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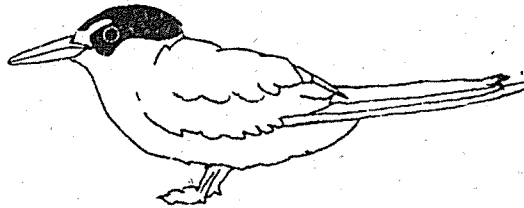
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**Behavioural ecology of the endangered New  
Zealand Fairy Tern (Tara-iti) *Sterna nereis davisae*:  
implications for management**



A thesis presented in partial fulfillment of the requirements for a degree of  
Masters of Science in Ecology

at

Massey University, Palmerston North  
New Zealand

Sara Jane Treadgold

2000



**To Jarn  
whose friendship I will always treasure**



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*"Home is not a place, it's wherever your passion takes you" Capt. John Sheriden (Babylon 5)*

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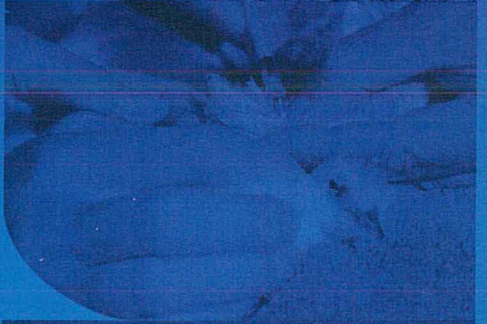
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# General Introduction





## 1.1 Introduction

There are 42 species of terns around the world of which 10 are in the genus *Sterna*. Six of these terns breed in New Zealand including the Antarctic (*S. vittata*), Black-fronted (*S. albobriata*), Caspian (*S. caspia*), White-fronted (*S. striata*), Sooty (*S. fuscata*) and Fairy Tern (*S. nereis davisae*) (Heather and Robertson 1996).

John Gould discovered Fairy Terns in Bass Strait in 1843 and was the first to describe the species (Oliver 1955). Shortly after Thomas Potts noted Fairy Terns breeding on the Rakaia River (South Island, New Zealand) in 1869, and suggested the name *Sterna alba*. However, Frederick Hutton identified two specimens at Canterbury Museum and listed the species as *Sterna nereis* (meaning water-sprite or sea-sprite) in his 'Catalogue' (Hutton and Drummond 1923, Oliver 1955). Although Mathews and Iredale described the New Zealand subspecies in 1913 (Parrish and Honnor 1997), this was largely ignored until it was re-confirmed as a subspecies by Turbott in the 1990 publication of the Checklist of the Birds of New Zealand (Turbott 1990). This taxonomy was supported by Higgins and Davies (1996), in the Handbook of Australian, New Zealand and Antarctic Birds. Fairy Terns have now been separated into three subspecies: *S. nereis davisae* in New Zealand; *S. n. nereis* in Australia; and *S. n. exsul* in New Caledonia and Australia (Parrish and Honnor 1997). In recent years, however, their taxonomic status has again been questioned as previously the differences were based on morphological characteristics (Parrish and Honnor 1997). Preliminary work with DNA material suggests that *S.n. davisae* is closely related to *S.n. nereis*. However, since a limited number of individuals were surveyed, it was suggested that the New Zealand Fairy Tern continue to be known as a separate subspecies (Chambers and Coddington 1998).

The New Zealand Fairy Tern (*Sterna nereis davisae*), appropriately named *Tara-iti* (little one) in Maori, is one of the two smallest species of tern in the genus *Sterna*. The other species is the Little Tern (*Sterna albibrons*). The Fairy Tern is the only small tern that breeds in New Zealand and it is our most endangered seabird. All three subspecies of *Sterna nereis* are classified as critically endangered (Taylor 2000). *S.n. davisae* is considered a Category A (endangered) species by the Department of Conservation (Molloy



and Davies 1992) and has been under crisis management since the New Zealand Wildlife Service began management in 1983 (Parrish and Honnor 1997, Taylor 2000). Note that from this point onwards only common names for birds will be used unless necessary. All birds mentioned are included in Appendix 1.1 (see pages 27-29) with common and scientific names.

The decline of Fairy Terns has probably resulted from a combination of factors including weather systems, mammal predation, human recreation and the degradation and development of beach environments. Although there are no accurate records of breeding from 1950s-1970s, in the last ten years weather has been an important factor troubling the terns, and one which commonly affects ground-nesting seabirds. Storms flood nests and inshore winds cause dunes to shift, burying nests or causing abandonment. Exposure to adverse weather effects, causing the death of embryos and chicks, have been responsible for 40 percent of failures or death in Fairy Terns (Parrish and Honnor 1997). Rain and strong sun has been found to cause death in chicks in Herring Gulls, Lesser Great Black-backed Gulls and Black-headed Gulls (Harris 1964), Sooty Terns (Taylor 1979), and Arctic Terns (Higgins and Davies 1996).

Cyclic extremes over periods of four to seven years caused by the Southern Oscillation have an interesting possible consequence for Fairy Terns. According to records of storm events and storm surges, the shifts of extreme variations of El Niño and La Niña, in combination with global changes in ocean circulation patterns, have created changeable conditions for New Zealand's coastal environments about every 25-35 years (de Lange and Gibb 1999). During the period 1951 to 1975, a La Niña-dominated pattern caused higher temperatures, increased rainfall, a higher frequency of onshore easterly winds, a rise in sea level, and more large storms and storm surges causing erosion of northeast coast beaches. This may correspond with the noticeable decrease in sightings of Fairy Terns and their breeding on the east coast in the 1950s (Macdonald 1952). From 1976 to the present an El Niño-dominated phase has produced the opposite conditions, especially for the north of the North Island (de Lange and Gibb 1999). The shift to El Niño dominated weather, together with the direct management of Fairy Terns in 1983, would have made breeding

conditions easier for the birds. Since then there has been a corresponding increase in productivity and the number of breeding pairs (Parrish and Honnor 1997) as has occurred with Little, Roseate, Arctic and Common Terns in Britain, Europe and Australia through the benefit of protection (Cramp 1985, Norman 1992, Higgins and Davies 1996).

Fairy Terns have always faced the challenge of weather but there are now pressures from human influence and mammalian predation that contribute to a decline in the population. Prior to human settlement there were only two indigenous mammals in New Zealand, both bats. However, with importation of exotic mammals this has expanded to at least 35 different species (Moors 1983). Predation has been a major cause of egg and chick loss in many birds: mustelids and rodents were responsible for 70 percent of nests of eight species of native bird in Kowhai Bush (Moors 1983); stoats were found to have a dramatic local effect on New Zealand Dotterels (Dowding 1996); ground predators have severely reduced numbers of Black Stilts (Pierce 1986); rats and cats are predators on nearly all seabirds on Raoul Island including Sooty Terns (Taylor 1979); herons and crows are predators of Herring Gulls, Lesser and Greater Black-backed Gulls (Harris 1964) and Least Terns (Brunton 1997); harriers kill waders (Dyrce *et al* 1981); and gulls take Arctic and Common Terns (Hatch 1970). Finally Smith (1990) notes that gulls, oystercatchers, rats and dogs prey on the eggs and chicks of Little Terns in America, Europe and Australia (cited in Parrish and Honnor 1997).

In Fairy Terns it is suspected that 32 percent of eggs and chicks since 1992/1993 have been taken by predators, most likely Black-backed Gulls or Harriers (Parrish and Honnor 1997). Jowett (1987) found rats preyed on Fairy Tern eggs on two occasions (cited in Parrish and Honnor 1997), though there are still other potential predators such as stoats, feral cats, ferrets, and wessels (Parrish and Honnor 1997). It is interesting to note that increases in two predators coincide with the decrease in Fairy Tern numbers. For instance there are documented increases in the distribution and abundance of hedgehogs from 1920-1950 in the North Island, specifically in Northland, as well as increases in the populations of gulls in the last 30 years probably as a consequence of human activities (Fordham 1967, Powlesland and Robertson 1987).

Of the other factors, human activities, land development and degradation (ie stabilisation) of habitats, have placed the birds under considerable pressure (Parrish and Honnor 1997). Jowett (1987) suggests that the development of coasts from Pakiri-Te Arai was the reason behind the decrease in both the number of pairs and their breeding success (cited in Parrish and Honnor 1997). Cummings (1991) found that stabilisation of dunes reduced the available breeding sites in the New Zealand Dotterel. Little, Roseate, and Common Terns are being put under increasing pressure from human activities in Britain, Europe and Australia (Cramp 1985, Norman 1992, Higgins and Davies 1996). Often this has led to poor nest attendance and consequently to overheating or chilling of eggs and chicks, or to abandonment by the parents (Parrish and Honnor 1997).

Infertility of eggs also has an effect on the population, being apparently responsible for 22 percent of the failures of nests since 1992/1993. Finally, adult mortality of Fairy Terns is a possibility but is not well understood. A banded individual, not seen for six years and presumed dead, was seen twice in 1999 (G. Pulham pers. comm.). There are also ten other banded individuals, which have not been seen for at least three years. Due to the difficulty of following their movements over winter months, it is unclear whether these birds are dead, have migrated (perhaps to Australia), or are breeding and wintering in unknown parts of New Zealand (T. Habraken pers. comm., G. Pulham pers. comm.).

The New Zealand Fairy Tern (*S.n. davisae*) is known to breed only on the North Island at three locations: Mangawhai and Waipu (east coast) and Papakanui Spit, South Kaipara Harbour (west coast). In autumn, Fairy Terns move to winter roosting sites around the Kaipara Harbour where they generally remain until July, before starting to return to the breeding grounds to claim territories. Some birds, possibly juveniles of non-breeding age, may range further. A one-year-old bird was seen at Foxton Estuary on 19 December 1999 (I. Saville pers. comm. P. Slack pers. comm.). Fairy Terns have not been seen at Foxton Estuary for over 60 years. There may also be breeding pairs outside the managed sites (possibly further north), since two unbanded juveniles were seen when all known juveniles for that season had been banded (T. Habraken pers. comm., G. Pulham pers. comm.). The solitary breeding by this subspecies (Higgins and Davies 1996) may be a consequence of the small total population. Territories are large, and when a pair nest in close proximity to

another and loss their eggs or chicks, while the other is successful there is the potential for the pair that failed to attack the chicks of the successful pair. This 'grieving parents' syndrome' has been seen at Waipu in the 1994/1995 season (G. Pulham pers. comm.) and at Mangawhai in the 1997/1998 season. Habitat quality, especially feeding opportunities, may also influence nest spacing.

The Australian subspecies (*S. n. nereis*) is probably the most numerous of the three subspecies, with approximately 1000 pairs breeding in the south-west of Australia as well as populations of up to 300 pairs breeding on offshore islands (Serventy *et al* 1971, Hill *et al* 1988). Although the species is a solitary breeder in New Zealand, the Australian subspecies is considered colonial, with small colonies of 250 pairs occurring in Victoria, South Australia, and 100-150 pairs in Tasmania where they breed alongside Little Terns (Hill *et al* 1988). Throughout their range, Fairy Terns breed in summer. However, in the Gulf of Carpentaria and north-east Cape York there have been reports of breeding occurring in late autumn and winter (Hills *et al* 1988).

The subspecies *S.n. exsul* occurs in New Caledonia and possibly in the Great Barrier Reef region of Australia (Hill *et al* 1988). There are also records from Western Australia and Glen Avon, Northam Shire, though these have never been confirmed. Two specimens of *S.n. exsul* were collected in 1950 from Heron Island, Queensland, however no sightings of Fairy Terns have been made there since then (Higgins and Davies 1996). *S.n. exsul* breeds in New Caledonia and possibly on Loyalty Island and a few other sites in the southwest Pacific Ocean. Apart from this, the breeding habits and movements of *S.n. exsul* are not known (Higgins and Davies 1996).

To date, little research has been carried out on any of the three subspecies. For the New Zealand subspecies, an observational study was carried out on seven pairs in the 1993/1994 breeding season (Parrish and Pulham 1995a). The need for detailed research was recognised by the Department of Conservation (DOC) with a permit to band Fairy Terns in 1991 and with the first Recovery Group meeting in 1993. Although the recovery group was not convened in the following three years, the Recovery Group for Fairy Terns and

publication of the Recovery Plan in 1997 formalised the need for priorities in research and management (Parrish and Honnor 1997).

## 1.2 Description

Fairy Terns are monomorphic in their plumage. The adults are 25 cm long and weigh 70 g (Reader's Digest 1985). In breeding plumage (Figure 1.1) they have a black cap extending to the forehead and backwards to a black nape and down in line with the eye. The black extends from the cap through the eye, the posterior lores being black. The lores colouring generally have rounded or square ends and are slightly larger than the eye. The forehead, and the neck are white. The junction between the white forehead and the black cap is well defined and straight, extending backward and ending at a rounded notch directly above the middle of the eye. The mantle, scapulars, back and upperwing are a uniform pale grey, with the outer primaries edged with white, giving an appearance of a white line when the bird is in flight or when it has its wings folded. The rump and tail is mostly white with the outer edges of the tail a pale grey. The bill is a yellow-orange colour, the legs are orange-red.

After the breeding season, the birds undergo their primary moult (eclipse stage) changing from their breeding to non-breeding plumage (Figures 1.2). The main change is the black cap recedes to above the eye, becoming white, mottled with black, while the black nape remains. The bill fades to pale yellow with a black line across the base and around the nostril, and a faint grey-black tip. The legs are a dull orange.

Juveniles have a black-brown band across the nape that extends forwards to encircle the eye. The top of the head is white, mottled with black-brown. Newly fledged juveniles have a light brown forehead and crown speckled with black, with a white spot in front of, and above, the eye. The upperparts are grey, their wing coverts fringed with rustic-brown and a dark grey carpal bar, which is eventually lost. The bill is black-red and the legs dark red-brown.





**Figure 1.1.** The *post-breeding plumage* of the New Zealand Fairy Tern. This female bird kept much of its breeding plumage for a month after breeding before progressing into its primary moult (*eclipse stage*). The faint black along the base and tip of the bill is not present in full breeding plumage and the bill seen here as being of a pale yellow, is a bright orange-yellow during breeding.



**Figure 1.2.** The *eclipse stage* of the New Zealand Fairy Tern between its breeding and non-breeding plumage. Note the loss of definition at the front of the cap to white, mottled with black, the black line across the base of the bill and the black tip on the bill. The bill is also a paler yellow.



There are differences between the three subspecies in their adult plumage (Higgins and Davies 1996). *S.n. davisae* is a darker grey on the mantle, scapulars, back and upperwing than the other subspecies. The black cap extends lower on the hindneck and it has a larger, black blotch on the posterior lores than *S.n. nereis*. *S.n. nereis* moults more of the primary wing feathers as well as retaining the black tip for longer than *S.n. davisae*, which gains the full yellow bill of its *breeding plumage* in mid June. *S.n. exsul* mostly resembles *S.n. nereis* though its upperparts are a paler grey, and it has a larger black tip to the bill. The first *non-breeding plumage* is markedly different in that it has a wholly white crown with only traces of dark flecks. *S.n. exsul* has a shorter wing, bill and tail of the three, while *S.n. davisae* has the longest wing (Higgins and Davies 1996).

The plumage of the Fairy Tern is very similar to that of the Little Tern, and the two species are often mistaken during austral spring and autumn when the Little Tern migrates to New Zealand. The Little Tern differs from the Fairy Tern in having silvery-grey upperparts and inner primaries. The outer primaries are dark grey, as compared with white in Fairy Terns. The forehead, breast and underparts are white. In *breeding plumage*, the black cap of the Little Tern extends around the eye, and extends forward through the lores to the base of the bill, tapering from in front of the eye. The bill is yellowish with a distinct black tip. The Little Tern is often seen in New Zealand, at the wintering sites of Fairy Terns, eclipsing into *breeding plumage* where it can be mistaken for a Fairy Tern eclipsing into winter *non-breeding plumage*, as both birds have varying amounts of black and yellow in their bills in austral autumn. Other distinctions between the two species include a flatter head and fully black bill in *non-breeding plumage* in the Little Terns, compared to a relatively rounded head and the pale yellow bill of the Fairy Tern.

### 1.3 Study Sites

There are three known breeding grounds for the Fairy Tern in New Zealand, all in the north of the North Island (Figure 1.3). Mangawhai Spit (36° 06' S, 174° 36' E) and Waipu Spit (36° S, 174° 29' E) are located on the east coast, approximately 130 km north of Auckland.

The third site, Papakanui Spit ( $36^{\circ} 26' \text{S}$ ,  $174^{\circ} 12' \text{E}$ ) is on the west coast, approximately 100 km from Auckland, at the South Head of the Kaipara Harbour (Figures 1.4.1 to 1.4.3). See Figures 4.1.1-4.1.3 for maps of the breeding sites (Chapter 4: pages 87-89).

Research was conducted over the 1997/1998 and 1998/1999 breeding seasons. All data were collected from the two east coast sites, Mangawhai and Waipu, owing to the difficulty of regularly accessing Papakanui Spit.

### 1.3.1 Mangawhai

The Mangawhai dune field evolved with the destruction of coastal forests about 800-900 years ago (LaBonté 1994). In the 1930s, the dunes extended over a large area of approximately 50000 ha, until marram grass (*Ammophila arenaria*) and Monterey pine (*Pinus radiata*) were planted on the back dunes by the Public Works Department. In 1963 the New Zealand Forest Service planted 1200 ha of pine on the back dunes at Te Arai Point ( $36^{\circ} 12' \text{S}$ ,  $174^{\circ} 38' \text{E}$ ), at the south end of Mangawhai Beach. The forest, known as Mangawhai Forest, was sold to Carter Holt Harvey Limited in 1991 (McKelvey 1999). Due to public support and the inquiry into the status of Fairy Terns by the Ornithological Society of New Zealand (OSNZ) in 1952, the Department of Internal Affairs declared Mangawhai Spit a wildlife sanctuary in 1953.

Mangawhai Spit is approximately 5 kms long and comprises some 12,000 hectares of beach and dunes, including one dune 50 m high, known as 'Big Dune'. On the eastern side there is the ocean beach, and on the western a large tidal estuarine system. The estuary stretches southwest towards Mangawhai Village breaking into two arms, one extending north towards Molesworth and the other passing Mangawhai (approximately 7 km south of Mangawhai Heads). Until 1980, the mouth of the estuary lay at the northern end of Mangawhai Heads. However, during a storm the spit was breached south of the mouth creating two inlets so that the tip of the spit became an island (this area is still referred to as 'Mangawhai Island'). This situation persisted until 1990 when sand erosion and westward advancement of dunes closed off the original inlet, producing a stagnant inner harbour.

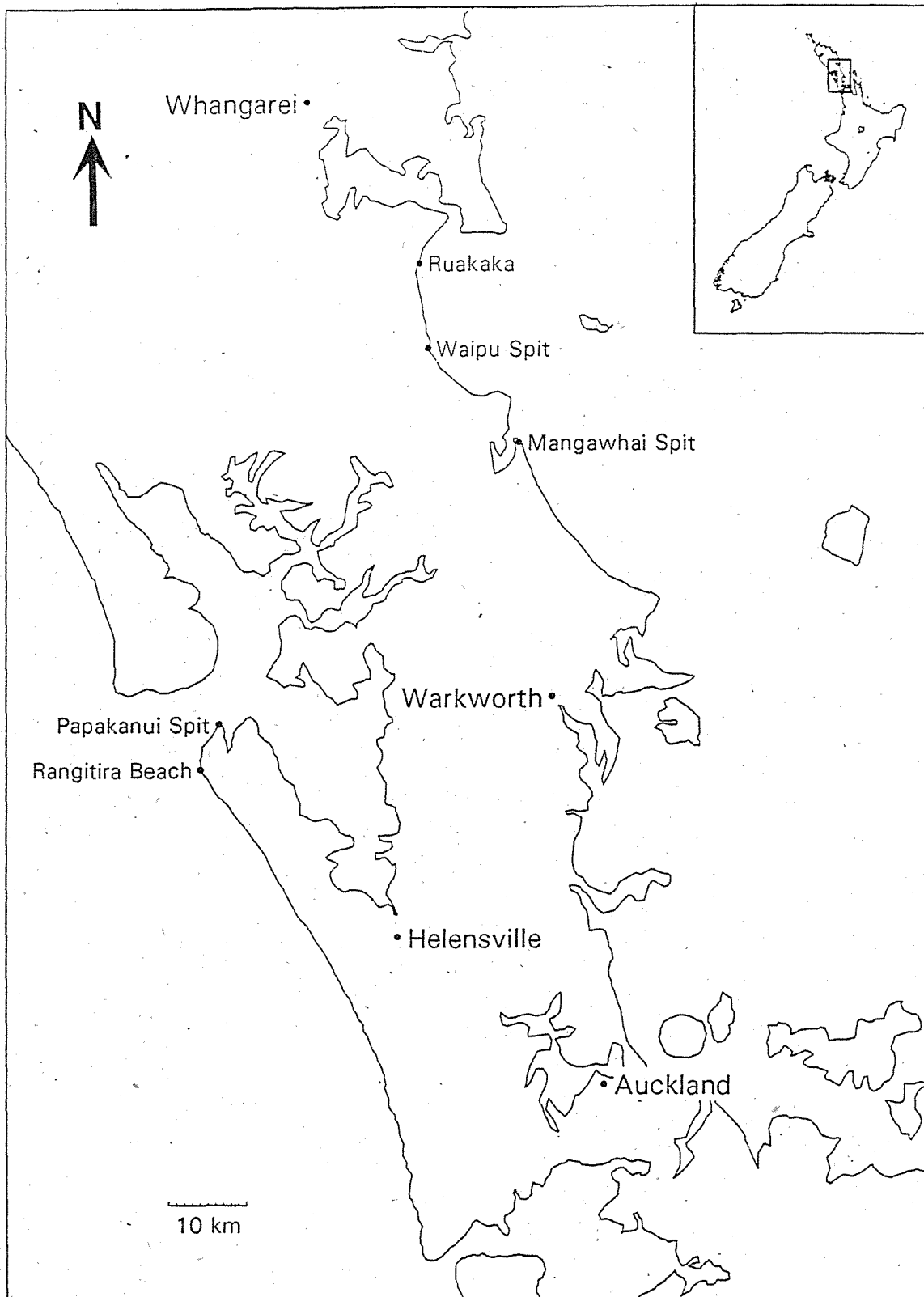


Figure 1.3. Map of the present breeding sites of the New Zealand Fairy Tern.

In 1991 dredging allowed the re-opening of the northern inlet, and then a barrier (known as 'the bund') was built across the southern inlet completed in 1996. This recreated the original harbour, with a tidal lagoon on the ocean side the remnant of the southern inlet (LaBonté 1994). Following the planting of native dune vegetation, the bund is now commonly used by nesting shorebirds, and the harbour has remained the same since its construction.

Mangawhai spit generally lacks vegetation except on a few foredunes and on 'Mangawhai Island' where native dune grasses such as spinifex (*Spinifex hirsutus*) and pingao (*Desmoschoenus spiralis*) stabilize these dunes. The beach is made up of fine white sand with shell patches and middens along its length. The lagoon is tidal, with mud flats creating good roosting and feeding habitats for sea and shorebirds and waders. Mangawhai Forest is a popular area for trail biking, swimming, fishing, horse trails and for people to access Mangawhai Beach, with the harbour used for boating, swimming and water skiing. In 1989 it was estimated that 50,000 people visited the area through the forest (McKelvey 1999). The breeding grounds were accessed either by kayak over the Mangawhai Harbour from Robert Street, Mangawhai Heads, or by foot through the Mangawhai Forest, Pacific Road end and Mangawhai Beach.

Mangawhai has a variety of sea and shorebirds that nest on the spit including annual colonies of Caspian Terns, and White-fronted Terns as well as nests of Black-backed Gulls (*Larus dominicanus*), Variable Oystercatchers (*Haematopus unicolor*), New Zealand Dotterel (*Charadrius obscurus*) and Banded Dotterel (*Charadrius bicinctus*). A stronghold for Fairy Terns, Mangawhai had eight breeding pairs nesting in the 1970s (Parrish and Honnor 1997). Subsequently, the number of pairs decreased until active management of the species began in the 1980s, with management on the east coast beginning in 1983, and a year earlier at Papakanui. Recently, Mangawhai has consistently has three or four pairs nesting along the spit. There are generally one or two pairs, which nest on Mangawhai Island, and one or two pairs at the south end of the bund on the beachfront. During the 1998/1999 season, a pair nested successfully on the bund itself.



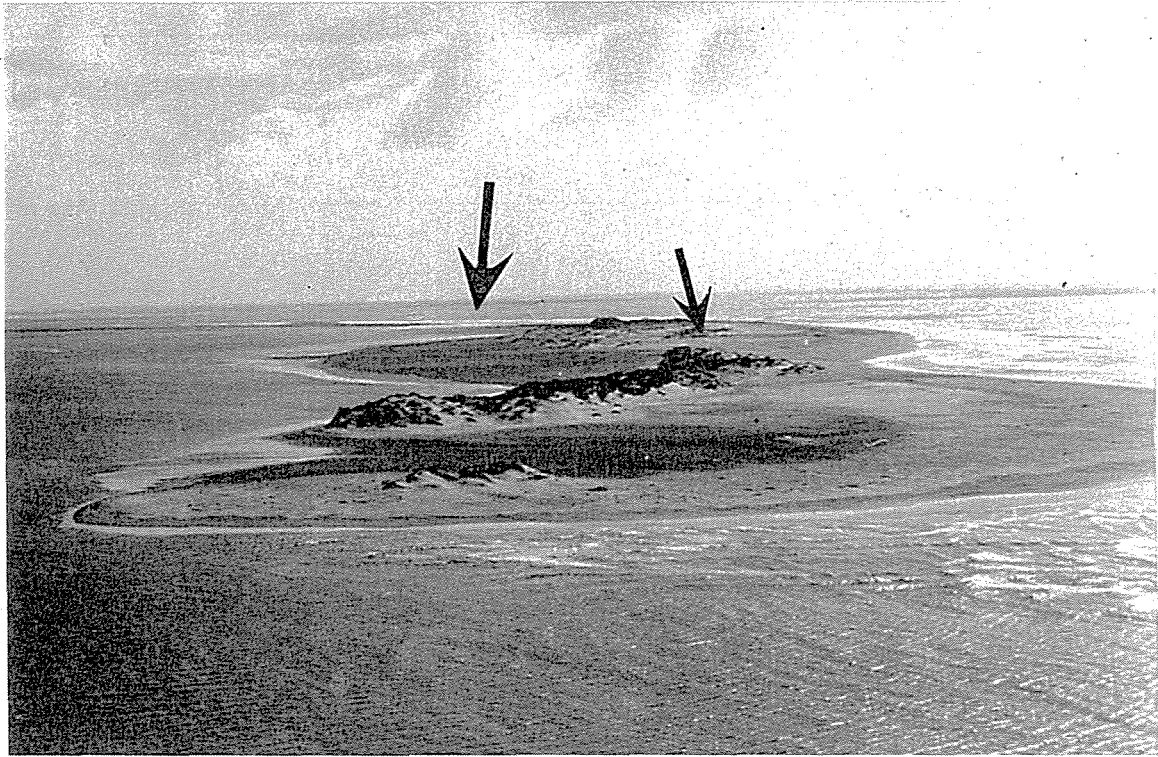


**Figure 1.4.1.** Overlooking Mangawhai Spit from the Mangawhai Heads, with 'the bund' and 'Big Dune' in the background. The small arrows show the location of Fairy Tern nests.



**Figure 1.4.2.** Waipu Spit from the south end of the spit. The sandy cliff where this photograph was taken is the original site where the Waipu River entered the sea. Fairy Tern nests have been situated in the two shell covered bays on the seaward side and amongst the dunes and on a small spit on the estuary side (see arrows).





**Figure 1.4.3.** Papakanui Spit south-west from South Head, Kaipara Harbour, with Rangitira Beach stretching west in the background. The cut, which developed in 1998 is indicated by a large arrow. The locations of the Fairy Tern nest on the spit are shown (small arrow). The other nests are further west along Rangitira Beach.

### 1.3.2 Waipu

Waipu is relatively small and narrow compared to the other two sites, being approximately 6250 ha (about 2.5 km long). Like Mangawhai, an ocean beach and a tidal estuarine system flank this site. However, the Waipu estuary is narrow and extends south with a single arm down the length of the spit to Waipu Cove. At present the inlet occurs at the end of the spit. In the 1950s it lay further south where a high sandy cliff can be seen (from where the photo was taken in Figure 1.4b). The rest of the spit was part of the northern coastline (G. Pulham pers. comm). The estuary side of the spit has also changed with large, flat, shelly areas beyond the back dunes having now been overgrown with estuarine plants, especially sea primrose (*Samolus repens*).

Of the three sites Waipu is the most vegetated, with most of the foredunes and back dunes covered with native grasses. The only significant part without vegetation is the tip of the spit which is a flat and shelly area. The beach has coarse white sand combined with shell fragments and intermittent shelly bays along the beachfront. Waipu is classified as a wildlife refuge, having many shorebirds sharing the dunes as nesting sites. It is also a popular recreational area for fishing, swimming, boating and surfing. Access to the spit is by foot via Johnson's Point Road, approximately 10 km south of Waipu Township.

### 1.3.3 Papakanui

Papakanui Spit (85000 ha) is the largest site, extending 15 km from its tip to 26 Mile Track on Rangatira Beach. It is north of Murawai Beach and part of South Head, south of the entrance to the Kaipara Harbour. The spit has an extensive tidal lagoon, the Waionui inlet with its mouth at the tip of the spit. This was the only inlet until 1998 when a new natural channel cut through the top end of the spit effectively forming an island referred to as Papakanui Island (Wright 1998). Since then the cut has widened and become deeper. The original channel has slowly accumulated silt, becoming shallower due north of Teatree Island (G. Pulham pers. comm).

The high rate of destabilization at Papakanui Spit is due to the continued lack of vegetation. With high back dunes, the beachfront is made up of small dunes, which continuously shift north with the prevailing southwest winds. The area is also subjected to many storms from the northeast, causing shifts in the high dunes. High dunes of 100 m or more were once common place along this coast (McKelvey 1999). Behind the back dunes a large area of sand covered with native grasses, marram and low shrubs is now used as a bombing range by the RNZAF for training exercises. In 1951 marram was planted to stabilize the shifting sand and tree planting began five years later (McKelvey 1999). Woodhill forest, now owned by Carter Holt Harvey Ltd, extends from Muriwai beach to behind the bombing range.



There are areas of shell at Papakanui Spit which are used for nesting by New Zealand Dotterel, Banded Dotterel, Variable Oystercatchers, Fairy Terns, White-fronted Tern colonies, and Black-billed Gull colonies. In the past, Fairy Terns nested on Papakanui Island and in an area referred to as 'the bowl', seven to eight km from the tip of the spit and the area where the cut is now. Forestry roads allow public access to Rangatira beach for fishing, swimming, as well as walking tracks, motorbike and horse trails and for OSNZ activities. Fishermen also access the area often by driving up from Muriwai beach in four-wheel drive vehicles. In 1984, an estimated 230,000 people used the forest for recreation (McKelvey 1999). Of the three study sites, access to Papakanui is difficult because of the extent of the area involved. Access to the Fairy Tern breeding sites is by foot, kayak and four-wheel drive vehicle.

In addition to its sea and shorebirds, waders such as the Bar-tailed Godwit (*Limosa lapponica*), Turnstones (*Arenaria interpres*), Wrybill (*Anarhynchus frontalis*), Lesser Knot (*Calidris canutus*), Red-necked Stint (*Calidris ruficollis*), Pied Stilt (*Himantopus himantopus*), and the Pied Oystercatcher (*Haematopus ostralegus*) also use these three areas as roost sites and feed in the nearby estuaries.

