resulting counts of breeding birds. This relatively simple method of analysis was used given the scarcity of historical ground counts and the use and calibration of two index methods. Data from the Ashburton River in Canterbury were also analysed.

Colony monitoring

Productivity monitoring

In Southland, estimates of the proportion of non-breeders present in colonies were obtained by estimating the number of gulls present (from counts of birds in aerial photographs) and counts of the number of nests present. Numbers of nests were estimated either by complete ground counts where colonies were sufficiently small or by using geo-referenced aerial photographs within a GIS. The latter method involved estimating different nest densities on mapped transects and relating this to areas of different nest densities across the entire colony that had been digitised in the GIS (Chapter 2).

Nest success (percentage of nests hatching at least one chick) was monitored in over 5000 nests in 21 colonies from 2004-2006 using 2 m strip transects. Nests were marked as they were initiated and checked every 3-5 days (occasionally longer when river levels were high or rain prevented monitoring; Chapter 5). Generalised linear modelling was used to investigate the relationship between a number of potential explanatory variables and nest success.

Estimating breeding success (the number of fledglings per nest) was complicated by the species' characteristic desertion of the nesting area when chicks are 4-8 days of age (R.K. McClellan unpubl. data) and was initially measured by mark-recapture of chicks prior to fledging at a small number of colonies. The method resulted in the fledgling population being overestimated, and a second method was trialled which involved 'herding' the chicks, photographing the group and counting the number of birds on a digital image (Chapter 5). The number of nests in the colony was measured as previously described.

Additionally, infra-red video camera equipment was used to investigate the impact and behaviour of predators within a bank colony which numbered approximately 2000 nests and the associated behaviour of the gulls. Three sets of cameras were installed for a two-month period. Cameras were moved when all nests had either failed or eggs had hatched and filmed multiple nests at each location (3-13 nests in view at night). Additionally, records were kept of dead adults found at colonies, the general abundance of dead chicks, and any obvious mortality events (Chapter 5).

Extremely few black-billed gull colonies have been monitored in other regions of New Zealand, and no information is published.

Colony site characteristics

In Southland, colony site selection was examined by assessing re-use of colony sites using logistic regression. Only re-use in the following year was considered i.e. colony sites used in 2004 re-used in 2005, and colony sites used in 2005 re-used in 2006. Potential explanatory variables were colony location (island, bank or partial bank), colony size, colony success, gravel extraction, weed cover within the colony, weed cover within the potential area, site stability, use in 2003 and the percentage area of dairy farms around colony sites (methods in Chapter 4). Site selection was also assessed by determining the use versus availability of island and bank sites within rivers and the use of key rivers versus availability of habitat. The possible influence of dairy farms was assessed by comparing the area of dairy farms within a 2 km radius of colonies to the area of dairy farms in a 2 km strip either side of the main rivers. The presence of weeds at the highest point within a colony's available area was recorded and the possibility that this increased vulnerability to flooding by forcing gulls to nest closer to the water line was determined by observations (Chapter 4).

The relationship between gravel patch sizes, colony size and colony productivity was examined. The available gravel area for colonies was calculated using geo-referenced vertical aerial photographs of the colonies and colony size was estimated by counts of gulls in the photographs (Chapters 4 and 5).

Colony site susceptibility to flooding was examined by surveying single cross-sections through the highest point of the colony using a staff and level. The cross-sections were then used to make hydraulic calculations using river flows measured at the nearest river gauge to identify the area of water required to reach the colony boundary. Results were checked against actual flood events that were observed at eight of 11 colony sites (Chapter 4). Using data from the same river gauges, changes in the frequency of floods greater or equal to that magnitude were measured between the start of September and the end of December (approximate length of the breeding season) since installation of the gauge (up to 54 years; Appendix J).

General observations at colonies

In Southland, observations of disturbance by black-backed gulls were recorded from a distance, either prior to colonies being approached for nest monitoring or during other observations (Chapter 4). Reduced productivity resulting from flood events was assessed from results from colony monitoring and from general observations (Appendix J). Disturbance of gull colonies by people and stock in Southland from 2004-2006 was recorded from visual observations and from reports from other members of the public. Mortality of adults within colonies was recorded, as was the general extent of chick mortality during the breeding season.

Banding and re-sighting

Banding and re-sighting projects

Tens of thousands of black-billed gulls have been banded throughout New Zealand over the last 60 years but band re-sighting is largely opportunistic. A banding study in Auckland at the northernmost extent of the species' range was initiated in 1994 and is ongoing (T. Habraken pers. comm. 2008).

In Southland, 1611 black-billed gull chicks were banded between 1997 and 2005. Just prior to fledging, several people herded 100-200 chicks into a temporary pen where they were captured, put into boxes, then banded and released. In 2005, 67 incubating adults were banded by capturing them on the nest using a drop trap (Mills and Ryder 1979). Chicks were banded with band combinations specific to colony and year, and adults were banded with unique combinations. Cohort combinations were used in keeping with original banding methods (1997-2000) and to allow farmers to report sightings with less chance of error. Searches for banded birds were undertaken during the 2005 and 2006 breeding seasons. Newly-forming colonies were located in August and September by driving roads in closest proximity to rivers. Further colonies were occasionally located during aerial monitoring in late October/November. Colonies were visited on a number of occasions throughout the season and banded birds were observed using telescopes. Other congregations of birds on rivers and paddocks were also searched. A large number of media releases in magazines, newspapers, rural newsletters, radio and television encouraged Southlanders to report banded bird sightings (Chapter 3).

Natal and breeding dispersal

Banding in Canterbury resulted in the documentation of a small number of dispersal events, some of which were of two-year old gulls (i.e. natal dispersal; Cunningham 1951; Bull 1953; Bull 1954). The Auckland banding study will result in records of natal and breeding dispersal within the northern half of North Island (T. Habraken pers. comm. 2005). In Southland, re-sighting of gulls banded as chicks was carried out during the 2005 and 2006 seasons throughout the region. Minimum rates for natal dispersal were obtained (birds banded as chicks in 2004 and re-sighted in 2006) as individual birds from a cohort could not be distinguished (unless they were observed at the same time). Re-sighting of gulls banded as adults in 2005 was carried out in 2006. Publicising the study resulted in sightings of Southland birds elsewhere in New Zealand (Chapter 3).

Survival of adults and juveniles

Birds banded in Rotorua in the 1980s (Innes and Taylor 1984) have provided estimates of longevity (G. Taylor pers. comm. 2008). Banding and re-sighting of black-billed gulls in the greater Auckland region will eventually lead to estimates of survivorship in the northernmost range of the species (T. Habraken pers. comm. 2008). In Southland, cohort banding of gull chicks means re-sighting data cannot be used to estimate survival using mark-recapture techniques. Minimum survival estimates were calculated from the re-sighting of cohorts in the 2006 season, but these were underestimates due to difficulty in distinguishing individuals of a cohort within a colony, the likelihood that some gulls would have dispersed out of the region and the difficulty in re-sighting banded gulls within dense, large colonies. Likewise, a minimum estimate for adult survival was obtained from re-sightings of adults banded in 2005 and re-sighted in 2006 (Chapter 3).

GIS analysis of vegetation change in aerial photographs of rivers

The extent of the spread of weeds, the potential loss of gravel breeding habitat and the reduction in gravel patch sizes on Southland rivers were assessed using remote sensing in a GIS. Two sections of similar length and distance inland were selected on both the Waiau and

Oreti rivers. The total length analysed for each river was approximately 21 km. Series of aerial photographs of the sections were sourced that were taken between 1949 and 2002 (approximately one per decade). The 2002 photographs were matched to existing geo-referenced orthophotographs, and each series was matched to the 2002 photographs by aerotriangulation using 20-40 ground control points per photograph. Habitat classification was done manually with ArcGIS 9. A polyline was drawn to represent the study limits which included all major morphological changes within the river during the period of investigation. Habitat types were kept simple, and related to both breeding habitat quality and the relative stability of the habitat (e.g. gravel-dominated versus tree/shrub-dominated). Polygons were drawn around each habitat type and, in addition to habitat classification the polygon was classified as island or bank habitat. Categories were summed for each year. The number and area of all gravel patches in the four sections was calculated (Chapter 4).

Population modelling

The population decline of Southland's black-billed gulls was examined using matrix models. Given many survival and reproductive parameters of the population were poorly known, data from the Kaikoura red-billed gull population were used as approximations for black-billed gull rates. This species is most closely related to black-billed gulls (Chu 1998) and the population has been intensively studied for over 40 years (Mills 1989; Mills 1991; Mills et al. 2008). The sensitivity and elasticity of λ (finite rate of increase) to survival and reproductive parameters was calculated (Chapter 6).

RESULTS

Population trends

Survey and monitoring methods

In Southland, the two index count methods (ground and aerial-based counts) were evaluated. Ground-based counts (1970s and 1980s) used an estimate of nest density calculated from a small number of colonies to extrapolate nest numbers across estimates of colony areas. The precision and accuracy of the method could not be measured. Aerial photography (1995 onwards) provided a quicker, relatively inexpensive method that involved no colony disturbance. Good quality photographs resulted in precise estimates of numbers as measured by three observers. However, the method was a poor index of the breeding population, largely because non-breeders were found to comprise a substantial proportion of each colony and the proportion varied significantly between colonies (from 0.9 gulls per nest to 3.95 gulls per nest). Additionally, the pilot study which investigated variation in colony counts over time found major discrepancies in colony size estimates with overall counts decreasing by over a quarter within a month, and one colony declining by over 60%. Vertical photography and automated counting may reduce the effort required to manually count aerial photographs, but its precision is not yet known (R. Mathieu and R.K. McClellan, unpubl. data).

Population trends

The number of breeding birds on Southland's four main rivers has undergone a very rapid decline in the past 30 years, exceeding 50% and possibly in excess of 80% (Chapter 2; Table 8). The number of colonies has also significantly decreased (Chapter 2; linear regression, $P<0.01$, Figure 4). However, no statistically significant trends in the number of breeding birds are apparent since aerial monitoring was initiated in 1995 although, overall, the trend is of a decline equating to 2.6%/year. Colony numbers have decreased at a rate of 4.9%/year since 1996 (linear regression, $P<0.10$). Correlation coefficients for colony numbers and total breeding bird numbers (corrected counts) for each river varied from those with relatively weak relationships to those with high correlation. Over all rivers, the correlation coefficient was 0.95.

Few datasets exist outside of Southland. Numbers of breeding birds on the Ashburton River, Canterbury have declined at a rate of 3.6%/year or 58.6% in 25 years ($P<10$; C. O'Donnell unpubl. data). In the greater Auckland region (part of the small North Island population), black-billed gulls were first observed during summer counts in the early 1960s, and varied between 0 and 200 birds until approximately 1990, after which numbers rapidly increased to c.1000 birds counted (Southey 2008).

Observations of the abundance of black-billed gulls in Southland prior to the first surveys in 1974 are sparse and difficult to interpret (Chapter 2). There is some suggestion that population levels were even higher in previous decades (Chapter 2), but it seems likely that earlier numbers (i.e. pre-1900) were lower given the probable unpredictability and availability of food sources.

Natal and breeding dispersal

The rate of natal and breeding dispersal of Southland's black-billed gulls is very high compared to that of other colonial seabirds, and is most likely due to the species' unstable breeding habitat. A minimum of 85 second-year birds (12.6% of the cohort) were re-sighted at 20 breeding colonies during 2006. Natal dispersal (dispersal from the site of hatching to the site of first or potential reproduction) was 100% as no colonies re-formed in natal locations. Mean dispersal was 35.7 km (SE 5.7) and approximately 70% of dispersal was out of the natal catchment. Larger colonies had less re-sightings than smaller colonies, demonstrating the difficulty in observing banded birds in dense aggregations. A one-year old bird was observed in a colony in Otago (c.250 km) and a seven- or nine-year old bird was sighted in a Canterbury colony (c.460 km) indicating that the study area was too small to determine true natal dispersal rates and distances. However, colonies further from natal locations had fewer re-sightings than those that were closer suggesting long distance dispersal events are uncommon. Overlap analysis of minimum convex polygons that delineated the extent of dispersal of all individuals from a cohort showed a high degree of overlap between all colonies. The range of the oldest cohort (year 2000) extended throughout lowland Southland. These results confirm that Southland black-billed gulls constitute a single intermixing population.

Sixty-seven adult gulls were banded in three colonies in 2005; 39 (58.2%) of these were re-sighted in 2006, 29 in breeding colonies. Mean breeding dispersal was 23.5 km (SE 4.3) and was significantly lower than the mean random dispersal distance to all colonies for adults from two of the three banding locations. Colonies re-formed at one of the three 2005 locations and nine of 12 gulls banded at this site and re-sighted returned the following season despite the complete failure of the colony in 2005. Though the adult sample was very small, breeding dispersal appeared to be unrelated to previous breeding success, the availability of the previous year's colony site and dispersing birds did not move as groups. For example, of 11 adults banded at a location that was not re-used the following season, six remained in the catchment but were divided among five colonies, and the five that dispersed from the catchment were in three different colonies in two different catchments.

Elsewhere in the South Island, observations of gulls banded on the Ashley River in Canterbury resulted in a small number of published dispersal events. A bird was found nesting at two years of age on the Waipara River, approximately 30 km distance (Bull 1954) and several were found at the natal colony at one and two years of age (Dawson 1954).

Out of the breeding season, banded Southland birds are known to migrate to southern, eastern and northern coasts of the South Island, and some birds may remain inland in Southland (Chapter 3). Post-breeding movements indicate Canterbury and Marlborough birds will migrate to the North Island (Cunningham 1951; Higgins and Davies 1996). Another Ashley bird was found at Picton on the northern coast of the South Island at seven months (Bull 1953; a Southland banded bird was also re-sighted here). Sutton (1966) observed from black-billed gull re-sighting reports that there was "a marked tendency" for first year birds to "move northwards" in the non-breeding season.

Impact of predation

Nest success in Southland colonies varied between 18.7% (SE 1.1) and 94.0% (SE 0.1) and was significantly higher on islands within rivers (mean 90.1%, SE 2.1) than on riverbanks (mean 66.8%, SE 2.2) suggesting reduced predator access to colonies surrounded by water flows of greater than approximately 1 cumec. Modelling indicated that the position of the colony (i.e. on a bank or island) best explained the variation in nest success implying that introduced terrestrial predators such as cats, stoats and ferrets are the principal cause of variation in colony productivity. The use of infra-red cameras in a bank colony recorded two or more cats and one or more ferrets causing several hundred disturbances during two months of the breeding season, resulting in half of all observed egg mortality. However, no eggs were taken by predators; instead, egg mortality was the result of predator disturbance only. Disturbances resulted in the abandonment of nests, knocking eggs out of nests, and predation of eggs by other black-billed gulls during disturbances. In contrast, direct predation resulted in 80% of all observed chick mortality (from 0-10 days of age).

Mean breeding success was 0.32 fledglings per nest (SE 0.08, range 0-0.88), however, too few data were available to examine differences in breeding success between islands and banks. Several further weeks elapse before the young of the year depart the colony sites (pers. obs.) during which time juveniles continue to be subject to predation pressure. Post-fledgling mortality was not measured (but see Keedwell 2003), however, 130 fledglings were found dead at one colony after the season had ended, and a further three major mortality events were reported (Chapter 5). Carcasses were always uneaten, and it is presumed that stoats were responsible.

Nest success and breeding success both showed a positive linear relationship with colony size. However, the three smallest colonies failed to produce fledglings, suggesting the existence of an Allee effect i.e. a colony size threshold below which colonies are less likely to be successful. The study also indicated that predatory black-backed gulls tended to disturb smaller colonies only.

Adult gulls were weighed as part of banding procedures at three colonies and birds were found to be significantly heavier in the island colony compared to the two bank colonies. The lightest adults were found in the colony that eventually abandoned.

Outside of Southland, few black-billed gull colonies have been monitored and no results have been published. Monitoring was initiated in several colonies in Canterbury and Marlborough in 2008 (F. Schmechel pers. comm. 2008; M. Sanders pers. comm. 2008).

Impact of weeds

In Southland, colony size was shown to be related to colony area which, in turn, was related to available area or gravel patch size (Chapter 4). Colony size was positively related to nest success and breeding success (Chapter 5) and, as a consequence, any reduction in gravel patch sizes due to encroachment by exotic vegetation is likely to result in lowered productivity of black-billed gulls. However, analysis of aerial photography of the Waiau and Oreti rivers using remote sensing indicated that the area of gravel habitats had not declined on the lower Waiau and mid Oreti over 30-50 years. Declines in gravel habitat on the lower Oreti were most likely due to excessive gravel extraction and other river modification works, while the gradual decline on the mid Waiau was most likely a response to damming although a decline may still be occurring. Approximately 200 gravel patches of greater than 900 m^2 in area (the smallest gravel patch used by colonies monitored from 2004-2006) were present in c.25 km of the Oreti and Waiau rivers in 2002 photographs. This suggests that in excess of 1000 patches may be present on Southland rivers in any year, although these may not necessarily represent quality habitat as they may be too low to the water. Given less than 25 colonies established in each year from 2004-2006, ample habitat appears to remain in Southland (Chapter 4).

Weeds were present at 47 of 48 colony sites but weed cover was very low within the immediate nesting area (generally 5% or less). Weeds were present at the highest point at 62.5% of colony sites, restricting use by gulls, and suggesting an increased vulnerability to flooding. However, gulls did not nest at the highest point on a quarter of occasions when it was free of vegetation. Logistic modelling indicated that low weed cover within the immediate nesting area increased the likelihood that a colony was re-used in the following season (Chapter 4).

No other research has been completed on the impact of weeds on black-billed gulls elsewhere in New Zealand. Maloney et al. (1999) showed that infestation by willow species decreased available nesting habitat and that willow removal benefitted some river-nesting bird species. The possibility that the presence of weeds increases predation rates by giving predators cover (Pascoe 1995; Rebergen et al. 1998) was investigated by Maloney et al. (1999) but results were inconclusive.

