Characteristics of White-chinned Petrels *Procellaria aequinoctialis* Linnaeus in New Zealand Waters

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ABSTRACT

Current taxonomy of the white-chinned petrel suggests that all populations are similar enough to be a single global taxon, *Procellaria aequinoctialis* Linnaeus. This thesis challenges that view with an analysis of morphological characteristics of white-chinned petrels from fisheries bycatch in the New Zealand Exclusive Economic Zone (EEZ). The two main aims were: first, to determine if white-chinned petrels in New Zealand waters comprise one taxon; and second, to determine if white-chinned petrels in New Zealand waters fit the proposition of a global taxon. Morphological characteristics included; standard external measurements (head, bill, tarsus, wing and tail measurements), descriptions (area of white on the chin and bodily descriptions), and measurements of internal organs of a sample of 723 bycatch white-chinned petrels. Twenty-five white-chinned petrel study skins from breeding islands in the South Pacific, Indian and Atlantic Oceans, and 29 study skins from birds caught off Chile were also measured for comparison with the bycatch birds.

I compared a range of external measurements from the bycatch sample taken by myself and 'the Laboratory' (measurements and descriptions of white-chinned petrels taken by C.J.R. Robertson and E. Bell) to estimate the measurement error between multiple observers measuring the same sample of birds. Results clearly showed very little measurement error between the two observers, and the small amount of error was biologically insignificant.

I found two cluster groups of bycatch white-chinned petrels, the 'Antipodes Island group' (n = 105) which was significantly larger in most external measurements than the 'Auckland Island group' (n = 45). Using discriminant analysis I could differentiate 93% males of the 'Antipodes Island group' versus the 'Auckland Island group' based on culmen and tail length. I could also differentiate 92% of females from the 'Antipodes Island group' versus the 'Auckland Island group' based on head and bill length, culmen depth at the base and wing length. Discriminant analysis indicates that the Antipodes Island population male and female white-chinned petrel study skins related closest to the 'Antipodes Island group' and the Auckland Island, South Indian Ocean, South Atlantic Ocean, and Chile male and female white-chinned petrel study skins related closest to the 'Auckland Island group'.

The results suggest that within the New Zealand EEZ there are two taxa of white-chinned petrels based on external morphology: '*aequinoctialis*' Linnaeus, the smaller sized white-chinned petrels from the Auckland Islands; and '*steadi*' Mathews, the larger sized white-chinned petrels from Antipodes Island and most likely Campbell Island.

The results also suggest that, globally, the external morphology of white-chinned petrels can be used to identify two taxa: '*aequinoctialis*' Linnaeus, the smaller sized white-chinned petrels which comprise the Auckland Islands, the South Indian Ocean, and the South Atlantic Ocean populations; and '*steadi*' Mathews, the larger sized white-chinned petrels which comprise the Antipodes Islands population. Further, most white-chinned petrels caught off Chile are likely to be from the Auckland Island breeding population or South Atlantic Ocean breeding populations.

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CONTENTS

1

INTRODUCTION

1.1 GENERAL INTRODUCTION

The group of seabirds collectively known as petrels and albatrosses form the order Procellariiformes Fürbringer. They are also commonly called tubenosed seabirds as their nostrils are encased in horny tubes set on top of the culmen (Warham 1990). Procellariiformes have developed systems specifically for aerial locomotion to exploit pelagic food resources (Warham 1990), and therefore spend a majority of their time at sea (del Hoyo *et al.* 1992). They also have a well developed sense of smell used to locate food, colonies and nest sites (Warham 1990; del Hoyo *et al.* 1992; Nevitt 1999). Procellariiformes occur in all oceans but are more numerous in the southern hemisphere, particularly in the New Zealand region which is the breeding ground for the greatest variety of petrels and albatrosses (Robertson *et al.* 2003b).

The largest family within Procellariiformes is the Procellariidae Leach. This family contains those species commonly termed 'true petrels' (Marchant and Higgins 1990) including fulmar-petrels, gadfly petrels, prions, and shearwaters (del Hoyo *et al.* 1992). Procellariidae are characterised by large nasal tubes set together on top of the culmen, separated by a thin septum (Campbell and Lack 1985; Warham 1990). Procellariidae comprise 14 living genera (Warham 1990; Dickinson 2003) including the genus *Procellaria* Linnaeus which is the second petrel genus described by Linnaeus and now includes the largest burrowing petrels in the world (Warham 1990).

With the exception of the giant petrels *Macronectes* Richmond, *Procellaria* petrels are the largest petrels in the family Procellariidae. This genus includes five species; the grey petrel *P. cinerea* Gmelin, the Westland petrel *P. westlandica* Falla, the black petrel *P. parkinsoni* Gray, the spectacled petrel *P. conspicillata* Gould, and the white-chinned petrel or shoemaker *P. aequinoctialis* Linnaeus. The spectacled petrel *P.*

conspicillata has only recently been given species status (Ryan and Moloney 2000), separated from the white-chinned petrel *P. aequinoctialis* based on its unique plumage and slightly small size, small isolated breeding population at Inaccessible Island that breeds earlier than the white-chinned petrel, and they are vocally different from white-chinned petrels (Ryan 1998; Ryan and Moloney 2000).

The white-chinned petrel *P. aequinoctialis* is the largest species within the genus *Procellaria* (Warham 1990), with body length 51-58 cm and wingspan 134-147 cm (Marchant and Higgins 1990). Males are also generally larger than females (Marchant and Higgins 1990). The white-chinned petrel is a heavy built sooty black petrel with black legs and feet (Marchant and Higgins 1990). There is a patch of white feathers on the chin and throat area which varies in size from very large to only a couple of feathers (Murphy 1936; Marchant and Higgins 1990; Warham 1990), and occasionally entirely absent (Serventy *et al.* 1971; Imber 1985b). The bill is large with a heavily hooked maxillary unguis and generally pale yellow to creamy white in colour (Murphy 1936; Marchant and Higgins 1990; Warham 1990). There is black on the bill around the nostrils, on the culminicorn, along the mandibular sulcus, and at the tip of the maxillary unguis (Murphy 1936; Marchant and Higgins 1990; Warham 1990).

White-chinned petrels have a circumpolar distribution and have breeding populations at the Kerguelen Islands, Crozet and Prince Edward Islands in the South Indian Ocean; at South Georgia and the Falkland Island in the South Atlantic Ocean; and at Auckland, Antipodes and Campbell Islands in the South Pacific Ocean (Murphy 1936; Falla 1937; Mougin 1970; Imber 1983; Jouventin *et al.* 1985; Marchant and Higgins 1990). The white-chinned petrel breeding season is broadly between September and May (Marchant and Higgins 1990) however, little is known about population dynamics of white-chinned petrels, especially in New Zealand.

Each year large numbers of Procellariiformes are caught and killed worldwide as bycatch to various fisheries including bottom longliners, tuna longliners, scampi, squid and fish trawlers (Robertson *et al.* 2003a, and drift netting (Brothers *et al.* 1999). White-chinned petrels are the most extensively caught bycatch species within the New Zealand Exclusive Economic Zone (Robertson *et al.* 2003b). Between

October 1996 and September 2003 944 were returned from observed vessels and these accounted for 27.5% of birds killed during that period (Bartle 2000; Robertson 2000; Robertson and Bell 2002a, 2002b; Robertson *et al.* 2003a; Robertson, C.J.R. *pers. comm.*).

The current taxonomy of the white-chinned petrel suggests that birds from all populations are similar enough to be considered a global taxon *P. aequinoctialis*. However, recent analysis of morphological characters of New Zealand fisheries bycatch white-chinned petrels suggests that some individuals do not fit the general description of a white-chinned petrel (Robertson, C.J.R. *pers. comm.*) and there is enough evidence to suggest that further research is needed into the taxonomy of the white-chinned petrel.

Therefore I proposed to use morphological characteristics to look at the taxonomy of white-chinned petrels in New Zealand to determine if they comprise one taxon and in turn fit the proposition of a global white-chinned petrel taxon. Morphological characteristics were used, rather than molecular and ecological characteristics, as they were available without using costly tests and they showed features that could be seen on individual specimens.

A selection of 723 fisheries bycatch white-chinned petrels provided an excellent sample for examining the taxonomy of white-chinned petrels in New Zealand. In addition to this bycatch sample, I used study skins of white-chinned petrels from breeding islands in New Zealand, in the South Indian and Atlantic Oceans, and from birds caught off Chile. It was impossible to determine which breeding island each bycatch bird was from, so morphological characteristics were collected from study skins from breeding islands to give an indication as to which breeding population the bycatch birds were from.

The results only give an indication of the taxonomy of New Zealand white-chinned petrels based on morphology and further research is needed on actual breeding birds from individual breeding populations at the Auckland and Antipodes Islands, and from breeding islands in the South Indian and Atlantic Oceans.

My research also provides a method, based on external morphology, for estimating the origin, Auckland or Antipodes Islands, for individual bycatch white-chinned petrels in New Zealand waters.

1.2 THESIS AIMS

The main aim of this research was:

1. To determine if white-chinned petrels in New Zealand waters comprise one taxon.

The secondary aim of this research was:

2. To determine if white-chinned petrels in New Zealand waters fit the proposition of a global taxon.

This thesis is divided into five chapters; Introduction, Methods, Results, Discussion, and Conclusions, followed by References and Appendices.

Chapter 1: Introduction

The general introduction outlines the reasons for undertaking this research, the two main thesis aims and how I propose to assess those aims.

The next sections provide background information on the order Procellariiformes 1.3, the family Procellariidae 1.4, and the genus *Procellaria* Petrels 1.5 to show how *P. aequinoctialis* was classified.

The following section 1.6 on fisheries bycatch of white-chinned petrels includes general information on worldwide fisheries bycatch finishing with New Zealand white-chinned petrel bycatch and the sample of birds used for this research.

Section 1.7 on *P. aequinoctialis* systematics begins with background information on taxonomy to give an indication of how species are named, then a taxonomic review of

the literature on white-chinned petrel taxonomy to show the need for further research to be conducted on this topic.

The chapter finishes with section 1.8 on *P. aequinoctialis* and provides information on what is known on white-chinned petrel features, distribution and breeding biology finishing with white-chinned petrels in New Zealand, indicating how little information is known on these birds.

Chapter 2: Methods

The methods chapter outlines the study specimens used in this thesis and where the research was conducted in sections 2.2 and 2.3. Section 2.4 outlines the descriptive methods used, including necropsy methods, full dissection of white-chinned petrels and measuring study skins, and section 2.5 outlines exactly how each of the external measurements were taken.

Section 2.6 then describes how each bycatch white-chinned petrel was aged and sexed and section 2.7 outlines exactly how all internal features were measured. Section 2.8 describes how all bill descriptions were taken including black lines on the bill, amount of dark colouring at the maxillary and mandibular tips, and nostril shapes. The final section 2.9 outlines the analyses used in the thesis including how 'cluster groups' were selected and what statistical analyses used.

Chapter 3: Results

The results chapter is divided into two main sections, the first a short section on sex and age determination (section 3.2) and the second section on external morphology of white-chinned petrels (section 3.3).

Section 3.3 shows the main results of the external morphology of 'the white-chinned petrel sample' compared with white-chinned petrels study skins from breeding islands. The first part of section 3.3 looks at the comparison of my measurements with the same measurements taken by 'the Laboratory' to give an indication of measurement error between two observers measuring the same sample of white-chinned petrels. The next part looks at morphological characteristics of study skins

from breeding islands to determine if there are morphological differences between breeding island populations, particularly the Auckland and Antipodes Islands. Next morphological characteristics of 'the white-chinned petrel sample' were analysed to look at differences between adults and non-adults, adult males and females and the 'Auckland and Antipodes Island cluster groups'. Finally differences between the 'Auckland and Antipodes Island cluster groups' were compared with study skins from breeding islands, the 'Chatham Rise and Puysegur Point cluster groups', bycatch birds caught outside the breeding season, and to non-adult white-chinned petrels.

Chapter 4: Discussion

Chapter 4 discusses firstly the two main reasons why these results were obtained, measurement error between observers and sample size; then white-chinned petrel external morphology; then white-chinned petrel taxonomy; and finally internal morphology of white-chinned petrels. Morphological differences between the 'Auckland and Antipodes Island cluster groups' and study skins from breeding islands combined with taxonomy then provided an indication to the number of white-chinned petrel taxa in New Zealand waters and the number of global taxa.

Chapter 5: Conclusions

Chapter 5 discusses with the main points and conclusions drawn from the results and reiterates what conclusions were drawn for the two main aims of the thesis; that were to determine if white-chinned petrels in New Zealand waters comprise one taxon and to determine if white-chinned petrels in New Zealand waters fit the proposition of a global taxon.

1.3 PROCELLARIIFORMES

Birds that forage at sea below the low water mark (Brothers *et al.* 1999), and support themselves away from land, are collectively known as seabirds (Campbell and Lack 1985). They include, along with Sphenisciformes Sharpe, Pelecaniformes Sharpe, Charadriiformes Huxley, the Procellariiformes Fürbringer (Mayr and Cottrell, 1979;

Turbott 1990; Warham 1990; del Hoyo *et al.* 1992). Sibley and Monroe (1990) place the orders Sphenisciformes, Pelecaniformes, Charadriiformes, and Procellariiformes in the order Ciconiiformes Bonaparte based on molecular analysis.

The Procellariiformes may have evolved from a late Cretaceous ancestor possibly shared with Sphenisciformes (Warham 1990) and appear to have first appeared in the Southern Hemisphere (del Hoyo *et al.* 1992). Procellariiformes now occur in all oceans, but are more numerous in the southern hemisphere (Warham 1990) where New Zealand is the breeding ground for the greatest variety of albatrosses and petrels (Robertson *et al.* 2003b). Procellariiformes have systems developed specifically for aerial locomotion to exploit pelagic food resources (Warham 1990), have similar life histories, and spend a majority of their time at sea (del Hoyo *et al.* 1992).

Procellariiformes are distinguished by nostrils that are encased in horny tubes on the dorsal surface of the bill, either separated by the ridge of the culmen (e.g. albatrosses) or as a single tube on top of the culmen separated by a septum (e.g. petrels, prions and shearwaters) (Warham 1990). Procellariiformes have a well developed sense of smell that may be used to locate food, colonies, nest sites, and perhaps partners (Warham 1990; del Hoyo *et al.* 1992; Nevitt 1999). Other features include the hard plates covering the bill being separated by deep grooves and the maxillary unguis being massive and strongly hooked (Warham 1990). The upper mandible fits neatly over the lower with the tomia and unguis tip very sharp designed for gripping and slicing slippery prey (Warham 1990). With some species (e.g. prions) the tomia form serrated combs for filter feeding (Warham 1990). The legs are long (Warham 1990). The three front toes are fully webbed, with large claws, and the hind toe is either vestigial or absent (Warham 1990). Procellariiformes have low reproductive rates but high life expectancy (Warham 1990).

The families within the Procellariiformes are: Diomedeidae Gray (Turbott 1990; Warham 1990; del Hoyo *et al.* 1992; Dickinson 2003); Oceanitidae Forbes (Turbott 1990) or Hydrobatidae Mathews (Mayr and Cottrell 1979; Warham 1990; del Hoyo *et al.* 1992); Pelecanoididae Gray (Mayr and Cottrell 1979; Warham 1990; del Hoyo *et al.* 1992); and Procellariidae Boie (Warham 1990; Turbott 1990; del Hoyo *et al.* 1992; Dickinson 2003). Turbott (1990) regards Pelecanoididae as a genus within the family

Procellariidae. Sibley and Monroe (1990), using molecular analysis, combine Diomedeidae, Oceanitidae, Pelecanoididae, and Procellariidae into one family, Procellariidae, within the order Ciconiiformes.

1.4 PROCELLARIIDAE

The largest family within Procellariiformes is the Procellariidae. They include the medium to large sized 'true petrels' (Marchant and Higgins 1990). They have large nasal tubes set together on top of the culmen, near the base, separated by a thin septum that does not always extend to the nostril apertures (Campbell and Lack 1985; Warham 1990). The nostrils are prominent and of varying length, with the most extreme belonging to the giant petrels *Macronectes* Richmond, where they extend three fifths the length of the bill (Marchant and Higgins 1990; Warham 1990). The bill varies in length and shape between species, depending on feeding habits, with all having a strongly hooked maxillary unguis (Marchant and Higgins 1990; Warham 1990; del Hoyo *et al.* 1992). Wings are proportionally long and narrow with eleven primaries, the tenth primary being the longest and eleventh minute, with legs set back on the body (Marchant and Higgins 1990). Three toes are webbed with large claws and the fourth, or hind toe, is vestigial located part way up the back of the tarsus (Marchant and Higgins 1990; Warham 1990).

The Procellariidae are sometimes split into two subfamilies Fulmarinae Stephens and Procellariinae Leach (Turbott 1990; del Hoyo *et al.* 1992). del Hoyo *et al.* (1992) also recognises four 'natural' groups based on similar characteristics and lifestyles; fulmar-petrels, gadfly petrels, prions, and shearwaters.

There are ten living genera within Fulmarinae (Warham 1990; Dickinson 2003), though del Hoyo *et al.* (1992) only give nine genera. Living genera in the Procellariinae include *Calonectris* Mathews and Iredale, *Puffinus* Brisson, *Pseudobulweria* Mathews, and *Procellaria* Linnaeus (Warham 1990; del Hoyo *et al.* 1992; Dickinson 2003).

1.5 PROCELLARIA PETRELS

The genus *Procellaria* Linnaeus comprises five species; the grey petrel *P. cinerea* Gmelin, the Westland petrel *P. westlandica* Falla, the black petrel *P. parkinsoni* Gray, the spectacled petrel *P. conspicillata* Gould, and the white-chinned petrel *P. aequinoctialis* Linnaeus.

Procellaria petrels are large petrels with robust, heavily hooked bills (Warham 1990). The bill varies from a yellow-white to cream colour with varying amounts of black along the dorsal surface of the culmen, along the mandibular grooves and at the ungues tips (Warham 1990). They have large upstanding nasal tubes set together at the base of the culmen that open forwards with the aperture V-shaped in dorsal view (Warham 1990). The apertures of the nostril tubes are rounded and slightly bevelled in contrast to the greatly bevelled apertures of *Calonectris* and *Puffinus* (Warham 1990).

All *Procellaria* petrels are blackish-brown in general body plumage, except the grey petrel *P. cinerea* which has body and wing upperparts and under wings grey-brown and body underparts white (Marchant and Higgins 1990; Warham 1990). The white-chinned petrel has white on and about the throat, and the spectacled petrel has white on and about the throat and face with rings of white around the eyes.

The *Procellaria* petrels are powerful fliers and morphological characteristics reflect their different flight and feeding habits (Warham 1990; del Hoyo *et al.* 1992). The four dark petrels the white-chinned petrel *P. aequinoctialis*, spectacled petrel *P. conspicillata*, Westland petrel *P. westlandica*, and black petrel *P. parkinsoni* have long wings and tail allowing them to glide well and cover great distances (Warham 1990; del Hoyo *et al.* 1992). The grey petrel *P. cinerea* has a stocky body with relatively short wings and tail for frequent diving (Warham 1990; del Hoyo *et al.* 1992).

Procellaria petrels all feed predominantly on cephalopods (with some fish and crustaceans taken) and feed mainly at night (Imber 1976; Warham 1990; del Hoyo *et al.* 1992). They also follow ships to scavenge food, more commonly the grey petrel *P.*

cinerea and the white-chinned petrel *P. aequinoctialis*, but recently the Westland petrel *P. westlandica* are becoming more dependent on offal (Warham 1990).

Breeding seasons vary within this genus with two species breeding in the winter, the grey petrel *P. cinerea* (Warham and Bell 1979; Imber 1983; Warham and Imber 1985; Jouventin *et al.* 1985) and the Westland petrel *P. westlandica* (Imber 1976; Baker and Coleman 1977; Bartle 1985), and three species breeding in the summer, the black petrel *P. parkinsoni* (Imber 1976; Imber 1985a; Imber 1987), the spectacled petrel *P. conspicillata* (Rowan *et al.* 1951; Ryan 1998; Ryan and Moloney 2000) and white-chinned petrel *P. aequinoctialis* (Mougin 1970; Imber 1976; Warham and Bell 1979; Jouventin *et al.* 1985; Hall 1987).

Lack (1966) suggested that segregation in breeding time for related species of seabirds was because of competition for nesting sites with other species, or competition for food during the breeding season. Barrat (1974) and Despin (1976) comment that segregation at breeding time for winter breeding *Procellaria* petrels may be due to competition for nesting sites with summer breeding *Procellaria* petrels, and at the Crozet Islands winter breeding grey petrels *P. cinerea* may be able to use the burrows of summer breeding white-chinned petrels *P. aequinoctialis*. However, Warham and Bell (1979) comment that this might not happen at the Antipodes Islands as white-chinned petrels there are still raising chicks when grey petrels arrive to lay eggs. Lack (1966) and Baker and Coleman (1977) suggest that for seabirds, e.g. *Procellaria* petrels, the second explanation of competition for food seems more likely as *Procellaria* species of similar size compete for similar food resources and do not breed at the same time of the year.

Four of the five species, *P. cinerea*, *P. westlandica*, *P. parkinsoni*, and *P. aequinoctialis*, have breeding grounds within the New Zealand region (Warham and Bell 1979; Bartle 1985; Imber 1985a; Imber 1985b; Warham 1990) with *P. westlandica* and *P. parkinsoni* both endemic to New Zealand (Warham 1990). *Procellaria* petrels have such long breeding seasons that they may not breed every year (Warham 1990).

1.6 FISHERIES BYCATCH WHITE-CHINNED PETRELS

1.6.1 General fisheries bycatch

Procellariiformes are known for their long migrations and foraging trips (Brothers *et al.* 1999; Weimerskirch *et al.* 1999; Berrow *et al.* 2000), especially during the non-breeding and adolescent periods of the life cycle (Robertson *et al.* 2003b). In the southern oceans high numbers of Procellariiformes are found in cooler waters on continental shelves or at oceanic fronts where they forage on the high concentration of food (Brothers *et al.* 1999). Fishing practices, such as bottom longliners, tuna longliners, scampi, squid and fish trawlers (Robertson *et al.* 2003a), and drift netting (Brother *et al.* 1999) in the southern oceans also concentrate in areas where there is high biological productivity (Brothers *et al.* 1999).

The concentration of Procellariiformes and fishing vessels in areas of high biological productivity has led to many species interacting with a wide variety of fishing practices and, as a consequence, some get caught and killed. These individuals that are incidentally killed during the process of fishing are termed fisheries bycatch. Each year large numbers of Procellariiformes worldwide are caught and killed during the fisheries process and end up as fisheries bycatch.

Birds can become fisheries bycatch statistics by: swallowing baited hooks and being pulled under the surface and drowned (Brothers *et al.* 1999); chasing baited hooks and getting foul hooked and pulled under the surface and drowned (Brothers *et al.* 1999); getting tangled in the machinery hauling the equipment in or out of the water (Brothers *et al.* 1999); diving into drift and trawl nets, getting caught and drowning; and getting caught in trawl warps and overhead wires and breaking bones. Some birds survive their initial injuries and are released, but many could die at a later date, although there has been no research to support this.

A problem with fisheries bycatch is identifying species and the breeding populations they come from (Robertson, C.J.R. *pers. comm.*). This problem arises where Procellariiformes travel long distances during foraging and migration trips and cross international borders. Therefore there is potential for birds to be caught by fisheries in

other parts of the world and be misidentified. More information is needed on physical characteristics for identifying procellariiform species from their relevant breeding populations. The white-chinned petrel *Procellaria aequinoctialis* is one such species that is caught as bycatch to various types of fisheries throughout the southern hemisphere. There is thus the potential for white-chinned petrels from various breeding populations to be caught as fisheries bycatch anywhere in the southern hemisphere.

1.6.2 *Procellaria aequinoctialis* worldwide fisheries bycatch

White-chinned petrels *Procellaria aequinoctialis* regularly associate with fishing vessels (Weimerskirch *et al.* 1999), predominantly bottom longliners and squid trawlers (Robertson *et al.* 2003a), and feed on offal discarded from the boats (Jackson 1988). White-chinned petrels with their large size and aggressive nature (Marchant and Higgins 1990) get caught and killed either by taking baited hooks or offal around the fishing vessels (Robertson *et al.* 2003b), and in the southern oceans, form the majority of seabird bycatch (Weimerskirich *et al.* 1999).

In the South Atlantic Ocean off South America and South Georgia white-chinned petrels are caught predominantly by bottom longline fisheries (Weimerskirch *et al.* 1999; Robertson *et al.* 2003b).

White-chinned petrels caught as fisheries bycatch in the South Indian Ocean off Prince Edward Islands and Kerguelen Island are caught predominantly by bottom longline fisheries (Cherel *et al.* 1996; Ryan 1999; Robertson *et al.* 2003b). It was estimated that a 61 vessel longline fleet fishing hake caught 58 800 white-chinned petrels in one year (Barnes *et al.* 1997) and that off Kerguelen Island up to 36 white-chinned petrels were caught on a single line, of which thousands are set annually (Weimerskirch *et al.* 1999). Lack of experience and failure to adhere to permit conditions led to a large number (923) of seabirds being killed by sanctioned longline vessels fishing for Patagonian toothfish around the Prince Edward Islands off South Africa in 1996 (Ryan 1999). Three hundred and ninety-three birds were returned to South Africa as fisheries bycatch of which 212 were white-chinned petrels (Ryan 1999).

1.6.3 *Procellaria aequinoctialis* fisheries bycatch in New Zealand

Within the New Zealand region the extent of interaction of seabirds with fisheries practices is well known as vessels with fisheries observers have all bycatch birds returned for autopsy (Robertson *et al.* 2003a). However, not all fishing vessels have observers and therefore information on species and numbers caught per fishing practice can only be estimated. Bottom longliners, pelagic tuna longliners, scampi, squid and fish trawlers operate extensively within New Zealand Exclusive Economic Zone (EEZ) and catch numerous white-chinned petrels (Robertson *at al.* 2003a).

The New Zealand Department of Conservation has an autopsy programme for seabird fisheries bycatch within the New Zealand EEZ (Robertson *et al.* 2003a). Thirty-seven species of seabird have been represented as seabird bycatch so far (Robertson *at al.* 2003b).

Of those species seven; white-chinned petrel *Procellaria aequinoctialis*, sooty shearwater *Puffinus griseus* (Gmelin), New Zealand white-capped albatross *Diomedea cauta steadi* Falla, grey petrel *Procellaria cinerea*, Salvin's albatross *Diomedea cauta salvini* (Rothschild), Buller's albatross *Diomedea bulleri* Rothschild, and Antipodean wandering albatross *Diomedea exulans* Linnaeus, have contributed 88 % of all birds caught by fisheries between October 1996 and September 2003 (Bartle 2000; Robertson 2000; Robertson and Bell 2002a, 2002b; Robertson *et al.* 2003a; Robertson, C.J.R. *pers. comm.*).

Within the New Zealand region white-chinned petrels are the most extensively caught species (Robertson *et al.* 2003b). New Zealand fisheries observers and voluntary researchers reported 944 white-chinned petrels were killed by interactions with fisheries between October 1996 and September 2003 (Plate 1.1) which accounted for 27.5 % of the total number of birds killed during that period (Bartle 2000; Robertson 2000; Robertson and Bell 2002a, 2002b; Robertson *et al.* 2003a; Robertson, C.J.R. *pers. comm.*).

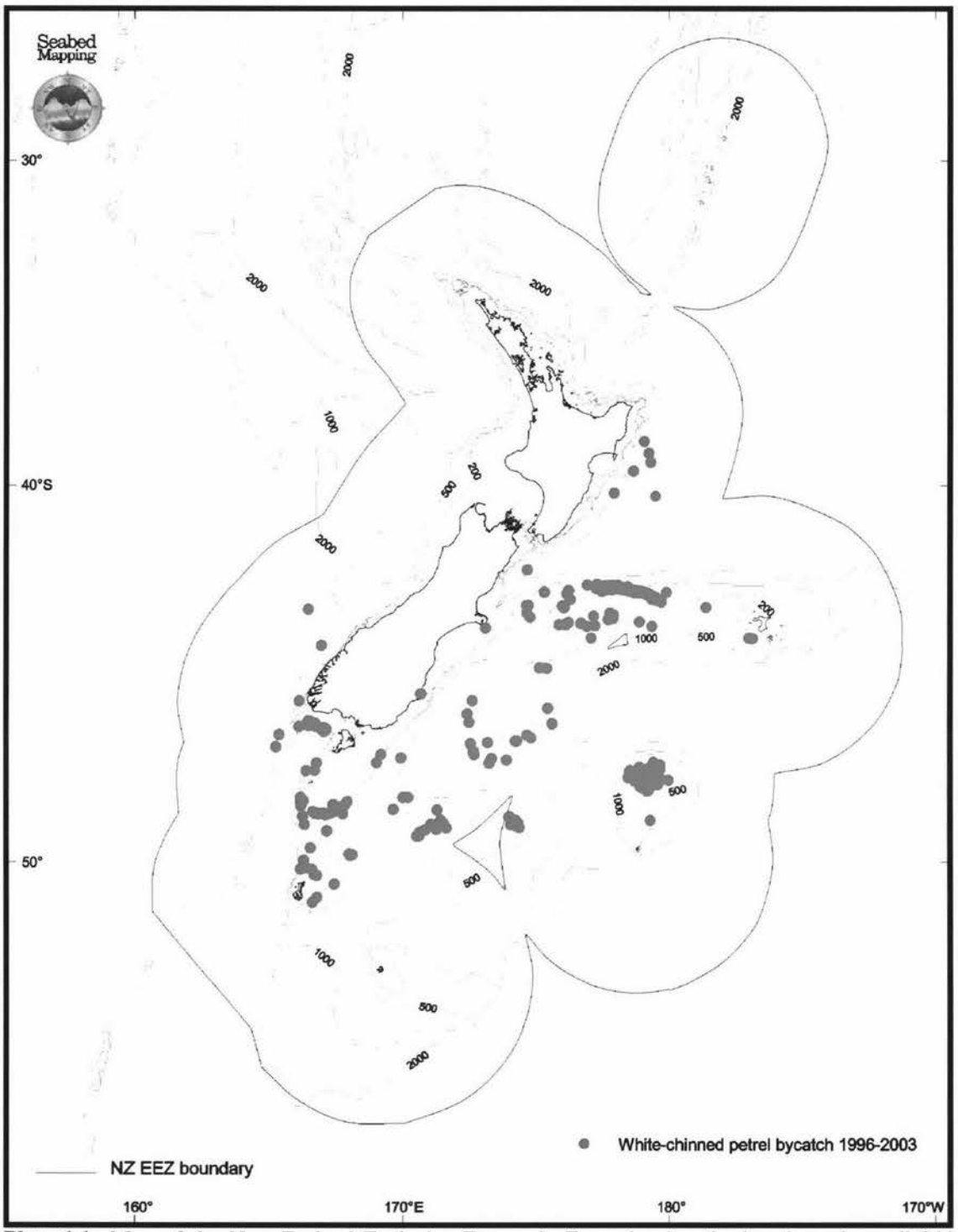

Plate 1.1 Map of the New Zealand Exclusive Economic Zone showing the location where all 944 bycatch white-chinned petrels were caught between 1996-2003.

White-chinned petrels caught as fisheries bycatch in the New Zealand EEZ were caught predominantly by bottom longliners and squid trawlers (Robertson *et al.* 2003a). The 944 white-chinned petrels caught provide an excellent sample to look at systematics of white-chinned petrels within the New Zealand EEZ.

A large selection of these fisheries bycatch birds were used as a representative sample of the New Zealand white-chinned petrel population, and were used to investigate the taxonomy of New Zealand white-chinned petrels using morphological techniques.

1.7 PROCELLARIA AEQUINOCTIALIS SYSTEMATICS

1.7.1 Background on Taxonomy

Taxonomy

The scientific study of recognising and grouping the diversity of living organisms is known as taxonomy (Jeffrey 1977; Mayr and Ashlock 1991). The process of taxonomy used to establish systematic groups of living organisms based on degrees of similarity is known as classification. These systematic groups are known as taxa (or taxon, singular) and the allocation of names to taxa is known as nomenclature (Jeffrey 1977; Mayr and Ashlock 1991). Taxon is defined as 'a taxonomic group of any rank' (Jeffrey 1977), for example *Procellaria aequinoctialis* is a taxon of species rank and *Procellaria* is a taxon of generic rank.

Biological nomenclature assigns scientific names to taxa at all levels using a strict set of rules called Codes of Nomenclature (Jeffrey 1977; Mayr and Ashlock 1991). There are three codes that each differ in approach and format. The first is the International Code of Zoological Nomenclature (ICZN) which is used to govern the use of scientific names to organisms classified as animals (Jeffrey 1977; Mayr and Ashlock 1991). The second is the International Code of Botanical Nomenclature (ICBN) which governs the use of scientific names of those classified as plants and fungi (Jeffrey 1977). The final code is the International Code of Nomenclature of Bacteria (ICNB) which governs the use of scientific names of those classified as bacteria (Jeffrey 1977).

Taxa at all levels are assigned a scientific name in the universal language of Latin (biological Latin) (Jeffrey 1977). Taxa names at all levels are unique, universal and stable (Mayr and Ashlock 1991). This means that each taxon has one unique universal

Latin name that is used worldwide and is different to all other taxon (Jeffrey 1977; Mayr and Ashlock 1991) for example *Procellaria aequinoctialis* refers to the white-chinned petrel, which is also known as the shoemaker (Murphy 1936). This avoids having to learn vernacular names of animals in various languages to be able to communicate with scientists internationally (Mayr and Ashlock 1991). If several Latin scientific names have been given to a taxon then the valid name is the one with priority, which is the oldest available published name, and the rest are considered synonyms (Jeffrey 1977; Mayr and Ashlock 1991).

At the species taxon level the Latin scientific name is binomial, i.e. consisting of two terms, a generic name and a specific name (Jeffrey 1977; Mayr and Ashlock 1991). The generic name comes first and is the genus in which the species in question is classified and is written with a capital initial letter (Jeffrey 1977; Mayr and Ashlock 1991). The specific name is the second term and is peculiar to the species and is written with a small initial letter (Jeffrey 1977; Mayr and Ashlock 1991). Subspecies are written as a trinomial with a generic, specific, and subspecific name. The subspecific name is peculiar to the subspecies (Jeffrey 1977; Mayr and Ashlock 1991).

Written scientific names of organisms are generally followed by a personal name or names and are termed the authority of the particular name (Jeffrey 1977). The authority of a name is the person who is first published the name and is responsible for both the name and the conditions that make it available (Jeffrey 1977; Mayr and Ashlock 1991). The authority is not part of the name but rather an abbreviated bibliographic reference which adds nomenclatural precision to the species name (Jeffrey 1977). When two names appear connected by 'in', the first name is the authority for the species name in a work edited by the second person (Jeffrey 1977). Also when two names appear connected by 'ex', the first person is the authority of a species name coined by the second person (Jeffrey 1977). If a species taxa generic name changes from one genus to another the original author is still the authority and their name is in parentheses (Jeffrey 1977). Square brackets surrounding an authority indicate that the taxon name was published anonymously, or in citations of synonymy are used to indicate statements of misidentification (Jeffrey 1977).

In taxonomic practice many early species descriptions are quite often not sufficient to establish identity, or a description can apply to several later described species because their specific diagnostic characters were not mentioned in the earlier description (Mayr and Ashlock 1991). Also when a higher taxon is split, which group should retain the species name? A system of reference used to tie taxonomic names to taxa is called type method and the standards are the types (Mayr and Ashlock 1991). Types are 'zoological objects' (Mayr and Ashlock 1991) that are standard references that unknown individuals can be compared with.

There are different kinds of types depending on how they were designated. A holotype is the specimen designated as the type by the original author at the time of publication (Jeffrey 1977; Mayr and Ashlock 1991). A syntype is a series of type specimens used by an author of a name who did not designate a holotype (Jeffrey 1977). A lectotype is a specimen selected from a series of syntypes to be the nomenclatural type (Jeffrey 1977; Mayr and Ashlock 1991). The selection of a lectotype is careful and has to be based on all evidence available at the time of the original publication (Jeffrey 1977). A neotype is a specimen selected to be the nomenclatural type if the original type was lost or destroyed (Jeffrey 1977; Mayr and Ashlock 1991). Again careful selection is needed when selecting a neotype (Jeffrey 1977). Paratypes are specimens used by the original author that were not used as holoyypes or lectotypes (Jeffrey 1977; Mayr and Ashlock 1991).

Taxonomy is important as it orders organic diversity to allow possible scientific explanation (Mayr and Ashlock 1991). Without taxonomy, classification and nomenclature other biological disciplines would be unable to give meaning to their findings (Mayr and Ashlock 1991).

Species Concepts

The branch of taxonomy that looks at taxonomy at the species level is known as Microtaxonomy (Mayr and Ashlock 1991). Microtaxonomy looks at the process of discriminating species, but there is continuing controversy on how species should be discriminated and this has been refered to as the 'species problem' (Mayr and Ashlock 1991; Mayr 1996).

First you need to be able to discriminate between the species as a taxon and as a category (concept) (Mayr and Ashlock 1991; Mayr 1996). Mayr (1996) describes the species taxon as 'a concrete zoological or botanical object consisting of a classifiable population (or group of populations) of organisms' (Mayr 1996). The white-chinned petrel (*Procellaria aequinoctialis*) and the grey petrel (*Procellaria cinerea*) are examples of species taxa. Species taxa are particulars and can therefore be described and delimited against other species taxa (Mayr 1996). The species category 'indicates the rank of 'species' in the Linnaean hierarchy, in other words, species category is the class that contains all taxa of species rank' (Mayr 1996).

Second, Mayr (1996) makes it clear that there are two different sets of species problems within the 'species problem' argument. The first problem is how to define the species, i.e. what species concept to use, and the other problem is how to apply this concept in the differentiation of species taxa (Mayr 1996).

To define a species, species concepts, or ways in which a species is defined are used (Mayr and Ashlock 1991; Mayr 1996). There are four main species concepts; the typological species concept, the nominalistic species concept, the biological species concept, and the evolutionary species concept.

The typological species concept is based on species as 'a class of objects, members of which shared certain defining properties' (Mayr 1996). The criterion for species status is the degree of morphological difference by using a procedure of downward classification (Mayr and Ashlock 1991). The typological species concept has been the traditional decisive criterion of species and was used by naturalists such as Linneaus. However when species were studied more carefully it was found that morphological characters by themselves, were generally unreliable in recognising biological species, and properties were discovered that did not fit a strictly morphological based species concept, such as behavioural and ecological properties (Mayr 1996). Another reason that the typological species concept proved unsatisfactory is that there are numerous morphological types within a species due to life history categories, males, females and immatures, and to genetic variation within individuals (Mayr 1996). The typological species concept has generally been replaced by the biological species concept (Mayr and Ashlock 1991; Mayr 1996).

The nominalistic species concept denies the existence of species in nature and that only individuals exist (Mayr and Ashlock 1991). Species are considered as mental concepts invented to refer to large numbers of individuals collectively (Mayr and Ashlock 1991). However it is known that species of animals are not human constructs and though this concept was popular in France in the eighteenth century it is not readily accepted today (Mayr and Ashlock 1991).

The biological species concept is based on a biological species definition that 'species are groups of interbreeding natural populations that are reproductively isolated from other such groups' (Mayr 1996), and that maintenance and integrity of a populations gene pool via isolating mechanisms is what determines a species (Mayr 1996). Mayr (1996) states that properties of individuals themselves are the isolating mechanism by which reproductive isolation is obtained. Mayr (1996) also states that geographical isolation cannot be considered an isolating mechanism under the biological species concept. For example, Mayr (1996) states that if two populations meet at the same place and same time they either interbreed because they are conspecific or they do not because they are different reproductive communities (isolating mechanisms) i.e. different species. Mayr (1996) then goes on to say a geographically isolated population has these same isolating mechanisms, however they remain 'invisible' as they do not need to be activated, but if the geographical barrier ceased to exist and the population came into contact with another population then the isolating mechanism would be shown. The biological species concept is the most commonly used species concept today.

The evolutionary species concept is based on the definition that 'an evolutionary species is a lineage (an ancestral-descendant sequence of populations) evolving separately from others and with its own unitary evolutionary role and tendencies' (Mayr and Ashlock 1991). This concept was introduced by palaeontologists to deal with the time dimension, in determining fossil species, which is not considered in the biological species concept. Mayr and Ashlock (1991) point out that this concept definition is a definition of a lineage, not of a species, and Mayr (1996) points out that evolving is not a crucial criteria of a biological species, but that protecting its gene pool is.

Generally the most accepted species concept, as indicated by Mayr (1996) is the biological species concept, however ideas mentioned in the other concepts can combine morphology in conjunction with the biological species concept. Mayr (1996) mentions that, under the biological species concept, the degree of morphological difference can be used as an indicator of the underlying degree of reproductive isolation. However, to infer species status you need some sort of 'yard stick' to demonstrate which isolated populations have reached species status and which have not.

Methods of Taxonomy

To apply a species concept to differentiate species taxa you need an understanding of taxonomic techniques. There are several taxonomic methods that are used for describing species taxa including, morphological, molecular, behavioural, and ecological techniques.

By far the oldest and, until recently, a popular technique was the use of morphological techniques to describe species taxa. This involves taking morphological descriptions and measurements of individuals in a population to build up characteristics that make up a population that could then be compared with other similar population's characteristics. The degree of difference between populations gives an indication of whether they are separate species. It is not recommended to base species taxa solely on morphology, as mentioned under the typological species concept (Mayr and Ashlock 1991; Mayr 1996), unless that is all that is available.

In recent years molecular techniques have been the most popular technique used to describe species taxa and with the rapid growth of molecular phylogenetics and increasing ease of sequencing DNA it looks like this is not likely to change (Lee 2004). Molecular techniques involve using microsatellite DNA and gene sequencing (such as nuclear rRNA or mitochondrial cytochrome *b*) of individuals in a population to build up a picture of a populations gene pool (Lee 2004). Then different populations molecular build up can be compared and used to determine if they are different enough to be separate species taxa.

However, using information on a populations molecular build up does not provide any morphological characters for determining species taxa. A combination of morphological and molecular characteristics of populations can provide a method to determine species taxa.

Behavioural techniques involve using behaviours of populations to help describe species taxa. The behaviour of one population can be compared with another to provide an indication of species status.

The ecology, or life history, of a population can be helpful in determining separate species taxa. The time of the breeding cycle can be used to determine if two separate populations are one species taxa or two. Generally if the time of the breeding cycle between two populations differs enough to indicate that the two populations cannot interbreed then it is likely the two populations are separate species. An example is the spectacled petrel *Procellaria conspicillata*, which is closely related to the white-chinned petrel *Procellaria aequinoctialis*, whose breeding cycle is slightly earlier than the white-chinned petrels which led to the spectacled petrel being designated a separate species (Ryan 1998; and Ryan and Moloney 2000).

Therefore when determining what constitutes a species taxon the best approach is to combine morphological (descriptions and measurements), behavioural, molecular (DNA sequencing), and ecological (life history information) information on each population, with an appropriate species concept to determine species taxa status.

1.7.2 Taxonomic review of *Procellaria aequinoctialis*

A review of the taxonomy of the white-chinned petrel *Procellaria aequinoctialis* Linnaeus starts when the species was first described and illustrated by George Edwards in 1747.

1747 – 1900

The first description of the white-chinned petrel *Procellaria aequinoctialis* Linnaeus was published by George Edwards (1747 see Appendix 1.1) in *A Natural History of Birds, Vol. 2*. Edwards (1747) also included a figure of the bird with a full-scale

drawing of the bill. Edwards (1747) describes the bird as having universal blackish brown plumage with a creased or furrowed yellow bill with strongly hooked tip. The nostrils are set together in tubes extending from the forehead along the top of the culmen (Edwards 1747). Edwards (1747) describes the tarsus and feet as black with webs between all toes, and emphasises that there is a little claw at the back of the heel on the foot instead of a back toe. Edwards (1747) also gives two measurements of the length of the bill, from forehead to point 2 inches (50.8 mm) and from the corner of the mouth to the bill point 3 inches (76.2 mm), and a measurement of the length of the wing when closed near 15 inches long (381 mm). Edwards (1747) believed the bird had never been described and named it 'The Great Black Peteril'.

Edwards (1747) likened 'The Great Black Peteril' to 'the *Albatroſs'* (Edwards 1747) (that he also described), based on the shape of the bill, nostrils, and webbed feet, but is a great deal smaller; to 'a *Sea-Gull*' (Edwards 1747) based on physical characteristics; and to 'the *Fulmar*' (Edwards 1747) based on the description of a bird seen off St. Kilda, which he claimed also had a claw rising out of the back of the heel of the foot and had a bill exactly the same shape as 'The Great Black Peteril', though with different plumage.

Edwards (1747) believed 'The Great Black Peteril' and 'the *Fulmar*' were related, belonging in the same family. However, Edwards (1747) description is based on a dead bird that 'came with the *Albatroſs* by an *India* Ship', and it is unclear where the specimen was collected, as he states that 'I am of Opinion it is from the Seas about the Cape of *Good Hope*: I could not gather any more certain Account of its Place' (Edwards 1747). Edwards (1747) makes no mention of any white feathers on the chin and throat area of the bird.

Klein (1750) groups Edward's (1747) 'Great Black Peteril', 'White and Black Spotted Peteril' and 'Little Peteril' under the name 'Plautus Albatroſs ſpurius major'.

Linnaeus (1758 see Appendix 1.2) formally described the genus *Procellaria* in *Systema Naturae 10th edition*. Linnaeus (1758) describes the genus based on physical characteristics of the bill, nostrils and feet, and it seems is based on Edwards (1747) description of 'The Great Black Peteril'. Linnaeus (1758) placed three species within

the genus *Procellaria*. The second species is referenced as Edwards (1747) for which Linnaeus (1758) gives the name *P. aequinoctialis*. Linnaeus (1758) gives a brief description of the species as 'P. fuſca immaculate, roſtro flavo', which approximately translates as uniformly dark coloured with a golden yellow coloured bill, referring to Edwards (1747) as the reference. Linnaeus (1758) did not mention any white feathering on the chin or throat area. Linnaeus (1758) gives the type locality for *P. aequinoctialis* as the Cape of Good Hope without mentioning that Edwards (1747) was not sure of the locality himself.

Brisson (1760) used Edwards (1747) description of 'The Great Black Peteril', Linnaeus (1758) description of *P. aequinoctialis*, Browne's (1756) description of 'Sterna $_2$, the larger dark Petterill, or Shearwater', and Klein's (1750) description of 'Plautus Albatroſs ſpurius major' to give his own account of the bird which he described as 'Le Puffin du Cap de Bonne Esperance'. Brisson (1760) does not mention and white feathering on the underside of the lower mandible. Apparently he never saw the bird (Godman 1907-1910), and cites the type locality as the Cape of Good Hope.

Linnaeus (1766 see Appendix 1.3) published another description of *P. aequinoctialis* in *Systema Naturae* I adding 'pedibus fuſcis' (Linnaeus 1766), which approximately translates as 'dark coloured feet', and 'Narium tubus conſtat cylindris duobus diſtinctis parallelis' (Linnaeus 1766), which approximately translates as 'nostril tubes sit together as two distinct cylinders that are parallel'. Linnaeus (1766) based his description on Edwards (1747), as well as Browne (1756), Brisson (1760), and Redi's dissertation 1674 (which is in fact Lachmund 1674). Linnaeus (1766) repeats the locality for this the type specimen as from the Cape of Good Hope.

Dr. Daniel Solander, a student of Linnaeus, accompanied Captain James Cook as an assistant to naturalist Sir Joseph Banks on his first voyage from 1768-71 (Loomis 1918). Solander noted a large dark coloured petrel in the Antarctic Ocean off Tierra del Fuego at latitude 58°S on February 2nd 1769 and another in the South Pacific Ocean at latitude 44°S longitude 109°W on February 23rd 1769 that were similar to Linnaeus (1758) *P. aequinoctialis*, but had a white interramal patch 'mento albo' (Mathews 1912-13).

Solander named the bird *Procellaria fuliginosa* (nec. Gmelin) and included a simple pencil drawing (No. 19) by Sydney Parkinson of the white interramal patch (Mathews 1912-13).

This is the first mention of white feathering on the chin and throat area of *P. aequinoctialis*. Upon his return Solander compiled his notes on albatrosses and petrels into detailed taxonomic descriptions but died before they were published (Loomis 1918). Solander (Mathews 1912-13) gives a detailed taxonomic description of *P. fuliginosa*, which is noted by Salvin (1896) and Godman (1907-10), but was not published until 1912-13 by Mathews in his second volume of *Birds of Australia* (Mathews 1912-13). Solander listed several measurements including, body length 20 inches (50.8 cm) and bill length 2.2 inches (55.88 mm). However since Solander's work was not published until 1912-13 priority of the name was lost and it is now considered as a synonym for *P. aequinoctialis*.

On Captain James Cook's second voyage from 1772-75, Dr. Johann Forster accompanied Cook as naturalist and collected a specimen of *P. aequinoctialis* on 24 October 1772 in the South Atlantic (Hoare 1982). Forster (Hoare 1982) notes that '*aequinoctialis*' is 'a very improper name, for it is never seen near the equinoctial line and is rather near the tropics to be met with and beyond that' (Hoare 1982). Forster (1844) gives a description of the bird, resembling *P. aequinoctialis,* except that it has a white interramal patch, as noted by Solander on Cook's previous voyage 1769-71, and proposed the name *Procellaria nigra* Forster. Forster (1844) gives a bill length measurement as 2.25 inches (57.15 mm). However because of disagreements with the British Government, Forster's description was not published until 1844 by Dr. Martin Lichtenstein in *Descriptiones Animalium*, and by then the priority of that name was lost (Loomis 1918) and is also now considered a synonym for *P. aequinoctialis*.

Buffon (1783) gave a short description of *Procellaria aequinoctialis* under the name 'Le Petrel-Puffin Brun'. Buffon (1783) also noted Edwards as the initial describer. Buffon (1786) also published the same description under the same name in 1786.

Dr. John Latham published his *General Synopsis of Birds III* in 1785 compiling ornithological work collected on Cooks three voyages. Latham (1785) provided

descriptive information of the birds compiled by other authors rather than following the Linnaean nomenclature code and therefore most of his species names were not accepted (Loomis 1918). Latham (1785) gives a short description of *Procellaria aequinoctialis* as the 'Black Petrel' from a specimen from the Leverian Museum, and includes measurements of body length, 23 inches (58.4 cm) and bill length 3 inches (76.2 mm). The bill length is large, but there is no mention of how it was measured, however it fits a bill length from the corner of the mouth to the tip as measured by Edwards (1747). The specimen is noted for having a large white chin-patch (Latham 1785) which he also notes was found on a bird in latitude 35˚15˚S longitude 7˚45˚W on Cooks third voyage (1776-80), but that bird has both bill and legs black (*Cook's Last Voyage* i. p. 36 - cited in Latham 1785 page 398). Latham (1785) does not mention where the specimen was from, but mentions that they inhabit the Cape of Good Hope 'and neighbouring parts'. Latham (1785) also mentions that these birds have been seen in New Zealand waters (Forster 1777: cited in Latham 1785 page 399). Latham (1785) also lists reference publications by Edwards (1747), Brisson (1760), Linnaeus (1766), and Browne (1756).