#### **1.4, Past and Present Distribution**

The New Zealand Fairy Tern was recorded as being 'tolerably common' on all New Zealand coasts before the turn of the century (Buller 1888a), and T.F. Cheeseman even collected specimens in Orakei Bay, Auckland in 1878 (B. Gill pers. comm). Since then the numbers of sightings suggest Fairy Terns have been at least widespread around the coast of the North Island and eastern parts of the South Island (Falla *et al* 1979, Parrish and Honnor 1997), (Figure 1.5). Records of Fairy Terns in coastal areas of the North Island include Whangaroa, Pawarenga, Whangarei Harbour, Leigh, Firth of Thames, Kaipara and Manukau Harbours, Port Waikato, Raglan, Tauranga. Other, inland sites, include the Rangitikei River, Waikanae River, Lake Papaitonga (Levin), Ahuriri Estuary, and Porangahau (Oliver 1955, Parrish and Honnor 1997). In the South Island sightings have

been made on the Rakaia River, Rangitata Gorge and at Lake Ellesmere (Oliver 1955, Heather and Robertson 1996, Parrish and Honnor 1997). Fairy Terns were also formerly common in Marlborough and Canterbury regions (Oliver 1955). Buller (1888b) stated that a nestling, presumably *Sterna nereis*, was 'received' from the Chatham Islands in 1917 and was held in the Canterbury Museum. It was later found, however, that this specimen was misidentified and was a Little Tern (*Sterna albifrons sinensis*) (G. Tunncliffe pers. comm.).

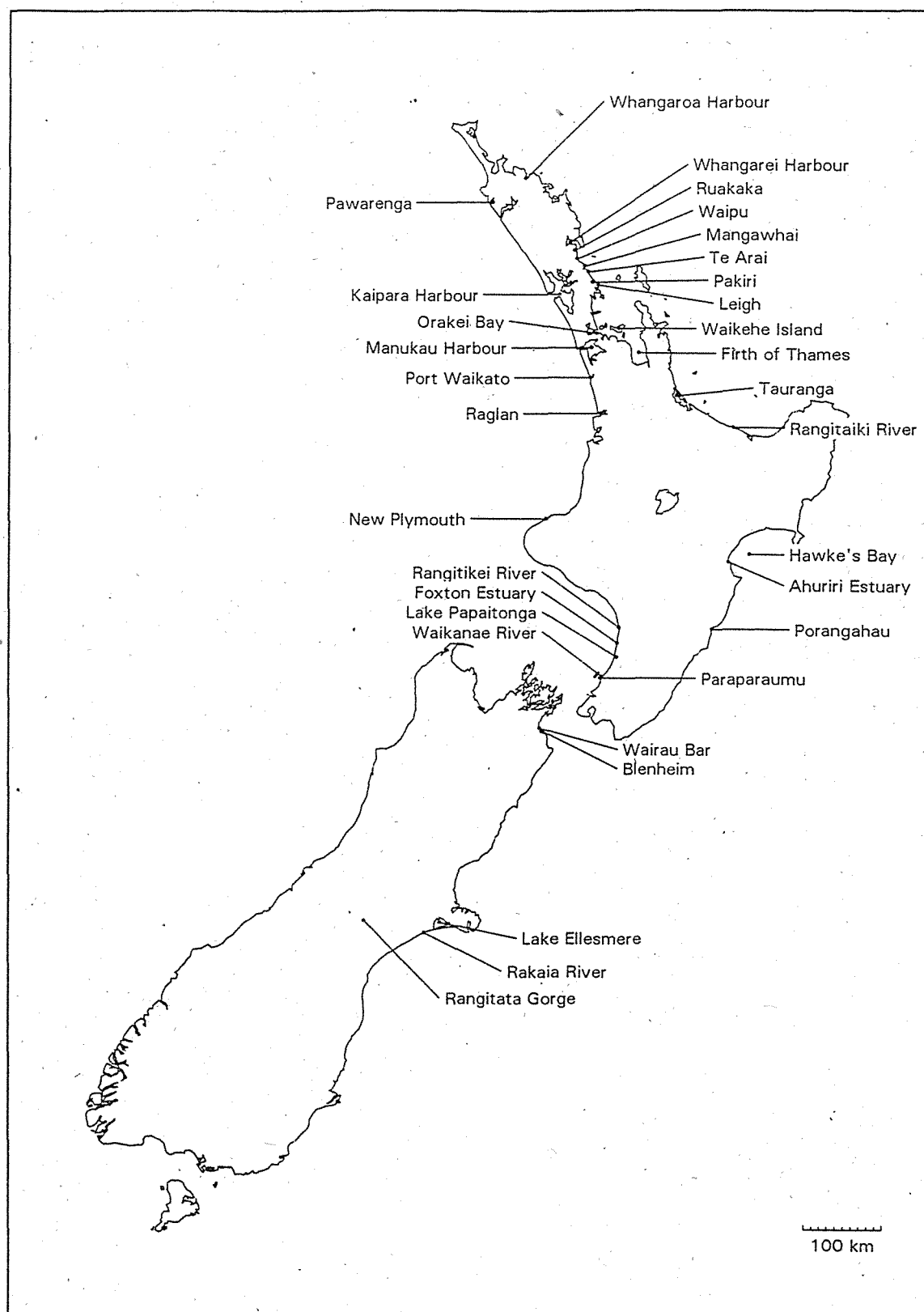
An OSNZ inquiry into the status of the New Zealand Fairy Tern in 1952 concluded that nationally the numbers of terns had fallen, especially in the South Island (Macdonald, 1953). Only a few sightings were recorded for the South Island, and these were mostly of single birds. Between 1930-1950 there were records of Fairy Terns in Tauranga, Manawatu, Blenheim, Rangitikei River and Hawke's Bay. By the early 1950s, records were confined to the North Island (Macdonald 1952). Eighty-two sightings of Fairy Terns were recorded within the Pakiri-Mangawhai and Waipu-Ruakaka areas (Macdonald 1952). Other records included Paraparaumu, Muriwai, Rangitikei River, Tauranga, Whangaroa Harbour, Napier, and Waiheke Island (Macdonald 1952).

There is reason to doubt some of the early records of Fairy Terns however. Up until 1949 'small terns' (as Fairy Terns and Little Terns are often described) had been recorded at places like the Firth of Thames (McKenzie and Sibson 1957). As the number of sightings increased so did the opportunities to closely examine these small terns, and it became apparent that many sightings were of the Little Tern (*Sterna albifrons*). The number of records of Little Terns increased from the Firth of Thames, as well as many sites in the Kaipara and Manukau Harbours (McKenzie and Sibson 1957).

At present the population appears to be restricted to upper North Island particularly in Northland. However, there are signs that these terns are dispersing further than was thought. For instance the one-year-old juvenile seen at Foxton estuary, lower North Island (P. Slack pers. comm.). There have also been sightings of Fairy Terns with single metal bands at Karaka, Manukau Harbour. As only a partial band number could be obtained, an

exact identification could not be established, however the birds were identified as either Australia Little Terns or Fairy Terns (T. Harbraken pers. comm.). This suggests that it is possible for New Zealand Fairy Terns to migrate over to Australia (T. Harbraken pers. comm), as yet no banded birds have been reported in Australia (Parrish and Honnor 1997).

Even as early as the 1950s, interest in the Fairy Tern was increasing and eight pairs were recorded breeding along the east coast from Pakiri to Te Arai (Parrish and Honnor 1997), with six nesting along Waipu beach (M. Morris pers. comm). In the late 1970s there were fewer than ten pairs restricted to the Northland area (Falla *et al* 1979, Chamberlin and Dowding 1985). By 1983, however, only three pairs were recorded (Parrish and Pulham 1995b, Heather and Robertson 1996). This fall in numbers may be related to a long period of unfavourable La Nina-dominated weather (de Lange and Gibb 1999) and it prompted intense management by the Wildlife Service at Mangawhai and Papakanui in 1983, Waipu in 1984. Papakanui management ceased in 1987, which was resumed in 1993. Note that the Wildlife Service became the Department of Conservation in 1987 (Campbell 1999). In the seventeen years since management was put in place, the population is thought to have increased to about 30 individuals (Parrish and Honnor, 1997). However, population estimates from recent sightings suggest there are perhaps only 21-26 individuals (S. Ferreira pers. comm.).



**Figure 1.5.** Map of the past distribution of the New Zealand Fairy Tern.

## **1.5 Behavioural Ecology**

Much of the ecology of the New Zealand Fairy Tern is not known because finding and following birds is extremely difficult. Moreover, only in the last 10 years has colour-banding of individuals been carried out. With the inquiry into the status of Fairy Terns in the 1950s, the public were made aware of the real need for information about the tern's life history (N. Macdonald, letter to P.C. Bull about ringing permit, 1955). This information was not forthcoming until the initiation of management by the Wildlife Service in 1983. That management required a more substantial knowledge of Fairy Tern ecology. Dr. Ray Pierce commenced a banding project in 1991, which enabled a study to be carried out in the 1993/1994 breeding season (Parrish and Pulham 1995a) significantly advancing knowledge of the ecology of Fairy Terns. Information was collected on incubation periods and parental care of chicks, prey items, nest sites, and inter- and intra-specific interactions. The findings of this research are summarised below under three headings: reproduction, longevity and nutrition, with a few additional notes from further observations.

### **1.5.1 Reproduction**

Fairy Terns nest from November to February, with the earliest first clutch found on 2 November and the latest recorded as 17 December. Generally, Fairy Terns will relay about 12 days after the loss of the first clutch. One pair produced a third clutch in the 1997/1998 and 1998/1999 breeding season after abandoning the first two (Wright 1998, Campbell 1999). Females generally breed at three years old, while males are thought to be able to breed at only two years (Parrish and Pulham 1995a). Nests are generally located in low-lying, shelly areas that camouflage the eggs and chicks from predators and are often devoid of vegetation. The nest consists of a simple 'scrape' in the sand, which the terns excavate by crouching down, kicking out sand with their legs, turning around a few degrees, and then repeating the process until the scrape is completed. The birds will usually construct trial scrapes two days before deciding to lay in one of these (pairs have been known to lay in a scrape one hundred metres away from the trial scrapes). The clutch consists of one or two eggs of a stone grey colour with white, grey and black spots (Figure 1.6). The second

egg is usually laid one to four days after the first. The parents incubate the eggs for 22-23 days. Pairs will sit for longer periods. One pair sat on infertile eggs for 42 days and then a further 13 days on translocated eggs. During daylight incubation, females have longer incubation stints than the males (average incubation period: female=58min, male=39 min.). Based on a single night of observation, the female may incubate all night.

Chicks are brooded until day 6, with the female brooding more than the male (average brooding period: female=67 min., male=38 min.). Generally, chicks are not left unattended for longer than a few minutes until at least day 14 or 15, and will fledge by day 22-24. The parents feed their chicks at least once every couple of hours at 5-6 days old. After 14-15 days this rate doubles to once every hour.



**Figure 1.6.** A New Zealand Fairy Tern egg compared with a size-six chicken egg. The Fairy Tern egg is approximately 30mm long.

### 1.5.2 Longevity

Ageing Fairy Terns has been possible only since colour-banding became part of standard management. A Fairy Tern banded as an adult (R-M) in 1977 was re-sighted in 1990 (G.Pulham pers. comm.). In 1990 it would have been at least 14 years of age, since terns reach adult plumage in their second summer. Four chicks were banded over 1978/1979, and one was re-sighted in 1989, giving it an age of 11.5 years. A banded Australian Fairy Tern (*S.n. nereis*) recovered at Lake Walyungup, Western Australia was at least 17 years old, while two were recovered in Victoria at 12 and 15 years old respectively (Higgins and Davies 1996).

### 1.5.3 Nutrition

Fairy Terns generally hunt in shallow estuaries or just beyond the surf zone of ocean beaches. They feed mostly on fish (between 1-9 cm long), and have been known to eat gastropods, amphipods, and plant material. Only four species of fish have been positively identified: goby (*Favonigobius lentiginosus*), elvers (*Anguilla* sp.), flounder (*Rhombosolea* sp.) and anchovies (*Engraulis australis*) (Moon 1988, Parrish and Pulham 1995a).

Tentative identifications include spotties (*Notolabrus celidotus*), triplefin (*Forsterygion* sp.), gudgeon (*Grahamichthys* sp.), yellow-eyed mullet (*Aldrichetta forsteri*), smelt (*Retropinna retropinna*), and whitebait (*Galaxias* sp.) (Parrish and Pulham 1995a). Other identified fish species which Fairy Terns have been seen to take elsewhere are elvers (*Anguillidae*), skipjack (*Anguilla*, *Carangidae*), sardines (*Clupeidae*), garfish (*Hemiramphidae*), mullet (*Mugilidae*), flounder (*Pleuronectidae*), and smelt (*Retropinnidae*) (Higgins and Davies 1996).

The present research aims to complement and build on what was achieved by Parrish and Pulham (1995a,b), by clarifying some of the findings, and broadening the knowledge of the life history of the Fairy Tern.



## 1.6 Thesis Objectives

The objectives of the research programme were to obtain information on the breeding and feeding ecology of the New Zealand Fairy Tern (*Sterna nereis davisae*), and to determine the sex ratio of the population. The specific aims were:

- 1) to determine the behavioural patterns of reproduction in male and female Fairy Terns during incubation and chick development.
- 2) to determine the sex and sex ratio of chicks and adults in order to evaluate the viability of the population.
- 3) to describe interactions between Fairy Terns and other species and to determine whether those interactions may be a threat to productivity.
- 4) To determine whether there are any environmental characteristics which Fairy Terns prefer when choosing a nest site.

## 1.7 Thesis Organization

**Chapter One** outlines the thesis objectives, and provides background information about the New Zealand Fairy Tern, including historic and present distribution, current population status, the description of Fairy Terns (including changes in plumage), information on the study sites in which research was conducted, and an overview of the basic breeding and feeding ecology of the Fairy Tern.

**Chapter Two** analyses in detail aspects of the breeding ecology of the New Zealand Fairy Tern including incubation stints and care of chicks by both male and female parents, egg turning frequencies, and rates of feeding chicks.

**Chapter Three** looks at intra- and inter-specific interactions between breeding adults and other avian species and people. The behaviour of males and females is considered for each potential threat encountered. Defensive behaviour is analysed in relation to the stage of incubation and chick-rearing as well as the competitive or potential threat of those species.

**Chapter Four** uses the characteristics of nest sites and surrounding areas to analyse nest site selection by Fairy Terns on a gross and fine level. Successful and unsuccessful nests sites, and sites between the coasts are compared.

**Chapter Five** describes the results from DNA tests of material collected from chicks to indicate the sex-ratio of offspring over two breeding seasons. Similar material taken from some adults is used to assist in understanding the population sex-ratio and for confirmation of their sex.

**Chapter Six** comprises a synthesis of the findings, recommendations, and future directions in research and management of the New Zealand Fairy Tern.

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**Appendix 1.1.** The scientific names of bird species mentioned in the text using only the common names.

Amazon Kingfisher (*Chloroceryle amazona*)  
American Jacana (*Jacana spinosa*)  
American Oystercatcher (*Haematopus palliatus*)  
Antarctic Tern (*Sterna vittata*)  
Arctic Tern (*Sterna paradisaea*)  
Australian Fairy Tern (*Sterna nereis nereis*)  
Australasian Gannet (*Morus serrator*)  
Australasian Harrier (*Circus approximans*)  
Banded Dotterel (*Charadrius bicinctus*)  
Bar-tailed Godwit (*Limosa lapponica*)  
Black-headed Gull (*Larus ridibundus*)  
Black-fronted Tern (*Sterna albobriata*)  
Black Skimmer (*Rynchops niger*)  
Black Swan (*Cygnus atratus*)  
Black Stilt (*Himantopus spp.*)  
Brown Skua (*Catharacta skua*)  
Black-tailed Godwit (*Limosa limosa*)  
California Gull (*Larus californicus*)  
Caspian Tern (*Sterna caspia*)  
Chatham Oystercatcher (*Haematopus chathamensis*)  
Common Gull (*Larus canus*)  
Common Tern (*Sterna hirundo*)  
Damara Tern (*Sterna balaenarum*)  
European Starling (*Sturnus vulgaris*)  
Forster's Terns (*Sterna forsteri*)  
Great Black-backed Gull (*Larus marinus*)  
Greater Golden Plover (*Pluvialis apricaria*)  
Great Reed Warbler (*Acrocephalus arundinaceus*)  
Great Tit (*Parus major*)

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Herring Gull (*Larus argentatus*)  
House Sparrow (*Passer domesticus*)  
Kakapo (*Strigops habroptilus*)  
Killdeer (*Charadrius vociferus*)  
Kingfisher (*Halcyon sancta*)  
Kittiwakes (*Rissa tridactyla*)  
Laughing Gull (*Larus atricilla*)  
Least Sandpiper (*Calidris minutilla*)  
Least Tern (*Sterna antillarum*)  
Least Tern subspecies (*Sterna albifrons antillarum*)  
Lesser Black-backed Gull (*Larus fuscus*)  
Lesser Knot (*Calidris canutus*)  
Lesser Snow Goose (*Chen c. caerulescens*)  
Long-toed Lapwing (*Vanellus crassirostris*)  
New Zealand Dotterel (*Charadrius obscurus*), Northern subspecies (*Charadrius obscurus aquilonius*)  
Northern Mockingbird (*Mimus polyglottos*)  
Myna (*Acridotheres tristis*)  
Oystercatchers (*Haematopus ostralegus*)  
Pied Oystercatcher (*Haematopus ostralegus*)  
Pied Shag (*Phalacrocorax varius*)  
Pied Stilt (*Himantopus himantopus*)  
Pied Wagtail (*Motacilla alba*)  
Piping Plover (*Charadrius melodus*)  
Pukeko (*Porphyrio porphyrio melanotus*)  
Purple Sandpiper (*Calidris maritima*)  
Red-billed Gull (*Larus novaehollandiae*)  
Red-necked Stint (*Calidris ruficollis*)  
Red-capped Dotterel (*Charadrius alexandrinus*)  
Red-winged Blackbird (*Agelaius phoeniceus*)

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Ring-billed Gull (*Larus delawarensis*)  
Ringed Plover (*Charadrius hiaticula*)  
Roseate Tern (*Sterna dougallii*)  
Royal Tern (*Thalasseus maximus*)  
Sabine's Gull (*Xena sabinii*)  
Sandwich Tern (*Sterna sandvicensis*)  
Semipalmated Plover (*Charadrius semipalmatus*)  
Short-tailed Shearwater (*Puffinus tenuirostris*)  
Skylark (*Alauda arvensis*)  
Spur-wing Plover (*Vanellus miles*)  
Stripe-backed Wren (*Campylorhynchus nuchalis*)  
Sooty Tern (*Sterna fuscata*)  
South Polar Skua (*Catharacta maccormicki*)  
Southern Black-backed Gull, Black-backed Gull or Dominican Gull (*Larus dominicanus*)  
Turnstone (*Arenaria interpres*)  
Variable Oystercatcher (*Haematopus unicolor*)  
White Spoonbill (*Platalea leucorodia*)  
Welcome Swallow (*Hirundo tahitica*)  
Western Gull (*Larus occidentalis*)  
Western Sandpiper (*Ereunetes mauri*)  
White-faced Heron (*Ardea novaehollandiae*)  
White-fronted Tern (*Sterna striata*)  
White-rumped Sandpiper (*Calidris fuscicollis*)  
Wilson's Plover (*Charadrius wilsonia*)



# Breeding Ecology





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## Chapter 2. Breeding Ecology of the New Zealand Fairy Tern: the role of the sexes during reproduction and how the environment can alter behaviour

### 2.1 Introduction

Parental investment and the roles of the sexes during reproduction has attracted much interest in recent years. Birds, in particular seabirds, have been the subject of a number of studies on investment (Pierotti 1981, Bergstrom 1986, Wiggins and Morris 1987, Brunton 1988a, Wagner and Safina 1989, Uttley 1992, Fasola and Saino 1995, Thibault and McNeil 1995, Warnock and Oring 1996). These have provided valuable information on the sex roles in species, as well as insights into the evolution of parental behaviour (Miller 1985, Brunton 1988a, Pierce 1997). Many studies have concentrated on monogamous species because this mating system predominates in seabirds (Wiggins and Morris 1987).

Monogamy is also often associated with biparental care, where the participation of both sexes in parental duties is widespread and easily understood (Lenington 1980, Cartar and Montgomerie 1985, Fasola and Saino 1995, Blanken and Nol 1998). Biparentalism has been seen as significantly improving the efficiency of care and increasing reproductive success (Byrkjedal 1985, Brunton 1988b).

The most commonly used definition of parental investment is that given by Trivers (1972) as "any investment by the parent in an individual offspring that increases the offspring's chance of surviving (and hence reproductive success) at the cost of the parent's ability to invest in other offspring". Activities such as feeding and guarding the young, and egg production, were included, though not the effort in finding a mate (Trivers 1972). This definition comes from an evolutionary point of view in which the female, by producing eggs has already made a greater investment than the male, who invests only sperm (Burger 1981a, Butler and Janes-Butler 1983). By this view in the majority of bird species the contribution of the female would exceed that of the male (Trivers 1972). Although some studies support this idea (Lenington 1980, Bergstrom 1981, Pierotti 1981), others do not (Gladstone 1979, Burger 1981a, Butler and Janes-Butler 1983, Wiggins and Morris 1987) suggesting the possibility that the energy involved in egg production has been



overestimated (Wiggins and Morris 1987). Males can also spend more energy than the female in other activities such as the raising chicks of chicks as found in Western Gulls (Pierotti 1981), Caspian Terns (Burger 1981a), Great Black-backed Gulls (Butler and Janes-Butler 1983) and Common Terns (Wiggins and Morris 1987).

If the energy needed for the female to produce eggs, and therefore by implication their investment, has been overestimated, there has also been some confusion over which activities should be included in parental investment. Among gulls and terns, the female appears to invest more in egg formation. The male expends energy in courtship feeding, territory establishment, and protection of the female during the pre-laying period (Burger 1981a, Byrkjedal 1985, Wiggins and Morris 1987).

Courtship feeding has been correlated with clutch size and fledging success, so this behaviour is an important male contribution to breeding success (Nisbet 1973, Wiggins and Morris 1987). Courtship feeding is also an important source of nutrition for the female at a time when she is less able to forage for herself (Wiggins and Morris 1987, Uttley 1992, Ratcliffe *et al* 1998). Through the indirect protection of a nest, eggs and chicks, and territorial defence is a further investment in offspring. Defence of the territory has often been associated with a relatively greater loss of weight in the male (Burger 1981a, Byrkjedal 1985, Wiggins and Morris 1987, Uttley 1992). Post-fledging care is another activity, which is often overlooked when considering the parental investment in offspring (Ogden and Stutchbury 1997). Clearly, these behaviours fall within the definition of parental investment by having a positive effect on the parent's ability to invest in the survival of its offspring and not others, and they should be included when considering the roles of each sex.

Environmental conditions can also have a significant effect on behaviour, particularly for sea and shorebirds. Varying conditions of cloud cover, temperature, windspeed and sea conditions affect a bird's ability to fish and feed their young, and the amount of time spent in incubation or brooding by each of the sexes (Skutch 1957, Dunn 1973, Dunn 1975, Birkhead 1976, Grubb 1978, Cartar and Montgomerie 1985, Murphy 1987, Becker and

Specht 1991, Beintema and Visser 1989, Quinn 1990, Frank 1992, Uttley 1992, Frank and Becker 1992, and Hegyi and Sasvári 1998). In waders females tend to increase the amount of time spent incubating in adverse weather conditions (Hegyi and Sasvári 1998) and can affect stored reserves in adults (Cartar and Montgomerie 1987). For terns, strong winds interfere with their ability to hover when foraging and calm conditions can do the same (Dunn 1973, Dunn 1975, Birkhead 1976, Grubb 1978, Cramp 1985, Becker and Specht 1991, Frank 1992). Weather conditions can also influence the prey's ability to see terns, and predatory fish, and affect the depth at which the fish live (Dunn 1973, Birkhead 1976, Safina 1990). Because weather can detrimentally affect adult condition this in turn influences the growth and survival of the young (Dunn 1975, Beintema and Visser 1989, Becker and Specht 1991).

The feeding rates of young can vary during the day with peaks in the morning and evening (Davies 1981, Cramp 1985, Quinn 1990, Frank and Becker 1992, Norman 1992), and incubating birds often sit on the nest for longer periods in the morning and evening (Cartar and Montgomerie 1985, Kålås 1986). In some birds during incubation there are more foraging trips and therefore nest changeovers in the middle of the day (Cartar and Montgomerie 1985) while in others this tends to occur either at dawn or dusk (Dorward 1963, Thibault and McNeil 1995). The number of changeovers may be partly related to the distance to the feeding grounds (Brown 1975), or to the risk of predation in low light (Thibault and McNeil 1995). Incubation shifts by the sexes vary during the day, as in Wilson's Plover where the female spends comparatively more time incubating during the day while the male spends comparatively more time in the evenings (Bergstrom 1981). However, the time spent incubating by males and females does not differ during the day in Common, Little and Sandwich Terns (Fasola and Saino 1995). Time of season also affects the behaviour of the sexes from day to day with males of some species increasing their contribution in territorial defense, late incubation and the feeding and raising of young (Bergstrom 1981, Miller 1985, Pierce 1997, Hegyi and Sasvári 1998).

The state of the tide can affect behaviour with nest reliefs, foraging by adults, and the feeding of young (Dunn 1975, Cramp 1985, Becker and Specht 1991, Frank and Becker,

1992). Some terns tend to feed their young more in the last few hours of the rising tide (Davies 1981, Frank 1992) while substrate-feeding shorebirds feed during the first two hours after low tide (Burger *et al* 1977). Inshore or estuary-feeding terns are potentially more affected by tides. Significantly higher feeding frequencies in calm weather when prey are abundant has been found in a number of species (Dunn 1975, Erwin 1977, Wagner and Safina 1989, Becker and Specht 1991, Frank 1992, Shealer 1998). However, Cramp (1985) found that the feeding rates in off-shore feeding Arctic Terns were not affected by tide.

The role of breeding males and females during the night and after the young fledge are often neglected. The nocturnal activity of the sexes has been studied in a few species, particularly plovers, though the majority of studies concentrate on incubation. The few studies that have considered night activity show great variability in which sex incubates. The male appears to incubate significantly more in Killdeer (Mundahl 1982, Brunton 1988a, Warnock and Oring 1996), Greater Golden Plovers (Byrkjedal 1985), Wilson's Plover (Bergstrom 1986), and Semipalmated Plovers (Blanken and Nol 1998). The female was found to incubate more in Amazon Kingfisher (Skutch 1957), Least Sandpiper (Miller 1985), White Spoonbills (Aguilera 1990), European Starlings (Smith *et al* 1995), and Pied Wagtails (Fitzpatrick 1996). In Little Terns the female is also presumed to incubate all night (Davies 1981).

Post-fledging care of young in many species, especially gulls and terns, can last a few weeks to several months (Dunn 1972, Burger 1981b, Davies 1981, Ashmole 1985, Cramp 1985), during which time the young can learn to fend for themselves, particularly in fishing. Only one parent, often the male, stays with the young (see Miller 1985 for cited studies, Pierce 1997). The exclusion of the post-fledging period from calculations of parental investment may therefore underestimate the male's effort in reproduction (Burger 1981a, Ogden and Stutchbury 1997).

All these factors need to be considered when assessing sex-related parental investment. Therefore, to understand the reproductive effort of male and female Fairy Terns, time-activity data of the sexes were recorded from the start of incubation (taken from the

completion of the clutch) to as long as families could be followed after the young fledged. The aim of this study was to look for sex-related activities that could influence the birds' survival and performance.

## 2.2 Methods

### 2.2.1 *Collection of data*

Information on the breeding ecology of the Fairy Tern was collected over the 1997/1998 and 1998/1999 breeding seasons. Data collection was concentrated on the east coast sites of Mangawhai and Waipu. Papakanui spit was not used because of difficulties in accessing the nest sites and the lower success rate of birds breeding there. On the east coast two pairs, one from each site, were followed intensively over each season. All pairs included at least one banded bird so the individuals could be identified over the reproductive season. The sex of each individual was determined by direct observation of copulation. Pairs that had been consistently successful in raising chicks in previous years were used to increase the probability that a complete breeding effort would be observed. As Fairy Terns nest in solitary pairs, not colonies, pairs including a previously observed individual were used over the second season in an effort to pick up consistent trends in behaviour.

The terns were observed from 50-100 m (as required by the Department of Conservation) with a 25 x 60 spotting scope and 10 x 45 binoculars. No hide was used, as it would have needed setting up afresh each day, which would have caused unnecessary disturbance.

Behavioural data were collected by continuous focal sampling as opposed to focal interval sampling. Rose (2000) found by comparing the two methods that continuous sampling gave better estimates of the time spent in various activities. Data were collected in discrete observation periods separating the daylight hours into three six-hour periods in the 1997/1998 season, from 0400-2200 h. Because it proved difficult to gain accurate information before dawn and after twilight in the 1997/1998 season these observation

periods were changed to four, four-hour periods, from 0500-2100 h in the 1998/1999 season.

In the first season only one pair could be monitored each day through incubation because of the six-hour observation periods. Subsequently each pair at the two sites was monitored on alternate days. The observation periods were also alternated according to what was carried out at a particular site the time before, ie. with the first observation period from 0400-1000 h, the second from 1000-1600 h and the third from 1600-2200 h. During the chick stage, each pair were monitored daily. With the shortened observation periods in the 1998/1999 season, one site was monitored in a morning from 0500-0900 h or from 0900-1300 h, with a four hour period before a second observation period at the other site in the afternoon/evening from 1300-1700 h or from 1700-2100 h. The four observation periods were alternated each day, at each site. Night observations with night vision equipment were attempted. However, because the birds could not be seen clearly from 40-50 m, night observations were not included in the monitoring scheme.

The time-activity data collected included the periods of incubation, brooding, and the guarding by the parents or absence from the young. The frequency of egg turning was noted during each incubation stint. The frequency of prey species fed to the young and their size (as compared to the parent's bill) were noted. The direction (from sea or estuary) in which a parent arrived and departed from the young when a feeding event occurred provided information on the bird's use of the estuarine or ocean systems for foraging. The percentage of cloud cover, wind direction, and the relative strength of winds were recorded for general weather conditions.

### 2.2.2 *Statistical Analysis*

Data were analysed using the computer software program SAS (SAS Institute 1990). Multivariate analysis using general linear model (GLM procedure), general models (GENMOD procedure) and Lifereg procedures were used to compare multiple measures of season, weather, day and tidal affects on the various roles of each individual during their



reproductive period. These numerical effects included season (the number of days of incubation or day since the first chick hatched), day (observation period which included the different times of the day, primarily the morning, middle of the day and evening periods); week (taken from the completion of the clutch with incubation and the hatching of the first chick in the parental care period); and tide (hours after the high tide until the next). Categorical effects included environmental effects of weather with S (sun: less than 50 percent of cloud) or C (cloud: greater than 50 percent) and NW (no wind: less than moderate winds (10-15km per hour winds) or W (wind: greater than 10-15km per hour winds). The response variables used included incubation stints, egg turning, parental activities (ie brooding, guarding of the young and the time young were left unattended), and the feeding of the young and the prey size. The size of fish and direction were divided into two categories for ease of analysis, with the size categories large (4 cm or larger) and small (2-3.5 cm) and direction as either estuary or sea. All variables were analysed with respect to possible differences between each individual in each pair, and therefore the male and female roles.