Impact of floods

Colony sites varied significantly in their vulnerability to flooding with some sites having a probability of flooding of almost four floods a season, indicating that gulls do not necessarily choose secure sites to breed. Unusually, no floods occurred during the 2004 and 2005 seasons, but in 2006 flooding affected the majority of colonies, mostly at the initiation of nesting and again towards the end of the season. Three colonies, however, experienced several floods but remained at the location, contrary to anecdotal observations that gulls will generally abandon sites if flooded (and will occasionally resort to breeding on adjacent pasture). Productivity appeared to be moderately to severely affected in these colonies (e.g. approximately 20 fledglings produced from c.700 nests in the most affected colony). Two of the three colonies had very extended breeding seasons, presumably due to extensive re-nesting (Appendix J). Though the species has most likely evolved to cope with the effects of flooding on productivity, changes in the frequency of flooding over time may impact overall productivity (Appendix J).

Impact of disturbance

During the 2004-2006 breeding seasons in Southland, a number of disturbance events were recorded that had the potential to affect colony productivity. Greatest impact was from vehicles driven through two monitored colonies and illegal shooting of adult gulls at two non-monitored colonies. At the latter, approximately 90 adults in total were shot; productivity may have been affected to some degree by disturbance as well as mortality. Children throwing rocks killed a banded bird at another non-monitored colony (M. Hug pers. comm. 2005) and probably damaged nests at another (O. Dovey pers. comm. 2006). Other observed human disturbances of colonies were likely to have had minimal impact. In recent years, a man was convicted for driving a vehicle through a black-billed gull colony (L. Esler pers. comm. 2004). In January 2008, several hundred adults and chicks were shot in a large Canterbury colony, a loss of more than half of the birds present (C. Alexander pers. comm. 2008).

Impact of land use changes

Southland's black-billed gull population is likely to have initially increased due to the almost complete conversion of lowland native forest and wetlands to agricultural land during the 19th and 20th centuries, although it is largely impossible to accurately infer early population trends from existing reports. The diet of black-billed gulls in Southland prior to deforestation is largely unknown. The few historical records that exist indicate that the species hawked for moths and beetles over forest and tussock grasslands (Travers 1871; Stead 1932; Anon 1946; Stidolph 1955) which still occurs (Stu Sutherland pers. comm. 2006; R.K. McClellan unpubl. data). Farmland is likely to have provided a more predictable, consistent food supply (Chapter 2). Chicks in Southland black-billed gull colonies are almost exclusively fed agricultural invertebrates, particularly earthworms (R.K. McClellan unpubl. data) which are taken from surrounding sheep, dairy, beef and deer farms. Diet studies in the Canterbury region are also dominated by pastoral invertebrates (Dawson 1958; Moeed 1976).

Gulls appear to have halted post-breeding migration during the 1940s to 1960s and remained inland throughout the year (Chapter 2). The common practice of leaving fields fallow over winter may have provided sufficient food well into winter months. Black-billed gulls may have been able to double brood during these times of high and consistent food availability; while a contentious idea, double-brooding has been reported for red-billed gulls in Western Australia (Nicholls 1972) and may occur in Hartlaub's gull in South Africa, a species once recognised as red-billed gull (Crawford and Underhill 2003). Likewise, the absence of migration would be likely to improve survival parameters, particularly of first year birds. These improvements in reproductive and survival parameters could have produced a major population increase over many decades, despite the effects of introduced predators.

In recent times, the number of sheep in Southland has begun to decline while the dairy cattle population has multiplied more than ten-fold (Table 1). Conversion of sheep and beef farms is continuing and it is predicted there could be as many as 900 farms in 2010/11 (G. Morgan, Environment Southland pers. comm. 2008). This may have some impact on food sources for gulls as cattle cause greater compaction of soil (Nguyen et al. 1998; Drewry et al. 2000; Murphy et al. 2006) which can reduce earthworm abundance (Hansen 1996; Murphy et al. 2006). In addition, dairy farms maintain long grass lengths, possibly reducing the availability of invertebrates such as earthworms (Innes 2003; pers. obs.). The apparently positive impact of historical land conversion from native vegetation to pasture and crops may be offset by these increasingly intensive farming practices, high conversion rates to dairy farming, high use of fertilisers, herbicides and pesticides (including historical use of DDT) and changes in land management including year-round maintenance of grassed pastures, direct drilling of new grass seed crops and less ploughing.

Table 1: *Changes in the number of sheep, dairy cattle and dairy farms in Southland between 1900 and 2008.*

Year	Sheep	Dairy cattle	Dairy farms
1900	1.2 million[1]	26,000[1]	
1950	3.5 million[1]	52,000[1]	
1990	8.9 million[2]	38,000[2]	c.200[3]
1999	6.7 million[2]	233,000[2]	c.560[3]
2007	5.7 million[2]	430,000[2]	
2008			c.750[4]

[1]Critchfield (1956)

[2]http://www.maf.govt.nz/mafnet/rural-nz/

[3]Environment Southland (2000)

[4]Gary Morgan, Environment Southland pers. comm. (2008)

However, research in Southland illustrated that gull colonies did not establish in areas away from dairy farms, although this method of investigating the influence of food availability on site selection may not have been particularly sensitive (Chapter 4).

Impact of river works

In Southland during 1974, 250,000 cubic yards of gravel per annum were extracted from a 12 km section of the lower Oreti River (Ledington 2007). This rate of extraction was considered to be far in excess of supply rates (and on other rivers; Hicks et al. 2005 in Ledington 2007);

the lower Oreti has since lowered by over one metre (Hudson 1997 in Ledington 2007). GIS analysis of aerial photographs of an area of the river that included part of this section showed that the majority of gravel habitat disappeared between 1976 and 2002. This section had supported the largest black-billed gull colonies ever reported in New Zealand during the 1970s and 1980s, but no colonies have been found since the initiation of aerial monitoring in 1995 (Chapter 4).

Paradoxically, logistic regression indicated that the presence of active gravel extraction works strongly increased the likelihood of re-use by black-billed gulls. This result was based on two sites with gravel extraction activities that were both re-used, and have been regularly used by gulls over the last 10 years. The sites presumably appeal to black-billed gulls as the activity from large machinery acts to clear gravel of weeds. This could potentially have negative results if extraction rates are greater than supply rates, as colony sites that establish at such locations could become more vulnerable to flooding as locations are gradually modified and lowered. Additionally, it is also problematic for extraction companies as it is illegal to disturb breeding gulls (Chapter 4).

The Manapouri dam was built in 1972 in the headwaters of the Waiau River, Southland. GIS analysis of aerial photography showed a substantial increase in gravel habitat after dam construction as water levels were reduced to less than 95% of the river's original flow. After this initial increase, gravel areas decreased on the mid Waiau as newly exposed areas were colonised by exotic vegetation; this trend may be continuing. On the lower Waiau, mobile substrates remained relatively stable. Prior to the dam's installation, approximately 80 islands were present within the study area. After dam construction, the number of islands decreased by approximately 75% with little variation between photographic series (Chapter 4).

Though Southland rivers have very few dams, many hydroelectric structures have been established on other South Island rivers and lakes (e.g. eight in the upper Waitaki River basin in Otago; Caruso 2006). Additionally, abstraction for horticultural or agricultural purposes is widespread throughout the South Island and may also affect gulls through lowering of water levels and other impacts (O'Donnell 2004). However, research documenting changes due to abstraction or hydroelectric development is sparse, particularly in regard to weed infestation and the resulting loss of breeding habitat for river bird species. Three hydroelectric dams and a network of canals and control structures on the Waitaki River reduced the riverbed from 2 km wide to approximately 0.5 km wide between 1936 and 2001. Trees and bushes on the riverbed increased from 7% to 55% over the same period despite 40 years of weed control and a 100-year return period flood in 1995 (Tal et al. 2004).

Influence of climate

In 2005, aerial photographic surveys of Southland's rivers found 25,000-30,000 less birds (approximately half the population) present in colonies compared to 2004 and 2006. It is thought that this represents birds that did not breed. The frequency of occurrence of breeding deferral is not known, but may related to one or more climatic factors.

Climate extremes

Major mortality events have occurred during extreme climate events in Southland over the last 30-40 years. Droughts occurred during several seasons in the 1970s and verbal reports indicate that many thousands of birds may have died of starvation when they were unable to access invertebrates in pastures. The single published estimate of mortality was of 326 dead gulls over 10 miles (16.1 km) on a minor road (Edgar 1975). The gulls were thought to have been attracted to the roads initially for invertebrates but, too weak to avoid traffic, the birds were killed, and the resulting carcasses became sources of further invertebrates. It is plausible that approximately 5% of the total population at the time died during the 1974 season, but possibly significantly more. It is not clear whether gulls were affected during other severe droughts that occurred in that decade.

In 1996, a heavy snowfall in late July and two weeks of subsequent severe frosts prevented many species of birds from feeding in paddocks. High mortality, particularly of black-billed gulls, was reported (Esler 1996; Wood 1998). A survey found 244 dead black-billed gulls on a 27 km stretch of highway between Invercargill and Winton. The birds were thought to have been attracted to the asphalt where the snow was quickest to clear. This cold snap is considered to be a one-in-one hundred year event (Fraser 2002).

No such reports of mortality exist from other regions in New Zealand despite the Otago, Canterbury and Marlborough regions being much drier and more prone to severe drought than Southland.

Climate change

Few reports or papers exist on the effects or possible effects of a changing climate on New Zealand's bird species. Reviewing published accounts of the timing of return from migration, laying of first eggs and mean laying dates suggests that black-billed gulls may now be laying approximately one month earlier than 50-70 years ago (Appendix K). The possible implications of earlier breeding include potentially positive outcomes such as larger clutch sizes (Winkler et al. 2002) or longer breeding seasons (Martin 2007), or negative outcomes such as poor synchrony with periods of high availability of food sources resulting in lower productivity (Visser et al. 1998; Both and Visser 2001). Global warming is also predicted to affect New Zealand's rainfall patterns (Ministry for the Environment 2001). Analysis of the frequency of floods over 2-5 decades that would reach individual study colonies indicates that the likelihood of flooding in two eastern Southland rivers has doubled over 50 years (Appendix J).

Population modelling

Black-billed gulls are able to breed at two years of age (Dawson 1954; Chapter 3) although the median age at first breeding is likely to be similar to the closely related red-billed gull (BirdLife International 2006). Black-billed gulls banded in Rotorua in the 1980s (Innes and Taylor 1984) have provided estimates of longevity; the oldest gull re-sighted to date was 23 (G. Taylor pers. comm. 2008). The oldest red-billed gull observed to date was 29 (Mills 1991). A matrix model was developed based on reproductive and survival rates published for the Kaikoura red-billed gull population. The model gave a greater rate of decrease than the observed population decline (λ=-0.075 compared to a fitted exponential trend of -0.039). The underestimation of one or more parameters could be due in part to adult survival estimates having been assessed many years ago (Mills 1991) as new and improved methods of analysis have resulted in higher survival rates from the same datasets (Weimerskirch 2002). The model was altered by replacing average breeding success of red-billed gulls (0.60 fledglings per nest) with the average breeding success found for Southland black-billed gulls (0.32) causing the rate of decrease to drop to λ=-0.092. This rate was very similar to the decline rate of black-billed gulls observed on the Oreti River, Southland, from 1974 to 2006 (fitted exponential trend =-0.100). The survival of black-billed gulls from fledging to 6-9 appeared to be lower than for Kaikoura red-billed gulls though emigration from the region and difficulty in re-sighting and individually identifying cohort banded birds were recognised as issues (Chapter 6).

Sensitivity and elasticity (including arcsine elasticity) estimates for adult survival were extremely high relative to other parameters indicating that management efforts directed towards improving adult survival would have the most impact on population trends. However, actions that improve other, less sensitive, parameters may be more cost-effective (Baxter et al. 2006). Models were trialled that altered one or more parameters sufficient to stabilise the population trajectory while keeping others constant. These models found that virtually 100% breeding success was necessary to create a stable population, or adult survival of 97%, or survival of 0-1 year olds of 80%. Breeding frequencies of 100% for all age groups was insufficient to create a stable population. These results indicate that significant improvements would need to be made across many survival and reproductive parameters to reverse the decline. Crucially, however, a large amount of fieldwork would need to be completed to verify the accuracy of survival and reproductive estimates used to represent Southland's black-billed gull population (Chapter 6).

DISCUSSION AND MANAGEMENT RECOMMENDATIONS

Status of black-billed gulls

The black-billed gull was upgraded to Endangered in 2005 in response to increased information regarding decline rates in Southland and elsewhere (BirdLife International 2006). Detailed analysis of population trends exposes the quality of the Southland data, raising questions about the accuracy of estimation procedures used in the 1970s and 1980s and about the sensitivity and accuracy of modern-day aerial monitoring methods. Calibrating the results from the two methods introduces a further set of assumptions.

A reasonable estimate of total mature individuals in New Zealand is approximately 90,000. This assumes that the Southland population is approximately 64,000 breeding birds (determined from the highest number found in a season during thorough surveys of the region from 2004-2006) and that Southland supports approximately 70% of the population (Powlesland 1998). Combining the overall decline rate in Southland (83.5% in 30 years) with the decline rate from the Ashburton River, Canterbury (58.6% in 25 years; the most robust of all datasets in New Zealand) and assuming this rate is representative of the remaining South Island population, the overall decline is equivalent to 78.0% in 30 years. This is well in excess of the IUCN criteria for Endangered of a 50% population reduction in three generations, and suggests that issues with the data would be unlikely to affect the current classification.

The New Zealand Threat Classification System was revised in 2008 (Townsend et al. 2008). Under this system, if a population consists of 20,000-100,000 mature individuals and there is an ongoing or predicted decline of 50-70% in three generations, the species is Nationally Vulnerable. However, once a population declines at over 70% in three generations, it becomes Nationally Critical. Given the uncertainties associated with the Southland data, and the possibility that the population may have stabilised to some extent in the last 10 years, the more appropriate listing is Nationally Vulnerable. The expert panel charged with classifying New Zealand's bird species has recognised that Nationally Vulnerable criteria best fit the species, but has given the black-billed gull a special designation of Nationally Endangered (Miskelly et al 2008) in recognition that the species may be significantly more threatened than the criteria suggest, and appears to be at greater risk than other Nationally Vulnerable seabirds.

Declines in other regions of the South Island (Ashburton River, lower Waitaki River, Otago and Canterbury rivers listed in Maloney (1999) suggest that rates may be similar to those found in Southland. Re-analysis of these and other unpublished counts that may be held by Department of Conservation offices and other organisations is of great importance and should be undertaken as soon as possible to ensure that the species is correctly classified. Should past rates of decline within the Southland population become evident (particularly if Southland is affected by further droughts or cold snaps) or rapid declines are proven elsewhere in the South Island, the species should be upgraded to Nationally Critical.

The complexity of the relationships of known threats with black-billed gull survival is shown in Figure 1 (similar relationships exist for other endemic, threatened, river-breeding species). Predation by terrestrial mammals and the native black-backed gull has a significant impact on black-billed gull productivity, whereas very limited evidence of mortality of adult gulls due to predation was observed. Long-lived seabirds such as black-billed gulls are relatively tolerant to variation in breeding success but extremely sensitive to changes in adult survivorship (Montevecchi 2002; supported by results from population modelling; Chapter 6). However, if reproductive success is consistently low, the population will eventually begin to decline (Montevecchi 2002). The observed relationship between nest success, breeding success and colony size suggests that excessive disturbance and predation of smaller colonies is occurring. Smaller colonies are common in regions such as Otago, Canterbury and Marlborough, and while persistence of colonies in these regions indicates that the story may be more complex, complete loss of colonies from some areas of Otago has been reported (Maloney 1999). Tentative evidence that adult body condition may be affected by predator disturbance suggests effects beyond reduced reproductive success. Poor adult condition has been shown to lead to poor body condition of chicks (Erikstad et al. 1997; Tveraa et al. 1998) which, in turn, can lead to poor post-fledging survival (Olsson 1997; van der Jeugd and Larsson 1998). Poor adult condition may also lead to skewed brood sex ratios (Nager et al. 2000). In summary, predation is the most severe of the known threats.

Ranking the severity of threats

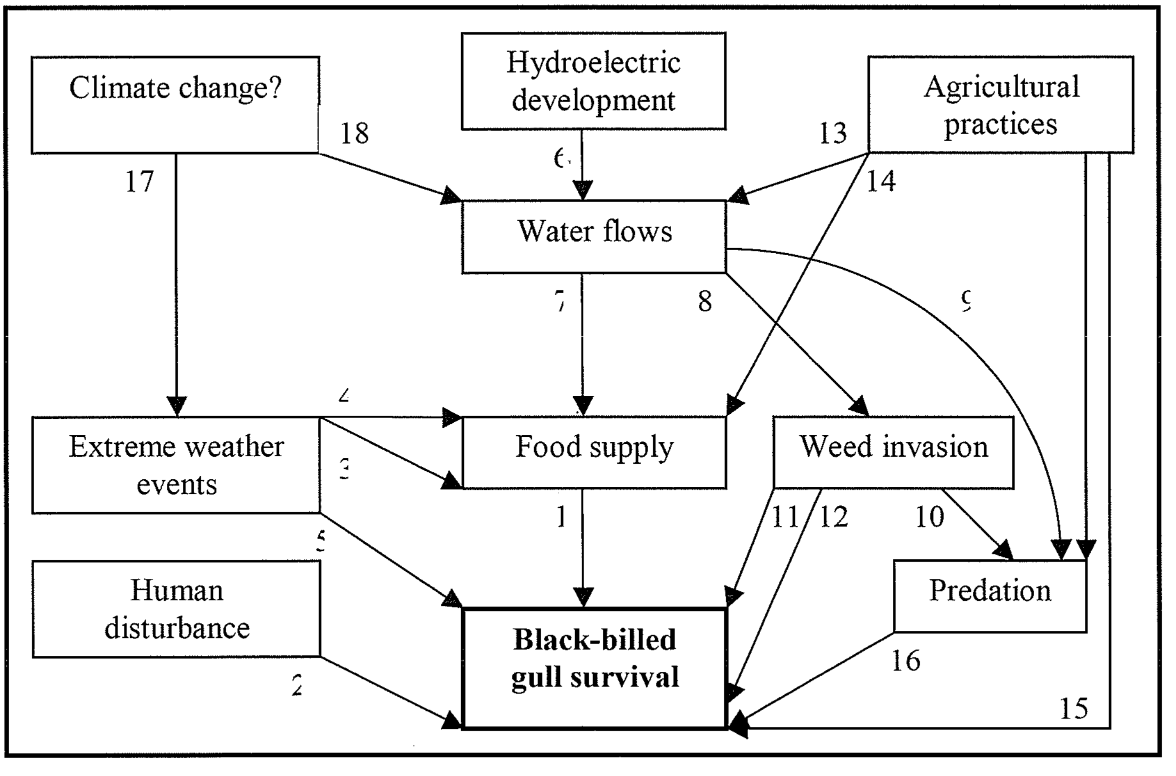

Figure 1: *Flow diagram depicting the key factors thought to impact black-billed gull survival in Southland. Modified from Keedwell (2004). Numbers beside boxes refer to the text below and are not ranks.*

Food supply directly affects survival (1). Human disturbance causes mortality of eggs, chicks and adults (2). Extreme weather events such as floods destroy colonies (3), and severe drought and freezing conditions restrict access to pasture invertebrates (4). Both directly affect survival (5). Hydroelectric development lowers water levels (6) which affects food supply (7), encourages weed invasion (8) and allows predator access to islands within the river (9). Weed invasion gives cover for predators allowing easier access to colonies (10), affects survival by forcing colonies to establish closer to the water line where they are more vulnerable to flooding (11) and reduces available habitat (12). Agricultural practices lower water levels through abstraction for irrigation (13), lower food supply using modern farming practices (14), and cause mortality through chemical ingestion (15). Introduced predators and black-backed gulls directly affect survival (16). The possible impacts of climate change include an increase in extreme weather events (17) and changes in water flows due to greater or lesser amounts of rainfall (18).