Gmelin (1788), Vieillot (1817) and Kuhl (1820) also published accounts of *Procellaria aequinoctialis* however they were unable to be viewed (cited in Salvin 1896).

Stephens (1826) introduces a new name *Puffinus aequinoctialis*, the aequinoctial shearwater, for *Procellaria aequinoctialis*, with the description 'Pu. fuscus immaculatus, rostro flavo, pedibus fuscis' also used by Linnaeus (1758 and 1766). Stephens (1826) referred to Latham's (1785) 'Black and Pacific Petrels' and suggested they both belong to this species, and then gave a description of both. The 'Black Petrel' (Latham 1785) description fits with Linnaeus (1758) description of *Procellaria aequinoctialis*, but with a large amount of white feathering on the chin area. Stephens (1826) lists the 'Black Petrel as inhabiting the Cape of Good Hope and New Zealand'. The description of the 'Pacific Petrel' (Latham 1785) does not fit that of *Procellaria aequinoctialis* and it seems Stephens has grouped two separate species into one under the name *Puffinus aequinoctialis*.

No type specimen had been mentioned for *Procellaria* in either of Linnaeus' publications in 1758 and 1766. Gray (1840) showed that Linnaeus' *Procellaria* was in fact *P. aequinoctialis* (Warham 1990) and gives the type specimen, by subsequent designation, as *Procellaria aequinoctialis* Linnaeus (1758) based on Edwards (1747) description of 'The Great Black Peteril'. This bird may no longer be in existence, making direct comparisons impossible.

White feathering on the interramal or chin area of *Procellaria aequinoctialis* was noted by Gould (1844) where he distinguishes two types of bird, those that have a white-chin patch and those which have a white-chin patch plus white extending onto the head and around the eyes. The latter form Gould (1844) named *P. conspicillata* Gould and distinguished it as a separate species from *P. aequinoctialis*. Gould (1844) considered the birds to be abundant in the Atlantic and Pacific Oceans, particularly in the seas around Australia, though their breeding location is unknown. Gould (1848) figures *P. conspicillata* in Birds of Australia and selects the type locality as Australian seas.

Reichenbach (1853) introduced a new genus, *Majaqueus* Reichenbach, to replace *Procellaria aequinoctialis*. Although no reason for the change is mentioned a likely explanation is that *P. aequinoctialis* was separated into its own genus because it was distinctly different from other species within the *Procellaria* group.

The type of *Majaqueus* as designated by Gray (1840) was *P. aequinoctialis* Linnaeus (1758) (Gray 1855).

Bonaparte (1856) considered Gould's *Procellaria conspicillata* to be a separate species and placed *P. aequinoctialis* and *P. conspicillata* within the genus *Majaqueus* under the names *M. aequinoctialis* and *M. conspicillata*. Bonaparte (1856) gave a short description of *M. aequinoctialis* that included white on the throat 'gula albo', and that they were found in the African and Australian seas. Bonaparte (1856) also gave a short description of *M. conspicillata* that included white on the throat and face 'gulo-genali albis' and that they were found in Australian seas and at Tristan da Cunha.

Coues (1864) provided a detailed description of the genus *Majaqueus*, following Bonaparte (1856), and mentions this genus is easily distinguished from all other Procellariidae by its large size, robust bill and feet, unusually short wings and tail, and dark plumage. Coues (1864) also mentions the two genera *Majaqueus* and *Adamastor* Bonaparte (synonym for *Procellaria cinerea*) are closely related based on the similarity between the bills. Coues (1864) recognises two species within the genus *Majaqueus*, *M. aequinoctialis* and *M. conspicillatus* Bonaparte (Bonaparte (1856) only mentions '*conspicillatus*' as a synomyn for '*conspicillata*'), and according to Schlegel (1863 - cited in Coues 1864 page 117-118) it is differences in size and form that distinguish *M. conspicillatus* from *M. aequinoctialis*.

Coues (1864) considered the white feathering on the throat and cheeks of *Majaqueus aequinoctialis* varied with age. Coues (1864) mentioned that white feathering was seen to extend on to the cheeks on immature birds and adult birds had a perfectly triangular white chin that was not connected with any white feathering on the cheeks. Also immature birds had almost wholly white 'underparts' which darkened to sooty black plumage with age (Coues 1864). Coues (1864) mentioned most naturalists considered the Linnaean name *aequinoctialis* to be 'geographically erroneous', however, he also mentions the limits to Procellariidae range are not fully known and there was no need to change the Linnaean name.

Coues (1864) also considered *Majaqueus conspicillatus* to be larger than *M. aequinoctialis* with a longer more robust bill and bluish black maxillary and mandibular ungues, compared to the yellow ungues of *M. aequinoctialis*. Coues (1864) also noted the wings and tail of *M. conspicillatus* were on average up to an inch longer than *M. aequinoctialis* but there was variation between the species.

Gould (1865) was of the opinion that *M. conspicillatus* is distinct from *M. aequinoctialis* based on white markings on the face around the eyes and the much shorter robust bill. Gould (1865) describes the species as having uniformly sooty black plumage with white on the chin area and across the face in broad bands around the eyes, and with a yellow coloured bill with black along the culmen, maxillary and mandibular ungues tips and along the mandibular groove, and with black feet. Gould (1865) suggests *M. conspicillatus* is found in both the Pacific and Atlantic Oceans

between 25-50°S off St Paul and Amsterdam Islands, Tasmania, the Falkland Islands, and Tristan da Cunha. Gould (1865) also admits that though there are some differences both species are very similar.

Giglioli (1870) recognised *Majaqueus aequinoctialis* and *M. conspicillatus* as separate species based on size, bill colouring, and white feathering on the head. He also stated *M. aequinoctialis* could be distinguished from *M. conspicillatus* but its pale yellow bill, lack of white feathering on the head (only white feathering on the chin and throat area), and its smaller size. Giglioli (1870) considered *M. conspicillatus* to be larger with blackish bill tips and white feathering on the head.

Gray (1871) in his Hand-List of Birds included *Majaqueus* with three species, *M. aequinoctialis*, *M. conspicillatus*, and *M. parkinsoni* Gray. *M. aequinoctialis* was listed as from the South Pacific Ocean, New Zealand, and Isle of Bourbon in the Mascarene Islands. The inclusion of the Isle of Bourbon as a location of *M. aequinoctialis* is unusual as it has not been mentioned in the literature to date.

Kidder (1875) reported five specimens of *Majaqueus aequinoctialis* were collected on Kerguelen Island during the Transit of Venus Expedition 1874-75. The first specimen was collected from 'a very deep burrow under a clump of *Azorella*' on October 12 (October 14th mentioned in table for same specimen) 1874 (Kidder 1875). Further specimens with eggs were collected on December 16 from 'deep burrows, with almost always a little pool of water at their entrance' (Kidder 1875). This is the first mention of breeding location and ecology of *M. aequinoctialis*. A list of measurements (in inches) for two specimens included bill length 2.90 (73.66 mm) and 2.35 (59.69 mm), wing length 15.00 (381 mm) and 15.34 (389.6 mm), and tarsus length 2.50 (63.5 mm) and 2.75 (69.8 mm) (Kidder 1875), although there is no description of how the measurements were taken. The measurements of bill length are vastly different between the two specimens. Kidder (1875) also gave a general description one *M. aequinoctialis* specimen, although they did not mention which, similar to the Linnaeus (1758) description that included 'a white spot around the base of the lower mandible, and for one inch below and behind it' and an unusual mention of 'a small tuft of white feathers on abdomen'. Kidder (1875) also examined stomach contents which included remains of crustaceans and beaks of cephalopods.

Kidder (1876) gave a more detailed description of the eggs of *Majaqueus aequinoctialis* from the Transit of Venus Expedition 1874-75. Kidder (1876) said *M. aequinoctialis* lay a single, white, regularly ovoid egg that is generally covered in secretions from the oviduct and dirt from the burrow. The egg has a thin shell that is compact in structure and smooth to touch, but if viewed under a lens is marked by small pits and shallow depressions (Kidder 1876). Kidder (1876) also lists measurements of seven eggs which range between 3.00-3.32 x 2.10-2.20 inches.

Sydney Parkinson's drawing No. 19, a sketch of the head of a petrel outlined in pencil with the bill carefully coloured, had a single pencil line in the vicinity interramals (Salvin 1876). The label states 'Feb. 2, 1769. Lat. 58°. S. Parkinson' in ink and '*Procellaria fuliginosa*' in pencil (Salvin 1876). Gray (1862) considered it to be a bird without white feathering on the chin and described it as a new species *Procellaria parkinsoni*.

Salvin (1876) however, considered Parkinson's drawing No. 19 to be of *Majaqueus aequinoctialis* with the white interramal patch only indicated by a line. Kuhl (1820) mistakenly applied Solander's *P. fuliginosa* to a specimen in the British Museum (unable to be traced) with a dark coloured bill 'rostro compresso, nigro', which Salvin (1876) said was actually *Oestrelata fuliginosa*. Salvin (1876) mentioned Solander named a bird he caught on 2nd February 1769 with white feathering on the chin area *Procellaria fuliginosa*, and this is now a synomyn of *M. aequinoctialis*. Salvin (1876) therefore considered Parkinson's drawing No. 19, with *P. fuliginosa* on the label, to be of *M. aequinoctialis*.

Salvin (1878) reported five specimens of *Majaqueus aequinoctialis* collected on Kerguelen Island during the Voyage of H.M.S. Challenger 1872-76. Salvin (1878) mentions four males and one female were collected from Kerguelen Island during the Challenger Expedition.

Sharpe (1879) discussed *Majaqueus aequinoctialis* beginning with a description of a bird collected from Kerguelen Island during the Transit of Venus Expedition 1874-75, that had well developed white feathering on the chin area that extended onto the cheeks. Sharpe (1879) compared the size of white on the chin with specimens from

the Pacific Ocean, the white on the chin was very small (he considered the locality was 'doubtless erroneous'), and the Cape of Good Hope, where the white on the chin was large and extends on to the cheeks. Based on the difference in white chin size of *M. aequinoctialis* and variations of the white markings on the face of *M. conspicillatus*, Sharpe (1879), did not consider *M. conspicillatus* distinctly different from *M. aequinoctialis*, however he mentions that naturalists such as Gould and Coues did consider them separate species. Sharpe (1879) included a description of the burrow and nest chamber of *M. aequinoctialis*, as well as a description of birds with no white chin patch written by Rev. A. E. Eaton. Eaton also mentions the first use of the now widely used term 'white-chinned petrel' to describe *M. aequinoctialis* (Sharpe 1879). Sharpe (1879) also gave an extensive list of references including all those mentioned above.

Between 1880-1895 the taxonomic status of the white-chinned petrel remained as *M. aequinoctialis*. Naturalists working in different parts of the world found it difficult to communicate with each other, and so a single species could be published under various names that were all synonyms of the first published name. Heine and Reichenow (1890), in a very short description, published a new genus, *Cymatobolus* Reichenow for a specimen they claimed came from the Australian seas that resembled *conspicillatus*. Heine and Reichenow (1890) also showed that they think the bird belongs in the genus *Majaqueus* but they are not sure. *Cymatobolus* is now considered a synonym of *Procellaria*. Most publications during this time were short descriptions of the genus (e.g. Buller 1888), or accounts of where birds had been sighted.

Buller (1893a; 1893b) gave the first account of *M. aequinoctialis* on Auckland Islands, and Hutton (1895) gave the first account of *M. aequinoctialis* from Antipodes Islands. Hutton (1895) mentioned that Antipodes Island birds had white on the chin but no white markings on the face.

Salvin (1896) further described *M. aequinoctialis*, with an extensive list of references but did not include Linnaeus' (1758) paper on *P. aequinoctialis*. Instead he included Linnaeus' (1766) publication. Salvin (1896) mentioned the white-chin that can extend onto the face and that various amounts of the maxillary and mandibular tip are black. Salvin (1896) also gave a short account of *M. conspicillata* stating that it is not a

distinct species as proposed by Gould (1844). Along with a description of *M. aequinoctialis* is a list of where skins had been collected, including the Cape of Good Hope, Cape Seas, Southern Ocean, Kerguelen Islands, Australian Seas, New Zealand, and Valparaiso from various dates between 1847-1882 (Salvin 1896).

1901 – Present

Buller (1905) described *M. aequinoctialis* from Auckland Islands and gives an account of birds from the Kerguelen Islands, including nesting habits and notes on the breeding season. Buller (1905) also mentions *M. conspicillata* with reference to Salvin (1896) that it is not a distinct species.

Godman (1907-10) gives a general account of the literature on *M. aequinoctialis* from Edwards (1747) to his publication in 1907-10, working closely with Osbert Salvin. He also did not include Linnaeus' (1758) paper on *P. aequinoctialis* but did cite Linnaeus' (1766) where he mentions that Linnaeus (1766) based his *P. aequinoctialis* description on Edwards (1747) and Brisson (1760). Godman (1907-10) is incorrect as Linnaeus (1758) based his original description solely on Edwards (1747) description of 'The Great Black Petrel'. He however noted that Linnaeus (1766) gave no indication of a white feathering on the chin area. Godman (1907-10) gave a description of *M. aequinoctialis* with measurements of birds from the Cape of Good Hope and of breeding localities and behaviour.

Godman (1907-10) noted that the amount of white on and around the chin area is a variable character with the amount of white on the chin generally increasing with the eastward distribution of the species, till, in Australian specimens white extends from the chin onto the cheeks with two white bands around the eyes on the head. He suggests birds from the Cape seas and South Indian Ocean have a large amount of white on the chin area that sometimes extends asymmetrically onto the cheeks; those from Auckland Islands and Chile have a small amount of white on the chin area; while those from Australia have white on the chin and extending onto the face in bands behind the ears and eyes (Godman 1907-10). Godman (1907-10) examined several specimens of *M. aequinoctialis* and the form *M. conspicillata*, considered distinct by Gould (1844), Coues (1864), Giglioli (1870) and Reichenow (1908).

But Godman (1907-10) was unable to separate the two species, as was Salvin (1896), noting that intermediate forms exist and that the white on the head of Australian birds varied considerably. Godman also compared the size of *M. aequinoctialis* and *M. conspicillata*, after Giglioli (1870) considered *M. conspicillata* to be larger, and noted that there was no difference in size between the two species. Godman (1907-10) and Salvin (1896) both reached the conclusion that despite variations in the amount of white on the chin the two forms were really one species, *M. aequinoctialis*, and therefore disagreed with Gould (1844).

As previously mentioned Gray (1840) showed that Linnaeus' (1758) *Procellaria* description is of *P. aequinoctialis* (Warham 1990). *Procellaria* was used before *Majaqueus* and therefore has priority. By the time Mathews' Birds of Australia (1912-13) was published *Majaqueus aequinoctialis* was changed back to *Procellaria aequinoctialis*. Mathews (1912-13) mentioned that the Linnaeus' (1758) *P. aequinoctialis* did not have white feathering on the chin area, yet no birds had been collected without white chins, and questioned whether the *P. aequinoctialis* should be used for all white chin variations. Mathews (1912-13) suggested that *P. aequinoctialis* could be separated into five races or subspecies on the basis of size of the white chin, the opposite conclusion to that reached by Salvin (1896) and Godman (1907-10).

Mathews (1912-13) further suggested that the specimen of *P. aequinoctialis* described by Linnaeus (1758) was likely to have come from the South Atlantic, near South Georgia or the Falkland Islands, as he mentions these birds closely resemble the Linnaeus (1758 see appendix) bird by all have small white chins. He therefore suggested using *aequinoctialis* for the South Atlantic form naming it the sub species *P. aequinoctialis aequinoctialis*, with the type being Linnaeus (1758) (Mathews 1912-13). He suggested these birds have small white chins and breed at South Georgia and Falkland Islands (Mathews 1912-13). Mathews (1912-13) also mentioned that Forster (1844) described a bird resembling Linnaeus (1758) description of *P. aequinoctialis*, but with a white chin, of which he suggests *P. nigra* as a more appropriate name. Mathews (192-13) suggests *P. nigra* was meant to be the new name for *P. aequinoctialis* and groups it with *P. a. aequinoctialis* with the type locality therefore as the Falkland Islands.

The second sub species Mathews (1912-13) suggests is *P. a. mixta* with the type specimen in Mathew's collection. He suggests these birds have large white chins with some white extending on to the cheeks, usually unsymmetrical, and they breed in the South Indian Ocean at Kerguelen and Crozet Islands (Mathews 1912-13).

Mathews considered the spectacled form of *P. aequinoctialis* as the third sub species giving it the name *P. a. conspicillata* with the type locality as the Australian Seas (Mathews 1912-13). These birds he suggests as having a white chin with white extending onto the face around the eyes joining on the top of the head have black maxillary and mandibular ungues tips and are quite distinct from the other sub species, with no information known on breeding location.

The fourth sub species Mathews (1912-13) suggests is *P. a. brabournei* and refers to the birds of the west coast of South America. This form Mathews (1912-13) suggests was originally described by Solander in 1769 while on Captain James Cook's first voyage as *P. a. fuliginosa*. These birds Mathews (1912-13) suggests have small to medium white chin spots, with the breeding place unknown.

The fifth sub species Mathews (1912-13) suggests is *P. a. steadi* (see Appendix 1.4) with the type specimen from Antipodes Island (in Mathew's collection) and found in seas around New Zealand. He suggests these birds have very small white chins and they breed in the South Pacific Ocean at Auckland and Antipodes Islands (Mathews 1912-13). For the sub species *P. a. steadi* Mathews (1912-13) gives a general description of the bird, with a figure, and a little information on habitat and breeding ecology, including, he suggests the breeding season as 'December' (Mathews 1912-13).

Carter (1913) published a confusing short note in Emu of observations of *P. aequinoctialis* in the Southern Indian Ocean. Carter (1913) confirmed his observations as the new sub species *P. a. mixta* of Mathews (1912-13) of which he then call spectacled petrels. He noted that they were common around the Crozet Islands and 'spectacled petrels that were under observation, not a single bird was seen with any white on the plumage except the chin spot, and this varied considerably in

extent' (Carter 1913). It seems as if Carter (1913) mixed up two of Mathews (1912-13) sub species.

Mathews and Iredale (1913) published a reference list of New Zealand birds with the white-chinned petrel still as sub species *Procellaria aequinoctialis steadi* Mathews.

Iredale (1913) after examining birds held in the Vienna Museum suggested that the *P. a. conspicillata* of Mathews (1912-13) should be recognised as a distinct species *P. conspicillata* as intended by Gould (1844). He then went on to suggest that there were two races or sub species of *P. conspicillata* based on the extent of white on the head and their location. The first is *P. c. conspicillata* Gould which has a white chin that extends on to the face around the eyes connecting on the top of the head and is found in Australian Seas, with breeding place unknown (Iredale 1913). The second is *P. c. larvata* Lesson which has a white chin and white on the face in loop in front and under the eyes and does not connect on the top of the head or to the white chin, and is found in the South Atlantic, with breeding place also unknown (Iredale 1913).

Loomis (1918) does not agree with Mathews (1912-13) or Iredale (1913) as in his publication of a review of the albatrosses, petrels and diving petrels he groups *P. aequinoctialis* and *P. conspicillata* as one species *P. aequinoctialis*. However Loomis (1918) only references Coues (1864), Salvin (1896) and Godman (1907-10).

Mathews and Iredale (1921) based on Iredale (1913), considered *P. aequinoctialis* and *P. conspicillata* separate species in their list of Australian Birds. They considered there were four sub species of *P. aequinoctialis* based on white chin size; *P. a. aequinoctialis* from South Atlantic, *P. a. mixta* from Cape Seas, *P. a. brabournei* from west coast of South America, and *P. a. steadi* from New Zealand as mentioned in Mathews (1912-13) (Mathews and Iredale 1921). Mathews and Iredale (1921) also considered two sub species within *P. conspicillata* based on arrangement of white on the face (see Iredale 1913 for descriptions); *P. c. conspicillata* from the Australian Seas, though they question this locality as 'no authentic specimens known' (Mathews and Iredale 1921) which they also label as from the Cape Seas, and *P. c. larvata* from the Cape Seas.

Dabbene (1923) published a classification of albatrosses and petrels, along with a key, for all species in the South Atlantic Ocean off South America. The white-chinned petrel is classified *P. a. aequinoctialis*, from Mathews (1912-13), with distribution noted as Atlantic Ocean into Antarctic waters around South America and South Georgia (Dabbene 1923). Dabbene (1923) noted that the type location as designated by Linnaeus (1758) was the Cape of Good Hope, and that Mathews (1912-13), however, considered the type location of *P. a. aequinoctialis* to be South Georgia and the Falkland Islands. Dabbene (1923) therefore changed the type locality from the Cape of Good Hope to South Georgia keeping the type specimen as Linnaeus (1758). Dabbene (1923) gives an extensive list of publications and sighting locations of *P. a. aequinoctialis* for the various synonyms previously mentioned and also mentions the distribution of birds in South Indian Ocean and Australian waters, however he does not mention *P. conspicillata*, suggesting that it has been grouped under *P. aequinoctialis*.

Mathews (1927) published a systematic list of the birds of Australia suggesting *P. aequinoctialis* and *P. conspicillata* are separate species. Mathews (1927) suggests two sub species of *P. aequinoctialis* in the Australian Seas; *P. a. aequinoctialis* off the west of Australia in the Cape Seas, and *P. a. steadi* in South East Australian Seas and New Zealand Seas. Mathews (1927) groups *P. c. conspicillata* and *P. c. larvata* into the species *P. conspicillata* and suggests an error in the location that they do not occur in Australian Seas but occur in Cape Seas or the Cape of Good Hope. Mathews (1928) supports his findings on *P. conspicillata* in his 1927 publication that the locality is not the Australian Seas, as he mentions 'I have never heard of an authentic occurrence of *conspicillata* in Australian waters' (Mathews 1928) and 'Gould's 'Australian Seas' practically meant 'south of the line'' (Mathews 1928). Mathews (1928) mentions the location is most likely the Cape Seas and therefore removes *P. conspicillata* from the Australian List of Birds.

Oliver (1930) gives a brief account of Edwards (1747) first describing 'the Great Black Peteril' and Linnaeus (1758) giving the scientific name as *P. aequinoctialis* and considers the Cape of Good Hope as the locality of where it was found, not referring to the fact that Edwards (1747) did not know himself. Oliver (1930) considers the white-chinned petrel to be *P. aequinoctialis*, but gives a small section on forms based

on white chin size using Mathews (1912-13) and Mathews and Iredale (1921) four sub species, with *P. a. steadi* the form Oliver (1930) found in New Zealand. Oliver (1930) however does not agree that *P. conspicillata* is a separate species or even sub species but rather a 'mutation' (Oliver 1930) of *P. aequinoctialis*. Oliver (1930) gives a description of the species as well as distribution, concentrating on New Zealand Auckland and Antipodes Islands, and breeding habits of a species to which he gives the name *P. a. steadi*.

Murphy (1936) disagrees entirely with Mathews (1912-13) that size of the white chin and locality of birds separates them into races or sub species. Murphy (1936) points out that the white chin size varies between birds in all populations and that geographical variation shows no significant difference in white chin size and as an example gives white-chinned petrels off Valparaiso where some have a trace of white to all black chins (birds collected by Beck in 1913) and others have the chin entirely white. Murphy (1936) considers the race *conspicillata* to be a 'phase' of *P. aequinoctialis* and he groups them together as one species. Murphy (1936) notes that Linnaeus (1758) *P. aequinoctialis* described no white chin and the birds he examined from South Atlantic off South America, South Pacific off west South America, and from Australian Seas varied from large white chins to no white on the chin at all proving that they exist. Murphy (1936) gives a detailed account of *P. aequinoctialis* at South Georgia and includes distribution information on birds at Falkland Islands and Sub Antarctic New Zealand Islands.

Falla (1937) agrees with Murphy (1936) that variation in white chin size varies in each population and that there is only one species of *P. aequinoctialis* and it has considerable variation in size of the white chin in each population. Falla (1937) examined birds primarily from Kerguelen but also from New Zealand and Valparaiso, South America, and concluded that 'no two are exactly alike' (Falla 1937) and there seems to be no evidence for uniformity within populations, especially not enough to distinguish sub species. Falla (1937) gives some information on breeding biology of birds at Kerguelen Islands and sightings of birds at sea with variable white chins.

Mathews and Hallstrom (1943) give notes on Procellariiformes and consider the white-chinned petrel as *P. aequinoctialis*. They give measurements of birds from

South America but do not include any information on birds from the South Pacific or South Indian Ocean (Mathews and Hallstrom 1943).

Rowan *et al.* (1951) again raised the question of whether the spectacled form of *P. aequinoctialis* is a separate species. The spectacled form of *P. aequinoctialis* were found to breed at Inaccessible Island in the 1920's and found to stay around the breeding ground all year (Rowan *et al.* 1951). Rowan *et al.* (1951) also noted that only spectacled forms were found breeding at Inaccessible Island. They also noted that the spectacled form was smaller than the white-chinned form and their nesting habits were also different from the white-chinned form (Rowan *et al.* 1951). Based on these features Rowan *et al.* (1951) consider the spectacled form to be a sub species of *P. aequinoctialis*, *P. a. conspicillata*.

In Oliver (1955) second edition of New Zealand Birds he gives the white-chinned petrel as *P. a. aequinoctialis* and agrees with Murphy (1936) that the white chin is variable in all populations and therefore assumes *P. a. aequinoctialis* as a single global species.

Bailey and Sorensen (1962) consider the white-chinned petrel in New Zealand waters to be the subspecies *P. a. steadi.* They found a small colony on Campbell Island, New Zealand, in 1943 and give a description of the bird with external measurements (Bailey and Sorensen 1962).

Mougin (1970) mentions that the systematics of the time considers *P. aequinoctialis* to comprise two subspecies, *P. a. aequinoctialis* and *P. a. steadi* (the New Zealand variation). He however suggests that there are problems with the systematics and both sub species should be combined as one species *P. aequinoctialis* (Mougin 1970). Mougin (1970) gives measurements of birds from all breeding locations in the South Pacific, South Atlantic and South Indian Ocean and mentions all are similar is size. He concentrates ecology and breeding biology of birds from the Crozet Islands and compares results found with those of other breeding localities (Mougin 1970).

Kinsky (1970) in the Checklist of New Zealand Birds considers the New Zealand form of the white-chinned petrel to be *P. a. steadi* based on Mathews (1912-13) description of the sub species.

Serventy *et al.* (1971) considered the white-chinned petrel to be one species *P. aequinoctialis* that breeds at various locations in the Southern Oceans and conspicillata as a form of *P. aequinoctialis* rather than a full sub species, though they mention *P. aequinoctialis* is uncommon in Australian waters. They give a description of the species with breeding locations (Serventy *et al.* 1971).

Mayr and Cottrell (1979) consider the white-chinned petrel *P. aequinoctialis* to be two distinct sub species, *P. a. aequinoctialis* and *P. a. conspicillata. Procellaria a. aequinoctialis* was considered to be the actual white-chinned petrel, with no white on the head, which have breeding locations in all Southern Oceans, but were all similar in morphological characteristics (Mayr and Cottrell 1979). *Procellaria a. conspicillata* was the spectacled form with white extending onto the head and around the eyes that breeds only at Inaccessible Island (Mayr and Cottrell 1979).

The third edition of the Checklist of New Zealand Birds by Turbott (1990) suggests the white-chinned petrel in New Zealand is part of global sub species *P. a. aequinoctialis* as mentioned by Mayr and Cottrell (1979). This suggests the white-chinned petrel is distinctly separate from the other sub species *P. a. conspicillata,* the spectacled petrel (Turbott 1990).

Marchant and Higgins (1990) and del Hoyo *et al.* (1992) both consider *P. aequinoctialis* as a species but mention that the two variations in form are considered sub species. These sub species are as mentioned by Mayr and Cottrell (1979) and Turbott (1990) are *P. a. aequinoctialis*, the white-chinned petrel, and *P. a. conspicillata*, the spectacled petrel (Marchant and Higgins 1990; del Hoyo *et al.* 1992). Both give descriptions of *P. aequinoctialis* including ecology and breeding biology (Marchant and Higgins 1990; del Hoyo *et al.* 1992).

The general notion from 1971 to 1998 suggested that *P. aequinoctialis* was distinctly divided into two sub species, *P. a. aequinoctialis* the white chinned petrel, and *P .a.*

conspicillata the spectacled petrel based primarily on physical characteristics. The perception of *P. a. conspicillata* being significantly different was confirmed by Ryan (1998).

Ryan (1998) backed up the notion of the spectacled form of *P. aequinoctialis* being a sub species and noted that the Inaccessible Island birds have unique plumage of white on the head around the eyes, are smaller in size than the general *P. aequinoctialis*, they breed earlier than *P. aequinoctialis*, and they are 'vocally distinct from white-chinned petrels' (Ryan 1998). Based on this information Ryan (1998) argues that they should be considered a separate species, *P. conspicillata*. Ryan (1998) also notes that the population size is small with very little information known on ecology and breeding biology. The spectacled petrel is now a recognised species separate from *P. aequinoctialis* as shown by Ryan and Moloney (2000) based on features noted by Ryan (1998).

The separation of the spectacled petrel *P. conspicillata* by Ryan (1998) and Ryan and Moloney (2000) as a separate species changed the status of the white-chinned petrel back to *P. aequinoctialis*. The current taxonomic definition of a white-chinned petrel in 2003 is of a global taxon *Procellaria aequinoctialis*, which includes birds from all breeding locations in the South Indian, South Atlantic and South Pacific Oceans.

1.8 PROCELLARIA AEQUINOCTIALIS

1.8.1 Features of the global *Procellaria aequinoctialis* taxon

Currently the white-chinned petrel *Procellaria aequinoctialis* Linnaeus, or shoemaker as is known to sailors (Murphy 1936), is described as a large robust, heavy built, petrel with uniform sooty black plumage (Murphy 1936; Oliver 1955; Serventy *et al.* 1971; Imber 1985b; Lindsey 1986; Marchant and Higgins 1990; Warham 1990; del Hoyo *et al.* 1992; Endicott and Tipling 1997), fading to blackish-brown with wear, especially on the belly, breast, vent and flanks (Murphy 1936; Imber 1985b; Marchant and Higgins 1990; Endicott and Tipling 1997). The wings and tail (slightly wedge-shaped) are black, and can fade to a blackish-brown colour with wear. The underwing

when in flight can appear silvery according to lighting (Marchant and Higgins 1990; Endicott and Tipling 1997).

The bill is large and robust with a heavily hooked maxillary unguis, large in proportion to the rest of the bill (Murphy 1936; Marchant and Higgins 1990; Warham 1990; Endicott and Tipling 1997; Shirihai 2002). The two nasal tubes are set together in a case on top of the culmen, at its base, and are separated by the nasal septum (Marchant and Higgins 1990; Warham 1990; Heather and Robertson 2000). The nostrils are prominent and open forwards with rounded apertures (Warham 1990). The bill is pale yellow, straw coloured, or blue to greenish horn, sometimes appearing almost white or cream, on the nostrils, latericorn, ramicorn, and on both maxillary and mandibular ungues (Murphy 1936; Oliver 1955; Serventy *et al.* 1971; Imber 1985b; Marchant and Higgins 1990; del Hoyo *et al.* 1992; Shirihai 2002), and black or bluish-black on the naricorn around the nostrils, on the culminicorn, along the mandibular sulcus (groove) (Murphy 1936; Oliver 1955; Serventy *et al.* 1971; Imber 1985b; Lindsey 1986; Marchant and Higgins 1990; Warham 1990; Endicott and Tipling 1997), and at the tip of the maxillary unguis (Murphy 1936; Serventy *et al.* 1971; Imber 1985b). Occasionally the mandibular unguis is black or bluish black at the tip.

The legs and feet are black (Murphy 1936; Oliver 1955; Serventy *et al.* 1971; Imber 1985b; Lindsey 1986; Marchant and Higgins 1990; Endicott and Tipling 1997) with 'long, sharp and flinty claws' (Murphy 1936).

There is a patch of white feathers on and around the chin and throat area that varies in size from very large, covering the whole chin and extending slightly onto the cheeks, to being generally small and inconspicuous (Plates 1.3-1.5) (Murphy 1936; Oliver 1955; Serventy *et al.* 1971; Imber 1985b; Marchant and Higgins 1990; Warham 1990; del Hoyo *et al.* 1992; Endicott and Tipling 1997; Shirihai 2002) and even entirely absent (Plate 1.2) (Serventy *et al.* 1971; Imber 1985b; Endicott and Tipling 1997). Mathews (1912-13) noted birds from the South Indian Ocean, Kerguelen Island, had large amounts of white on the chin slightly extending onto the side of the face while birds from the South Pacific, Antipodes and Auckland islands and South Atlantic, South Georgia, had small amounts of white on the chin. Birds in the New Zealand

region, South Pacific, are noted for having only a small amount of white on the chin (Warham and Bell 1979) with occasional birds having no white at all (Oliver 1955; Imber 1985b; Marchant and Higgins 1990; Warham 1990).

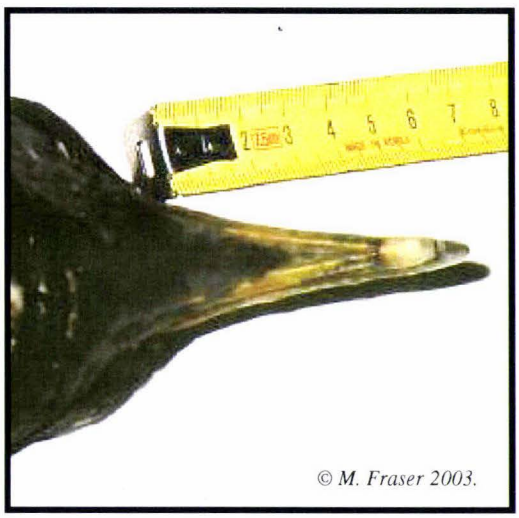

Plate 1.2 Underside of a white-chinned petrel bill showing an individual with no white chin.

Plate 1.3 Underside of a white-chinned petrel bill showing a small white chin (arrowed).

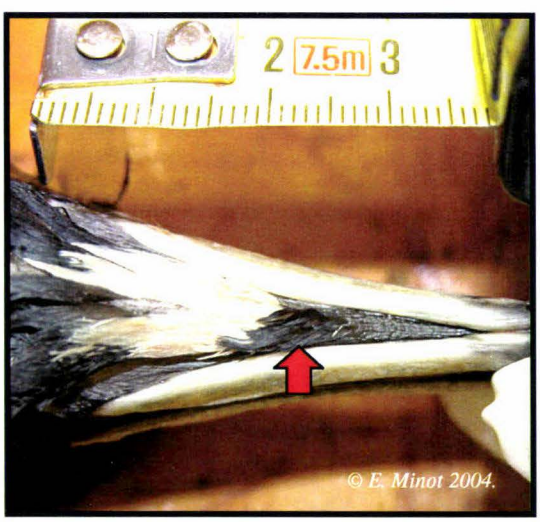

Plate 1.4 Underside of a white-chinned petrel bill showing a large white chin with a large black tip (black tip arrowed).

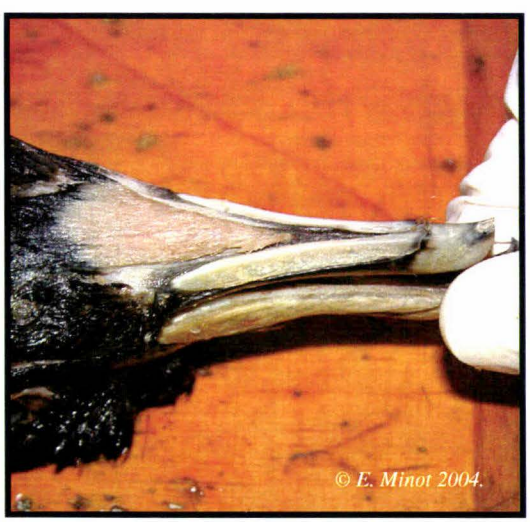

Plate 1.5 Underside of a white-chinned petrel bill showing a large white chin.

White-chinned petrels feed on predominantly cephalopods and fish, crustaceans, such as krill *Euphausia* spp, large amphipods and shoaling crabs, and offal from fishing vessels (Oliver 1955; Mougin 1970; Serventy *et al.* 1971; Imber 1976; Croxall and Prince 1980; Imber 1985b; Lindsey 1986; Jackson 1988; Croxall *et al.* 1995; Shirihai 2002). Breeding white-chinned petrels at the Crozet Islands (Mougin 1970), Auckland and Campbell Islands (Imber 1976), and at South Georgia (Croxall and Prince 1980) feed predominantly on cephalopods with some crustaceans and fish taken as well.

However Croxall *et al.* (1995) found that at South Georgia breeding white-chinned petrels fed predominantly on crustaceans and fish with some cephalopods taken. Adult white-chinned petrels are also known to take offal and baits from fishing vessels, where they are often killed, in the South Indian Ocean (Cherel *et al.* 1996; Barnes *et al.* 1997; Ryan 1999; Weimerskirch *et al.* 1999; Robertson *et al.* 2003b), the South Atlantic Ocean (Ashford *et al.* 1994; Ashford *et al.* 1995; Weimerskirch *et al.* 1999; Robertson *et al.* 2003b), and the South Pacific Ocean (Bartle 1990; Robertson *et al.* 2003a; Robertson *et al.* 2003b). Jackson (1988) found that non-breeding white-chinned petrels throughout the year in the Southern Benguela region fed predominantly on offal off the back of trawlers. Shirihai (2002) claims that during the breeding season white-chinned petrels feed predominantly on cephalopods with some fish, crustaceans and offal while during the non-breeding season rely more on fish and offal.

Food is taken by mostly by surface-seizing or surface-diving (Harper 1987; Marchant and Higgins 1990; Shirihai 2002), deep-plunging up to 13 metres (Huin 1994) and pursuit-plunging (Harper *et al.* 1985; Harper 1987; Marchant and Higgins 1990; Shirihai 2002). Imber (1976) showed that white-chinned petrels also forage at night and may obtain most of their natural prey during this time and produced the hypothesis that they be detecting prey at night by bioluminescence. Barnes *et al.* (1997) found that white-chinned petrels were the only birds caught when longlines were set at night. Food is located strongly by scent (Lequette *et al.* 1989; Marchant and Higgins 1990; Shirihai 2002) but may also be by prey bioluminescence at night (Imber 1976).

1.8.2 Distribution and breeding locations of *Procellaria aequinoctialis*

Information on distribution of white-chinned petrels during the breeding and non-breeding seasons is based on distribution of the species as one population. White-chinned petrels have a circumpolar distribution (Plate 1.6) (Marchant and Higgins 1990; del Hoyo *et al.* 1992; Endicott and Tipling 1997), being marine pelagic in Antarctic, subantarctic and sub-tropical waters in the Southern Ocean, Southern Indian, Pacific and Atlantic Oceans (Oliver 1930; Murphy 1936; Hall 1987; Harper 1987; Marchant and Higgins 1990; del Hoyo *et al.* 1992).

During their breeding season in summer white-chinned petrels are widespread through the Southern Ocean from the Subantarctic Zone at about 55°S to Subtropical Convergence 42°S and extending up to 30-35°S in the South Indian, Atlantic and Pacific Oceans (Marchant and Higgins 1990). White-chinned petrels are less common in the Antarctic Zone 60°S occasionally reaching the edge of the ice pack during the summer months (Murphy 1936). White-chinned petrels are abundant around breeding grounds in the South Indian, South Atlantic and South Pacific Oceans, concentrating on areas of high productivity on offshore ocean shelves often with numerous other birds (Marchant and Higgins 1990).

Murphy (1936) mentions white-chinned petrels have been observed on the west coast of South America in the Humboldt Current up to 6°S throughout the year. Ashford *et al.* (1994) observed white-chinned petrels in waters off the South Sandwich Islands and South Georgia towards the end of the breeding season in February and March.

Falla (1937) found white-chinned petrels abundant in spring to summer from Cape Town to the pack-ice and through the southern Indian Ocean into the Southern Ocean but not further south than 61°S. Barnes *et al.* (1997) observed white-chinned petrels from fishing vessels on the Agulhas Bank off Cape Town at the beginning of the breeding season between October and December and Cherel *et al.* (1996) observed large numbers of white-chinned petrels from fishing vessels in waters around the Kerguelen Islands at the end of the breeding season in February. White-chinned petrels are present in waters around the Prince Edward Islands from October to June based on birds caught on longlines during that period (Ryan 1999).

Falla (1937) noted that white-chinned petrels were less common in Australian waters in early summer (November) between Hobart and Macquarie Island and Blaber (1986) noted white-chinned petrels were present is low numbers off the south east coast of Tasmania in April.

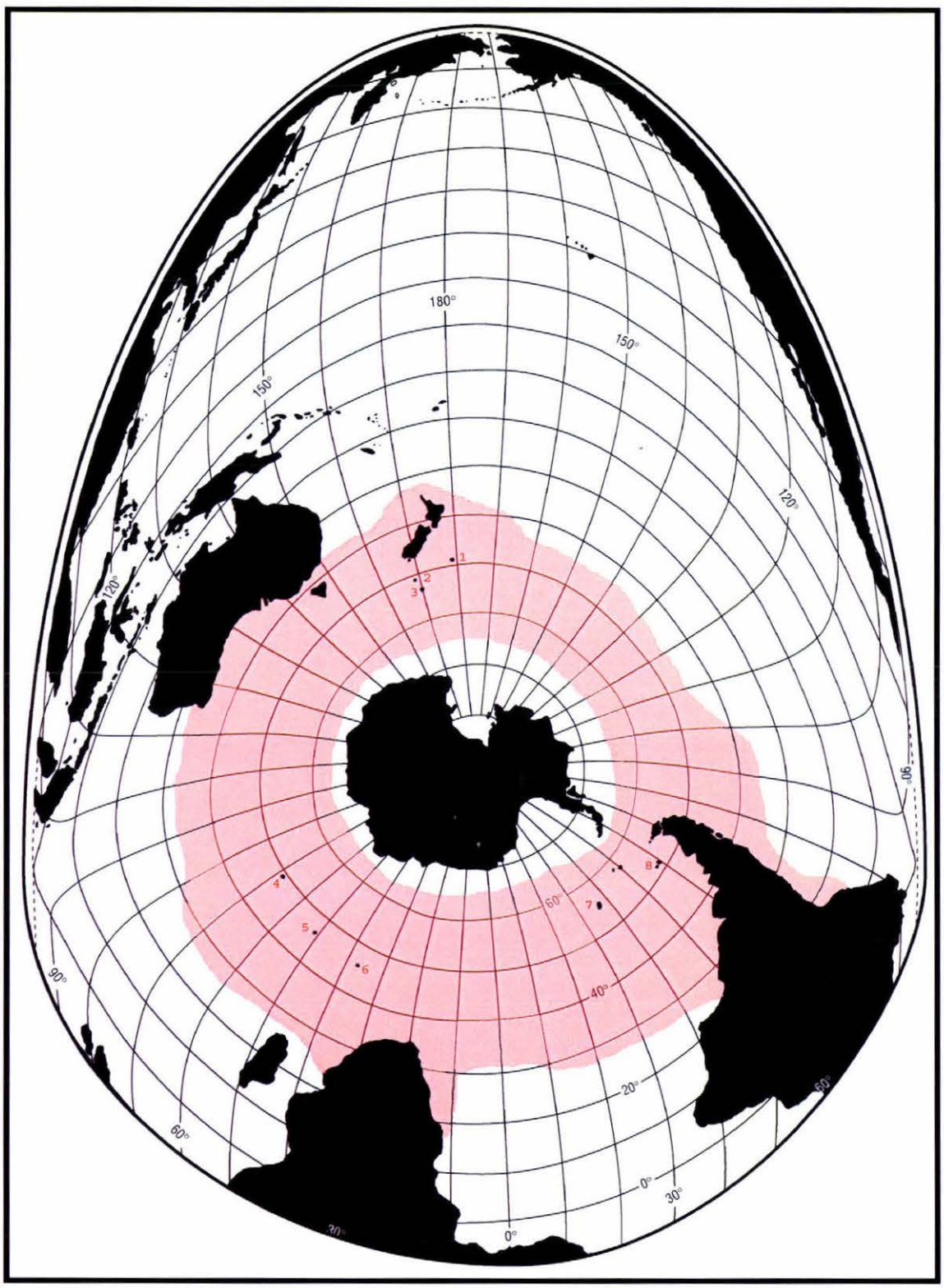

Plate 1.6 Global distribution of white-chinned petrels showing breeding island locations, based on Marchant and Higgins (1990). 1 = Antipodes Island; 2 = Auckland Islands; 3 = Campbell Island; 4 = Kerguelen Islands; 5 = Crozet Islands; 6 = Marion and Prince Edward Islands; 7 = South Georgia; and 8 = Falkland Islands.

Gales *et al.* (1998) noted white-chinned petrels were present in waters off south Western Australia and Tasmania during the summer. Vooren (1973) noted white-chinned petrels were common in the South Pacific on the Pukaki Rise in December. White-chinned petrels are common in New Zealand waters between the Chatham Rise and the Auckland Islands during the breeding season determined from location of fisheries bycatch birds (Robertson *et al.* 2003a).

Marchant and Higgins (1990) consider white-chinned petrels to be migratory. During the non-breeding season in winter they move into subtropical waters mostly north of 44°S over continental shelves along the west coast of South America up the Humboldt Current to 6°S (Marchant and Higgins 1990; Endicott and Tipling 1997), along the entire coast of South Africa up to 12°S along the Benguela Current (Marchant and Higgins 1990; Endicott and Tipling 1997), and along the south Australian coast up to 33°S in the Tasman Sea (Marchant and Higgins 1990).

At the Crozet Islands white-chinned petrels have not been observed ashore during the non-breeding season (Jouventin *et al.* 1985). However Murphy (1936) found that white-chinned petrels were present in South Georgian waters and in the Humboldt Current on west coast of South America all year round. Ashford *et al.* (1995) also observed white-chinned petrels in waters south of South Georgia at the end of the breeding season and into the non-breeding season in April to May. Jehl (1973) recorded regularly sighting white-chinned petrels 5 to 200 miles off the west coast of South America between Golfo de Trinidad and Valparaiso from mid May to early July 1970 and also mentions they 'seemed to avoid waters close inshore, where sooty shearwaters were common' (Jehl 1973). Gales *et al.* (1998) recorded white-chinned petrels in the waters off south eastern Australia in winter and Robertson *et al.* (2003a) recorded a few white-chinned petrel fisheries bycatch birds caught in New Zealand waters on the Bounty Platform and Pukaki Rise during winter.

There is little known on dispersal of white-chinned petrels from each of the breeding populations in the South Indian, South Atlantic and South Pacific Oceans during the breeding and non-breeding seasons, except that Croxall and Prince (1980) estimate a maximum foraging range from breeding islands during summer at 1650 km. Weimerskirch *et al.* (1999) satellite tracked six birds during the breeding season at the

Crozet Islands that travelled to the coast of South Africa and as far south as 65°S during the incubation period with the average distance travelled 8355 km and the maximum distance from the nest 2390 km.

Also, satellite tracked birds at South Georgia travel to the east coast of South America off the coast off Argentina during the incubation period with the average distance travelled 6999 km and the maximum distance from the nest 2190 km (Weimerskirch *et al.* 1999). White-chinned petrels tracked using satellite telemetry during the breeding season at South Georgia travel to the Patagonian shelf from the Falkland Islands and to the east coast of South America off Argentina during the incubation period covering 3000-8000 km, and during the chick rearing period still travelled to the Falkland Islands the coast of Argentina but tend to stay closer to Bird Island at South Georgia covering 1100-5900 km (Berrow *et al.* 2000). Berrow *et al.* (2000) also found that white-chinned petrels that had failed breeding attempts travelled to the South Orkney Islands and Falkland Islands and tended to stay in the general vicinity of South Georgia which may indicate that they do not disperse far from the breeding grounds during winter.

White-chinned petrels are summer breeders and have breeding populations at Kerguelen, Crozet and Prince Edward Islands in the South Indian Ocean (Murphy 1936; Falla 1937; Mougin 1970; Imber 1983; Jouventin *et al.* 1985; Marchant and Higgins 1990; del Hoyo *et al.* 1992; Endicott and Tipling 1997; Shirihai 2002), at South Georgia and Falkland Islands in the South Atlantic Ocean (Murphy 1936; Mougin 1970; Hall 1987; Marchant and Higgins 1990; del Hoyo *et al.* 1992; Endicott and Tipling 1997; Shirihai 2002), and at Auckland, Antipodes and Campbell Islands in the South Pacific Ocean (Oliver 1930; Murphy 1936; Falla 1937; Mougin 1970; Warham and Bell 1979; Imber 1983; Imber 1985b; Marchant and Higgins 1990; Endicott and Tipling 1997; Shirihai 2002). White-chinned petrels are the largest burrowing petrels in the world and the breeding season is broadly between September and May (Plate 1.7) (Marchant and Higgins 1990).

White-chinned petrels arrive at breeding grounds from mid September to mid October (Mougin 1970; Warham and Bell 1979; Imber 1985b; Jouventin *et al.* 1985; Hall 1987; Weimerskirch *et al.* 1989; Marchant and Higgins 1990; del Hoyo *et al.* 1992),

and after the pre-laying exodus one egg is laid from early November to mid December (Mougin 1970; Warham and Bell 1979; Imber 1985b; Jouventin *et al.* 1985; Hall 1987; Marchant and Higgins 1990; del Hoyo *et al.* 1992).

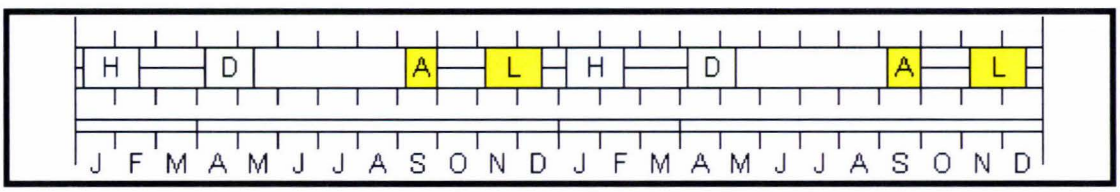

Plate 1.7 White-chinned petrel breeding season, based on Marchant and Higgins (1990). A = arrival; L = laying; H = hatching; and D = departure.