Parametric linear models were used to fit a model with a linear effect based on the response variable. The Lifereg procedure and general linear models (GLM) were used for incubation stints and the parental activity data (as well as comparing any differences between breeding seasons) respectively. Least square differences were calculated to establish which interactions were significant for the parental care activity data. Differences in feeding frequency, feeding with the state of the tide, and the possibility that there was division of labour with a preference for one parent to feed the same chick is also explored using general models (GENMOD procedure). Contrasts were also preformed for feeding frequency, size of fish and direction between pairs. These included comparison between rising and falling tides, high tide and mid tide falling, mid tide to low tide, low tide to mid tide rising and mid tide to high tide. Interactions with the variables were also performed. A significance level of  $\alpha=0.05$  was used for all procedures.

### 2.3 Results

Two pairs were observed at each of the breeding sites (Mangawhai and Waipu) over the two seasons, with at least one individual the same in each pair. Continuous sampling totaled 524.5 hours with 204.5 hours for the first season (Mangawhai: 116.5 hours, Waipu: 88 hours) and 320 hours (Mangawhai: 191 hours and Waipu: 129 hours) for the second. The pairs observed and their breeding outcomes are shown in Table 2.1. Each individual is denoted by letters abbreviating their colour band combinations ie G = green, B = blue, and W = white and the numbered metal band (M).

**Table 2.1.** The breeding success of pairs observed in the study. <sup>1</sup> UBB is an abbreviation for an individual with no bands. <sup>2</sup> G-M and UBB second nest produced an infertile egg. As a management strategy, an egg from a two egg clutch of M-R and UBB was placed under this pair on the 26/12/98.

#### *Mangawhai*

Season	Female	Male	Eggs Laid	Chicks Hatched	Chicks Fledged
1997/1998	G-M	B-M	2	2	2
1998/1999	G-M	UBB	1	1	1

#### *Waipu*

Season	Female	Male	Eggs Laid	Chicks Hatched	Chicks Fledged
1997/1998	UBB	WB-M	2	2	2
1998/1999	UBB	WB-M	2	1	1

#### 2.3.1 Incubation

Data on the frequency of egg turning were collected only in the 1997/1998 season.

Significance was found only in the SUN\*INDIV interaction ( $P>0.0382$ ) for the Mangawhai pair with G-M (female) doing more egg turning on sunny days than B-M. No significant difference was found in the Waipu pair.

In the 1997/1998 season the first nest of the Mangawhai pair was flooded during a storm. Therefore the second nest was observed. However, the single egg that was laid in that nest was infertile. On day 23 of incubation the egg had not developed, and on 26 December 1998 it was replaced by the Department of Conservation with an egg from another pair with a two egg clutch. Because this egg was laid after the pair's original egg, the incubation period was extended to 35 days. These changes of eggs in the nest, brought about by management decisions, complicated the analysis. Separate analyses were carried out to exclude and then include data collected after the manipulation, and include only the last 9 days after the manipulation, to see whether there was a change in the birds' behaviour.

The length of the incubation stints of the female and male varied with season, pair and environmental conditions. The longest stint recorded for a female was 240 minutes (four hours) by the unbanded female of the Waipu pair in the 1998/1999 season. This stint was incomplete because it covered the whole four hour observation period, and may have been influenced by an approaching easterly storm. For the females, the longest complete stints ranged from 71- 101 minutes, with the Mangawhai female at the upper end of the range. The shortest stints recorded were between 4-28 minutes long with the Waipu female having the upper range. Thus, in general, the Mangawhai female demonstrated most variation in incubation behaviour.

The longest stint recorded for a male, 177 minutes (approximately 3 hours), may have been affected by replacing the original egg with an egg from a nest a week behind in timing. During that week the female was less attentive, often not returning to the nest even when the male left it unattended and flew calling over the estuary. After a few minutes the male would return to the nest to incubate and, unusually, would often continue to call while sitting. For the males, the longest stints were 71-172 minutes, with the Mangawhai males at the upper end of the range. The shortest stints were between 2-17 minutes long, with the Waipu male being in the upper range. Again, the Mangawhai male showed most variation in incubation behaviour.

The average length of complete incubation stints only appeared to differ between the sexes rather than between the pairs or between seasons. Table 2.2 shows the mean lengths and standard errors of the incubation stints for each individual in the two seasons. The average length of stints was similar for females and males of both pairs, in the 1997/1998 season. There were differences, however, in the 1998/1999 season. At Mangawhai, the female averaged slightly less than in the same as in the first season. The male, however, incubated for longer in the second season, although this was a different individual from that in the first season. The male incubated for longer after the manipulation was carried out, whereas the average incubation stints were similar during the natural incubation period and with all days included.

**Table 2.2.** The mean and standard errors of the complete incubation stints of the male and female in the 1997/1998 and 1998/1999 seasons. The average periods of incubation excluding and including the manipulation data, and after the manipulation are shown.

Season	Site	Individual	Means (mins)	Standard error	Days included
1997/1998	Mangawhai	G-M	55	6	All
		B-M	42	7	All
	Waipu	UBB	43	4	All
		WB-M	38	4	All
1998/1999	Mangawhai	G-M	44	4	All
			44	5	Excluding manipulation
			42	8	Manipulation only
		UBB	62	7	All
			58	7	Excluding manipulation
			70	16	Manipulation only
	Waipu	UBB	38	2	All
		WB-M	38	3	All

Weather, day, season and individual did not affect time spent incubating by either pair in the 1997/1998 season. In the 1998/1999 season, incubation was not affected by the amount of sun or wind, or time of season. However, there were significant differences between individuals with time of day in the 1998/1999 season. Table 2.3 shows the results of the

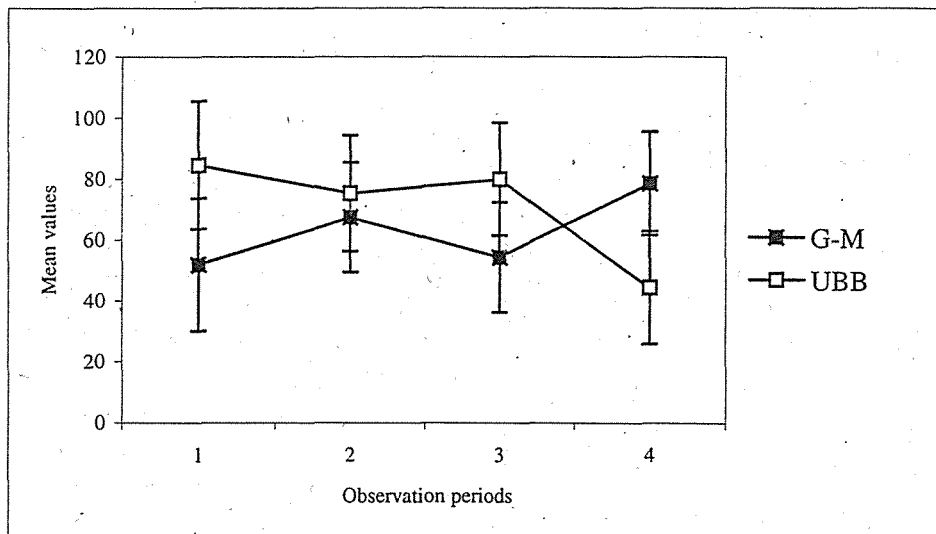
significant interactions for the pairs. For the Mangawhai pair the analysis took account of the extended incubation period which appeared to have caused a change in behaviour of the birds during different times of day. Exclusion and inclusion of the data collected after the manipulation showed that the male appeared to perform more incubation than the female during the morning to late afternoon, while the female incubated more in the evening (Figures 2.1.1a and b). However, after the manipulation (Figure 2.1.1c) the birds incubated for considerably longer than during their natural incubation period. The male incubated more in the morning to early afternoon, the female incubated considerably more in the early to late afternoon period, and the sexes were fairly equal in incubation in the evening. In the Waipu pair, the sexes also only differed by day with the female incubating more in the evening (Figure 2.1.1d). Because the Lifereg procedure makes an assumption about the length of the uncompleted stints, all figures of incubation stints between the sexes will have been underestimated.

**Table 2.3.** The results from the Lifereg procedure performed on the incubation stints of the pairs observed in the 1998/1999 season. Significant differences in behaviour were found between individuals with time of day (OBSP) only. The manipulation of G-M and UBB nest meant three separate analyses were carried out to look for any differences in the birds' behaviour.

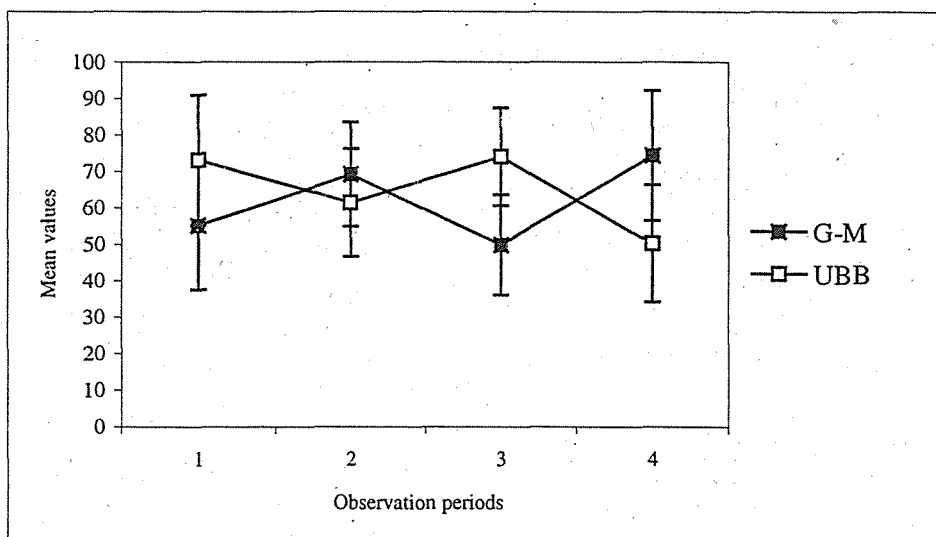
Pair	Days included	Interaction	<i>P</i> value
GM x UBB	All days	Individual*Obsp	0.0016
GM x UBB	Excluding manipulation	Individual*Obsp	0.0390
GM x UBB	Manipulation only	Individual*Obsp	0.0026
WB x UBB	All days	Individual*Obsp	0.0080



(a)

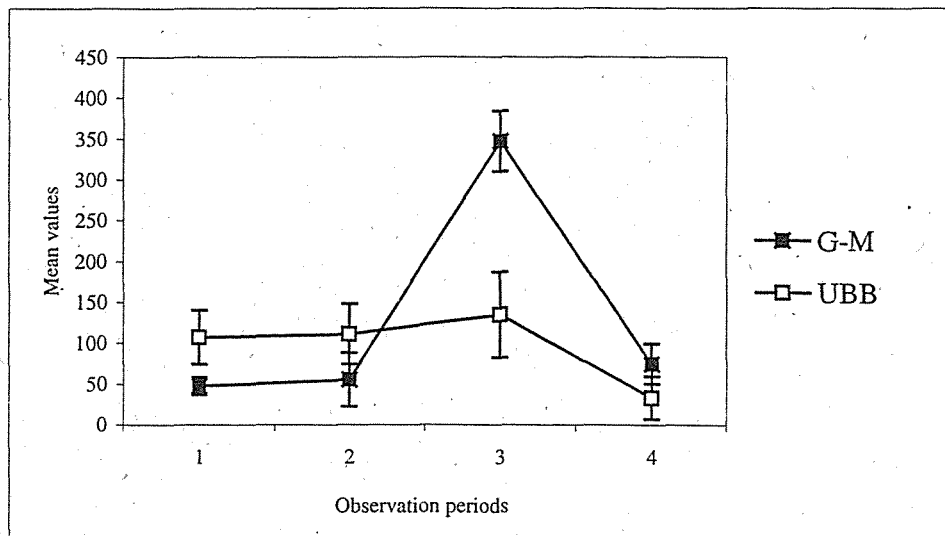


(b)

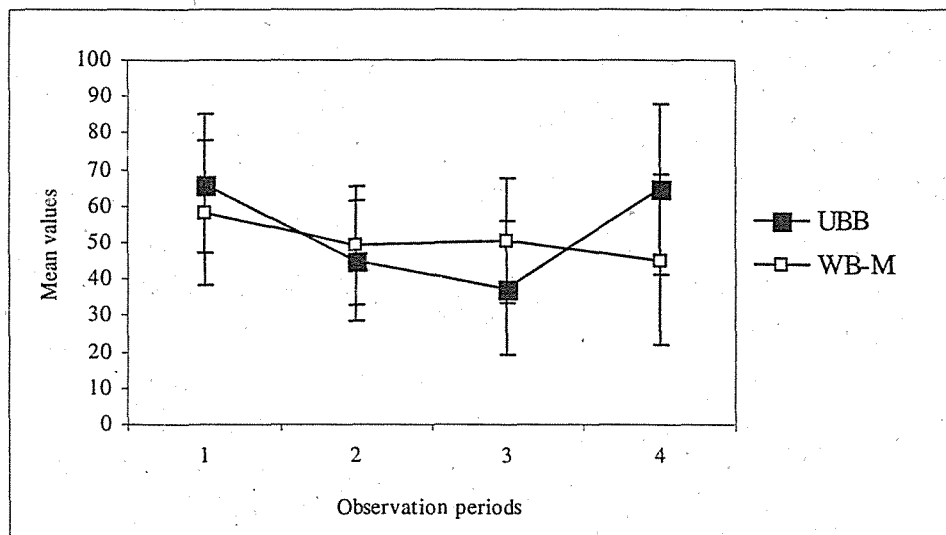


**Figure 2.1.1.** The individual differences in the incubation stints with time of day in the pairs in the 1998/1999 season. The incubation behaviour of the Mangawhai pair is shown (a) including and (b) excluding the manipulation period.

(c)



(d)



**Figure 2.1.2.** The individual differences in the incubation stints with time of day in the pairs in the 1998/1999 season. The incubation behaviour of the Mangawhai pair is shown in the manipulation period only in (c) while (d) shows the incubation behaviour of the Waipu pair.

### 2.3.2 Parental care of the young

Analysis of parental care of the young was based on the main three activities: brooding, guarding of the young, and absence of the parent. No differences were found between the sexes in any of the three activities, in either season. Most brooding ceased when the young were 6-10 days old. Occasionally older young were brooded, particularly at the end of the day when temperatures were cooler. Guarding tended to be fairly similar for individuals. Since both pairs had two young in the 1997/1998 season and only one in the 1998/1999 season, parental behaviour in the two seasons was compared (Figures 2.2 and 2.3).

Table 2.4 shows the means and standard errors of the three activities between the male and female in each pair for each season. The means of each activity did vary between years for both pairs, with increased presence and brooding and less absence from young. When a comparison of activities with each pair for week, time of day or individual were performed, there was no significant differences in activity at Mangawhai between breeding seasons, however there was in the Waipu pair. No differences were found in brooding, however, there was significantly less absence from the single chick in the 1998/1999 season, with the parents guarding the young more in this year.

**Table 2.4.** Mean and standard errors of time (minutes) spent guarding, brooding and absence from young over the 1997/1998 and 1998/1999 seasons.

Season	Site	Individual	Sex	Guarding		Brooding		Absence	
				Mean	SE	Mean	SE	Mean	SE
1997/1998	Mangawhai	G-M	Female	74	14	34	16	38	10
		B-M	Male	50	9	8	5	66	17
	Waipu	UBB	Female	78	16	29	14	24	7
		WB-M	Male	72	15	29	9	28	10
1998/1999	Mangawhai	G-M	Female	86	16	73	19	1	1
		UBB	Male	81	17	45	12	4	3
	Waipu	UBB	Female	111	18	40	14	3	1
		WB-M	Male	112	15	20	14	2	1

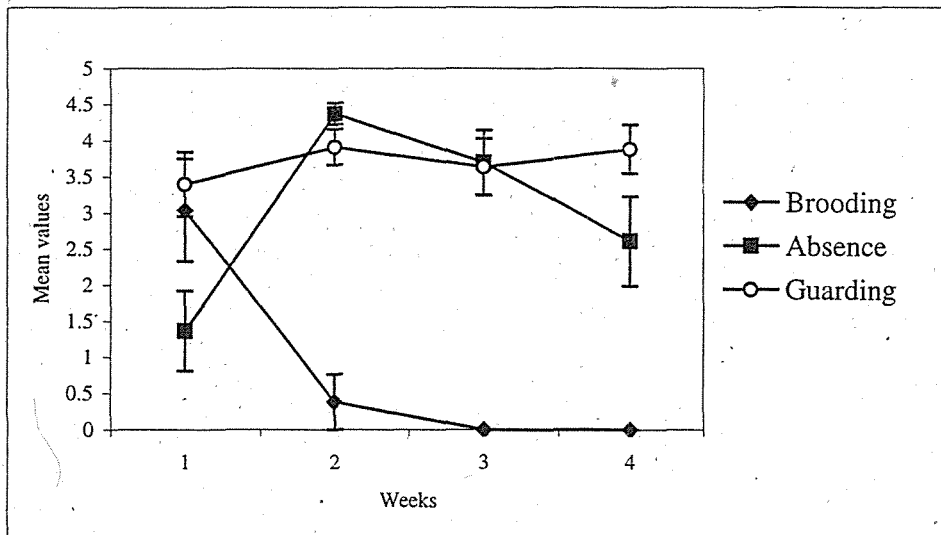
There were significant differences in parental activities, however, with week and time of day in both seasons. Wind affected only the Mangawhai pair in the 1997/1998 season. Table 2.5 gives the *P* values for the significance with each pair in the two seasons. Least square differences (LSD) were calculated to establish where the differences in activities occurred. If the mean time was greater than the LSD then it was significant.

**Table 2.5.** The significant interactions of the main effects (wind, week and time of day (obsp)) in relation to the three activities (brooding, guarding of an adult and absence from the young) performed by the parents over the 1997/1998 and 1998/1999 seasons.

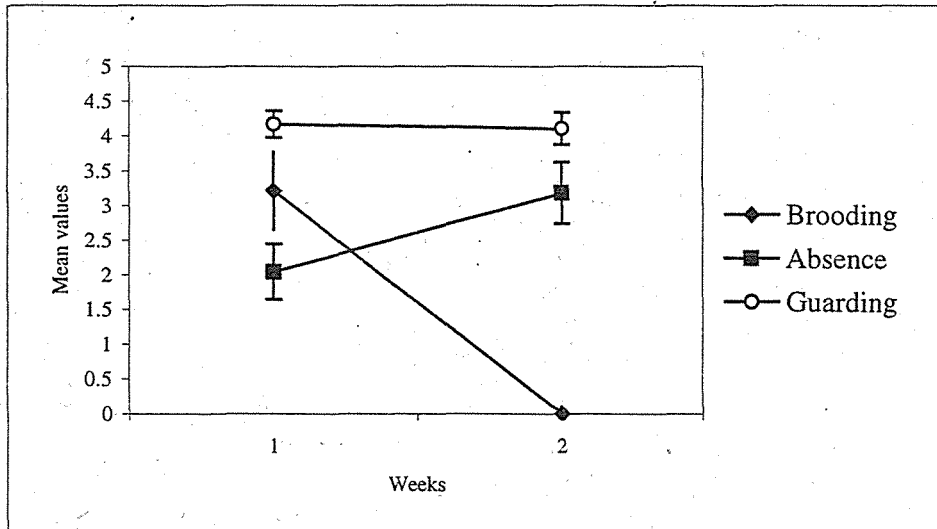
Season	Pair	Interaction	<i>P</i> values
1997/1998	G-M x B-M	Week*Activity	0.0001
		Obsp*Activity	0.0023
		Wind*Activity	0.0118
	WB-M x UBB	Week*Activity	0.0001
		Obsp*Activity	0.0001
1998/1999	G-M x UBB	Week*Activity	0.0001
		Obsp*Activity	0.0001
	WB-M x UBB	Week*Activity	0.0012
		Obsp*Activity	0.0001

Results show that in the 1997/1998 season the Mangawhai pair were absent from the young significantly more on calm days than on windy days (LSD  $0.88 < 1.8$ ). Brooding and guarding of the young was unaffected by the level of wind. The only changes in activity were by week (Figure 2.2.1-2.2.2) and time of day (Figure 2.3.1-2.3.2). There was significantly more brooding by parents and less absence in week one than in week two (Figure 2.2.1a), and significantly less absence from the young in the late afternoon and evening (Figure 2.3.1a). The Waipu pair also brooded more and was absent less in week one than week two (Figure 2.2.1b).

(a) G-M and B-M



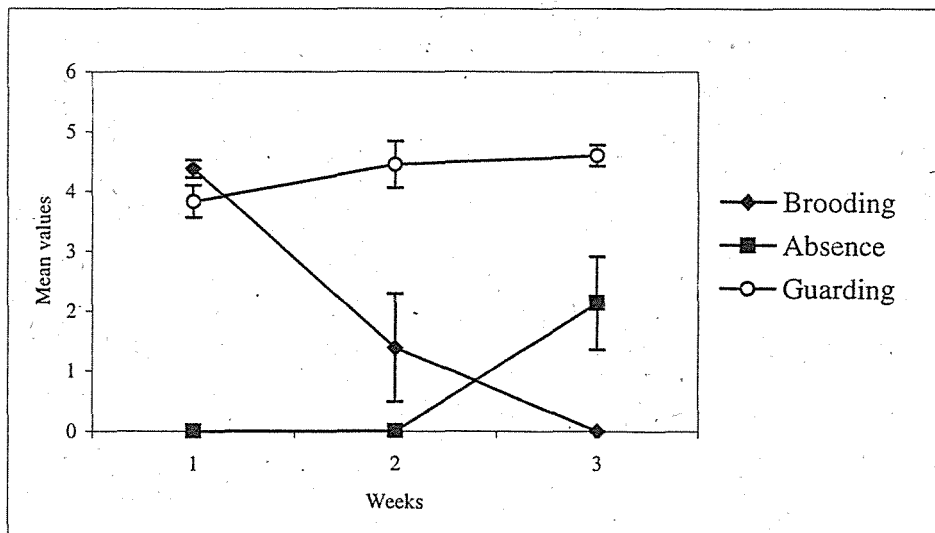
(b) WB-M and UBB.



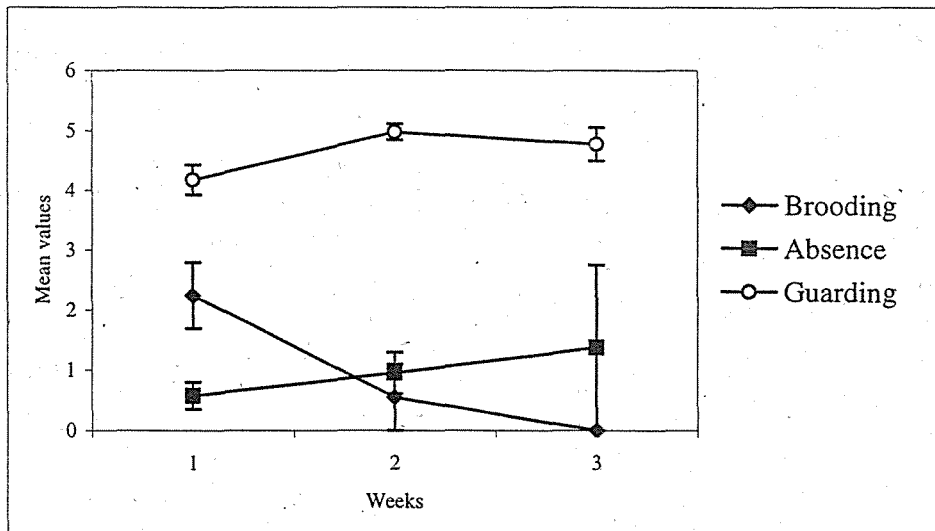
**Figure 2.2.1.** Changes in parental activities over week for each pair at (a) Mangawhai and (b) Waipu in the 1997/1998 season using the means and standard error calculated by the general model.



(c) G-M and UBB



(d) WB-M and UBB



**Figure 2.2.2.** Changes in parental activities over week for each pair at (c) Mangawhai and (d) Waipu in the 1998/1999 season using the means and standard error calculated by the general model.

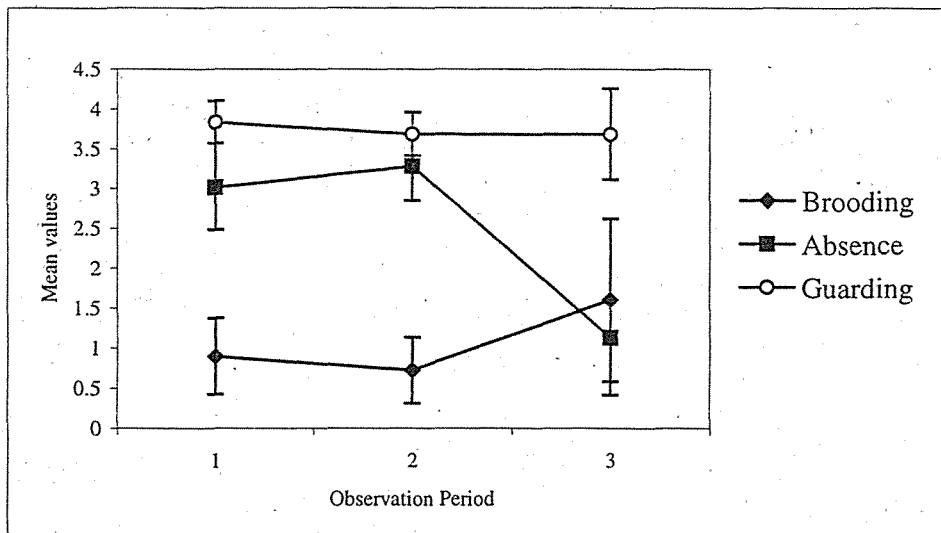
In the 1998/1999 season, the Mangawhai pair again showed more brooding in the first week than the second and third weeks (Figure 2.2.2c). No real difference was seen with the guarding of young. The parents were also absent from the young more in the third week than either of the first two weeks. There was less absence from the chicks in the first as well as the last observation periods (morning and evening), with more occurring in the middle two periods (Figure 2.3.1b). At Waipu the only change was with brooding by the pair, with a decrease from week one (Figure 2.2.2d). Both parents brooded in the morning and evening periods and were present fairly evenly during the day (Figure 2.3.2c).

### 2.3.3 Feeding of the young

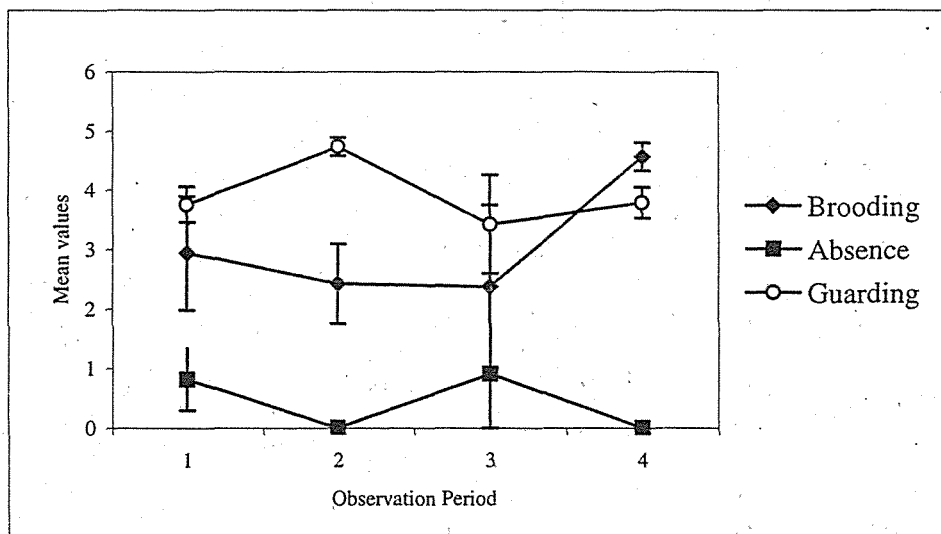
In the 1997/1998 season the Mangawhai pair tended to feed the young more on cloudy days ( $P < 0.0273$ ). Both parents fed the young equally from the morning to late afternoon, while the male performed relatively more feeding in the evening. No time of season or day effects were found in the Waipu pair in the 1997/1998 season or in either pair in the 1998/1999 season. There was a significant difference in feeding between the individuals for both pairs in the 1998/1999 season, with the male tending to feed the chick more than the female (Mangawhai pair ( $P < 0.0286$ ) and the Waipu pair ( $P < 0.0014$ )). The possibility of division in labour between young by the parents was tested for the 1997/1998 season. The analysis, however, showed that no parent preferentially fed one of the chicks over the other.

There were differences in parental behaviour found with feeding frequency and with the state of the tide for both seasons, though not between the sexes. There were also no differences with either size of fish or the direction from which the parents brought the fish. In the 1997/1998 season, the birds at each site differed in their feeding of young between low tide and mid tide rising ( $P < 0.0483$ ) than between other tides.

## (a) G-M and B-M

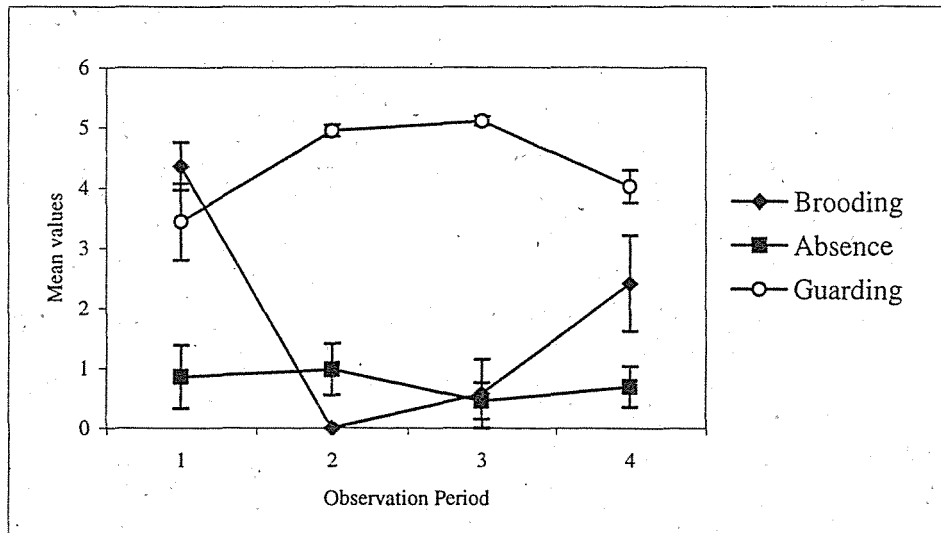


## (b) G-M and UBB



**Figure 2.3.1.** Changes in parental activities over the day for the Mangawhai pair in (a) the 1997/1998 season and (b) the 1998/1999 season using the means and standard error calculated by the general model.

(c) WB-M and UBB



**Figure 2.3.2.** Changes in parental activities over the day for the Waipu pair in the 1998/1999 season using the means and standard error calculated by the general model.

At Mangawhai the pair delivered considerably more fish to the chicks during this period. The Waipu pair feed the chicks more during these tides than others, however, did not feed their young as often as the Mangawhai pair. In the 1998/1999 season, feeding differed over the high tide to mid tide falling ( $P < 0.0005$ ) and the low tide to mid tide rising ( $P < 0.0177$ ). Both pairs fed the young more from low to mid tide rising, however, the Waipu pair fed their chick more in the second hour after low tide. The Mangawhai pair also tended to feed the chick more from high to mid tide falling than the Waipu pair.

## 2.4 Discussion

The behavioural ecology of many seabirds, particularly northern hemisphere terns, has been studied over the last decade. However, southern hemisphere terns such as the New Zealand Fairy Tern have been neglected, as have many solitary nesting sea and shorebirds (Burger 1987). This study sought to quantify the roles of male and female Fairy Terns during their reproductive cycle and determine whether major environmental factors affected their behaviour.