All other threats are likely to have less influence on the survival and productivity of black-billed gulls, although disturbance and severe weather events can reduce adult survivorship and may prove to have a greater impact than presently believed. Most recreational users are likely to cause only minimal disruption of reproductive behaviour as the species is relatively tolerant of human disturbance. Abandonment of colonies due to excessive disturbance could potentially stop some birds from breeding in that season although birds are capable of re-laying. Driving vehicles through colonies inevitably destroys eggs and chicks, but again, birds may re-lay. The killing of adult birds, however, is a major concern. The shooting of 90 birds in Southland in 2006 is not likely to have had a significant impact on population trends; however, the shooting of several hundred adults in a Canterbury colony in January 2008 is on a different scale. Regular losses such as these (and many incidents may go unnoticed) in regions that support smaller populations are sufficient on their own to cause rapid population decline.

The mortality events that occurred as a result of extreme weather events in Southland affected adults and, as such, would have had a serious effect on an already declining population. Though the cold snap of 1996 is considered a very rare event, unusually dry springs and summers are relatively common, but have not resulted in such obvious mortality. Nevertheless, reoccurrence of mortality events is a real threat, but is not controllable. In Otago, Canterbury and Marlborough, all of which are much more prone to extreme drought, similar mortality events have not been reported suggesting a difference in diet (e.g. possibly more aquatic). However, it may also be that the smaller populations in these regions are not as visible.

Research in Southland demonstrates the importance of islands as potentially safer breeding habitat. River works that reduce the availability of islands by reducing water flow (such as damming, high levels of water abstraction, gravel extraction from island habitat) or excessive gravel extraction leading to channelisation, will reduce the likelihood that gulls will select island habitat to breed and, as a consequence, colonies will become more vulnerable predation to terrestrial predators.

Weeds are likely to be less of an issue, at least in Southland where similar amounts of habitat were available on key rivers in 2002 as was present several decades earlier. The unavailability of high points at colony sites due to weed infestation is likely to lower productivity on occasion, but birds are capable of re-laying. Additionally, infestation of high points may prove to be relatively insignificant if modelled using historical flood data (i.e. a colony's chance of flooding may not significantly decrease if only 10-20 cm were gained were the site free of weeds). However, the severity of weed invasion varies among and within regions (Maloney 1999; C. O' Donnell pers. comm. 2006; pers. obs.) and the situation may be more severe elsewhere.

Lastly, risks from ingestion of chemicals used on farms (Taylor 2000) have not yet been studied, but its potential to significantly affect the species warrants discussion. Persistent organochlorines such as DDT were used extensively for the control of grass grub and porina caterpillars throughout New Zealand from the 1940s to the 1970s (Taylor 1997). Some farms in Southland and Canterbury have elevated levels of DDT and its metabolite DDE and paddocks within some farms remain unusable for dairying or livestock (Taylor 1997). The effects of organochlorines on birds have been studied since the 1960s. The most well known effect is eggshell thinning and the associated lowering of reproductive success (see summary of effects in Blus and Henny 1997). Effects of organochlorines on gull species are wide-ranging and include reduced hatching success (Gilman et al. 1977), skewed sex ratios at birth (Fry and Toon 1981), high parasitic loadings (indicating compromised immune function; Sagerup et al. 2000) and altered reproductive behaviour (Bustnes et al. 2001). As such, the effects of DDT would have a significant lag as lowered breeding success in long-lived species such as black-billed gulls would take several decades to have noticeable effects on population trends (Montevecchi 2002). Earthworms accumulate DDT and its metabolites (Edwards and Thompson 1973), suggesting that black-billed gulls may have been and may still be ingesting significant quantities of the toxins.

A large variety of other chemicals are still used on New Zealand farms, the majority being herbicides such as glyphosate (which is generally regarded as having low toxicity to many animals including birds; Sullivan and Sullivan 2003) and fertilisers, though insecticides are still widely used (Wilcock and Close 1990). Ranking the severity of the threat of chemical ingestion is impossible without further research, but effects may be significant, particularly if adult or juvenile survival is affected.

Research to date indicates that gulls are not influenced by the presence of dairy farms when selecting a colony site. However, the possibility that dairy farming may reduce the availability of food sources by soil compaction and long grass lengths justifies further attention as reduced food availability can have wide-reaching consequences including reduced clutch sizes, hatching success, breeding success, post-fledging survival and adult survival (Annett and Pierotti 1999; Oro and Furness 2002; Mills et al. 2008).

Management recommendations

Collation and analysis of existing count data

Many counts of black-billed gull numbers in rivers and other locations throughout the South and North Islands have been undertaken since the 1960s; most is unpublished and difficult to locate. All information should be collated from Department of Conservation offices, other organisations and private individuals and stored within a single, national location with the agreement of the owners of the data. Where possible, methods used to collect count data should be recorded. Where sufficient, quality data exists from rivers or other waterways, it should be analysed and published.

Monitoring

While no trends in black-billed gull numbers are observable from aerial monitoring in Southland, numbers of colonies show a significant decline within the same 11-year period. This may be due to unexplained variation inherent in aerial counts. The pilot study indicated that the timing of aerial photography during the breeding season can have a major influence (Chapter 2). In addition, variation may occur due to the time of day at which photographs are taken if gulls are more likely to be feeding at certain times, and from day to day due to weather, proximity of food sources (e.g. cultivators/ploughs) or other unknown factors (Johnson and Krohn 2001; Steinkamp et al. 2003). Research has also shown that aerial photography is potentially a poor index of the breeding population as nests cannot be identified in photographs and the proportion of non-breeders varies significantly between colonies (Chapter 2).

In order for conservation and environmental managers to have confidence in monitoring results (and the outcome from management actions), aerial monitoring needs to be thoroughly tested. Time of day, daily and weekly variation in the number of gulls present within aerial photographs of the colony should be trialled by flying two main rivers (preferably with a minimum of six colonies) at three times of day (e.g. 0900, 1200 and 1500 hours) on three consecutive days, and then flying for a further three consecutive days at two two-week intervals. This equates to 15 flights of approximately 1 hour each. The results of the trial will clarify the extent of variation and can be used to develop a more robust methodology if required. Given aerial monitoring may not be able to detect trends in breeding birds (for example, if greater proportions of birds in colonies were not breeding), aerial counts should be done in conjunction with ground counts in a selection of colonies every five years.

Annual aerial monitoring of Southland's Aparima, Oreti and Mataura rivers and Canterbury's Ashburton River is a key recommendation in New Zealand's Seabird Action Plan (Taylor 2000). At a minimum, three consecutive annual counts should be undertaken before being discontinued for 3-5 years. This will help to ensure that major annual within-river and regional fluctuations in numbers are accounted for. In Southland, however, annual monitoring over the majority of waterways known to support gull colonies is preferable as this will determine the frequency at which black-billed gulls defer breeding. A second recommendation in the Action Plan is a repeat every 10 years of the nationwide surveys completed in 1995-1997 (Taylor 2000). This action should also be undertaken and is now overdue. All survey and monitoring results should be passed on to the single national location.

The efficacy and precision of automated counting is not yet clear, but the method has the potential to considerably reduce the time required to count colony photographs. Further work should be done to investigate the method, particularly with a very high resolution digital camera (which will allow a greater flying height ensuring an entire colony can fit within a single image).

Advocacy

The majority of New Zealand's threatened bird species survive only in national parks and reserves, often on offshore islands. Black-billed gulls, however, nest and feed almost exclusively within the highly modified agricultural environment. An advocacy strategy is critical for the conservation management of the species for several reasons:

(1) Gull colonies and feeding flocks are highly visible to the public, particularly in rural communities. Observations of banded birds can increase knowledge of dispersal and the survival of juveniles and adults. The public can be directly involved in this work.

(2) The direct involvement of the public in the species' conservation will foster ownership and guardianship. Raising awareness of the uniqueness and plight of the species may lead to less disturbance and damage to colonies.

(3) Any colony work or predator control programme requires the support of adjacent landowners to allow access to colonies and/or the control predators on private land.

Weed control

Weed control on rivers is undertaken by regional councils throughout the South Island though data on effort and locations is difficult to obtain. Even less clear is the availability of bare gravel habitat on various rivers (but see Wilson (2001) and discussion in Chapter 4). Extensive weed control is undertaken on most of Southland's waterways by Southland's regional council (Environment Southland) in order to maintain clear floodways and ensure river gravels remain mobile. Target species are willow (*Salix* spp.), broom (*Cytisus scoparius*) and gorse (*Ulex europaeus*). It seems highly likely that this work is largely responsible for maintaining extensive areas of open gravel suitable for nesting birds such as black-billed gulls. However, issues remain with weed invasion of high points within rivers and, although data are inconclusive, it is likely that some colonies are forced to nest closer to flowing water due to weeds.

Major regional weed control programmes require millions of dollars to sustain (for example, removal of willow from 19 km of the Mararoa River in Southland cost NZ$2.96 million and the annual weed control budget for Southland's rivers for the purposes of floodway maintenance is approximately $610,000). Extensive weed control on a river improves overall biodiversity, recreational and aesthetic values, and provides habitat for other threatened river-breeding birds, however, targeted control is feasible for black-billed gulls. High quality sites should be selected on key rivers which are then managed for weeds on an annual basis if required. Gulls show an increased likelihood to return to stable sites, sites that have been used in the last few years and sites with very low weed cover. Consequently, sites selected for weed control should be those known to be regularly used and sites that have been used in the past but have become weedy, and, in particular, island sites (which will not require terrestrial predator control). Sites that are less flood prone should also be a priority.

Predator control

The possibility that an Allee effect exists (i.e. an inverse density dependent relationship between colony size and productivity) should be of great concern to conservation managers. Southland colonies that failed to produce fledglings numbered between approximately 120-550 gulls, and the colonies significantly affected by black-backed gulls numbered approximately 120-2000 gulls. These colony sizes are typical of colonies in all other regions except for Southland where mean colony size from 2004-2006 was c.2400 gulls. Allowing black-billed populations to continue to decline in Southland and in other regions will almost certainly make reversing the decline at some later stage much more difficult.

Terrestrial predators

A terrestrial predator control trial should be undertaken to protect black-billed gull colonies on banks with an aim to raise nest and breeding success to levels that are found on islands. A minimum of four colonies should be included in the trial to ensure a high likelihood of being able to detect a significant difference (Appendix L). If possible, four island colonies should also be monitored (to take account of possible yearly variations in nest and breeding success) but results from bank colonies can be compared to existing data from Southland island colonies if necessary. It should be noted, however, that predator control has been undertaken to protect other threatened colonial riverbed species with variable and often poor success (Keedwell et al. 2002; Cranwell 2006; Boffa Miskell Ltd. 2007). Refinement of control methods for black-billed gulls should be undertaken using an adaptive management approach (Keedwell et al. 2002).

Black-backed gulls

Black-backed gulls are a partially protected species in New Zealand. Culling of black-backed gulls to protect various species of threatened birds is undertaken throughout the country, particularly on offshore islands. Control methods tend to involve pricking of eggs, but the culling of adults is occasionally undertaken (Biswell 2005). However, internationally, the efficacy of culling has been debated; substantial bodies of work examine both the effects of culling on the population dynamics of the predatory gull species (summary in Bosch et al. 2000) and the impact on the prey species (Nettleship 1972; Spear 1993; Hario 1994; Harris and Wanless 1997; Guillemette and Brousseau 2001; Oro and Martínez-Abraín 2007). Predatory individuals tend to comprise approximately 1% of the nesting population (summary in Guillemette and Brousseau 2001). Bosch (et al.) found that culling caused a large increase in emigration rates, and concluded that any problems caused by the gulls had subsequently shifted somewhere else. Decreases in numbers of breeding gulls have been found to lead to increases in various parameters including clutch size, egg volume, breeding success and adult condition (Coulson et al. 1982; Spaans and Blokpoel; Coulson 1991). Oro and Martínez-Abraín (2007) found that yellow-legged gulls affected productivity, survival, foraging ecology and habitat availability of the majority of 10 species of threatened waterbirds, but that growth rates of predator and prey species were positively associated and population extinction rates were similar for both. They concluded that prey species had evolved alongside the yellow-legged gull and presumably had mechanisms with which to maintain population stability in the presence of such predation.

The extent to which black-backed gulls pose a serious threat to black-billed gull productivity nationally is unclear. Average black-billed gull colony size in Southland is c.2400 breeding birds, and these colonies tend not to be disturbed by black-backed gulls. However, smaller colonies are commonplace elsewhere and may be vulnerable to complete failure if they nest within the foraging range of a black-backed gull colony. Populations of black-backed gulls appear to have been very low prior to human occupation (Worthy and Holdaway 2002) and records suggest the species was also uncommon at the arrival of Europeans (Worthy and Holdaway 2002; Biswell 2005). However, increased populations of black-backed gulls could act as a replacement for reduced and extinct species that may have once preyed on black-billed gulls (Chapter 5). Research should be undertaken to further investigate the actual extent of disturbance and predation. A key issue, should management of black-backed gulls be considered necessary, is that black-billed gull colonies would need to be located at the start of the season, their vulnerability assessed, i.e. size and location and distance of black-backed gull colonies, and attempts to largely eradicate any colonies deemed problematic would need to be undertaken immediately.

Other management actions

Decoys

The use of decoy gulls to encourage colony establishment at 'quality sites' should be trialled for a number of reasons: (1) decoys have been used successfully to attract various bird species to feeding grounds, such as ducks (Ackerman et al 2006), geese (Harvey et al. 1995), egrets and herons (Crozier and Gawlik 2003; Green and Leberg 2005), ibis (Crozier and Gawlik 2003) and pelicans (Anderson 1991) and to attract species to potential colony sites, primarily terns (e.g. Dunlop et al. 1991; Blokpoel et al. 1997; Collis et al. 2002) but also herons (Dusi 1985); (2) 'quality' sites, i.e. islands with low probability of flooding, could be preferentially chosen and managed annually for weeds prior to commencement of the breeding season; (3) gulls have been shown to return to sites that have been recently used, are morphologically stable and have low weed cover (Chapter 4), consequently, if management sites are eventually used, the probability of those sites being re-used increases significantly; and (4) if successfully attracted to islands, this could preclude the requirement for a predator trapping programme.

Creation of islands

The creation of islands for black-billed gulls and other birds using heavy machinery has already been undertaken in Southland, in man-made wetlands on private and public property and a lake formed above the Manapouri Dam. Gulls have nested on several of these islands but productivity has not been monitored. Scope exists for clearing channels in rivers that have recently become aggraded to recreate islands. However, a number of matters would need to be addressed such as access for diggers, support of adjacent landowners who may be concerned about erosion potential, and legal consent issues for working in riverbeds. Additionally, works should preferably be completed prior to the breeding season (unless the site is very large and operations would be a sufficient distance from the colony). Also, there is no guarantee that the site will be used.

Research

Research opportunities exist which will directly aid management decisions and could be taken up by universities and/or the Department of Conservation, and include:

- Small colony productivity: further examine the hypothesis that smaller colonies have lower productivity and a greater likelihood of failure below a certain size, particularly in regions other than Southland.
- Survival of juveniles and adults: modelling indicates that increased survival of juveniles and adults is required in addition to improved breeding success in order to stabilise the population. This long-term project would identify if survival is indeed reduced.

- If adult survival is found to be reduced, urgent study needs to determine causes of increased mortality of adults (e.g. predation, ingestion of agricultural chemicals, food availability during the breeding and non-breeding season).
- Nationwide dispersal: examine the extent of long-distance dispersal and population mixing. Determine where gulls are migrating post-breeding season in order to identify potential threats during this part of the life cycle.
- Deferral of breeding: determine whether there are in fact seasons where birds are less likely to attend colonies, the frequency of these occurrences and what influences breeding frequency.
- A wide range of often inter-related diet studies, such as:
    - Food availability and colony site selection;
    - Food availability, foraging ranges and energy expenditure;
    - The impact of land use changes on food availability;
    - Diet during the non-breeding season and possible changes in marine food availability due to climate warming;
    - The occurrence and impact of ingestion of agricultural chemicals.
- Impact of black-backed gulls on productivity.