The incubation period is shared by both parents and lasts 57-62 days (Mougin 1970; Jouventin *et al.* 1985; Hall 1987; Marchant and Higgins 1990). Chicks hatch between mid January to late February (Mougin 1970; Warham and Bell 1979; Imber 1985b; Jouventin *et al.* 1985; Hall 1987; Marchant and Higgins 1990; del Hoyo *et al.* 1992) with a long chick rearing period that lasts 87-106 days (Mougin 1970; Jouventin *et al.* 1985; Hall 1987; Marchant and Higgins 1990) after which the adults leave the chicks to fledge by themselves (Imber 1985b; Jouventin *et al.* 1985; Marchant and Higgins 1990; del Hoyo *et al.* 1992).

The hatching period for white-chinned petrels is shorter than the laying period (Mougin 1970; Jouventin *et al.* 1985; Warham 1990) as late layings are usually abandoned during incubation (Mougin 1970; Warham 1990). Chicks fledge independent of adults from early April to May (Jouventin *et al.* 1985; Weimerskirch *et al.* 1989; Marchant and Higgins 1990). The last adults depart after all chicks have fledged in mid May (Jouventin *et al.* 1985).

Little information is known on moult in white-chinned petrels except that it is thought to occur during winter between breeding seasons (Imber 1985b). However, Marchant and Higgins (1990) note that moult occurs during the breeding season with body moult beginning in November followed by wing moult, observed from January to March, and tail moult begins when wing moult almost complete.

The white-chinned petrel can be divided into three geographical groups based on the three ocean sectors in which they have breeding populations (Plate 1.6). The three groups are: the South Indian Ocean group, which includes Kerguelen, Crozet and

Prince Edward Islands; the South Atlantic Ocean group, which includes South Georgia and Falkland Islands; and the South Pacific Ocean group, which includes Auckland, Antipodes and Campbell Islands.

The South Indian Ocean group

White-chinned petrels in the South Indian Ocean have breeding grounds at Kerguelen, Prince Edward and Crozet Islands (Falla 1937; Mougin 1970; Jouventin *et al.* 1984; Williams 1984; Jouventin *et al.* 1985; Weimerskirch *et al.* 1989; Marchant and Higgins 1990). At the Kerguelen Islands the population of white-chinned petrels is estimated at 100 000-300 000 breeding pairs (Weimerskirch *et al.* 1989; Endicott and Tipling 1997). At the Prince Edward Islands the population of white-chinned petrels is estimated at tens of thousands of breeding pairs (Williams 1984; Endicott and Tipling 1997). At the Crozet Islands the population of white-chinned petrels is estimated at tens of thousands of breeding pairs (Jouventin *et al.* 1984; Endicott and Tipling 1997).

White-chinned petrels in the South Indian Ocean are characterised, on average, by a large amount of white on and around the chin area (Sinclair *et al.* 1997) with unsymmetrical patterns of white on the chin extending onto the side of the face (Falla 1937).

White-chinned petrels in the South Indian Ocean are summer breeders with birds returning to breeding grounds at the Kerguelen Islands on 16 September (Weimerskirch *et al.* 1989), at the Crozet Islands on 15 September (Jouventin *et al.* 1985), and at Marion Island 10 September (Marchant and Higgins 1990).

Courtship takes place soon after arrival from mid September to mid October (Jouventin *et al.* 1985). Little is known of the pre laying exodus in the South Indian Ocean, except, that at the Crozet Islands the pre laying exodus lasts an average of 48 days, range 36-68 days, (Jouventin *et al.* 1985). Female white-chinned petrels at the Crozet Islands return at the end of the pre laying exodus in November and lay a single white egg on a raised pedestal in their burrow (Jouventin *et al.* 1985).

The egg laying period at the Crozet Islands is between 8 November and 20 December peaking at 22 November (Jouventin *et al.* 1985). The egg laying period at the Prince Edward Islands is between mid to late November (Brooke 1986). The egg laying period is not known at the Kerguelen Islands. Incubation is shared by both sexes in a number of shifts, with the female starting with a short stint (Jouventin *et al.* 1985; Marchant and Higgins 1990). The average number of shifts for white-chinned petrels at the Crozet Islands is 6-7 with the males averaging 9.5 days (range 5-13 days) per stint and the females averaging 6.1 days (range 1-15 days) per stint (Jouventin *et al.* 1985).

The length of the incubation period at the Crozet Islands is 57-58 days (Jouventin *et al.* 1985). The length of the incubation period is not known for white-chinned petrels at the Kerguelen or Prince Edward Islands. At the Crozet Islands the hatching period is between the 2 January and 16 January (Jouventin *et al.* 1985), and at the Kerguelen Islands hatching occurs in the last two weeks of January (Weimerskirch *et al.* 1989). White-chinned petrel chicks at the Crozet Islands are fed by both parents during the fledging period and reach weights of up to 17% heavier than adult weights two thirds through the fledging period (Jouventin *et al.* 1985). White-chinned petrel chicks lose 30% of their maximum weight at the end of the fledging period before they fledge (Jouventin *et al.* 1985).

The chick rearing period for white-chinned petrels at the Crozet Islands lasts on average 96 days (range 91-105 days) with fledglings departing the colony between 4-29 April, with the mean fledging day 17 April (Mougin 1970; Jouventin *et al.* 1985). The chick rearing period is not known for white-chinned petrels at the Kerguelen Island or Prince Edward Islands, though fledglings at the Kerguelen Islands depart at the end of April (Weimerskirch *et al.* 1989). The last adult white-chinned petrels at the Crozet Islands depart the colony on the 7 May after all chicks have fledged (Mougin 1970; Jouventin *et al.* 1985).

The South Atlantic Ocean group

White-chinned petrels in the South Atlantic Ocean breed at South Georgia and possibly at the Falkland Islands (Croxall *et al.* 1984a; Croxall *et al.* 1984b; Hall 1987;

Marchant and Higgins 1990). There are an estimated 2 million breeding pairs at South Georgia (Croxall *et al.* 1984a) and an estimated breeding population of 100-1000 at the Falkland Islands (Croxall *et al.* 1984b).

Adult white-chinned petrels arrive at South Georgia from early to late September, the earliest being 10 September (Hall 1987). Eggs are laid from the 13 November to the 10 December with 92% of eggs laid in the first 15 days (Hall 1987). The incubation period is between 57-62 days with the average length 58.9 days, with the mean hatching date 20 January (range 13-28 January) (Hall 1987). Both adults share incubation with the male spending on average 9.4 days per stint and the female spending on average 6.5 days per stint (Hall 1987).

The chick rearing period at South Georgia is on average 98.1 days, ranging 87-106 days, with the mean fledgling date 21 April, ranging from 9 April to 9 May (Hall 1987). Hunter *et al.* (1982) reported the mean fledgling date between 1978-81 as 19 April (range 16-25 April).

Winter dispersal of white-chinned petrels from South Georgia is unknown, however they are common on the Patagonian shelf in winter (Olmos 1997; Berrow *et al.* 2000). Berrow *et al.* (2000) also suggest the Patagonian shelf is where white-chinned petrels from South Georgia go during winter as this is where failed white-chinned petrels head northwest from South Georgia.

White-chinned petrels feeding off South Georgia in the South Atlantic feed more on crustaceans and fish with some taking cephalopods (Croxall *et al.* 1995).

The South Pacific Ocean group

The White-chinned Petrel *Procellaria aequinoctialis* is classed as a protected native in New Zealand (Heather and Robertson 2000). The white-chinned petrel breeds in three localities in the New Zealand region at, the Auckland Islands, Antipodes Island, and Campbell Island (Warham and Bell 1979; Robertson and Bell 1984; Marchant and Higgins 1990; Heather and Robertson 2000). The two main breeding populations within New Zealand are Auckland Islands with an estimated 100,000 breeding pairs

and Antipodes Island with an estimated 100,000 breeding pairs (Heather and Robertson 2000). The Campbell Island breeding population is relatively small at about an estimated 10,000 breeding pairs (Heather and Robertson 2000).

Virtually nothing is known of the breeding cycle of white-chinned petrels at Auckland, Antipodes and Campbell Islands except that it is 'apparently earlier than the more southern breeding populations' (Serventy *et al.* 1971). It is not known when white-chinned petrels return to the Auckland, Antipodes and Campbell islands at the start of summer or the length of the courtship and prelaying exodus periods. The only information known is that in 1950 adults were arriving at night in early November and a few in burrows were calling during the day (R. A. Falla *in litt.*: cited in Warham and Bell 1979). At Antipodes Island egg laying peaks at the end of November (Imber 1983) and Hutton (1895) reports adults incubating eggs in December.

The length of the incubation period is not known, however Warham and Bell (1979) found a female incubating an egg on 1 February that hatched on 6/7 February. Warham and Bell (1979) also found a chick in a burrow on 2 February and found small to medium sized young in burrows in early February. The fledgling period for Antipodes, Auckland and Campbell Island birds is not known, however Warham and Bell (1979) note that most young probably fledge in early May (based on Mougin 1970), and Hutton (1895) noted chicks were fully feathered in May.

The dispersal of white-chinned petrels during the breeding season in the New Zealand region is poorly known as no birds in the New Zealand region have been satellite tracked, though birds are commonly caught by fisheries through the summer months near breeding islands, on the Chatham Rise and off Puysegur Point (Robertson *et al.* 2003a). Vooren (1973) reported sighting white-chinned petrels during December on the Pukaki Rise. Sightings have been made of white-chinned petrels just outside the New Zealand EEZ during the breeding season at 38°S, 172°W in October during the voyage of the *Akaroa* from Panama to Auckland 1939 (Fleming 1950).

During the winter months white-chinned petrels have been seen in the waters off south eastern Australia (Gales *et al.* 1998), though it is not known whether these were New Zealand birds. Fleming (1950) recorded white-chinned petrels at 41°S, 179°E in

July during the voyage of the *Rakaia* from Wellington to Panama 1948. Robertson *et al.* (2003a) recorded a few white-chinned petrel fisheries bycatch birds caught in New Zealand waters on the Bounty Platform and Pukaki Rise during winter months.

Very little information on moult is known for New Zealand white-chinned petrels except Marchant and Higgins (1990) note moult has been observed as early as November at the Antipodes Islands with body moult beginning before wing moult.

White-chinned petrels feeding in the New Zealand region of the South Pacific feed mainly on cephalopods with some fish and crustaceans taken (Imber 1976; Robertson *et al.* 2003a).

2

METHODS

2.1 INTRODUCTION

In this chapter are outlined the history of the study specimens; descriptions of necropsy and histological methods; measurement of study skins; descriptions of external and internal measurements; determination of sex and age; description of the bill; identification of abnormal tissue found during the necropsy; and the methods of analysis.

2.2 STUDY SPECIMENS

A sample of 723 white-chinned petrel *Procellaria aequinoctialis* fisheries bycatch birds caught between 2000-2003 within the New Zealand Exclusive Economic Zone (EEZ) (Robertson and Bell 2002b; Robertson *et al.* 2003a; Robertson, C.J.R. *pers. comm.*) and 117 white-chinned petrel study skins, from several museums, were assessed to provide taxonomic information. The sample of 723 fisheries bycatch white-chinned petrels caught between 2000-2003 in the New Zealand EEZ is called 'the white-chinned petrel sample'.

I measured white-chinned petrel study skins from breeding populations at the Auckland Islands (n = 11), Antipodes Island (n = 3), and Campbell Island (n = 5) in the South Pacific Ocean; and from the Kerguelen Islands (n = 3) in the South Indian Ocean; as well as 12 skins not collected from breeding islands. C.J.R. Robertson measured study skins from breeding populations at the Auckland Islands (n = 1) and Antipodes Island (n = 7), including the type specimen of *P. a. steadi*, in the South Pacific Ocean; from the Kerguelen islands (n = 1) in the South Indian Ocean; and from South Georgia (n = 4); and the Falkland Islands (n = 1) in the South Atlantic

Ocean; as well as 69 skins not collected from breeding islands, including the type specimen of *P. a. mixta* and 30 birds caught in south east Pacific Ocean off Chile.

Laboratory work was carried out principally at C.J.R. Robertson's Laboratory at Shelly Bay, Wellington, and also at Massey University Palmerston North between October 2002 and September 2003. Study skins were measured between March 2003 and August 2003. I measured eight white-chinned petrel study skins at Canterbury Museum, Christchurch; four at Otago Museum, Dunedin; six at Auckland Memorial Museum, Auckland; and 16 at Museum of New Zealand Te Papa Tongarewa, Wellington. C.J.R. Robertson measured 77 study skins, including type specimens of *P. a. steadi* and *P. a. mixta*, at the American Museum of Natural History (A.M.N.H.), New York; and six at Albany Museum, South Africa using the same measuring techniques (see section 2.5 on external measurements).

With the permission of Dr. John Warham external measurements of live white-chinned petrels taken at the Antipodes Islands in 1969 were included for comparison. Other external measurements from publications by Murphy (1936), Falla (1937), Rowan *et al.* (1951), Rand (1954), Bailey and Sorensen (1962), Swales (1965), Mougin (1970), Serventy *et al.* (1971), Warham and Bell (1979), Jouventin *et al.* (1985), Hall (1987), Marchant and Higgins (1990), Ryan (1999) were also included for comparison, and are shown in Appendix 4.1.

2.3 THE WHITE-CHINNED PETREL SAMPLE

New Zealand fisheries observers and voluntary returns from fishers reported 944 white-chinned petrels killed and returned between October 1996 and September 2003 (Bartle 2000; Robertson 2000; Robertson and Bell 2002a, 2002b; Robertson *et al.* 2003a; Robertson, C.J.R. *pers. comm.*). All 723 white-chinned petrels sampled were incidentally killed as bycatch by various fishing practices, including bottom longliners, tuna longliners, squid trawlers, and trawlers within the New Zealand EEZ (Robertson *et al.* 2003a). Only 723 white-chinned petrels were assessed as that was all there was available at the time the research was conducted. Most birds from observers were initially identified, general position noted (latitude and longitude), labelled and

frozen aboard the vessels, and sent from the Port of arrival to Wellington. At Wellington all fisheries bycatch birds were necropsied as part of the Department of Conservation autopsy programme on seabird bycatch research by C.J.R. Robertson and E. Bell at the Shelly Bay Laboratory under Conservation Services Levy (CSL) Contract 3051 (Robertson *et al.* 2003a).

At the Shelly Bay Laboratory, the birds were thawed overnight, then formally identified, given a unique identification number, and necropsied. The necropsy included taking several external measurements: head and bill length; head width; culmen length; culmen width at the base; culmen depth at the base; culmen least depth; tarsometatarsus length; mid toe and claw length; wing length; and tail length; as well as a description of the feather covering on the brood patch and moult condition. The birds were then opened from the bottom of the sternum, through the brood patch, to the cloaca, sexed and aged by examination of the gonads, and had a fat score taken. The external measurements, sex, age and fat score, were determined by the methods described below. The necropsy sheet included the date each bird was caught, the location in general, latitude and longitude coordinates, and vessel type. Information also gathered but not used in this thesis included the contents of the proventriculus and gizzard, and liver samples for possible DNA analysis were retained for a 50% sample of the birds. Measurements and descriptions of the white-chinned petrels taken by C.J.R. Robertson and E. Bell at the Shelly Bay Laboratory are here called 'the Laboratory' measurements.

After the necropsy each bird was re-bagged, with its identification number, and stored in boxes at the C.J.R. Robertson cold storage facility in Wellington. Relevant information on the necropsy sheets was added to the autopsy database on seabirds killed by fisheries in the New Zealand EEZ (1996-present).

2.4 DESCRIPTIVE METHODS

This section describes the descriptive techniques used on the white-chinned petrel sample, including trialling techniques and the necropsy process. Testicular histological techniques and assessment of the study skins are summarised. All data

recorded were entered onto a necropsy sheet with the bird's identification number, date measured, species, external and internal measurements, sketch of white chin shape, sketch of the dorsal surface of the nostrils (nostril shape), and sketch of the bill colouration (appendix 2.1). Importantly, I worked blind where all measurements and descriptions of the 723 white-chinned petrels and 117 study skins were taken before being given access to 'the Laboratory' database. 'The Laboratory' database included information on location, date and fishery where each white-chinned petrel was caught as well as moult and feather wear data for all individuals.

2.4.1 Trialling the techniques for measuring and describing white-chinned petrels

A sample of 12 fisheries bycatch white-chinned petrels was used to trial the techniques for taking external measurements: head and bill length, culmen length, head width, culmen depth at the base, culmen width at the base, bill least depth, tarsometatarsus length, mid-toe and claw length, wing length, and tail length; and internal measurements: sexing and aging males and females, measuring testis length and width, and taking a fat score. These techniques were overseen by C.J.R. Robertson and were those used for 'the Laboratory' measurements. The techniques for measuring internal organs: gall bladder length, liver and gall bladder weight, right ventricle length, width of heart, heart weight, intestine length, kidney length, and kidney weight, were overseen by a veterinary pathologist, Dr. B. Gartrell. I devised all other measurements and body descriptions.

2.4.2 Necropsy methods

The white-chinned petrels were thawed overnight in batches of 24-36 and assessed the following day. Protective clothing was worn at all times. External measurements: head and bill length; head width; culmen length; culmen width at the base; culmen depth at the base; culmen least depth; nostril length; nostril least width; tail length; wing length; tarsometatarsus length; mid-toe and claw length; and white chin length were recorded, plus a sketch of the white chin and an estimate of the percentage of white on the chin. All external measurements and sketches are described in section 2.5 on external measurements.

The birds were sexed and aged by inspection of the gonads. The length and width of the left testis was measured as was the length of the gall bladder. A fat score was estimated. These procedures are described in sections 2.6 on sex and age determination and 2.7 measurements of internal features. Bill colour and bill wear were described and the bill sketched to show the amount of dark colouring at the tip of the maxillary and mandibular ungues and the length of dark lines along the top of the maxillary unguis. The shape of the dorsal surface of the nostrils was also sketched and recorded. These techniques are described in section 2.8 on bill descriptions.

Damage sustained during capture prevented all measures being taken from every bird. After necropsy and measurement the birds were either re-bagged and refrozen, or taken to the Wellington tip for disposal.

2.4.3 Full dissection of the white-chinned petrel

A random sample of white-chinned petrels (34 males and 34 females) was fully dissected in the INR (Ecology) and IVABS post mortem laboratories, Massey University. The thawed birds were opened by an incision from the cloaca through the brood patch up the right side of the keel of the sternum to the neck. The skin, sternum, ribs, furcula and overlying muscles were removed to expose all the viscera. The heart, liver and gall bladder were removed from the body cavity to be measured and weighed. Then the proventriculus, gizzard and intestine were removed, the intestine being cut from the gizzard, and measured. Testes and kidneys were also removed, measured and weighed. The measurement techniques are described under the section 2.7 on measurements of internal features.

2.4.4 Testicular histology

The reproductive state of male white-chinned petrel testes was determined using histological techniques. These techniques were used to establish stages of testicular development based on development of spermatogenic tubules at different times of year. The testes of 25 bycatch white-chinned petrels were removed and fixed in 10% neutral buffered formalin. Blocks of selected tissues were embedded in paraffin, and sections cut and stained with haemotoxylin and eosin (Gartrell, B. *pers. comm.*).

Slides of each sectioned testis were viewed microscopically and the stage of development of spermatogenic tubules determined.

2.4.5 Measuring study skins

A sample of 117 white-chinned petrel study skins from various museums was measured. Measurements taken from study skins were standard external measurements and bill descriptions. When handling study skins I wore gloves to avoid contact with any arsenic on older specimens. The skin identification number and all label descriptions were noted including collector, date collected, location, sex and any measurements and descriptions taken from the bird when it was alive. External measurements: culmen length; culmen width at the base; nostril length; nostril least width; tail length; wing length; tarsometatarsus length; mid-toe and claw length; and white chin length were taken and recorded. The white chin was also sketched and the percentage of white on the chin estimated.

The measurement of head and bill length was not taken on study skins because the back of the skull was removed during the preparation of the skins. Culmen depth at the base and bill least depth measurements were taken only on study skins where the bill was closed completely. Descriptions of bill colour and wear were taken, along with a sketch of the bill showing the amount of dark colouring at the tip of the maxillary and mandibular ungues, and the length of dark lines along the top of the maxillary unguis. A sketch of the nostril shape was also taken. Bill and plumage colour were not noted because they are known to change colour after death (Marchant and Higgins 1990).

2.5 EXTERNAL MEASUREMENTS

Measurements were taken with Mitutoyo 250mm vernier callipers, a 600mm butted ruler and a Komelon® Toplock KMC-76 7500mm butted measuring tape. Measurements on study skins were taken the same way as for fisheries bycatch specimens, except for wing length (described below). Post-mortem study skin shrinkage may have substantial effects on some measurements (Marchant & Higgins

1990; Lee and Griffiths 2003) and those from fisheries bycatch birds and study skins were treated separately.

External measurements taken were:

Head and bill length	Nostril length
Head width	Tarsometatarsus length
Culmen length	Mid toe and claw length
Culmen width at the base of the bill	Tail length
Culmen depth at the base of the bill	Wing length
Bill least depth	Length of white chin patch
Minimum nostril width	Area of white chin patch

Culmen length

The technique used to measure culmen length (±0.1mm) is based on Marchant and Higgins (1990) (Plate 2.1).

Culmen width at the base of the bill

The technique used to measure culmen width at the base of the bill (±0.5mm) is based on Marchant and Higgins (1990) (Plate 2.2).

Culmen depth at the base of the bill

The technique used to measure culmen depth at the base of the bill (±0.5mm) is based on Marchant and Higgins (1990) (Plate 2.3).

Mid toe and claw length (MTC)

The technique used to measure mid toe and claw length (±1mm) is based on Marchant and Higgins (1990) (Plate 2.4).

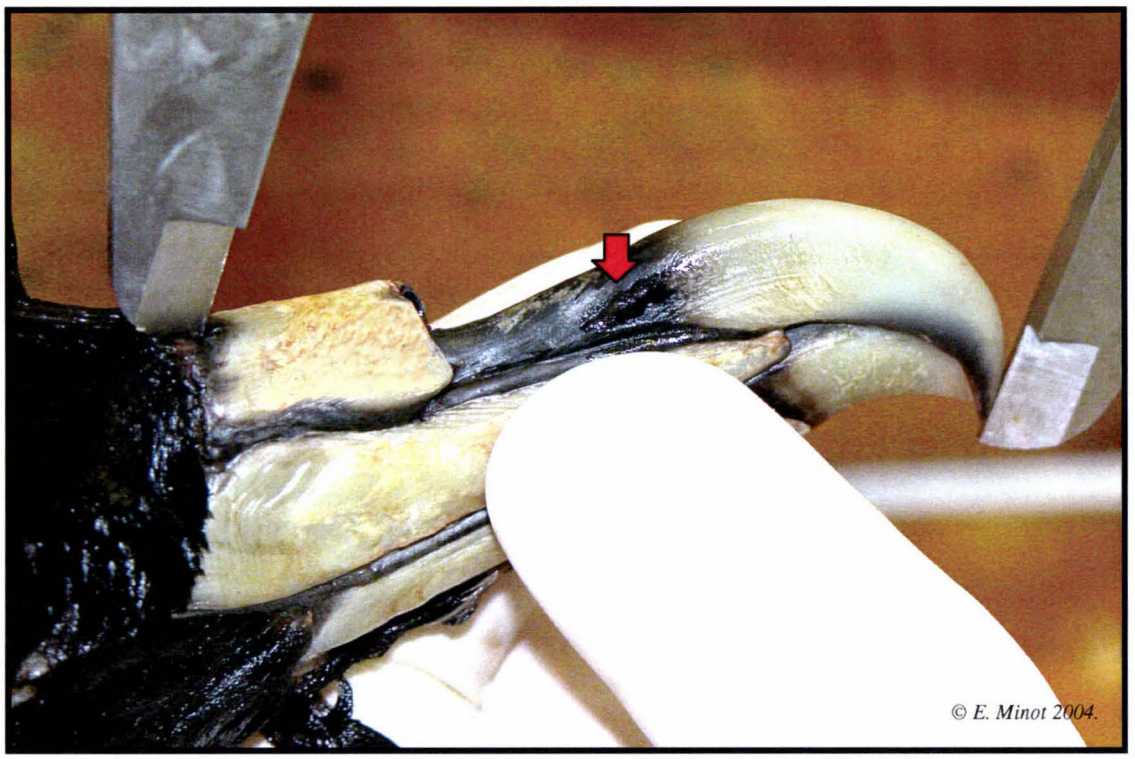

Plate 2.1 Culmen length. Culminicorn arrowed.

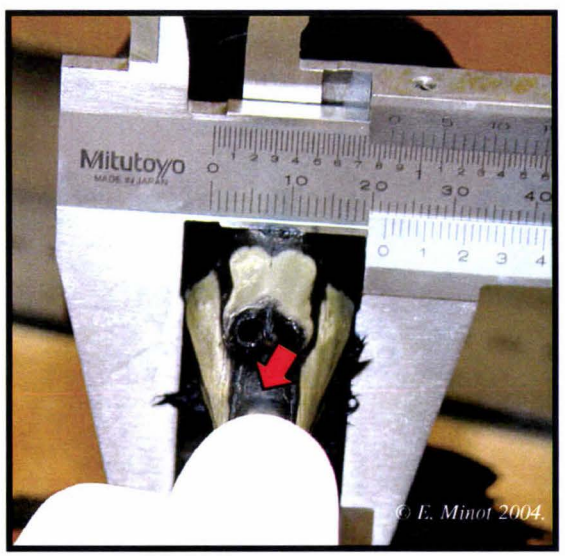

Plate 2.2 Culmen width at the base of the bill. Dorsal surface of the culminicorn arrowed.

Plate 2.3 Culmen depth at the base of the bill. Left nostril arrowed.

Tail length

The technique used to measure tail length (±1mm) is based on Marchant and Higgins (1990) (Plate 2.5).

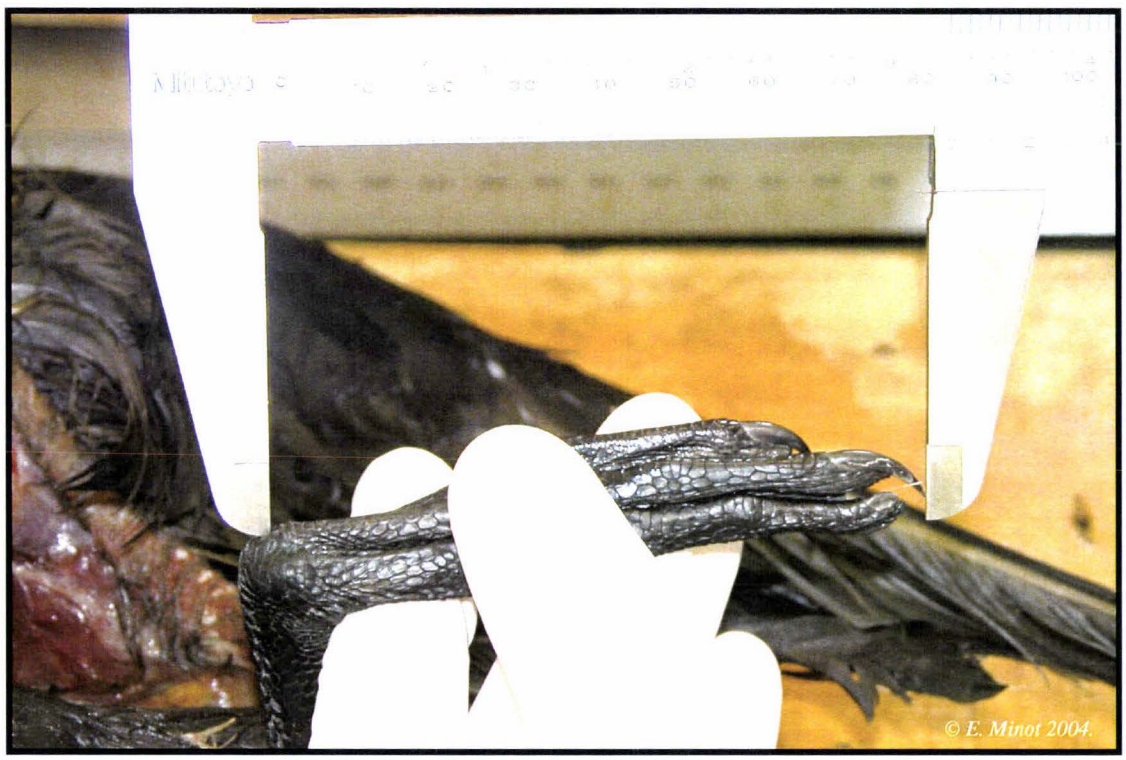

Plate 2.4 Mid toe and claw length.

Plate 2.5 Tail length. Pygeal preen gland arrowed.

Head and bill length

Head and bill length was measured (±1mm) from the occipital crest at the caudal margin of skull to the terminal curve of the maxillary unguis (Plate 2.6). The birds

head was manipulated by holding the culmen between the fingers and thumb and tilting the head so the neck was at a 45° angle to the head. This exposed the bones at the back of the skull enabling an accurate and repeatable measurement. Head and bill length was measured only on fisheries bycatch birds, not museum skins from which the back of the skull had been removed during preparation (Marchant and Higgins 1990).

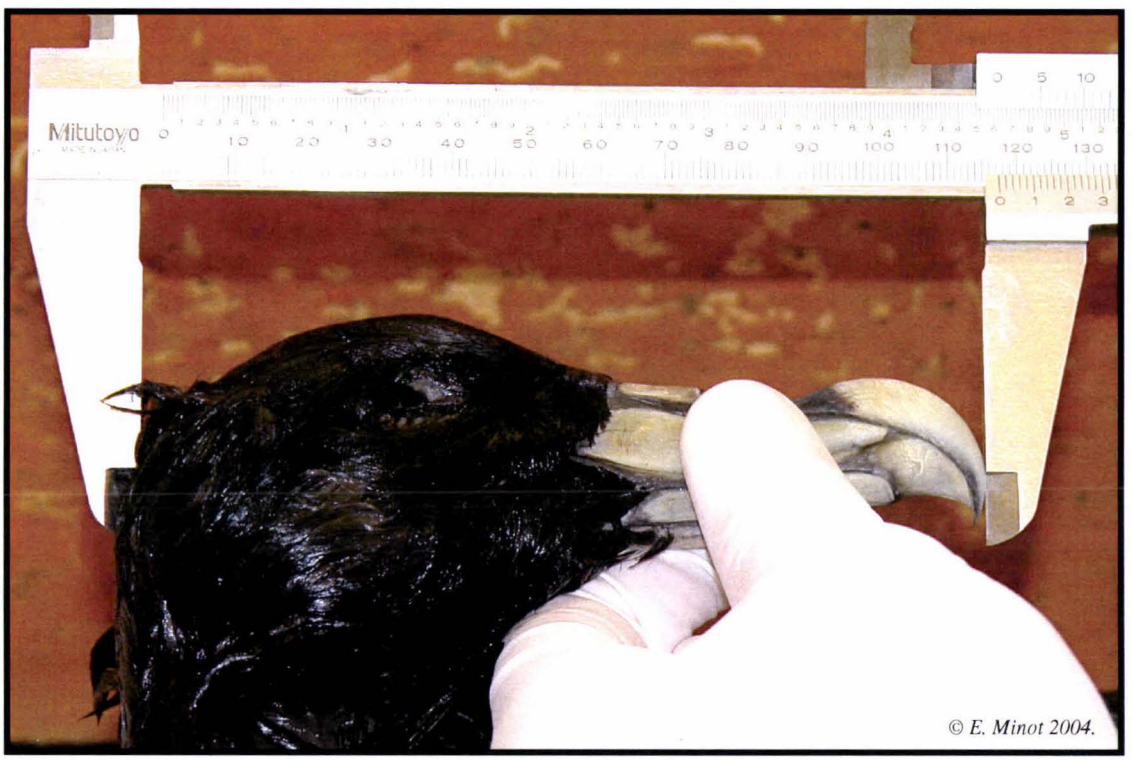

Plate 2.6 Head and bill length.

Head width

Head width was taken (±1mm) as the narrowest width of the head (with skin and muscle still attached), between the narrowest part of the squamosal plate below the postorbital process (Plate 2.7). Plate 2.8 shows precisely how head width was taken on a skull. With the culmen held between the fingers and thumb the callipers were placed behind the postorbital process and then closed firmly until they stopped moving. This measurement can vary slightly depending how hard the callipers are closed.

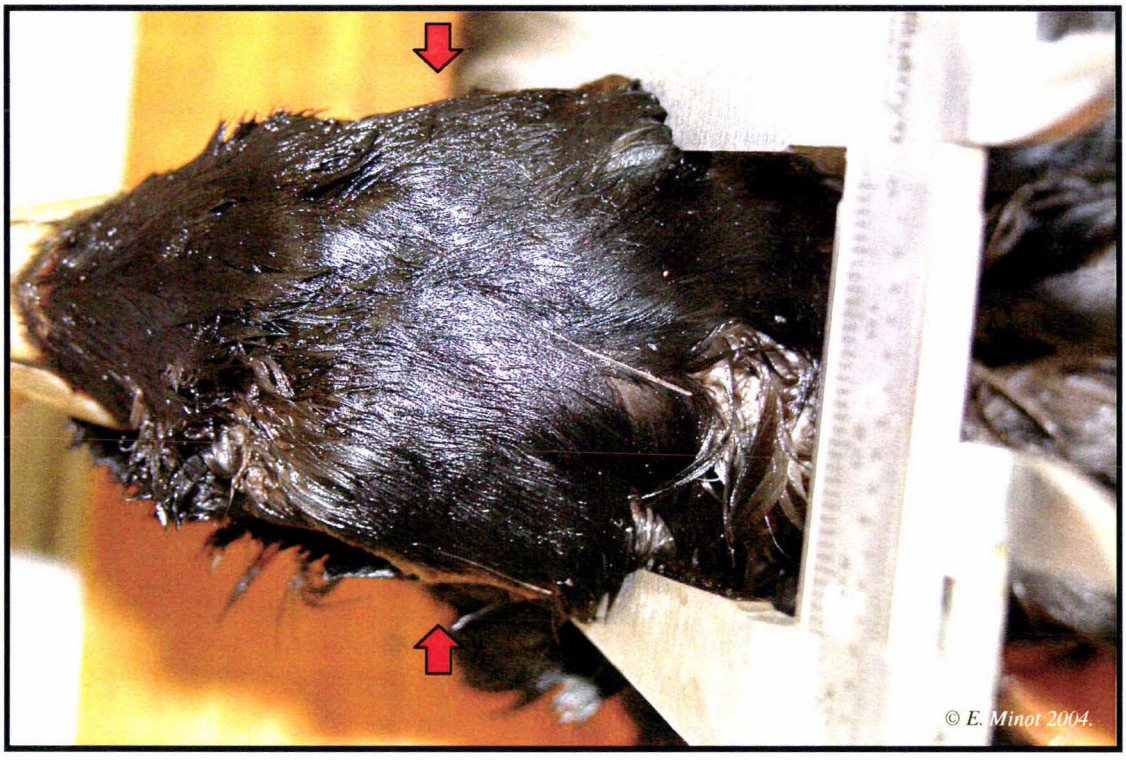

Plate 2.7 Head width. Dorsal view, eye socket arrowed.

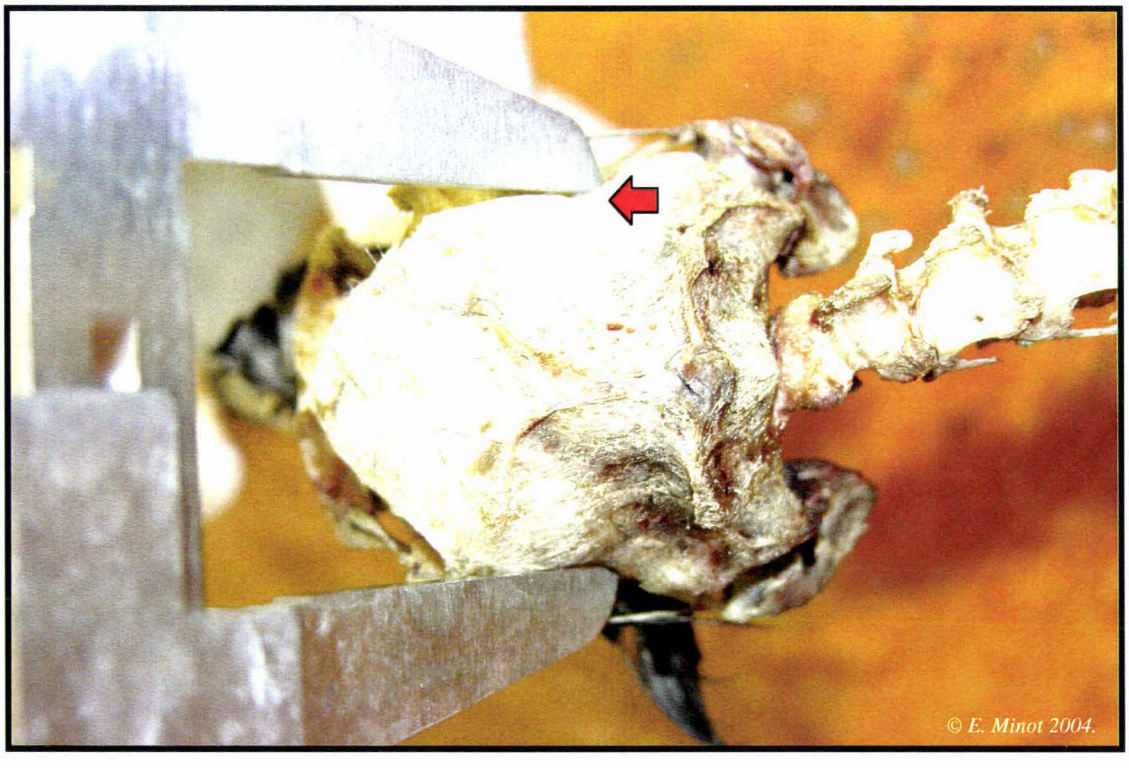

Plate 2.8 Dorsal view of skull showing where head width was measured. Right squamosal plate arrowed.

Bill least depth

Bill least depth is the narrowest measurement of the bill across both the ramphotheca and gnathotheca. The culmen was held at the tip between fingers and thumb. The measurement was taken (±0.5mm) from the narrowest point along the culminicorn on the ramphotheca to the ventral edge of the mandibular ramus below (Plate 2.9). The callipers were held at a 90° angle to the mandibular ramus and flat across both mandibular rami.

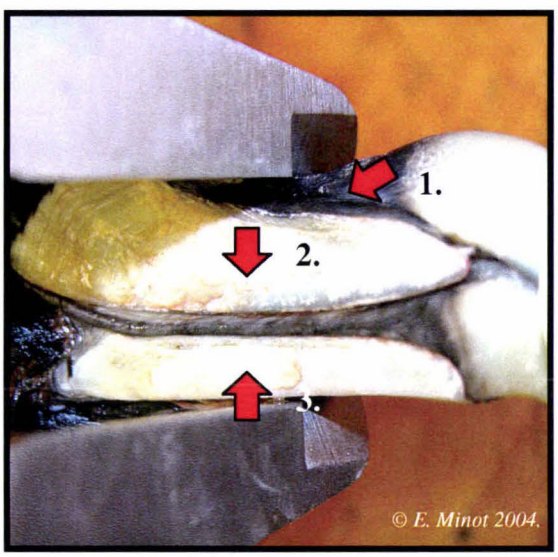

Plate 2.9 Bill least depth. Culminicorn (1.), rhamphotheca (2.) and gnathotheca (3.) arrowed.

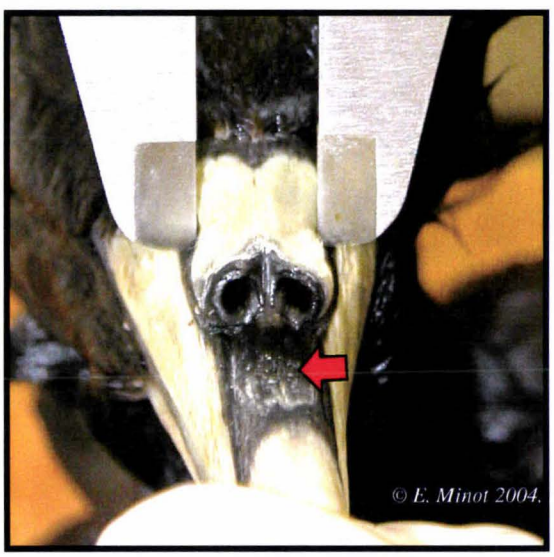

Plate 2.10 Minimum nostril width. Culminicorn arrowed.

Minimum nostril width

Minimum nostril width was taken (±0.5mm) as the narrowest distance across the nares looking from the dorsal aspect (Plate 2.10).

Nostril length

Nostril length was measured (±0.5mm) from the junction of the frontal feathering on the culmen on the dorsal ramphotheca to the junction of the base of the nasal septum with the culminicorn (Plate 2.11).

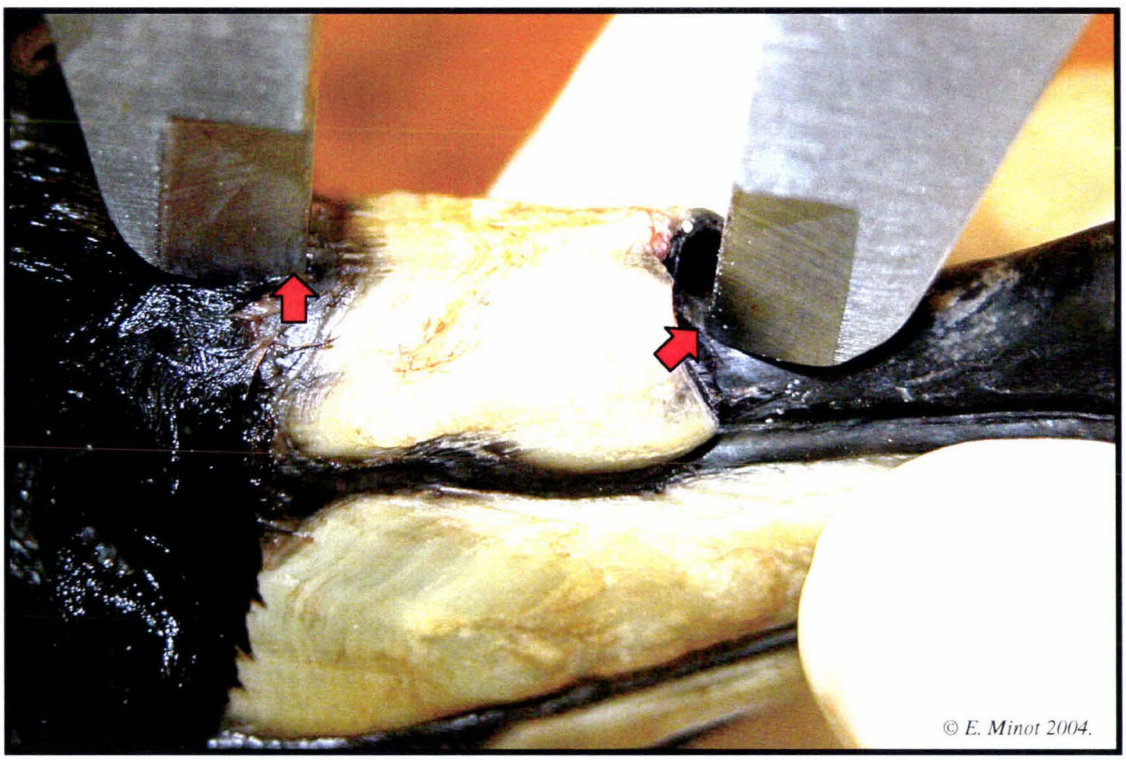

Plate 2.11 Nostril length. Edge of frontal feathers (left) and base of nasal septum (right) arrowed.

Plate 2.12 Right tarsometatarsus length. Fossa in the cotyla medialis arrowed.

Tarsometatarsus length

The length of the right and left tarsometatarsus (±1mm) was measured from the fossa at the top of the tarsometatarsus to the midpoint of the joint between the tarsometatarsus and middle toe (trochlea metatarsi III). Upon examination of the above technique it was found that the medial side of the right tarsometatarsus and the lateral side of the left tarsometatarsus was being measured and this led to asymmetries between the right and left measurements. Therefore a description of how each tarsometatarsus was measured is included below.

The medial side of the right tarsometetarsus was measured (±1mm) from the proximal end, from the fossa in the cotyla medialis, to the midpoint of the joint between the tarsometatarsus and middle toe (trochlea metatarsi III) (Plate 2.12). The lateral side of the left tarsometatarsus was measured (±1mm) from the proximal end, from the fossa in the cotyla lateralis, to the midpoint of the joint between the tarsometatarsus and middle toe (trochlea metatarsi III).

Wing Length

Wing length (±1mm) was measured using two different techniques.

Maximum chord length of the wing

The wings of fisheries bycatch specimens were measured using the flattened straightened wing (maximum chord) (Plate 2.13). The maximum chord of the wing was measured from the carpal joint to the tip of the longest primary (Marchant & Higgins 1990), with the wing bent to expose the carpal joint. The carpal joint was placed against the butt of the ruler and flattened. The primaries were then flattened and straightened on the ruler to give the maximum measurement (Lowe 1989; Marchant & Higgins 1990). Wear on the feather tips was also noted and scored as either 'very worn' ('v' notches in feather tips), 'worn' (feather tips frayed), or 'not worn' (feather rounded and even at tip). Birds with 'worn' or 'very worn' tips were not included in the data set.

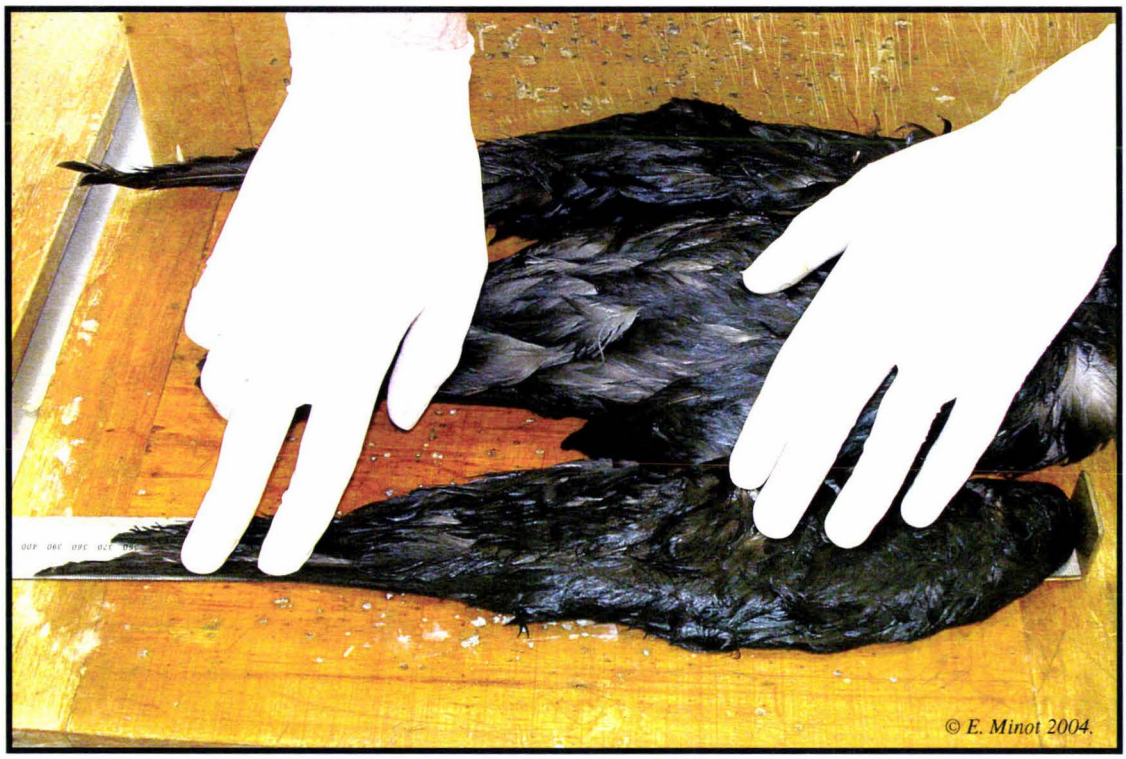

Plate 2.13 Maximum chord length of the wing.

Natural chord length of the wing

Dried study skins wings were rigid and difficult to manipulate, so the natural chord length of the wings was measured without bending or straightening the wing (Marchant and Higgins 1990) using a butted measuring tape. Study skins already have the wing bent to expose the carpal joint. The butted end of the tape was placed over the carpal joint and the tape was run over the curved dorsal surface of the wing to the tip of the longest primary. Wear on the feather tips was also noted and scored as either 'very worn', 'worn', or 'not worn'. Birds with 'worn' or 'very worn' tips were not included in analyses.

A sample of 30 fisheries bycatch birds had their wings measured using both the maximum chord length and the natural chord length.

Length of the white chin patch

The white chin patch is located on the ventral surface of the mouth between the mandibular ramicorns. The amount of white feathering was calculated by measuring the length (antero-posteriorly) of the white feathered area. The length of white was measured (±0.5mm) from the anterior margin of white (at or near the tip) to its

posterior margin on the throat. Plates 2.14-2.17 show how different white chin patches were measured. The percentage area of white within the white chin patch was estimated and a diagram of the shape was drawn showing where the white occurred.

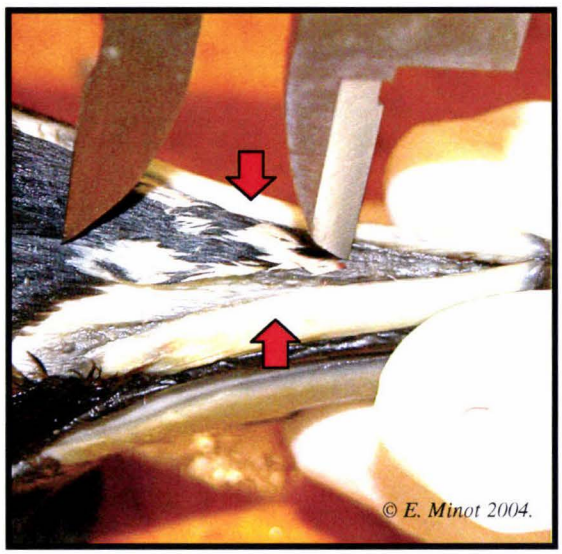

Plate 2.14 Shows how the length of white chin patch was measured. Mandibular ramicorns arrowed.