Courtship feeding was only observed in the second season. Of the incidences seen, 37 out of 42 (88%) at Mangawhai and all 47 at Waipu (100%) were performed by the male. This distinct responsibility by the male during courtship has been found in a number of species, including other terns (Nisbet 1978, Walsberg and King 1978, Pierotti 1981, Cramp 1985, Haftorn and Reinertsen 1985, Wiggins and Morris 1987, Uttley 1992, Fitzpatrick 1996, Ratcliffe *et al* 1998). Courtship feeding is a major nutritional contribution to the female (Nisbet 1978, Pierotti 1981, Cramp 1985, Wiggins and Morris 1987, Uttley 1992) and has been found to improve breeding success (Nisbet 1973, Morris 1986). It also reduces a female's need to forage, thereby increasing her attentiveness at the nest (Sanz 1996, Martin and Ghalambor 1999). Courtship feeding is often associated with loss of weight in the male because of the high energy demands of extra foraging. It therefore constitutes an important contribution to the survival of the young and is a significant cost to the male (Burger 1981a, Pierotti 1981). Although no appropriate work has been done in New



Zealand, it is likely that the benefits and costs of courtship feeding demonstrated in other terns apply also to Fairy Terns.

No consistent sexual differences could be found in egg turning. The exception of G-M turning the eggs more often than its mate on sunny days, behaving in a similar manner on cloudy days, may be a peculiarity of this individual or just a statistical artifact. This aspect would need more work to clarify whether egg turning is affected by the sex of the sitting bird, or by the weather.

No major differences were found between the female and male in overall incubation behaviour in the 1997/1998 and 1998/1999 seasons in relation to season (day to day variation), week of incubation, or weather conditions. Although this has been found in other species (Pienkowski 1984, Quinn 1990, Pierotti 1981, Pierce 1997, Hegyi and Sasvári 1998), among terns it is variable between and within a species. Table 2.6 provides a summary of the role of the sexes of terns including Fairy Terns for incubation as well as chick rearing. Note that there are instances of the male exceeding the female in incubation in a Least Tern subspecies (*Sterna albifrons antillarum*) (Cramp 1985). Uttley (1992) found that the amount of incubation by male and female Arctic Terns was dependent on the food supply. When food was plentiful the sexes incubated equally, whereas when it was short the female performed more incubation than the male (Uttley 1992). Therefore, it is difficult to compare the behavioural data for Fairy Terns, as the roles of the sexes seem to be dependent on the species, the time periods, and external factors such as food supply.

At Mangawhai in the 1998/1999 season, the female incubated more than the male particularly in the evening. However, after the manipulation, the male sat more in the early morning to early afternoon while the female incubated significantly more from early to late afternoon. In the evening the sexes were fairly equal. This change in behaviour may have been caused by the unnaturally long incubation period. The female tended to be less attentive, particularly in the morning when the male incubated for extended periods of up to three hours. At Waipu the only difference between the sexes consisted of the male performing slightly more incubation in the morning. No day effect was found in Common, Little or Sandwich Terns (Fasola and Saino 1995). These differences between sexes may

be peculiar to the New Zealand Fairy Tern or individuals, and not a characteristic of terns in general.

Individuals did not differ in their behaviour during care of the young, particularly brooding. This pattern of equal sharing, as in incubation, has been found in a number of gulls (Tinbergen 1956, Morris and Bidochka 1982; Butler and Janes-Butler 1983, Morris 1986), terns (Table 2.6) and plovers (Blanken and Nol 1998). In some species, however, brooding was often performed more by females than by males: in terns (Table 2.6) and other species (Carey 1990, Quinn 1990, and Hegyi and Sasvári 1998). In other species, the male provides more chick care than the female (Burger 1981a, Brunton 1988a, Pierce 1997). Variability between the sexes is also seen in their guarding at the nest, when the female spends more time in attendance in some species (Lenington 1980, Pierotti 1981), and the male in others (Burger 1981a).

**Table 2.6.** Summary of the contribution of the sexes in terns during incubation, brooding, feeding and guarding of the young, and absence. M= male and F= female.

Tern Species	Activity					Source
	Incubation	Brooding	Absence	Guarding	Feeding	
Roseate	F > M	-	-	-	M > F	Cramp (1985), Wagner and Safina (1989)
Common	F > M	F > M	-	F > M	M > F	Nisbet (1973), Cramp (1985), Wiggins and Morris (1987), Fasola and Saino (1995)
					M = F	Wagner and Safina (1989)
Sandwich	M = F	M = F	-	M = F	M > F	Fasola and Saino (1995)
Arctic	M = F	M = F	-	-	-	Uttley (1992)
Caspian	F > M	-	-	-	F > M	Quinn (1990)
Least	M > F	-	-	-	-	Cramp (1985)
Little	F > M	F > M	-	F > M	M > F	Uttley (1992), Fasola and Saino (1995)
Fairy	M = F	M = F	M = F	M = F	M = F	this study
					M > F (1 chick)	

Weather conditions, week, and time of day were associated with changes in the activities performed by the birds. Moderate to strong winds was associated with less absence by the male and female at Mangawhai in the 1997/1998 season. Elsewhere, wind and temperature have been correlated with mortality of young, particularly in terns, and therefore are important factors in the survival of young (LeCroy and Collins 1972, Dunn 1975, Beintema and Visser 1989, Becker and Specht 1991). Predominant northeast to easterly winds meant the Mangawhai nest was exposed, and the fine sand and lack of vegetation, created a problem with sand-blasting. Often the adults were seen covered in sand while brooding the young and were observed kicking sand out of the nest. This behaviour was rarely seen in the Waipu pair. Therefore, brooding in such adverse conditions may protect the young from sand-blasting as well as keeping them warm. This behaviour may not have been as necessary in the 1998/1999 season because both pairs nested in areas where they were better protected from the wind.

Although parental behaviour did not change as the chicks got older (day to day variation), there was a consistent cumulative week effect during the season. The results (Figures 2.2.1-2.2.2) emphasise the similarity in the behaviour of each pair. Brooding showed the most dramatic change as the adults brooded the young intensively in the first week but reduced or stopped brooding completely in the second week. This result partly agrees with Parrish and Pulham (1995) who found the young were not brooded at all after day seven. However, in the 1998/1999 season both pairs did a lot of brooding in the second week. It appears that a pair with two chicks do not continue brooding after the first week, possibly because by then the chicks are too large to fit under the adult, or require frequent feeding. Adults with a single chick brooded for longer but by the third week there was little or no brooding of chicks in any clutch.

Behaviour changed with time of day in all pairs in both seasons, except for WB-M and UBB in the 1997/1998 season (Figures 2.3.1-2.3.2). The reason why this pair behaved differently is unclear. The unbanded bird is assumed to be the same individual in both seasons. Although the Mangawhai pair in the 1997/1998 season brooded the same amount of time throughout the day, both pairs in the 1998/1999 season tended to brood more in the

morning and evening periods. However, there were differences between the pairs, with the adults at Mangawhai brooding more in the evening while the Waipu pair brooded more in the morning. This coincided with little absence from the territory in these periods, particularly in the evening. During the day, the adults spent equal amounts of time in the guarding of the young during the day. To be brooding and present in the morning and evening periods would be advantageous, because it is generally cooler at these time and predators are less visible in periods of low light (Thibault and McNeil 1995). The reason for the differences between the pairs is unclear.

Parents were absent from the territory more frequently from the second week, though pairs with two chicks left them earlier, and unattended for longer, than the pairs with a single chick. Davies (1981) found for Little Terns that considerable growth occurred between 10-14 days of age. Thus, the absence of Fairy Tern parents at that stage may have been a response to increasing demands for food by the young. Parrish and Pulham (1995) found that at least one adult was present (even if at a distance), and that the young were not left totally unguarded for long periods until 14-15 days old. Results of the present study show that such absence can occur earlier, and that the change in adult behaviour depended on the number of young they had. Comparison of activity of the parents over the two seasons showed that only the Waipu pair differed in behaviour with a single chick, spending more time guarding the chick and not leaving it unattended for long. The reasons why the pairs differed in their behaviour towards a single chick as opposed to two are unclear. Waipu does have large numbers of other birds near, including some potential predators (see Chapter 3). This may induce guarding by parents associated with perceived greater risk and the high reproductive investment in a single chick. Guarding remained fairly constant over the weeks. Few studies have considered what effect the weather, week, or time of day may have on the behaviour of birds with their young. For gulls (Butler and Janes-Butler 1983) and terns (Fasola and Saino 1995) there is no reported effect of time of day on parental behaviour and attendance.

Weather conditions and time of day did not affect parental feeding of the young except at Mangawhai in the 1997/1998 season. In that pair, the male tended to feed the young more

in the evening period than did the female, being fairly equal during the morning to late afternoon periods. Among terns, wind effects on feeding rates have been found in many species (Dunn 1975, Cramp 1985, Safina 1990, Frank and Becker 1992, Frank 1992, Norman 1992). Cloud cover, however, does not appear to affect an adult's ability to forage (Dunn 1973). Wind affects a species morphologically adapted for frequent, prolonged hovering, particularly small terns such as the Little Tern (Cramp 1985). Moderate winds can aid hovering in the larger Common and Sandwich Terns (Safina 1990), although it can affect foraging ability through its effect on the water surface (Dunn 1973). Fairy Terns clearly have trouble flying against moderate to strong winds, so perhaps not enough windy days were sampled to detect its effect in this study. No time of day effect on feeding has been found in other terns (Fasola and Saino 1995) or in Fairy Terns, but higher feeding rates in morning and evening periods have been found in other seabirds (Kirkham and Morris 1979, Cramp 1985, Norman 1992).

With the effect of time of day excluded, male Fairy Terns carried out more feeding than females in the 1998/1999 season, with no significant difference in the 1997/1998 season. Male dominated feeding has been found in gulls (Pierotti 1981) and terns (Table 2.6). However, there are studies which found no differences between the sexes (Butler and Janes-Butler 1983, Wagner and Safina 1989, Uttley 1992), and one which found that Caspian Tern males fed the young less than their mates (Quinn 1990). Food stocks can influence the amount of feeding. For example, male Arctic Terns feed chicks more than the female where there is a rich food supply, but the sexes feed equally when there is a reduced food supply (Uttley 1992).

When a pair has two chicks there is the possibility that one parent may preferentially feed one of the chicks. Often an adult seemed to prefer feeding a particular chick. A parent would even walk around a soliciting chick to feed the other chick, which was not soliciting. Solicitation is generally thought to facilitate the transfer of food, though Ricklefs (1992) suggests that the parents do not always act upon it. Although it appeared that a parent would preferentially feed a particular chick, it was not found to be significant in this study.



The frequency of feeding in relation to the state of the tide differed between the two pairs but not with individual, size of fish or the areas Fairy Terns used to forage. It would seem that there is a different feeding regime particularly from low to mid tide rising. At Waipu, Fairy Terns tend to feed their chicks less during this time than the Mangawhai pair, while the Mangawhai pair chose to fish at higher states of the tide as well. This pattern of increased feeding after low tide has been found with other terns (Dunn 1975, Burger *et al* 1977, Davies 1981, Frank 1992, and Norman 1992), although Frank and Becker (1992) found that Arctic Terns preferred the four hours before low tide. The influence of tide on feeding behaviour is likely to be site driven, in that the Mangawhai estuary is large compared to the Waipu estuary and therefore the upper reaches of the arms of the estuary would be exposed earlier. Parrish and Pulham (1995) classified Fairy Terns as shallow-water feeders. If so, Fairy Terns at Mangawhai may be less restricted at the time when the water is falling, allowing them to forage at higher tides. At Waipu, the estuary is covered for some time after high tide. Therefore, the foraging times of Fairy Terns at Waipu may be more restricted by tide.

For male Fairy Terns, there are important roles in courtship feeding and feeding of the young. However, most parental care seems to be shared by the sexes, and there may be energetic advantages in sharing. It has generally been thought that the energy requirements of the female during the breeding season are high, because she lays the eggs (Trivers 1972, Bergstrom 1981, and Mertens 1987). Certainly this requirement may become higher if nest failure is included (Brunton 1988b). Although gulls and terns appear to invest heavily in egg formation (Wiggins and Morris 1987), the cost of egg production seems to be balanced by the male providing the female with food through courtship feeding (Uttley 1992, Fasola and Saino 1995). Loss of weight is significantly greater in males (due to courtship feeding and territorial defence) than in females, and suggests that the male makes a significant contribution to egg production (Burger 1981a, Uttley 1992). Males react more aggressively than the female only during incubation (see Chapter 3).

Care of the young after fledging can also assist their survival. The post-fledging period is particularly long in gulls and terns, as their foraging methods require judgement and coordination (Dunn 1972, Ashmole 1985) and learning. In seabirds and shorebirds one

parent, often the male, performs the post-fledging care of the young (Cramp 1985, Miller 1985, Pierce 1997). Efforts by the male may, therefore, equal or exceed those of the female, and exclusion of this period may distort the overall investment given by each parent (Burger 1981b, Ogden and Stutchbury 1997). Following Fairy Tern adults and their chicks after fledging to study post-fledging care was difficult because of the large area and extremely small number of individuals involved. On the few occasions when juveniles were observed, one parent accompanied them only, this being the male on at least one occasion. This suggests that only one parent takes part in post-fledging care and it is possibly the male in the New Zealand Fairy Tern. On no occasion was an identifiable female observed with the juveniles, even on the wintering grounds.

Some authors imply that incubation and brooding are energetically inexpensive (Walsberg and King 1978, Beintema and Visser 1989, Frank and Becker 1992, Fasola and Saino 1995), though energy demands could rise during low ambient temperatures, particularly at night (Haftorn and Reinertsen 1985, Bergstrom 1986). If female Fairy Terns do incubate all night, as suggested by Parrish and Pulham (1995), there may be an additional cost to the female in keeping the eggs warm. However, sharing the incubation during daylight would mean less time spent away from feeding and adults could replenish energy reserves (Kålås 1986). The costs of feeding young depend on their demands and the availability of food (Uttley *et al* 1994). Energy expenditure was not part of this research. Comparisons with other studies, however, suggest that, overall, female and male Fairy Terns appear to make equal reproductive effort. The male shares the cost of egg laying by courtship feeding and possibly post-fledging care. Whether the male effort actually exceeds that of the female requires more information on nocturnal activity, and post-fledging care of young.

Although the sample size in this study is necessarily small, for the New Zealand Fairy Tern there is evidence to question Trivers' (1972) theory that the female exceeds the male in investment. As far as diurnal behaviour is concerned, although there are some defined roles for the sexes, this study indicates that Fairy Terns share the responsibilities of reproduction equally, though the behaviour can change depending on weather conditions, time of day and the number of chicks.

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# Bird Interactions





### **Chapter 3: The response of New Zealand Fairy Terns to interactions with other birds and people: implications for management**

#### **3.1 Introduction**

Predation is one of the most important selective pressures that all birds' face according to Gochfeld (1984) and Radford and Blakey (2000), and many birds have adapted their behaviour to minimise predation and dispel intruders from their territory. Various terms have been used to reflect these behaviours, including 'nest protection displays', 'distraction displays' and 'lure displays' (Gochfeld 1984). These terms have included both defensive and distraction components with no consideration of how they are perceived by the predator (Gochfeld 1984).

The term 'antipredator behaviour' covers displays directed at predators and generally includes descriptions of the types of behaviour employed. Such displays are characteristic of a number of ground-nesting birds, particularly sea and shorebirds nesting in open, exposed areas that are explored by predators. There is variation between species in the response to predators as well as variation in the influence the antipredator behaviour has on the predator. Nevertheless, the reason for antipredator behaviour is the same: to protect eggs or young in order to ensure successful reproduction and to maintain the individual's own survival.

The antipredator strategies of ground nesting birds include displacement, distraction and aggressive behaviours. Displacement displays, a form of distraction display, involve 'normal' breeding activities away from the nest or chicks including 'false preening' and 'pseudo-sleeping'. It has been argued by Gochfeld (1984) that 'false preening' is a misnomer, as it would be difficult to differentiate between actual and false preening. These behaviours delude predators into thinking there is no egg or chick near (Gochfeld 1984). When a predator appears some shorebirds leave the nest, land nearby, and perform these behaviours with a heightened alertness towards the predator (Gochfeld 1984). Oystercatchers carry out pseudo-sleeping where the bill is tucked under the wing but the

eyes are open watching an intruder (Williamson 1950). Nest betrayal is another variant of displacement display in which an incubating bird runs to another bird's nest, displays and then flies away when approached. This has been observed in species such as the Ringed Plover and the Least Tern (Gochfeld 1984).

Distraction displays have been described as presenting predators with an attractive, apparently easy hunt, deflecting them from nests or young (Simmons 1955), and include impeded flight (wing fluttering with legs hanging), injury-feigning (broken wing) and distraction runs (Gochfeld 1984). Often these sorts of displays are seen in solitary Charadriiformes such as Western Sandpipers (Brown 1962), Red-capped Dotterel (Hobbs 1972), Killdeer (Phillips 1972, Mundahl 1982) and New Zealand Dotterels (J. Dowding pers. comm.), although this behaviour has also been seen in colonial Black Skimmers (Gochfeld 1984). In general, gull and tern species do not lure predators away (Skutch 1955), but a few show distraction displays eg Least Terns, Sabine's Gulls, and Common Gulls (Gochfeld 1984). Smaller species tend to specialise in these displays, as larger ones are able to mob or attack predators (Simmons 1955, Gochfeld 1984).

Aggressive behaviour by nesting birds is well known, although there are assumptions made about the motivations behind it (Gochfeld 1984). Often combined with vocalisations, such behaviour either intimidates predators or focuses their attention on the adults and away from nests or young (Gochfeld 1984). Nesting in colonies or with other species can provide increased protection and reduce individual vigilance. Colonies particularly central positions in colonies were thought to provide protection for birds and their young (Burger 1981, Wittenberger and Hunt 1985, Bruntón 1997, Yorio and Quintana 1997). Other studies suggest, however, that colonies, especially centres of colonies attract predators because of the concentration of a food source, and are vulnerable (Dyrce *et al* 1981, Wittenberger and Hunt 1985, Bruntón (1997,1999). Mobbing of predators can benefit colonial breeders (Wittenberger and Hunt 1985). However, unless species have some form of aggressive behaviour, predation is often high. In mixed colonies of Royal and Cayenne Terns, the Cayenne Terns, being less aggressive, were heavily preyed upon (Yorio and Quintana 1997) but there was little predation on the Royal Terns. Larger colonies can

suffer from increased predation, which implies there could be a critical size at which they offer optimum protection (Gochfeld 1984, Brunton 1999). Semi- or loose-colonies have been found to have a lower rate of predation than both larger colonies and scattered nests (Dyrce et al 1981, Gochfeld 1984). Lemmetyinen (1971) examined this idea by placing eggs at solitary nests and near colonies of Arctic and Common Terns. He found that eggs near solitary nests survived longer than those near colonies where predators tended to congregate (see Wittenberger and Hunt 1985). Birds can often benefit from other nesting birds to alert them of potential danger as was found in Western Grebes nesting among Forster's Terns (Wittenberger and Hunt 1985).

While the majority of studies have emphasized distraction displays (Simmons 1955), aggressive responses are relatively easy to observe, and recent studies have used quantitative approaches to look at these responses in Common Terns (Becker 1984), Arctic Terns (Lemmetyinen 1971), Royal Terns (Buckley and Buckley 1972), Killdeer (Philips 1972), Oystercatchers (Baker 1974), and Royal and Cayenne Terns (Yorio and Quintana 1997). The factors influencing aggressive responses are many. The choice of habitat, stage in breeding cycle, length of the breeding season, type of predator (avian or mammalian), size of predator and bird, and the predator's distance and approach towards the nest can potentially influence a bird's behaviour (Gochfeld 1984). The roles of the male and female in defence are also important when considering the investment of sex in reproduction.

To understand passive and aggressive behaviour directed at intruders and potential predators, this study looked at the interactions and responses of Fairy Terns towards other birds, and to people over the reproductive cycle. Factors that could influence these responses included time of season, time of day, type of intruder and its potential as a competitor or predator.



## 3.2 Methods

### 3.2.1 *Collection of data*

The responses of Fairy Terns to other birds were recorded during the reproductive cycle of the pairs observed over the two seasons. Any bird within 100 m of the nest or young was recorded. The species involved included Black-backed Gull, Banded Dotterel, Bar-tailed Godwit, Black Swan, Caspian Tern, White-faced Heron, House Sparrow, Australasian Gannet, Kingfisher, Lesser Knot, New Zealand Dotterel, Pied Shag, Pied Stilt, Red-billed Gull, Skylark, Spur-wing Plover, Turnstone, Welcome Swallow, White-Fronted Tern, and Variable Oystercatcher. In addition, the response of all interactions with people, Black-Backed Gulls and Harriers within 800 m of the nest were recorded because they were potential threats to Fairy Terns. Details noted included the species, estimated distance and direction from the nest or chicks, whether calls were made, and whether the bird was flying or on the ground. The reactions of Fairy Terns to these 'interactions' were separated into three intensity responses: no response (0), look or alert (1) and chase or dive-bombing (2).

### 3.2.2 *Statistical Analysis*

Intensity responses were initially grouped into two categories: passive and active, to establish any differences in distance and species between the pairs over their reproductive cycle. Passive responses included no response or look or alert reactions and active responses included chase or dive-bomb reactions. The active response data only were then analysed using a general model (SAS GENMOD procedure) to compare the intensity of response of Fairy Terns to other birds and people. Differences in response were with respect to species, calls, whether the bird was flying or on the ground, distance, the direction in which they were closest to the nest or young and whether there were differences between the individuals. The time of season and time of day were also considered, particularly in relation to species and distance. Distances were grouped into four categories: 0-5m, 5-25m, 25-75m, and 75m and above. Data for male and female Fairy Terns were also combined to look at general responses between the sexes.

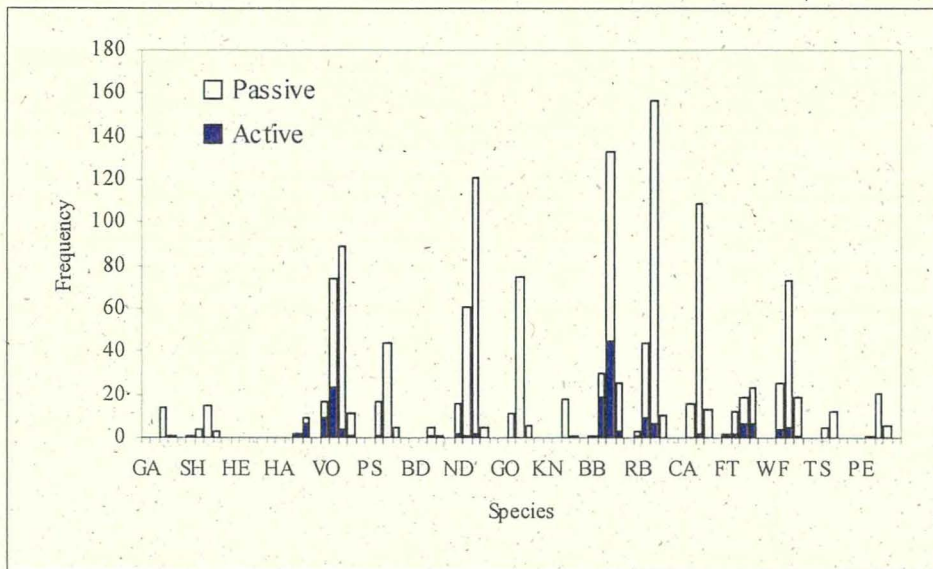
To understand why Fairy Terns reacted more aggressively to some species than to others, two contrasts were performed using suitable groups of birds. The first compared competitive birds (those nesting at the same time, such as Black-backed Gulls, White-fronted Terns, Caspian Terns, New Zealand Dotterels, Variable Oystercatchers, and Red-billed Gulls) with 'passerby' birds (Black Swans, Welcome Swallows, Kingfishers and so on). The second compared potential predators (Black-backed Gulls, Harriers and people) with birds which would have been no threat to Fairy Terns.

### 3.3 Results

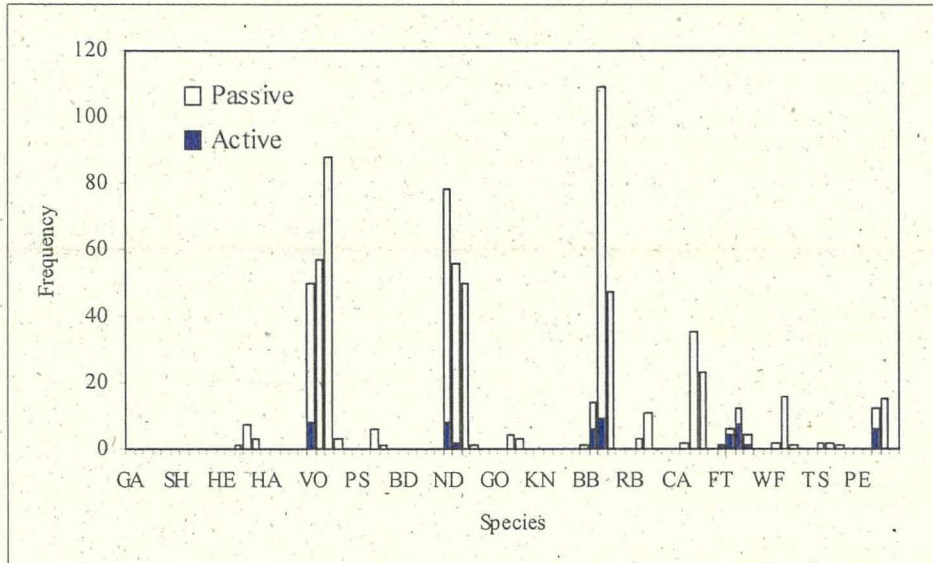
Only data from the 1998/1999 season were used for the analysis because they were the most complete. A total of 3300 interactions with other species and people were recorded over the incubation period and care of the young for the two pairs. Those species with five or less interactions were excluded. These included infrequent species such as Black Swans, Kingfishers, White-faced Herons, House Sparrows, Mynas, Spur-wing Plovers and Welcome Swallows, to which Fairy Terns often did not respond.

Over all, Fairy Terns responded passively (83%) in most interactions with other species. The birds' responses to various species at different distances are shown for each pair during the incubation period (Figures 3.1.1a and b) and while caring for the young (Figures 3.1.2a and b). The majority of the interactions, occurred with those birds nesting at the same time, such as Black-backed Gulls, Caspian Terns, other Fairy Terns, New Zealand Dotterels, Red-billed Gulls, Variable Oystercatchers, and White-fronted Terns. At Waipu there was considerable movement of Black-backed Gulls and nesting New Zealand Dotterels and Variable Oystercatchers through the Fairy Terns territory. Fairy Terns tended to respond to other birds more actively during the care of their young (22-24%) than during the incubation period (8-14%), when their investment in reproduction is high. Black-backed Gulls, New Zealand Dotterels, and Variable Oystercatchers were often chased or dive-bombed, particularly when they strayed close to the young.

## (a) G-M and UBB



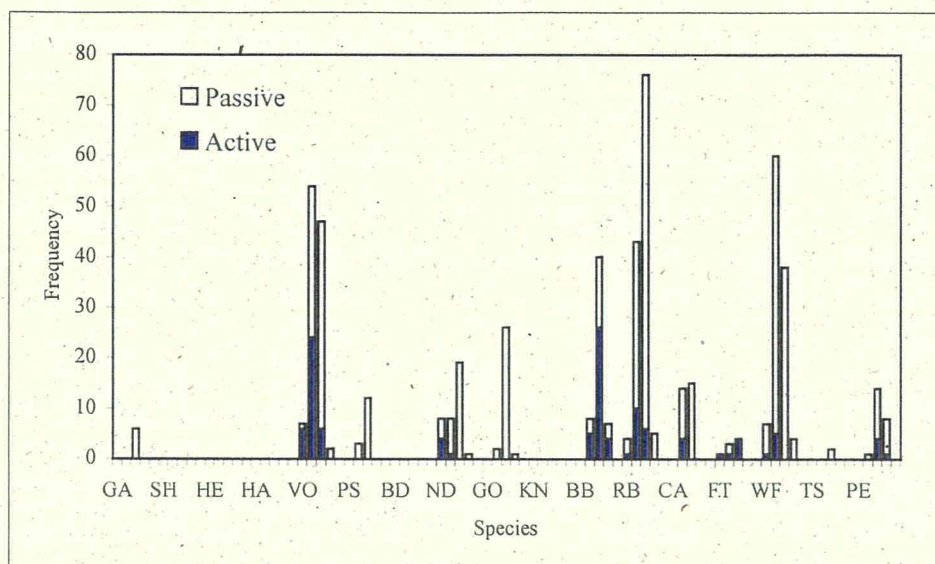
## (a) WB-M and UBB



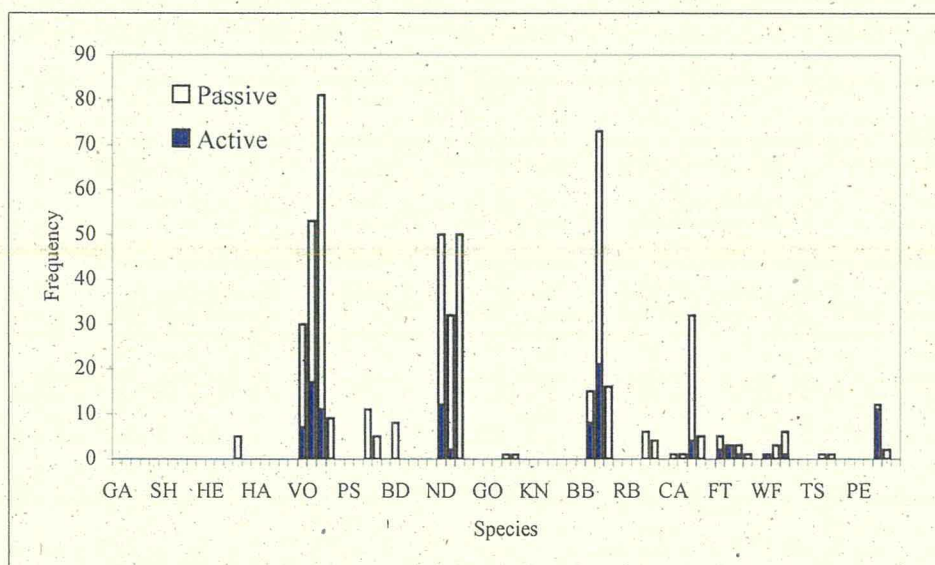
**Figure 3.1.1.** Passive and active responses of Fairy Terns to other bird species and people during the incubation period. GA=Australasian Gannet, SH=Pied Shag, HE=White-faced Heron, HA= Australasian Harrier, VO=Variable Oystercatcher, PS=Pied Stilt, BD=Banded Dotterel, ND=New Zealand Dotterel, GO=Bar-tailed Godwit, KN=Lesser Knot, BB = Black-backed Gull, RB=Red-billed Gull, CA=Caspian Tern, FT=Fairy Tern, WF=White-fronted Tern, TS=Turnstone, and PE=people.



## (a) G-M and UBB



## (b) WB-M and UBB



**Figure 3.1.2.** Passive and active responses of Fairy Terns to other bird species and people during the care of the young. GA=Australasian Gannet, SH=Pied Shag, HE=White-faced Heron, HA= Australasian Harrier, VO=Variable Oystercatcher, PS=Pied Stilt, BD=Banded Dotterel, ND=New Zealand Dotterel, GO=Bar-tailed Godwit, KN=Lesser Knot, BB = Black-backed Gull, RB=Red-billed Gull, CA=Caspian Tern, FT=Fairy Tern, WF=White-fronted Tern, TS=Turnstone, and PE=people.