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APPENDICES

Dive-bombing gull, Lumsden colony, 2004 (R. McClellan)

APPENDIX A: EXAMPLES OF VERTICAL AERIAL PHOTOGRAPHY OF BLACK-BILLED GULL COLONIES

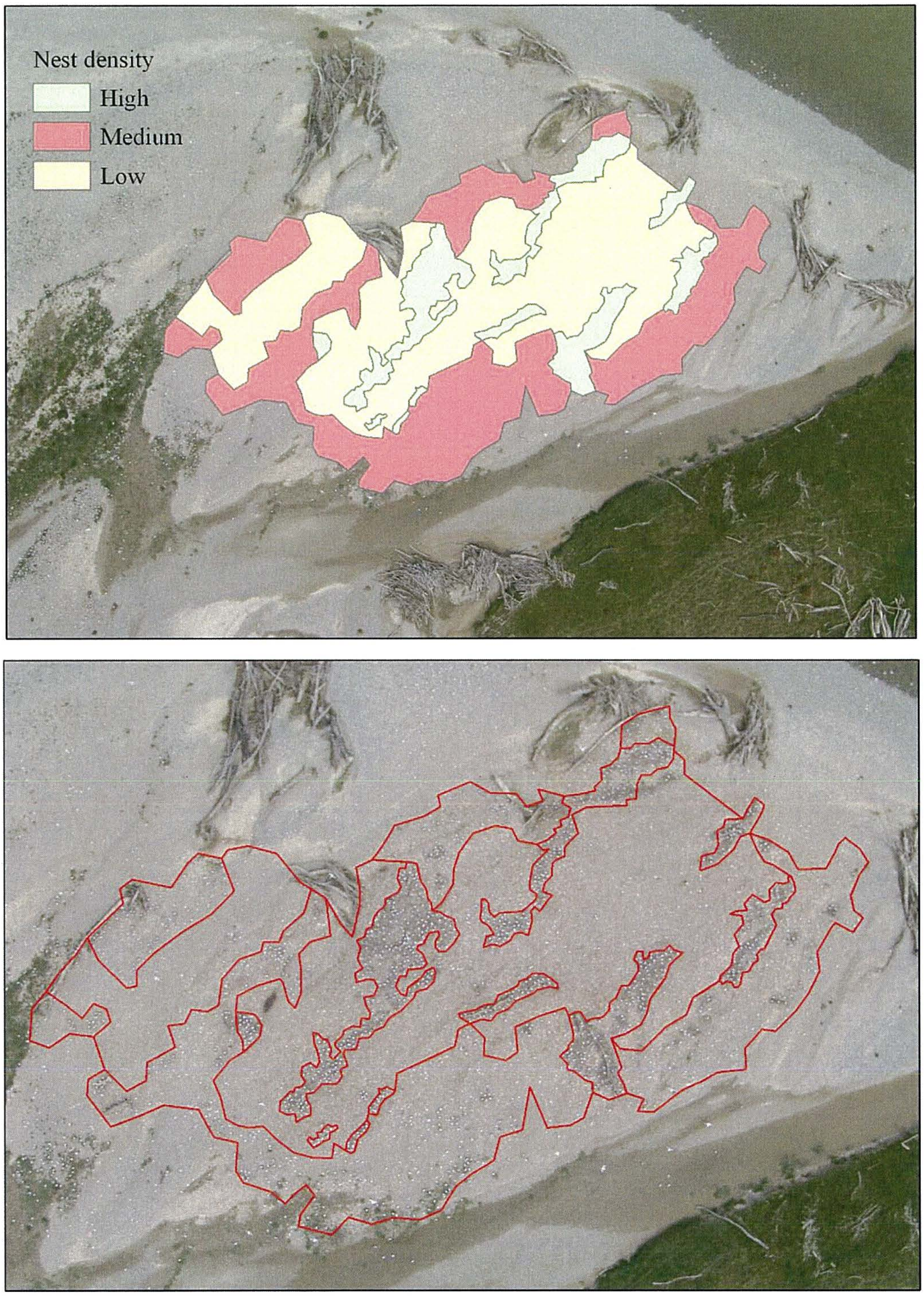


Figure A: *Vertical aerial photograph of Otama North colony, Mataura River, 2006. GIS graphic showing different areas of nest density*

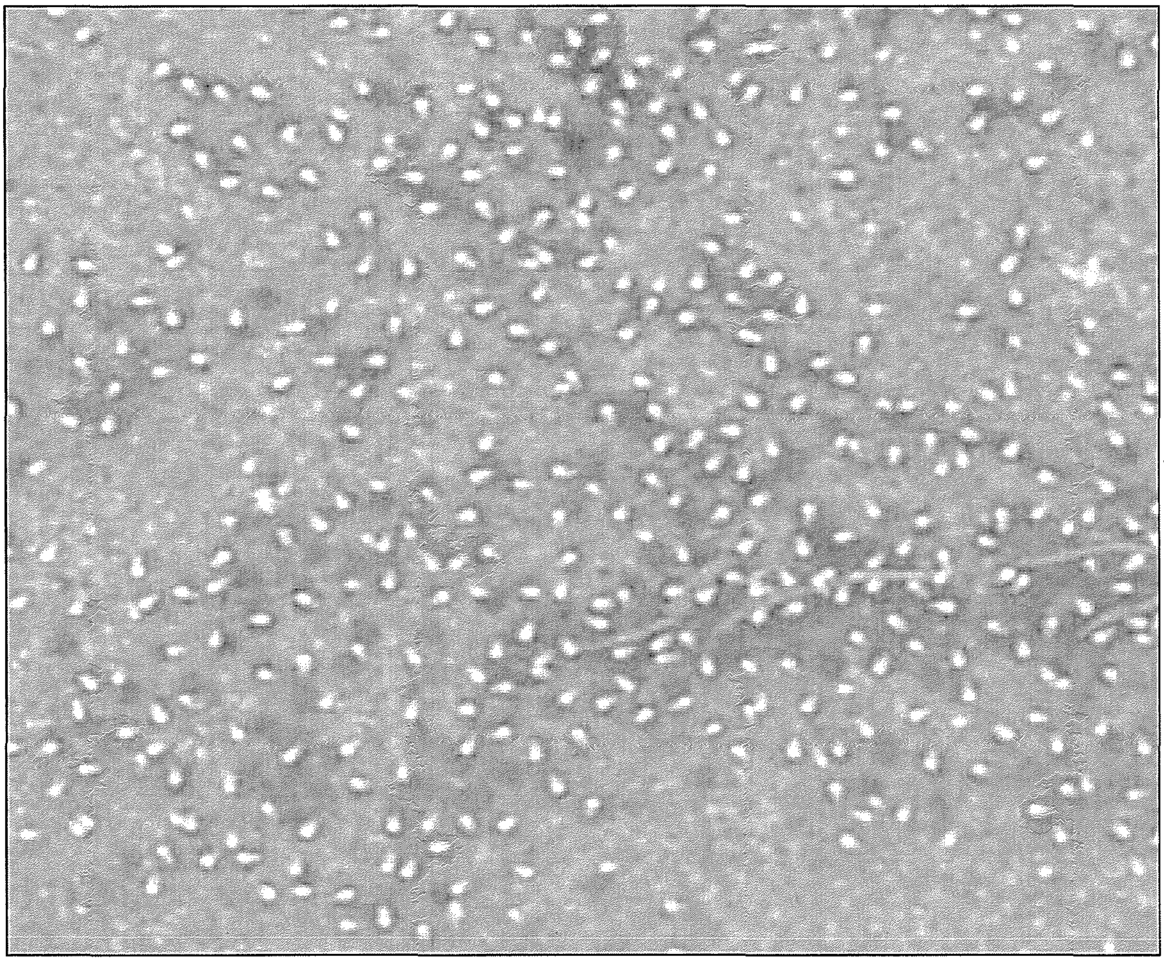


Figure B: *Vertical aerial photograph Otama South colony, Mataura River, 2006, showing a small section of the colony at full scale. Nests are visible, but cannot be separated from one another in high density areas around logs (lower right).*

APPENDIX B: HISTORICAL REFERENCES OF BLACK-BILLED GULL ABUNDANCE IN SOUTHLAND

1. A "huge Gull colony" was visited by Guthrie-Smith on the Mararoa River, Southland, approximately 10 km from its confluence with the Waiau River, presumably during the 1930s (Guthrie-Smith 1936).
2. In May 1939, "thousands" of gulls were reported flying up the Oreti River every night; the birds were apparently returning from downstream farms where they were feeding on larvae of the porina moth (Anon 1940).
3. In 1947, 12 seen on Mataura River near Otamita; pairs on creeks and rivers between Mossburn and Te Anau; c.100 on Mararoa River; and c.85 near Mossburn (Stidolph 1949).
4. A colony comprising 250-300 nests was sighted on the Oreti River in 1949 (Sansom 1950).
5. A colony of at least 5000 birds nested at Mandeville on the Mataura River in 1949 as well as a number of smaller colonies. Also reported were many hundreds of gulls in paddocks around Freshford, Jacobstown, Gore and Mandeville, and a flock of c.150 flying upstream of Garston (Stidolph 1951).
6. In the 1950s, black-billed gulls nested "in colonies of about 50-100, or in colonies up to several thousand birds" in riverbeds in Southland (Boud and Cunningham 1959).
7. Ornithologist, Robert Stidolph, noted all observations of black-billed gulls during a two-month camping tour of Otago and Southland in late 1951. His diary annotations for this species can be summarised as follows: c.10 gulls past Athol; c.135 gulls in paddock near Parawai; c.100 following plough near Lumsden; groups of 1-8 gulls seen between Mossburn and Nightcaps (total 28); c.1100 nesting at Awatata on Aparima River; flocks of c.40, c.25 and 100 gulls following tractors near Orawia River; at Pukemaori 20 gulls and three chicks; colony of c.100 gulls at Waiau River mouth (R.H.D. Stidolph in litt. 1951).
8. "Hundreds" were following a tractor near Balfour (close to Mataura River) in 1952, as well as flocks of up to 50 on tilled land and one in a field of turnips, also in the Mataura Valley (McKenzie 1953).
9. Around Te Anau and Manapouri during December 1953-January 1954, "thousands" of gulls were seen on and around the lakes feeding on a "golden white moth" which became briefly abundant (Stidolph 1955).

10. In July 1954, 400-500 birds were "selecting a resting site" below the Benmore Bridge, Oreti River, and 300-400 were seen on Hamilton Burn (Stidolph 1955).
11. In January 1952, 800 were seen on the Mataura River at Otamita (Stidolph 1954).
12. In May 1955, "scores" were in paddocks "attending the harvesting of the potato crop" on the Oreti River (Sibson 1956).
13. In 1957, five colonies were present on the Aparima River between the Wrey's Bush bridge and the Jacob's River bridge. The study colonies numbered approximately 3000 nests and 500 nests (Boud and Cunningham 1959)[2].
14. In 1961, 600+ were seen on a ploughed paddock at Pukarau, near Gore (Sibson 1961).

[2] This same stretch supported two colonies in 1977 and 1985, one in 2004 and 2005, and two in 2006.

APPENDIX C: SOUTHLAND SURVEY AND MONITORING DATA

Table A: *Number of colonies and breeding black-billed gulls, Waiau, Aparima, Oreti and Mataura rivers; 1974-2006.*

Year	Waiau		Aparima		Oreti		Mataura			
	No. of colonies	Birds	No. of colonies	Birds	No. of colonies	Birds	No. of colonies	Birds	Total birds	Total colonies
1974						84971				
1977	7	17368	6	41702	11	51838	9	25704	136612	33
1983							7	92661		
1985			5	50308						
1986					7	62838				
1993	4	8731								
1995	1	632	11	11913	4	16623				
1996	2	2200	3	8385	5	7622	8	10065	28272	18
1997			1	1441	3	8534	6	11240		
1998	3	12651	4	3839	6	9831	5	9331	35652	18
1999			3	11261	3	1252	4	6226		
2000	2	7878								
2001	4	5898	4	3408	3	6222	3	7136	22664	14
2003	3	100*	2	8795	1	1667	4	3909	14371	10
2004	4	11627	3	11079	5	9065	1	8216	39987	13
2005	2	878	1	2709	2	4339	4	6298	14224	9
2006	2	5000	6	8313	3	5770	4	14756	33839	15

Table B: *Number of colonies and breeding black-billed gulls, Waiau River; 1977-2006. Revised number is the number of breeding birds multiplied by a factor derived from the ratio of numbers of gulls in aerial photographs versus nests on the ground (Chapter. 2).*

Approx. date of survey	Number of colonies	Breeding birds	Revised number	Notes
23-Oct-77	7	17368		
23-Nov-93	4	8731	9778.72	
11-Dec-95	1	632		High river levels
15-Nov-96	2	2200	2464.00	High river levels
24-Nov-98	3	12651	14169.12	
15-Oct-00	2	7878	8823.36	
3-Oct-01	4	5898	6605.76	
10-Dec-03	1	100	112.00	Two large colonies known to have gone by survey date
3-Oct-04	4	11627	13022.24	
1-Oct-05	2	878	983.36	
1-Nov-06	2	5000	5600.00	

Table C: *Number of colonies and breeding black-billed gulls, Aparima River; 1977-2006. Revised number is the number of breeding birds multiplied by a factor derived from the ratio of numbers of gulls in aerial photographs versus the number of nests on the ground (Chapter 2).*

Approx. date of survey	Number of colonies	Breeding birds	Revised number
23-Oct-77	6	41702	
1-Oct-85	5	50308	
1-Oct-95	11	11913	13342.56
1-Oct-96	3	8385	9391.20
1-Nov-97	1	1441	1613.92
21-Nov-98	4	3839	4299.68
31-Oct-99	3	11261	12612.32
1-Oct-01	4	3408	3816.96
10-Dec-03	2	8795	9850.40
1-Oct-04	3	11079	12408.48
1-Oct-05	1	2709	3034.08
17-Oct-06	6	8313	9310.56

Table D: *Number of colonies and breeding black-billed gulls, Oreti River; 1974-2006. Revised number is the number of breeding birds multiplied by a factor derived from the ratio of numbers of gulls in aerial photographs versus the number of nests on the ground (Chapter 2).*

Approx. date of survey	Number of colonies	Breeding birds	Revised number
1-Oct-74	Unknown	84971	
23-Oct-77	11	51838	
1-Oct-86	7	62838	
1-Oct-95	4	16623	18617.76
1-Oct-96	5	7622	8536.64
1-Oct-97	3	8534	9558.08
1-Oct-98	6	9831	11010.72
1-Oct-99	3	1252	1402.24
3-Oct-01	3	6222	6968.64
10-Dec-03	1	1667	1867.04
3-Oct-04	5	9065	10152.80
1-Oct-05	2	4339	4859.68
1-Nov-06	3	5770	6462.40

Table E: *Number of colonies and breeding black-billed gulls, Mataura River; 1977-2006. Revised number is the number of breeding birds multiplied by a factor derived from the ratio of numbers of gulls in aerial photographs versus the number of nests on the ground (Chapter 2).*

Approx. date of survey	Number of colonies	Breeding birds	Revised number
23-Oct-77	9	25704	
1-Oct-83	7	92661	
1-Oct-96	8	10065	11272.80
1-Oct-97	6	11240	12588.80
1-Oct-98	5	9331	10450.72
1-Oct-99	4	6226	6973.12
3-Oct-01	3	7136	7992.32
10-Dec-03	4	3909	4378.08
3-Oct-04	1	8216	9201.92
1-Oct-05	4	6298	7053.76
1-Nov-06	4	14756	16526.72

APPENDIX D: BANDED ADULT RE-SIGHTING DETAILS

Table F: *Locations and dates of 2006 re-sightings of adult black-billed gulls banded at Mararoa Weir in 2005.*

Adult	Colony	Foraging	Post-breeding
G/YG	Mararoa 12, 17, 20, 24, 27 Oct, 3 Nov		
L/LO	Mararoa 4, 31 Oct, 3 Nov		
O/OG	Eyre Creek 8 Dec		
O/OW	Eyre Creek 8 Dec		
O/YY		Te Anau farm 27 Nov	
O/OR			North Clifden farm 11 Dec
R/RG	Mararoa 27 Oct	North Clifden farm 29 Nov	
R/RO	Mararoa 31 Aug		
R/RW	Mararoa 31 Oct	North Clifden farm 29 Sep	
R/RY	Mararoa 12, 31 Oct		
R/WW			North Clifden farm 9 Dec
W/RR	Mararoa 31 Oct, 3 Nov		
W/WL	Mararoa 3 Nov, 5 Dec	South Clifden farm 1 Dec	
W/WO	Dunrobin 18 Oct		
Y/WW	Mararoa 31 Aug, 4 Oct		

Table G: *Locations and dates of 2006 re-sightings of adult black-billed gulls banded at Avondale North in 2005.*

Adult	Pre-breeding	Colony	Post-breeding
G/GL	Otautau 6 Sep		
G/OO		Otama South 3 Nov	
L/OO	Otautau 6, 14 Sep		
L/RR	Otautau 6 Sep		
O/RR	Otautau 6, 14 Sep	Etal Creek 2 Oct	
O/LL			Papatotara farm 20 Dec
			2nd Papatotara farm 21 Dec
R/LL		Dunrobin 6 Dec	
R/OO		Eyre Creek 6 Nov	
W/LL		Eyre Creek 6 Nov	
W/OO		Dunrobin 2, 6 Nov	
W/WR			Papatotara farm 20 Dec
W/WY	Mararoa 31 Aug	Fairfax 3 Oct	
	Otautau 6, 14, 25 Sep		
Y/OO		Eyre Creek 15 Nov	Tuatapere farm 8 Dec
Y/YG	Mararoa 31 Aug	Dipton 19 Sep, 6 Dec	
Y/YL	Otautau 6 Sep	Thornbury 6 Oct, 7 Nov	
Y/YO	Wrey's Bush 10 Aug		

Table H: *Locations and dates of 2006 re-sightings of adult black-billed gulls banded at Mossburn in 2005.*

Adult	Pre-breeding	Colony	Foraging	Post-breeding
G/YY	Avondale 6 Sep			South Clifden 1 Dec
G/GG	Avondale 6 Sep			
L/LL		Mararoa 27/31 Oct		
O/OO		Mararoa 3 Nov		
W/GG		Eyre Creek 6 Nov		
W/WW		Dunrobin 6 Oct		
Y/GG		Mossburn 31 Oct, 3 Nov	Ellis Road farm Dec*	
Y/YY		Mossburn 27 Oct		

* Date uncertain, within 5-10km of colony site.