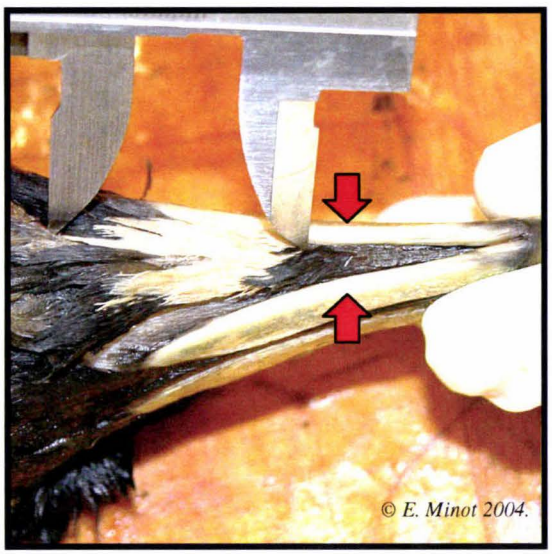

Plate 2.15 Shows how the length of white chin patch was measured. Mandibular ramicorns arrowed.

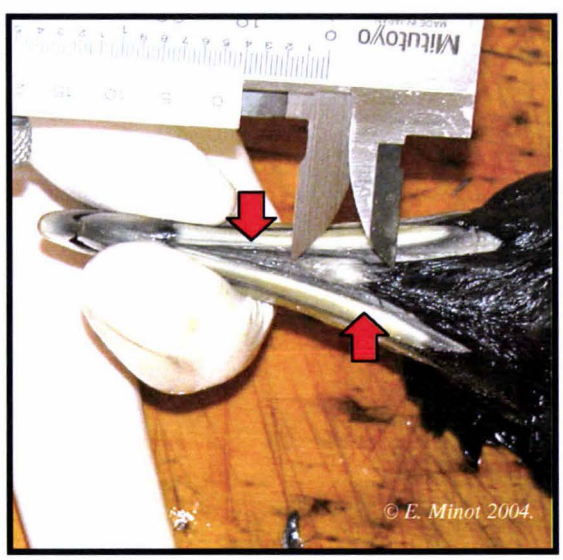

Plate 2.16 Shows how the length of white chin patch was measured. Mandibular ramicorns arrowed.

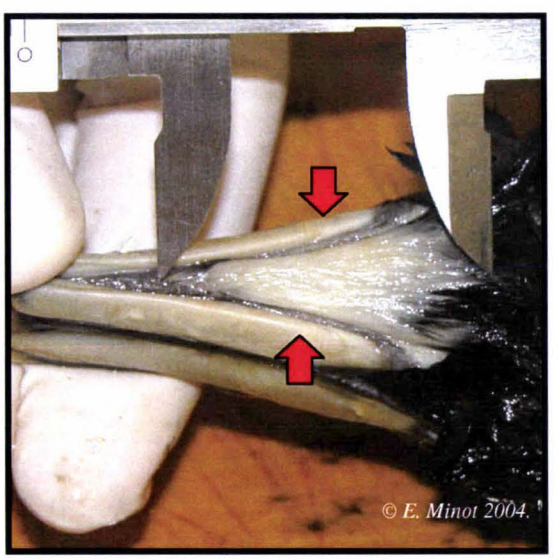

Plate 2.17 Shows how the length of white chin patch was measured. Mandibular ramicorns arrowed.

Area of the white chin patch

The area of white on the chin was estimated using the length of white on the chin and the percent of white within this area.

The shape of the triangular white area between the mandibular ramicorns varied little between specimens, accordingly a standard isosceles triangle shape with a height (=length) of 50mm was used to estimate the area. The area of an isosceles triangle is calculated using the formula $0.5b \cdot h$ where b= width of the white on the chin at its widest point and h= length of white on the chin.

At a length of 50mm the width of the white chin between the mandibular ramicorns, measured on a specimen, was 20mm. The 50mm x 20mm isosceles triangle was sketched on 2mm graph paper and enlarged 400% for ease of working. The width for every millimetre from 0-50mm was measured on the isosceles triangle and divided by four to give the actual width. The area (mm^2) of white on the chin was estimated by multiplying the percent of white on the chin by the area.

2.6 SEX AND AGE DETERMINATION

Birds were sexed by gonadal examination, except where the specimen was severely damaged by sea lice (Robertson *et al.* 2003a). Males had a pair of oval or round testes located at the anterior end of the kidney near the midline (Campbell and Lack 1985; Proctor and Lynch 1993). The single left ovary was located at the anterior end of the left kidney near the midline, with the oviduct extending from the ovary on top of the left kidney to the cloaca (Campbell and Lack 1985; Proctor and Lynch 1993).

Where possible all white-chinned petrels were classified as adult (males and females that had reached sexual maturity) or non-adult (males and females that had not yet reached sexual maturity) by gonad size and development.

Brood patch condition could not be used to age birds because the brood patch was destroyed during the initial necropsy before I had access to the birds. Moreover, the specimens were too wet to provide accurate information on general moult condition. During later analysis, information on the brood patch, moult, date of capture, and general notes from 'the laboratory' database were checked for each specimen to reassess age.

Adult male and female petrels

Adult white-chinned petrels were those that had reached sexual maturity and included non-breeding as well as breeding birds. These birds were aged using a combination of notes on gonad size, condition of the brood patch, and moult condition when they were caught.

Non-adult male and female petrels

Non-adult males and females were those birds that had not reached sexual maturity. The age of these birds was determined using a combination of notes on gonad size, condition of the brood patch, and moult condition.

2.7 MEASUREMENTS OF INTERNAL FEATURES

Measurements were taken using a standard pair of Mitutoyo 250 mm vernier callipers, a pair of dividers, a 600 mm butted ruler, and a set of Mettler PJ3600 scales accurate to 0.01g.

Fat Score

As a bird loses condition (i.e. from hunger sitting on an egg in a burrow) it starts to use up its fat reserves, mainly subcutaneous fat under the skin, fat on the intestine, and fat on the proventriculus and gizzard. Bile, produced in the gall bladder, is used to break down this fat to be used as energy. The size of the gall bladder may give an indication as to the amount of bile been produced by an individual and may in turn relate to the amount of fat used up by the bird.

Body condition was inferred from the extent of fat deposits on the proventriculus and gizzard, amount of fat between the intestines, and the thickness of subcutaneous fat under the skin on the pectoral muscles. Total amount of fat was scored on a scale from 1-5 (see below), and when the amount of fat deposits fell between two scores it was recorded as 2.5, 3.5, 4.5. There are two types of fat that occur in the fat deposits; white fat which is laid down as reserves and yellow fat, the remains of fat that has

been used (generally on birds in poor body condition) (Robertson, C.J.R. *pers. comm.*). The five categories are detailed below:

Fat score 1

No subcutaneous fat. No fat on the proventriculus and gizzard, or a residual amount of yellow. No fat between the intestines.

Fat Score 2

Residual white fat in thin lines or yellow subcutaneous fat (under 1mm thick) in small amounts, in patches on the pectoral muscles. Thin (under 1mm thick) patchy covering of white and yellow fat on proventriculus and gizzard, with more yellow fat than white fat. Small globules of fat between the intestines.

Fat score 3

A thin covering (0.5-1mm) of patchy subcutaneous white fat and small amounts of yellow fat on the pectoral muscles. Fairly thick (1mm thick patches) white fat covering up to 75% of proventriculus and gizzard. Small amounts of yellow fat present where white fat is thin. Small globules (about 1mm thick) of white fat, in separate patches, between intestines with some yellow fat present.

Fat score 4

Thick (1-2mm) white subcutaneous fat covering the pectoral muscles. Thick (2-4mm) white fat covering most of the proventriculus and gizzard. There was generally 1-2 small patches on the proventriculus or gizzard that were bare or with a thin covering of fat. Occasionally there was a very small amount of yellow fat present. Thick (about 3mm) white globules of fat in small clumps between the intestines. The globules of white fat almost form a thick band between the intestines.

Fat score 5

Very thick (2-3mm) white subcutaneous fat covering the pectoral muscles. Very thick (about 5mm) white fat covering the proventriculus and gizzard. Very thick (about 5mm) globules of white fat form a thick band between the intestines. Examination of the body cavity was difficult because of the thick fat deposits.

A measurement of the length of the gall bladder was also taken (explained below) to compare with fat score to see if there was a relationship between fat score and gall bladder size to determine if white-chinned petrels with low fat scores produce more bile than white-chinned petrels with high fat scores.

Gall bladder

Gall bladder length was measured (±0.5mm) by lifting up the right liver lobe and measuring the distance between where the gall bladder exited the liver to its tip (Plate 2.18). The amount of bile in the gall bladder was also estimated, on a scale: empty, ¼ full, ½ full, ¾ full, and full.

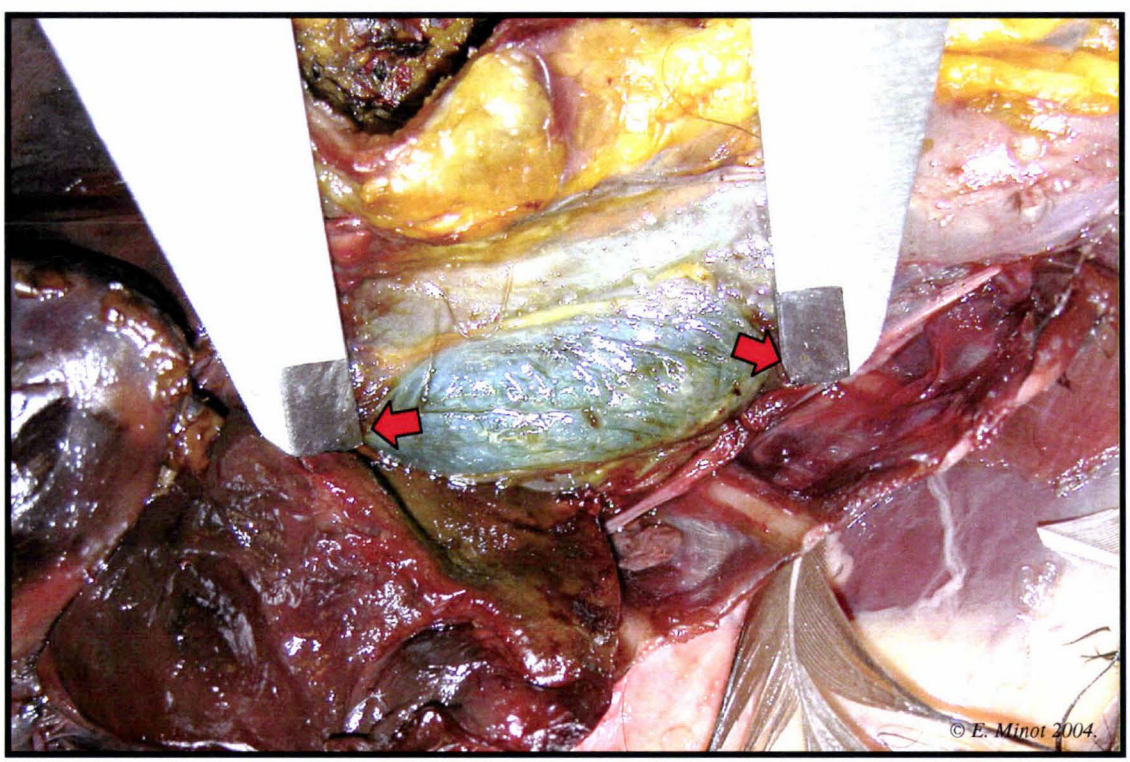

Plate 2.18 Length of a full gall bladder. Entrance (left and tip (right) of the gall bladder are arrowed.

Heart

The heart was removed by cutting supporting membranes, and all veins and arteries as close to the heart as possible. The pericardium was then removed and the heart placed with the right ventricle facing up. The right ventricle was measured (±0.5mm) from its junction with the right and left atria to its point at the apex of the heart (Plate 2.19). The width of the heart was measured (±0.5mm) from the coronary band (widest part)

between the edges of the right and left atria (Plate 2.20), and heart weight (±0.1g) was taken on a set of Mettler PJ3600 scales.

Plate 2.19 Length of right ventricle.

Plate 2.20 Width of heart.

Liver

The liver plus gall bladder were removed and weighed (±0.1g) on Mettler PJ3600 scales by cutting all membranes holding them in place. Only intact organs were weighed.

Testes

The maximum length and width (±0.5mm) of the left testis (or where possible both testes) was measured *in situ* with callipers (Plates 2.21 and 2.22). The mean testis volume (±0.1 mm^3) was calculated using the formula for the volume of an ellipsoid, $V=4/3\pi a^2 b$, where a= half the width and b= half the length (Bullough 1942). The testes were removed by cutting membranes and sectioning the vasa deferentia, and weighed (±0.01g) on Mettler PJ3600 scales. After measuring testes were retained in 10% buffer formalin for histological examination.

Small intestine

The proventriculus, gizzard and intestine were removed together by cutting through the oesophagus, cutting the intestine below the rectal caeca and cutting the

membranes that held the organs in place. The intestine was excised at the junction of the gizzard and intestine, and the length (±1mm) taken from the junction with the gizzard to the bases of the rectal caeca (Plate 2.23). Restricting mesenteries were cut, and the pancreas attached to the duodenum was removed. The small intestine was laid out in a straight line from the caeca end to the gizzard end by holding it above the table and letting it gently fall back on the table. This stopped any stretching of the small intestine that could alter its length.

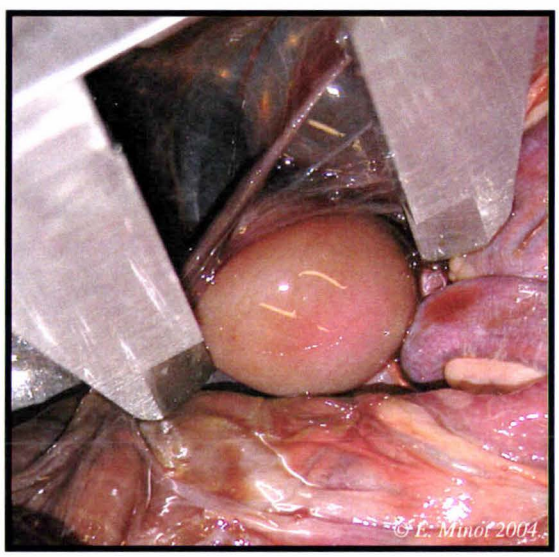

Plate 2.21 Length of testis.

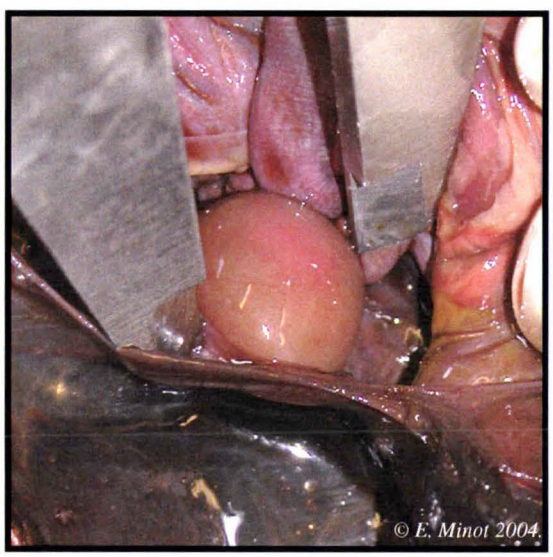

Plate 2.22 Width of testis.

Kidneys

Both kidneys were removed from the body cavity by cutting the membranes holding them in place and sectioning the ureters. Both kidneys were joined by peritoneal tissue in the midline and in all cases had to be separated by cutting.

Membranes surrounding the kidneys were removed and the ureters trimmed to their junction with the kidney. Each kidney was then laid flat on the table and measured (±0.5mm) from the tip of the cranial pole to the tip of the caudal pole (Plate 2.24). Each kidney was weighed (±0.1g) on Mettler PJ3600 scales.

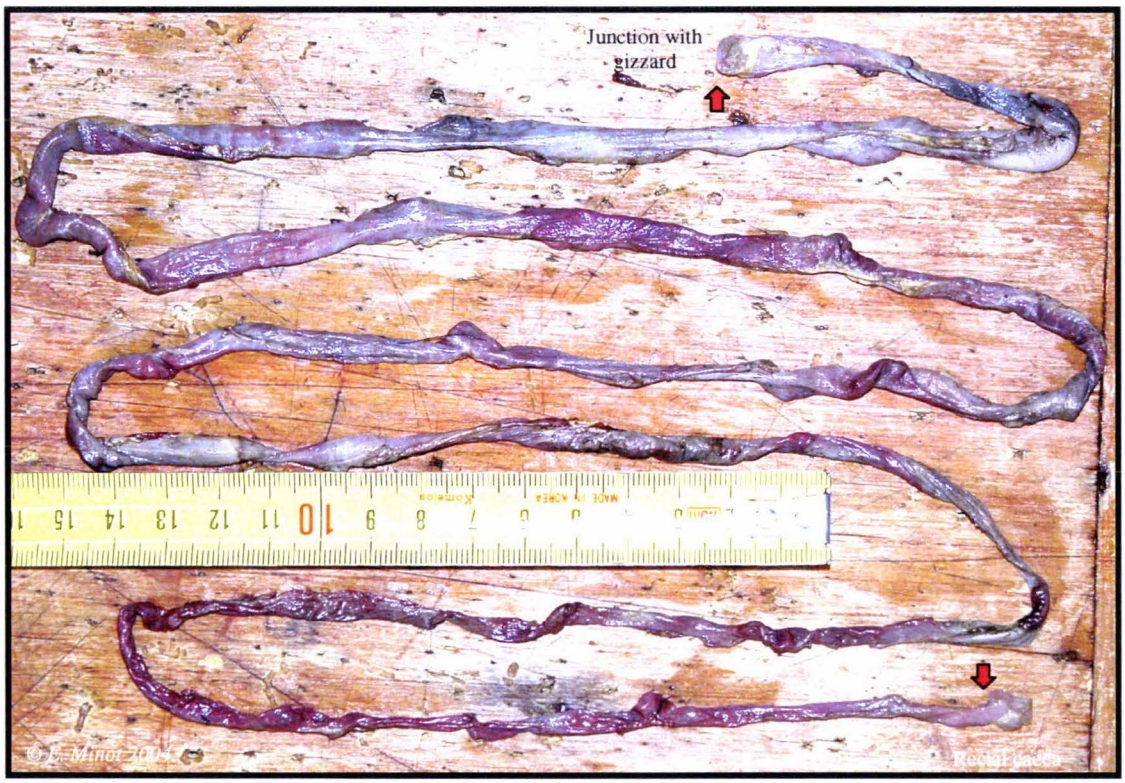

Plate 2.23 Intestine. Two points (arrowed) indicate where the intestine was measured.

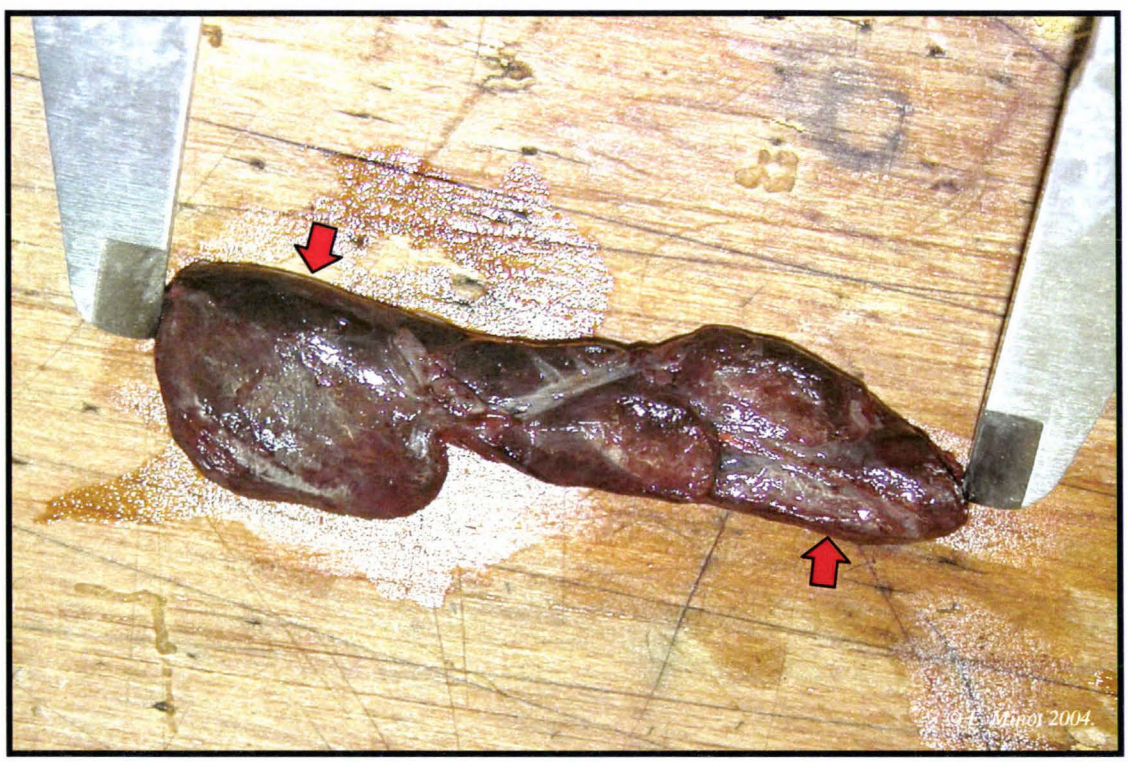

Plate 2.24 Length of kidney. Cranial pole (left) and caudal pole (right) arrowed.

2.8 BILL DESCRIPTIONS

To better describe the bill it was sketched (Appendix 2.1) and the degree of dark colouring on the maxillary and mandibular ungues and nostril colourings noted. The shape of the dorsal surface of the nostrils and the wear and moult on the bill plates was also noted. The length of dark lines down the centre of the maxillary unguis, and the amount of dark colouring at maxillary and mandibular unguis tips were scored.

Length of dark lines along the top of the maxillary unguis

Dark lines along the top of the maxillary unguis were drawn on the bill sketch and scored (0-3) according to their length. A note of the thickness and definition of colour was also made. The score for dark lines on top of the maxillary unguis were termed '*Dark line scores*'.

'*Dark line score*' 0: No dark lines along the top of the maxillary unguis (Plate 2.25).

'*Dark line score*' 1: A dark line extends from the base of the maxillary unguis 25% along the top of the bill towards the tip of the bill (Plate 2.26).

'*Dark line score*' 2: A dark line extends from the base of the maxillary unguis up to 50% along the top of the bill towards the tip (Plate 2.27).

'*Dark line score*' 3: A dark line extends from the base of the maxillary unguis over 50% along the top of the bill occasionally right to the bill tip (Plate 2.28). The line occasionally joined with the black at the bill tip.

Amount of dark colouring at tip of maxillary unguis

The amount of dark colouring along the cutting edge of the maxillary unguis to the tip ('*Nail scores*') was noted on the bill sketch along with the shades of colour and thickness and scored from 0-3.

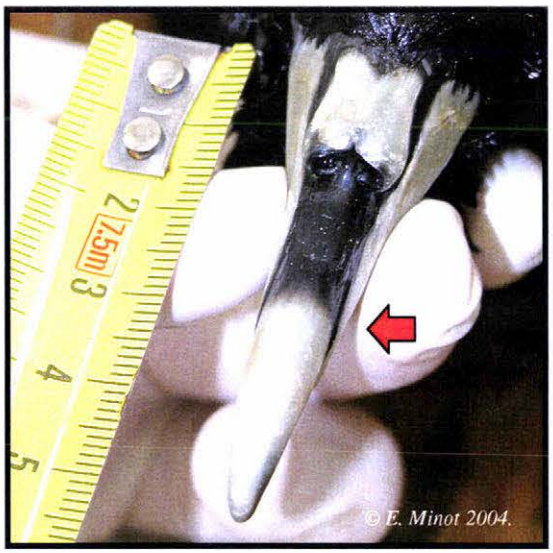

Plate 2.25 '*Dark line score*' 0 (arrow shows base of maxillary unguis).

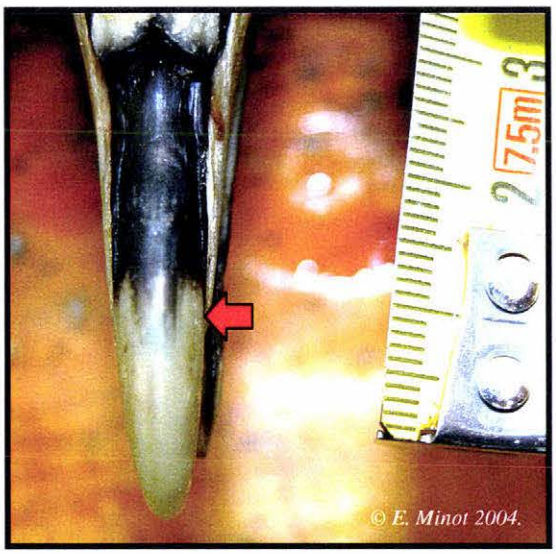

Plate 2.26 '*Dark line score*' 1 (lines arrowed).

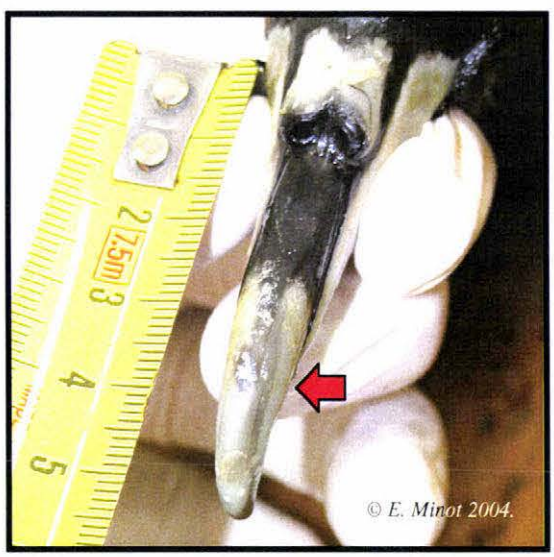

Plate 2.27 '*Dark line score*' 2 (lines arrowed).

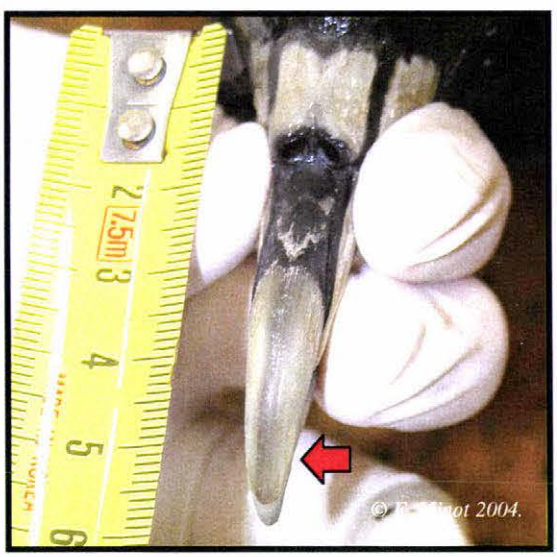

Plate 2.28 '*Dark line score*' 3 (lines arrowed).

'*Nail score*' 0: A very small amount of dark colouring (faint) at the tip of the maxillary unguis with either a very faint dark line along the cutting edge of the bill or no dark edge at all (Plate 2.29).

'*Nail score*' 1: A dark tip to the maxillary unguis that is up to 5mm long with a thin dark line (2mm) along the cutting edge of the maxillary unguis (Plate 2.30).

'*Nail score*' 2: A dark tip to the maxillary unguis that is up to 10mm long extending slightly on to side of plate with a dark line (2-3mm thick) on the cutting edge of the bill (Plate 2.31).

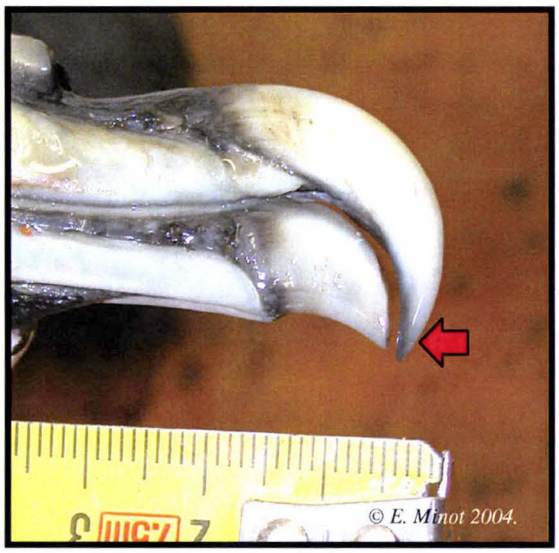

Plate 2.29 *'Nail score'* 0 (dark tip arrowed).

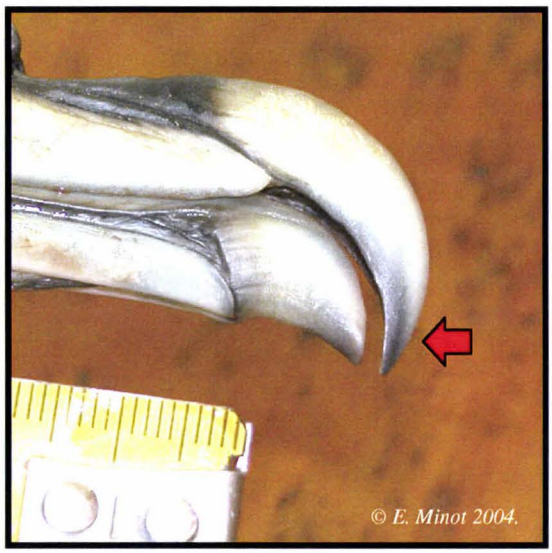

Plate 2.30 *'Nail score'* 1 (dark tip arrowed).

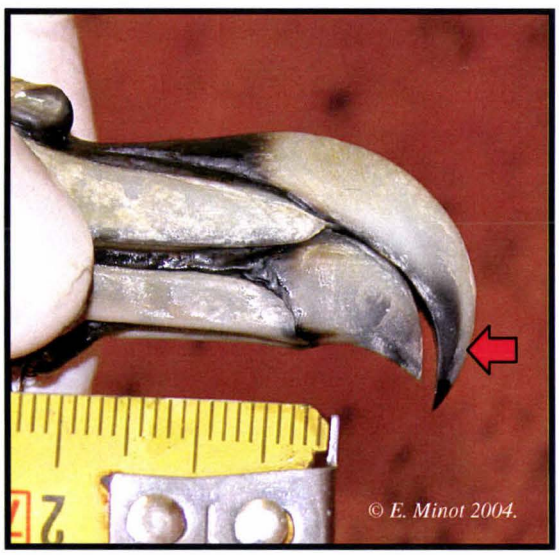

Plate 2.31 *'Nail score'* 2 (dark tip arrowed).

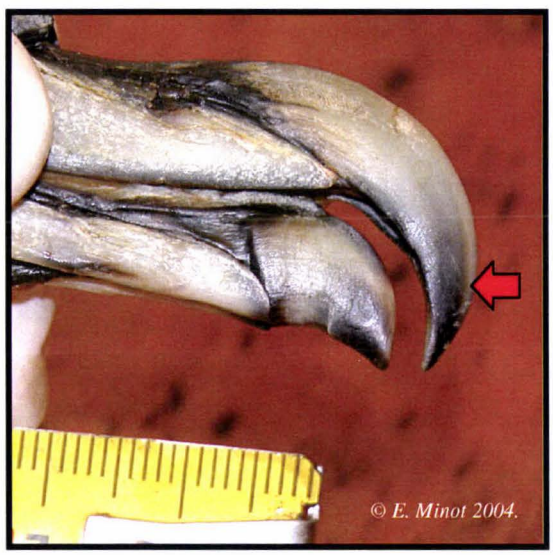

Plate 2.32 *'Nail score'* 3 (dark tip arrowed).

'Nail score' 3: A dark tip to the maxillary unguis that was greater than 10mm long extending from the cutting edge of the unguis to centre of plate (Plate 2.32). A thick dark line on the cutting edge of the maxillary unguis (3-5mm thick) extends up the edge of the plate (Plate 2.32).

Amount of dark colouring on mandibular unguis

The amount of dark colouring on the mandibular unguis was added to the bill sketch and scored on a scale from 0-3 according to the size of the dark wedge at the tip. These were termed *'Unguis score'*.

'*Unguis score*' 0: No dark colouring on the mandibular unguis (Plate 2.33).

'*Unguis score*' 1: A dark tip to the mandibular unguis extending 25% the length of the plate from the tip (Plate 2.34).

'*Unguis score*' 2: A dark tip to the mandibular unguis extending up to 50% the length of the plate from the tip (Plate 2.35).

'*Unguis score*' 3: A dark tip to the mandibular unguis extending more than 50% the length of the plate from the tip (Plate 2.36).

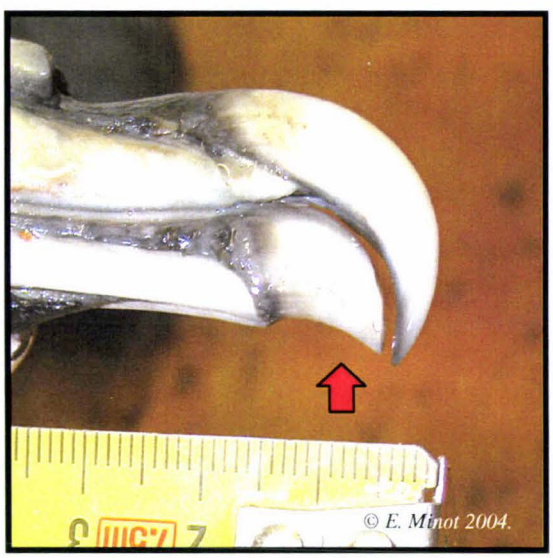

Plate 2.33 '*Unguis score*' 0 (dark tip arrowed).

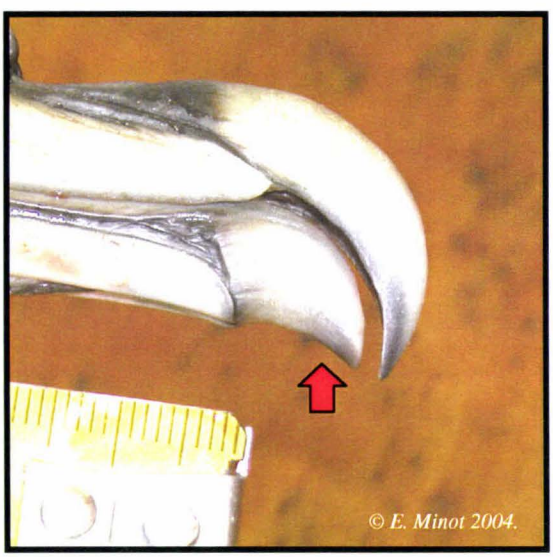

Plate 2.34 '*Unguis score*' 1 (dark tip arrowed).

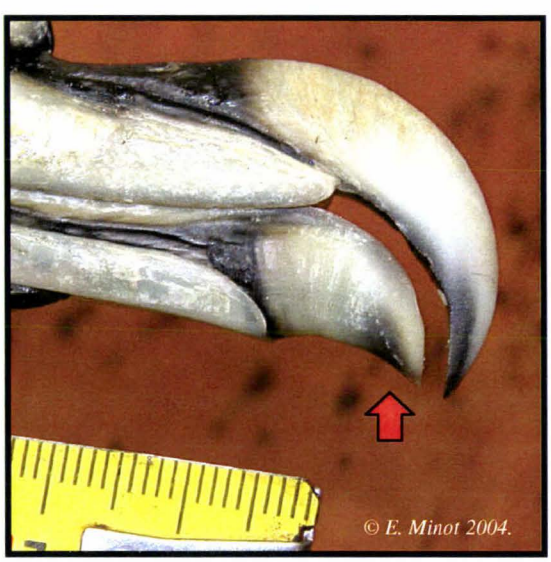

Plate 2.35 '*Unguis score*' 2 (dark tip arrowed).

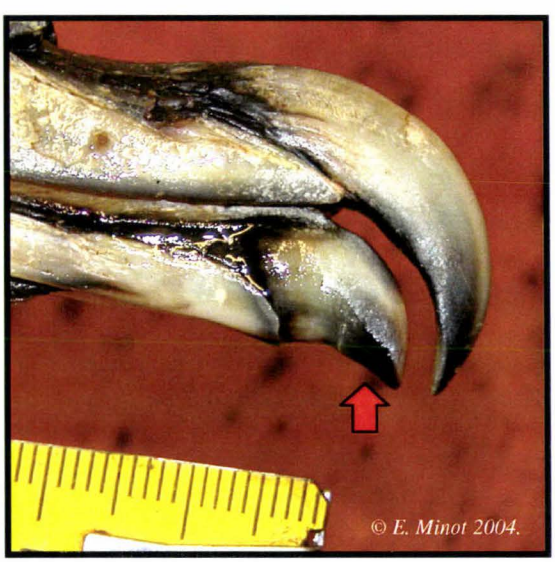

Plate 2.36 '*Unguis score*' 3 (dark tip arrowed).

Nostril shape

The nostrils in *Procellaria* petrels are encased in a tube and sit together on top of the culmen at its base. The nostril case for white-chinned petrels is yellow and stands out from the black base of the culmen. The shape of the yellow dorsal surface of the nostril cover varied markedly between birds. The dorsal surface of the nostrils was categorised into five shapes, termed '*nostril shape*'.

'Nostril shape' 1

The outer edges of the nostril tubes are straight or very slightly concave towards the centre (Plate 2.37). Minimum nostril width is across the centre of the nostril tubes where the outer sides of the nostrils are slightly concave.

'Nostril shape' 2

The outer edges of the nostril tubes are concave forming an 'X' shape in dorsal view (Plate 2.38). Minimum nostril width is across the centre of the nostril tubes where the outside edges of the nostrils are at their narrowest point.

'Nostril shape' 3

The outer edges at the posterior end of the nostril tubes are slightly convex forming the narrowest distance across the nostrils, and this is where the minimum nostril width was taken (Plate 2.39). The remainder of the outer edge of the nares are convex.

'Nostril shape' 4

The outer edges of the nostril tubes are straight except for the anterior end that is convex forming a bulbous tip (Plate 2.40). The minimum nostril width is across the nostril tubes behind the bulbous tip.

'Nostril shape' 5

The outer edges of the nostril tubes are straight but angled outwards so the narrowest point across the nostrils is at the base of the tubes at the posterior end and the widest point across is at the anterior end of the tubes (Plate 2.41). Minimum nostril width is taken across the base of the nostrils at the posterior end where it tapered the most.

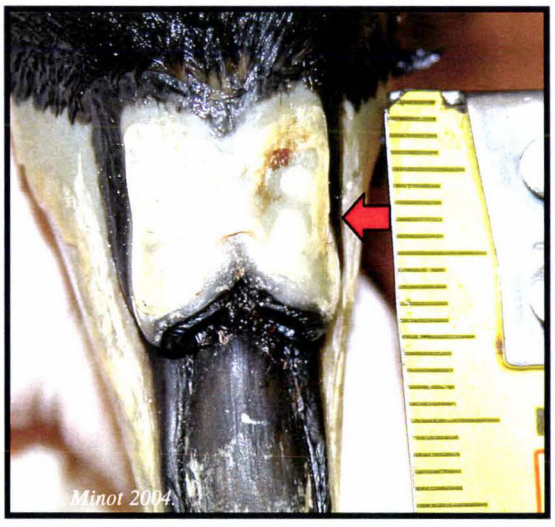

Plate 2.37 *'Nostril shape'* 1 (arrow - least width).

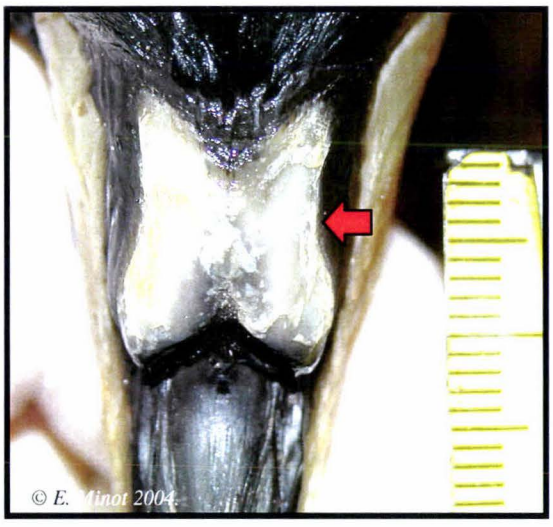

Plate 2.38 *'Nostril shape'* 2 (arrow - least width).

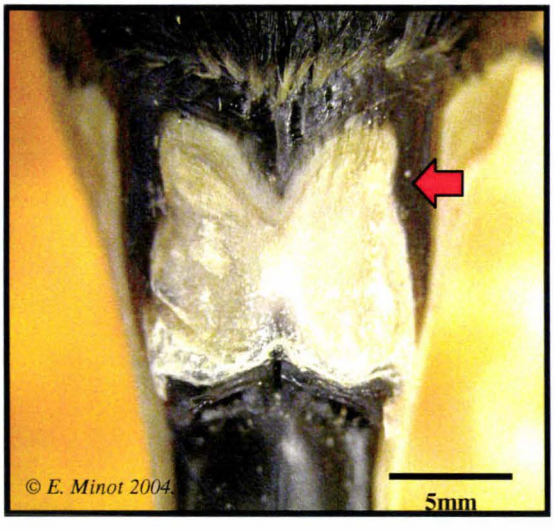

Plate 2.39 *'Nostril shape'* 3 (arrow - least width).

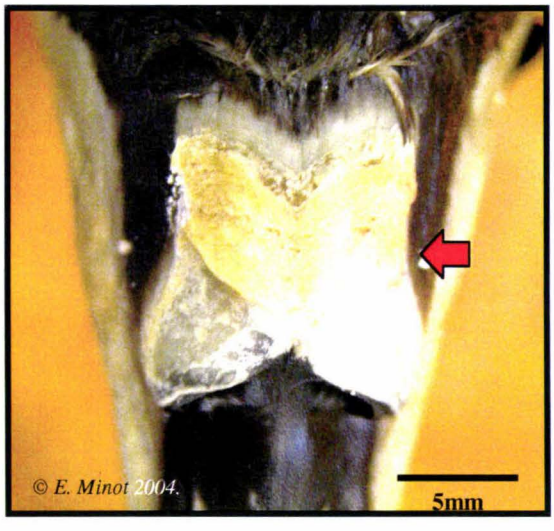

Plate 2.40 *'Nostril shape'* 4 (arrow - least width).

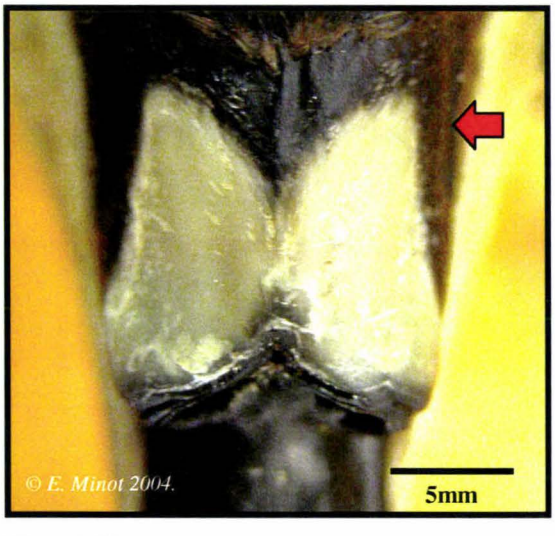

Plate 2.41 *'Nostril shape'* 5 (arrow - least width).

2.9 ANALYSIS

2.9.1 Cluster Groups

White-chinned petrels in the New Zealand EEZ have breeding populations at the Auckland Islands, Antipodes Island and Campbell Island (Warham and Bell 1979; Robertson and Bell 1984; Marchant and Higgins 1990; Heather and Robertson 2000).

It was impossible to discern which breeding population each bycatch white-chinned petrel was from, however, Berrow *et al.* (2000) state that adult white-chinned petrels were more likely to forage closer to the breeding islands during breeding season. Based on this assumption, adult white-chinned petrels caught close to breeding islands during the breeding season within the New Zealand EEZ are likely to be from those particular islands.

There were large groups of white-chinned petrels caught close to the Auckland Islands and Antipodes Island, but none caught close to Campbell Island. Grids were placed around the Auckland and Antipodes Islands and adult birds caught closest to the Auckland Islands and Antipodes Island, within each grid, during the breeding season between October and March were selected to represent each of the two populations.

Two further 'cluster groups' were selected where large groups of white-chinned petrels were caught further away from the Auckland and Antipodes islands. These large groups were on the Chatham Rise and off Puysegur point. They were selected to give an indication where white-chinned petrels from the Auckland and Antipodes Islands forage during the breeding season. Again grids were placed on the Chatham Rise and around Puysegur Point and adult birds caught within each grid during the breeding season between October and March were selected to represent each location.

The 'Auckland Island cluster group'

The Auckland Islands are located south of Stewart Island, New Zealand, at 50°35'S 166°00'E. The grid around the Auckland Islands measured 60 000 km² and all adult

fisheries bycatch white-chinned petrels caught between October and March within the grid made up the 'Auckland Island cluster group' (Plate 3.7).

The 'Antipodes Island cluster group'

The Antipodes Island is located south-west of the Chatham Islands, New Zealand, at 49°40'S 178°50'E. The grid around the Antipodes Islands measured 56 000 km² and all adult fisheries bycatch white-chinned petrels caught between October and March within the Antipodes Island grid made up the 'Antipodes Island cluster group' (Plate 3.8).

The 'Chatham Rise cluster group'

The Chatham Rise is located between the Chatham Islands and Banks Peninsula, New Zealand. The grid on the Chatham Rise measured 111 000 km² and all adult fisheries bycatch white-chinned petrels caught between October and March within the Chatham Rise grid made up the 'Chatham Rise cluster group' (Plate 3.9).

The 'Puysegur Point cluster group'

Puysegur Point is located at the bottom of Fiordland National Park, New Zealand. The grid around Puysegur Point measured 40 000km² and all adult fisheries bycatch white-chinned petrels caught between October and March within the Puysegur Point grid made up the 'Puysegur Point cluster group' (Plate 3.10).

2.9.2 Maps

Plate 1.1 showing the distribution of all 944 white-chinned petrel bycatch birds caught within the New Zealand EEZ up to September 2003 was constructed by Seabed Mapping International Limited from the autopsy database (Robertson, C.J.R. *pers. comm.*). Plates 3.1-3.10 showing the distribution of the 723 white-chinned petrel bycatch birds used in this study were constructed by M. Valentine and M. Tuohy (Institute of Natural Resources, Massey University) using the mapping programme Arc Map. The projection used on all maps was WGS84.

2.9.3 Statistics

External measurements of all white-chinned petrels were compared with external measurements taken by 'the Laboratory' to estimate the amount of observer error between two separate observers measuring the same sample of birds.

A student t-test was used to compare means of adult, non-adult, male, female, and 'Auckland and Antipodes Island cluster group' measurements.

Multivariate statistical analysis was used to analyse the data. The two analyses used were principal component analysis and discriminant analysis using Minitab™ 14. Graphs were constructed using Minitab™ 14 and Sigmaplot 8™.

3

RESULTS

3.1 INTRODUCTION

In this chapter are outlined the results of sex and age determination and external morphology of 'the white-chinned petrel sample' compared with white-chinned petrel study skins from breeding islands.

Section 3.2 on sex and age determination includes sections on white-chinned petrel sex and age (3.2.1), and aging adults (3.2.2) and non-adults (3.2.3).

Section 3.3 on external morphology of white-chinned petrels begins with a comparison of external measurements with 'the Laboratory' sample (section 3.3.1). I compared my external measurements with those of 'the Laboratory' and to produce an estimation of inter-observer bias and reliability. External measurements of white-chinned petrel study skins from breeding populations were then compared to determine if, initially, there were size differences between breeding populations (section 3.3.2). Section 3.3.3 then looks at the location and average external measurements of 'the white-chinned petrel sample'. External morphology of adult and non-adult petrels was then compared to determine if there were size differences between the two age classes (section 3.3.4). Then the external morphology of adult males and females was compared to determine if there was any sexual dimorphism between male and female white-chinned petrels (section 3.3.5).

Section 3.3 continues with section 3.3.6 on the comparison of external morphology of the 'Auckland and Antipodes Island cluster groups' to determine if there were size differences between the two 'cluster groups'. Discriminant analysis was used to determine which measurements best differentiated 'Auckland and Antipodes Island cluster group' males and females. Section 3.3.7 then compared the functions for

differentiating 'Auckland and Antipodes Island cluster group' males and females with study skins from Antipodes Island, Auckland Island, Campbell Island, the South Atlantic and South Pacific Oceans populations and to birds caught off Chile to try to relate the 'cluster groups' to breeding populations. The functions for differentiating 'Auckland and Antipodes Island cluster group' males and females were then compared with the 'Chatham Rise and Puysegur Point cluster groups' to indicate where Auckland and Antipodes Island white-chinned petrels forage during the breeding season (section 3.3.8). The functions for differentiating 'Auckland and Antipodes Island cluster group' males and females were also tested on petrels caught at the end of the breeding season (section 3.3.9) and on non-adults (section 3.3.10).

Results are expressed as means ± 1 standard error of the mean unless otherwise stated. Results of white-chinned petrel internal morphology including testicular development and general internal organ descriptions are shown in Appendix 3.15.

3.2 SEX AND AGE DETERMINATION

3.2.1 Sex and age

The white-chinned petrels in the sample were sexed by examination of the gonads. 'The white-chinned petrel sample' consisted of 572 (79.1%) males, 144 (19.9%) females, and seven (1.0%) birds not sexed because gonads were missing. The testes are located at the anterior end of the kidneys towards the midline, tend to be round or oval in shape, and vary in size depending on age and time of year. Testis colour varied from pinkish red, light grey, grey, to dark grey. Occasional testes carried a black spot as well. Females have a single ovary on the left side at the anterior end of the left kidney near the midline. The single oviduct extends from the ovary on top of the left kidney to the cloaca. The size of the ovary and condition of the follicles varied between individuals depending on age and time of year. The oviduct also varied in size depending on age and time of year.

Initial age of 'the white-chinned petrel sample' was estimated by size and development of gonads and birds were classed as either adult (those that had reached

sexual maturity) or non-adult (those that had not reached sexual maturity). During analysis a more accurate estimate of age was determined using development of gonads, brood patch, moult, date of capture, and general notes from 'the Laboratory' database. These were again classified as either adult or non-adult. There were 691 adults, 31 non-adults and one bird of unknown age out of the total 723 sample. All petrels in my sample were very wet (from having been taken from the ocean, frozen and thawed), so information on moult and brood patch was difficult to collect.

3.2.2 Adults

A total of 691 (95.6%) birds from 'the white-chinned petrel sample' were classified as adults, based on combined information on development of gonads, date of capture and brood patch and moult data. 547 (75.7%) of the adults were males and 138 (19.1%) were females. Six (0.8%) petrels aged as adults, solely on moult and brood patch data because internal organs were missing, were not sexed.