*The Mangawhai Pair*

Fairy Terns varied in the intensity of response to intruders depending on a number of factors. Table 3.1 shows the factors considered and their significance level. The behaviour of Fairy Terns generally did not differ with distance, with sex or species, over the season, or with time of day, therefore, these interactions were excluded from the analysis.

**Table 3.1.** Active responses of the Mangawhai Fairy Terns and their significance level with respect to age of young (season), time of day (obsp), species, calls, whether the intruder was flying or on the ground, distance, the direction in which they were closest to the nest or young and whether there were differences between the individuals. Significant factors are shown with an asterisk.

REPRODUCTIVE STAGE	FACTORS	DF	PR>CHI
Incubation	Week	4	0.0963
	Obsp	3	0.0018*
	Species	15	0.0001*
	Ground/Flying	1	0.0001*
	Calls	1	0.0001*
	Distance	3	0.0001*
	Direction	5	0.0003*
	Individual	1	0.0008*
Parental care of young	Week	2	0.1491
	Obsp	3	0.5323
	Species	12	0.0001*
	Ground/Flying	1	0.0001*
	Calls	1	0.0001*
	Distance	3	0.0009*
	Direction	4	0.4435
	Individual	1	0.8505

While incubating the Fairy Terns would always react to Harriers, and were highly likely to react to Black-backed Gulls, and other Fairy Terns more than any of the other species. Red-billed Gulls, Variable Oystercatchers, Pied Stilts and White-fronted Terns attracted

more responses than Caspian Terns or New Zealand Dotterels. Other species including people caused little response from Fairy Terns at this site. Fairy Terns did not respond more intensely as the eggs developed, although were more likely to react to birds in the evening. Fairy Terns were also more aggressive to birds on the ground than those flying, whether a bird called or not, and responded more aggressively to birds that approached close, particularly within 25 m of the nest. The birds reacted more aggressively when an intruder approached the nest from the north or at its closest point, was directly above the nest. There was a difference between the sexes in this pair. The female (G-M) was less likely to react aggressively than the male. When examining the response of individual terns to other bird species, the female responded more to Black-backed Gulls than did the male, whereas the male reacted more readily to Harriers. To all other bird species and people, the sexes reacted to a similar degree.

During care of the young, the Mangawhai pair would respond to Black-backed Gulls and other Fairy Terns more actively than to other bird species or people. No interactions with Harriers were seen during this period. However, there was a change in their reaction to other species. Caspian Terns, Red-billed Gulls and Variable Oystercatchers received aggressive responses while New Zealand Dotterels, White-fronted Terns and people were unlikely to elicit a response. Birds within 25 m of the nest were highly likely to initiate an active response, particularly if they were on the ground. These Fairy Terns did not increase their defence intensity with the age of young, or the time of day, as was expected, particularly when the young were vulnerable such as in the first week or with low light conditions at dawn and dusk. Fairy Terns did not differ in their response as to which direction intruders approached. The male and female were equally aggressive to intruders.



*The Waipu Pair*

This pair did not react any different with distance, between sexes with the species of intruder over incubation or aging of young (season) and time of day (ie the interactions). However, Table 3.2 shows that there were differences in Fairy Tern active responses over the factors themselves.

**Table 3.2.** Active responses of the Waipu Fairy Terns and their significance level with respect to age of the young, time of day (obsp), species, calls, whether the intruder was flying or on the ground, distance, the direction in which they were closest to the nest or young and whether there were differences between the individuals. Significant factors are shown with an asterisk.

REPRODUCTIVE STAGE	FACTORS	DF	PR>CHI
Incubation	Week	3	0.2429
	Obsp	3	0.8494
	Species	12	0.0001*
	Ground/Flying	1	0.0001*
	Calls	1	0.3020
	Distance	3	0.0001*
	Direction	4	0.5299
	Individual	1	0.2823
Parental care of young	Week	2	0.0035*
	Obsp	3	0.0001*
	Species	16	0.0001*
	Ground/Flying	1	0.1692
	Calls	1	0.0001*
	Distance	3	0.0001*
	Direction	4	0.0001*
	Individual	1	0.1320

During incubation the Waipu pair responded differently to people and to the species of approaching bird, whether the intruder was on the ground or flying, and its distance from the nest. This pair reacted strongly to other Fairy Terns but were less responsive to Black-

backed Gulls and people. Surprisingly, the Fairy Terns were also less responsive to New Zealand Dotterels, Variable Oystercatchers, White-fronted Terns and Caspian Terns, species that elicited a brisk response from the Mangawhai pair. For all other species, the Waipu terns were unlikely to respond. There were more aggressive encounters up to 75 m, further than the distance at which the Mangawhai pair would react. The Waipu pair also behaved the same during the whole incubation period and at different times of day. The direction from which the birds or people approached did not alter the intensity of the terns' reaction, and the two birds behaved similarly.

With young, this pair reacted highly to the majority of birds including Black-backed Gulls, Caspian Terns, other Fairy Terns, New Zealand Dotterels, Variable Oystercatchers, White-fronted Terns, and people. Red-billed Gulls and Pied Stilts evoked a lesser response. The aggressive responses increased within 75 m whether birds were on the ground or flying, and approaching from the north or were directly above the young. This pair did not change in aggressive responses with the age of the chicks, but responded more aggressively during late morning. There was no difference in reactions between the sexes.

All Fairy Terns were more aggressive to competitive than passerby species ( $P < 0.0001$ ) during incubation and parental care, with the exception of the Waipu pair during incubation. In this case, the likelihood of these birds reacting to competitive species was low. The Mangawhai pair did not appear to react differently to potential predators than to other birds during incubation ( $P < 0.0906$ ), although the pair responded aggressively to all birds during parental care. During incubation and parental care, the Waipu pair reacted more strongly to the potential predators than to those considered as not being a threat to eggs or chicks ( $P < 0.0001$ ).

When male and female Fairy Terns were compared collectively over the two pairs, most factors had an affect on their behaviour. These were similar over incubation and care of young, with the terns being more aggressive towards Black-backed Gulls, Harriers, and Variable Oystercatchers; during early morning; and intruders within 50 m of the nest or chicks, particularly on the ground. Although direction of approach made no difference to

Fairy Terns over incubation, those intruders approaching from the north or were directly above the nest to young caused the most aggressive response. Differences between the sexes only occurred during incubation, the male being more aggressive than the female.

### 3.4 Discussion

Fairy Terns in this study did not show peaks in intensity of aggression during incubation or chick rearing. This result was unexpected because other studies have found an increase in intensity of response during reproduction, especially when eggs were near to hatching or when the chicks were young (Simmons 1955, Skutch 1955, Mundahl 1982, Gochfeld 1984, Dulude *et al* 1987, Brunton 1990, Fasola and Saino 1995, Larsen *et al* 1996). Fairy Terns, however, did increase active responses over the whole period with caring for chicks as has been found in American Jacana (Jenni and Betts 1978), Killdeer (Mundahl 1982), Mockingbirds (Breitwisch 1988), Black-tailed Godwits (Green *et al* 1990), and Arctic and Common Terns (Whittam and Leonard 2000).

Differences between individuals might have been expected, yet this was found only in the Mangawhai pair during incubation. Quantitative studies of sexual differences in defense behaviour are scarce because of the difficulty in sexing birds in the field (Brunton 1990). In most cases, however, the male performs the majority of the defense as in Ring-billed Gulls (Southern 1981, Dulude *et al* 1987), Piping Plover (Cairns 1982), Great Black-backed Gulls (Butler and Janes-Butler 1983), Ringed Plover (Pienkowski 1984), Laughing Gulls (Burger and Beer 1975), Little, Common and Sandwich Terns (Fasola and Saino 1995), Purple Sandpiper (Pierce 1997) and Long-toed Lapwings and Black-tailed Godwits (Hegyi and Sasvári 1998). However, when the data for males and females were combined, Fairy Tern males responded more readily than females during incubation but not during care of the young. The female and male of a pair, however, would often work together to repel intruders, particularly in the case of Harriers or Variable Oystercatchers.

The response distance of Fairy Terns was generally the same, with a high level of response to any birds within 25 m, whether the birds were on the ground or flying. This is similar to what Rodgers and Smith (1995) found with most upflights of Least Terns occurring at 50 m in response to disturbance by people. Fairy Terns reacted more intensely to birds on the ground as Brunton (1990) found in Killdeer, and Whittam and Leonard (2000) in Arctic and Common Terns. Harriers always caused an active response independent of the distance, whereas Black-backed Gulls and Variable Oystercatchers stimulated an active response within 25 m for 50 percent of the time while other Fairy Terns almost always caused individuals to respond. Burger (1980) found that during incubation Herring Gulls only chased conspecifics from their territory, but when chicks were present all intruders were chased away. Great Tits also responded to models of predators more intensely when brooding chicks (Radford and Blakey 2000). Overall, Fairy Terns with young were more aggressive to intruders approaching from the north or were directly above. Fairy Terns may feel more threatened with birds flying directly above or on the ground near the young, however, why they were more aggressive to intruders from the north is unclear. Perhaps due to the position of the nest or young, the visibility of intruders was more prominent to the north than other directions.

The Fairy Terns at Waipu were tolerant of most birds and people during incubation. After chicks hatched, however, they were highly likely to react to any bird, even at a distance of 75 m. Often birds respond by increasing the size of their territory when guarding chicks as in Herring Gulls (Burger 1980), Western Gulls (Pierotti 1981) and Great Black-backed Gulls (Butler and Janes-Butler 1983). Even though this was generally the case for Fairy Terns, a high level of response, particularly with distance was not observed in the Mangawhai pair. The Waipu pair appeared especially sensitive to people, despite the fencing of nest areas restricting the number of close encounters. Even the movement of orange fencing tape in the wind 40-50 m away appeared to concern the Waipu pair. On many occasions the male was seen to fly towards an area of tape visible from the nest area, hover over it looking down, and then fly back to land near the chick. This heightened response could be explained by the site being small and having a high population of breeding birds in close proximity. The large number of birds passing close to this pair meant the birds' would need to be continuously vigilant. The Waipu pair may therefore

have had a lower threshold of tolerance to disturbances because of the nature of the site. On the other hand, it might be expected that the Waipu pair would become habituated to other birds as in Royal Terns with Laughing Gulls (Buckley and Buckley 1972). The reason why this is not the case is unclear.

Fairy Terns also appeared to respond to the degree of danger posed to their eggs or chicks by behaving aggressively to potential predators and to competing species, particularly when young were present. For example with Harriers which are considered as the most likely potential predator of eggs or chicks and elicited aggressive responses whether they were close or not.

The type of analysis carried out in this study was difficult to compare with other species, because remarkably few include all factors such as sexual differences, response distances and bird species reacted too (Gochfeld 1984, Brunton 1990). However, male Fairy Terns appear to respond more than the female during incubation, but the sexes share territorial defense during parental care. Generally, no increase in responses during vulnerable times in the reproductive cycle were found, though the birds reacted more aggressively when with chicks than with eggs.

This study has shown that the responses of Fairy Terns can be used to identify management protocols that will enhance reproductive success. For example, by fencing nesting areas it is possible to minimise the risk of potential predation or disturbances, particularly with from people. Moreover, in changing the fencing of nesting areas, managers should consider the reaction distances of parents, and their tolerance of other birds. These protected areas need enlarging when the chicks hatch to minimise disturbance and parental stress. It will be difficult to discourage natural (native) predators or competing species, particularly as some species are also endangered such as the New Zealand Dotterel. Fortunately, however, these birds do not prey on Fairy Tern eggs or chicks. Mammalian predators remain the greatest threat to breeding Fairy Terns and will always need to be controlled.

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# Nest-site Selection





## Chapter 4. Nest-site selection in the New Zealand Fairy Tern: a comparison of environmental characteristics of nest sites and the surrounding available habitat

### 4.1 Introduction

Birds populate a wide range of habitats and of all vertebrates, are arguably the most mobile. Because birds use specific habitats for breeding, foraging and wintering; and because they coexist with other birds in these areas, there is the potential for habitat selection (Cody 1985). Habitat selection involves the choice by birds of particular elements from the available habitat, and results in their nonrandom distribution in space (Rosenzweig 1981, Burger 1987). The grouping of birds into forest birds, seabirds and shorebirds often defines the general habitat in which they are found. This gross level of partitioning suggests that birds have evolved or adapted to these areas because they inhabit them for most of their life.

The habitat chosen by a bird generally encompasses a breeding habitat, and involves a series of choices of general habitat selection, territory selection and on the finer scale nest-site selection (Burger 1987). This process may include physical features of the environment, the proximity of conspecifics or other species, a bird's previous nest site and the availability of food (Birkhead *et al* 1985, Burger and Gochfeld 1985, Cody 1985, Burger 1987, Eberl and Picman 1993). Habitat selection has been studied in various shorebirds and seabirds (Hockey 1982, Burger and Gochfeld 1985, Page *et al* 1985, Burger 1987, Jehl and Mahoney 1987, Lauro and Burger 1989, Gaines and Ryan 1988, Cumming 1991, Flemming *et al* 1992). Nest-site selection has also been studied in a number of ground-nesting terns (Common Terns: Blokpoel *et al* 1978, Burger and Lesser 1978, Richards and Morris 1984, Burger and Gochfeld (1988a, 1988b), Fasola and Canova 1992; Roseate Terns: Burger and Gochfeld 1988a; Least Terns: Kotliar and Burger 1986, Burger and Gochfeld 1990; Sooty Terns: Saliva and Burger 1989; Little Terns: Fasola and Canova 1992, Wilson 1996; and Sandwich Terns: Fasola and Canova 1992.

When studying nest-site selection, there is the question of what determines this preference in birds and what would be the value of choosing one site over another. Understanding habitat preferences requires identifying the advantages a bird gains by making a choice (Bongiorno 1970). Logically, habitat selection ought to be important for birds confined to the nest site for long periods during egg laying, incubation and for some species, during care of young (Burger and Gochfeld 1988a). Habitat selection could also affect the subsequent survival and breeding success of the adults, and the raising of their young (Birkhead *et al* 1985, Cody 1985, Saliva and Burger 1989, Wilson 1996, Pribil and Picman 1997).

The selection pressures that may underlie habitat selection include predation, and the way the environment alters the habitat from year to year. Predation is the most important selection pressure affecting birds' habitat selection according to Gochfeld (1984). Birds could be expected, therefore, to select a habitat that minimises predation (Cody 1985, Saliva and Burger 1989). They may achieve this through the selection of various environmental characteristics. Some birds nest under vegetation to hide from aerial predators (Burger and Gochfeld (1988a, 1988b), Saliva and Burger 1989). Other birds nest in areas devoid of vegetation, on wide, open beaches between water and dunes so that mammalian and avian predators are clearly visible (Kotliar and Burger 1986, Jehl and Mahoney 1987, Burger and Gochfeld 1988b, Gaines and Ryan 1988, Saliva and Burger 1989).

The tendency for some individuals to prefer open areas, while in different areas conspecifics nest in high vegetation, is paradoxical. Metcalfe (1984) found that Turnstones and Purple Sandpipers increase their vigilance with increasing complexity in their environment in order to detect predators. Lazarus and Symonds (1992) found that vigilance increased in House Sparrows with distance from less dense cover while it decreased with distance from dense cover. Birds such as waders (or seabirds) have no refuge to escape into, and therefore to detect predators early the birds need an unrestricted view (Metcalfe 1984). Moreover, dense vegetation can often cause problems for nesting birds exiting their nest (Burger and Gochfeld 1985, Kotliar and Burger 1986).



Variation in habitat may affect the choice of nest site by ground-nesting birds, because changes in habitat can be considerable. Coastal areas are generally dynamic and offer a wide choice of potential nest sites (Wiens 1985), but because these areas are often unstable, site-tenacity would be a disadvantage (McNicholl 1975). Rapid change in habitat at breeding colony sites led McNicholl (1975) and Burger (1982) to conclude that site tenacity was an advantage only when the habitat was stable. Colony-site shifts have been found in several terns and gulls including the Least Tern, Royal Tern and Sandwich Terns (McNicholl 1975), Ring-billed Gulls (Southern 1977), and Laughing gulls (Burger and Shisler 1980).

Birds may also select sites for protection from extreme weather conditions. Vegetation or objects can minimise the effects of rain, wind and high temperatures by sheltering the adults and young (Burger 1982, Burger and Gochfeld 1985, Page *et al* 1985, Burger 1987, Jehl and Mahoney 1987, Burger and Gochfeld 1988b, Saliva and Burger 1989). Nesting on wide beaches, on substrates such as windrow or shell patches, and on elevated or sloping areas can reduce the risk of flooding (Burger and Lesser 1978, Kotliar and Burger 1984, Burger 1987, Gaines and Ryan 1988). However, relatively high places are subject to sandblasting and can increase visibility to predators (Burger 1987). Potentially there is a trade off between height to aid visibility, and shell cover to provide camouflage and wind protection for incubating adults and young (Burger 1987). Therefore there is an advantage for birds having some flexibility in their choice of habitat in response to a changeable environment and available habitat (Burger and Gochfeld 1985, Rodway and Regehr 1999).

Birds do not select nest sites by environmental variables alone, they may also respond to historical factors (Jehl and Mahoney 1987, Saliva and Burger 1989). For instance the experience of the individual may be important in the choice of a site (Orians 1971, McNicholl 1975, Burger and Lesser 1978, Jehl and Mahoney 1987), and may mean birds are more likely to return to a site where they bred successfully. However, Burger (1982) found that Herring and Ring-billed Gulls persisted in using the same site despite continuous predation. These birds may have been simply returning to their natal sites (Cody 1985). Past success or experience is particularly difficult to quantify when considering a bird's choice of nest site. Past human disturbance can also affect nest-site selection (Burger 1982,

Wiens 1985, Kotliar and Burger 1986, Cumming 1991, Wilson 1996), by causing birds to abandon sites or shift from preferred sites to less suitable ones (Burger 1982). Disturbance can lower reproductive success through decreased attentiveness at the nest. This can lead to loss of body weight and condition in adults with consequences for overheating and cooling eggs and slower growth or higher mortality of young (Cumming 1991, Wilson 1996).

For seabirds and shorebirds, the nesting habitat generally comprises long, flat, sandy beaches, often with little vegetation. Thus, there are few features from which to choose, and therefore selection could be based on minor differences such as vegetation, elevation, and shell cover for protection from the elements and predators (Burger 1987).

With the loss and degradation of many coastal habitats, the importance of understanding habitat selection in coastal birds is imperative for their management (Richards and Morris 1984, Kotliar and Burger 1986, Gaines and Ryan 1988, Cumming 1991, Flemming *et al* 1992, Wilson 1996, Watson *et al* 1997). However, much of the work done on nest-site selection has been on colonial species, particularly terns, and the lack of studies on solitary breeding birds is evident (Martinka 1972, Burger 1987, Flemming *et al* 1992). Mostly this has been due to the difficulty in locating nests (Burger 1987).

New Zealand's coastal areas are extensive, including 100,000 ha of dune country (Courtney 1984). Parrish and Pulham (1995) described the nest sites selected by New Zealand Fairy Terns (*Sterna nereis davisae*) as being in low-lying areas, generally above the spring high tide mark. They noted that most were found on slightly raised mounds, in shell patches with little vegetation, or among large pieces of debris (Parrish and Pulham 1995). Beyond this description there has been no quantitative work to establish particular characteristics involved in the choice of nest site. This chapter presents and analyses measured characters associated with nest sites to better understand nest-site selection in the New Zealand Fairy Tern, a rare solitary breeding tern, and to better inform management decisions involving the coastal habitats in which the birds choose to breed.

## 4.2 Methods

### 4.2.1 *Collection of measurements*

All three of the established breeding sites (Mangawhai, Waipu and Papakanui) of New Zealand Fairy Terns (see Chapter 1) were surveyed. Each site has at a tidal estuary adjoining the ocean. Mangawhai and Papakanui include sparsely vegetated dynamic dune fields that are large in area, particularly at Papakanui. In comparison, Waipu is a small area of essentially stable low dunes, with a less extensive estuarine system. The dunes are fairly uniformly vegetated with mature *Spinifex hirsutus*, and pingao (*Desmoschoenus spiralis*), and introduced marram (*Ammophila arenaria*).

In all sites, Fairy Tern nests were generally located above the high tide mark in low-lying shell-patches. Because only seven pairs bred in any one season, all nests (including second and third attempts) were measured. Each site was mapped (see Figures 4.1.1- 4.1.3) to show the general features of the breeding sites and the location of each nest measured in this study.

The position of each nest site was noted and, where possible, close-up photographs of the nest site and surrounds were taken while it was still active, for later analysis of the substrate. The environmental characteristics measured (Table 4.1) were similar to those used by Cumming (1991) for the New Zealand Dotterel, and others working on nest-site selection in seabird and shorebird species (Blokpoel *et al* 1978, Metcalfe 1984, Burger and Gochfeld 1985, Burger 1987, Burger and Gochfeld 1988a, 1988b, Cumming 1991, Wilson 1996). Available habitat was also measured using the nest site as the centre point. Three 'habitat points' were established 15, 30 and 45 metres respectively north, south east, and west of the nest. At these points, the same characteristics were measured as for the nest site itself. The characteristics chosen appear to be important in nest-site selection in other species, and have been associated with reproductive success (Burger 1982, Pierotti 1982, Eberl and Picman 1993, Stokes and Boersma 1998). The success or failure of each Fairy Tern nest was later related to the characteristics of the site.

**Figure 4.1.1.** Map of Mangawhai Spit with the general features and location of the nests.

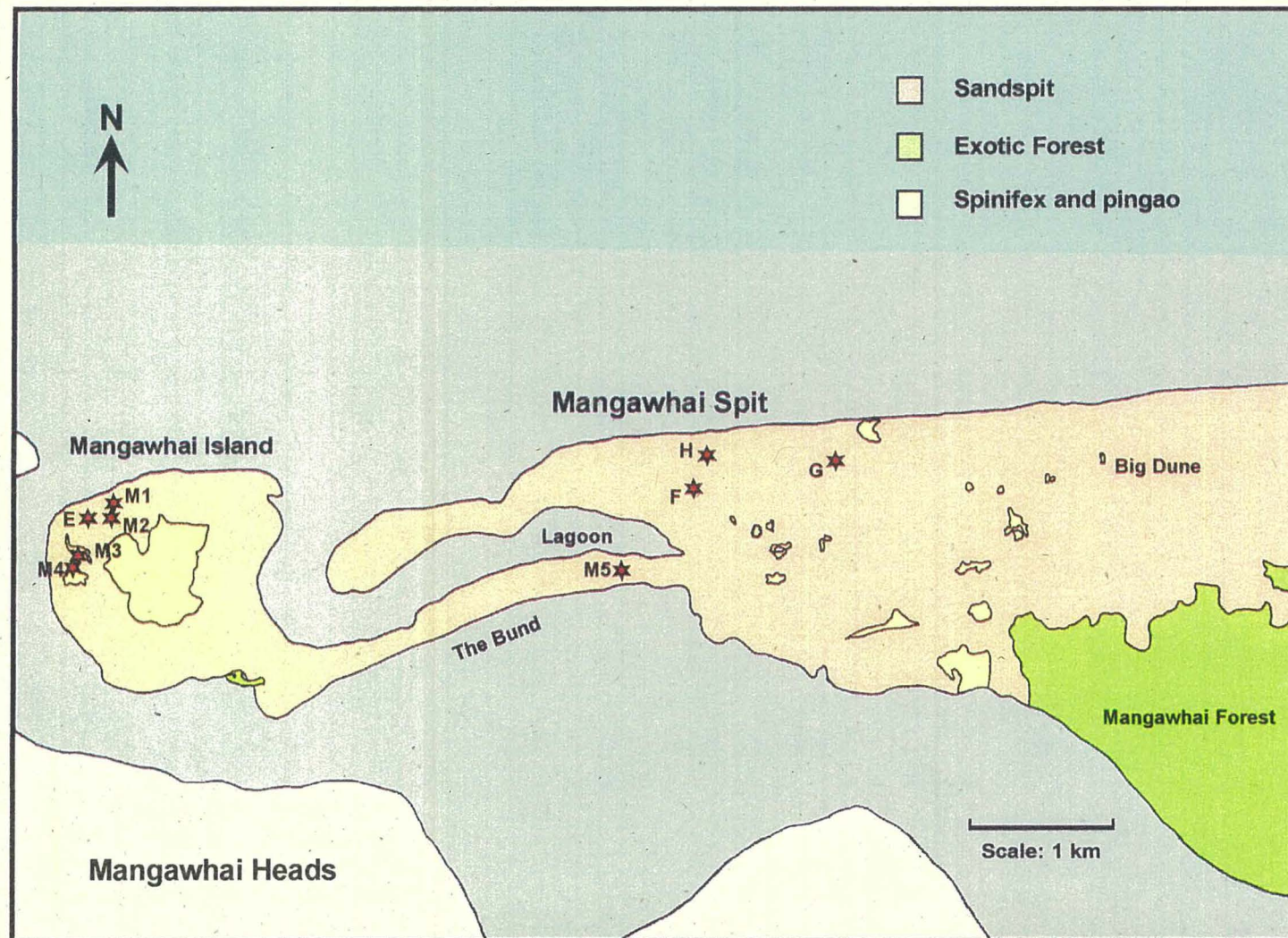




Figure 4.1.2. Map of Waipu Spit with the general features and location of the nests.

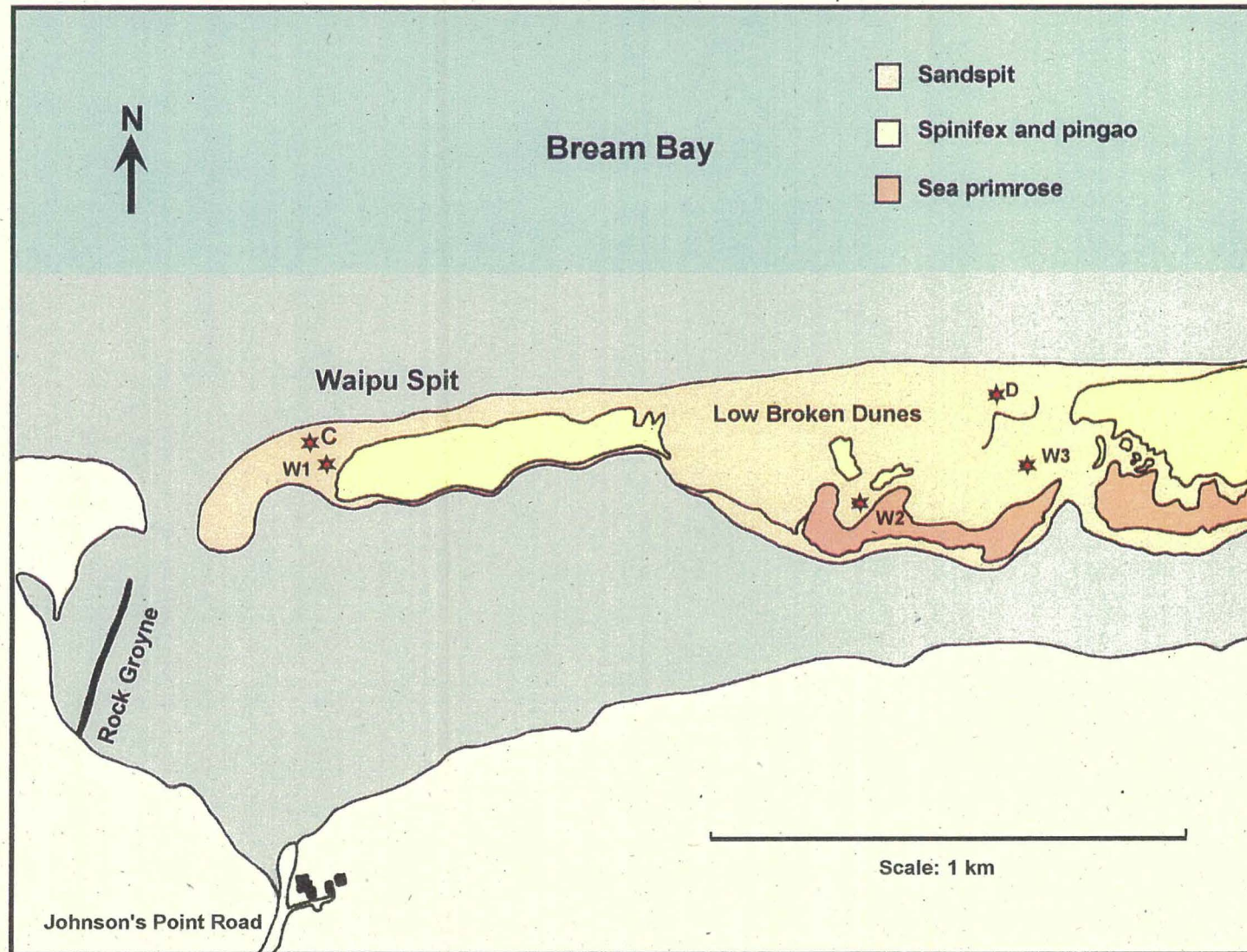
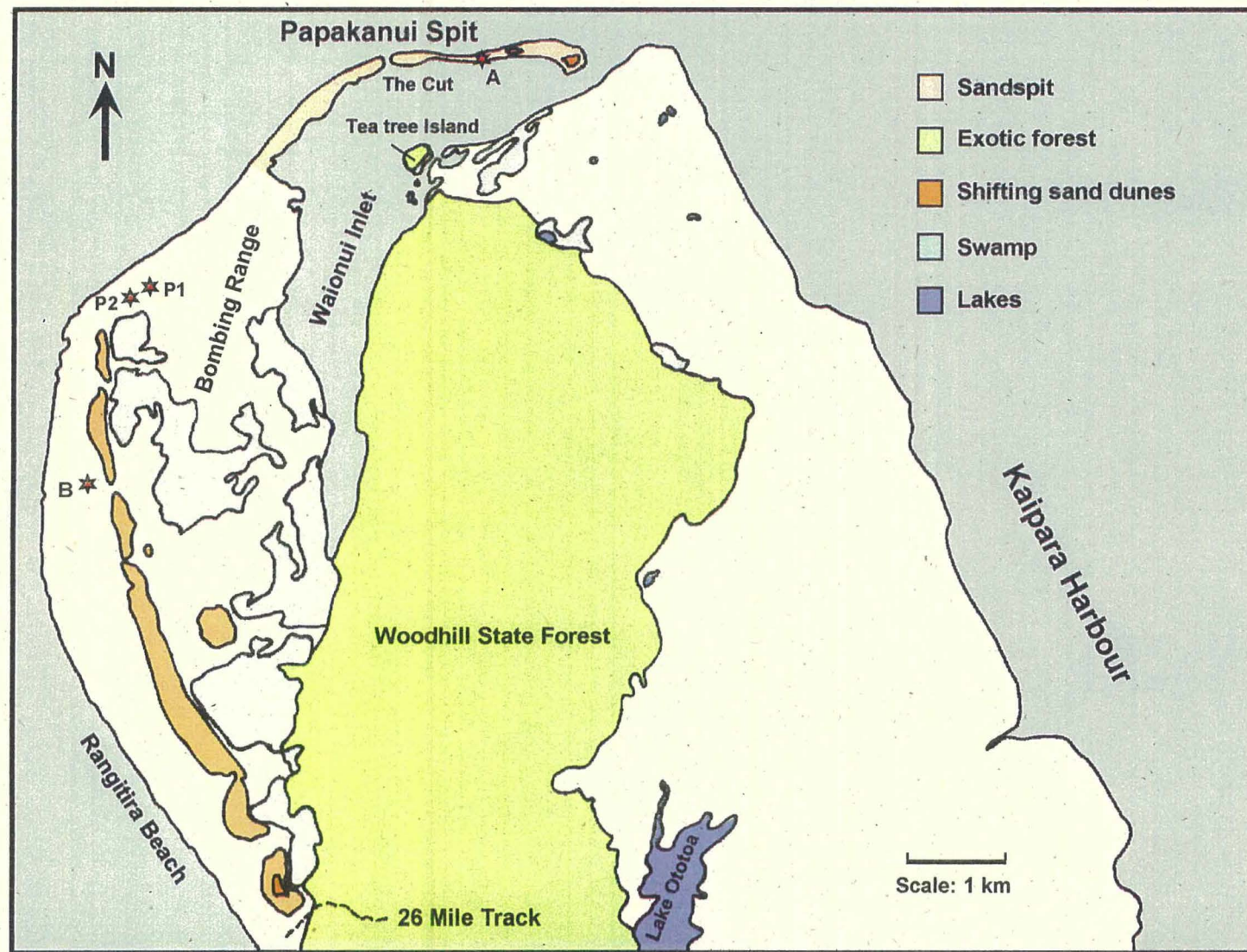




Figure 4.1.3. Map of Papakanui Spit with the general features and location of the nests.