4 News Thursday August 24 2006 Southland Express

Southlanders urged to report gulls

BY AMY JOHNSTONE

NEW Zealand's black-billed gull is the most threatened gull in the world, and Southlanders are being called on to report any sightings of colonies.

Otago University researcher Rachel McClellan said there are 44 recognised species of gull in the world and the black-billed gull is the most threatened of them all.

"People don't seem to realise that these birds are classified internationally as endangered, the same as the takahe, the yellow-eyed penguin and the blue duck."

Investigation is crucial to the population's survival, because Southland holds the vast majority of the world's population, probably 80 to 90%, she said.

"They are a pretty iconic Southland species."

In 1977 there were an estimated 150,000 breeding birds on the Waiau, Aparima, Oreti and Mataura Rivers and 35 colonies. Last year it was approximately 10,000 birds and nine colonies, an incredible 93% decline in the population.

So far there has been a good response in reporting colonies, particularly from farmers, as birds tend to follow behind their tractors while ploughing, she said.

Observation is particularly important at this time of year, as the birds are coming back in to breed from the coast and no one is quite sure exactly where they come in from. The birds' nesting sites change each year also, so colonies really need to be found as quickly as possible.

Large rivers were the most common site for colonies, but the species was also known to start colonies at small creeks.

If people spot any of the birds, band colours need to be reported so Ms McClellan can identify the bird correctly.

To date, over 1300 birds have been banded in Southland. When banding chicks, six to eight volunteers help, as it is quite an event trying to herd all the chicks into pens, then boxes and then banding them, Ms McClellan said.

However, banding adults is a different procedure. They are caught on their nests while incubating eggs and a cage trap is used, which requires two people, she said.

"Banding work will give me really good information about whether mortality concerns are with adults or chicks not reaching breeding age.

"So, the more sightings from Southlanders the better."

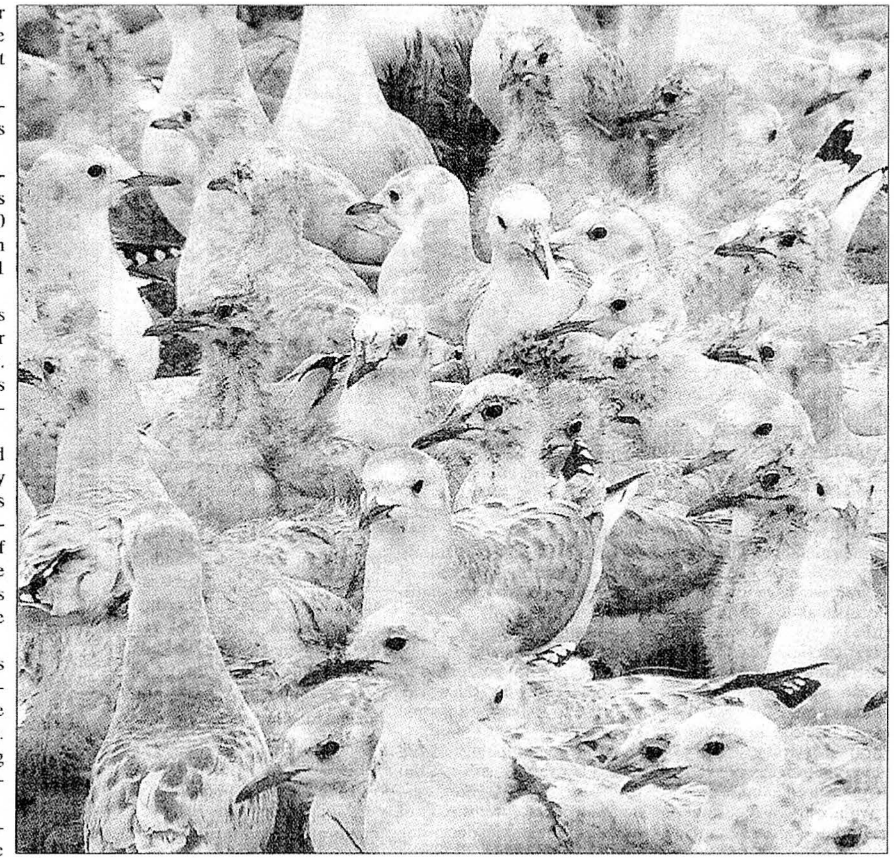
However, there is concern over the numbers being sighted. Of the 400 juveniles banded between 1997 and 2000, only 11 have since been sighted.

Introduced predators are probably a key factor in the species' decline. However, other threats are also likely to be involved.

"I'm not convinced predators are the only problem, which is why it is so crucial that I find banded birds, as this is one of the main ways I'll be able to work out what factors are causing the massive decline."

Ms McClellan has spent the past two breeding seasons examining the population for her PhD. This is the last breeding season she will be studying the birds intensely.

"However, (the population) is in such a severe decline the work will need to be continued into the future."



A herd of chicks waiting to be banded.

Photo: Chris Garden

Figure C: *Southland Express 24 Aug. 2006: "Southlanders urged to report gulls".*

Black-billed gull and chicks. Classified as a threatened species in serious decline.

Picture: ROD MORRIS-DOC

Keep an eye out for these rare seagulls

FARMERS could prove a valuable resource for PhD student Rachel McClellan, who has embarked on a three-year study of Southland's declining population of black-billed gulls.

While seagulls are generally regarded as common, the distinctive black-billed species has become a rare sight throughout New Zealand, with Southland boasting the country's largest known population.

Farmers may know them as the small gull that follows their plough.

Black-billed gulls are listed as a vulnerable species by the IUCN (World Conservation Union).

They have also been reclassified in New Zealand, under the new national classification system, as a threatened species in serious decline — the same classification given to the North Island brown kiwi.

The black-billed gull is a fully protected species, whereas the larger, common black-backed gull is not.

"Black-billed gulls are only found in New Zealand, and approximately 80 percent of the New Zealand population breeds on Southland's rivers during spring and summer," Ms McClellan said.

"They have all but disappeared from some river catchments in Canterbury and survey work over the last 20 years in Southland suggests numbers are declining here as well, estimated at up to 80 percent in some areas," she said.

Ms McClellan's PhD study aims to assess the extent and importance of identified threats on the survival of black-billed gulls in Southland and to examine aspects of the species' population dynamics and movements.

From there, she intends to assess the effectiveness of some key management options to improve both the habitat and breeding success on the Waiau, Aparima and Oreti rivers. "I hope to be able to locate the majority of colonies on the rivers as they form and birds begin nesting.

"I'm hoping farmers may be able to assist me with this project by way of helping to identify these sites and inform me of any sightings of black-billed gulls on their daily travels in the specified river catchments," Ms McClellan said.

Introduced predators were at least partly responsible for the decline of black-billed gulls.

Video evidence shows feral cats, stoats, ferrets and hedgehogs killing adults and chicks and taking the eggs of species breeding on Canterbury's braided riverbeds.

"In some cases, colonies of bird species have produced no young in a season due to predation.

"It's likely that black-billed gulls are affected by predation as well, but no one knows to what extent," she said

Weeds are another problem in the birds' decline, often invading the bare gravel habitat preferred for breeding and nesting and forcing the birds to nest closer to the waterline where they are more vulnerable to floods.

In the first two years of her PhD, Ms McClellan expects to band about 700 adult and 6000 black-billed chicks.

The adult birds will have three plastic bands that allow them to be individually identified.

The chicks will have two that identify them to their colony site.

If you see a banded bird or black-billed gulls nesting in the Waiau, Aparima or Oreti river catchments, contact Rachel McClellan on 03 218 7809 or rachel.mcclellan@xtra.co.nz

Volunteers are also needed to help with monitoring and banding work.

The project is being supported by Meridian Energy, Department of Conservation and Environment Southland.

Figure D: *Southland Times 4 Sep. 2004: "Keep an eye out for these rare seagulls".*

APPENDIX F: DIAGRAMMATIC EXAMPLES OF DISPERSAL OF GULLS BANDED AS CHICKS RE-SIGHTED IN 2006

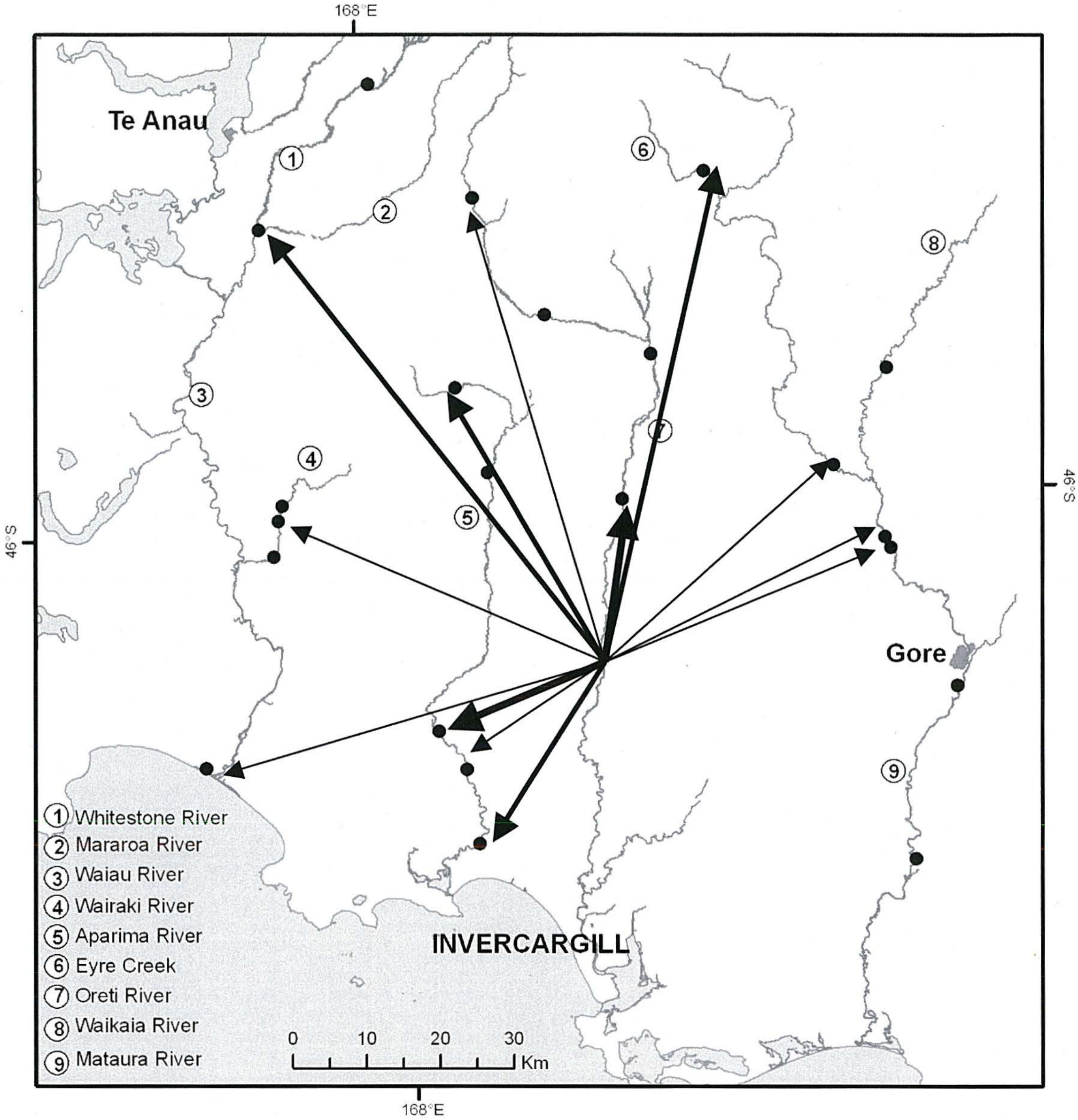


Figure E: *Dispersal of birds banded as chicks at Centre Bush, 2000, in 2006 (n=21). Thickness of arrows indicates number of birds; thinnest lines equate to a single individual.*

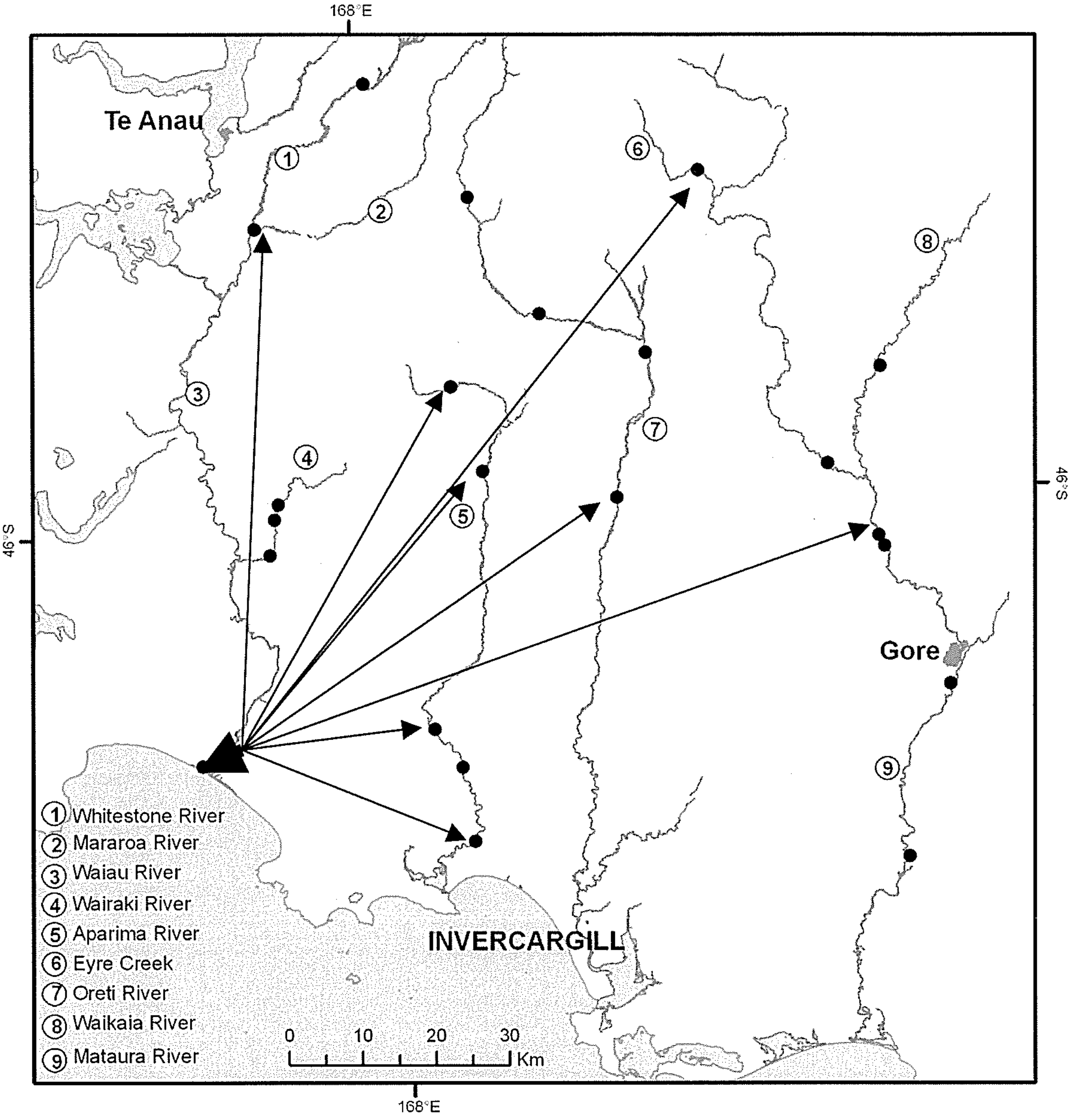


Figure F: *Dispersal of birds banded as chicks at Papatotara, 2004, in 2006 (n=13). Thickness of arrows indicates number of birds; thinnest lines equate to a single individual.*

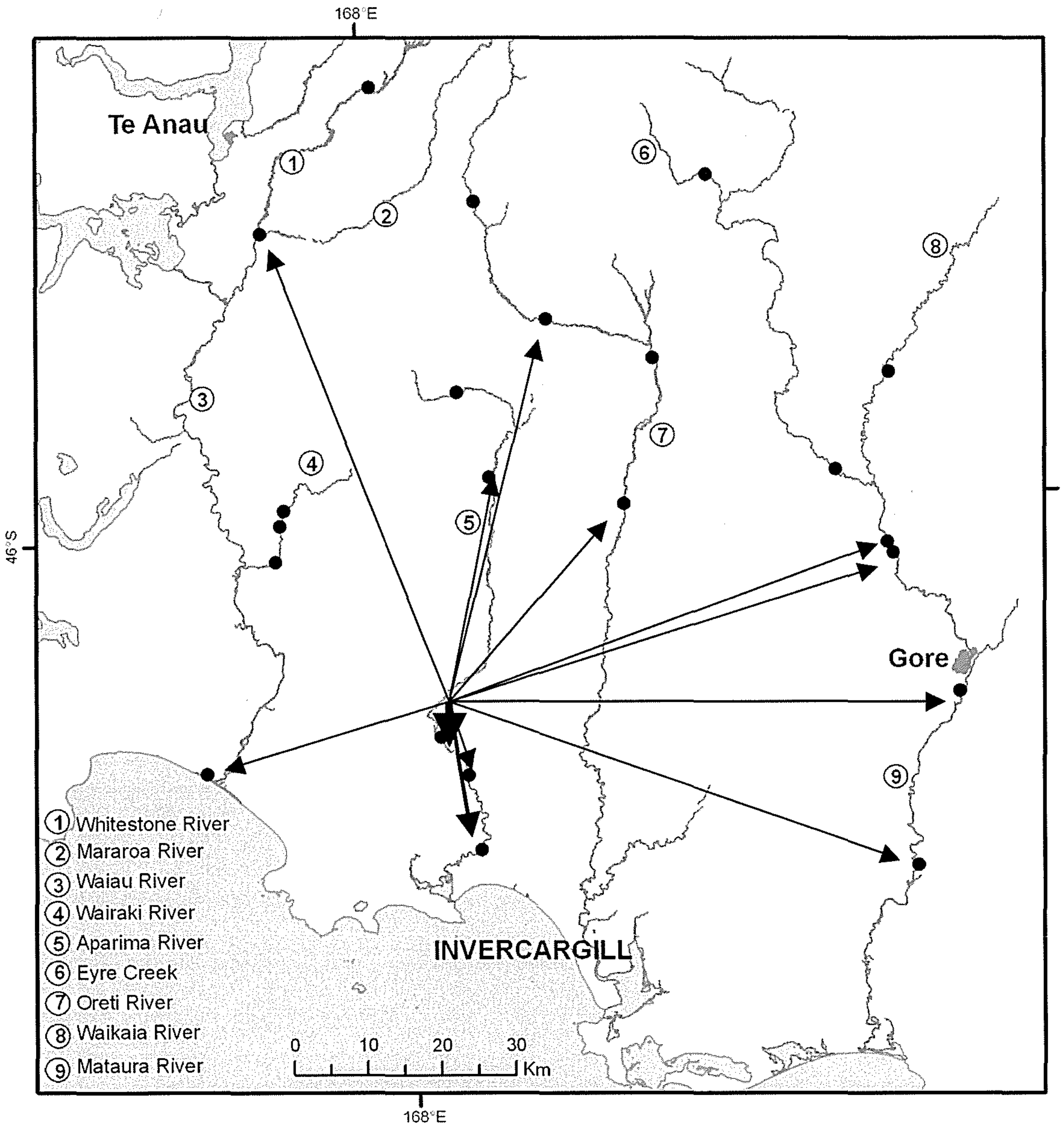


Figure G: *Dispersal of birds banded as chicks at Bayswater, 2004, in 2006 (n=16). Thickness of arrows indicates number of birds; thinnest lines equate to a single individual.*