The range of adult male left testis volume varied between 8.4 mm^3 to 3350.9 mm^3 with an average weight of 0.48 g ± 0.07 g (n = 31). During the non-breeding season from May to August, testis volume varied between 58.6 mm^3 to 157.1 mm^3, while at the start of the breeding season it varied between 41.7 mm^3 to 3350.9 mm^3 (the largest volume of 3350.9 mm^3 was recorded in November), and between January and April testis volume varied between 46.1 mm^3 to 282.2 mm^3 (Figure 3.1).

The condition of the adult ovary, ovarian follicles, and oviduct varied from a small ovary with small follicles (0.5-2.0 mm) and a thin convoluted oviduct during the non-breeding season between May and August to a thicker convoluted oviduct and ovarian follicles of various size (generally 1.0-5.0 mm) at the start of the breeding season from September to December to a thin convoluted oviduct smaller ovarian follicles (1.0-3.0 mm) towards the end of the breeding season between January and April.

The condition of the brood patch of adults varied from being totally covered in feathers ('downy') between May and August to becoming bare from September to December and becoming covered, or pinning (start of regrowth of feathers), to being covered from January to April. Adults tended to under go some moult through the

breeding season but most adult birds caught showed heavy body moult towards the end of the breeding season and during the non-breeding season.

At the start of the breeding season between September and December in 'the white-chinned petrel sample' 444 adult male and 96 adult female white-chinned petrels were caught. In September adult testis volume was an average 931.59 mm^3 ± 111.04 mm^3 (n = 4), peaking at an average 1265.30 mm^3 ± 102.06 mm^3 (n = 18) in October to an average 948.20 mm^3 ± 26.03 mm^3 (n = 378) with an average weight of 0.65 g ± 0.08 g (n = 21) in November to 303.94 mm^3 ± 53.13 mm^3 (n = 18) with an average weight of 0.15 g ± 0.02 g (n = 3) in December.

From September to December white-chinned petrels with testis volume greater than ~500 mm^3, or with developing ovarian follicles between 1.0-5.0 mm and a heavily thick convoluted oviduct, had a brood patch that was generally becoming bare (especially in November and December) and had slight body moult.

Females caught during November occasionally had one large developing ovarian follicle that varied in size from 10-44 mm in diameter and had a convoluted oviduct that was wide enough to pass an egg. These large ovarian follicles were most likely the reserve egg. Adult petrels caught between September and December with small testis volumes (below ~500 mm^3) or with small ovarian follicles between 0.5-2.0 mm in diameter and a thin convoluted oviduct, tended to have 'downy' brood patches and were undergoing heavy moult.

Between January and April, 100 adult male and 42 adult female petrels were caught. From January to February adults had a bare to pinning (start of regrowth of feathers) 'downy' brood patch and some birds had slight body moult. Adults caught in January tended to show bare brood patches and only slight pinning, while those in February had more 'downy' brood patches and some with a feathered stripe down the centre with considerably more pinning.

Adults caught in March and April had 'downy' brood patches and most were undergoing heavy body moult, and some tail moult. Male testes were receding by this stage with average testis volumes 144.27 mm^3 ± 13.12 mm^3 (n = 20) with an average

weight of 0.09 g (n = 1) in January, 112.74 mm^3 ± 5.56 mm^3 (n = 52) with an average weight of 0.11 g ± 0.01 g (n = 6) in February, 126.19 mm^3 ± 16.30 mm^3 (n = 14) in March, and 110.14 mm^3 ± 12.88 mm^3 (n = 14) in April. Adult females caught between January and April had thin convoluted oviducts with ovarian follicles 0.5-2.0 mm in diameter.

Only three adults were caught outside the breeding season between May and August and all were males, undergoing heavy body moult, with some tail moult, and all had a 'downy' brood patch. Adult males had average testis volume of 98.09 mm^3 ± 30.05 mm^3 (n = 3). No females were caught in my sample between May and August. However, it was still difficult to distinguish adults from non-adults during the non-breeding season.

Of the six birds aged solely on moult and brood patch data, two caught in January had bare to pinning brood patches with slight body moult, and three caught in April had 'downy' brood patches and were undergoing body moult.

There was a significant difference in volume between adult left and right testes. The average volume of the left testis (877.80 mm^3 ± 86.80 mm^3, n = 58) was significantly higher ($P = 0.0052$) than the average volume of the right testis (581.50 mm^3 ± 57.17 mm^3, n = 58). The results that follow refer only to the left testis.

There were significant differences in left testis size of adult males between the period September to May ($F_{(8, 513)} = 40.493$, $P < 0.001$, n = 521) (Figure 3.1). Testis volume of adults in September (931.59 mm^3 ± 111.04 mm^3 (n = 4)), October (1265.30 mm^3 ± 102.60 mm^3 (n = 18)) and November (948.20 mm^3 ± 26.03 mm^3 (n = 378) were significantly higher ($P < 0.001$) than in December (303.94 mm^3 ± 53.13 mm^3 (n = 18)), January (144.27 mm^3 ± 13.12 mm^3 (n = 20)), February (112.74 mm^3 ± 5.56 mm^3 (n = 52)), March (126.19 mm^3 ± 16.30 mm^3 (n = 14)), April (110.14 mm^3 ± 12.88 mm^3 (n = 14), and May (98.09 mm^3 ± 30.05 mm^3 (n = 3). The testis volume of adults in October was significantly higher than in November ($P = 0.010$), December was significantly higher ($P < 0.001$) than in January, February, March, April, and May, and January was also significantly higher ($P < 0.001$) than in February and April.

Adult testis volume was not significantly different between September and October (P = 0.157) or September and November (P = 0.941). Neither was adult testis volume significantly different between January and March (P = 0.390) or May (P = 0.213). Adult testis volume was also not significantly different between February and March (P = 0.326), February and April (P = 0.837), February and May (P = 0.546), March and April (P = 0.447), March and May (P = 0.472), or April and May (P = 0.703).

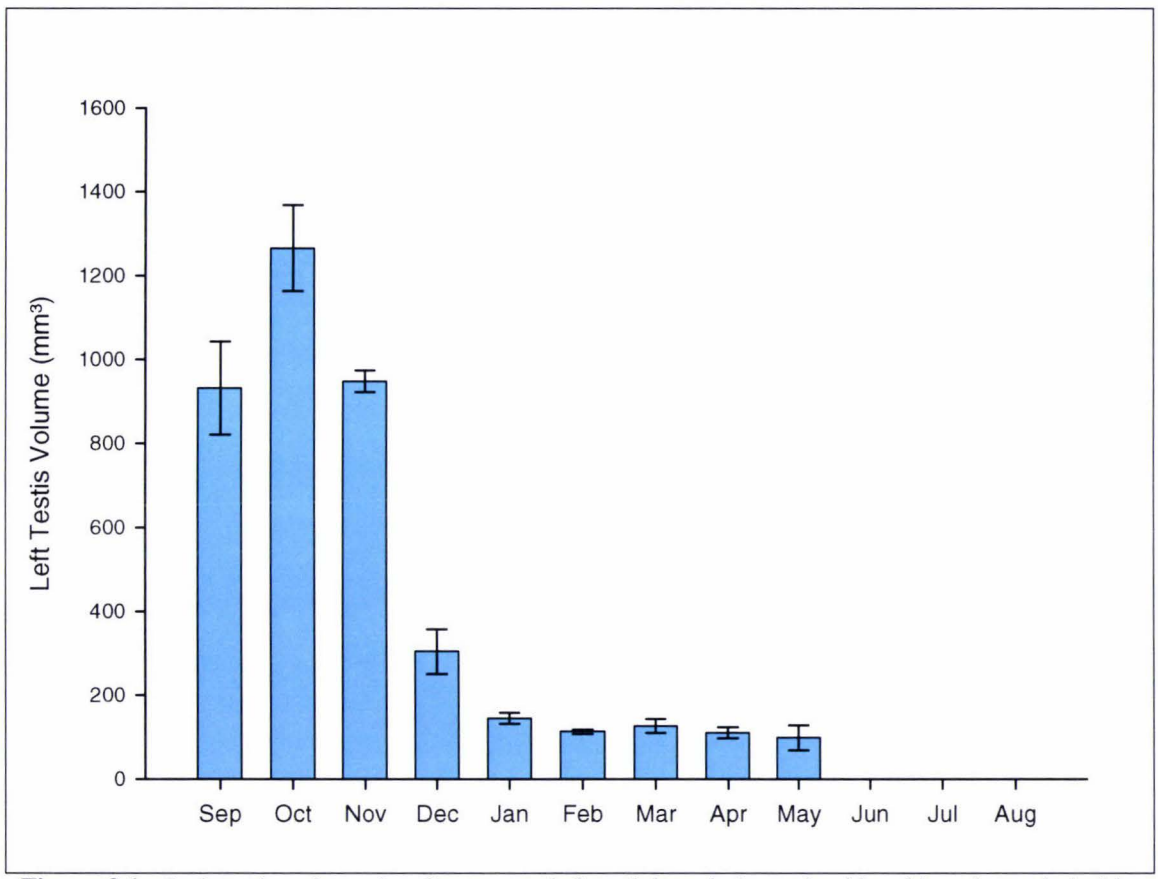

Figure 3.1 Left testis volume (mm³) per month for adult male bycatch white-chinned petrels in 'the white-chinned petrel sample'. Sample sizes: September, n = 4; October, n = 18; November, n = 378; December, n = 18; January, n = 20; February, n = 52; March, n = 14; April, n = 14; May, n = 3; June, n = 0; July, n = 0; August, n = 0. Error bars represent 1 standard error of the mean.

Unusual cases included a few males with one testis enlarged in breeding condition and one testis of immature size e.g. a bird had left testis volume 8.4 mm³ (4 mm in length) and the right testis 226.2 mm³ (12 mm in length). These birds were still considered adults as they had one testis of adult size.

3.2.3 Non adults

A total of 31 petrels were classified as non-adults based on development of gonads, date of capture, brood patch and moult data. This accounted for only 4.3% of 'the

white-chinned petrel sample', and within this were 25 (3.5%) males caught in February and March and six (0.8%) females caught in February and November. Non-adult males in general have small testes with an average left testis volume of 90.27 mm^3 ± 4.80 mm^3 (n = 25), with an average weight of 0.07 g ± 0.02 g (n = 2), ranging in volume between 58.60 mm^3 to 131.90 mm^3.

Twenty-four non-adult males caught in February had an average left testis volume 90.75 mm^3 ± 4.98 mm^3 (n = 24) and weight 0.07 g ± 0.02 (n = 2) while three non-adult females all had small similar sized ovarian follicles (0.5-1.0 mm in diameter) and a thin straight oviduct. The brood patch of these birds was generally all 'downy' and all birds were moulting heavily. One non-adult male was caught in March and had a left testis volume of 78.50 mm^3 and had a 'downy' covered brood patch. Three non-adult females were caught in November and all had thin straight oviducts, ovarian follicles 0.5-1.0 mm in diameter and 'downy' covered brood patches. There was no significant difference in left testis volume of non-adults between February and March ($P = 0.628$).

There was no significant difference in volume between non-adult male left and right testes ($P = 0.328$). The average volume of the left testis was 82.90 mm^3 ± 4.36 mm^3 (n = 3) and the average volume of the right testis was 68.50 mm^3 ± 12.18 mm^3.

3.3 EXTERNAL MORPHOLOGY OF WHITE-CHINNED PETRELS

This includes the following sections: comparison of my external measurements with 'the Laboratory'; study skin measurements; 'the white-chinned petrel sample'; adult and non-adult white-chinned petrel external morphology; adult male and female white-chinned petrel external morphology; the 'Auckland and Antipodes Island cluster groups'; comparison of 'cluster groups' to study skins; the 'Chatham Rise and Puysegur Point cluster groups'; white-chinned petrels caught outside the breeding season; and non-adult white-chinned petrels.

3.3.1 Comparison of external measurements with 'the Laboratory'

This section shows external measurements of the 'the white-chinned petrel sample' that were measured by 'the Laboratory' and then by me. These results show the amount of error in observers measuring the same sample of birds separately, and determining which standard external measurements are the most accurate and easily repeatable.

My measurements and 'the Laboratory's' standard external measurements of 'the white-chinned petrel samples' are summarised in Tables 3.1 and 3.2, along with the difference between means for each measurement.

Table 3.1 Average head and bill measurements of 'the white-chinned petrel sample' (n = 723) measured by the myself and 'the Laboratory'. MF = my measurements; The lab = 'the Laboratory' measurements; Difference between means = difference between MF and The Lab means; HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; SD = standard deviation; SE = standard error; and n = sample size.

		HBL (mm)	HW (mm)	CL (mm)	CDB (mm)	CWB (mm)	BLD (mm)
MF	mean	115.5	35.7	52.8	22.3	21.1	15.7
	SD	2.95	1.29	1.83	0.85	0.87	0.79
	SE	0.11	0.05	0.07	0.03	0.03	0.03
	n	697	720	690	722	723	716
The Lab	mean	115.7	35.5	52.8	21.8	20.6	15.6
	SD	3.01	1.67	1.90	0.97	1.02	0.83
	SE	0.11	0.06	0.07	0.04	0.04	0.03
	n	697	720	690	722	723	716
Difference between means	mean	-0.2	0.2	0.0	0.5	0.5	0.1
	SD	0.99	1.65	0.77	0.60	0.72	0.34
	SE	0.04	0.06	0.03	0.02	0.3	0.01
	n	697	720	690	722	723	716

The measurements with the least difference between mine and 'the Laboratory' means were culmen length and bill least depth (Table 3.1), and left wing length (Table 3.2). There were significant differences between the means of all measurements, except culmen length, tail length and left wing length (ruler), as shown in Table 3.3. However, the differences between means of 'the Laboratory' and my measurements

are relatively small (Tables 3.1 and 3.2) and do not indicate a large measurement error between myself and 'the Laboratory'.

Each external measurement of each specimen I took was subtracted from those taken by 'the Laboratory'. The differences were then plotted to produce bell shaped curves that show the difference (as an error expressed as a percent of the mean and in millimetres) between 'the Laboratory' and my measurements. The measurements which peaked at zero and had narrow curves are the most accurate and easily repeatable measurements.

Table 3.2 Average bodily measurements of 'the white-chinned petrel sample' (n = 723) measured by myself and 'the Laboratory'. MF = my measurements; The lab = 'the Laboratory' measurements; Difference between means = difference between MF and The Lab means; RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsometatarsus length; TL = tail length; RWLr = right wing length (ruler); LWLr = left wing length (ruler); SD = standard deviation; SE = standard error; and n = sample size.

		RMTC (mm)	LMTC (mm)	RTL (mm)	LTL (mm)	TL (mm)	RWLr (mm)	LWLr (mm)
MF	mean	85.2	85.1	66.8	65.9	125.1	390.5	390.5
	SD	2.80	2.64	1.80	1.75	5.28	9.65	9.65
	SE	0.11	0.10	0.07	0.07	0.20	0.37	0.37
	N	663	657	720	717	671	663	662
The lab	mean	85.5	85.6	66.4	65.5	124.9	390.3	390.4
	SD	2.77	2.67	1.80	1.79	6.06	9.71	9.76
	SE	0.11	0.10	0.07	0.07	0.23	0.38	0.38
	N	663	657	720	717	671	663	662
Difference between means	mean	-0.2	-0.5	0.4	0.3	0.2	0.2	0.1
	SD	1.41	1.22	0.65	0.64	3.10	1.87	2.07
	SE	0.05	0.05	0.02	0.02	0.12	0.07	0.08
	N	663	657	720	717	671	663	662

Figure 3.2 shows a selection of these graphs of three external measurements, head and bill length, culmen length, and bill least depth, with the least amount of error (expressed as percent of the mean and in millimetres) between 'the Laboratory' and my measurements. Head and bill length had an error of 0-4% of the mean (up to 3 mm excluding outliers) between 'the Laboratory' and my measurements.

Table 3.3 Significant difference between means for 'the Laboratory's' and my external measurements. HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsomematarsus length; TL = tail length; RWLr = right wing length (ruler); and LWLr = left wing length (ruler).

	HBL	HW	CL	CDB	CWB	BLD	TL
P value	<0.001	<0.001	0.358	<0.001	<0.001	<0.001	0.096
Significant difference	yes	yes	no	yes	yes	yes	no
	RMTC	LMTC	RTL	LTL	RWLr	LWLr	
P value	<0.001	<0.001	<0.001	<0.001	0.004	0.069	
Significant difference	yes	yes	yes	yes	yes	no	

Culmen length had an error of 0-6% of the mean (up to 3 mm) and bill least depth an error of 0-6% of the mean (up to 1 mm) between 'the Laboratory' and my measurements. Error graphs of all other external measurements are shown in Appendix 3.1.

The left and right tarsometatarsus measurements were not quite as accurate but were repeatable, I consistently over measured both tarsometatarsus by 0.5 mm (1% of the mean) (Appendix 3.1). There was a significant difference ($P < 0.001$) between the average length of the left and right tarsometatarsus. This difference, however, was discovered to be a technique error, based on observer handedness, where the medial side of the right tarsometatarsus was measured and the lateral side of the left tarsometatarsus was measured. This resulted in a difference of 0.9 mm between the left and right tarsometatarsus, with the latter being longer. Both 'the Laboratory' and myself were right handed and measuring with the left hand got the opposite results.

The mid toe and claw length is an accurate measurement (error 0-7% of the mean) (Appendix 3.1). However, claw length can change over time due to wear making this measurement not as reliable.

Left and right wing length (ruler) showed slightly more error in length (up to 8 mm) compared to the rest of the external measurements. However, this only equated to an error of 2% of the mean (Appendix 3.1). Right and left wing length (ruler) is an accurate measurement.

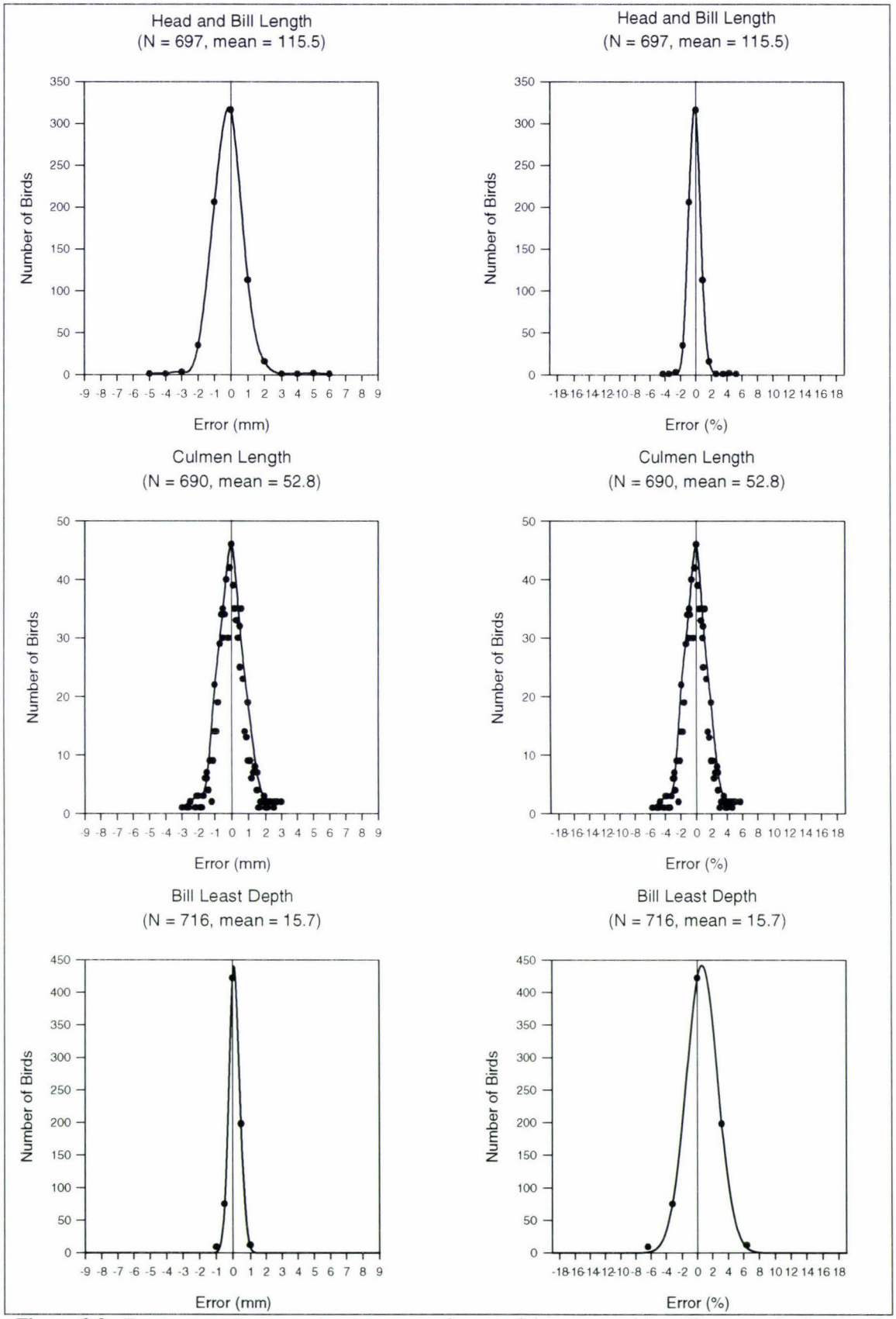

Figure 3.2 Error curves (expressed as a percent of error of the mean and in millimetres) for head and bill length, culmen length, and least bill depth comparing 'the Laboratory' with 'the white-chinned petrel sample'.

However, it changes over time due to wear and moult so is less reliable than bill and tarsometatarsus measurements. Tail length is less accurate and reliable than wing length but only had an error of up to 7% of the mean.

A sample of 35 white-chinned petrels had both left and right wings measured using a ruler and a tape, though six specimens had damaged wings and were not included.

The average right wing length (ruler) was 391.7 mm ± 1.68 mm (n = 29), and the average right wing length (tape) was 393.6 mm ± 1.71 mm (n = 29). The average left wing length (ruler) was 391.5 mm ± 1.73 mm (n = 29) and the average left wing length (tape) was 394.0 mm ± 1.74 mm (n = 29). There was no significant difference in length between right wing length (ruler) and right wing length (tape) ($P = 0.416$), or between left wing length (ruler) and left wing length (tape) ($P = 0.309$).

The least accurate and least replicable measurements were head width, culmen width at the base, and culmen depth at the base (Appendix 3.1), however the amount of error for all measurements was small, between 0.2-0.5 mm (Table 3.1). Head width was a difficult measure to take because the callipers were pressured on the side of the head to get a measurement of the narrowest width of the skull with the skin and muscle still covering it. The amount of pressure applied to the callipers could vary between specimens and time of day.

The amount of error between 'the Laboratory' and my external measurements overall was quite small and these results show that both sets of measurements were reasonably accurate and repeatable indicating they were measured using the same techniques. These results then allowed me to combine C.J.R. Robertson's study skin measurements with my study skin measurements.

3.3.2 Study skin measurements

The 117 white-chinned petrel study skins were measured by two observers, C.J.R. Robertson and myself, and as shown in the previous section (3.3.1) measurements were conducted using the same techniques by both observers and could therefore be combined to increase the sample sizes of all populations. Only 29 white-chinned

petrel study skins were collected as breeding individuals from actual breeding islands during the breeding season between September and March, 11 from the Auckland Islands, six from the Antipodes Islands, three from Campbell Island, four from breeding islands in the South Indian Ocean, and five from breeding islands in the South Atlantic Ocean. A further 29 study skins were collected throughout the year at sea off the coast of Chile and were used to give an indication as to where New Zealand white-chinned petrels might disperse. Bill descriptions were not collected from study skins as colouring on the bill could be altered by drying of the specimens.

The remaining 59 white-chinned petrel study skins were either collected at sea near breeding islands or as beach wrecked specimens or were non-adults and were not included for further analysis. Four white-chinned petrel study skins had no data on where or when they were collected and were also not included in further analysis.

I measured 10 Auckland Island breeding population study skins, two Antipodes Island breeding population skins, three Campbell Island breeding population skins, and three South Indian Ocean breeding population skins. C.J.R. Robertson measured one Auckland Island breeding population study skin, four Antipodes Island breeding population skins including the type specimen of *Procellaria aequinoctialis steadi* Mathews, one South Indian Ocean breeding population skin and the type specimen of *P. a. mixta* Mathews (not included in analysis as was caught at sea), five South Atlantic Ocean breeding population skins, and 29 study skins of birds caught off Chile. Average head and bill measurements are shown in Table 3.4 and average bodily measurements are shown in Table 3.5.

The Antipodes Island study skins were, on average, larger in culmen length, culmen depth at the base, left and right wing length, and tail length (except Campbell Island tail length) than all other study skin locations (Tables 3.4 and 3.5). Figure 3.3 shows the average culmen lengths of all study skin locations. The Antipodes Island study skins had the largest culmen length followed by the Campbell Island study skins. The Auckland Island, Campbell Island, South Atlantic Ocean, South Indian Ocean study skins and the bird skins caught off Chile all had similar average culmen lengths (Figure 3.3).

Table 3.4 Average head and bill measurements of white-chinned petrel study skins from breeding island populations at the Auckland Islands (n = 11); Antipodes Islands (n = 6); Campbell Island (n = 3); from the South Indian Ocean (n = 4); from the South Atlantic Ocean (n = 5); and birds caught off Chile in the South East Pacific Ocean (n = 29). CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; AW = area of white chin patch; SD = standard deviation; SE = standard error; and n = sample size.

		CL (mm)	CDB (mm)	CWB (mm)	BLD (mm)	AW (mm²)
Auckland Islands	mean	51.7	21.0	20.5	14.3	62.53
	SD	1.40	*	20.5	0.35	31.83
	SE	0.47	*	0.62	0.25	9.60
	n	9	1	11	2	11
Antipodes Island	mean	54.0	21.1	20.2	15.1	101.54
	SD	2.30	1.03	0.93	1.03	50.09
	SE	0.94	0.52	0.38	0.52	20.45
	n	6	4	6	4	6
Campbell Island	mean	52.0	*	20.3	*	52.19
	SD	1.56	*	1.04	*	75.30
	SE	1.10	*	0.60	*	43.48
	n	2	*	3	*	3
South Indian Ocean	mean	50.7	*	20.6	15.0	228.04
	SD	0.63	*	0.48	*	164.64
	SE	0.31	*	0.24	*	82.32
	n	4	*	4	1	4
South Atlantic Ocean	mean	50.8	21.0	18.3	15.1	91.76
	SD	1.25	1.87	0.97	1.55	31.22
	SE	0.56	0.94	0.44	0.77	13.96
	n	5	4	5	4	5
Caught off Chile	mean	51.2	20.3	19.1	15.0	81.29
	SD	1.49	1.06	0.85	1.11	67.65
	SE	0.28	0.75	0.16	0.21	12.56
	n	29	2	28	28	29

Table 3.5 Average bodily measurements of white-chinned petrel study skins from breeding island populations at the Auckland Islands (n = 11); Antipodes Islands (n = 6); Campbell Island (n = 3); from the South Indian Ocean (n = 4); from the South Atlantic Ocean (n = 5); and birds caught off Chile in the South East Pacific Ocean (n = 29). RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsometatarsus length; TL = tail length; RWLr = right wing length (ruler); LWLr = left wing length (ruler); SD = standard deviation; SE = standard error; and n = sample size.

		RMTC (mm)	LMTC (mm)	RTL (mm)	LTL (mm)	TL (mm)	RWLr (mm)	LWLr (mm)
Auckland Islands	mean	88.3	87.7	64.2	63.5	118.6	377.1	378.1
	SD	2.31	2.89	2.71	2.30	6.86	8.03	9.51
	SE	1.33	1.67	0.82	0.69	2.07	3.03	3.60
	n	3	3	11	11	11	7	7
Antipodes Island	mean	90.5	90.0	64.5	64.0	125.3	394.4	395.3
	SD	1.12	2.83	1.87	2.45	5.12	8.73	10.72
	SE	1.50	2.00	0.76	1.10	2.56	3.91	5.36
	n	2	2	6	5	4	5	4
Campbell Island	mean	*	*	65.3	65.0	126.0	384.0	387.7
	SD	*	*	1.53	2.00	6.00	5.66	6.66
	SE	*	*	0.88	1.15	3.46	4.00	3.84
	n	*	*	3	3	3	2	3
South Indian Ocean	mean	*	*	63.5	63.0	120.0	382.0	382.0
	SD	*	*	0.58	1.00	0.00	1.41	*
	SE	*	*	0.29	0.58	0.00	1.00	*
	n	*	*	4	3	2	2	1
South Atlantic Ocean	mean	*	*	63.0	66.0	118.6	375	379.0
	SD	*	*	1.00	1.41	1.67	*	2.74
	SE	*	*	0.58	1.00	0.75	*	1.47
	n	*	*	3	2	5	1	4
Caught off Chile	mean	*	*	64.7	64.0	118.83	388	382.9
	SD	*	*	1.73	1.46	5.89	*	10.56
	SE	*	*	0.46	0.37	1.70	*	2.73
	n	*	*	14	16	12	1	15

Figure 3.4 shows the average wing length of all study skin locations. The Antipodes Island study skins had, on average, longer wing lengths than all other study skin locations (Figure 3.4). The Auckland Island, South Atlantic Ocean, South Indian Ocean study skins and the bird skins caught off Chile all had, on average, similar wing lengths (Figure 3.4). The Antipodes Island population also had, on average, a longer tail length than all populations except the Campbell Island population (Figure 3.5). The Auckland Island, South Atlantic Ocean, South Indian Ocean study skins and the bird skins caught off Chile also all had, on average, similar tail lengths (Figure 3.5).

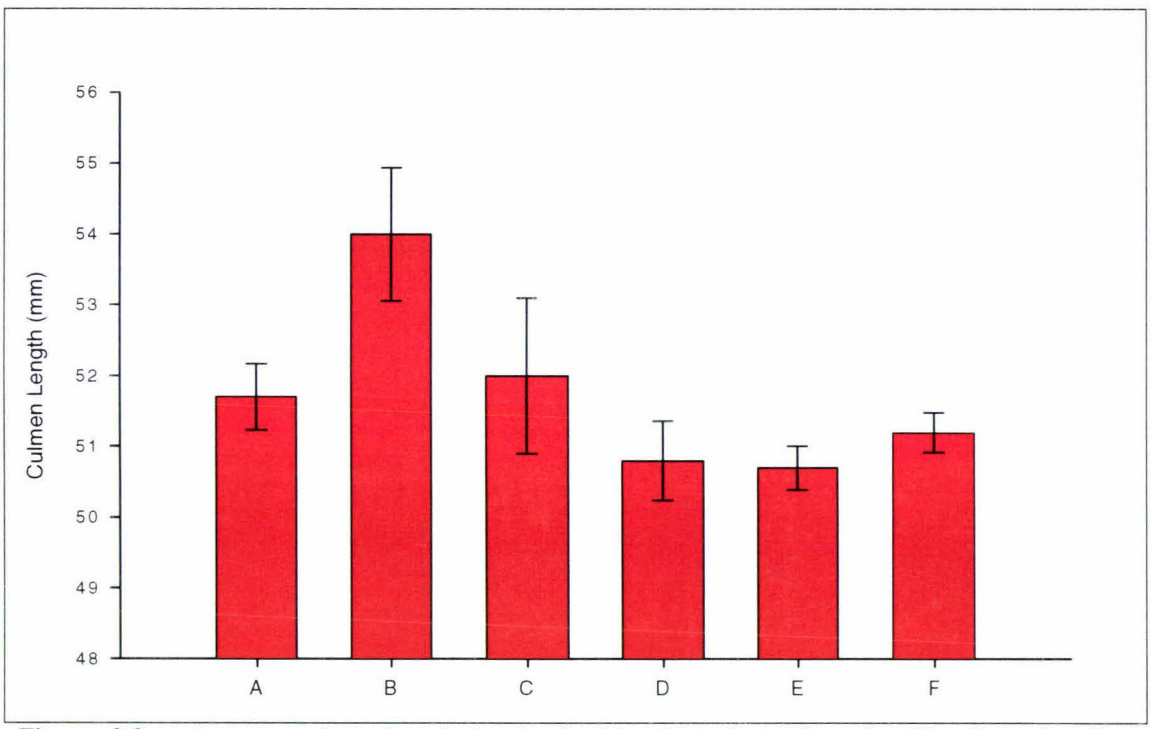

Figure 3.3 Average culmen length (mm) of white-chinned petrel study skins from breeding populations and birds caught off Chile. A = Auckland Island study skins (n = 9); B = Antipodes Island study skins (n = 6); C = Campbell Island study skins (n = 2); D = South Atlantic Ocean breeding population study skins (n = 5); E = South Indian Ocean breeding population study skins (n = 4); and F = study skins of birds caught off Chile (n = 29). Error bars represent 1 standard error of the mean.

The area of the white chin of study skins varied in all populations and there was overlap in standard deviation between all populations (Figure 3.6). White-chinned petrel study skins from breeding populations in the South Indian Ocean had on average the largest white chin area (Figure 3.6). No South Indian Ocean specimens were without a white chin and the smallest white chin area was 55.13 mm^3. The average white chin area was similar for Auckland Island, Antipodes Island, Campbell Island, the South Atlantic Ocean specimens, and birds off Chile study skins (Figure 3.6).

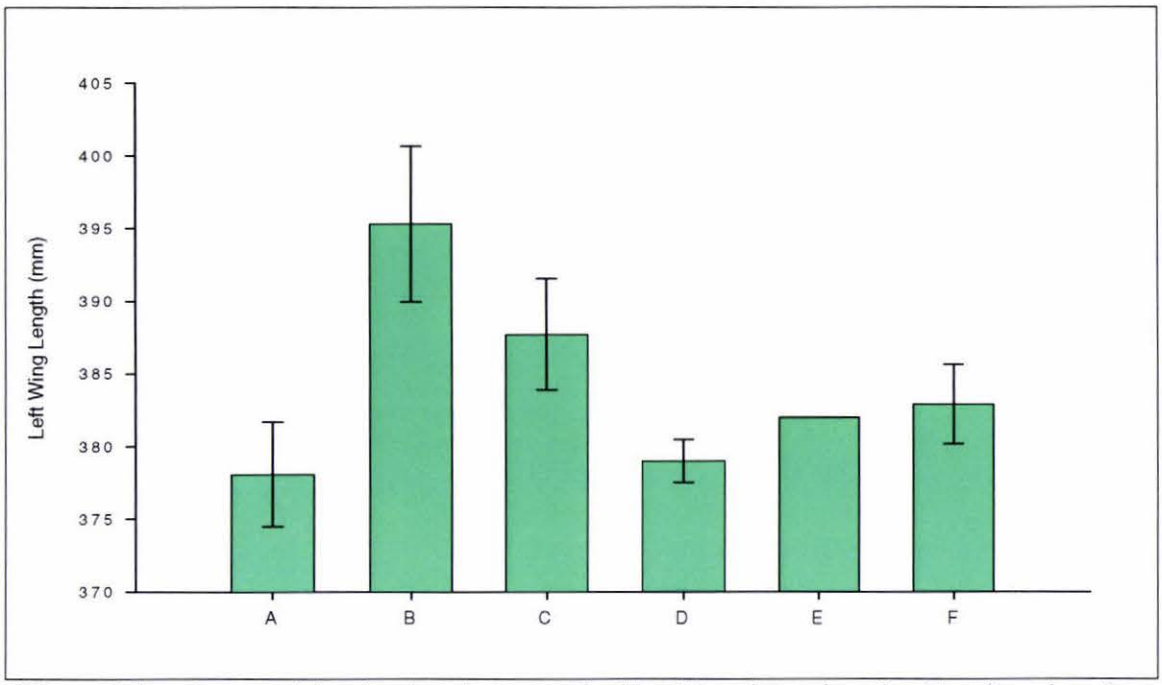

Figure 3.4 Average left wing length (mm) of white-chinned petrel study skins from breeding populations and birds caught off Chile. A = Auckland Island study skins (n = 7); B = Antipodes Island study skins (n = 4); C = Campbell Island study skins (n = 3); D = South Atlantic Ocean breeding population study skins (n = 4); E = South Indian Ocean breeding population study skins (n = 1); and F = study skins of birds caught off Chile (n = 15). Error bars represent 1 standard error of the mean.

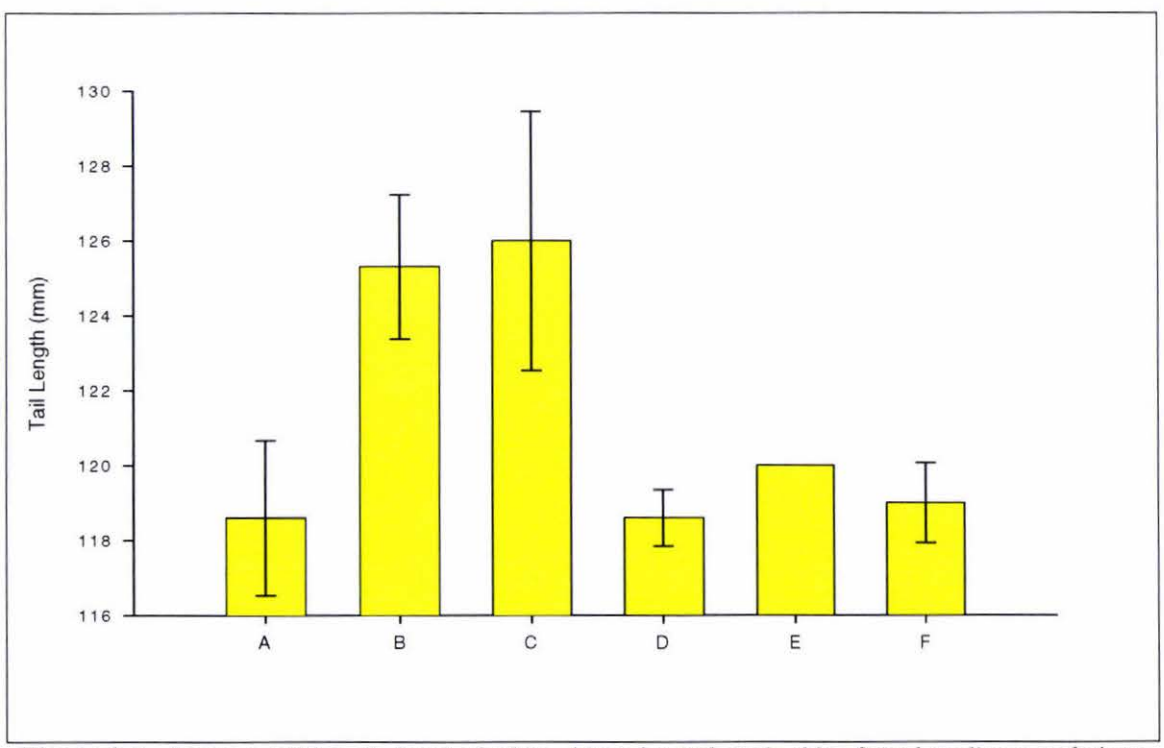

Figure 3.5 Average tail length (mm) of white-chinned petrel study skins from breeding populations and birds caught off Chile. A = Auckland Island study skins (n = 11); B = Antipodes Island study skins (n = 5); C = Campbell Island study skins (n = 3); D = South Atlantic Ocean breeding population study skins (n = 5); E = South Indian Ocean breeding population study skins (n = 2); and F = study skins of birds caught off Chile (n = 25). Error bars represent 1 standard error of the mean.

There was one specimen from the Auckland Islands, one from Campbell Island that had no white chin and two skins from Antipodes Island with a trace of white on the chin (< 5.0 mm²).

The type specimen of *P. a. steadi* Mathews was collected from Antipodes Island in March 1894 and was included in the Antipodes Island sample as its external measurements were similar to those of the Antipodes Island breeding population. The type specimen *P. a. steadi* had a culmen length of 56.1 mm, culmen width at the base 21.0 mm, and right wing length of 396.0 mm.

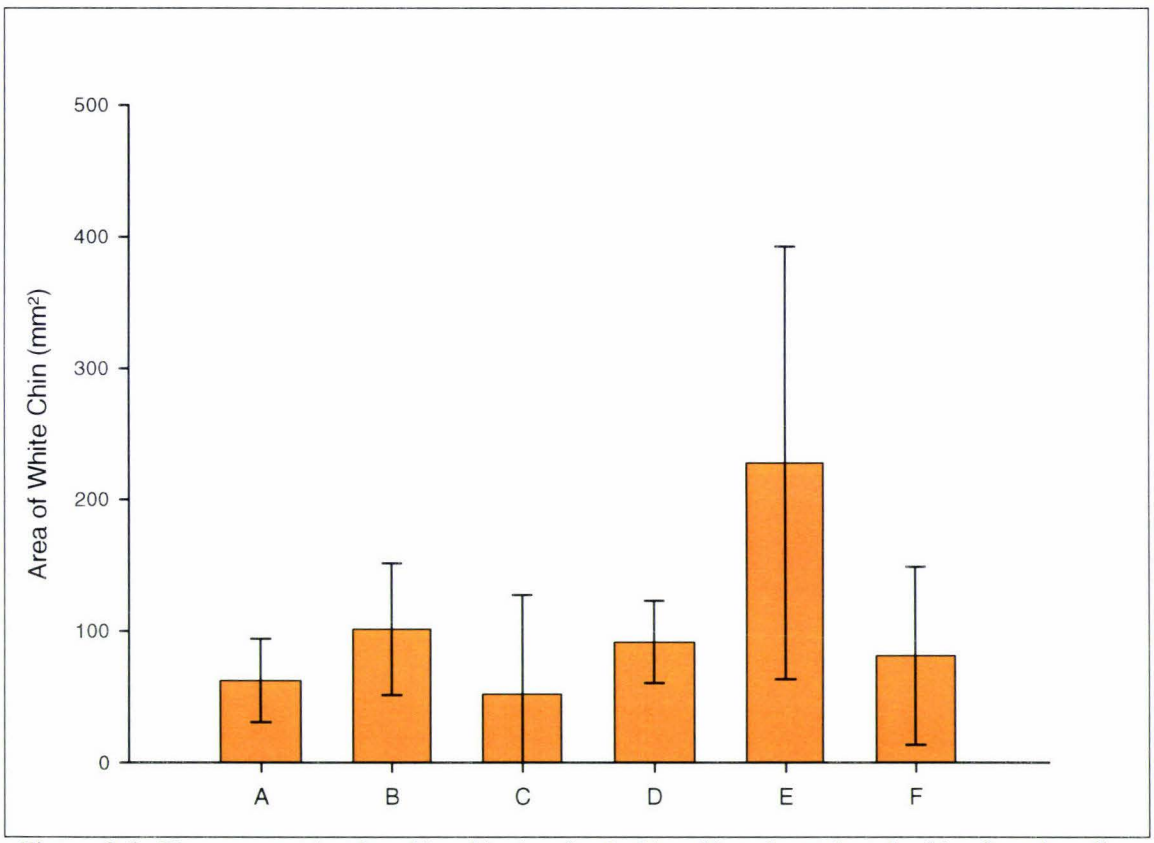

Figure 3.6 The average size the white chin (mm²) of white-chinned petrel study skins from breeding populations and birds caught off Chile. A = Auckland Island study skins (n = 11); B = Antipodes Island study skins (n = 6); C = Campbell Island study skins (n = 3); D = South Atlantic Ocean breeding population study skins (n = 5); E = South Indian Ocean breeding population study skins (n = 4); and F = study skins of birds caught off Chile (n = 29). Error bars represent 1 standard deviation.

The type specimen of *P. a. mixta* Mathews was caught at sea 300 miles north of Cape Town in the east South Atlantic Ocean. The measurements of this specimen, culmen length 52.2 mm, culmen width at the base 20.0 mm, tail length 119 mm, and wing length 377.0 mm, resemble those of the South Indian Ocean population and also of the South Atlantic Ocean population. However, the white chin area is large (583.20

mm^2) and characteristic of the South Indian Ocean population rather than the South Atlantic Ocean population (Table 3.6).

3.3.3 'The white-chinned petrel sample'

'The white-chinned petrel sample' consisted of 723 birds of which five were considered skeletons. The five skeletons had been mostly consumed by sea lice as they were just feathers and bones, with some skin, but with no internal organs present. One white-chinned petrel skeleton was unable to be aged or sexed. Four of the white-chinned petrel skeletons were able to be aged using moult and brood patch data but were unable to be sexed. A further two white-chinned petrels had all internal organs eaten by sea lice but were otherwise whole and were not considered skeletons. These two birds were aged using moult and brood patch data, but were unable to be sexed. 'The white-chinned petrel sample' consisted of 572 (79.1%) males and 144 (19.9%) females, with seven (1.0%) white-chinned petrels unable to be sexed as gonads were missing and one unable to be aged, indicating a sex ratio of 5:1 males to females.

Location of 'the white-chinned petrel sample'

The locations, based on latitude and longitude coordinates, where all the 723 white-chinned petrels were caught are summarised in Plate 3.1 'The white-chinned petrel sample' is mostly concentrated south east of New Zealand from the Hawkes Bay, 38°S to the Chatham Islands and down to and around the Subantarctic Antipodes and Auckland Islands, 51°S. The five main locations (Plate 3.1) where most birds were caught are: along the Chatham Rise (n = 278); on the Bounty Platform (n = 131); on the Pukaki Rise (n = 19); off Puysegur Point (n = 227); and above the Auckland Islands (n = 55). These locations generally relate to underwater shelves, where food is likely to be abundant.

All 723 white-chinned petrels were caught by various fishing practices, bottom longliners, tuna longliners, squid trawlers, and fish trawlers, during various times of the year between October 1996 and September 2003.

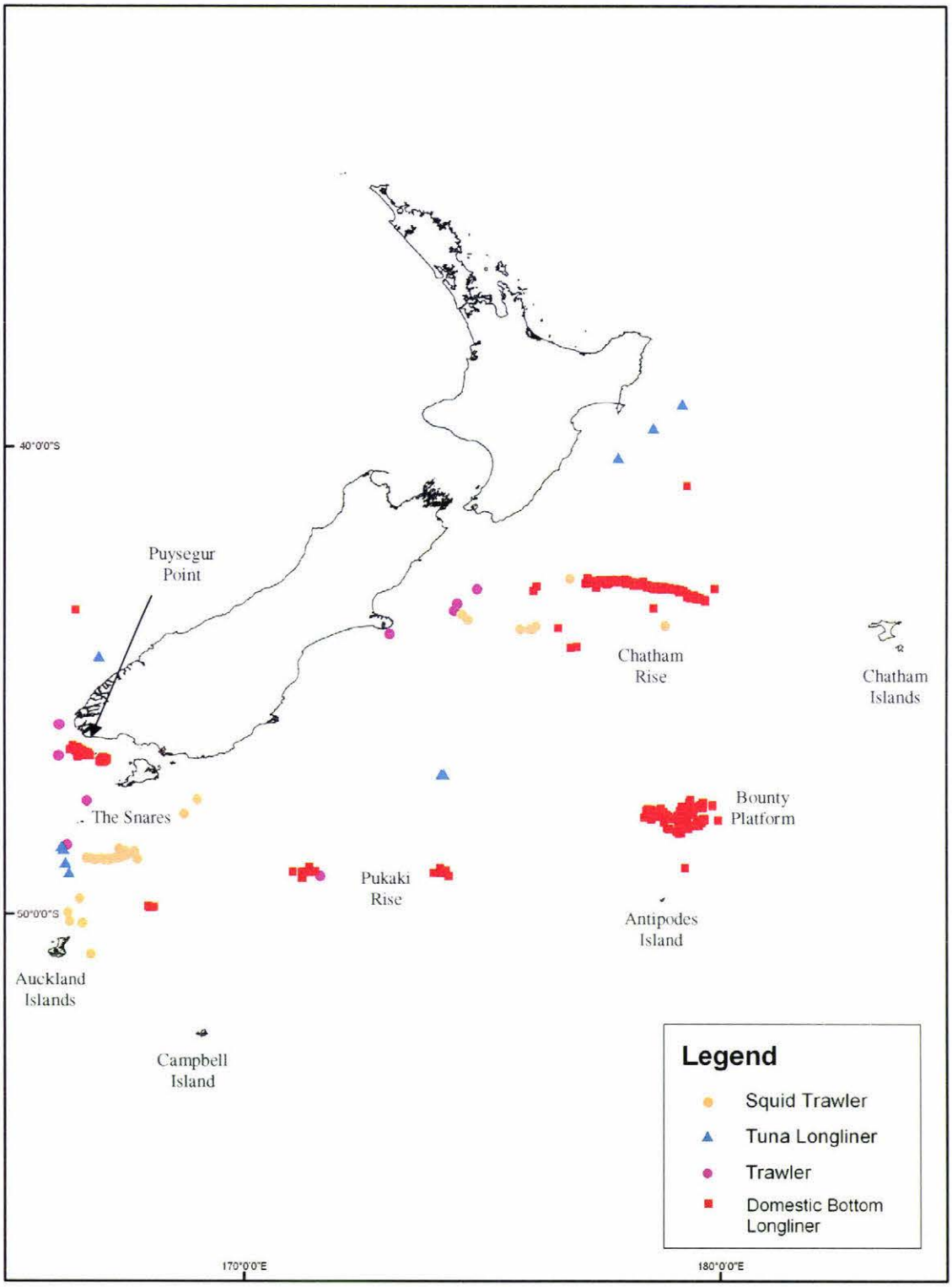

Plate 3.1 Map of the New Zealand Exclusive Economic Zone showing the location where all 723 bycatch white-chinned petrels used in this study were caught between 2000-2003, and by which fishery. Squid trawlers, n = 65; tuna longliners, n = 10; trawlers, n = 12; and bottom longliners, n = 636.

Bottom longliners caught 636 birds, 88.0% of the sample, in four main areas (Plate 3.1): along the Chatham Rise (n = 258); on the Bounty Platform (n = 130); on the Pukaki Rise (n = 15); and off Puysegur Point (n = 227). Four birds were also caught on the Campbell Plateau and one was caught on the Hikurangi Trench.

Ten white-chinned petrels were caught by tuna longliners (Plate 3.1) accounting for 1.4% of the sample. Four of these birds were caught between the Snares and Auckland Islands, three off Hawkes Bay, two on the Pukaki Rise, and one was caught off the West Coast off Fiordland.

Squid trawlers caught 65 white-chinned petrels, (9.0% of the sample) in two main areas (Plate 3.1), 16 on the Chatham Rise and 49 off the Auckland Islands. Fish trawlers caught 12 white-chinned petrels (1.7% of the sample), four on the Chatham Rise, four off Puysegur Point, two on the Pukaki Rise, one south west of The Snares, and one off Banks Peninsula (Plate 3.1).