**Table 4.1.** Environmental variables and a summary of the sampling methods used to analyse the nesting habitat of New Zealand Fairy Terns. MHW=mean high water mark.

Variable	Sampling Method
1. Distance to MHW to sea	tape measure (+/- 0.5m)
2. Distance to MHW to estuary	see 1.
3. Distance to nearest dune	see 1.
4. Distance to nearest vegetation	see 1.
5. Maximum height of nearest vegetation	see 1. (+/- 1cm)
6. Percentage vegetation cover	visual estimation within 5m of nest site or habitat point
7. Slope	Abney level
8. Elevation about sea level	Thommen altimeter
9. Aspect	Compass
10. Substrate	
a. percentage shell cover	photographs taken of 0.5 metre square quadrat
b. percentage of colour	percentage of shell cover, white or white/orange present in substrate shell cover

Unlike a number of species, New Zealand Fairy Terns nest in areas that are fenced to reduce human disturbance. Moreover, unlike species such as the New Zealand Dotterel, Fairy Terns forage outside the immediate territory. Food resources and disturbance have been included in other studies to quantify nest-site selection (Cumming 1991, Kotliar and Burger 1986) but were not applicable in this study.

#### 4.2.2. Statistical Analysis

A Multi-response Permutation Procedure (MRPP) was performed on the nest site data using the ordination program PcOrd (McCune and Mefford 1995) to identify any difference between the three breeding areas and the eventual outcome of the nests. A separate analysis was used to test between the nest sites and available habitat. MRPP is a non-parametric, multivariate procedure, which tests the hypothesis of no difference between two or more categorical variables (McCune and Mefford 1995). MRPP makes no assumptions of normality or homogeneity of variances (as does Discriminant Analysis) which are seldom met by ecological data. Four analyses were performed on the variables for each nest: a comparison between each of the three breeding sites, between the two east coast sites, and between each east coast site with the west. A further analysis was performed on successful (where a pair raised a chick to fledging) and unsuccessful nests to establish whether there were differences in the nest variables that were associated with success of a particular nest.

To determine whether there is evidence of nest-site selection in Fairy Terns, an ordination using Principal Component Analysis (PCA) was performed with the PcOrd ordination program. Bray and Curtis (1957) originally developed ordination for looking at different species in forest ecosystems. PcOrd is based on their ordination technique, though it is designed more for community ecology data with multivariate techniques including PCA. To adapt the nest data, the environmental variables were used in the main data matrix, while categorical variables of nest or non-nest, east or west coast, and nest site and its surrounding habitat points, were used in a second matrix to establish how the environmental data differ according to these groups. As well as using the raw data, a log transformation was also performed (on the distance measures only) to try to improve the ordination. Ordination was used to look for any 'gross' differences between the chosen nest site and what was available as an initial exploratory look at the data. Any differences between the east and west coasts, and which characteristics had a strong correlation on the nests and the available habitat were also explored.

A logistic regression analysis was used as a second technique to test the influence of environmental characteristics on nest-site selection on a finer scale than the ordination. This was achieved by centering the data (subtracting the mean of the available data from the raw available data) to smooth out gross differences in any of the environmental variables. This type of regression analysis is the most popular statistical modeling method used for categorical data where there is a binary response (Agresti 1996), in this case with 'nests' and 'available habitat'. This method examined the environmental characteristics to see which was the best predictor of whether a site was a nest or not. A consistent high probability in the actual nest sites as opposed to its surrounds would suggest these characteristics are good descriptors of the nest sites chosen by Fairy Terns. For the ordination and the logistic regression the percentages of shell cover were split into two categories: percent of white shell, and percent of orange and white shell.

### 4.3 Results

Eighteen nests were measured out of a total 23 nests over the two seasons. Environmental characteristics of the surrounding available habitat were collected only in the 1998/1999 season from 10 of the nests. At Papakanui the successful nest of Y-M and UBB in the 1997/1998 season, and the nest they abandoned early in the 1998/1999 season, were not included because of the difficulty in accessing the site. In both seasons the second attempts at nesting by WpG-M and UBB were abandoned early and could not be relocated. At Mangawhai, the majority of nests were measured with the exception of the first attempt by G-M and UBB in the 1998/1999 season which was lost during a storm and could not be relocated. All nest sites at Waipu were successfully measured in the 1997/1998 and 1998/1999 seasons. Table 4.2 shows the pairs and their associated nests in which environmental characteristics were measured. The majority of nests that failed were abandoned because of bad weather during the egg stage.

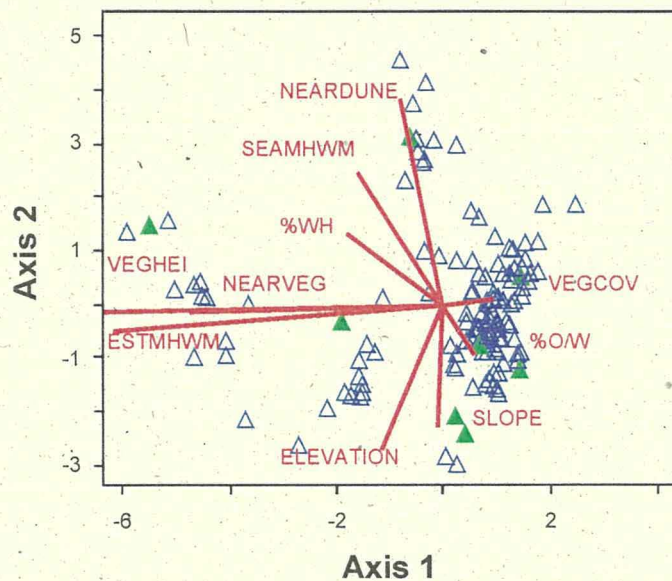
For breeding site and success or failure comparisons of a nest to produce fledged chicks all measurements for nests in the 1997/1998 and 1998/1999 seasons were included. Aspect

was excluded because the bearings differed simply from Papakanui being on the west coast, and Mangawhai and Waipu on the east coast. The nests were different between the east and west coasts ( $P < 0.001$ ) with Mangawhai ( $P < 0.016$ ) and Waipu ( $P < 0.019$ ) being significantly different from Papakanui. There was also a difference found between the two east coast sites ( $P < 0.017$ ). Relating nest site characteristics to their eventual success or failure found no difference between these outcomes between the three breeding sites ( $P < 0.846$ ) or between coasts ( $P < 0.577$ ).

**Table 4.2.** Shows each breeding site, nest code, the female and male of the pair associated with each nest, the nest attempt and the outcome of each nest with S=success and F=failure. \*The nests in the first season were designated with only letter codes as they were not included in the ordination or logistic regression analysis to compare nest and available habitat.

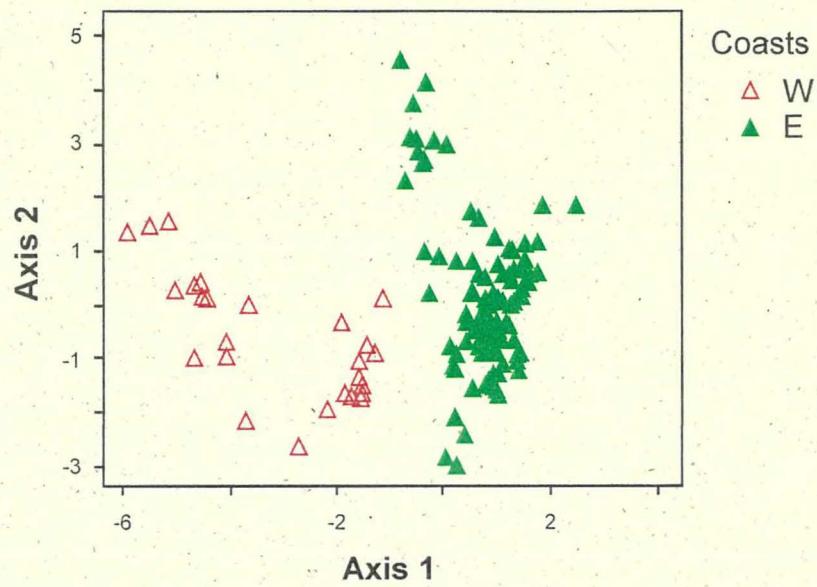
SEASON	LOCATION	NEST CODE	FEMALE	MALE	ATTEMPT	OUTCOME
1	Papakanui	A*	WpG-M	UBB	1	F
		B*	WpG-M	UBB	2	S
2		P1	WpG-M	UBB	1	F
		P2	WpG-M	UBB	3	F
1	Waipu	C*	M-W	pGY-M	1	F
		D*	UBB	WB-M	1	S
2		W1	M-W	pGY-M	1	F
		W2	UBB	WB-M	1	F
		W3	UBB	WB-M	2	S
1	Mangawhai	E*	UBB	UBB	1	S
		F*	G-M	B-M	1	S
		G*	M-R	UBB	1	F
		H*	M-R	UBB	2	F
2		M1	UBB	R-M	1	F
		M2	UBB	R-M	2	F
		M3	M-R	UBB	1	F
		M4	M-R	UBB	2	S
		M5	G-M	UBB	2	S

The ordination performed better than chance using the raw data, therefore the log-transformed data was not used. Axis one explained most of the variance ( $r^2=0.82$  or 82%), therefore scatter plots for only axes one and two are shown (Figure 4.2.1-4.2.6). These used the categorical groups for nest sites in relation to the available habitat (Figure 4.2.1), the coast on which each nest is located (Figure 4.2.2), and each nest with its associated available habitat (Figure 4.2.3). Labels for each symbol are excluded from the plot so that the chosen nest sites can be seen.

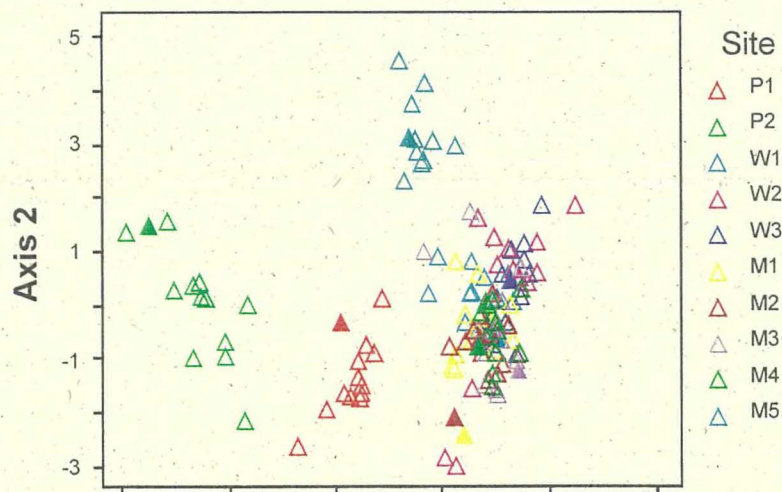


**Figure 4.2.1.** A scatter plot of the chosen nests (full green triangles) and the available habitat (open blue triangles) with vectors of the environmental characteristics showing how they are correlated with each other. NEARDUNE=distance to nearest dune, SEAMHWM=distance to sea MHW, %WH=percentage of white shell cover, VEGHEI=vegetation height, NEARVEG=distance to nearest vegetation, ESTMHWM=estuary MHW, %O/W=percentage of orange/white shell cover, VEGCOV=vegetation cover.





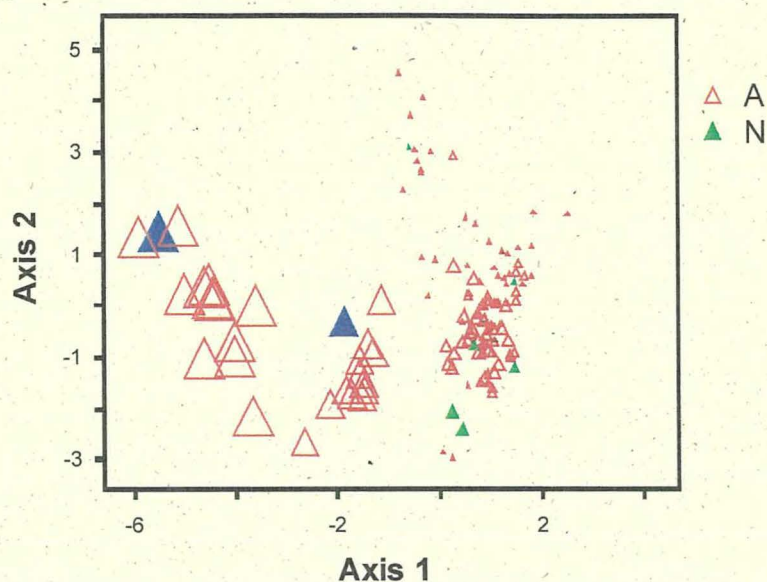
**Figure 4.2.2.** A scatter plot illustrating the ordination of the east coast nest sites (E) as compared to those on the west coast (W).



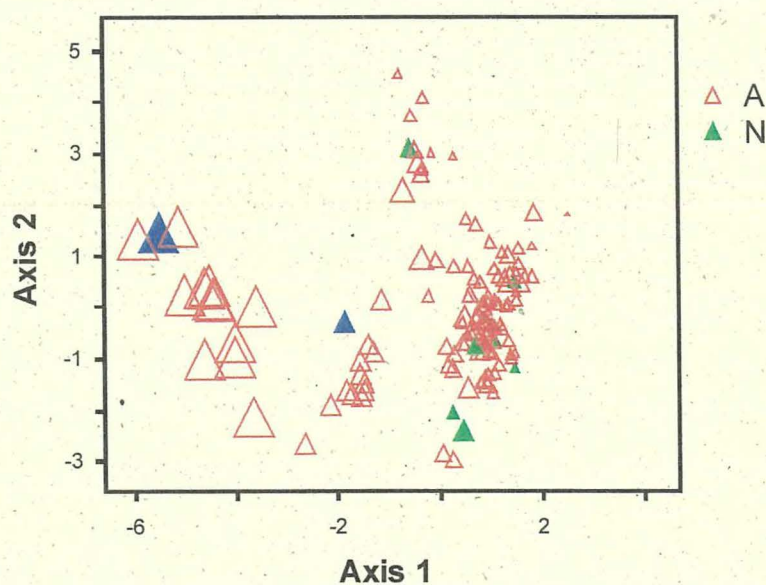
No clear distinction between the chosen nest sites and the available habitat could be found on a 'gross' level (Figures 4.2.1 and 4.2.3), with the available habitat similar to that of the associated nest (Figure 4.2.3). Comparison between nests and available habitat was non-significant ( $P < 0.986$ ). This suggests that on a gross level, there were no environmental characteristics measured that could distinguish between the birds' choice and what was available to them. The nests at Papakanui and R-M nests (M1, M2), however, were set away from their surrounding (Figure 4.2.3). This was unexpected considering that the available habitat was measured in close proximity to the nest, and therefore it might have been expected that characteristics of the area would be similar. Generally, the Papakanui nests had high shell cover relative to the surrounding habitat, while the Mangawhai nests were on raised, sloping ground and M1 was relatively close to a dune.

The split between the Papakanui nest sites and their available habitat from the east coast sites (Figure 4.2.2), was highly significant ( $P < 0.000$ ). These differences were characterised by high correlations on axis one between estuary MHW, nearest vegetation and vegetation height, as shown by the large length of the vectors for these characteristics (Figure 4.2.1). Scatter plots illustrate these differences in elevation (Figure 4.2.4), nearest vegetation (Figure 4.2.5), and vegetation height (Figure 4.2.6). The size of the triangle denotes the strength of the correlation of characteristics in influencing the west and east coast split in the ordination. For example, with elevation (Figure 4.2.4) the large triangles show that most west coast nest and habitat points had high elevation while the east coast sites had low elevation (denoted by the small triangles). Papakanui sites were generally further from the estuary and the nearest vegetation, and had higher vegetation, than the sites on the east coast. The east coast sites were similar in these characteristics. On axis two, the nest on the bund at Mangawhai (M5) split from the other east coast sites (Figure 4.2.3). The bund site is far from the sea and nearest dune, at a low elevation and with high white shell cover. Plots for the other environmental characteristics are shown in Appendix 4.1 (see page 111). These plots show that most characteristics were similar within sites and therefore they may offer little choice to the birds, while a few were more variable. The sites at Papakanui were more distant from the sea and estuary, with very little vegetation cover or shell cover, and high elevation. Generally the east coast had high variation in

vegetation cover, , and percent of orange/white shell cover and therefore the Fairy Terns nesting here would have more choice. while other variables were relatively similar.

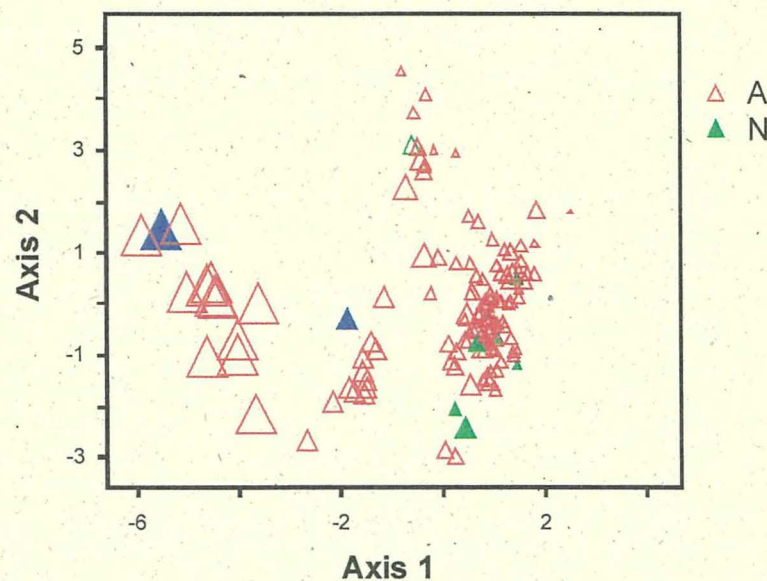


**Figure 4.2.4.** A scatter plot showing the strong influence which elevation had on the ordination to split the two coasts on axis one (nest=N, full green triangles; available=A, open red triangles). The Papakanui chosen nests are blue to distinguish them from the east coast nests.



**Figure 4.2.5.** A scatter plot showing the influence that distance to nearest vegetation had on the ordination to split the two coasts on axis one (nest=N, full green triangles; available=A, open red triangles). The Papakanui chosen nests are blue to distinguish them from the east coast nests.





**Figure 4.2.6.** A scatter plot showing the influence that vegetation height had on the ordination to split the two coasts on axis one (nest=N, green full triangles; available=A, red open triangles). The Papakanui chosen nests are blue to distinguish them from the east coast nests.

On a finer scale, chosen nest sites were highly elevated, lacked vegetation cover, and had a high percentage of white shell or orange and white shell compared to the surrounding habitat. Table 4.3 shows the results of the logistic regression carried out on the environmental characteristics. These characteristics were related to their probability of a site being chosen as a nest site to establish the goodness of fit of the model. Of the ten nests six had higher probabilities than most, or all, of their surrounding habitat. This suggests that these characteristics are a reasonable predictor of sites chosen for nests by Fairy Terns, in relation to what is available in the surrounding habitat.

**Table 4.3.** The results from the logistic regression model showing which environmental characteristics were important in the choice of nest sites by the New Zealand Fairy Tern. The significant characteristics are shown with an asterisk. MHW= mean high water mark.

ENVIRONMENTAL CHARACTERISTICS	DEVIANCE	F	PR>F	CHISQUARE	PR>CHI
Elevation	62.38	6.8104	0.0102	6.8104	0.0091*
Vegetation Cover	60.42	4.6175	0.0337	4.6175	0.0316*
Percent of white shell cover	57.62	6.5799	0.0116	6.5799	0.0103*
Percent of orange/white shell cover	52.29	12.518	0.0006	12.518	0.0004*
Distance to nearest dune	52.28	0.0170	0.8965	0.0170	0.8963
Distance to nearest vegetation	51.53	1.7670	0.1863	1.7670	0.1837
Distance to sea MHW	50.69	1.9686	0.1632	1.9686	0.1606
Distance to estuary MHW	50.65	0.0819	0.7752	0.0819	0.7747
Slope	50.65	0.0083	0.9277	0.0083	0.9276
Vegetation height	50.23	0.9934	0.3210	0.9934	0.3189

#### 4.4 Discussion

It was the aim of this study to build on the general description of nest sites of New Zealand Fairy Terns given by Parrish and Pulham (1995), and to see if choice of nest site could influence management decisions about the areas in which the birds breed. The Fairy Tern population is relatively endangered however, the terns tend to return to a similar locality within the breeding areas. Terns in the larger Australian populations also return to the same general breeding area, though not to the same fixed sites (Higgins and Davies 1996). An understanding of habitat selection rather than habitat use is important in the management of any species (Burger 1987). The necessity for habitat protection (from stabilisation or development) or improvement, reducing human disturbance, and having areas suitable for reintroductions of captive bred birds is always important, particularly in areas of high use



such as beaches (Kotliar and Burger 1986, Cumming 1991, Flemming *et al* 1992, Wilson 1996, Watson *et al* 1997). Understanding the breeding biology of endangered seabirds is also critical in developing sound recovery plans aimed at their survival and population increase (Kotliar and Burger 1986, Burger 1987, Gaines and Ryan 1988). An understanding of nest-site selection in Fairy Terns, therefore, is critical to appreciating their biology and future management.

There were no characteristics typical of successful or failed nests, however, there were differences between the breeding sites. There was greater variation in characteristics such as vegetation and shell cover on the east coast. It is likely that Fairy Terns on the east coast have a greater choice of nest site characteristics on the east coast, but are more restricted at Papakanui. Whether this influences the low reproductive rate at Papakanui is unclear, because there was no habitat difference between successful and unsuccessful nests. However, in relation to the characteristics measured, Fairy Terns have a wider choice in nest sites on the east coast, and this may be related to the higher reproductive success on this coast.

Nest sites chosen by the birds were found to be no different from the surrounding available habitat on a gross level, by the ordination and MRPP analysis. However, the Papakanui nests and R-M nests (M1,M2) were extreme in comparison to their surrounding habitat (Figure 4.2.3). Papakanui has few shell areas, which were often small in area. Hence most available habitat had zero shell cover, and therefore the Fairy Terns in this instance appeared to prefer a higher percentage of shell cover. The nests of R-M were on the raised area of Mangawhai Island close to the sea and had high values for elevation and slope. As most habitat points were just above the sea MHWL, they had no shell cover and therefore would have affected the correlation, setting the nest away from its respective available habitat, particularly since it is unlikely that Fairy Terns would have nested there.

Interestingly, the logistic regression also gave these nests a high probability in comparison to their associated available habitat compared to the other nests, with shell cover a significant predictor characteristic in what Fairy Terns prefer for nest sites. Papakanui is characterised by lack of vegetation and shifting sand dunes that prevent vegetation from

taking hold. Fairy Terns at Papakanui also nest far along the beach and thus were a great distance from the estuary (between 1000-1500 m in some cases). These conditions are obviously site dependent. The east coast nests were on their respective spits, therefore the distance to the estuary was small and more vegetation was available compared to Papakanui.

The split of the nest on the 'bund' at Mangawhai from its associated available habitat is interesting. A man-made structure - the bund is relatively close to the estuary and far from the sea. It also supports plenty of shell cover because this was used to stabilise the sand, and, since the bund is relatively new, little vegetation has yet established. The reason why a pair of the Fairy Terns chose to nest here in 1998/1999 is unclear. No other pair has done so since the bund was completed in 1996. It may have appeared inviting to the terns because the birds would be highly camouflaged and some vegetation would provide shelter for chicks. Since the pair's original nest was washed out, the terns possibly chose a more sheltered and higher site, not so easily flooded.

Logistic regression analysis was able to identify fine differences between nests and the surrounding habitat, in that the Fairy Terns preferred nest sites with higher elevation, less vegetation cover and a high percentage of shell cover. These features characterise the preferences of a number of tern species (Burger 1987). Radar diagrams (see Appendix 4.2, page 115) illustrate these characteristics in relation to the ten individual nests. Minimum, and maximum values for the surrounding habitat and nests were standardised to set the mean at zero with a standard deviation at one. Generally, elevation and shell cover in nest sites chosen by Fairy Terns were close to, or greater than, the maximum available in the surrounding habitat, an extremely high value for shell cover was seen in WpG-M and UBB first attempt (1WpG). Vegetation cover was less distinct (though still significant) with most of the nests close to the minimum value or mean obtained from the available habitat. This is most likely due to the general lack of vegetation around the nests. Some of the available habitat points would have had high vegetation, and therefore would give a disproportionately high maximum. Although slope was quite high in the nests of R-M and

M-R (Appendix 4.2), over all, most nests were situated on flat areas, and therefore slope was insignificant.

The results gained in this study compare well with general observations of nesting areas of Fairy Terns in Australia and New Zealand. Australian Fairy Terns nest amongst shell, shingle or gravel covered areas (Higgins and Davies 1996) as well as sandy patches on rock flats or on mud (Higgins and Davies 1996). The closely related Little Tern also prefers to nest in areas with 15-60 percent shell cover (Wilson 1996). Parrish and Pulham (1995) mentioned the lack of vegetation surrounding nests in New Zealand Fairy Terns and, although this is not mentioned for Fairy Terns in Australia, Wilson (1996) found Little Terns also preferred sparsely vegetated areas. The New Zealand Fairy Tern has been described as preferring to nest in low-lying areas, which only suggests that they do not generally nest on high dunes (Parrish and Pulham 1995). There is no information on whether Fairy Terns in Australia prefer highly elevated sites, however, Wilson (1996) mentioned that Little Terns preferred highly elevated nest sites only when there was a lack of vegetation.

A nest site raised well above sea level provides a buffer zone against high spring tides, or high tides raised by storms, and reduces the risk of flooding (Burger 1984, Burger 1987, Burger and Gochfeld 1990). Burger and Gochfeld (1990) also suggest birds choosing to nest by dunes far from the ocean could have a higher breeding success, as floods affecting low areas might occur every year, whereas the risk of predation (from predators hiding among dunes) occurs only in some years (Burger and Gochfeld 1990). Fairy Terns are also under risk of flooding and predation and therefore appear to prefer nesting on elevated sites. However, they were not found to prefer nesting near dunes. Fairy Terns like other seabirds would have adapted to the weather not predators due to the relatively recent release in New Zealand. Elevated nest sites are also important in Laughing Gulls (Bongiorno 1970), Common Terns (Burger and Lesser 1978, Storey 1987) American Oystercatchers (Lauro and Burger 1989) and Least Terns (Burger and Gochfeld 1990). Distance from the high tide mark is probably associated with elevated nest sites because beaches tend to rise with increasing distance from the sea. Although not statistically

significant in Fairy Terns, this association has been found in Piping Plover (Burger 1987, Gaines and Ryan 1988), Least Terns (Burger and Gochfeld 1990) and Damara Terns (Watson *et al* 1997). Choice of a nest site away from the sea may also be linked with reduced disturbance from people walking along the beach.

General lack of vegetation is commonly associated with beach habitats where birds nest (Page *et al* 1985, Jehl and Mahoney 1987, Gaines and Ryan 1988, Lauro and Burger 1989, Cumming 1991), including terns such as Least Terns (Kotliar and Burger 1986), Common Terns (Burger and Gochfeld (1988a, 1990) and Little Terns (Goutner 1990, Wilson 1996). Fairy Terns, like other beach nesting birds may use this to their advantage by nesting in open habitat for better detection of predators (Blokpoel *et al* 1978, Burger and Gochfeld 1990, Cumming 1991, Lazarus and Symonds 1992, Wilson 1996). Since vegetation can be important in providing young with shelter from weather and aerial predators (Blokpoel *et al* 1978, Burger and Gochfeld 1985, Burger 1987, Burger and Gochfeld (1988a 1988b), Saliva and Burger 1989), there is perhaps a threshold in the amount of vegetation birds will prefer. In terns, choice of nest sites in open areas or under vegetation varies within a genus and even within a species. In two separate studies in Puerto Rico, Roseate and Sooty Terns nested under vegetation in some areas while preferring open habitat in others (Burger and Gochfeld 1988b, Saliva and Burger 1989). Choice of nest site may, therefore, be dependent on what selection pressures individuals or groups have experienced in the past in a local area, as to where they nest. For Fairy Terns, the weather appears to have a predominant affect, then predation, however, the Waipu pair nesting in a blow-out clear of vegetation (W3: Figure 4.2.3) may suggest that vegetation is still important in Fairy Terns choice of nest site and not just a characteristic of beach habitats.

For seabird and shorebirds, nesting in shell patches or gravel is common (Burger 1987, Gaines and Ryan 1988, Lauro and Burger 1989, Flemming *et al* 1992), particularly in terns, for instance Arctic Terns (Lemmetyinen *et al* 1974), Least Terns (Kotliar and Burger 1986), Little Terns (Wilson 1996), and Damara Terns (Watson *et al* 1997). Burger (1987) and Gaines and Ryan (1988) suggest a shell substrate provides shelter for adults and young from the wind and a camouflaged background for adults, their eggs and cryptically coloured young against aerial predators (Richards and Morris 1984, Kotliar and Burger

1986, Burger 1987, Gaines and Ryan 1988). Fairy Terns prefer to nest in shell-covered areas with little or no vegetation, which suggests that parent birds must rely on their plumage for concealment from aerial predators. Moreover, the cryptic colours of their chicks is well suited to an orange, black and white substrate, and may have evolved some time ago. Whether the relatively greater reproductive success on the east coast is related to a higher frequency of orange and white shell substrate (Appendix 4.1e) compared to the west coast is unclear. However, good shell cover may improve the chances of breeding success by reducing the exposure of chicks to aerial predators.

Beach habitats can change dramatically over a relatively short time so a site may be suitable one year, but not the next (Burger 1982, Wiens 1985, Carter 1988, Lauro and Burger 1989, Cumming 1991, Rodway and Regehr 1999). These changes are likely to influence the choice birds make (Wiens 1985), particularly because features such as shell cover, survival and spread of vegetation, and the elevation of areas with water or wind movement of sand (Cumming 1991, Wilson 1996) are readily affected. For instance, Fairy Terns at Waipu once nested on the estuary side of the spit where there were flat, shell covered patches (G. Pulham pers. comm.). These areas are now covered with *Salicornia* and other vegetation Fairy Terns may have responded to this encroachment of vegetation. Fairy Terns now nest on seaward shell patches with little vegetation. The response of birds to any change depends on the significance of each habitat variable in habitat selection (Wiens 1985), though at best this can only be inferred by human observers. Birds may abandon nest sites that have been unsuccessful over successive years (Birkhead 1977, Burger 1982) or change their 'traditional' nesting habitat in response to a selection pressure such as predation (Burger and Gochfeld 1988b, Saliva and Burger 1989). Plainly, it is an advantage for a species to maintain flexibility in its choice of nest site, thereby minimising conflicts with changeable selective pressures and increasing reproductive success (Lauro and Burger 1989, Rodway and Regehr 1999).