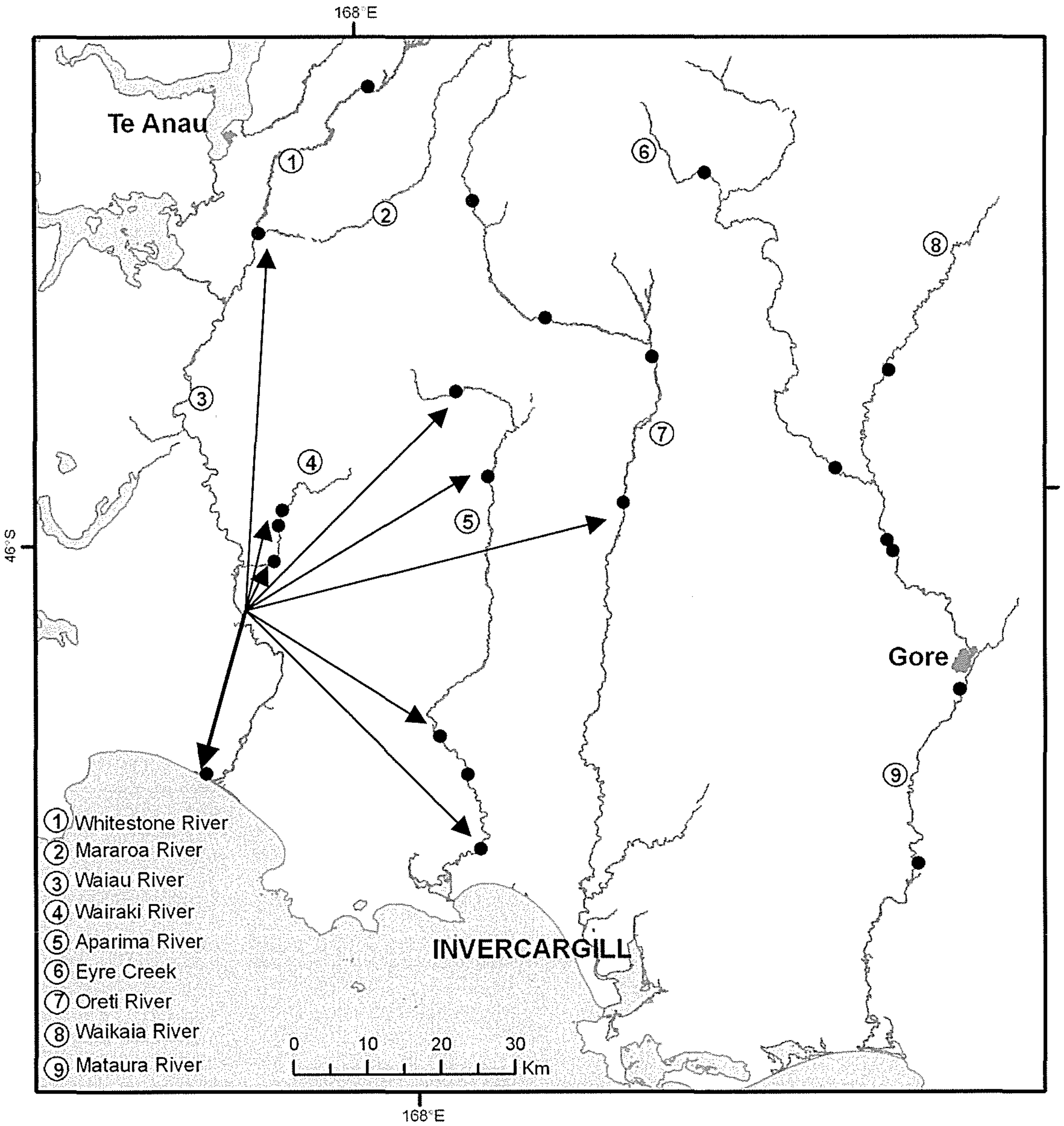


Figure H: *Dispersal of birds banded as chicks at Lill Burn, 2004, in 2006 (n=10). Thickness of arrows indicates number of birds; thinnest lines equate to a single individual.*

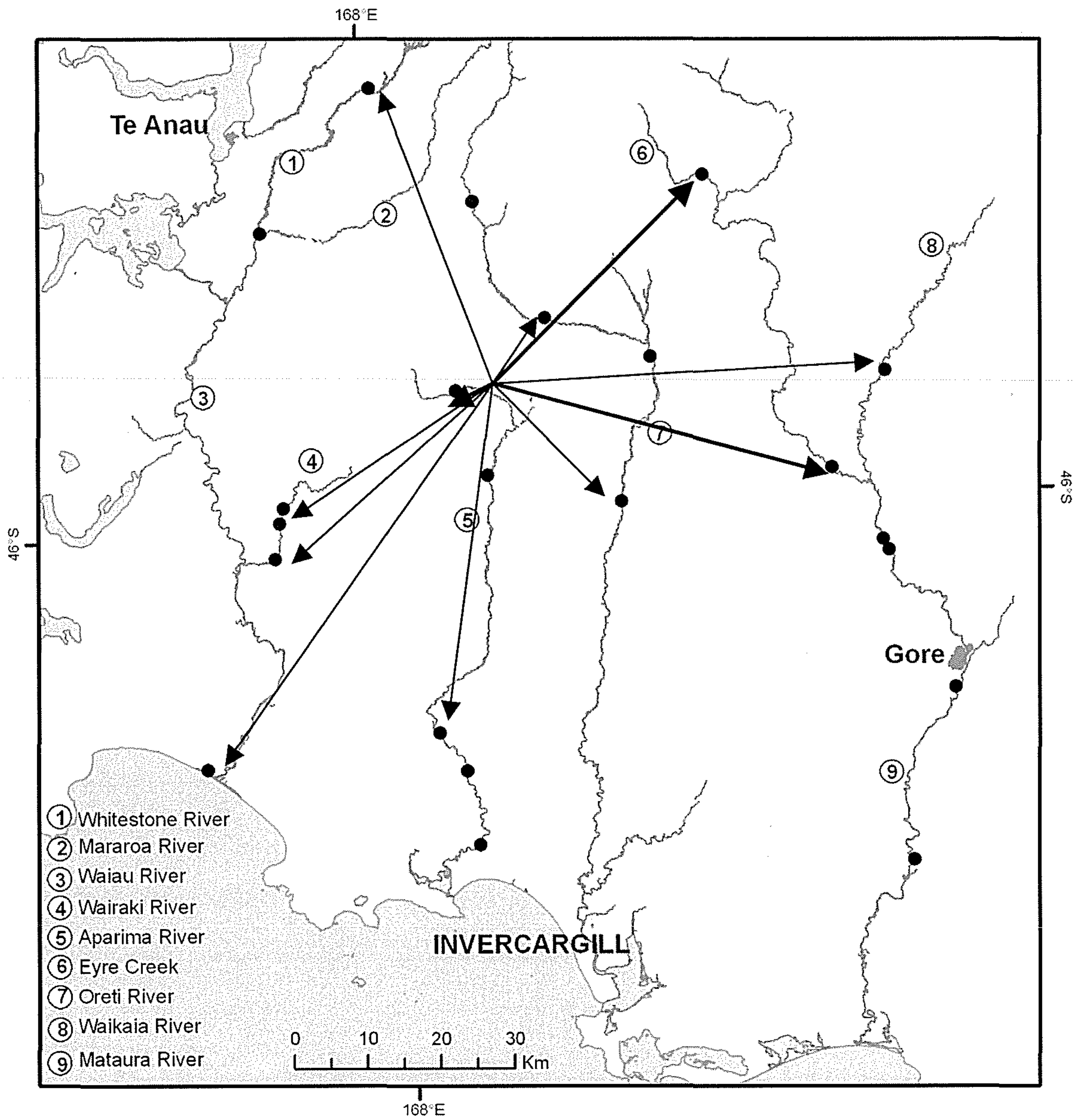


Figure I: *Dispersal of birds banded as chicks at Dunrobin, 2004, in 2006 (n=14). Thickness of arrows indicates number of birds; thinnest lines equate to a single individual.*

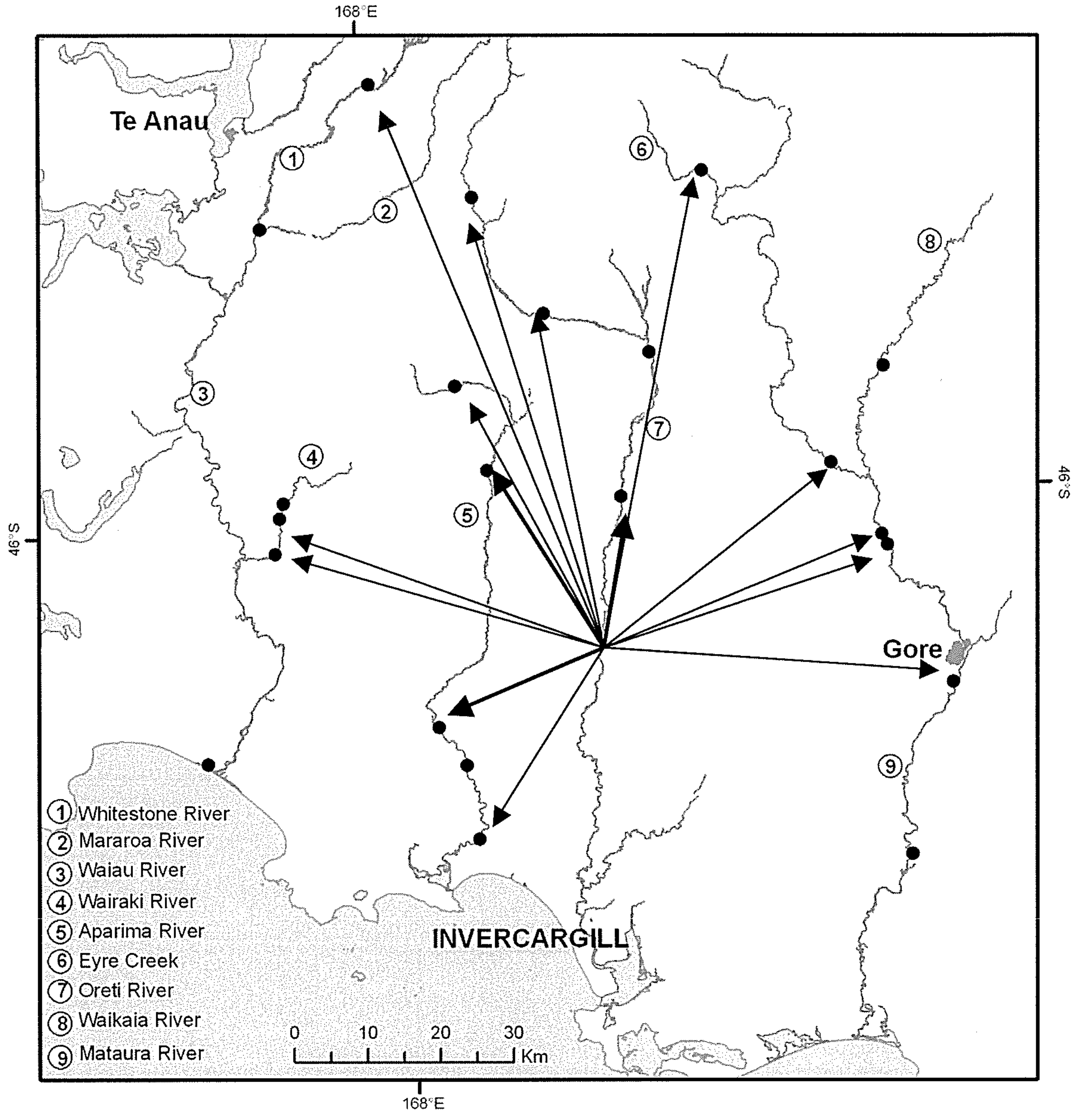


Figure J: *Dispersal of birds banded as chicks at Benmore, 2004, in 2006 (n=18). Thickness of arrows indicates number of birds; thinnest lines equate to a single individual.*

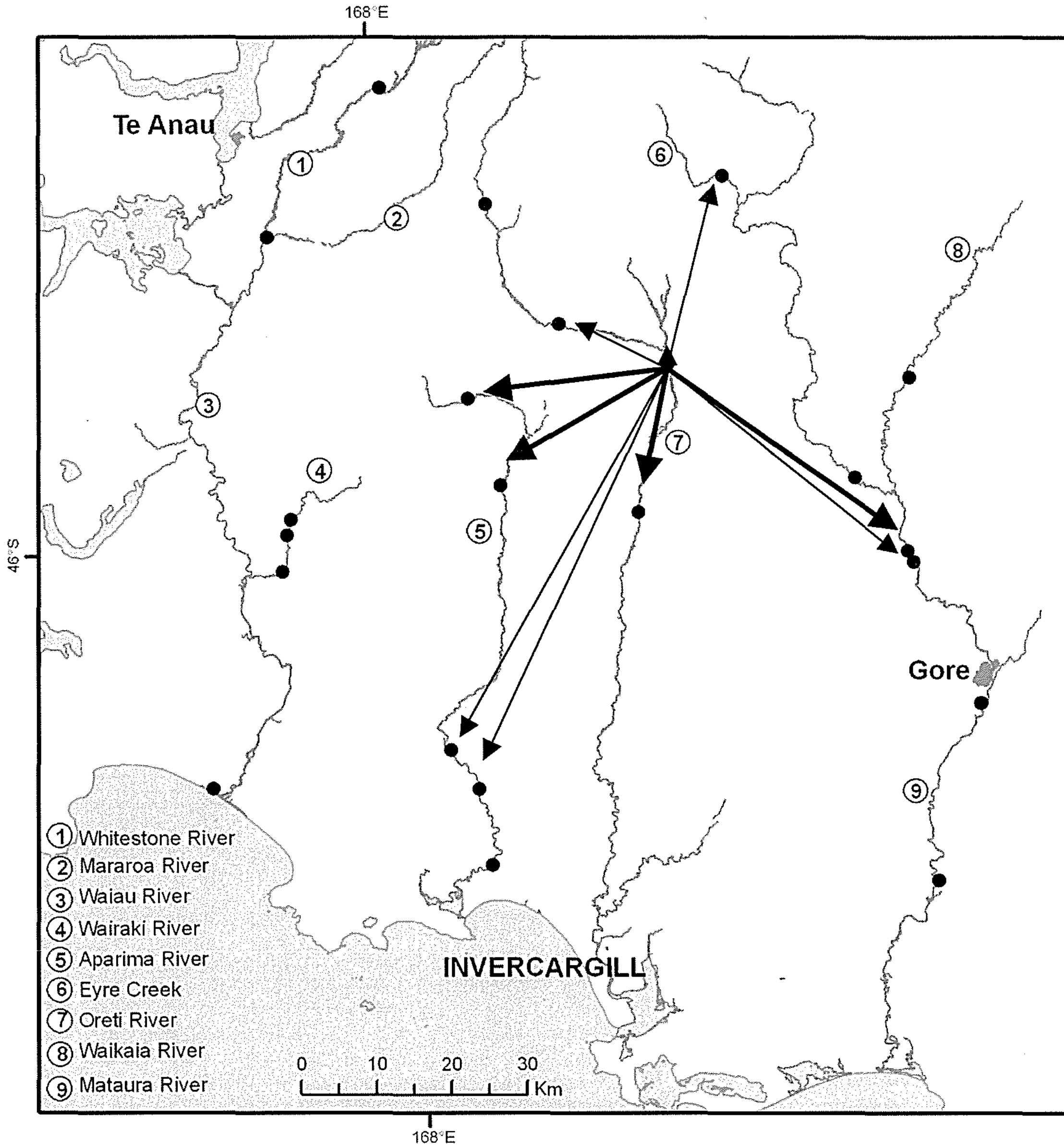


Figure K: *Dispersal of birds banded as chicks at Lumsden, 2004, in 2006 (n=14). Thickness of arrows indicates number of birds; thinnest lines equate to a single individual.*