A total of 488 white-chinned petrels were caught during November, which accounted for 67.5% of the total sample, and all except one were caught by bottom longliners (Table 3.6).

Table 3.6 Fisheries type and the number of white-chinned petrels in the sample (n = 723) caught per month between 2000-2003 within the New Zealand EEZ. Jan = January; Feb = February; Mar = March; Apr = April; Jun = June; Jul = July; Aug = August; Sep = September; Oct = October; Nov = November; Dec = December.

	Jan	Feb	*Mar*	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Domestic Bottom Longliners	15	77	0	8	2	0	0	0	5	19	487	23	636
Tuna Longliners	0	3	2	4	1	0	0	0	0	0	0	0	10
Squid Trawlers	12	17	19	17	0	0	0	0	0	0	0	0	65
Fish Trawlers	2	0	0	0	0	0	0	0	1	8	1	0	12
Total	29	97	21	29	3	0	0	0	6	27	488	23	723

Ninety-seven birds were caught during February (13.4% of the sample) of which 77 were caught by bottom longliners, 12 by squid trawlers and two by fish trawlers (Table 3.6). Other months which contributed highly to 'the white-chinned petrel

sample' were January and April with 29 birds each (each 4.0% of the sample), and October with 27 birds (3.7% of the sample) (Table 3.6).

External measurements of 'the white-chinned petrel sample'

The average head and bill measurements of 'the white-chinned petrel sample' (n = 723) are shown in Table 3.7, and the average bodily measurements (n = 723) are shown in Table 3.8. Not all measurements could be taken from all individuals due to damage, feather wear and moult. The head and bill length varied between 105.0-122.0 mm and the head width between 33.0-39.0 mm. Measurements of the bill varied between; culmen length 47.3-57.6 mm, culmen depth at the base 20.0-23.5 mm, culmen width at the base 19.0-22.5 mm, and bill least depth 13.0-16.5 mm. Nostril measurements varied from; nostril length 11.0-16.0 mm to minimum nostril width 7.5-10 mm.

Table 3.7 Average head and bill measurements of 'the white-chinned petrel sample' (n = 723). HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; MNW = minimum nostril width; NL = nostril length; AW = area of white chin patch; SD = standard deviation; SE = standard error; and n = sample size.

	HBL (mm)	HW (mm)	CL (mm)	CDB (mm)	CWB (mm)	BLD (mm)	MNW (mm)	NL (mm)	AW (mm^2)
mean	115.5	35.7	52.8	22.3	21.1	15.7	9.8	13.8	98.60
SD	2.95	1.29	1.83	0.85	0.87	0.79	0.70	1.16	62.07
SE	0.11	0.05	0.07	0.03	0.03	0.03	0.03	0.04	2.35
n	697	720	690	722	723	716	715	710	699

White chin area varied from 0.0-367.0mm^2. The area of the white chin patch varied from a large solid triangular white patch that was clearly visible, to a speckled white dispersed with black patch that was slightly more difficult to see, to a small structure that was occasionally only one white feather. Two birds had a small white patch on the left side of the face behind the bill plates, and three had a small white patch on the right side of the face. Three individuals had a small white patch on both sides of the face behind the bill plates. White feathers were also recovered on other parts of the body, including face, head and neck. 70.0% of specimens had at least some black feathering in the white chin patch, which included a black tip at the junction of the mandibular ramicorns, in front of the white chin patch.

Eighteen petrels had no white chin patch (2.6% of the sample) and a further 11 individuals had a white chin patch under 5.0 mm² (1.6% of the sample). One hundred and forty-two specimens had a white chin patch between 5-50 mm², 211 a white chin patch between 50-100 mm², 274 a white chin patch between 100-200 mm², 39 a white chin patch between 200-300 mm², and 4 with a white chin patch greater than 300 mm². White chin patch size seemed to be a very variable character within 'the white-chinned petrel sample'.

Length of the right mid toe and claw was between 74.0-95.0 mm and the left mid toe and claw between 72.0-94.0 mm. There was no significant difference (P = 0.323) between the average length of the right and left mid toe and claw.

Table 3.8 Average bodily measurements for 'the white-chinned petrel sample' (n = 723). RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsomematarsus length; TL = tail length; RWLr = right wing length (ruler); RWLt = right wing length (tape); LWLr = left wing length (ruler); LWLt = left wing length (tape); SD = standard deviation; SE = standard error; and n = sample size.

	RMTC (mm)	LMTC (mm)	RTL (mm)	LTL (mm)	TL (mm)	RWLr (mm)	LWLr (mm)
mean	85.2	85.1	66.8	65.9	125.1	390.5	390.5
SD	2.80	2.64	1.80	1.75	5.28	9.65	9.65
SE	0.11	0.10	0.07	0.07	0.20	0.37	0.37
n	663	657	720	717	671	663	662

Length of the right tarsometatarsus was between 61.0-73.0 mm and the left tarsometatarsus between 60.0-72.0 mm. There was a significant difference (P < 0.001) between the average length of the left and right tarsometatarsus. However, the difference was a technique error as described in the section 3.3.1 (comparison of external measurements with 'the Laboratory').

All individuals that were undergoing moult or had broken or worn tail or wing feathers were not included in the sample. The length of the tail was between 107.0-144.0 mm.

The length of the right wing (ruler) was between 358.0-419.0 mm and the left wing between 356.0-420.0 mm. There was no significant difference (P = 0.845) between the average lengths of the right and left wings for 'the white-chinned petrel sample'.

Culmen length, tail length and right wing length of 'the white-chinned petrel sample' were compared between the periods October to December and January to March. These comparisons were conducted to see if tail length and right wing length differ in length over the season compared with culmen length.

There was no significant difference between the average culmen length (P = 0.678) (Figure 3.7), tail length (P = 0.133) (Figure 3.8) or right wing length (P = 0.255) (Figure 3.8) between the periods October to December and January to March.

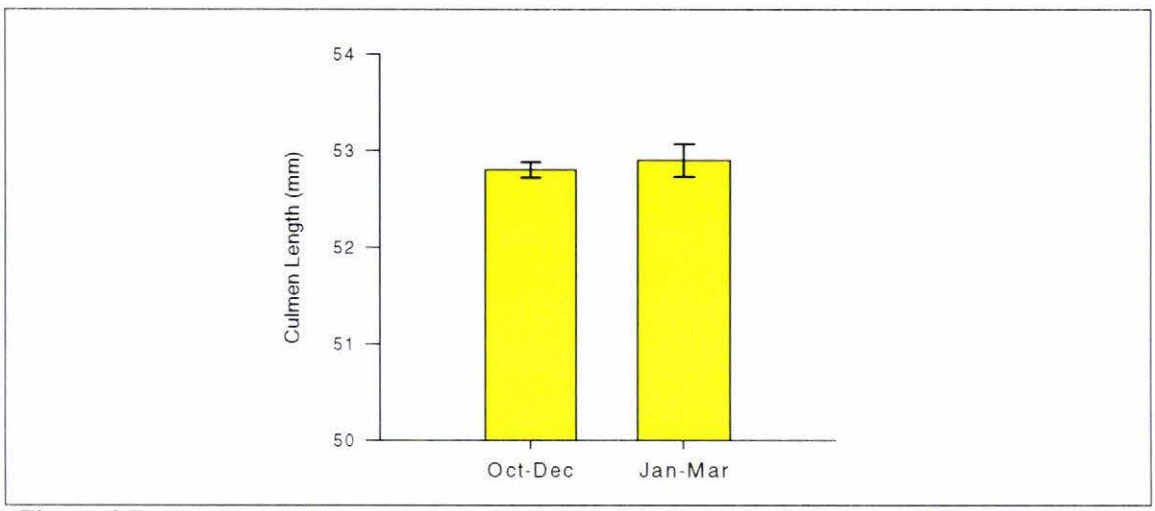

Figure 3.7 Average culmen length (mm) of 'the white-chinned petrel sample' caught between October - December and January - March. October - December, n = 469; and January - March, n = 116). Error bars represent 1 standard error of the mean.

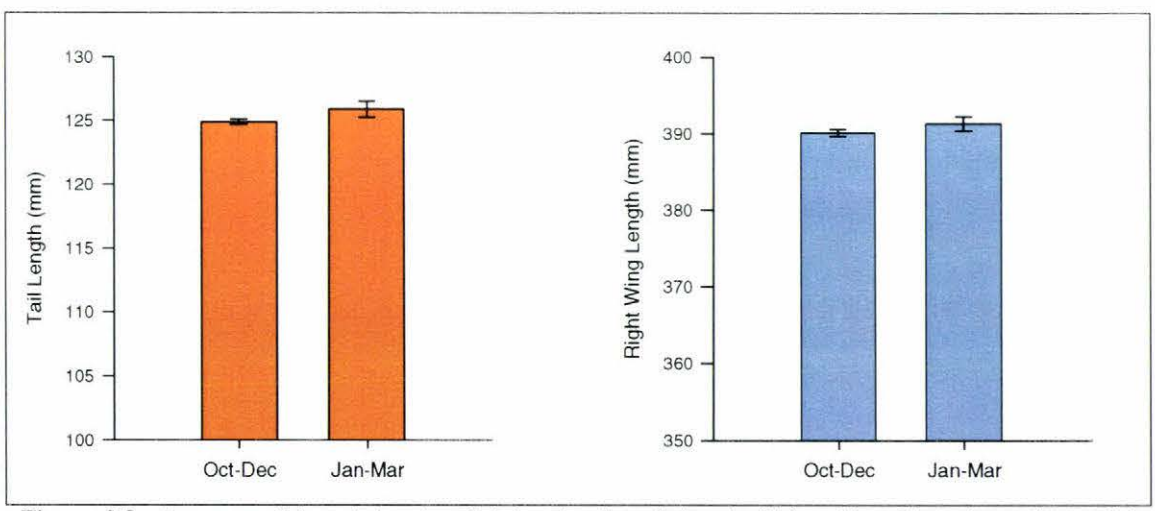

Figure 3.8 Average tail length (mm) and right wing length (mm) of 'the white-chinned petrel sample' caught between October - December and January - March. Tail length October - December, n = 469; tail length January - March, n = 116; right wing length October - December, n = 469; and right wing length January - March, n = 116. Error bars represent 1 standard error of the mean.

Significant positive correlations were found between several combinations of external measurements as shown in Table 3.9 for 'the white-chinned petrel sample'.

Other than the obvious positive correlations between left and right mid toe and claw, tarsometatarsus, and wing, the significant correlations were between head and bill length and culmen length, head and bill and culmen depth at the base, head and bill and bill least depth, culmen length and culmen depth at the base, culmen depth at the base and culmen width at the base, culmen depth at the base and bill least depth, tarsometatarsus and mid toe and claw length, wing length and tarsometatarsus length, and wing length and tail length, which seem to be size based. The white chin area did not highly correlate with any of the external measurements (Table 3.9).

A principal component analysis using 12 external measurements was done on 'the white-chinned petrel sample' (Appendix 3.2). The first principal component explained 41.9% of the variation within 'the white-chinned petrel sample' (Appendix 3.2.).

This variation is attributed to individual size variation as all variables strongly influence the first principal component.

The second principal component explained 10.6% of the variation in 'the white-chinned petrel sample'. This variation in the second principal component is at one end attributed to variation within bill measurements, which strongly influence the component, and at the other end variation within the tarsus, tail, and wing measurements that also strongly influence the component. The first and second principal component scores for each bird in 'the white-chinned petrel sample' were plotted to show the distribution of the sample (Figure 3.9). The distribution of 'the white-chinned petrel sample' (Figure 3.9) does not show any apparent clusters.

Bill descriptions of 'the white-chinned petrel sample'

Bill colouring of the maxillary and mandibular ungues varied throughout 'the white-chinned petrel sample'.

Table 3.9 Significant correlations for combinations of external measurements for 'the white-chinned petrel sample' based on a Spearman rank correlation coefficient greater than 0.432 ($P = 0.01$). HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; MNW = minimum nostril width; NL = nostril length; RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsomematarsus length; TL = tail length; RWLr = right wing length (ruler); LWLr = left wing length (ruler); and AW = area of white chin patch.

	HBL	HW	CL	CDB	CWB	BLD	MNW	NL	RMTC	LMTC	RTL	LTL	TL	RWLr	LWLr	AW
HBL	-															
HW	**0.453**	-														
CL	**0.850**	0.403	-													
CDB	**0.554**	**0.452**	**0.531**	-												
CWB	**0.483**	0.426	**0.442**	**0.636**	-											
BLD	**0.538**	0.389	**0.493**	**0.699**	**0.497**	-										
MNW	0.207	0.202	0.174	0.274	0.284	0.255	-									
NL	0.328	0.277	0.365	0.270	0.214	0.175	0.208	-								
RMTC	**0.485**	0.310	0.381	0.373	0.307	0.321	0.205	0.151	-							
LMTC	**0.493**	0.282	0.390	0.374	0.299	0.323	0.189	0.195	**0.849**	-						
RTL	**0.590**	0.358	**0.470**	0.407	0.335	0.358	0.179	0.240	**0.668**	**0.684**	-					
LTL	**0.581**	0.351	**0.462**	0.396	0.325	0.359	0.182	0.231	**0.653**	**0.670**	**0.961**	-				
TL	0.374	0.255	0.338	0.247	0.182	0.242	0.143	0.244	0.133	0.144	0.279	0.259	-			
RWLr	**0.504**	0.311	**0.433**	0.352	0.278	0.318	0.102	0.209	0.406	**0.433**	**0.535**	**0.523**	**0.580**	-		
LWLr	**0.523**	0.298	**0.450**	0.365	0.282	0.318	0.089	0.198	0.409	**0.439**	**0.559**	**0.548**	**0.571**	**0.978**	-	
AW	0.198	0.182	0.179	0.142	0.160	0.173	0.009	0.180	0.120	0.132	0.129	0.115	0.118	0.119	0.130	-

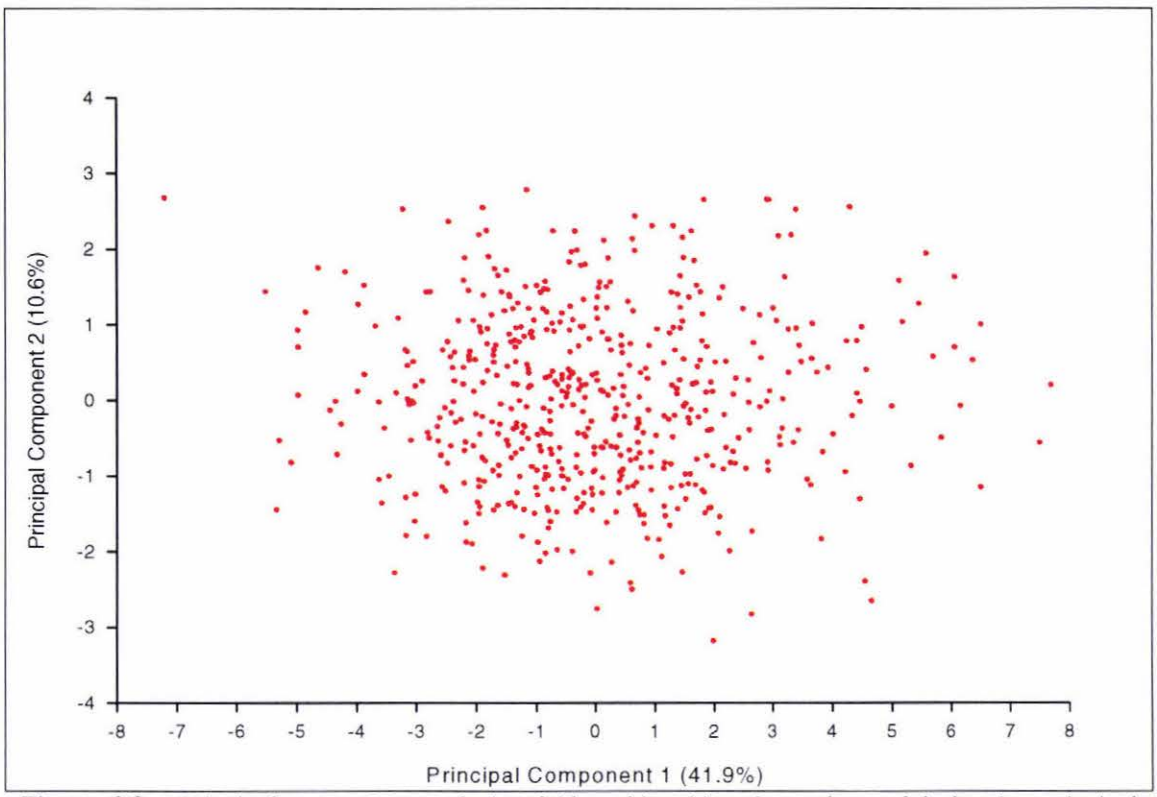

Figure 3.9 Principal component analysis of 'the white-chinned petrel sample' showing principal component 1 (41.9%) and principal component 2 (10.6%) with no apparent clusters. Sample size = 550.

Five hundred and ninety-two individuals had a '*Dark line score*' taken and 243 of those (41.0%) had a dark line along the top of the maxillary unguis. Seventy-two (12.2%) had a '*Dark line score*' of 1, 53 (8.9%) had a '*Dark line score*' of 2, and 118 (19.9%) had a '*Dark line score*' of 3. A total of 349 individuals (59%) had a '*Dark line score*' of 0 indicating that over half of the birds in this sample had no dark lines along the top of the maxillary unguis.

Five hundred and eighty-eight white-chinned petrels had a '*Nail score*' taken and 599 had an '*Unguis score*' taken. Of the 588 petrels that had a '*Nail score*' taken, five (0.8%) individuals had a '*Nail score*' of 0, 271 (46.1%) a '*Nail score*' of 1, 110 (18.7%) a '*Nail score*' of 2, and 202 (34.4%) a '*Nail score*' of 3. This indicates that 99.2% of individuals within this sample (n = 588) had at least some dark colouring at the maxillary unguis tip.

Of the 599 petrels that had an '*Unguis score*' taken, 100 (16.6%) had an '*Unguis score*' of 0, 92 (15.4%) an '*Unguis score*' of 1, 189 (31.6%) an '*Unguis score*' of 2, and 218 (36.4%) an '*Unguis score*' of 3. This shows that 83.4% of white-chinned petrels within this sample (n = 599) had some dark colouring on the mandibular

unguis. It was also found that 487 white-chinned petrels had some degree of dark colouring on both maxillary and mandibular ungues and four petrels had no dark colouring on either unguis. There was a slight positive correlation (0.166) between an increase in '*Nail score*' and an increase in '*Unguis score*' for 'the white-chinned petrel sample' (n = 586) (Figure 3.10). Uneven sample sizes between '*Nail scores*' and '*Unguis scores*' were due to damaged bill plates in some specimens that did not allow a score to be taken. There was no relationship between '*Dark line scores*' and '*Nail*' and '*Unguis scores*' as those specimens with '*Dark line scores*' had varied '*Nail*' and '*Unguis scores*'.

All '*Dark line scores*', '*Unguis scores*' and '*Nail scores*' were found throughout all the main locations; along the Chatham Rise, on the Bounty Platform, off Puysegur Point, and between Stewart Island and the Auckland Islands.

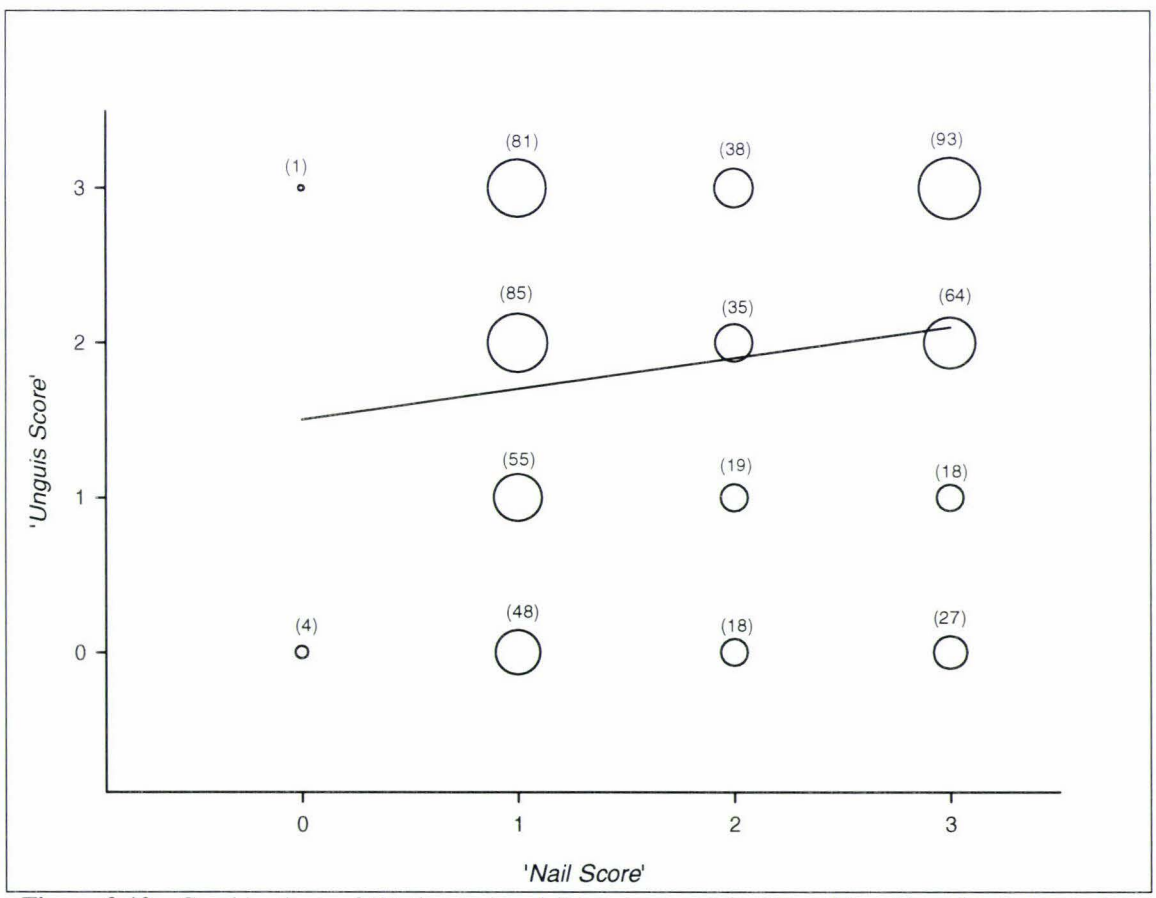

Figure 3.10 Combinations of '*Nail score*' and '*Unguis score*' for 'the white-chinned petrel sample'. Bracketed numbers indicate the number of individuals with each particular combination of scores. The linear regression is y = 0.1984x + 1.5047, r^2 = 0.0277. y = '*Nail score*' and x = '*Unguis score*'.

Nostril shapes of 'the white-chinned petrel sample'

The shape of the dorsal surface of the nostrils were categorised into five shapes. A total of 592 individuals within 'the white-chinned petrel sample' had the nostril shape scored. Four hundred and three (68.1%) had a '*Nostril shape*' 1, 78 (13.2%) a '*Nostril shape*' 2, 30 (5.1%) a '*Nostril shape*' 3, 42 (7.1%) a '*Nostril shape*' 4, and 39 (6.5%) a '*Nostril shape*' 5.

'*Nostril shapes*' 1 and 2 both had an average minimum nostril width that was significantly wider than '*Nostril shapes*' 2, 4 and 5 (t-test $P < 0.001$ (Figure 3.11).

All five '*Nostril shapes*' were found in all five main locations; along the Chatham Rise, on the Bounty Platform, off Puysegur Point, between Stewart Island and the Auckland Islands, and on the Pukaki Rise. Therefore nostril shape does not seem to be related to location of 'the white-chinned petrel sample'.

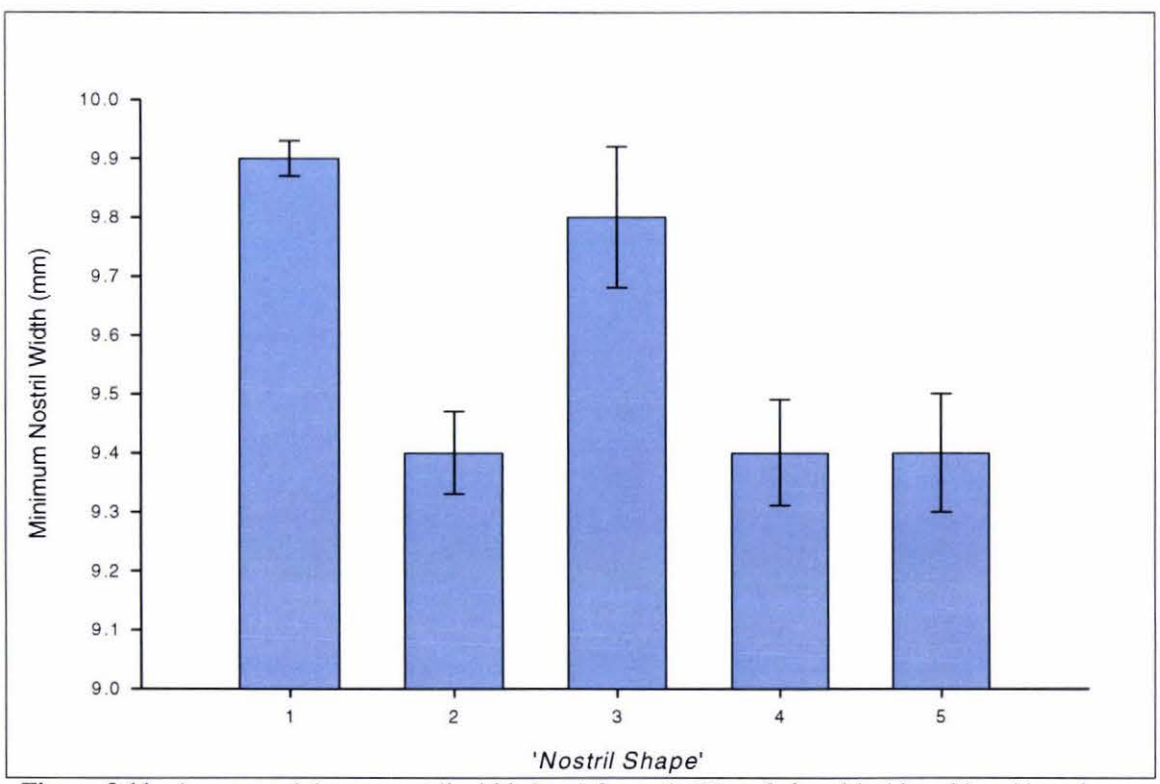

Figure 3.11 Average minimum nostril width (mm) for each '*Nostril shape*' in 'the white-chinned petrel sample'. '*Nostril shape*' 1, n = 401: '*Nostril shape*' 2, n = 78; '*Nostril shape*' 3, n = 30; '*Nostril shape*' 4, n = 42; and '*Nostril shape*' 5, n = 38. Error bars represent 1 standard error of the mean.

3.3.4 Adult and non-adult white-chinned petrel external morphology

This section examines the external morphology of adult and non-adult white-chinned petrels. Within 'the white-chinned petrel sample' there were 691 adults and 31 non-adults, with one individual unable to be aged.

The adult's external measurements were compared to the non-adults to determine if non-adults differed in size to adult white-chinned petrels. There were 547 adult males, 138 adult females (see section 3.3.5 on adult male and female white-chinned petrel external morphology), 25 non-adult males, 6 non adult females, and six individuals of unknown sex in 'the white-chinned petrel sample'.

Location

The location where all 691 adult white-chinned petrels were caught based on time of year is shown in Plate 3.2 and the location where the 31 non-adult petrels were caught based on time of year is shown in Plate 3.3.

Most adults (533) were caught between October and December (Table 3.10) along the Chatham Rise, off Puysegur Point, and on the Bounty Platform (Plate 3.2). One hundred and eighteen adults were caught between January and March (Table 3.10) mainly along the Chatham Rise, on the Bounty Platform, off the Auckland Islands, and a few on the Pukaki Rise (Plate 3.2).

Table 3.10 Total number of adult and non-adult white-chinned petrels in 'the white-chinned petrel sample' caught per month. Jan = January; Feb = February; Mar = March; Apr = April; May = May; Jun = June; Jul = July; Aug = August; Sep = September; Oct = October; Nov = November; and Dec = December.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
adults	29	69	20	29	3	0	0	0	6	27	485	23
non-adults	0	27	1	0	0	0	0	0	0	0	3	0

The largest number of adult white-chinned petrels caught per month was 485 in November followed by 69 caught in February (Table 3.10). Thirty-two adults were caught between April and June mainly along the Chatham Rise, on the Pukaki Rise and off the Auckland Islands (Plate (3.2). Six adults were also caught between July and September (Table (3.10) mostly off the Auckland Islands (Plate (3.2).

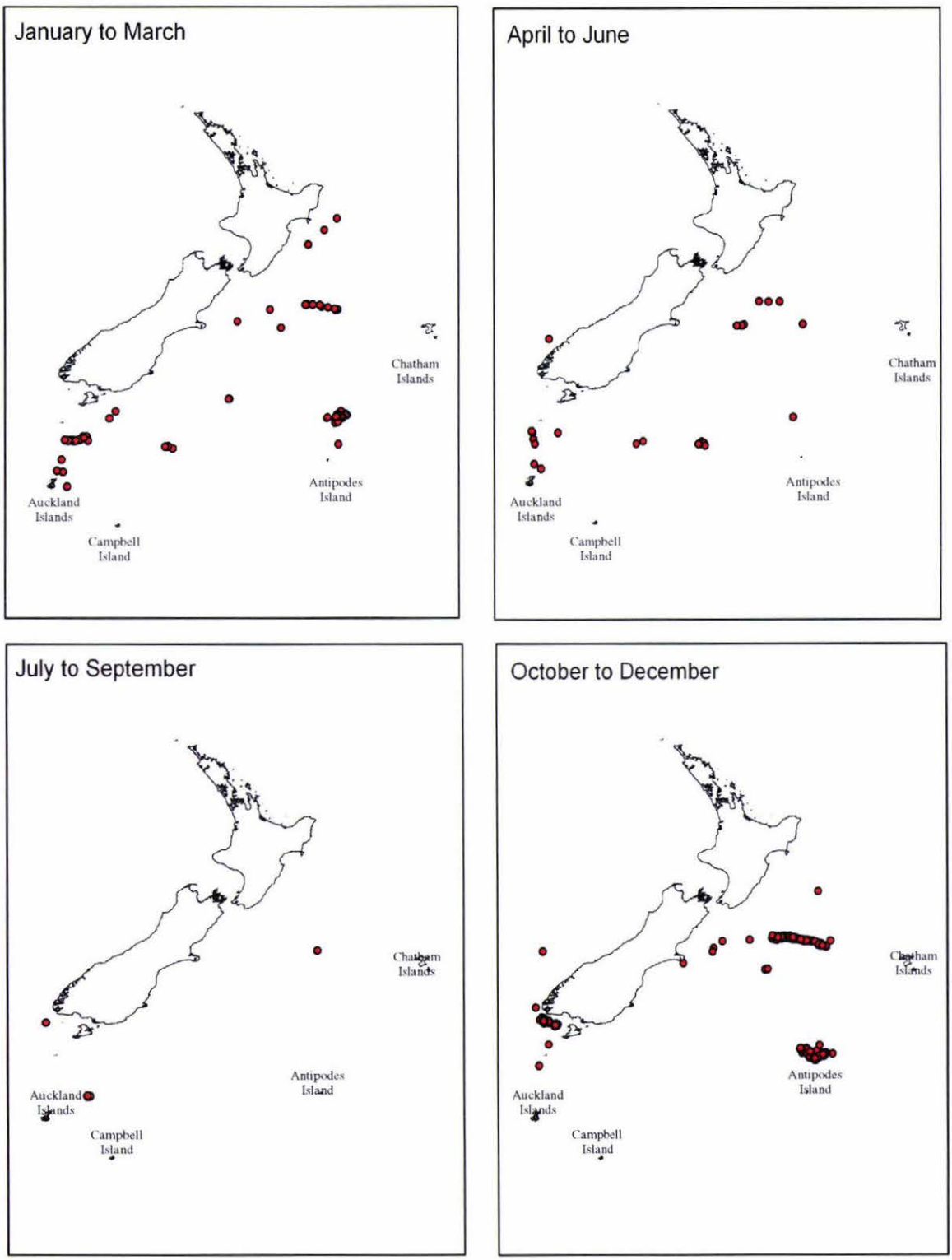

Plate 3.2 Map of the location where all 691 adult bycatch white-chinned petrels were caught based on latitude and longitude coordinates and time of year. January to March, n = 118; April to June, n = 32; July to September, n = 6; and October to December, n = 535.

Plate 3.3 Map of the location where the 25 non-adult male and 6 non-adult female bycatch white-chinned petrels were caught based on latitude and longitude coordinates and time of year. January to March males, n = 25; January to March females, n = 3; April to June males, n = 0; April to June females, n = 0; July to September males, n = 0; July to September females, n = 0; October to December males, n = 0; and October to December females, n = 3.

Non-adults were only caught during the breeding season in February, March and September (Table 3.10). Twenty-four non-adult males were caught in February mostly on the Bounty Platform and on the Pukaki Rise with one on the Chatham Rise (Plate 3.2). One non-adult male was caught in March on the Chatham Rise (Plate 3.2).

Three non-adult females were caught in February, two on the Bounty Platform and one on the Chatham Rise, and three non-adult females were caught in November, two off Puysegur Point and one on the Chatham Rise (Plate 3.2).

External measurements

The principal component analysis results (Appendix 3.2) as mentioned in section 3.3.3 ('the white-chinned petrel sample') above did not show any apparent clusters. The first and second principal component scores for each individual adult and non-adult in 'the white-chinned petrel sample' were plotted to determine if the distribution showed any trends (Figure 3.12).

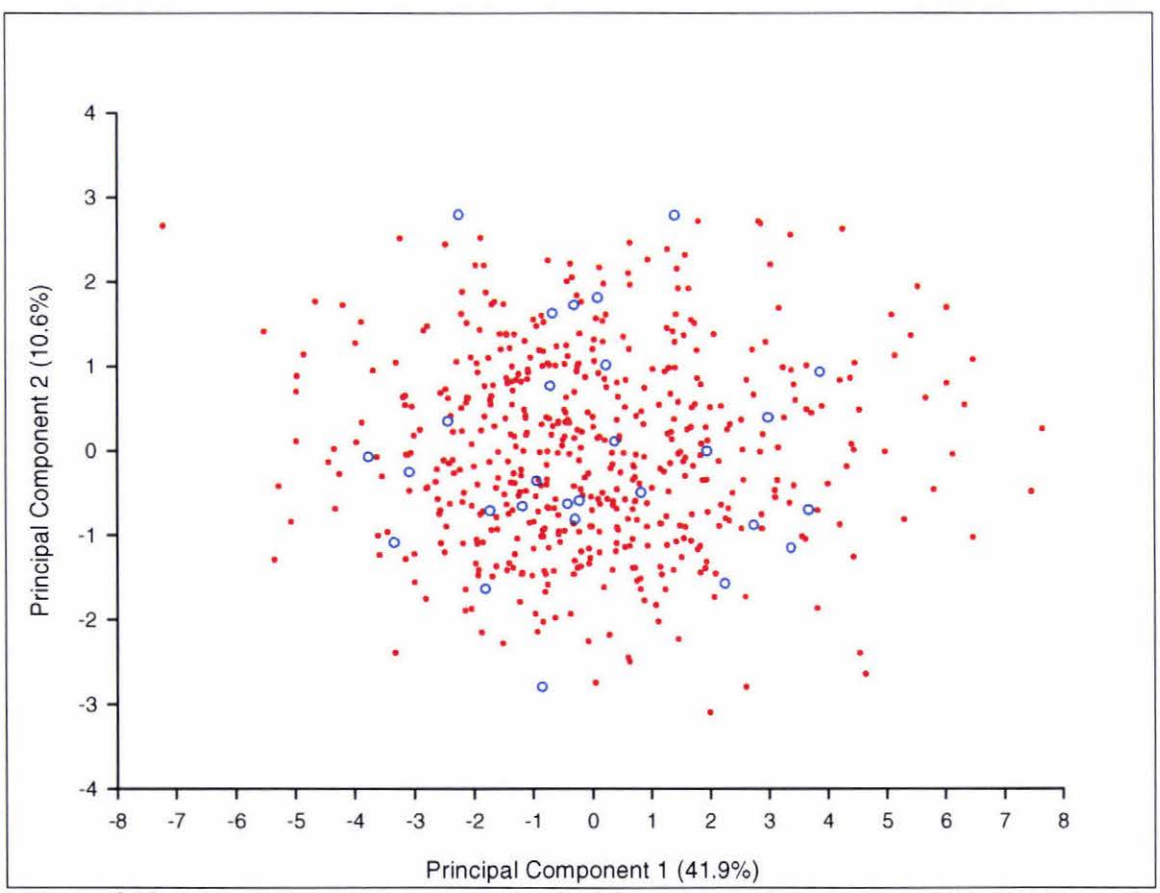

Figure 3.12 Principal component analysis of adults and non-adults in 'the white-chinned petrel sample' showing principal component 1 (41.9%) and principal component 2 (10.6%). Red dots = adults (n = 521); and blue circles = non-adults (n = 28).

One petrel was unable to be aged and is not included. The distribution showed that non-adults fit in the distribution of the adults (Figure 3.12), which indicates that non-adult white-chinned petrels are not different in size to adults.

The average head and bill external measurements for adult and non-adult white-chinned petrels are shown in Table 3.11. There were no significant differences, based on a t-test, between the average head and bill measurements of adults and non-adults except, head width and nostril length (Table 3.12).

Table 3.11 Average head and bill measurements of adults (n = 691) and non-adults (n = 31) in 'the white-chinned petrel sample'. HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; MNW = minimum nostril width; NL = nostril length; AW = area of white chin patch; SD = standard deviation; SE = standard error; and n = sample size.

		HBL (mm)	HW (mm)	CL (mm)	CDB (mm)	CWB (mm)	BLD (mm)	MNW (mm)	NL (mm)	AW (mm^2)
adults	mean	115.4	35.7	52.8	22.3	21.1	15.7	9.7	13.8	98.85
	SD	2.97	1.29	1.83	0.85	0.88	0.79	0.70	1.17	61.89
	SE	0.12	0.05	0.07	0.03	0.03	0.03	0.03	0.04	2.40
	n	666	689	660	690	691	684	683	678	667
non-adults	mean	116.1	35.1	53.2	22.4	21.0	15.6	10.0	14.2	91.62
	SD	2.70	0.96	1.83	0.79	0.76	0.69	0.72	0.89	67.02
	SE	0.48	0.17	0.34	0.14	0.14	0.12	0.13	0.16	12.04
	n	31	31	29	31	31	31	31	31	31

Table 3.12 Significant difference between means for adult (n = 691) and non-adult (n = 31) white-chinned petrels using a t-test. Adult and non-adult measurement means are shown in Tables 3.11 and 3.24 HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsomematarsus length; TL = tail length; RWLr = right wing length (ruler); LWLr = left wing length (ruler); and AW = area of the white chin patch.

	HBL	HW	CL	CDB	CWB	BLD	MNW	NL
P value	0.202	0.001	0.267	0.650	0.514	0.457	0.104	0.012
Significant difference	no	yes	No	no	no	no	no	yes
	RMTC	LMTC	RTL	LTL	TL	RWLr	LWLr	AW
P value	0.037	0.186	0.220	0.314	0.003	0.479	0.164	0.560
Significant difference	yes	no	No	no	yes	no	no	no

The average white chin area for adults was not significantly different in size to the average white chin area of non-adults (Table 3.12), however a higher percent of non-adults had a white chin area under 50 mm² and a higher percent of adults had a white chin area between 50-100 mm² (Table 3.13). There were no non-adults without a white chin patch (Table 3.13), but this could be due to the small sample size (n = 31). At the opposite end of the scale there was a slightly higher percent of non-adults with a white chin area over 300 mm² (Table 3.13).

Table 3.13 White chin patch area categories (mm²) with the percentage of adults (n = 667) and non-adults (n = 31) within each category.

	0.0 mm²	<5.0 mm²	5-50 mm²	50-100 mm²	100-200 mm²	200-300 mm²	300 + mm²
% of adults	2.7	1.3	19.8	30.7	39.4	5.7	0.4
% of non-adults	0.0	6.5	29.0	19.4	38.7	3.2	3.2

The average bodily measurements of adults and non-adults are shown in Table 3.14. There was no significant difference between the average length of the right and left mid toe and claw for adults (P = 0.293), or non-adults (P = 0.784). There was no significant difference between the average right and left wing length of adults (P = 0.896), or non-adults (P = 0.754).

Table 3.14 Average bodily measurements of adults (n = 691) and non-adults (n = 31) in 'the white-chinned petrel sample'. RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsometatarsus length; TL = tail length; RWLr = right wing length (ruler); LWLr = left wing length (ruler); SD = standard deviation; SE = standard error; and n = sample size.

		RMTC (mm)	LMTC (mm)	RTL (mm)	LTL (mm)	TL (mm)	RWLr (mm)	LWLr (mm)
adults	mean	85.3	85.1	66.8	65.9	125.0	390.4	390.4
	SD	2.83	2.66	1.81	1.75	5.22	9.72	9.70
	SE	0.11	0.11	0.07	0.07	0.21	0.38	0.38
	n	633	628	688	686	643	642	639
non-adults	mean	84.4	84.5	67.1	66.2	128.4	391.6	392.9
	SD	2.26	2.39	1.42	1.58	5.82	9.22	8.81
	SE	0.41	0.44	0.26	0.29	1.04	1.71	1.67
	n	31	30	31	30	31	29	28

There were significant differences in average tail and right MTC lengths between adults and non-adults (Table 3.12), which in the case of feathers could to be due to wear of adults tail feathers.

Culmen length, tail length and right wing length of adult white-chinned petrels were compared between the periods October to December and January to March. There was no significant difference between the average culmen length (P = 0.616) (Figure 3.13), tail length (P = 0.718) (Figure 3.14) or right wing length (P = 0.514) (Figure 3.14) of adults between the periods October to December and January to March.

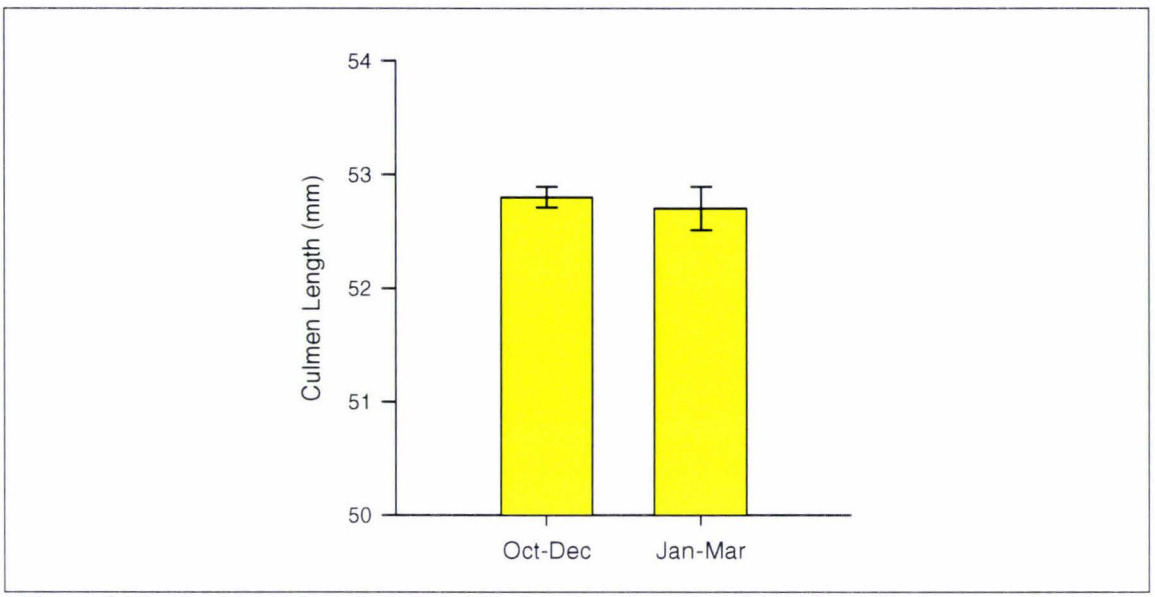

Figure 3.13 Average culmen length (mm) of adult white-chinned petrels caught between October to December and January to March. October to December, n = 466; and January to March, n = 91). Error bars represent 1 standard error of the mean.

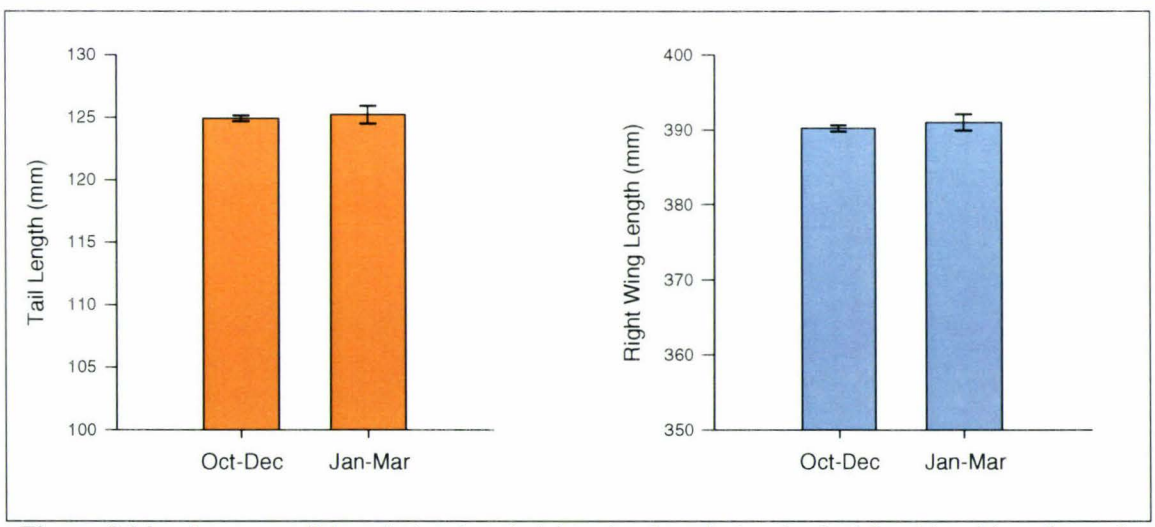

Figure 3.14 Average tail length (mm) and right wing length (mm) of adult white-chinned petrels caught between October - December and January - March. Adult tail length October - December, n = 466; adult tail length January - March, n = 91; adult right wing length October - December, n = 466; and adult right wing length January – March, n = 91. Error bars represent 1 standard error of the mean.

Single external measurements showed little variation between adult and non-adults. Combinations (pairs) of external measurements were compared to see if they showed any variation between adults and non-adults. Figure 3.15 shows combinations of head,

bill and bodily measurements that show that non-adult white-chinned petrel size is the same as adult white-chinned petrel size.

A further six combinations of head, bill and bodily measurements (Appendix 3.3) also show that non-adults fit within the distribution of the adults. All combinations of external measurements in Figure 3.15 and Appendix 3.3 indicate that non-adult white-chinned petrels are not different in size to adults.

Bill descriptions

The bill descriptions for adults and non-adults were similar with almost all '*Dark line scores*', '*Nail scores*' and '*Unguis scores*' present in each group. Sample sizes varied; 561 adults and 30 non-adults had a '*Dark line score*' taken, 558 adults and 29 non-adults had a '*Nail score taken*', and 568 adults and 30 non-adults had an '*Unguis score*' taken. Differences in sample size were due to bill plates of some specimens being damaged.

Table 3.15 shows the percent of adults and non-adults with each '*Dark line score*'. There was a higher percent of non-adults with a '*Dark line score*' 0 and a slightly higher percent with a '*Dark line score*' 3 (Table 3.15). Adults had a higher percent of individuals with a '*Dark line score*', 41.9%, compared to 26.6% of non-adults, indicating that non-adults did not have more dark lines down the maxillary unguis than adults (Table 3.15).

Table 3.15 The percent of adult (n = 561) and non-adult (n = 30) white-chinned petrels with each '*Dark line score*'.

	'*Dark line score*' 0	'*Dark line score*' 1	'*Dark line score*' 2	'*Dark line score*' 3
% of adults	58.1	12.8	9.3	19.8
% of non-adults	73.4	0.0	3.3	23.3

Table 3.16 shows the percent of adults and non-adults with each '*Nail score*' and '*Unguis score*'. There was a slightly higher percent of non-adult white-chinned petrels with a '*Nail score*' and '*Unguis score*' of 0 (Table 3.16).

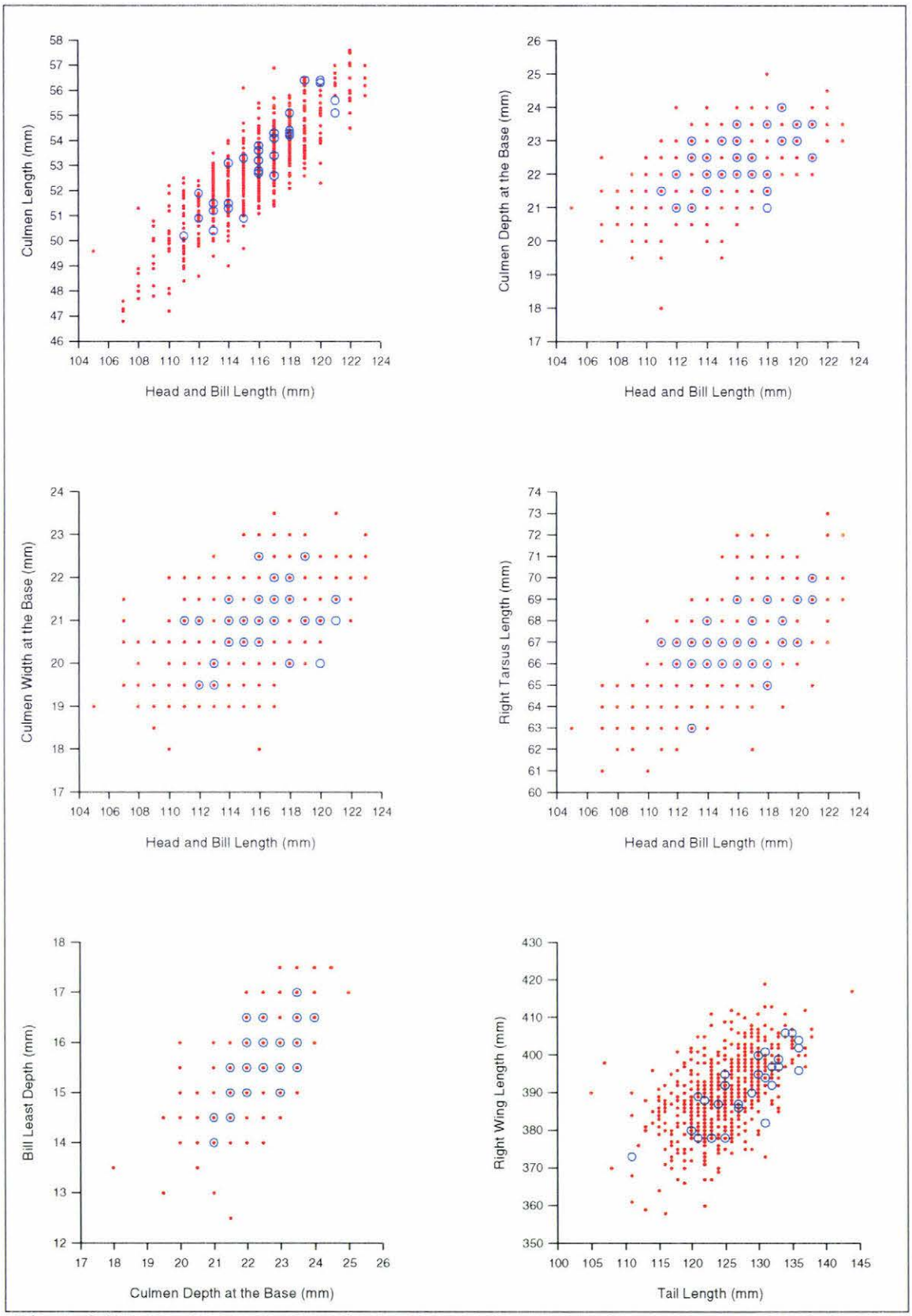

Figure 3.15 Combinations of external measurements for adult and non-adult white-chinned petrels showing non-adults were similar in size to adults. Red dots = adult white-chinned petrels (n = 691); and blue circles = non-adult white-chinned petrels (n = 31). Sample sizes differ on each graph because some measurements could not be taken from some specimens.