How birds interact with features of the habitat can be seen by their behaviour and nesting success. Ultimately however, the question of whether the habitat features measured are really what the birds use when selecting a nest site must be approached with caution. The



importance of using gross and fine levels of environmental characteristics (as in this study) is potentially a more suitable method for qualifying nest-site selection (Warnock and Takekawa 1995, Watson *et al* 1997). If variables on only one level are used, some of the choices made by the bird may not be recognised. Pribil and Picman (1997) demonstrated the importance of using multiple levels of measures when examining nest-site preferences of female Red-Winged Blackbirds. On a gross level only, the importance of one variable, cattail density, would not have been recognised as important to the blackbirds. Past experience, and imprinting on natal habitats could also be involved in nest-site selection (Cody 1985), but are not readily amenable to rigorous analysis. For endangered species like Fairy Terns, reliable historic and reproductive data have been available only recently. More of these data are required in order to consider questions such as the importance of natality in the choice of nest sites.

This study shows that Fairy Terns prefer nest sites with certain environmental characteristics among which high elevation, low vegetation cover and abundant shell cover appear to be significant. This has important implications for the management of the species. For instance, increasing human use of the beaches where Fairy Terns nest means protecting potential breeding areas from future development or stabilisation or if artificial nest areas need to be created in the future, as with Little Terns in Australia (Wilson 1996). The areas may also need active management to prevent encroachment of vegetation, loss of shell cover, or loss of the beachfronts themselves by natural coastal processes.

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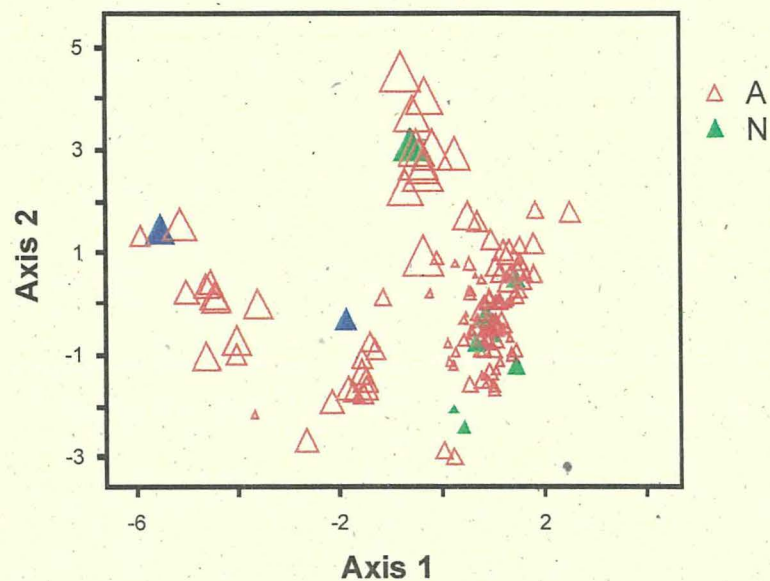


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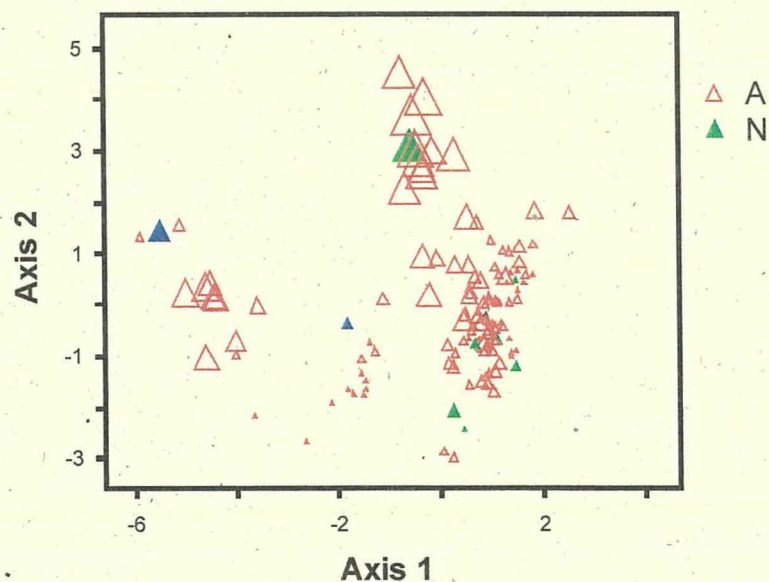
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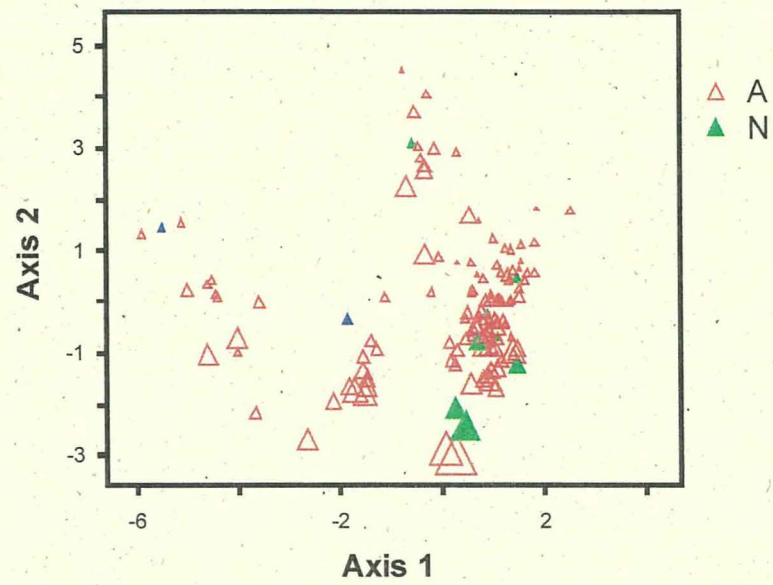
**Appendix 4.1.** The scatter plots showing how the environmental characteristics influenced the split of the west and east coast in the ordination. The Papakanui nests are the full blue triangles, to distinguish them from the east coast nests. Both Papakanui nest symbols were enlarged in the plots of vegetation cover and percentage orange/white shell cover to distinguish them from their surrounding habitat. Only one of the Papakanui nests (right) was enlarged in the plots for distance to nearest vegetation and percentage of white shell cover. A=available habitat; N=Nest.



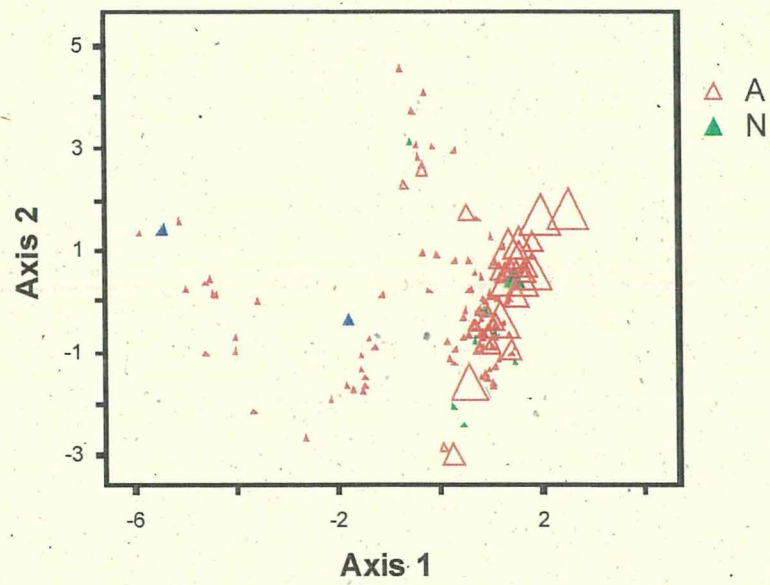
(a) Sea mean high water mark



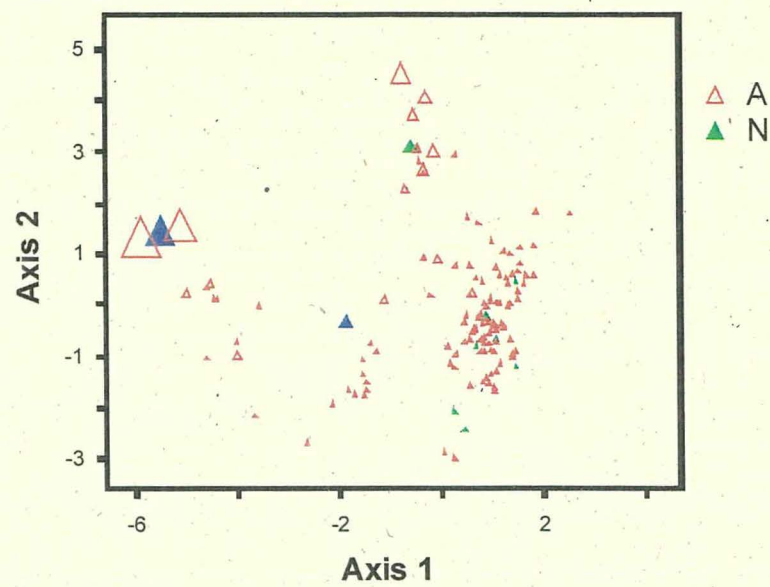
(b) Distance to nearest dune



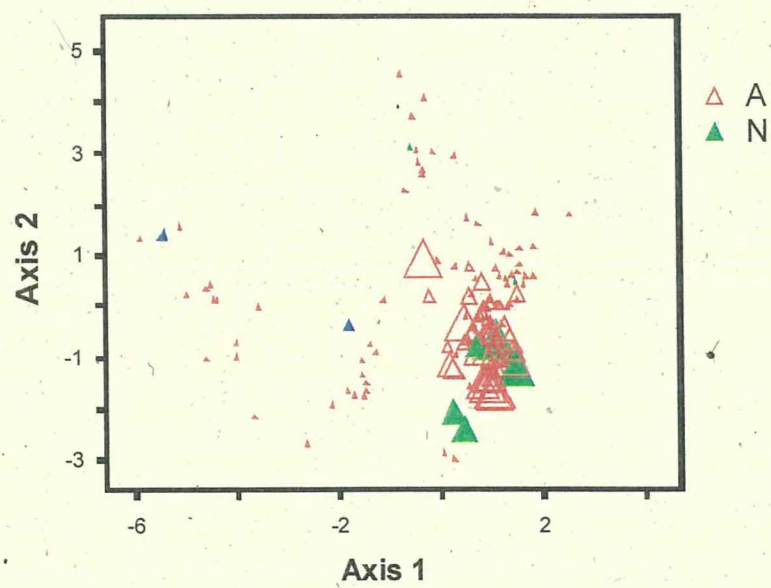
(c) Slope



(d) Vegetation cover

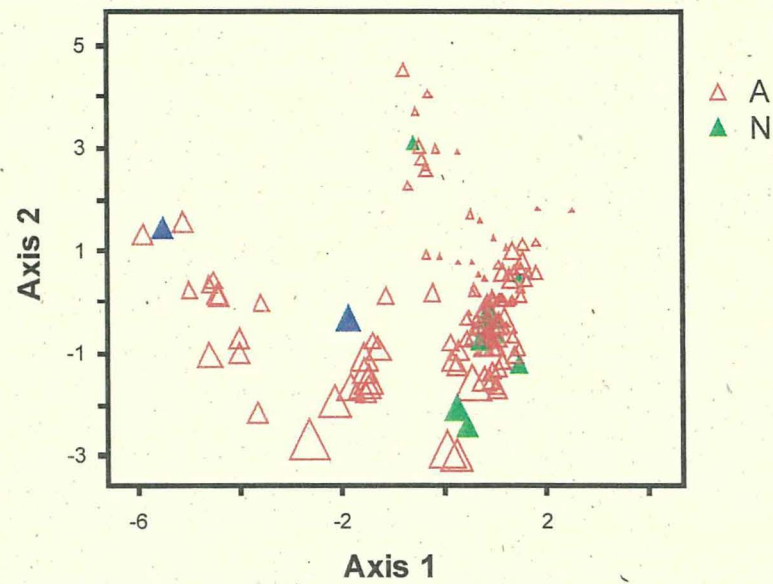


(e) Percentage of white shell cover



(f) Percentage of orange/white shell cover

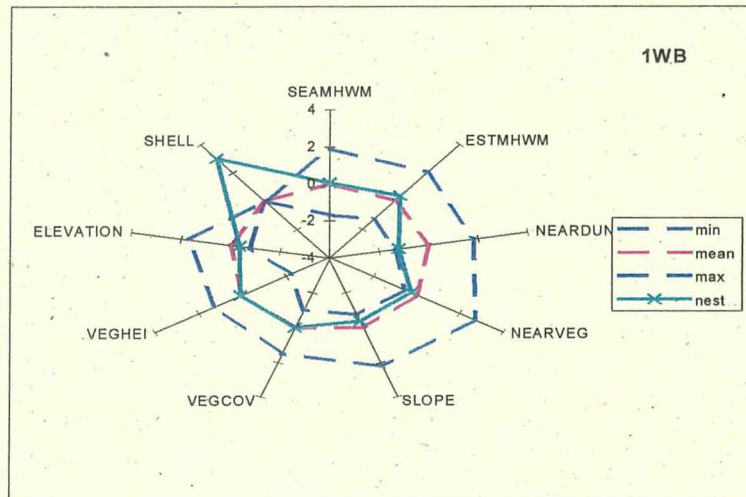
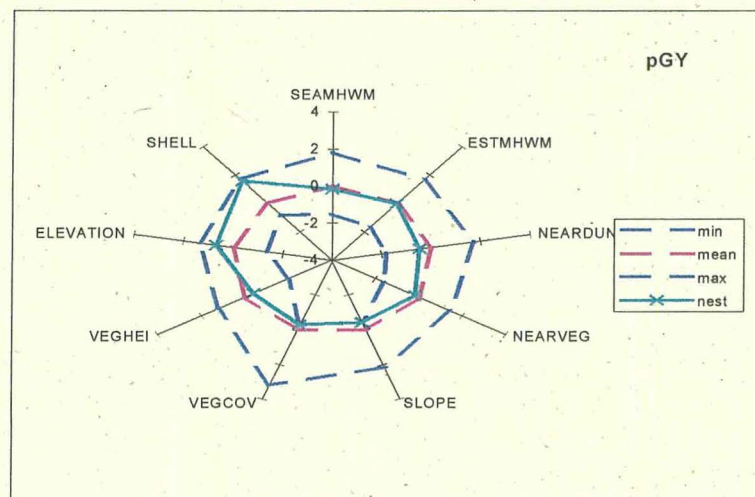
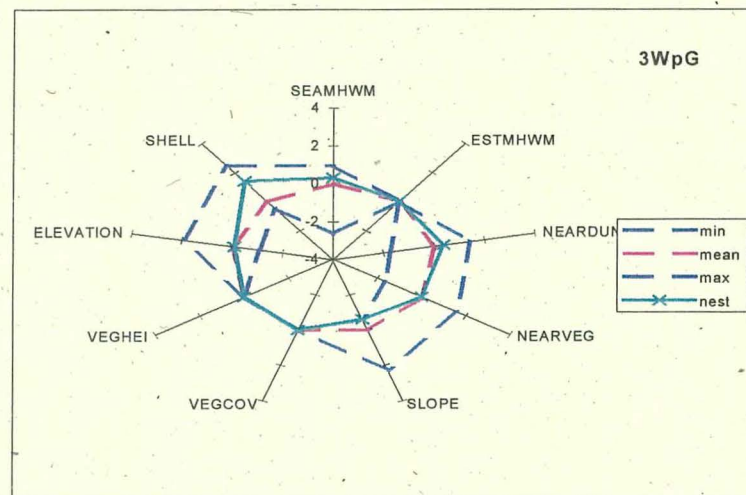
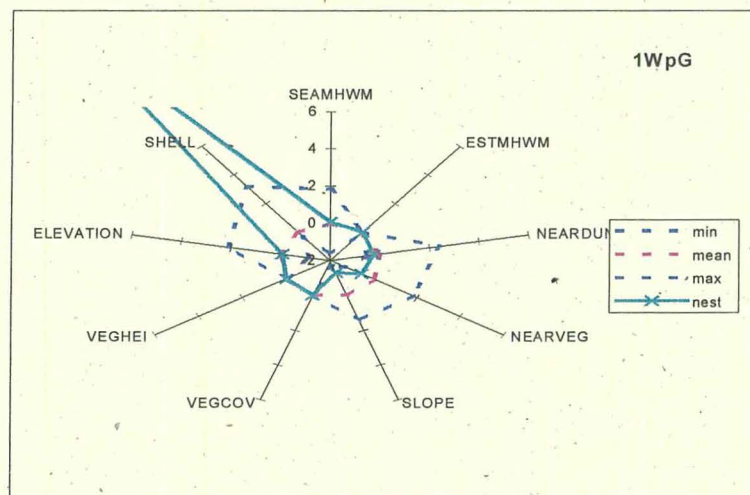


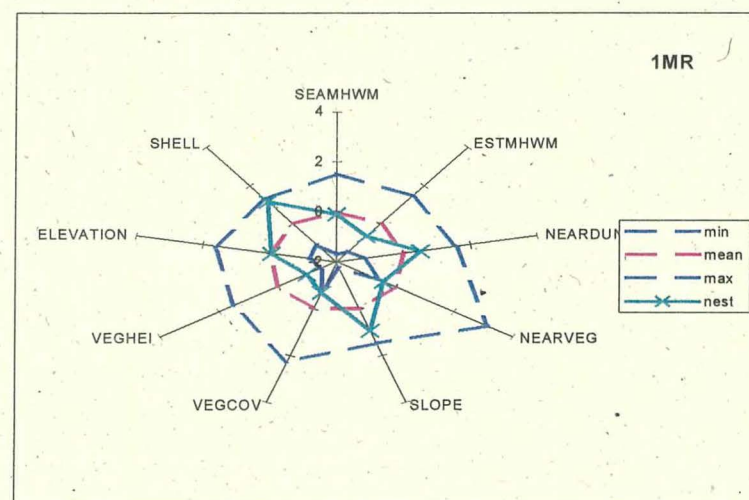
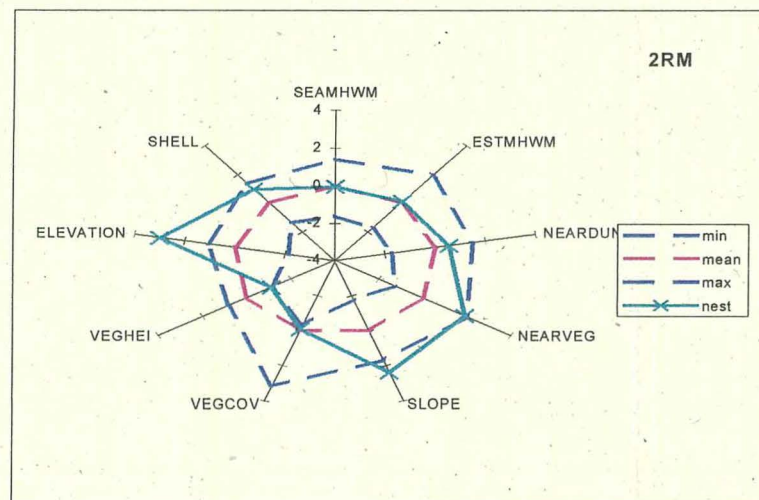
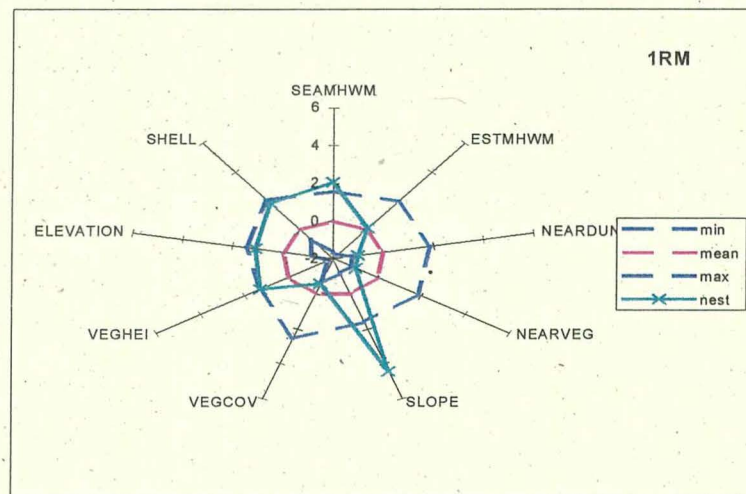
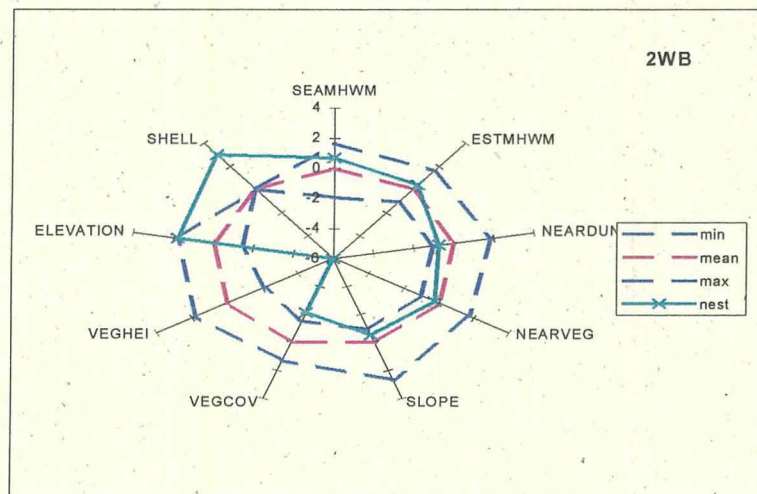


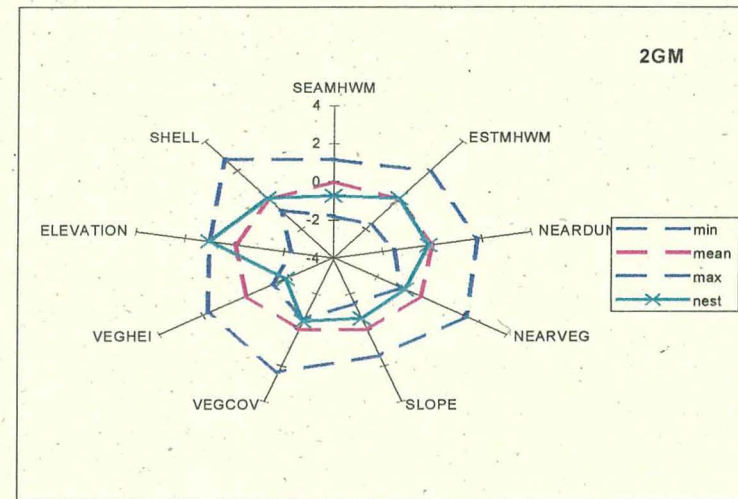
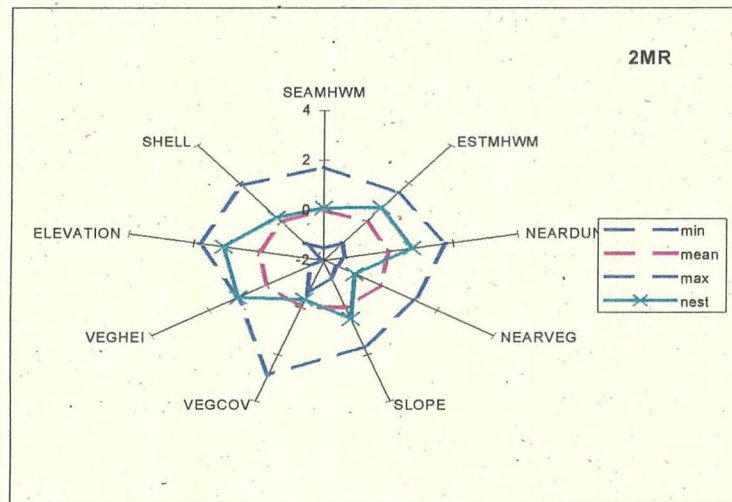
(g) Elevation



**Appendix 4.2.** Standardised nest values, and the means, minimum and maximum values for the surroundings available habitat of the environmental characteristics to establish nest-selection selection in the New Zealand Fairy Tern.

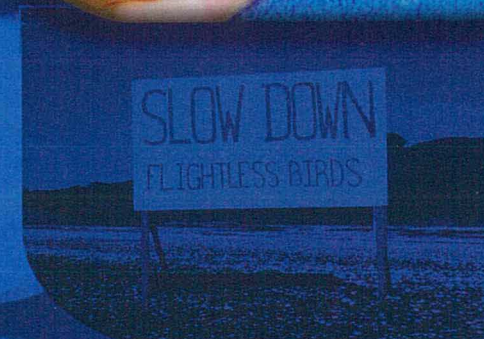








# DNA Sexing





## Chapter 5. Determining the Sex of New Zealand Fairy Terns: implications for behavioural ecology and management

### 5.1 Introduction

Ecological studies of any species depend on the knowledge of its life history. Important parameters such as reproductive success, mortality, and the sex composition of the population can be central to conservation efforts. Sex composition is one of the most significant parameters as it can directly affect population dynamics, behaviour, and ecology. However, this parameter is often difficult to determine in birds where over 50 percent of the world's species, (including many of the seabird species) are sexually monomorphic (Griffiths *et al* 1998).

In the past, sexing of individuals has relied on sexual differences in morphology such as plumage, size, or weight. The adults of some species are sufficiently dimorphic to reliably be assigned to one sex, for instance Pied, Variable and Chatham Oystercatchers (Baker 1974), and the New Zealand Dotterel (J. Dowding pers. comm.). However, external morphology between male and female are often small or indistinct (Millar *et al* 1992, Lessells and Mateman 1998). Thus, the use of weight in the South Polar Skua (Millar *et al* 1992), and plumage and size in the Pukeko (Millar *et al* 1996) showed that assignment of sex based on these morphological characters was no different than by chance (Millar *et al* 1996). In most avian species chicks cannot be sexed using morphometrics or behavioural observations (Lambert and Millar 1995, Millar *et al* 1996, Millar *et al* 1997). Other methods of sexing, such as surgical examination, are expensive and invasive (Griffiths 1992, Longmire *et al* 1993), while karyotype analyses are laborious and unreliable due to the lack of distinguishable sex chromosomes (Longmire *et al* 1993). Empirical studies have found that blood withdrawal causes no significant stress by changes in body weight or mortality with specific reference to chicks and small birds (Utter *et al* 1971, Stangel 1986, Ardern *et al* 1994). As birds are handled only briefly in field situations, stress associated with this is minimised.



With the use of molecular genetics, previously obscure aspects of species' life history such as paternity, genetic variation between populations and the sex of individuals has been brought into the management of endangered species. The use of genetics for sexing birds came about with the discovery of two copies of the CHD (chromo-helicase-DNA-binding) gene each located on a different sex chromosome in birds, with the exception of the ratites (Ellegren 1996, Griffiths *et al* 1996, Griffiths *et al* 1998). Across all mammalian species, the sex-specific region on the Y chromosome was found to be heterogametic (XY) in males (Griffiths and Tiwari 1993). In birds, however, this sexual dimorphism in chromosomes has been identified in the female as the heterogametic sex, ZW, while the male is ZZ (Rabenold *et al* 1991, Ellegren 1996, Millar *et al* 1996, Millar *et al* 1997). O'Neill *et al* (2000) identified a avian sex-specific W-linked (ASW) gene in 17 bird species which is exclusively W-linked, and therefore only expressed in females, which maybe more reliable for future bird studies. This ASW gene has also been found in ratites (Huynen and Lambert unpublished data) where the CHD gene could not be identified.

The Polymerase Chain Reaction (PCR) has enabled a single set of PCR primers to be used to identify sex, and amplify the homologous part of the W as well as the related Z genes of birds. Because these fragments are of the similar size, a restriction enzyme is needed to cut the fragments before gel electrophoresis to visualise both. As a result, the heterogametic females have two bands and the homogametic male only one (Berube and Palsbøll 1996, Millar *et al* 1996, Bradbury and Griffiths 1997, Millar *et al* 1997, Griffiths *et al* 1998). The use of these genetic markers has been successful in determining sex in a number of birds including Snow Geese (Quinn *et al* 1989), Stripe-backed Wrens (Rabehold *et al* 1991), Great Tits (Griffiths *et al* 1996), Pukeko (Millar *et al* 1996), Great Reed Warblers (Westerdahl *et al* 1997), and the Kakapo (Robertson *et al* 1999).

Few studies have used these techniques to assign sex in seabirds. Species examined include Shags (Graves *et al* 1993), Short-tailed Shearwaters (Austin and Parkin 1995), South Polar Skuas (Millar *et al* 1992, Millar *et al* 1997), Lesser Black-backed Gulls (Griffiths *et al* 1998), and Oystercatchers (Treuren *et al* 1999, Lessells and Mateman 1998). The only known published study on assigning sex in any *Sterna* species is by Sabo *et al*

(1994) on Roseate and Common Terns. They used random-amplified polymorphic DNA (RAPD) markers to identify 21 Common Terns of known sex and 52 Roseate Terns of unknown sex. The Roseate Tern banding patterns were identical to those in the Common Terns therefore correctly identifying their sexes. The only genetic work carried out on Fairy Terns investigated genetic variation between the New Zealand and Australian Fairy Terns (Chambers and Coddington 1998) with no definite variation being found.

To date, the sexes of Fairy Terns have been determined from the courtship and copulation behaviour of banded individuals. However, because same-sex pairs may occur, this method might not always be reliable (Parrish and Honnor 1997). Female-female pairs have been recorded in Lesser Snow Goose (Quinn *et al* 1989), Western Gulls (Hunt and Hunt 1977), California Gulls (Conover *et al* 1979), and Caspian Terns (Conover 1983). As the numbers of Fairy Terns are so low, it is important to establish the sex of adults and chicks to better manage productivity in the wild population, and carry out a captive breeding programme. In this study PCR techniques are used to find sex-specific restriction fragments in Fairy Terns using the PCR primers P2, P3 and P8. These findings will be used to look at the sex ratio of adults and chicks in the population.

## **5.2 Methods**

### **5.2.1 *Tissue Collection***

Blood samples and feathers were obtained from juvenile and adult Fairy Terns in 1998 and 1999. Birds were sampled from four locations: Mangawhai, Waipu and Papakanui Spit (breeding grounds) and Te Arai canal (at the southern end of Mangawhai beach). Chicks were run down and caught by hand a few days before they were able to fly (between 18-21 days old). Adults were caught using noose mat nets. These nets comprise a long, narrow mat of plastic chicken wire with a set of nylon monofilament nooses attached at various points. The nets were buried in the sand and the birds were herded over the nets so that their legs became caught in the nylon nooses. Individuals were weighed, and

morphological measurements included the bill, bill and head, tarsus, and wing length, as well as a moult score. Blood samples were taken from the cutaneous ulnar vein of the right wing using a heparinized 27-gauge-needle, or by pricking the vein and collecting blood using heparinized capillary tubes. The amount of blood taken from the chicks and adults was approximately 0.15 and 0.35-0.4 ml respectively, the recommended volume (1% of the body weight) considered safe to sample in birds (Ardern *et al* 1994). The samples were placed in liquid nitrogen until transported to a laboratory and stored at -80°C. Feathers were collected from two chicks, one of which had been losing weight due to the loss of a parent. Predation of a second chick left behind some feathers which were collected. Feathers were also collected from an adult found dead ten days after it disappeared from the nest site.