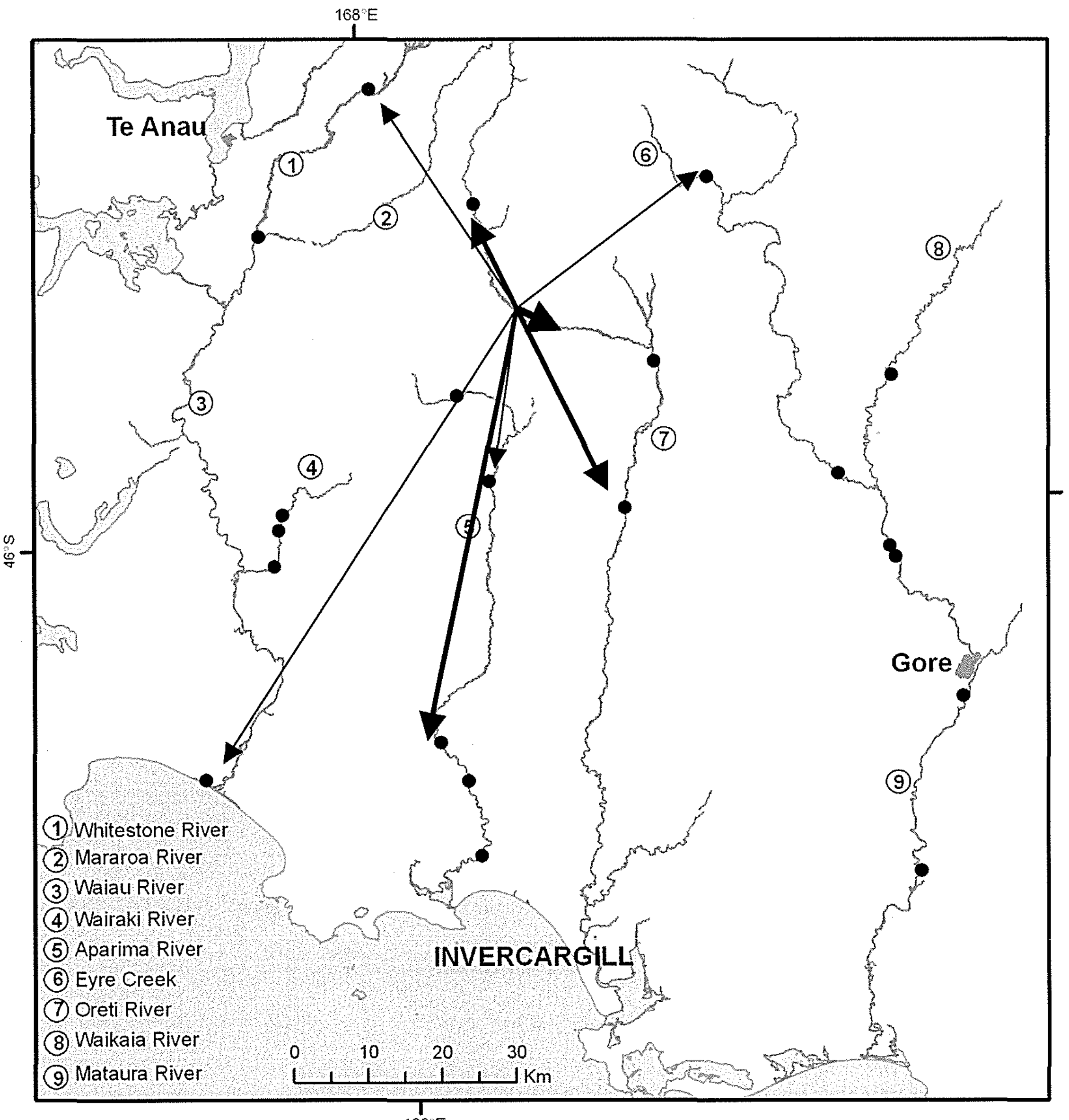


Figure L: *Dispersal of birds banded as chicks at Mossburn, 2005, in 2006 (n=13). Thickness of arrows indicates number of birds; thinnest lines equate to a single individual.*

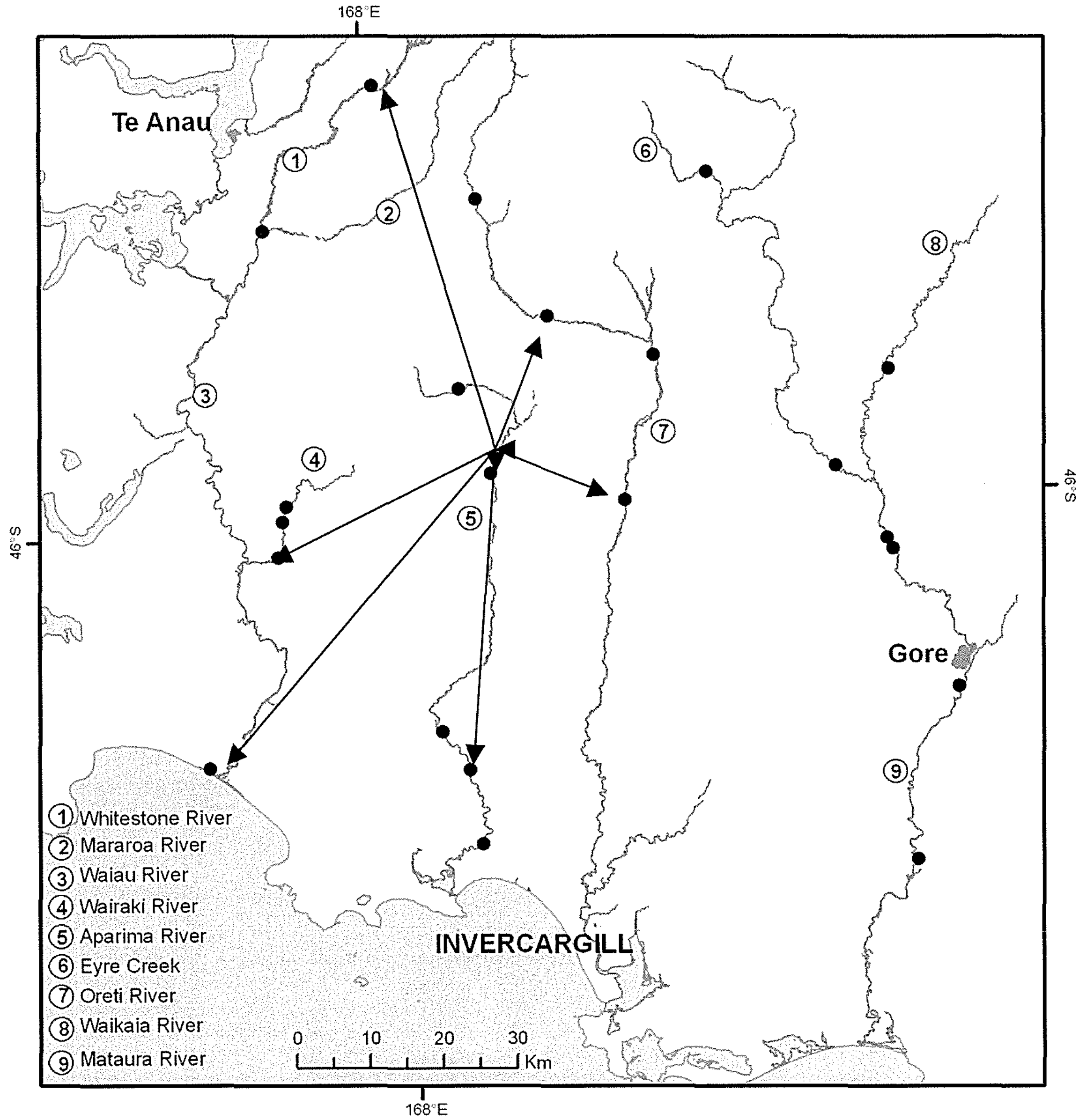


Figure M: *Dispersal of birds banded as chicks at Avondale, 2005, in 2006 (n=7). Thickness of arrows indicates number of birds; thinnest lines equate to a single individual.*

APPENDIX G: RAINFALL DATA DETAILS FOR REMOTE SENSING ANALYSIS

Oreti River

March 1949

- 143 mm; monthly mean 73 mm (SD 35 mm). Rainfall data from 'Otama' station, 1917-1979, located approximately 64 km due east of northern end of mid Oreti section on Mataura River. The highest March rainfall in the 62 years was 158 mm. On comparison with 1956 photographs, however, the width of the river appears virtually identical (see Appendix B, Figure B) suggesting normal flow at the time of photography (see October 1975).

March 1956

- 29 mm; monthly mean 73 mm (SD 35 mm). Rainfall data from 'Otama' station.
- 60 mm; monthly mean 95 mm (SD 50 mm). Rainfall data from Invercargill airport station, 1939-1984, located approximately 51 km due south of northern end of mid Oreti section, adjacent to Oreti River. Daily rainfall data: no rainfall on previous day or day of photography, 32 mm total in previous week.

October 1975

- 47 mm; monthly mean 64 mm (SD 30 mm). Rainfall data from 'Otama' station.
- 71 mm; monthly mean 86 mm (SD 29 mm). Rainfall data from 'Lumsden' station, 1970-1979, located approximately 26 km due north of northern end of mid Oreti section, on Oreti River.
- 67 mm; mean 78 mm (SD 39 mm). Rainfall data from Invercargill airport station. Daily rainfall data: no rainfall on two previous days or day of photography, 41 mm total in previous week.

February 1976

- 37 mm; monthly mean 64 mm (SD 38 mm). Rainfall data from 'Otama' station.
- 27 mm; monthly mean 57 mm (SD 32 mm). Rainfall data from 'Lumsden' station.

- 29 mm; monthly mean 83 mm (SD 45). Rainfall data from Invercargill airport station. Daily rainfall data: no rainfall on previous day or day of photography, 45 mm total in previous week.

Waiau River

March 1963

- 64 mm; monthly mean 111 mm (SD 63 mm). Rainfall data from 'Te Anau' station, 1961-1979, located approximately 58 km due north of northern end of mid Waiau section.
- 41 mm; monthly mean 102 mm (SD 54 mm). Rainfall data from 'Manapouri' station, 1913-1979, located approximately 41 km north of northern end of mid Waiau section at head of Waiau River.
- 48 mm; monthly mean 103 mm (SD 57 mm). Rainfall data from 'Monowai' station, 1920-1979, located approximately 18 km north-north-west northern end of mid Waiau section on Waiau River.

March 1975

- 143 mm; monthly mean 111 mm (SD 63 mm). Rainfall data from 'Te Anau' station.
- 137 mm; monthly mean 102 mm (SD 54 mm). Rainfall data from 'Manapouri' station.
- 123 mm; monthly mean 103 mm (SD 57 mm). Rainfall data from 'Monowai' station.

February 1978

- 39 mm; monthly mean 66 mm (SD 36 mm). Rainfall data from 'Te Anau' station.
- 58 mm; monthly mean 70 mm (SD 44 mm). Rainfall data from 'Manapouri' station.
- 63 mm; monthly mean 86 mm (SD 53 mm). Rainfall data from 'Monowai' station.

APPENDIX H: STUDY COLONY PRODUCTIVITY RESULTS INCLUDING LOCATION AND YEAR

Table I: *Black-billed gull colonies monitored from 2004-2006, details and parameter estimates*

Colony	River	Year	Site	Colony size[1]	Ratio gulls to nests[2]	Clutch size	Nest success (%)	Chicks from eggs (%)[3]	Breeding success	Density (nests/ m^2)	Synchrony (SD of first egg date)[4]	Available area (m^2)[5]
Papatotara	Waiau	2004	Island	1217	3.01:1	2.05	94.0	73.1	0.44[6]		0.8	
Motu Bush	Waiau	2004	Island	6029		1.98	92.2	74.4		1.37	13.5	30039[8]
Mossburn	Oreti	2005	Island	2006	2.60:1	1.88	89.7	71.6		1.33	5.0	5910
Lill Burn	Waiau	2004	Island	3520		1.98	84.3	67.9	0.93[7]	1.72	10.0	12939[8]
Dunrobin	Aparima	2004	Bank	2552		1.96	80.3	65.9		1.68	6.1	
Otama South	Mataura	2006	Partial bank	4266	2.12:1	1.90	78.5	62.5	0.88		14.5	5220
Dipton	Oreti	2006	Bank	1884	3.95:1		77.6	55.1	0.55			3615
Bayswater	Aparima	2004	Bank	2927	3.69:1	2.00	75.3	59.5	1.00[7]	2.54	25.8	
Mararoa 06	Waiau	2006	Partial bank	1828	1.01:1	1.92	74.1	56.0	0.37	3.77	8.5	904
Avondale North	Aparima	2005	Bank	2709	1.28:1	1.74	70.6	51.7		0.66	10.9	
Mossburn Bridge	Oreti	2006	Partial bank	2517		1.87	70.2	48.1				5778
Dunrobin South	Aparima	2006	Partial bank	3453	0.90:1	1.88	69.5	52.8	0.34	1.95	7.4	6513
Otama North	Mataura	2006	Bank	3169	1.23:1	1.91	68.8	50.8	0.31	0.66	22.9	
Benmore	Oreti	2004	Bank	721	2.25:1	1.85	63.8	41.4	1.01[7]		13.0	
Thornbury	Aparima	2006	Bank	909	2.21:1	2.04	63.6	42.6	0.45			30652[8]
Mararoa 05	Waiau	2005	Bank	536	1.94:1	1.72	63.1	46.6	0.01	1.43	10.6	3251
Avondale	Aparima	2004	Bank	5600		1.80	62.0	49.7		1.56	9.1	
Lumsden	Oreti	2004	Bank	4358		1.82	61.4	48.5			21.9	
Etal Creek	Aparima	2006	Bank	882	2.10:1	1.79	58.9	39.8	0.21	1.07		3905[9]
Fairfax Island	Aparima	2006	Island	100*		1.91	31.5	18.6	0.02	0.88		1826
Fairfax bank	Aparima	2006	Bank	100*		1.69	18.7	10.0	0	0.43		17229

1 Counts of gulls in aerial photographs (Chapter 2); *Deserted prior to photography, counts are twice the number of nests.

2 Derived from aerial photograph counts and nest counts (Chapter 2)

3 Total number of chicks seen in the nest by the total number of eggs seen in the nest

4 Photographic estimate except where stated

5 Total amount of bare gravel within immediate colony area (Chapter 4), derived from GIS analysis of aerial colony photographs except where stated

6 All fledglings caught and all nests counted: actual figure

7 Mark-recapture estimate

8 Derived from GIS analysis of professional aerial photographs

9 Derived as for Note 5 except only partial area analysed. Full area approximated from oblique photographs.

APPENDIX I: DETAILS OF PREDATOR-RELATED EGG MORTALITY EVENTS RECORDED ON INFRA-RED VIDEO CAMERAS IN A BANK COLONY

Table J lists 13 egg mortality events presumed to be due to 'natural' causes. One clearly purposeful removal of an egg was observed where the parent picked up the egg and flew away with it. A further two egg losses may also have been purposeful given the parents were brooding 4-5 day old chicks. Three eggs were knocked out of nests, presumably by accident. A gull was seen pushing the egg back towards the nest on one occasion. One parent appeared to have a severe spasm, falling on its side for a minute. It returned to its nest, still with its body arched, and then began to sit as normal. The egg was not observed to roll away from the nest, but it was no longer present. Most 'natural' egg loss was due to gull predation. It was impossible to tell whether the 'predator' was the second parent or other opportunistic gulls, although on two occasions the same incubating gull ate one of its eggs.

Table J: *Details of 'natural' egg and chick mortality events as recorded by infra-red video cameras.*

Camera/ nest	Mortality type	Description
AV1-2	Purposeful removal?	Egg rolls out as parent shuffles. No disturbances. First egg hatched 5 days earlier.
AV1-6	Purposeful removal?	Egg loss not observed. No disturbances. First egg hatched 4 days earlier.
AV2-1	Accidental loss	Egg disappears when parent flies away. No disturbances. Second egg not yet hatched.
AV2-6	Gull predation	Gull approaches, parent steps off nest, gull eats eggs, parent finishes eggs, second parent takes over incubation.
AV2-14	Gull predation	Parent leaves nest momentarily, gull enters and eats eggs. No disturbances.
AV3-A	Purposeful removal	Parent is incubating, moves egg with bill, then picks it up and flies away and returns to sit.
AV3-B	Accidental loss	Egg rolls out as parent flies away. No disturbances. Second egg not yet hatched.
AV3-F	Natural mortality	Chick is left behind when parent and first chick desert nest site; much smaller than sibling. Dies soon after.
AV3-H	Accidental loss	Incubating parent falls on its side in a contorted shape for 1 minute, then sits up. Egg is no longer present.
AV4-F	Natural mortality	Two chicks die soon after hatching. Disturbance within this time, but parent quickly returned to nest.
AV6-E	Gull predation	Gulls approach and predate eggs
AV7-B	Gull predation	Incubating bird stands and eats one of its eggs; another gull appears and also eats.
AV7-B	Gull predation	Second of two eggs eaten by parent.

Table K details all known and possible predator visitation events that caused egg mortality. Of the 13 predator visitation mortality events, five were considered to be caused by predators – a ferret or a cat was seen entering the view of the camera within 1-10 minutes of incubating gulls leaving the camera view. Six were assumed to be due to predator visitations within the colony as a ferret or a cat was seen at one or both of the remaining cameras within two minutes of the mortality event occurring. Two are also assumed to be due to predator visitations as disturbances also occurred at other cameras within two minutes, but no predator was identified.

Table K: *Details of egg mortality events due to known and 'possible' predator visitation as recorded by infra-red video cameras.*

Camera/ nest	Mortality type	Description
AV2-1	Possible predator visitation	Egg disappears as parent is disturbed (can see a possible lump in brood feathers). Disturbance in adjacent camera at same time.
AV4-B	Predator visitation	Egg rolls out when parent is disturbed. Ferret runs past camera at back of nests within the minute.
AV4-C	Possible predator visitation	Egg rolls out when parent is disturbed. Disturbance in adjacent camera at same time.
AV4-D	Predator visitation	Egg disappears when parent is disturbed. Cat walks past nests a few minutes later.
AV4-G	Possible predator visitation	Egg rolls out as parent is disturbed. Cat at adjacent camera at same time. Two different cats seen three times in previous 90 minutes at AV4.
AV6-F	Possible predator visitation	Egg caught in brood feathers and carried away when parent is disturbed. Cat seen in a second camera, and the third camera also disturbed within this time. Egg is seen dropping.
AV6-I	Possible predator visitation	Parent is disturbed and egg is eaten by a gull. Ferret at adjacent camera at same time.
AV6-J	Possible predator visitation	Parent is disturbed and egg is pecked at by a gull. Cat seen at both adjacent cameras within the minute.
AV7-C	Possible predator visitation	Parent deserts nest during a disturbance. The two eggs are later eaten by gulls. Cat seen at adjacent camera at same time.
AV7-D	Possible predator visitation	Parent deserts nest during a disturbance. Two eggs are later eaten by gulls. Cat seen at adjacent camera at same time. Cat seen twice and three other 'possible' cat disturbances in previous six hours.
AV8-B	Predator visitation	Parent deserts nest during a disturbance during which a cat passed through twice. Two eggs are later eaten by gulls.
AV8-E	Predator visitation	Parent deserts nest during one of three visitations by a cat over four hours. Two eggs are later eaten by gulls.
AV9-B	Possible predator visitation	Egg loss not observed. Cat visits twice in 2.5 hours, parent is kept off nest for several hours. Several hours later the egg is observed to have gone.