Overall there was a higher percent of adults with a 'Nail score' and 'Unguis score' between 1-3, however there was a slightly higher percent of non-adults with a '*Nail score*' and '*Unguis score*' of 3 (Table 3.16).

Table 3.16 The percent of adult and non-adult white-chinned petrels with each '*Nail score*' and '*Unguis score*'. Adults '*Nail score*' n = 558; non-adults '*Nail score*' n = 29; adults '*Unguis score*' n = 568; and non-adults '*Unguis score*' n = 30.

	'*Nail score*' 0	'*Nail score*' 1	'*Nail score*' 2	'*Nail score*' 3	'*Unguis score*' 0	'*Unguis score*' 1	'*Unguis score*' 2	'*Unguis score*' 3
% of adults	0.7	46.6	18.6	34.1	16.5	15.8	31.7	36.0
% of non-adults	3.4	34.5	20.8	41.3	20.0	6.7	30.0	43.3

Nostril shapes

A total of 561 adult and 30 non-adult white-chinned petrels had their nostril shape scored. Table 3.17 shows the percent of adults and non-adults with each '*Nostril shape*'. '*Nostril shape*' 1 was the most common nostril shape for adults and non-adults (Table 3.17). There was a similar percent of adults and non-adults with '*Nostril shapes*' 3, 4 and 5, and the larger difference between the percent of adults and non-adults with '*Nostril shape*' 2 is likely to be due to the small non-adult sample size (Table 3.17).

Table 3.17 Percent of adult (n = 561) and non-adult (n = 30) white-chinned petrels with each '*Nostril shape*'.

	'*Nostril shape*' 1	'*Nostril shape*' 2	'*Nostril shape*' 3	'*Nostril shape*' 4	'*Nostril shape*' 5
% of adults	67.0	13.9	5.0	7.3	6.8
% of non-adults	86.7	0.0	6.7	3.3	3.3

3.3.5 Adult male and female white-chinned petrel external morphology

As mentioned in the above section 3.3.4 (adult and non-adult white-chinned petrel external morphology) non-adult white chinned petrels do not appear to be significantly different in size to adults. However non-adults were removed from the sample as there is a chance some could be from outside the New Zealand region.

This section examines the external morphology of adult male and female white-chinned petrels in 'the white-chinned petrel sample'. There were 547 adult males and

138 adult females examined, with a ratio of about 5:1 males to females. There were six adults that were unable to be sexed and are not included.

Location

The location where all 547 adult males were caught based on time of year is shown in Plate 3.4 and the location where all 138 adult females were caught based on time of year is shown in Plate 3.5.

Four-hundred and forty adult males were caught between October and December at the start of the breeding season, with 403 of those caught in November (Table 3.18). Four-hundred and thirty-five of these adult males were caught in three main areas; 202 along the Chatham Rise, 181 off Puysegur Point, and 52 on the Bounty Platform (Plate 3.4). Eighty-six adult males were caught between January and March (Table 3.18). Eighty were caught in four main areas: 43 on the Bounty Platform, 28 off the Auckland Islands, six on the Chatham Rise, and three on the Pukaki Rise (Plate 3.4).

Table 3.18 Total number of adult male (n = 547) and females (n = 138) white-chinned petrels caught per month. Jan = January; Feb = February; Mar = March; Apr = April; May = May; Jun = June; Jul = July; Aug = August; Sep = September; Oct = October; Nov = November; and Dec = December.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
adult males	20	52	14	14	3	0	0	0	4	18	403	19
adult females	7	17	6	12	0	0	0	0	2	9	81	4

Seventeen adult males were caught between April and June (Table 3.18); six off the Auckland Islands, five on the Chatham Rise, four on the Pukaki Rise, one on the Bounty Platform, and one off Fiordland (Plate 3.4). Four adult males were also caught in September (Table 3.18), two off the Auckland Islands, one off Puysegur Point and one on the Chatham Rise (Plate 3.4).

Ninety-four adult females were caught between October and December (Table 3.18) in three main areas; 43 off Puysegur point, 40 along the Chatham Rise, and nine on the Bounty Platform (Plate 3.5). Thirty adult females were caught between January and March (Table 3.18) in two main areas; 16 off the Auckland Islands and nine along the Chatham Rise (Plate 3.5).

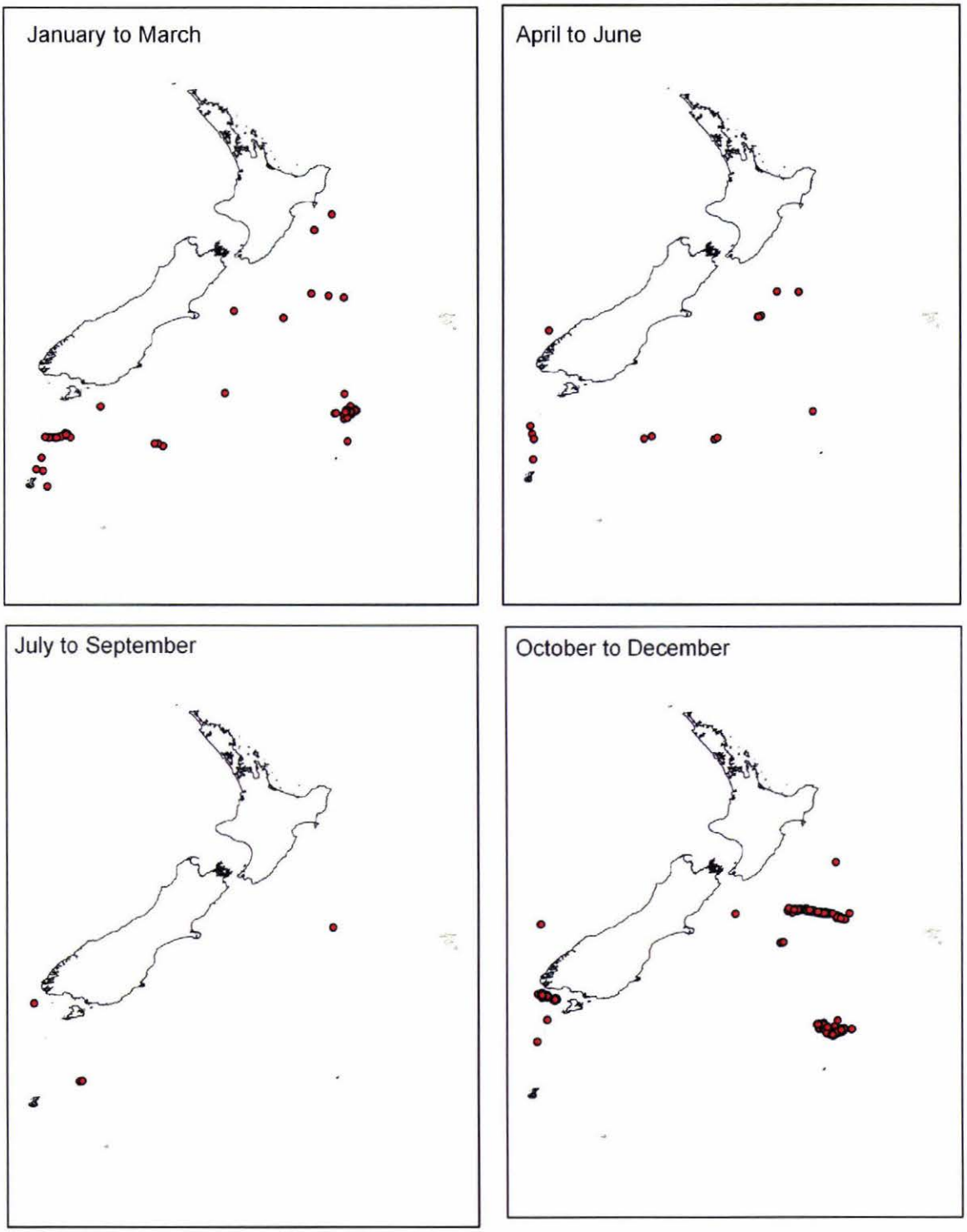

Plate 3.4 Map of the location where all 547 adult male white-chinned petrels were caught based on latitude and longitude coordinates, and time of year. January to March, n = 86; April to June, n = 17; July to September, n = 4; and October to December, n = 440.

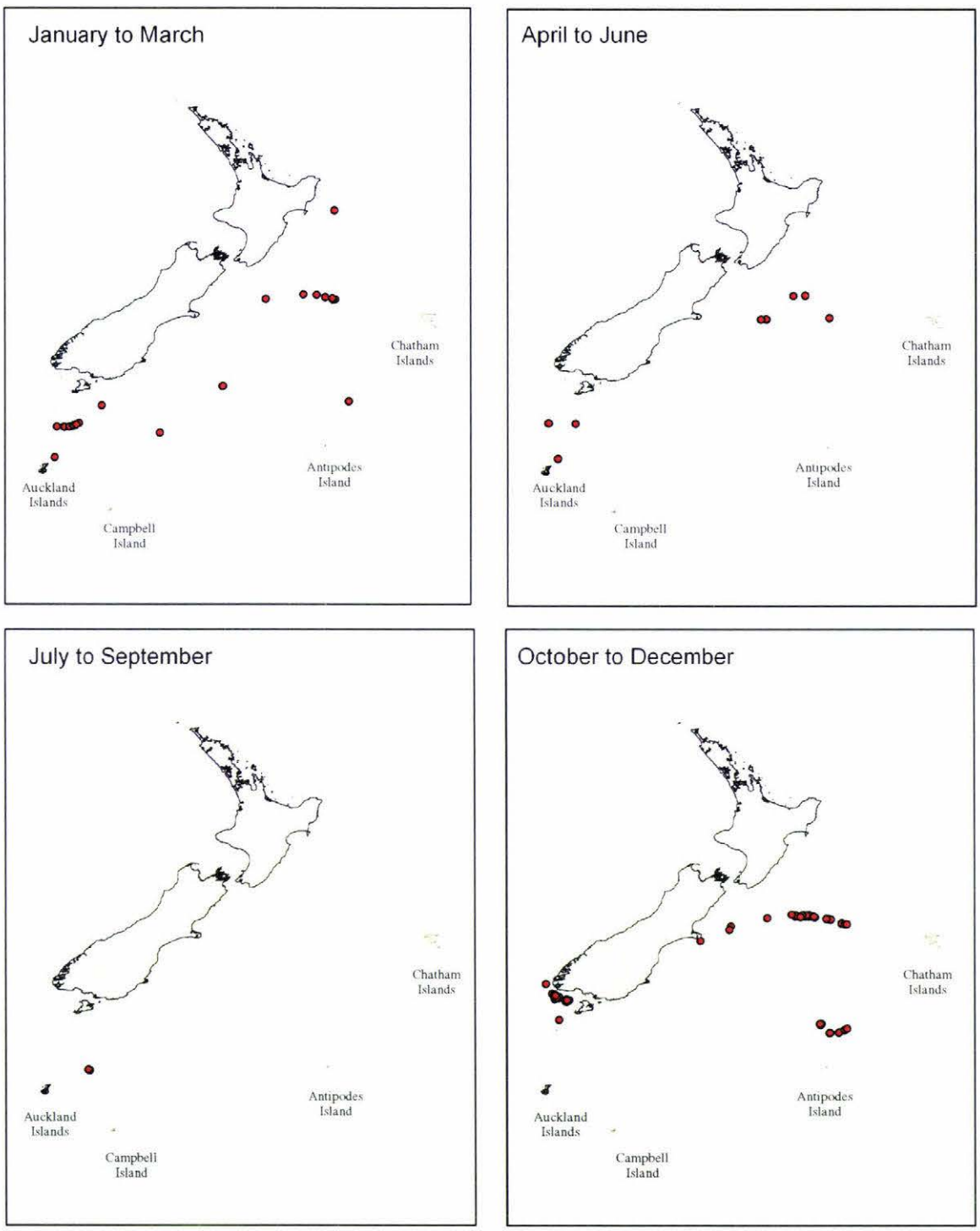

Plate 3.5 Map of the location where all 138 adult female white-chinned petrels were caught based on latitude and longitude coordinates, and time of year. January to March, n = 30; April to June, n = 12; July to September, n = 2; and October to December, n = 94.

A further 12 adult females were caught between April and June (Table 3.18), nine off the Auckland Islands and three along the Chatham Rise (Plate 3.5). Two adult females were caught in September (Table 3.18), both off the Auckland Islands (Plate 3.5).

External measurements

A principal component analysis was done using 12 external measurements using only adult male and female white-chinned petrels Appendix 3.4. Not all measurements could be taken from all individuals. The principal component analysis results for adult males (n = 421) and females (n = 98) are shown in Appendix 3.4. The first three components explain 61.7% of the variation of the adult male and female sample.

The first and second principal component scores for each individual adult male and female were plotted to look for differences in distribution (Figure 3.16). The graph shows that adult males are generally distributed separately from the adult females, although there is a large amount of overlap in the centre (Figure 3.16).

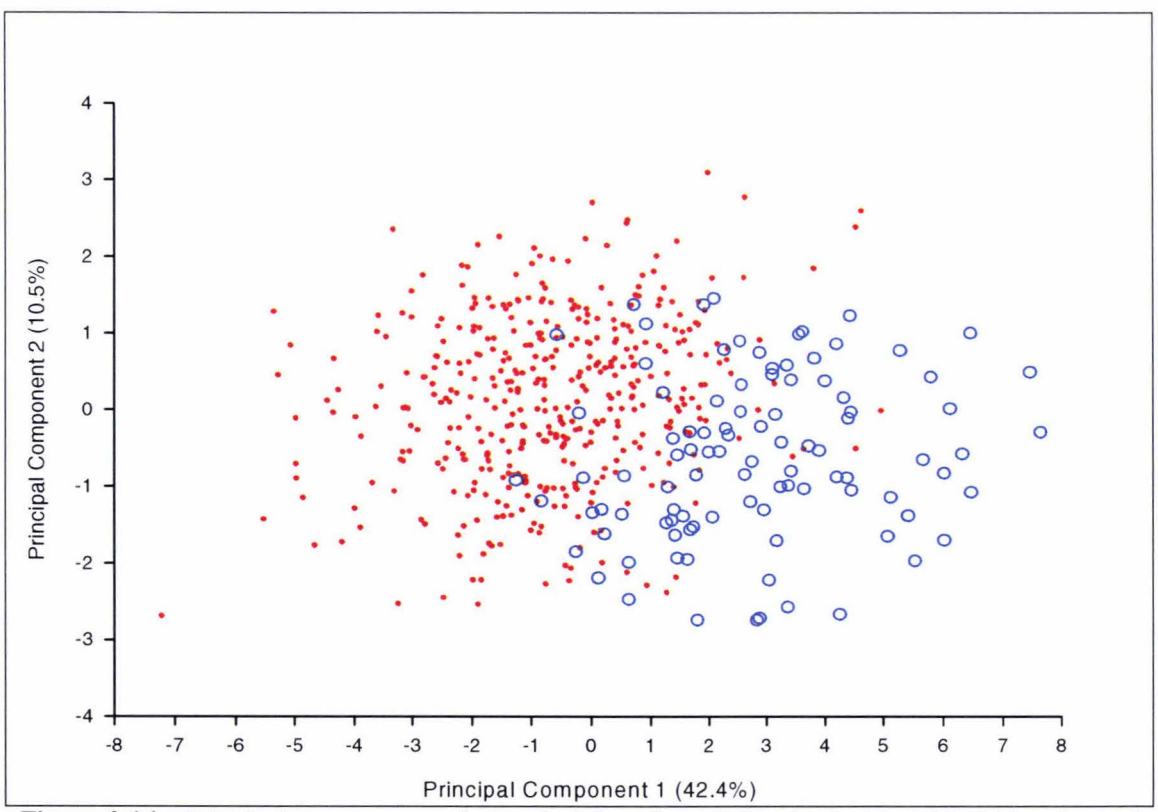

Figure 3.16 Principal component analysis of adult males and females in 'the white-chinned petrel sample' showing principal component 1 (42.4%) and principal component 2 (10.5%). Red dots = adult males (n = 421); and blue circles = adult females (n = 98).

The first principal component is attributed to individual size variation within adult male and female sample, and explained 42.4% of the variation (Figure 3.16 and Appendix 3.4). The second principal component explained 10.5% of the variation also based on size (Figure 3.16 and Appendix 3.4).

The average head and bill external measurements for adult male and female white-chinned petrels in are shown in Table 3.19. The averages of all adult male head and bill measurements are larger than the corresponding averages of the adult female head and bill measurements (Table 3.19).

Table 3.19 Average head and bill measurements of adult male (n = 547) and adult female (n = 138) white-chinned petrels. HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; MNW = minimum nostril width; NL = nostril length; AW = area of the white chin patch; SD = standard deviation; SE = standard error; and n = sample size.

		HBL (mm)	HW (mm)	CL (mm)	CDB (mm)	CWB (mm)	BLD (mm)	MNW (mm)	NL (mm)	AW (mm^2)
	mean	116.2	36.0	53.2	22.6	21.3	15.9	9.8	13.9	107.30
adult	SD	2.51	1.10	1.57	0.66	0.76	0.67	0.66	1.17	61.92
males	SE	0.11	0.05	0.07	0.03	0.03	0.03	0.03	0.05	2.69
	n	527	546	523	546	547	541	540	536	529
	mean	112.4	34.4	50.9	21.3	20.3	14.8	9.5	13.4	66.54
adult	SD	2.44	1.09	1.55	0.73	0.83	0.63	0.75	1.08	50.63
females	SE	0.21	0.09	0.13	0.06	0.07	0.05	0.06	0.09	4.36
	n	133	137	132	138	138	137	137	136	135

The average white chin area for adult males was significantly larger than the average white chin patch area for adult females (Table 3.22). Table 3.20 showed that 52.2 % of adult males had a white chin patch area 100-300+ mm^2, higher than that for adult females (23.7 %), while 76.1 % of adult females had a white chin patch area 0-100 mm^2 and adult males only 48.8 %.

Table 3.20 White chin patch size categories (mm^2) with the percentage of adult male (n = 529) and adult female (n = 135) white-chinned petrels within each category.

	0.0 mm^2	<5.0 mm^2	5-50 mm^2	50-100 mm^2	100-200 mm^2	200-300 mm^2	300 + mm^2
% of adult males	1.9	0.9	15.9	30.1	44.0	6.6	0.6
% of adult females	5.9	3.0	34.8	32.6	21.5	2.2	0.0

However there were adult male and female individuals within each white chin patch area category, except no adult females with a white chin patch area greater than 300 mm^2 (Table 3.20).

Average bodily measurements for adult males (n = 547) and adult females (n = 138) are shown in Table 3.21. The averages of all adult male bodily measurements are larger than the corresponding adult female bodily measurements (Table 3.21). There was no significant difference ($P = 0.207$) between the average length of the right and left mid toe and claw for adult males, and there was also no significant difference ($P = 0.961$) between the average length of the right and left mid toe and claw for adult females.

Table 3.21 Average bodily measurements of adult male (n = 547) and adult female (n = 138) white-chinned petrels. RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsometatarsus length; TL = tail length; RWL.r = right wing length (ruler); LWL.r = left wing length (ruler); SD = standard deviation; SE = standard error; and n = sample size.

		RMTC (mm)	LMTC (mm)	RTL (mm)	LTL (mm)	TL (mm)	RWL.r (mm)	LWL.r (mm)
adult males	mean	85.7	85.5	67.0	66.1	125.4	391.5	391.6
	SD	2.67	2.51	1.77	1.72	5.10	9.53	9.40
	SE	0.12	0.11	0.08	0.07	0.22	0.42	0.42
	n	500	499	544	542	519	509	509
adult females	mean	83.5	83.6	65.6	64.8	123.0	386.1	385.7
	SD	2.75	2.67	1.55	1.52	5.26	9.40	9.63
	SE	0.24	0.24	0.13	0.13	0.48	0.82	0.86
	n	127	124	138	138	121	130	126

There was a significant difference ($P < 0.001$) between the average length of the right and left tarsometatarsus for adult males and females. This difference was due to technique error as explained in section 3.3.1, comparison of external measurements with 'the Laboratory'.

There was no significant difference ($P = 0.856$) between the average length of the right and left wings (ruler) for adult males. There was also no significant difference ($P = 0.952$) between the average length of the right and left wings (ruler) for adult females.

There were significant differences between the averages of all external measurements between adult male and female white-chinned petrels (Table 3.22). These results indicate a size difference with the adult males being, on average, significantly larger than adult females.

Table 3.22 Significant difference between means for adult male (n = 547) and adult female (n = 138) white-chinned petrels. Adult male and female measurement means are shown in Tables 3.19 and 3.21. HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsomematarsus length; TL = tail length; RWLr = right wing length (ruler); LWLr = left wing length (ruler); and AW = area of the white chin patch.

	HBL	HW	CL	CDB	CWB	BLD	MNW	NL
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Significant difference	yes	yes	yes	yes	yes	yes	yes	yes
	RMTC	LMTC	RTL	LTL	TL	RWLr	LWLr	AW
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Significant difference	yes	yes	yes	yes	yes	yes	yes	yes

Culmen length, tail length and right wing length of adult males and females were compared between the periods October to December and January to March. There was no significant difference between the average culmen length (P = 0.402) (Figure 3.17), tail length (P = 0.389) (Figure 3.18) or right wing length (P = 0.195) (Figure 3.18) of adult males during the periods October to December and January to March.

There was also no significant difference between the average culmen length (P = 0.903) (Figure 3.17), tail length (P = 0.766) (Figure 3.18) and right wing length (P = 0.969) (Figure 3.18) of adult females during the periods October to December and January to March.

Combinations of external measurements of adult male and female white-chinned petrels were compared to see if they showed any size difference. Figure 3.19 clearly showed adult males were generally larger in size in all measurements than adult females. However, there is a large amount of overlap between small adult males and large adult females. A further six combinations of external measurements differentiating between adult males and females shown in Appendix 3.5, also show

the same result that adult males are generally larger than adult females but there is a large amount of overlap between small adult males and large adult females.

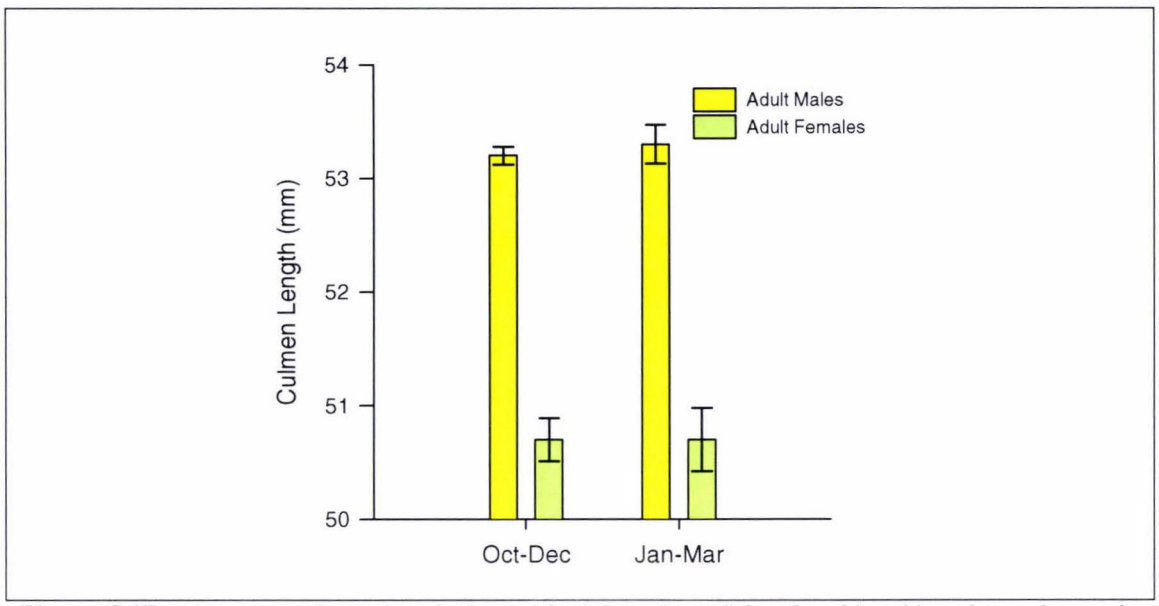

Figure 3.17 Average culmen length (mm) of adult male and female white-chinned petrels caught between October - December and January - March. Adult males October - December, n = 388; adult females October - December, n = 78); adult males January - March, n = 67); and adult females January - March, n = 23). Error bars represent 1 standard error of the mean.

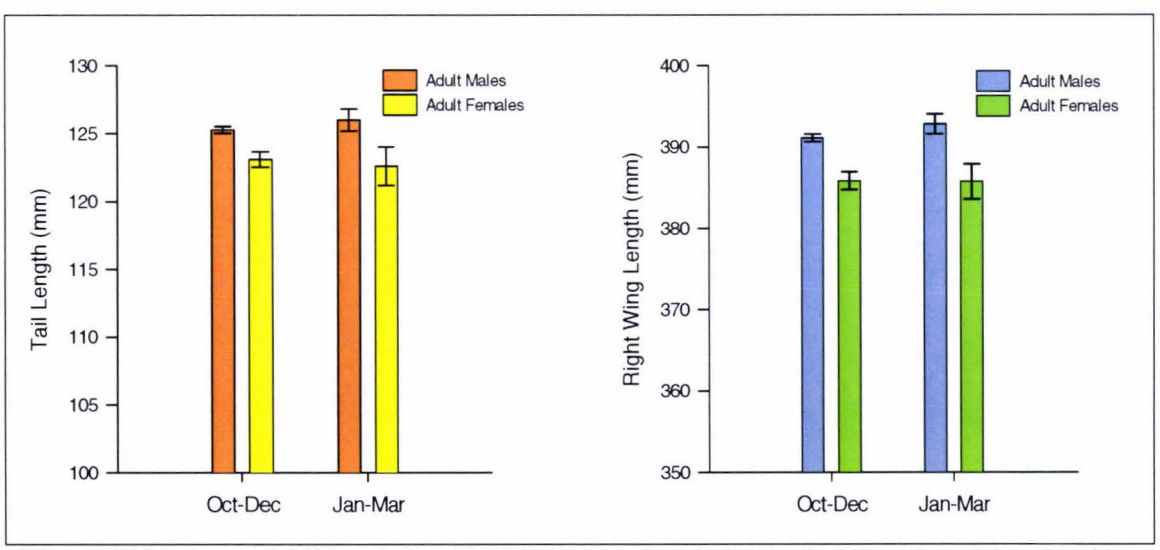

Figure 3.18 Average tail length (mm) and right wing length (mm) of adult male and female white-chinned petrels caught between October - December and January - March. Adult males tail length October - December, n = 388; adult females tail length October - December, n = 78; adult males tail length January - March, n = 67; adult females tail length January - March, n = 23; adult males right wing length October - December, n = 388; adult females right wing length October - December, n = 78; adult males right wing length January - March, n = 67; and adult females right wing length January - March, n = 23. Error bars represent 1 standard error of the mean.

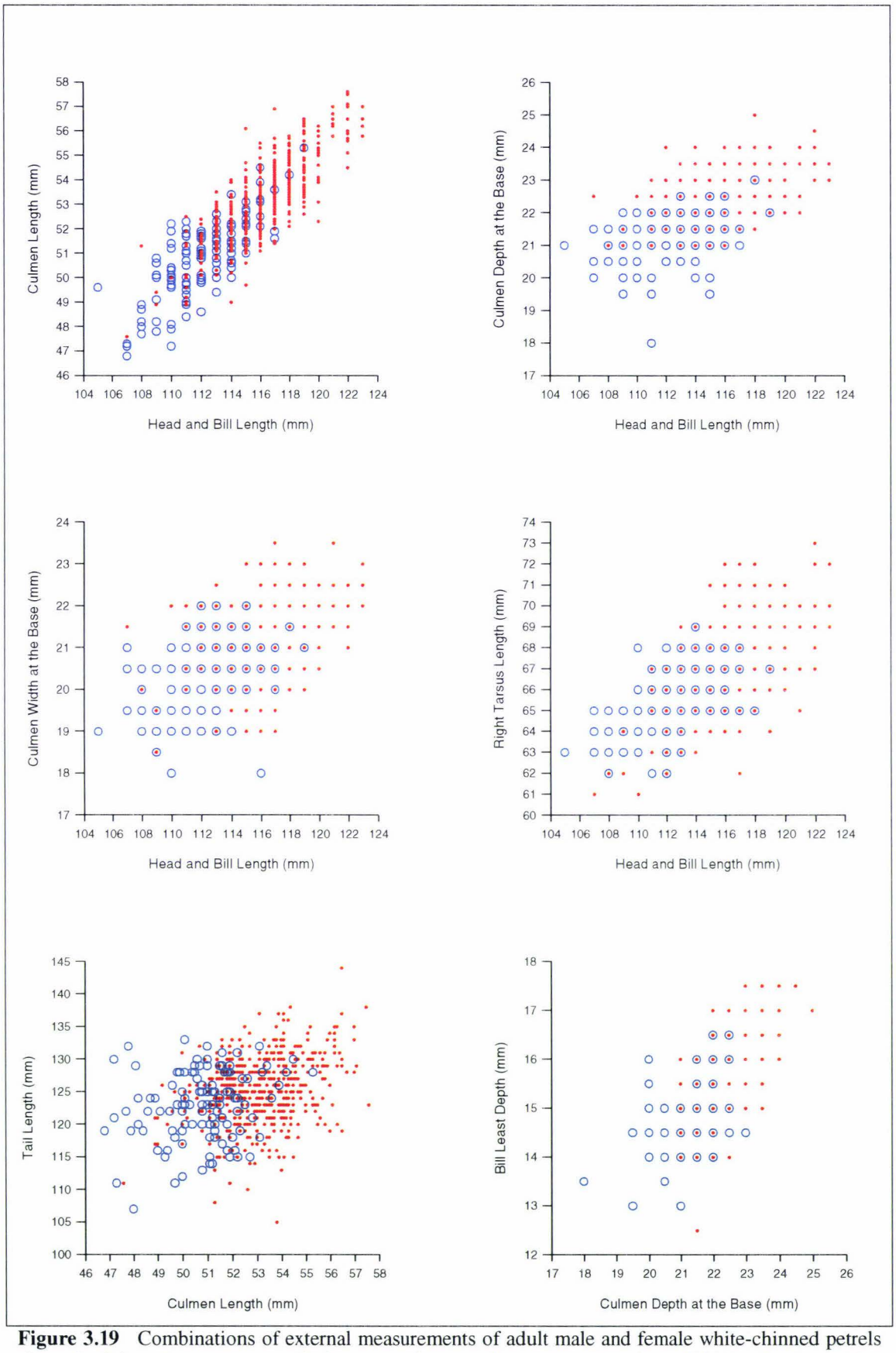

Figure 3.19 Combinations of external measurements of adult male and female white-chinned petrels showed adult males were generally larger in all external measurements than adult females but with a large amount of overlap. Red dots = adult male white-chinned petrels (n = 547); and blue circles = adult female white-chinned petrels (n = 138). Sample sizes differ on each graph due to measurements unable to be taken from some specimens.

Bill descriptions

Adult males and females had a similar percent of '*Dark line scores*' in each category (Table 3.23).

Table 3.23 Percent of adult male (n = 438) and adult female (n = 118) white-chinned petrels with each '*Dark line score*'.

	'*Dark line score*' 0	'*Dark line score*' 1	'*Dark line score*' 2	'*Dark line score*' 3
% of adult males	57.8	13.9	8.2	20.1
% of adult females	60.2	8.5	11.8	19.5

The adult males and females both had a higher percent of '*Nail scores*' 1 and 3 and '*Unguis scores*' 2 and 3, which gives an indication that the amount of black on the maxillary and mandibular ungues was spread throughout both groups (Table 3.24).

Table 3.24 Percent of adult male and female white-chinned petrels with each '*Nail score*' and '*Unguis score*'. Adult male '*Nail score*' n = 434; adult female '*Nail score*' n = 118; adult male '*Unguis score*' n = 444; and adult female '*Unguis score*' n = 119.

	'*Nail score*' 0	'*Nail score*' 1	'*Nail score*' 2	'*Nail score*' 3	'*Unguis score*' 0	'*Unguis score*' 1	'*Unguis score*' 2	'*Unguis score*' 3
% of adult males	0.5	44.0	20.7	34.8	15.8	14.9	32.0	37.3
% of adult females	1.7	55.9	11.0	31.4	20.2	20.2	30.2	29.4

Nostril shape

All nostril shapes were present in both groups of adult males and females, with the most common nostril shape in both groups '*Nostril shape*' 1 and the least common '*Nostril shape*' 3 (Table 3.25).

Table 3.25 Percent of adult male (n = 438) and adult female (n = 118) white-chinned petrels with each '*Nostril shape*'.

	'*Nostril shape*' 1	'*Nostril shape*' 2	'*Nostril shape*' 3	'*Nostril shape*' 4	'*Nostril shape*' 5
% of adult males	67.1	14.2	5.0	8.0	5.7
% of adult females	66.9	12.7	5.1	4.3	11.0

3.3.6 'Auckland and Antipodes Island cluster groups'

As shown in section 3.3.5 above (adult male and female white-chinned petrel external morphology), adult males are generally larger than adult females, however there is still a considerable amount of overlap between small adult males and large adult females. A selection of adult white-chinned petrels caught close to the Auckland and Antipodes islands during the breeding season was looked at to determine if there were morphological differences between the two populations.

White-chinned petrels representing these two breeding islands were termed the 'Auckland Island cluster group' and the 'Antipodes Island cluster group' (refer to section 2.10.1 on cluster groups). A further two cluster groups, the 'Chatham Rise cluster group' and the 'Puysegur Point cluster group' were used to represent white-chinned petrels caught further from breeding islands (refer to section 2.10.1 on cluster groups). The location of all four cluster groups is shown in Plate 3.6. This section looks at the 'Auckland Island cluster group' and the 'Antipodes Island cluster group'.

Location

The 'Auckland Island cluster group' consisted of 45 white-chinned petrels (6.2% of 'the white-chinned petrel sample') of which 29 were adult males and 16 were adult females. Plate 3.7 shows the location of the 'Auckland Island cluster group' and where the individual white-chinned petrels were caught.

The 'Antipodes Island cluster group', Plate 3.8, consisted of 105 white-chinned petrels (14.5% of 'the white-chinned petrel sample') of which 95 were adult males and 10 were adult females.

There was more than twice the number of white-chinned petrels in the 'Antipodes Island cluster group' than in the 'Auckland Island cluster group'. Also there were almost twice as many males as females in the 'Auckland Island cluster group' and there were almost ten times more males than females in the 'Antipodes Island cluster group'.

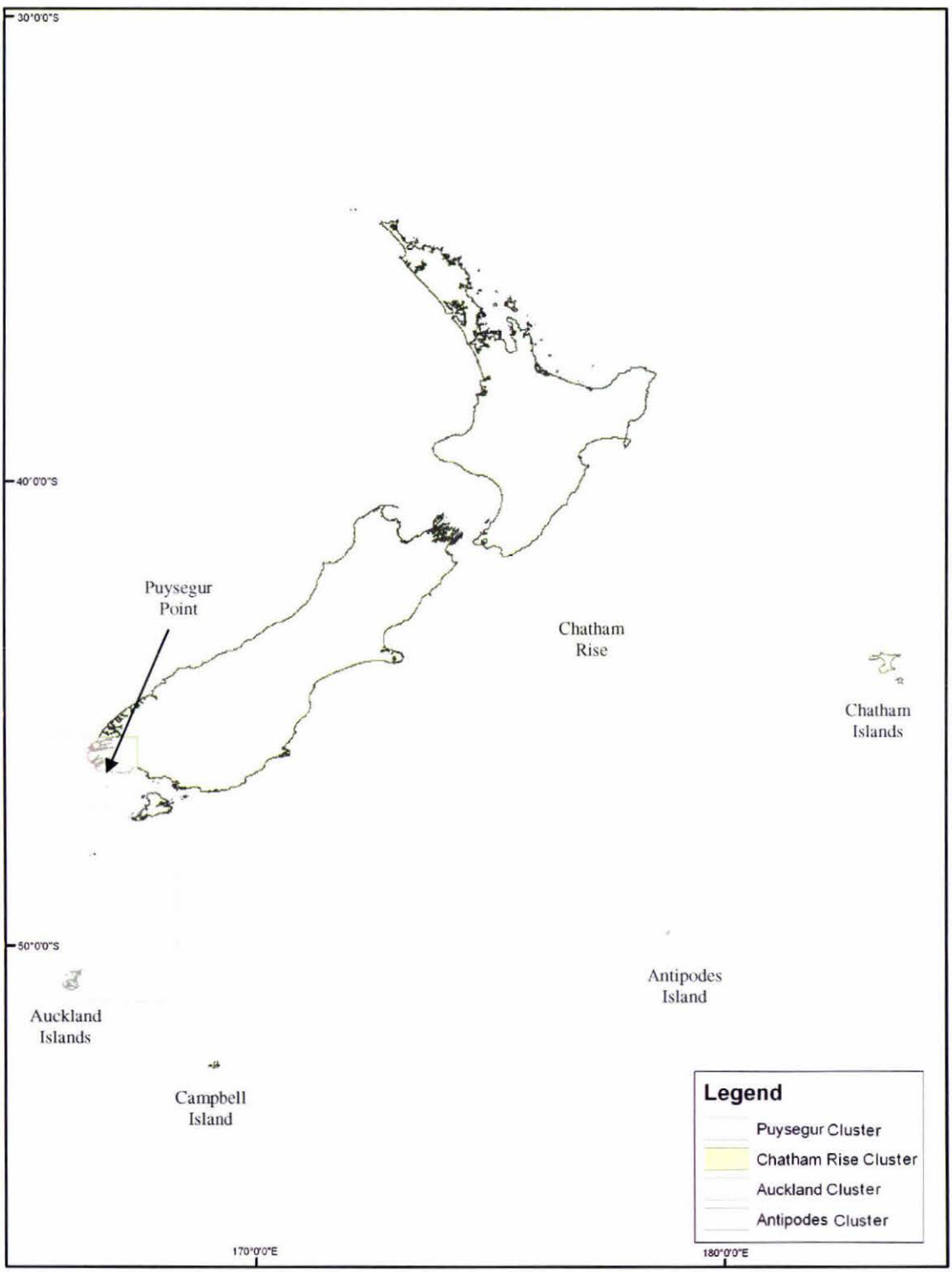

Plate 3.6 Map of the location within the New Zealand Exclusive Economic Zone of the 'Auckland Island cluster group', 'Antipodes Island cluster group', 'Chatham Rise cluster group', and 'Puysegur Point cluster group'.

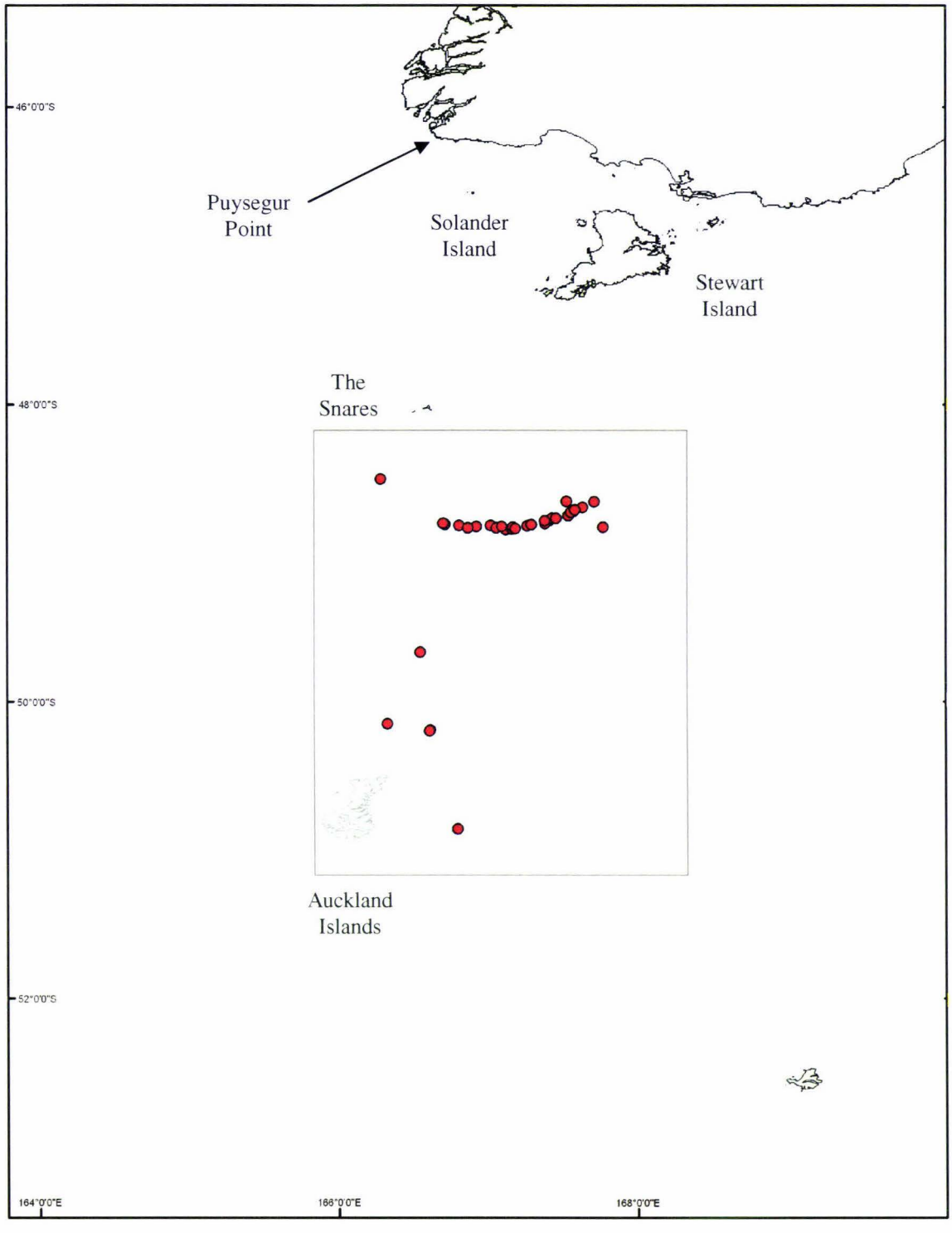

Plate 3.7 Map of the location of the 'Auckland Island cluster group', and where the 45 adult white-chinned petrels were caught between November and March.

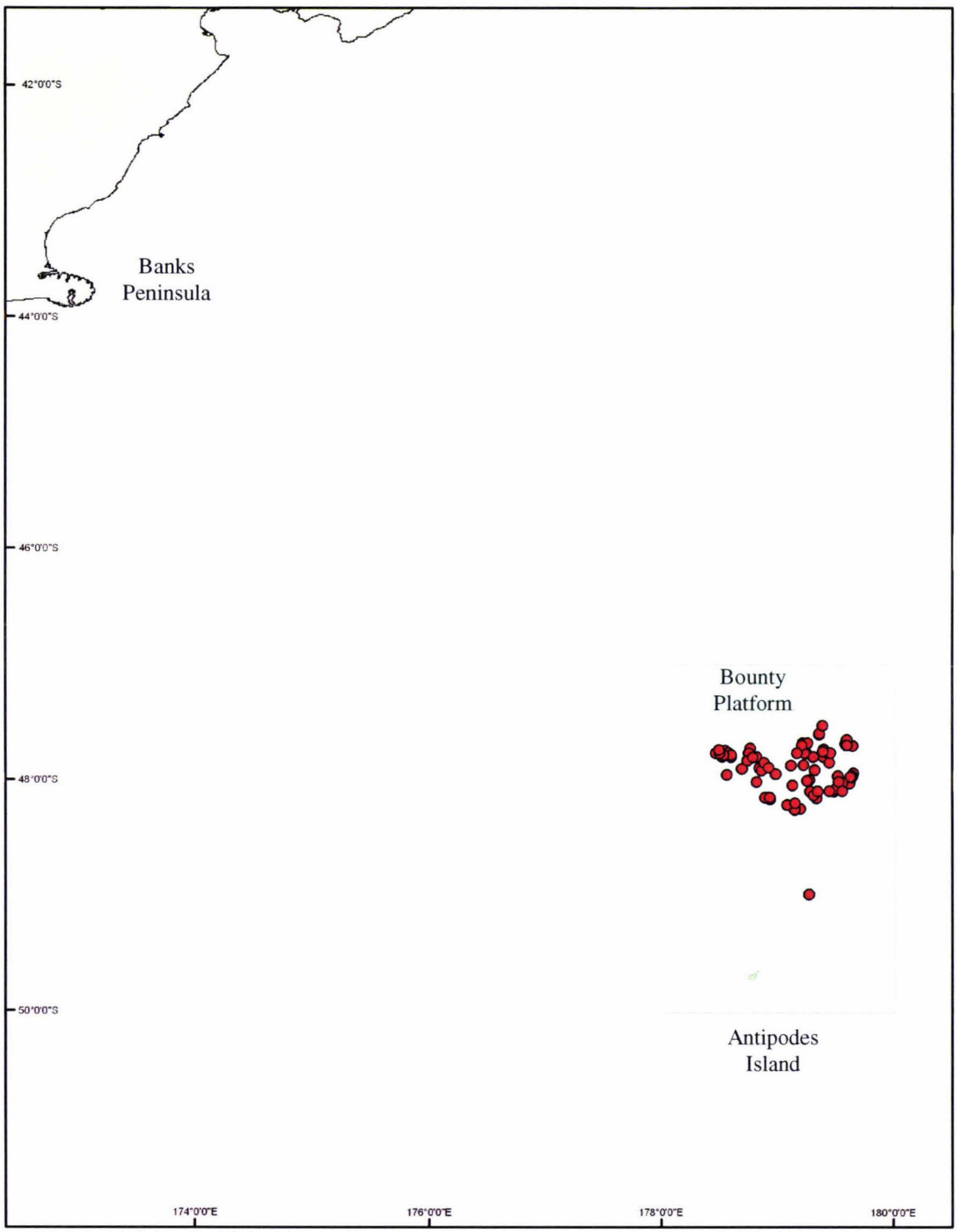

Plate 3.8 Map of the location of the 'Antipodes Island cluster group', and where the 105 adult white-chinned petrels were caught between November and March.

All white-chinned petrels in the 'Auckland Islands cluster group' were caught between January and March, except one adult male that was caught in October (Table 3.26). Sixty-one adult white-chinned petrels were caught between October and December and 44 adults were caught between January and March in the 'Antipodes Island cluster group' (Table 3.26). Slightly more adult males in the 'Antipodes Island cluster group' were caught between October and December (52) than between January and March (43), while all except one adult female was caught between October and December (Table 3.26).

Table 3.26 The number of adult male and female white-chinned petrels caught per month for the 'Auckland Island cluster group' (n = 45) and the 'Antipodes Island cluster group' (n = 105). Oct = October; Nov = November; Dec = December; Jan = January; Feb = February; and Mar = March.

		Oct	Nov	Dec	Jan	Feb	Mar
'Auckland Island cluster group'	adult males	1	0	0	7	9	12
	adult females	0	0	0	3	8	5
'Antipodes Island cluster group'	adult males	6	36	10	7	36	0
	adult females	0	8	1	0	1	0

Initially the 'Auckland Island cluster group' and the 'Antipodes Island cluster group' were analysed together to determine if there were any morphological differences between them. Then the 'Auckland Island cluster group' male and female data were analysed to determine if there were any morphological differences. The 'Antipodes Island cluster group' male and female data were then analysed to determine if there were any morphological differences.

Then males from the 'Auckland and Antipodes Island cluster groups' were analysed to determine if a discriminant function could be used to separate them. 'Auckland and Antipodes Island cluster group' females were then analysed to determine if a discriminant function could be used to separate them. Finally, 'Auckland Island cluster group' females were compared to 'Antipodes Island cluster group' males and 'Auckland Island cluster group' males were compared to 'Antipodes Island cluster group' females.

'Auckland and Antipodes Island cluster group' external measurements

Average head and bill measurements for the 'Auckland Island cluster group' and the 'Antipodes Island cluster group' are shown in Table 3.27. The average 'Antipodes Island cluster group' head and bill measurements are larger than the corresponding average head and bill measurements of the 'Auckland Island cluster group' (Table 3.27).

Table 3.27 Average head and bill measurements of the 'Auckland Island cluster group' (n = 45) and the 'Antipodes Island cluster group' (n = 105). AKICG = 'Auckland Island cluster group'; ANICG = 'Antipodes Island cluster group'; HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; MNW = minimum nostril width; NL = nostril length; AW = area of the white chin patch; SD = standard deviation; SE = standard error; and n = sample size.