#### 5.2.2 DNA Extraction, Precipitation and PCR techniques

##### Whole Blood

Genomic DNA was extracted from whole blood by first resuspending 5 µl blood in 400µl of SET Buffer (0.1 M Tris -HCl pH 8.0, 0.1 M NaCl, 1.0 mM EDTA) to which 20µl of sodium dodecyl sulphate (SDS) and 20 µl proteinase K were added at a concentration of 10% and 20 mg/ml respectively.

After an overnight incubation at 56°C, high molecular weight DNA was extracted by using 400µl each of phenol, phenol-chloroform-isoamyl and chloroform-isoamyl. These were added separately to the samples, which were rocked for 15 minutes and then centrifuged for 5 minutes at 13000 rpm. The bottom layer (extraction mixture) was removed after centrifuging and a second phenol mix was added to the sample. The process was repeated and the third mix was added. For precipitation of the DNA, 40µl of 3M NaOAc pH 5.2 and 1 ml 100% of cold ethanol was added, shaken to help precipitation and then rocked for 15 minutes. After centrifuging for 30 minutes at 13000 rpm, the ethanol was removed and 1 ml of 70% cold ethanol was added (to remove salts and other soluble material), centrifuged for 5 minutes and the ethanol removed. The samples were covered and left to dry overnight. The DNA was diluted in 50 µl milli-Q-water and left to resuspend at room

temperature. For those samples that were 'globy' (contained a large amount of DNA), an extra 50 µl of milli-Q-water was added and left to resuspend.

An extraction gel was used to visualise the efficiency of the extraction. A concentration of 1% agarose in 1 x TBE buffer was used with 2 µl of ethidium bromide (EtBr) added to stain the DNA. Approximately 2 µl of each DNA sample was added to a loading dye (bromophenol blue, ficoll and TBE buffer) and placed in a well. A sample of 5 µl of a  $\lambda$ HindIII molecular weight marker was placed in the first well. Electrophoresis was run at 100 volts for 25 minutes and viewed under ultraviolet light. All samples contained enough genomic DNA to continue.

A Polymerase Chain Reaction (PCR) technique was used to amplify DNA segments using the P2 and P8 primers. A PCR mixture of 2.5µl of 10x buffer, 1.5µl of 25 mM MgCl<sub>2</sub>, 0.2µl of 10 mM dNTPs, 2.0µl of P2 and of P8, 0.2 of Taq and 15.7 µl of milli-Q-water was used with 1 µl of DNA extraction. A positive control of a known sex female was used to compare the DNA bands of the unknown individuals.

Once placed in the PCR machine, the initial DNA denaturation was set at 94°C for 90 seconds, followed by 30 cycles of denaturation at 94°C for 30 seconds; primer annealing at 48°C for 45 seconds; DNA denaturation at 72°C for 45 seconds and primer extension at 72°C for 5 minutes. Approximately 8 µl of DNA of each sample was digested for 45 minutes with 0.3 µl of *Hae III* and 1 µl of buffer. A gel was run (as in the extraction gel above) with a 2% Agarose/1% Nusieve concentration gel with 7 µl of DNA product from each sample. Electrophoresis was run for 25 minutes and the results viewed under ultraviolet light.

#### Feathers

For the extraction of DNA, the shaft of each feather was placed into 200 µl of Extraction Buffer (1 ml 5M NaCl, 86 ml milli-Q-water, 1 ml 1M Tris, pH 8.0, 2 ml 0.5M EDTA) with

20  $\mu$ l SDS, 4  $\mu$ l proteinase K (at a concentration of 20% and 20 mg/ml respectively) and 4  $\mu$ l DTT. After incubating overnight at 55°C, high molecular weight DNA was extracted as above using 500 $\mu$ l of each phenol mixture. The samples were rocked and centrifuged for 5 minutes at 6000 rpm after each addition with the overlay (upper aqueous phase) removed after centrifuging to a new tube before the addition of the next phenol mix. For precipitation of the DNA, 1 ml 100% of cold ethanol was placed in new tubes, the overlay added and stored at -20°C for 2 hours. After centrifuging for 30 minutes at 13000 rpm, the ethanol was removed and 1 ml of 70% cold ethanol was added. The tubes were then centrifuged for 5 minutes, most of the ethanol removed and dried in a concentrator. The DNA was then resuspended in 50  $\mu$ l of milli-Q-water.

An extraction gel was run as above. There was good extraction of DNA from the first two samples (20 and 21) and poor in the third (22). This was good enough, however to proceed with a PCR.

For these samples, a nested PCR with the primers P2 and P8 in the first and P2 and P3 in the second were used. The nested PCR has a better capability of using extractions with small amounts of DNA. A PCR mixture is the same as above, with the exception of the use of 2.5 $\mu$ l (instead 1.5 $\mu$ l) of 25 mM MgCl<sub>2</sub> with 1  $\mu$ l of DNA extraction. Two samples of a known sex (female and male) bird were used as positive controls to compare the DNA bands of the unknown individuals.

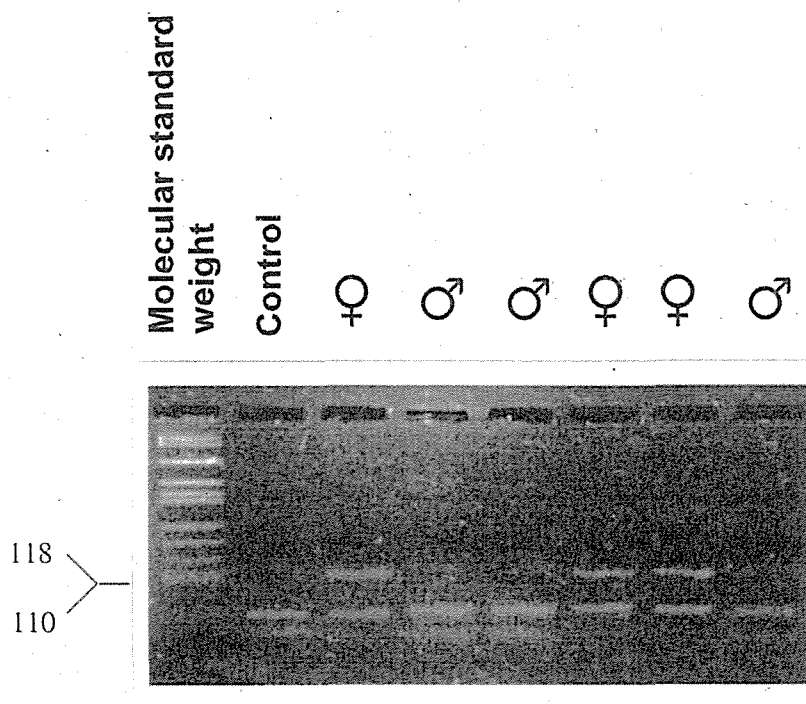
The PCR cycles used had an initial DNA denaturation set at 94°C for 2 minutes, followed by two separate cycles of denaturation, primer annealing and denaturation, first at 94°C for 15 seconds, 50°C for 30 seconds, 72°C for 30 seconds for 10 cycles, and then the second at 94°C for 15 seconds, 45°C for 30 seconds, 72°C for 30 seconds for 35 cycles.

A digestion of 8  $\mu$ l of the PCR product from each sample with 0.5  $\mu$ l of *Hae III* and 2  $\mu$ l of buffer was incubated for 45 minutes. A gel was run (as in the PCR gel above) and viewed under ultraviolet light.



### 5.3 Results

DNA samples were collected from thirteen individual Fairy Terns (juveniles  $n=9$ , adults  $n=4$ ), ten being blood samples and three feather samples. Figure 5.1 shows an example of the DNA profiles obtained from Fairy Terns. The presence in every female of the high molecular weight fragments, occurring between 110 and 118 bp, distinguishes female from male. Table 5.1 provides details of the designation of the sex based on the DNA profiles and from behavioural data. Morphological data are also included. For the juveniles, five were male and four female. Of the adults, three were female and one was a male. The adult male was originally unbanded before capture and sampling and therefore could not be recognised and sexed from its behaviour. There was agreement with all banded individuals of known sex from behavioural data and with the presence and absence of the high molecular weight fragment.



**Figure 5.1.** An example of profiles resulting from PCR amplification of genomic DNA from 3 female and 3 male Fairy Terns. The primers P2, P3 and P8 were used for the PCR reaction and digested with the restriction enzyme *HaeIII*. Molecular size markers are indicated on the left. The two high molecular weight fragments are present in females but absent in males.

**Table 5.1.** Assignment of sex in the Fairy Tern in the 1997/1998 and 1998/1999 breeding seasons based on the occurrence of high molecular fragments and on behavioural data. Morphometric measurements are also included. The morphometric measurements of juveniles were collected 2-6 days before fledging. In the 1997/1998 season three juveniles were not sampled. Three juveniles (not blood sampled) are included. See text below.

Band ID	Sex (DNA)	Sex (Behaviour)	Weight (g)	Wing length (mm)	Bill (mm)	Tarsus (mm)
G-M	Female	Female	73	192	30.9	17.2
M-W	Female	Female	68	194	29.4	16.7
M-R	Female	Female	-	-	-	-
M-RY	Male	-	70	190	29.6	16.8
BR-M	Male	Juvenile	54	93	18.5	18.4
BY-M	Male	Juvenile	60	97	18.3	18.8
RY-M	-	Female	54.0	89	16.9	19.0
RpG-M	-	Female	60.5	118	18.8	19.4
BpG-M	Male	Juvenile	52.5	93	17.3	17.1
RB-M	-	Male	-	104	16.4	18.7
M-WB	Female	Juvenile	56.6	89	17.6	18.0
M-BW	Female	Juvenile	59	100	17.5	-
pGW-M	Female	Juvenile	63.8	111	19.3	18.6
unbanded	Male	Juvenile	-	-	-	-
pGR-M	Male	Juvenile	-	-	-	-
WY-M	Female	Juvenile	-	-	-	-

Due to the difficulty of capturing adult Fairy Terns only four birds (3 female, 1 male) were sampled and therefore the sex ratio could not be determined. Of the nine samples collected from juveniles, there was no significant deviation from a 1:1 sex ratio. There was a higher annual ratio of males (4:2) in the 1997/1998 season and of females (4:2) in the 1998/1999 season. This has also been reported in Herring Gulls, with more males in two breeding seasons and visa versa in two other years (Ryder and Termaat 1987). The juveniles (RpG-M, RY-M, and RB-M) included in Table 5.1 were sexed from behavioural data by breeding in the 1999/2000 season with individuals of known sex, however, these await confirmation by blood samples. Two have been identified as female and the other male (G. Pulham pers. comm.), under the assumption that Fairy Terns are monogamous, and that there is no same-sex pairing. Extra-pair copulations could be a possibility though this has never been observed in the 17 years Fairy Terns have been managed. Until these individuals can be sexed genetically, they will not be included when comparing the sex ratios or bodily measurements.

## 5.4 Discussion

This study has shown that molecular techniques can be used to sex Fairy Terns, with significant benefits to the knowledge of the species from accurate determination of the sex of breeding birds and their sex ratio. Molecular approaches to sexing are more reliable than behavioural observations or morphometrics, especially for sexing juveniles.

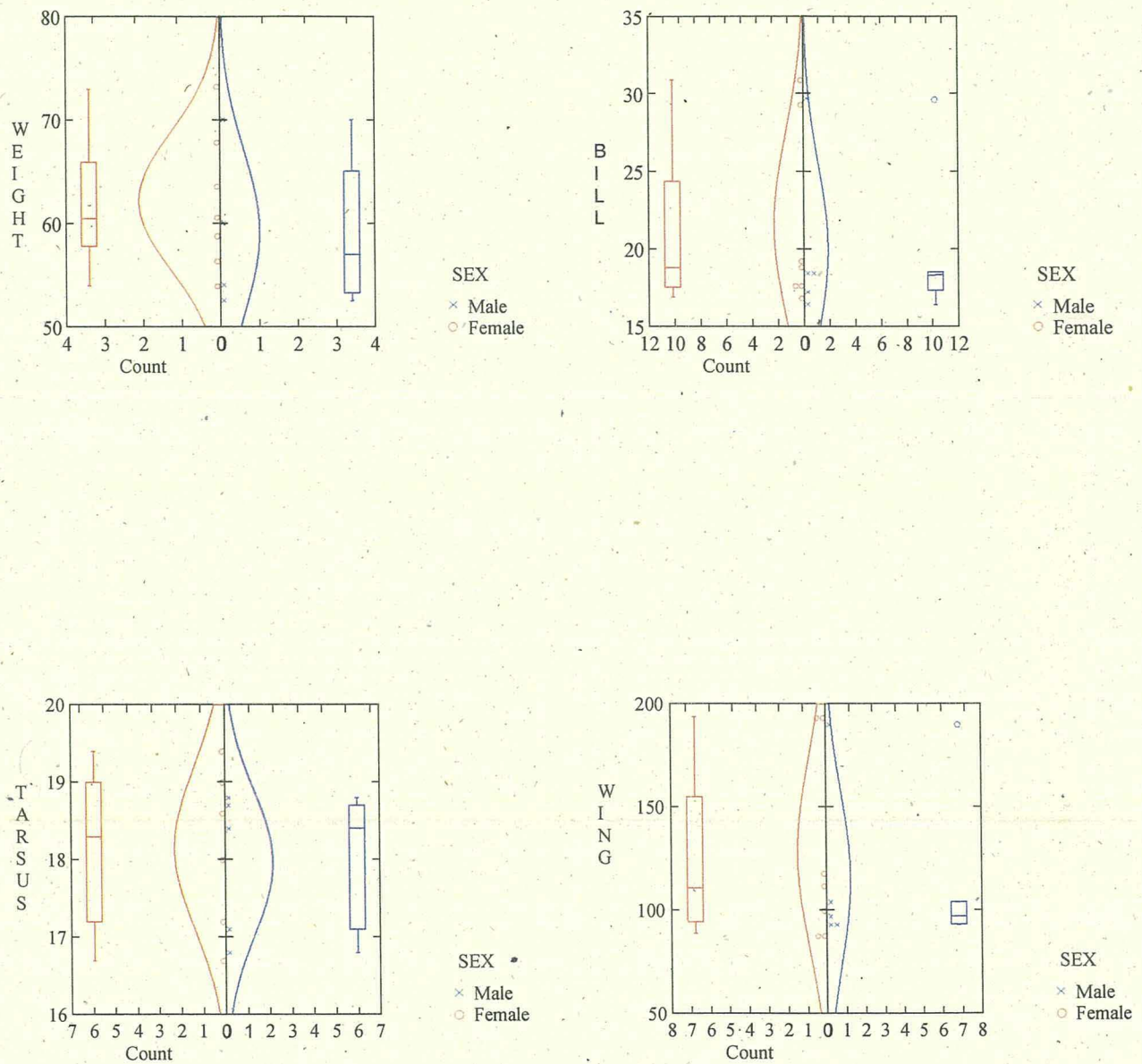
Copulation and nesting behaviour can be difficult to see and may be complicated by different mating systems, particularly in communal breeding birds such as Pukeko (Millar *et al* 1996), and South Polar Skua (Millar *et al* 1997). In seabirds, monogamy predominates, with polygyny only occurring in some species of gull and skua (Wiggins and Morris 1987). This is probably due to the need for both parents to participate in the care of eggs and young, and possibly to a shortage of mates (Wiggins and Morris 1987). Fairy Terns appear to be monogamous, as are other terns such as the Arctic, Common, Little, and Roseate (Cramp 1985, Wiggins and Morris 1987, Uttley 1992, Higgins and Davies 1996). Unpaired males of Least Tern (*S. albigrons antillarum*) have occasionally been seen to copulate with more than one female (Cramp 1985). Courtship, copulation and nesting behaviour in Fairy Terns is relatively easy to observe and there is no behaviour to suggest the occurrence of any other mating system. Nevertheless, the assignment of sex could be difficult, given that Fairy Terns may form same-sex pairs. This may be due to the small size of the population with birds unable to find a mate of the opposite sex, as shown experimentally with Ring-billed and California Gulls (Conover and Hunt 1984). It could also occur as a result of an imbalance in juvenile sex ratios, post-fledging mortality or adult mortality. These factors can, therefore, affect the accuracy of sex determination by direct observation of reproductive behaviour in many species (Millar *et al* 1996).

The results of this study show molecular sexing methods confirmed sex assigned by direct observation of behaviour with 100% agreement. Similarly, Sabo *et al* (1994) found that sexes assigned to Common Terns by the presence or absence of a palpable egg, and by weight, were in agreement with those arrived at by molecular techniques. Although the total sample size for Fairy Terns is small, it nevertheless represents birds accounting for most of the reproduction in the 1997/1998 and 1998/1999 breeding seasons, and 20 percent

of the estimated adult population. More work is needed, however, to confirm the reliability of behavioural sexing in the Fairy Terns.

Molecular sexing appears to be more reliable than morphometric sexing (Lambert and Millar 1995). Several seabird studies have shown differences between the sexes in morphological measurements: in bill length and depth in South Island Pied, Variable and Chatham Island Oystercatchers (Baker 1974), head and bill length in Southern Black-backed Gull (Nugent 1982), Herring and Lesser Black-backed gulls and Kittiwakes (Coulson *et al* 1983), and New Zealand Dotterels (J. Dowding pers. comm), and weight in South Polar Skuas (Millar *et al* 1992). However, Miller *et al* (1996) showed that in Pukeko sexed on morphometric criteria alone, 71% were misclassified, and overlapping morphological characteristics in Brown Skua show little sexual dimorphism (Lambert and Millar 1995). Table 5.1 illustrates four commonly used morphological measures for Fairy Terns: weight, wing length, bill and tarsus. A Kruskal-Wallis test compared these measures between the sexes using SYSTAT 6 (SYSTAT Inc 1996). There was no difference in any of the measures between the male and female (Figure 5.2). Males tend to have slightly longer wings in Roseate and Common Terns, and longer bills in Roseate and Arctic Terns (Cramp 1985, Sabo *et al* 1994). In Common Terns males also have longer tarsi and weigh more than females (Cramp 1985, Sabo *et al* 1994). Again, more work is needed before morphometrics can be completely ruled out as a reliable sex indicator in Fairy Terns.

Success in developing a genetic technique for sexing Fairy Terns provides an invaluable tool for the future management of the species. As more individuals are captured and sexed using the method described here, queries about the sex ratio, parentage and genetic variation can be addressed. Of these, the sex ratio of juveniles and adults is a major concern. With the apparently long time in which the population has been small, Parrish and Honnor (1997) suggested the low number of breeding pairs may result from a gender bias in the adults. Such a situation could result from sex-biased mortality and lead to same-sex pairings, particularly female-female pairs. The lack of a sex imbalance among juveniles in this study, however, has positive implications for recruitment into the adult population,



**Figure 5.2.** Comparison of the morphological measurements of male and female New Zealand Fairy Terns. Weight is expressed in grams; bill, tarsus and wing in millimetres.



for the eventual success of larger numbers of breeding pairs, and ultimately for population increase. With only four adults sampled, no conclusions for the current sex ratio of the adult population can be drawn. Determination of parentage and of genetic variation also requires large adult sample sizes, as well as samples from the other subspecies.

Many recent studies of the sex ratio in other monomorphic birds have found no significant deviation from unity, for instance Ryder and Termaat (1987), Parker *et al* (1991), Millar *et al* (1992), Graves *et al* (1993), Bretagnolle and Thibault (1995) and Millar *et al* (1996). There has been deviations found in a few species towards males (Gowaty and Lennartz 1985, Millar *et al* 1992, Rosenfield *et al* 1996, Svensson and Nilsson 1996, Trewick 1997) or females (Sayce and Hunt 1987, Ligon and Ligon 1990, Griffiths 1992). These cases, however, are relatively rare and generally when there is deviation from parity, females predominate (Clutton-Brock 1986). Clutton-Brock *et al* (1985) and Clutton-Brock *et al* (1986) suggest that declines in food availability could increase mortality of males because of their faster growth and food requirements, and lead to a sex imbalance in the adult population, as found in Western Gulls (Sayce and Hunt 1987).

Other factors that could affect the sex ratio in wild birds have been discussed by Fiala (1981), Ankney (1982), Ryder (1983), Ryder and Termaat (1987), Griffiths (1992), Bradbury and Griffiths (1999), though the evidence is marginal or often contradictory. Most of the studies have sought a gender bias in juveniles, which carries over into the adult population. The possibility remains, however, that disproportionate mortality of adult males or females could be of greater significance in skewing the sex ratio (J. Dowding pers. comm.). Conceivably, if food is short, Fairy Tern males could be disadvantaged in comparison to females, leading to poorer male survival, though this awaits demonstration.

The adult sex ratio and survival of the sexes in Fairy Terns is still unclear. Continued sexing of adults and juveniles is required to shed light on the structure of the population.

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# Synthesis and Recommendations





## 6.1 Thesis Synthesis

Numerous seabird studies have referred to the roles of males and females during breeding (Nisbet 1978, Burger 1981, Pierotti 1981, Cramp 1985, Haftorn and Reinertsen 1985, Wiggins and Morris 1987, Uttley 1992, and Fasola and Saino 1995). The majority of these, however, concern colonial species, with few studies discussing solitary-breeding birds because of the difficulty of locating nests (Burger 1987). This causes problems when considering sex-related roles such as defence, since most colonial species respond by mobbing predators (Goldfeld 1984). In this situation it can be difficult to identify the sex of the individual that responds in each pair. Although sexing in the field is generally problematic, with solitary breeders it is easier to see which individual reacts. This is improved with colour-banded birds.

The New Zealand Fairy Tern is one of New Zealand's most endangered seabirds and has been under crisis management for the last 17 years. During this time there has been an increase from three to seven breeding pairs and to an estimated total population of 21-26 individuals (S. Ferreira pers. comm.). With the beginning of colour banding in 1991, an initial study of the birds' behaviour was carried out in the 1993/1994 breeding season. Since then very little work has been conducted on their breeding ecology, and historic and reproductive information has been possible only since banding began.

In this thesis I report on the results of a two-year study of New Zealand Fairy Tern breeding ecology, interactions with other birds and people, and preferences in nest-site selection. I also establish a reliable technique for sexing the birds using DNA procedures and use it to test for a sex bias in the population.

Male and female Fairy Terns shared most activities (incubation, brooding, guarding and feeding the young and defence) during reproduction. There were some individual differences with time of day in incubation with the male sitting for longer during the morning to late afternoon while the female incubated more in the evenings. The contributions of the sexes could change when other behaviours are considered. Males may contribute more as they feed the female during courtship and early incubation, and possibly care for the young after fledging. The female may incubate all night (Parrish and Pulham 1995), as suggested for its closest relative, the Little Tern (Davies 1981).

When there was only one chick the male tended to feed it more than the female. However, in this study the sexes contributions were relatively equal.

Parental activities varied over time of day and by week. Brooding was generally performed early or late in the day, with most occurring during the first week. This dropped off to very little or none by the second week. Absence from the young increased during the middle of the day and as they got older, although with one chick, parental absence was low. Guarding the young did not change significantly with time and when there was only one chick it was consistently guarded. At Mangawhai Fairy Terns preferred to feed more on low to rising tides and high to falling tides while at Waipu they foraged at low to rising tides. This difference is possibly site-driven the whole of the Waipu estuary is covered for longer than at Mangawhai, restricting the foraging times.

The intensity of territorial defence increased when intruders, particularly Black-backed Gulls, Harriers and Variable Oystercatchers, were close. Intense responses to other birds and people, particularly within 75 m, heightened when the chicks hatched. Whittam and Leonald (2000) found similar responses in Arctic and Common Terns and Rodgers and Smith (1995) found that the majority of responses in Least Terns occurred when intruders were 35 to 80 m from the nest.

Measurements of environmental characteristics associated with nest-sites showed that Fairy Terns preferred to nest on elevated sites, with low vegetation and high levels of shell cover. This was expected as many other terns prefer nesting with these characteristics (Lemmetyinen *et al* 1974, Burger and Lesser 1978, Kotliar and Burger 1986, Burger 1987, Storey 1987, Burger and Gochfeld (1988, 1990), and Wilson 1996). There was a difference between east and west coast breeding areas. The west coast sites were split from the east coast in the ordination by the high correlation between three characteristics: large distances to the estuary mean high water mark, the distance to the nearest vegetation, and high vegetation cover. It appeared that Fairy Terns had more options to choose from in characteristics such as vegetation cover, shell cover, and elevation on the east coast, and therefore the birds may be able to chose nest sites which

are more suitable. No difference in nest site characteristics was found between successful and unsuccessful nests.

The sex of two adults identified as females from observations of copulation was confirmed by DNA analysis. One of these birds, female G-M, was observed over her reproductive cycle in both the 1997/1998 and 1998/1999 seasons. No sex bias was evident in nine chicks examined during the study. DNA techniques were found to be reliable in sexing Fairy Terns. A much larger base of morphological measurements is required for determining sex of adults or juveniles in the field.

## **6.2 Recommendations**

The manipulation of eggs for management purposes affected the behaviour of Fairy Terns. In particular, the foster-female spent much more time incubating in the afternoon but was less attentive at other times of the day. When possible eggs at the same stage of development as the foster-parent's original eggs should be used as replacements, to avoid loss of attentiveness.

The removal of eggs from a nest suspected as having been abandoned is a delicate balance between parents being the best in caring for the eggs, and the risk of overheating or cooling killing the embryo inside. The absence of the parents from the nest was seen to vary from 5-32 minutes in the pairs observed in the 1998-1999 season. Carter and Montgomerie (1985) suggest that windspeed has a cooling effect on eggs. This suggests that the time of absence of parents as well as weather conditions, and also time of day need to be considered before removing eggs from the field. There was also variation in the time young were left unattended, depending on whether pairs had two chicks or one chick. With two chicks, the Mangawhai pair was absent from between 0-209 minutes, and the Waipu pair from 0-106 minutes. When there was only one chick in the 1998/1999 season, the Mangawhai pair was absent for 0-37 minutes and the Waipu pair from 0-15 minutes. The welfare of unattended young may not require intervention unless the parents have not been seen for more than 4 hours or the chicks are young. The number of chicks should also be taken into account.



Larger fenced areas around the nesting sites are needed, particularly when pairs have chicks and are more reactive to people. The need to minimise disturbance so as to maximise attentiveness is important in improving the probability of successful reproduction in Fairy Terns. Rodgers and Smith (1995) suggested a buffer zone of 180 metres for mixed Least Tern and Black Skimmer colonies. Fairy Terns, however, are solitary breeders and defend even larger areas than birds in colonies. Terns in a colony may be more sensitive to disturbance, generally taking flight on mass as an initial upflight response to disturbance (Rodgers and Smith 1995). Although individual pairs may respond differently to an entire colony, fenced areas should be extended to at least 180 metres from the location of the nest or chicks to create an adequate buffer zone (particularly at Waipu). The size of the zone would have to be adjusted according to the location of the chicks and the proximity of mean high tide. Increasing the size of the fenced area may also avoid disturbance caused by movement of fencing tape in the wind.

Limited active management by removing encroaching vegetation, or protecting or restoring patches of shell cover, is recommended to increase and protect areas where Fairy Terns prefer to nest. The provision of shell cover and maintenance of sparse vegetation are also important for captive breeding programmes as they will familiarize the birds with the natural environment.

DNA sexing techniques provide a reliable way to establish the sex of individuals. This information is needed for reproductive studies, and to monitor the sex ratio in the population. Because Fairy Terns are so few in numbers there is an opportunity to collect information on the whole population. This has implications for sex ratio monitoring, parental and taxonomic studies. Blood samples, as opposed to feather samples, are recommended because extraction of DNA is easier, and because blood is required for any studies of parentage or taxonomy (D. Lambert pers. comm.).

Fairy Terns appeared to consider Australasian Harriers a significant threat to their eggs and chicks, and responded to them even when they were several hundred metres away. However, as there is little movement of Harriers on the east coast, the risk appears to be minimal. Harriers appeared to have no direct interest in particular Fairy Tern nests and

were immediately chased by other nesting birds, as well as Fairy Terns. Although Harrier presence is higher at Papakanui, trapping resident pairs could have the result that more individuals, particularly opportunistic juveniles, would enter the area during the breeding season and therefore increase any risk to Fairy Tern eggs and chicks. Setting up raised feeding stations baited with animals caught in the trapping programme could offer resident pairs an easy meal and possibly reduce foraging flights over Fairy Tern breeding areas. Although Black-backed Gulls are potential predators, they often appeared uninterested and were easily chased off by the adult Fairy Terns. Removing the eggs of gulls nesting near the Fairy Terns could displace the gulls and reduce the risk to the terns.

### **6.3 Future work and directions**

The current analytical research on the New Zealand Fairy Tern provides a foundation for understanding of the birds' breeding ecology and population dynamics. It indicates the roles of the sexes, as well as the effect of environmental factors on behaviour.

Further work is required in the period before breeding, during the season, and after breeding on other aspects of their behaviour to fully understand the roles of the sexes in Fairy Terns and how environmental factors can affect them. Such work should include:

1. Work is needed to confirm the overall contribution of the sexes to fully understand Fairy Tern ecology. The roles of the sexes at night during incubation and care of the young. The few nocturnal studies of other shorebirds (most during incubation) have shown that one sex appears to incubate for the entire night whether it be the male (Mundahl 1982, Byrkjedal 1985, Bergstrom 1986, Brunton 1988, Warnock and Oring 1996, Blanken and Nol 1998), or the female (Skutch 1957, Davies 1981, Miller 1985, Aguilera 1990, Smith *et al* 1995, Fitzpatrick 1996). Work is needed to confirm the suggestion that the female Fairy Tern incubates all night (Parrish and Pulham 1995). If so, the female's contribution could exceed that of the male during incubation.

2. The roles of sexes in courtship feeding. This appears to be a male-specific behaviour but more information from the early stages of Fairy Tern reproduction ie during courtship, egg laying and early incubation would confirm this.
3. Post-breeding care of the young. Occasional sightings of adults with juveniles immediately after the breeding season suggest that only the male may feed the juveniles after fledging, and teach them to fend for themselves. The role of adults in post-fledging care should be examined by following the juveniles for an extended period after fledging to establish parental involvement, and the length of time any care persists. This also may provide some insights into the juvenile or adult mortality.
4. Population dynamics of Fairy Terns. DNA work suggests that the recruitment of juveniles into the population is not sex-biased. Further blood sampling is required to establish the sex of juveniles, and adults, to monitor the sex ratio, and to provide information on the parents of young previously unbanded and taxonomy.

#### **6.4 Conclusion**

For New Zealand Fairy Terns the parental investment by male and females appears to be relatively equal, but better measures of nocturnal activity during incubation and brooding, and post-fledging care of young, could alter our understanding of the contributions of the sexes. In general, Fairy Terns behave similarly to other terns, however, Fairy Terns breed in single pairs not in colonies, so there is potential for individual behaviour. Differences between breeding sites may further complicate nesting behaviour, such as the feeding frequency in relation to the state of the tide. The fact that Fairy Terns breed in single pairs and comprise a tiny population provides a unique opportunity to study their ecology in detail, and can contribute to the future management of the species.

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## Minor Emendations

Throughout thesis incubation "stint" = incubation "period"

Table 2.5 "guarding of an adult" = "guarding by an adult"

Table 5.1 "high molecular fragments" = "high molecular weight fragments"

Appendix 4.2 "nest-selection" = "nest site selection"

p68 "... no threat to Fairy Terns (e.g. New Zealand Dotterel)"