APPENDIX J: CHANGES IN THE FREQUENCY OF MODERATE FLOODS OVER 20-50 YEARS

A possible effect of climate change is changes in the frequency of flooding of colonies. The flow required to reach colonies monitored from 2004-2006 was modelled from cross-sections taken through the highest point of the colony using a staff and level. Data from the closest river gauges was then used to determine the number of times the flow exceeded this level during the breeding season (from September to December) over a period of 25-50 years (full methods in Chapter 4).

Table L: *Changes in the frequency of floods over 30-60 years that meet or exceed flows required to reach monitored black-billed gull colonies, Mataura, Waikaia, Aparima and Waiau rivers, 2004-2006.*

Colony	River	Average number of floods					Significance
		1950s-69	1970-79	1980-89	1990-99	2000-07	(P)
Cattleflat	Mataura	1.0	1.8	2.8	2.2	2.1	<0.10
Waipounamu	Mataura	2.4	2.6	4.1	5.7	5.4	<0.01
Otama North	Mataura	1.0	1.8	2.0	3.0	2.0	<0.05
Otama South	Mataura	0.8	1.2	1.4	2.0	1.8	<0.01
Waikaia	Waikaia		2.3	3.0	5.1	7.6	<0.05
Dunrobin South	Aparima			4.6	4.0	0.4	<0.10
Avondale North	Aparima			2.3	2.4	0.9	NS
Motu Bush	Waiau		2.0	4.3	4.8	3.4	NS

Linear regression indicated that the number of floods which would reach the eight study colonies during September-December has doubled over 50 years on the Mataura River in eastern Southland (Table L; Figure N; Cattleflat, adj. R^2=0.05, df=50, P<0.10; Waipounamu, adj. R^2=0.24, df=50, P<0.01; Otama North, adj. R^2=0.09, df=48, P<0.05; Otama South, adj. R^2=0.13, df=48, P<0.01). A similar pattern has occurred on the Waikaia (Figure Oa; adj. R^2=0.12, df=29, P<0.05). On the Aparima River, flood frequency appears to have decreased in a much shorter timeframe though changes are not significant at one colony (Figure Ob and c; Dunrobin South, adj. R^2=0.09, df=28, P<0.10; Avondale North, adj. R^2=0.01, df=22, P>0.10). No change has occurred on the Waiau river in western Southland which has had a managed flow since 1970 (Figure Od; adj. R^2=0.00, df=34, P>0.10). In order to assess possible changes on the Oreti River, which was not able to be surveyed due to logistical difficulties, a flow was chosen that was likely to cause flooding to colonies. Flow history in the middle reaches of the river was assessed (at Lumsden) from 1976-2007 and no significant changes were found (adj. R^2=-0.02, df=30, P>0.10).

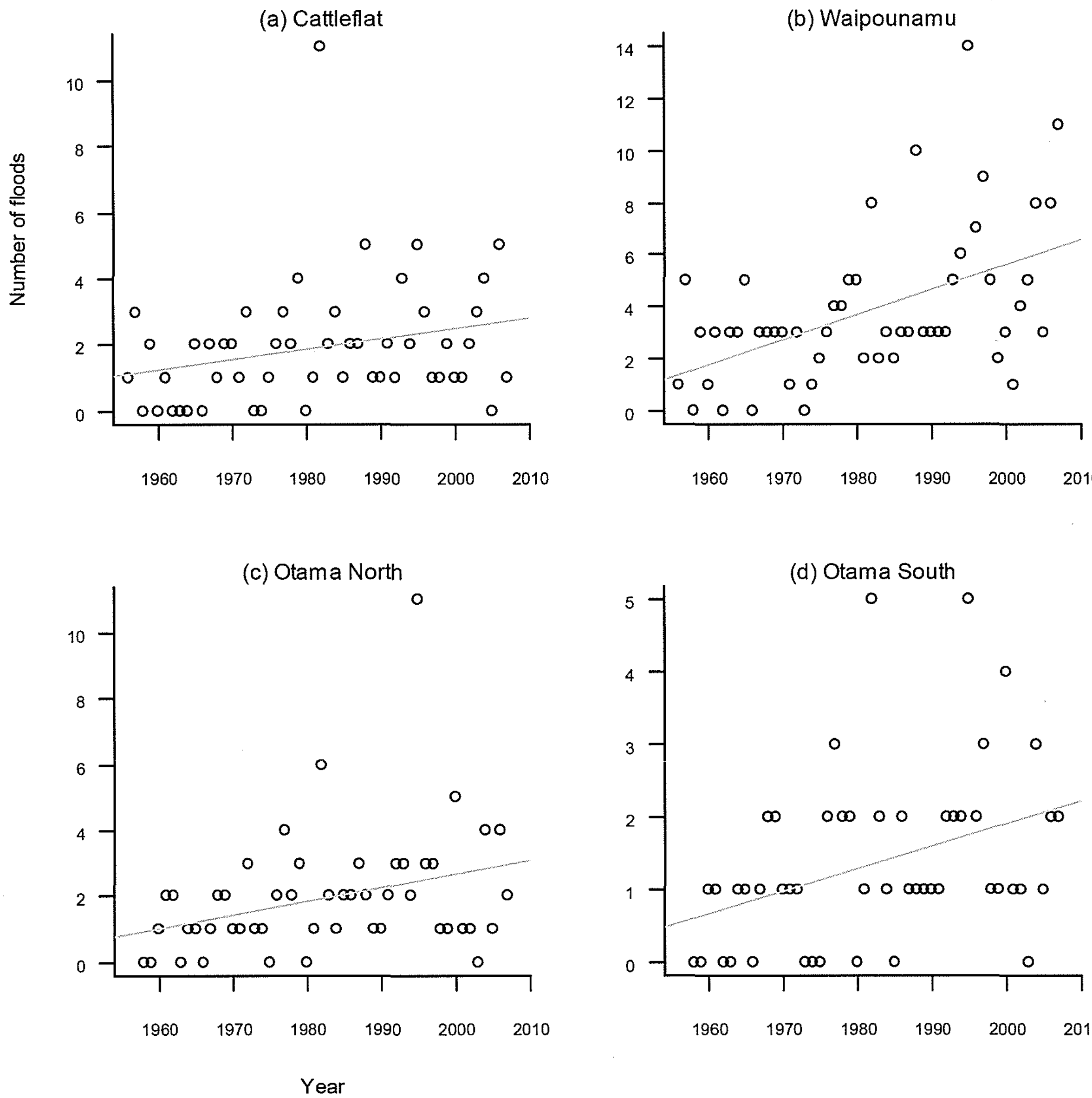


Figure N: *Number of floods exceeding the flow required to reach four black-billed gull colonies since first records: Mataura River (eastern Southland).*

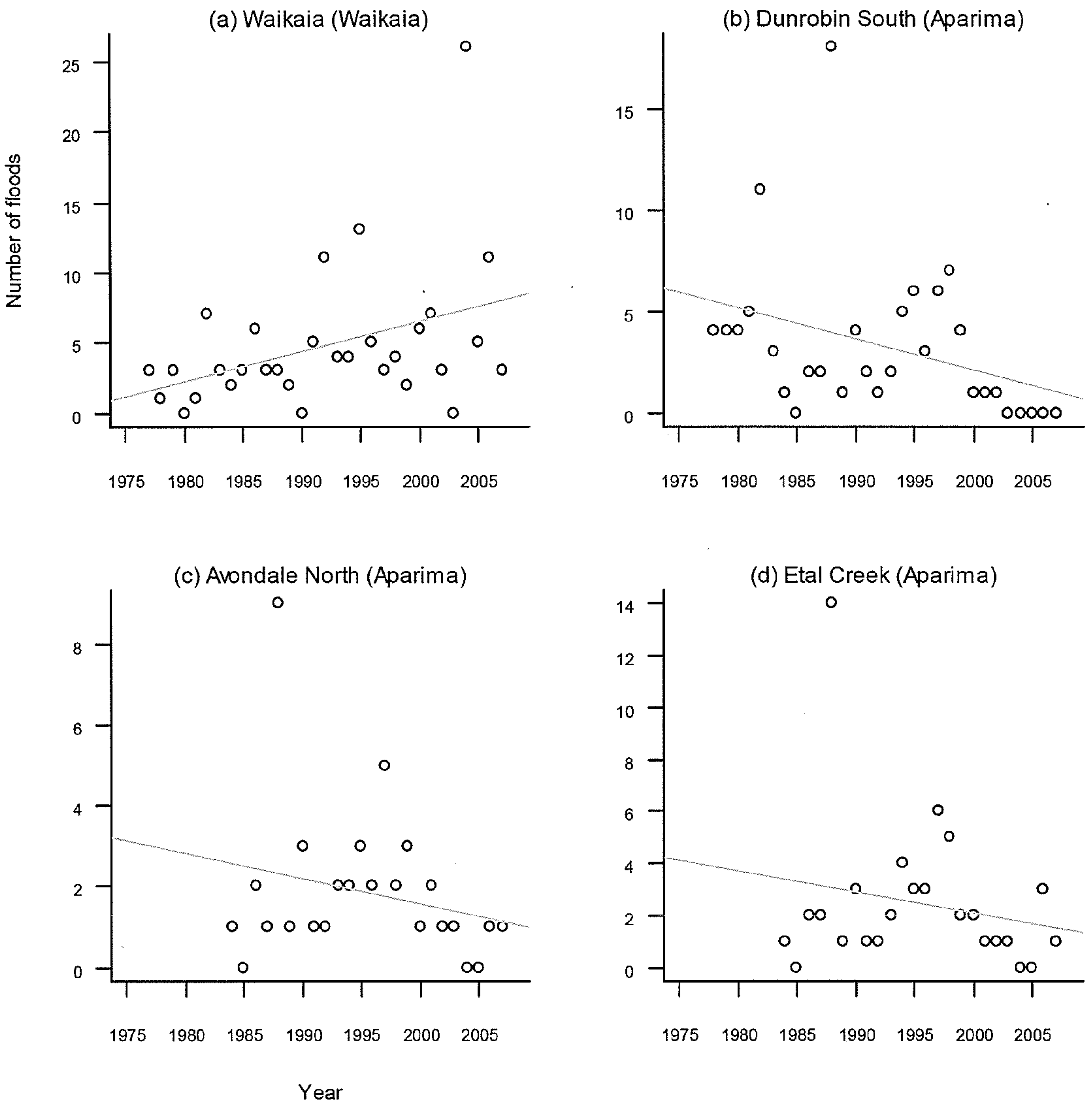


Figure O: *Number of floods exceeding the flow required to reach four black-billed gull colonies since first records: Waikaia River (eastern Southland), Aparima River and Waiau River (western Southland)*

The impact of floods on colony productivity proved difficult to monitor as, unusually, no significant floods occurred during the 2004 and 2005 breeding seasons. In 2006, floods affected seven colonies, mostly at the initiation of nesting and after the majority of incubation attempts had been completed. Mossburn Bridge colony (2517 gulls in aerial photograph) was flooded twice during incubation (Figure P) losing approximately half of its nests and no re-nesting was observed during the monitoring period. After monitoring ceased, the whole colony was submerged in another flood on December 1, however approximately 50 new nests and c.200 mobile chicks were present five days later. Small numbers of gulls were still at the site on January 31, including 28 fledglings. A second colony which was not monitored was flooded severely on several occasions but did not abandon the site and produced c.20 fledglings from approximately 700 nests.

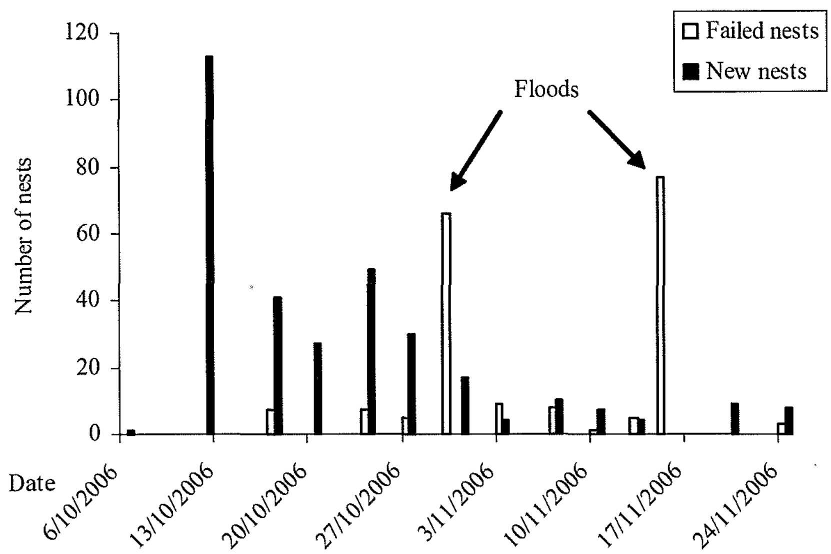


Figure P: *Dates of new nests and failed nests (as determined from monitoring) at Mossburn Bridge colony in relation to two floods that partially damaged the colony.*

APPENDIX K: CHANGES IN THE TIMING OF BLACK-BILLED GULL BREEDING OVER 70 YEARS

'Whale-birds' were recorded as returning inland on September 4 1902 in a landholders diary, a title thought to refer to black-billed gulls. As a comparison, red-billed gulls were recorded as returning the following year on September 5 (Child 1983). Wintering birds arrived on the coast in early April during the early 1940s, and many were still present in October (Anon 1944). Soper (1963) recorded gulls returning to breed in August; Beer (1966) noted that gulls were still common on the coasts in August-September. Child (1983) recorded seven years of arrivals from 1963-1970 and found that gulls returned in the last week of July. During 2004-2006 in Southland, gull flocks were seen as early as May, and sizeable numbers were present on rivers by July (pers. obs.)

Stead (1932) recording egg laying in Canterbury beginning at the end of October. Likewise, Guthrie-Smith (1936) observed that gulls selected their colony site in mid-October, with eggs appearing by the end of October, but most being laid in the first half of November. First eggs in 1947 were found on October 20 (Middleditch 1947). On 10 November 1956, of 260 nests only one contained a chick (Child 1957). Soper (1963) recorded first eggs by the end of September, though usually in October and sometimes as late as November. Beer (1966) recorded egg laying commencing in early to mid October. In 1979, Evans observed large variation in the initiation of laying, from September 1 to October 29 (mean 4 October). In comparison, mean first laying date from 15 colonies was 24 September and mean laying date was 14 October (Chapter 5). This suggests that black-billed gulls may be laying earlier than 70 years ago.

APPENDIX L: POWER ANALYSIS FOR TERRESTRIAL PREDATOR TRAPPING TRIAL

A series of power analyses were completed to examine whether a trapping experiment using four colonies for each treatment (trapped and non-trapped) had the ability to identify an improvement in nesting success. All power tests were one-tailed and $\alpha=0.05$. Analyses used Power and Precision™ release 2.00. Assessments used estimates obtained from bank colonies in 2004 and 2005 for the non-treatment mean (Mean1) and standard deviation (SD1).

Table M: *Power analysis for a terrestrial predator trapping trial showing results for different combinations of mean nest success, standard deviation of nest success and sample sizes (number of colonies).*

Scenario	Mean1	Mean2	SD1	SD2	N1	N2	Power
10% increase with varying numbers of colonies	68.9	78.9	8.3	8.3	3	3	0.34
	68.9	78.9	8.3	8.3	4	4	0.45
	68.9	78.9	8.3	8.3	5	4	0.49
	68.9	78.9	8.3	8.3	6	4	0.53
	68.9	78.9	8.3	8.3	8	4	0.57
15% increase with varying numbers of colonies	68.9	83.9	8.3	8.3	4	4	0.73
	68.9	83.9	8.3	8.3	5	4	0.78
	68.9	83.9	8.3	8.3	6	4	0.82
	68.9	83.9	8.3	8.3	8	4	0.86
20% increase with varying numbers of colonies	68.9	88.9	8.3	8.3	3	3	0.78
	68.9	88.9	8.3	8.3	3	4	0.85
	68.9	88.9	8.3	8.3	4	4	0.91
	68.9	88.9	8.3	8.3	5	4	0.94
	68.9	88.9	8.3	8.3	8	4	0.98
Varying increase with high variance in trapped colonies	68.9	78.9	8.3	14	4	4	0.29
	68.9	83.9	8.3	14	4	4	0.50
	68.9	88.9	8.3	14	4	4	0.70
15% increase with varying numbers of trapped colonies and different variances	68.9	83.9	8.3	4.3	4	4	0.88
	68.9	83.9	8.3	6.3	4	4	0.81
	68.9	83.9	8.3	10.3	4	4	0.64
	68.9	83.9	8.3	10.3	4	5	0.68
	68.9	83.9	8.3	14	4	10	0.59

Table M shows the scenarios tested using power analysis. The first scenarios examined a situation where only an average 10% increase in nesting success was achieved by trapping. The power of all the scenarios was low, even when sample sizes were raised to potentially impossible levels (i.e. an insufficient number of colonies on the rivers to monitor). Power was significantly higher if nesting success increased by 15%. If nesting success increased by 20%, with four colonies in each treatment, 91% of studies would reject the hypothesis that the two means are equal.

The scenarios modelled indicate that increasing sample sizes had less effect on the power of the proposed experiment than increasing nesting success of the trapped colonies or reducing variation in nesting success of one of the treatments. In summary, four colonies for each treatment is likely to be sufficient to observe an improvement in nesting success if predator control raises nesting success to similar levels found on islands (i.e. mean and variation).