		HBL (mm)	HW (mm)	CL (mm)	CDB (mm)	CWB (mm)	BLD (mm)	MNW (mm)	NL (mm)	AW (mm²)
AKICG	mean	113.2	35.5	51.7	22.0	20.9	15.2	9.7	14.0	89.39
	SD	2.92	1.60	1.30	0.92	0.89	0.88	0.68	0.84	71.01
	SE	0.44	0.24	0.20	0.14	0.13	0.13	0.10	0.13	10.59
	n	44	45	44	45	45	45	45	45	45
ANICG	mean	117.0	35.9	53.6	22.5	21.1	15.8	9.8	14.4	110.49
	SD	2.33	1.10	1.57	0.69	0.77	0.68	0.62	1.00	60.33
	SE	0.24	0.11	0.16	0.07	0.08	0.07	0.06	0.10	5.89
	n	98	105	97	105	105	100	105	102	105

The white chin patch area of the 'Auckland Island cluster group' varied between 0.00-274.36 mm² and of the 'Antipodes Island cluster group' between 0.00-296.45 mm². Table 3.28 showed that 57.1 % of the 'Antipodes Island cluster group' had a white chin patch between 100-300 mm² whereas only 37.8 % of the 'Auckland Island cluster group had a white chin patch between 100-300 mm².

Table 3.28 Percent of the 'Auckland Island cluster group' (n = 45) and the 'Antipodes Island cluster group' (n = 105) white-chinned petrels within each white chin area category. AKICG = 'Auckland Island cluster group'; and ANICG = 'Antipodes Island cluster group'.

	0.0 mm²	<5.0 mm²	5-50 mm²	50-100 mm²	100-200 mm²	200-300 mm²	300 + mm²
% of AKICG	11.1	0.0	28.9	22.2	28.9	8.9	0.0
% of ANICG	1.9	1.0	17.1	22.9	50.4	6.7	0.0

Furthermore 40 % the 'Auckland Island cluster group' had a white chin patch < 50.0 mm^2 whereas the 'Antipodes Island cluster group' had only 20.0% of individuals with a white chin patch <50.0 mm^2 (Table 3.28).

The average bodily measurements for the 'Auckland Island cluster group' and the 'Antipodes Island cluster group' are shown in Table 3.29. The average bodily measurements of the 'Antipodes Island cluster group' are all larger than the corresponding average bodily measurements of the 'Auckland Island cluster group' (Table 3.29).

Table 3.29 Average bodily measurements of the 'Auckland Island cluster group' (n = 45) and the 'Antipodes Island cluster group' (n = 105). AKICG = 'Auckland Island cluster group'; ANICG = 'Antipodes Island cluster group'; RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsometatarsus length; TL = tail length; RWLr = right wing length (ruler); LWLr = left wing length (ruler); SD = standard deviation; SE = standard error; and n = sample size.

		RMTC (mm)	LMTC (mm)	RTL (mm)	LTL (mm)	TL (mm)	RWLr (mm)	LWLr (mm)
AKICG	mean	84.4	84.6	66.0	65.1	119.0	385.1	384.6
	SD	2.84	2.60	2.00	1.93	5.97	8.88	8.71
	SE	0.44	0.40	0.30	0.29	0.98	1.37	1.36
	n	41	42	45	44	37	42	41
ANICG	mean	85.4	85.3	67.5	66.5	129.4	397.5	397.7
	SD	2.51	2.51	1.54	1.49	3.86	7.27	7.30
	SE	0.26	0.26	0.15	0.15	0.38	0.73	0.73
	n	90	93	103	104	101	100	99

There was no significant difference between the average length of the right and left wings (ruler) for the 'Auckland Island cluster group' (P = 0.808) or the 'Antipodes Island cluster group' (P = 0.984).

External measurements that showed significant size differences between the 'Auckland and Antipodes Island cluster groups' were head and bill length, culmen length, culmen depth at the base, bill least depth, tarsometatarsus length, tail length, and wing length (Table 3.30). These results indicate that most 'Antipodes Island cluster group' external measurements were on average significantly larger than the 'Auckland Island cluster group' external measurements. Minimum nostril width and nostril length were not considered measurements contributing to distinguishing the

'Auckland Island cluster group' and the 'Antipodes Island cluster group' and are therefore not used in further analyses.

Table 3.30 Significant difference between means for the 'Auckland Island cluster group' (n = 45) and the 'Antipodes Island cluster group' (n = 105). 'Auckland and Antipodes Island cluster group' measurement means are shown in Tables 3.27 and 3.29. HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsomematarsus length; TL = tail length; RWLr = right wing length (ruler); LWLr = left wing length (ruler); and AW = area of the white chin patch.

	HBL	HW	CL	CDB	CWB	BLD	MNW	NL
P value	<0.001	0.165	<0.001	<0.001	0.214	<0.001	0.384	0.021
Significant difference	yes	no	yes	yes	no	yes	no	no
	RMTC	LMTC	RTL	LTL	TL	RWLr	LWLr	AW
P value	0.045	0.126	<0.001	<0.001	<0.001	<0.001	<0.001	0.086
Significant difference	no	no	yes	yes	yes	yes	yes	no

Average tail and right wing length (ruler) of the 'Antipodes Island cluster group' were compared between the periods October to December and January to March. There was no significant difference (P = 0.201) in the average tail length of 'Antipodes Island cluster group' specimens caught between October and December and January and March (Figure 3.20).

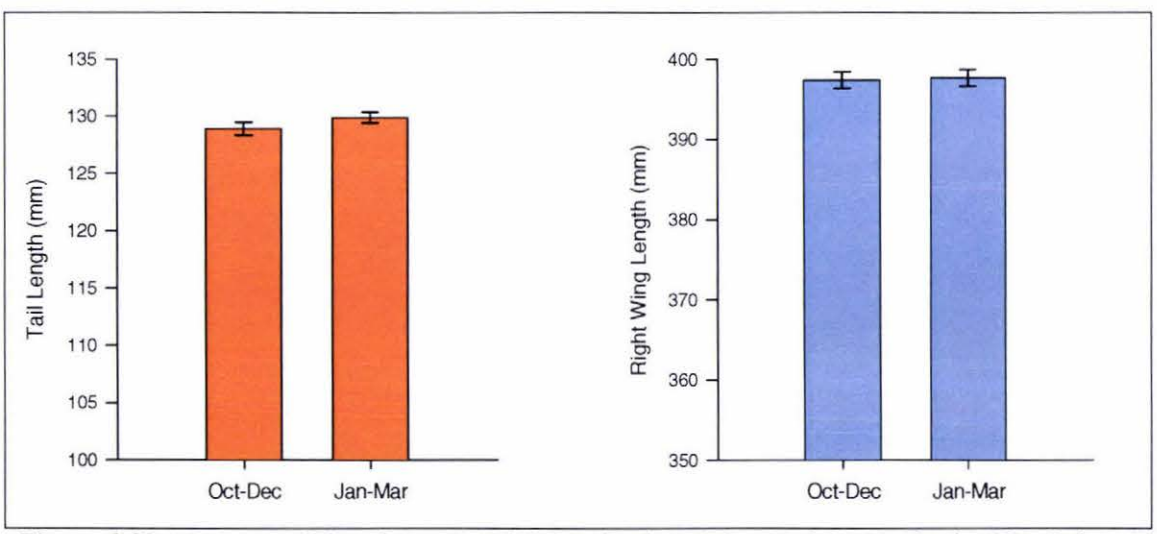

Figure 3.20 Average tail length (mm) and right wing length (mm) of the 'Antipodes Island cluster group' caught between October - December and January - March. 'Antipodes Island cluster group' tail length October - December, n = 57; 'Antipodes Island cluster group' tail length January - March, n = 40; 'Antipodes Island cluster group' right wing length October - December, n = 57; and 'Antipodes Island cluster group' right wing length January - March, n = 40. Error bars represent 1 standard error of the mean.

There was also no significant difference (P = 0.827) in average right wing length (ruler) of 'Antipodes Island cluster group' specimens caught between October and December and January and March (Figure 3.20).

The average 'Antipodes Island cluster group' tail length was significantly longer (P <0.001) than the 'Auckland Island cluster group' tail length between the period January to March (Figure 3.21), and the average 'Antipodes Island cluster group' right wing length (ruler) was significantly longer (P <0.001) than the 'Auckland Island cluster group' right wing length (ruler) between January to March (Figure 3.21).

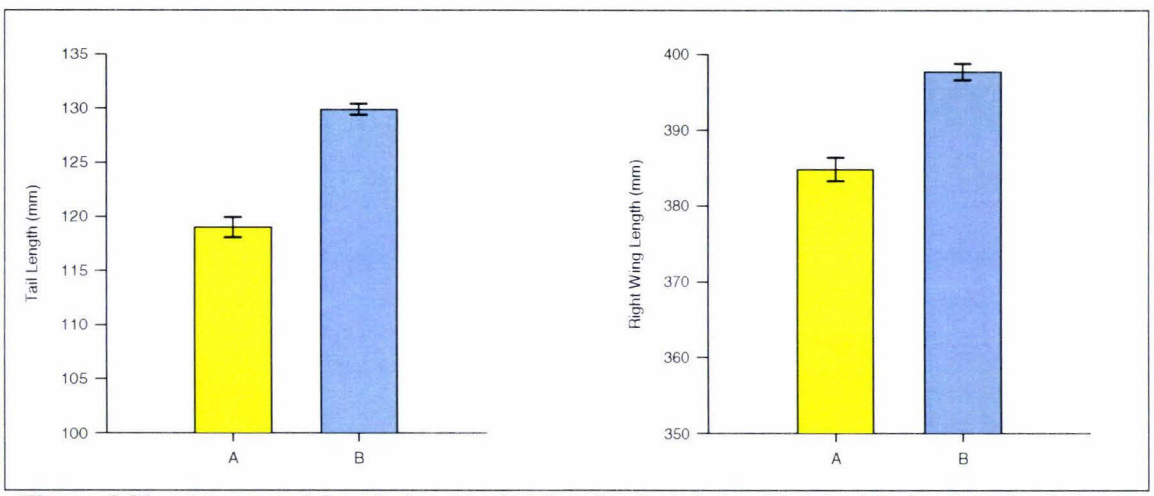

Figure 3.21 Average tail length (mm) and right wing length (mm) of the 'Antipodes Island cluster group' and the 'Auckland Island cluster group' caught between January - March. A = the 'Auckland Island cluster group' caught between January - March; and B = the 'Antipodes Island cluster group' caught between January - March. 'Auckland Island cluster group' tail length, n = 34; 'Antipodes Island cluster group' tail length, n = 40; 'Auckland Island cluster group' right wing length, n = 34; and 'Antipodes Island cluster group' right wing length, n = 40. Error bars represent 1 standard error of the mean.

A principal component analysis using 10 external measurements for the 'Auckland and Antipodes Island cluster groups' explained 68.8% of the variation with the first three components (Appendix 3.6). Nostril length and minimum nostril width measurements were not used because they showed the least amount of variation between 'cluster groups'.

The first principal component explained 45.0% of the variation, the second component explained 13.7% of the variation, and the third component explained 10.2% of the variation (Appendix 3.6). The first and second principal component scores for each individual in the 'Auckland and Antipodes Island cluster groups' were

plotted to show the distribution of the males and females within each cluster (Figure 3.22). Figure 3.22 showed approximately four groups, 'Auckland and Antipodes Island cluster group' males and females, with an amount of overlap between each group.

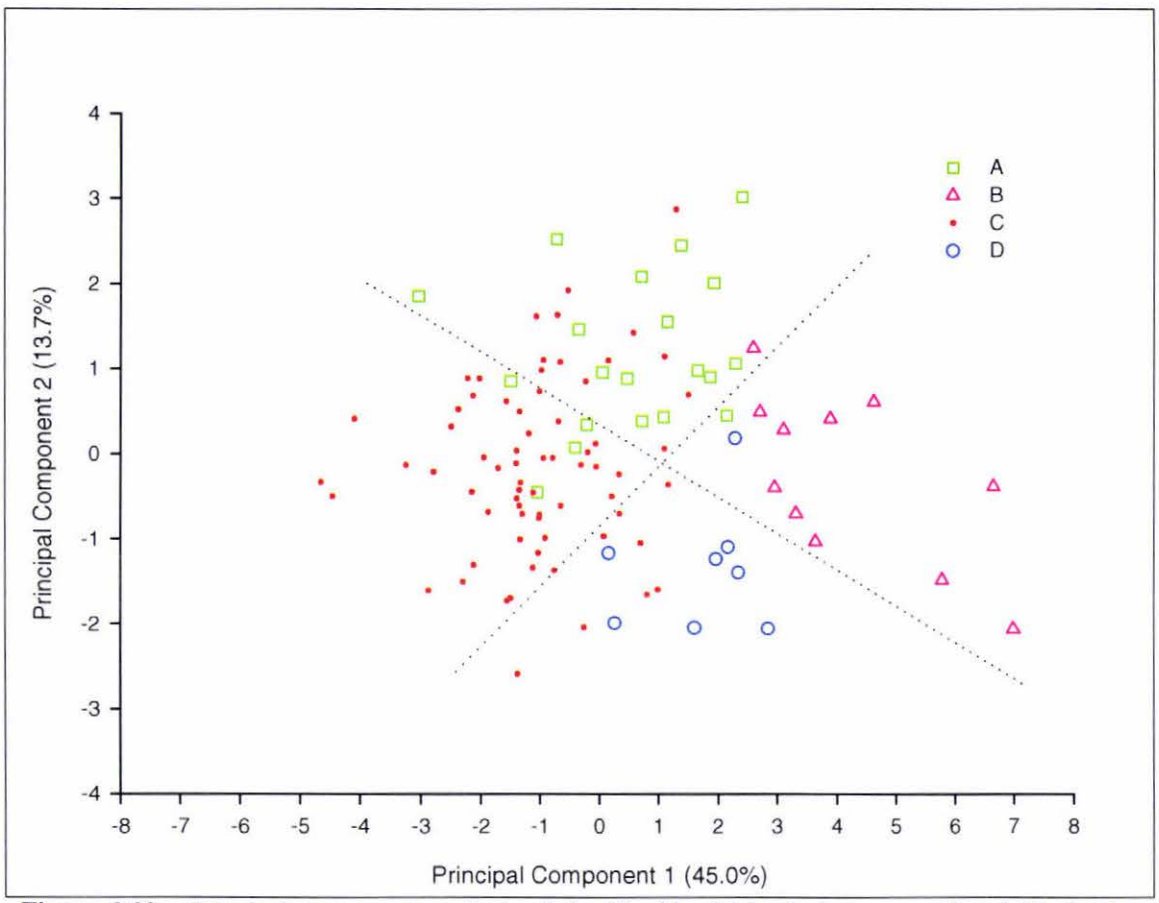

Figure 3.22 Principal component analysis of the 'Auckland Island cluster group' and 'Antipodes Island cluster group' males and females showing principal component 1 (45.0%) and principal component 2 (13.7%). A = 'Auckland Island cluster group' males (n = 19); B = 'Auckland Island cluster group' females (n = 11); C = 'Antipodes Island cluster group' males (n = 69); and D = 'Antipodes Island cluster group' females (n = 8). The dotted lines indicate approximate splits between the males and females of the 'Auckland Island cluster group' and 'Antipodes Island cluster group'

Combinations of external measurements showed that generally the 'Antipodes Island cluster group' was larger in size; however there is a lot of overlap between the 'Auckland and Antipodes Island cluster groups' (Figure 3.23). The best measurements for discriminating between the 'Auckland and Antipodes Island cluster groups' were head and bill length, culmen length, culmen depth at the base tail length, wing length, and tarsus length as shown in Figure (3.23).

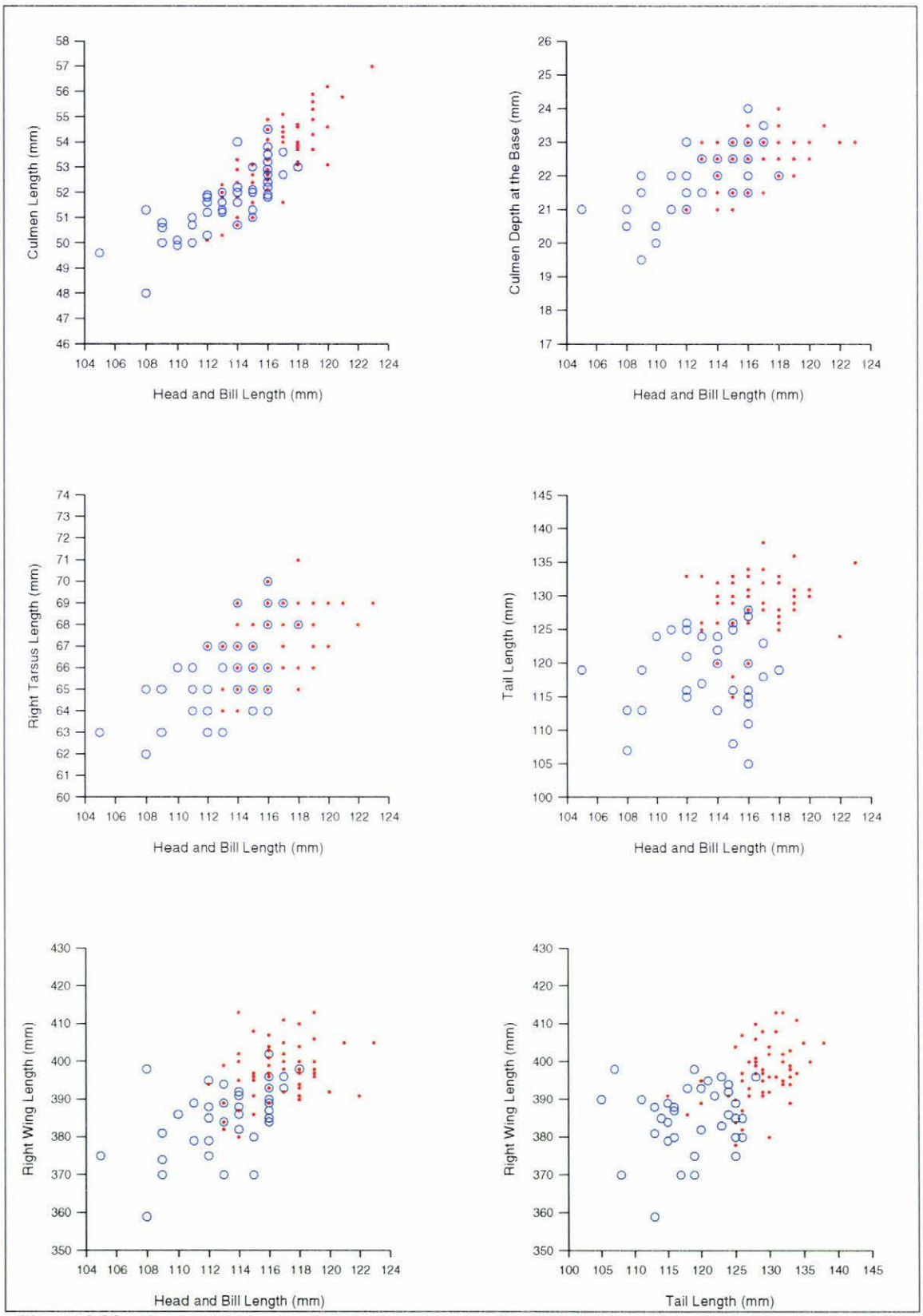

Figure 3.23 Combinations of external measurements for the 'Auckland Island cluster group' and the 'Antipodes Island cluster group' showing the 'Antipodes Island cluster group' were larger in all external measurements than the 'Auckland Island cluster group', but with some overlap. Red dots = the 'Antipodes Island cluster group' (n = 105); and blue circles = the 'Auckland Island cluster group' (n = 45). Sample sizes differ on each graph due to measurements unable to be taken from some individuals.

Discriminant analysis was used to determine which combination of external measurements best discriminate between the 'Auckland and Antipodes Island cluster groups'. Discriminant analysis showed that the best combination of external measurements for differentiating between the 'Auckland and Antipodes Island cluster groups' were head and bill length, right tarsometatarsus length and tail length (Table 3.31).

The proportion differentiated into the correct cluster group after cross-validation was 91.4 % as shown in Table 3.31. For the full results of this discriminant analysis see Appendix 3.7.

Table 3.31 Discriminant analysis summary of classification with cross validation between the 'Auckland Island cluster group' (n = 36) and the 'Antipodes Island cluster group' (n = 92). AKICG = 'Auckland Island cluster group'; and ANICG = 'Antipodes Island cluster group'.

	Classified in correct 'cluster group'	Classified in other 'cluster group'	% correctly classified
AKICG	31	5	86.1
ANICG	87	6	93.5
Total	117	11	**91.4**

'Auckland and Antipodes Island cluster group' bill descriptions

The 'Auckland Island cluster group' had a higher percentage of individuals with dark lines on the maxillary unguis (53.3 %) whereas the 'Antipodes Island cluster group' had only 25.7 % with dark lines on the maxillary unguis (Table 3.32).

Table 3.32 Percent of the 'Auckland Island cluster group' (n = 45) and the 'Antipodes Island cluster group' (n = 101) with each '*Dark line score*'. AKICG = 'Auckland Island cluster group'; and ANICG = 'Antipodes Island cluster group'.

	'*Dark line score*' 0	'*Dark line score*' 1	'*Dark line score*' 2	'*Dark line score*' 3
% of AKICG	46.7	4.4	20.0	28.9
% of ANICG	74.3	7.9	8.9	8.9

However, the 'Antipodes Island cluster group' had a higher percentage of individuals with '*Nail score*' 3 (43.4 %) and '*Unguis score*' 3 (51.0 %), compared to the 'Auckland Island cluster group' with 31.1 % of individuals with '*Nail score*' 3 and 24.4 % of individuals with '*Unguis score*' 3 (Table 3.33), indicating that the 'Antipodes Island cluster group' on average have slightly darker bill tips. Both the

'Auckland and Antipodes Island cluster groups' had no individuals with a '*Nail score*' 0 (Table 3.33).

Table 3.33 The percent of the 'Auckland Island cluster group' and the 'Antipodes Island cluster group' with each '*Nail score*' and '*Unguis score*'. AKICG = 'Auckland Island cluster group'; and ANICG = 'Antipodes Island cluster group'. 'Auckland Island cluster group' '*Nail score*' n = 45; 'Antipodes Island cluster group' '*Nail score*' n = 99; 'Auckland Island cluster group' '*Unguis score*' n = 45; and 'Antipodes Island cluster group' '*Unguis score*' n = 102.

	'*Nail score*' 0	'*Nail score*' 1	'*Nail score*' 2	'*Nail score*' 3	'*Unguis score*' 0	'*Unguis score*' 1	'*Unguis score*' 2	'*Unguis score*' 3
% of AKICG	0.0	42.2	26.7	31.1	24.4	17.8	33.4	24.4
% of ANICG	0.0	38.4	18.2	43.4	19.6	6.9	22.5	51.0

'Auckland and Antipodes Island cluster group' nostril shapes

All nostril shapes were present in both the 'Auckland and Antipodes Island cluster groups' (Table 3.34). '*Nostril shape*' 1 was the most common '*Nostril shape*' in both the 'Auckland and Antipodes Island cluster groups' (Table 3.34).

Table 3.34 Percent of the 'Auckland Island cluster group' (n = 45) and the 'Antipodes Island cluster group' (n = 102) with each '*Nostril shape*'. AKICG = 'Auckland Island cluster group'; and ANICG = 'Antipodes Island cluster group'.

	'*Nostril shape*' 1	'*Nostril shape*' 2	'*Nostril shape*' 3	'*Nostril shape*' 4	'*Nostril shape*' 5
% of AKICG	66.7	13.3	6.7	4.4	8.9
% of ANICG	70.6	12.7	2.0	10.8	3.9

'Auckland Island cluster group' male and female external measurements

Average head and bill measurements for 'Auckland Island cluster group' males and females are shown in Table 3.35. The means of all 'Auckland Island cluster group' male head and bill measurements are larger than the corresponding means of the 'Auckland Island cluster group' females (Table 3.35).

Average bodily measurements for the 'Auckland Island cluster group' males and females are shown in Table 3.36. Average bodily measurements of the 'Auckland Island cluster group' males are also all larger than the corresponding 'Auckland Island cluster group' female's measurements, except for tail length (Table 3.36).

Table 3.35 Average head and bill measurements of the 'Auckland Island cluster group' males (n = 29) and females (n = 16). AKICG = 'Auckland Island cluster group'; HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; SD = standard deviation; SE = standard error; and n = sample size.

		HBL (mm)	HW (mm)	CL (mm)	CDB (mm)	CWB (mm)	BLD (mm)
	mean	114.8	36.1	52.3	22.5	21.4	15.6
AKICG	SD	1.98	1.13	1.05	0.63	0.68	0.69
males	SE	0.37	0.21	0.20	0.12	0.13	0.13
	n	28	29	28	29	29	29
	mean	110.4	34.3	50.7	21.1	20.2	14.5
AKICG	SD	2.10	1.70	1.07	0.69	0.70	0.73
females	SE	0.52	0.43	0.27	0.17	0.18	0.18
	n	16	16	16	16	16	16

There were significant differences between all 'Auckland Island cluster group' male and female external measurements, except tail length and left wing length (Table 3.37). Combinations of external measurements showed the 'Auckland Island cluster group' males to be larger than the females, but with some overlap between all measurements (Figure 3.24).

Table 3.36 Average bodily measurements of 'Auckland Island cluster group' males (n = 29) and females (n = 16). AKICG = 'Auckland Island cluster group'; RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsometatarsus length; TL = tail length; RWLr = right wing length (ruler); LWLr = left wing length (ruler); SD = standard deviation; SE = standard error; and n = sample size.

		RMTC (mm)	LMTC (mm)	RTL (mm)	LTL (mm)	TL (mm)	RWLr (mm)	LWLr (mm)
	mean	85.4	85.3	66.4	65.5	118.8	387.3	386.2
AKICG	SD	2.99	2.71	2.13	2.08	6.09	8.85	9.20
males	SE	0.60	0.51	0.40	0.39	1.22	1.70	1.77
	n	25	28	29	28	25	27	27
	mean	82.8	83.2	65.1	64.3	119.3	381.3	381.4
AKICG	SD	1.68	1.72	1.39	1.35	5.96	7.78	6.93
females	SE	0.42	0.46	0.35	0.34	1.72	2.01	1.85
	n	16	14	16	16	12	15	14

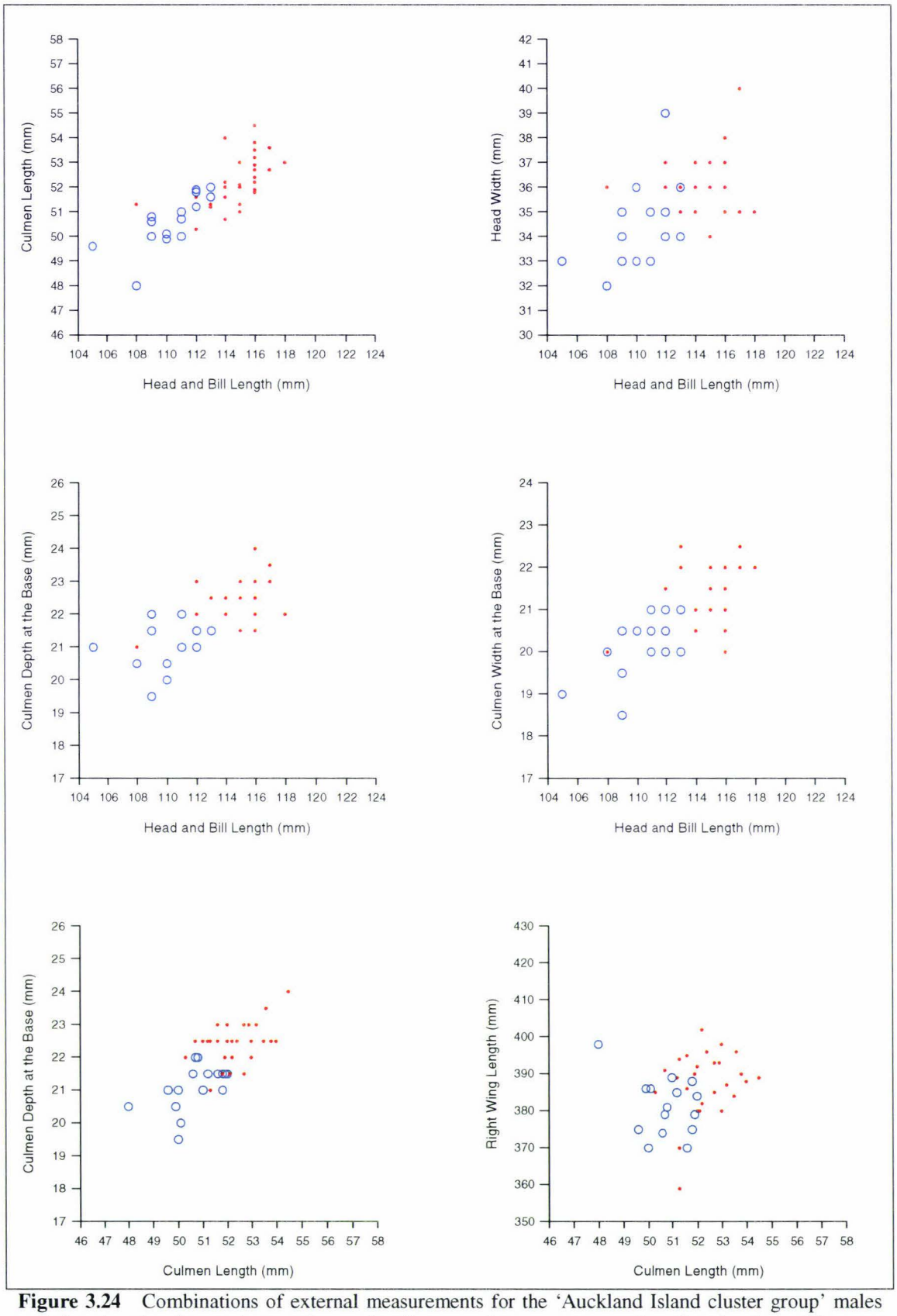

Figure 3.24 Combinations of external measurements for the 'Auckland Island cluster group' males and females showing males are larger in all external measurements than females but with some overlap. Red dots = 'Auckland Island cluster group' males (n = 29); and blue circles = 'Auckland Island cluster group' females (n = 16). Sample sizes differ on each graph due to measurements unable to be taken from some specimens.

The best measurements for discriminating between the 'Auckland Island cluster group' males and females were head and bill length, culmen length, culmen depth at the base, culmen width at the base, and head width as shown in Figure 3.24.

Table 3.37 Significant difference between means for the 'Auckland Island cluster group' males (n = 29) and females (n = 16). 'Auckland Island cluster group' male and female measurement means are shown in Tables 3.35 and 3.36. HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsomematarsus length; TL = tail length; RWLr = right wing length (ruler); and LWLr = left wing length (ruler).

	HBL	HW	CL	CDB	CWB	BLD	TL
P value	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	0.925
Significant difference	yes	yes	yes	yes	yes	yes	no
	RMTC	LMTC	RTL	LTL	RWLr	LWLr	
P value	0.001	0.009	0.015	0.030	0.029	0.068	
Significant difference	yes	yes	yes	yes	yes	no	

Discriminant analysis on the 'Auckland Island cluster group' was done to differentiate between 'Auckland Island cluster group' males and females. The best discriminant, after cross validation, differentiated 95.5 % between 'Auckland Island cluster group' males and females using head and bill length and culmen depth at the base (Table 3.38). For the full results of this discriminant analysis see Appendix 3.8.

Table 3.38 Discriminant analysis summary of classification with cross validation between the 'Auckland Island cluster group' males (n = 28) and females (n = 16). AKICG = 'Auckland Island cluster group'.

	Classified in correct 'cluster group'	Classified in other 'cluster group'	% correctly classified
AKICG males	26	2	92.9
AKICG females	16	0	100.0
Total	42	2	**95.5**

'Antipodes Island cluster group' male and female external measurements

Average head and bill measurements for 'Antipodes Island cluster group' males and females are shown in Table 3.39. The means of all 'Antipodes Island cluster group' male head and bill measurements were larger than the corresponding mean head and bill measurements of the 'Antipodes Island cluster group' females (Table 3.39).

Table 3.39 Average head and bill measurements of the 'Antipodes Island cluster group' males (n = 95) and females (n = 10). ANICG = 'Antipodes Island cluster group'; HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; SD = standard deviation; SE = standard error; and n = sample size.

		HBL (mm)	HW (mm)	CL (mm)	CDB (mm)	CWB (mm)	BLD (mm)
	mean	117.2	36.0	53.8	22.7	21.2	16.0
ANICG	SD	2.25	1.07	1.44	0.60	0.72	0.60
males	SE	0.24	0.11	0.15	0.06	0.07	0.06
	n	88	95	87	95	95	90
	mean	114.5	34.7	51.7	21.4	20.3	14.9
ANICG	SD	1.43	0.67	1.38	0.46	0.79	0.74
females	SE	0.45	0.21	0.44	0.15	0.25	0.23
	n	10	10	10	10	10	10

The average bodily measurements for the 'Antipodes Island cluster group' males and females are shown in Table 3.40. The means of all bodily measurements of the 'Antipodes Island cluster group' males are larger than the corresponding means of the 'Antipodes Island cluster group' females (Table 3.40).

Table 3.40 Average bodily measurements of 'Antipodes Island cluster group' males (n = 95) and females (n = 10). ANICG = 'Antipodes Island cluster group'; RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsometatarsus length; TL = tail length; RWLr = right wing length (ruler); LWLr = left wing length (ruler); SD = standard deviation; SE = standard error; and n = sample size.

		RMTC (mm)	LMTC (mm)	RTL (mm)	LTL (mm)	TL (mm)	RWLr (mm)	LWLr (mm)
	mean	85.6	85.4	67.6	66.6	129.7	397.9	398.0
ANICG	SD	2.53	2.57	1.55	1.51	3.50	7.31	7.36
males	SE	0.28	0.28	0.16	0.16	0.37	0.77	0.78
	n	82	84	93	94	91	90	89
	mean	84.3	84.6	66.9	66.1	126.8	394.2	394.8
ANICG	SD	2.05	1.81	1.37	1.29	5.88	6.21	6.36
females	SE	0.73	0.60	0.43	0.41	1.86	1.97	2.01
	n	8	9	10	10	10	10	10

There were significant differences between 'Antipodes Island cluster group' male and female head and bill length, head width, culmen length, culmen depth at the base, culmen width at the base, bill least depth, and tail length (Table 3.41). Combinations of external measurements showed the 'Antipodes Island cluster group' males were larger than the females, however there was some overlap between all measurements (Figure 3.25).

Table 3.41 Significant difference between means for the 'Antipodes Island cluster group' males (n = 95) and females (n = 10). 'Antipodes Island cluster group' male and female measurement means are shown in Tables 3.39 and 3.40. HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsomematarsus length; TL = tail length; RWLr = right wing length (ruler); and LWLr = left wing length (ruler).

	HBL	HW	CL	CDB	CWB	BLD	TL
P value	<0.001	<0.001	0.001	<0.001	0.006	0.002	0.024
Significant difference	yes	yes	yes	yes	yes	yes	yes
	RMTC	LMTC	RTL	LTL	RWLr	LWLr	
P value	0.160	0.331	0.192	0.331	0.226	0.187	
Significant difference	no	no	no	no	no	no	

Discriminant analysis on the 'Antipodes Island cluster group' differentiated males and females 91.8% after cross-validation using head and bill length, head width, culmen depth at the base, and right MTC length Table 3.42. For the full results of this discriminant analysis see Appendix 3.9.

Table 3.42 Discriminant analysis summary of classification with cross validation between the 'Antipodes Island cluster group' males (n = 77) and females (n = 8). ANICG = 'Antipodes Island cluster group'.

	Classified in correct 'cluster group'	Classified in other 'cluster group'	% correctly classified
ANICG males	70	7	90.9
ANICG females	8	0	100.0
Total	78	7	**91.8**

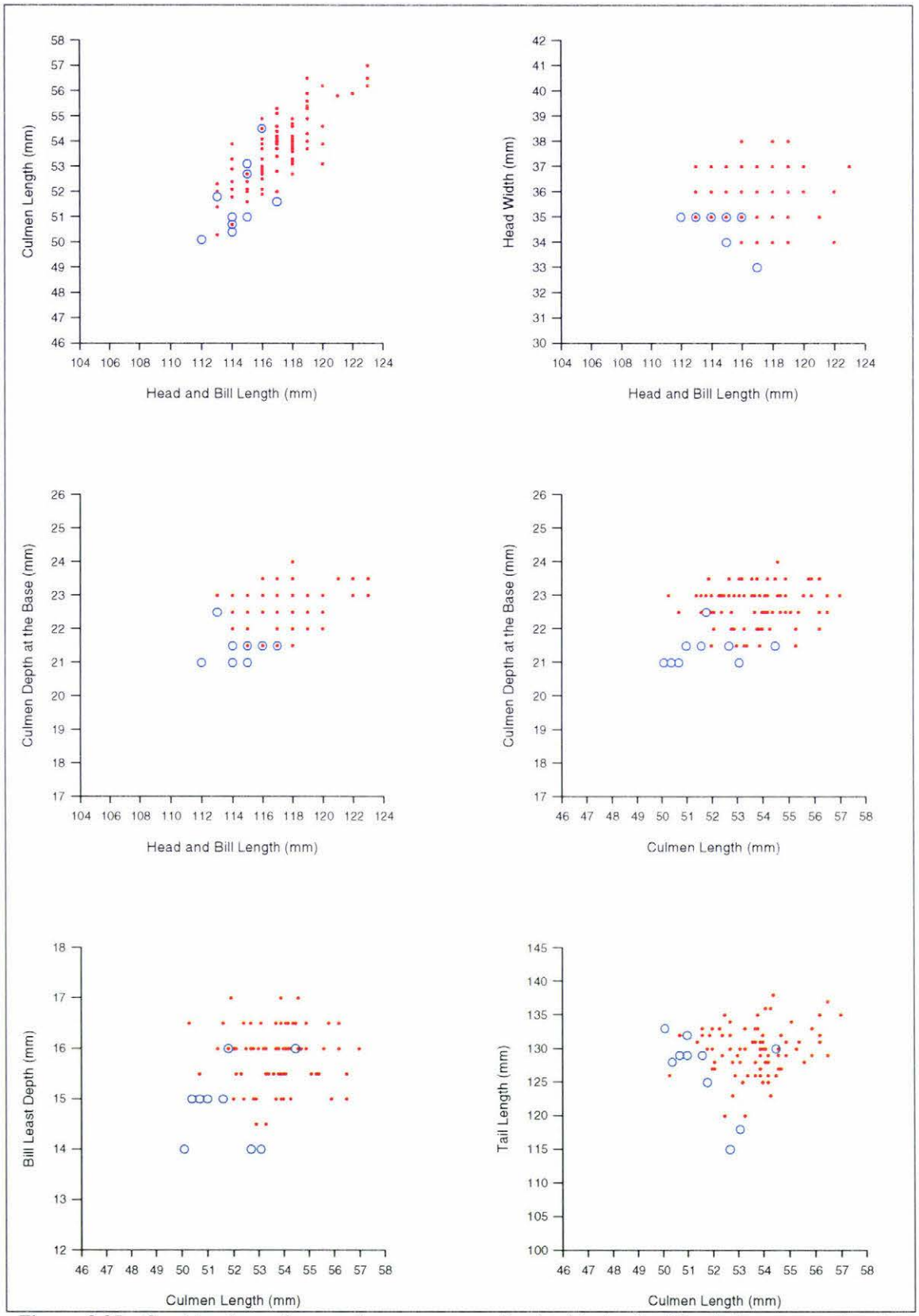

Figure 3.25 Combinations of external measurements for the 'Antipodes Island cluster group' males and females showing males are larger in all external measurements than females but with some overlap. Red dots = 'Antipodes Island cluster group' males (n = 95); and blue circles = 'Antipodes Island cluster group' females (n = 10). Sample sizes differ on each graph due to measurements unable to be taken from some specimens.

'Auckland and Antipodes Island cluster group' males

There were significant differences between the means of head and bill length, culmen length, tarsometatarsus length, tail length, and wing length of 'Auckland and Antipodes Island cluster group' males (Table 3.43). Combinations of external measurements showed the 'Antipodes Island cluster group' males were significantly larger in head and bill length, culmen length, tail length, and wing length than the 'Auckland Island cluster group' males (Figure 3.26), although there was some overlap between all measurements.

Table 3.43 Significant difference between means for 'Antipodes Island cluster group' males (n = 95) and 'Auckland Island cluster group' males (n = 29), as indicated by the *P* value. Measurement means for 'Auckland Island cluster group' males are shown in Tables 3.35 and 3.36 and 'Antipodes Island cluster group' males in Tables 3.39 and 3.40. HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsomematarsus length; TL = tail length; RWLr = right wing length (ruler); and LWLr = left wing length (ruler).

	HBL	HW	CL	CDB	CWB	BLD	TL
P value	<0.001	0.491	<0.001	0.115	0.317	0.017	<0.001
Significant difference	yes	no	yes	no	no	yes	yes
	RMTC	LMTC	RTL	LTL	RWLr	LWLr	
P value	0.790	0.818	0.002	0.004	<0.001	<0.001	
Significant difference	no	no	yes	yes	yes	yes	

The best discriminant analysis differentiated 93.5% 'Antipodes Island cluster group' males from 'Auckland Island cluster group' males after cross-validation using culmen length and tail length (Table 3.44). For the full results of this discriminant analysis see Appendix 3.10.

Table 3.44 Discriminant analysis summary of classification with cross validation between the 'Antipodes Island cluster group' males (n = 83) and 'Auckland Island cluster group' males (n = 24). ANICG = 'Antipodes Island cluster group'; AKICG = 'Auckland Island cluster group'.

	Classified in correct 'cluster group'	Classified in other 'cluster group'	% correctly classified
ANICG males	79	4	95.2
AKICG males	21	3	87.5
Total	100	7	**93.5**

The linear discriminant function for differentiating 'Auckland and Antipodes Island cluster group' males was:

$$\text{Function} = -114.8391 + (CL * 0.7297) + (TL * 0.6127)$$

CL = culmen length and TL = tail length. A negative result from the linear function = 'Auckland Island cluster group' and a positive result = 'Antipodes Island cluster group'.

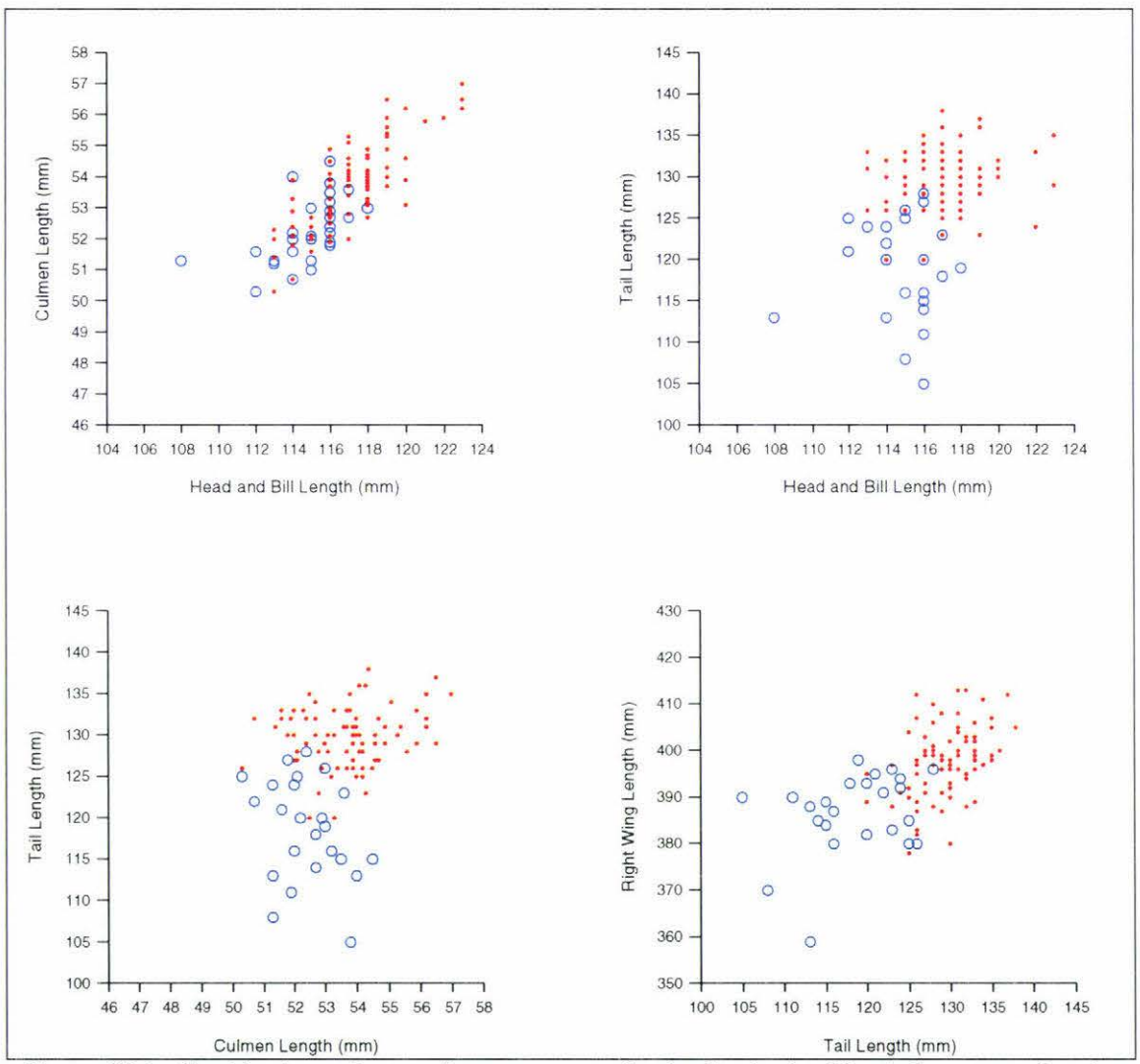

Figure 3.26 Combinations of external measurements for the 'Antipodes Island cluster group' males and 'Auckland Island cluster group' males showing the 'Antipodes Island cluster group males are larger in all external measurements than the 'Auckland Island cluster group' males but with some overlap. Red dots = 'Antipodes Island cluster group' males (n = 95); and blue circles = 'Auckland Island cluster group' males (n = 29). Sample sizes differ on each graph due to measurements unable to be taken from some specimens.

An alternate discriminant analysis without using tail length differentiated 76.7% 'Antipodes Island cluster group' males from 'Auckland Island cluster group' males after cross-validation using head and bill length and culmen width at the base (Table 3.45). For the full results of this discriminant analysis see Appendix 3.11.

Table 3.45 Alternate discriminant analysis summary of classification with cross validation between 'Antipodes Island cluster group' males (n = 88) and 'Auckland Island cluster group' males (n = 28). ANICG = 'Antipodes Island cluster group'; AKICG = 'Auckland Island cluster group'.

	Classified in correct 'cluster group'	Classified in other 'cluster group'	% correctly classified
ANICG males	67	21	76.1
AKICG males	22	6	78.6
Total	89	27	**76.7**

The alternate linear discriminant function for differentiating 'Antipodes Island cluster group' and 'Auckland Island cluster group' males was:

$$\text{Function} = -50.9259 + (\text{HBL} * 0.5579) + (\text{CWB} * -0.6491)$$

HBL = head and bill length and CWB = culmen width at the base. A negative result from the linear function = 'Auckland Island cluster group' and a positive result = 'Antipodes Island cluster group'.

'Auckland and Antipodes Island cluster group' females

'Antipodes Island cluster group' females were significantly larger in head and bill length, culmen length, tarsometatarsus length, tail length, and wing length than the 'Auckland Island cluster group' females (Table 3.46).

Combinations of external measurements showed 'Antipodes Island cluster group' females were larger in most external measurements than 'Auckland Island cluster group' females (Figure (3.27), although there was some overlap between all measurements. Sample sizes in both groups were small and may have contributed to some results being unsignificant.

Table 3.46 Significant difference between means for 'Antipodes Island cluster group' females (n = 10) and 'Auckland Island cluster group' females (n = 16), as indicated by the *P* value. Measurement means for 'Auckland Island cluster group' females are shown in Tables 3.35 and 3.36 and 'Antipodes Island cluster group' females in Tables 3.39 and 3.40. HBL = head and bill length; HW = head width; CL = culmen length; CDB = culmen depth at the base; CWB = culmen width at the base; BLD = bill least depth; RMTC = right mid toe and claw length; LMTC = left mid toe and claw length; RTL = right tarsometatarsus length; LTL = left tarsomematarsus length; TL = tail length; RWLr = right wing length (ruler); and LWLr = left wing length (ruler).

	HBL	HW	CL	CDB	CWB	BLD	TL
P value	<0.001	0.501	0.048	0.227	0.708	0.189	0.007
Significant difference	yes	no	yes	no	no	no	yes
	RMTC	LMTC	RTL	LTL	RWLr	LWLr	
P value	0.080	0.088	0.003	0.003	<0.001	<0.001	
Significant difference	no	no	yes	yes	yes	yes	

The best discriminant analysis differentiated 92.0% 'Antipodes Island cluster group' females from 'Auckland Island cluster group' females after cross-validation using head and bill length, culmen depth at the base, and wing length (Table 3.47). For the full results of this discriminant analysis see Appendix 3.12.

Table 3.47 Discriminant analysis summary of classification with cross validation between the 'Antipodes Island cluster group' females (n = 10) and 'Auckland Island cluster group' females (n = 15). ANICG = 'Antipodes Island cluster group'; AKICG = 'Auckland Island cluster group'.

	Classified in correct 'cluster group'	Classified in other 'cluster group'	% correctly classified
ANICG females	9	1	90.0
AKICG females	14	1	93.3
Total	23	2	**92.0**

The linear discriminant function for differentiating 'Auckland and Antipodes Island cluster group' females was:

$$\text{Function} = -220.7114 + (\text{HBL} * 1.0361) + (\text{CDB} * 0.4612) + (\text{WL} * 0.2435)$$

HBL = head and bill length, CDB = culmen depth at the base, and WL = wing length. A negative result from the linear function = 'Auckland Island cluster group' and a positive result = 'Antipodes Island cluster group'.

An alternate discriminant analysis without using wing length differentiated 84.6% 'Antipodes Island cluster group' females from 'Auckland Island cluster group' females after cross-validation using head and bill length and culmen depth at the base (Table 3.48). For the full results of this discriminant analysis see Appendix 3.13.

Table 3.48 Alternate discriminant analysis summary of classification with cross validation between the 'Antipodes Island cluster group' females (n = 10) and 'Auckland Island cluster group' females (n = 16). ANICG = 'Antipodes Island cluster group'; AKICG = 'Auckland Island cluster group'.

	Classified in correct 'cluster group'	Classified in other 'cluster group'	% correctly classified
ANICG females	8	2	80.0
AKICG females	14	2	87.5
Total	22	4	**84.6**

The alternate linear discriminant function for differentiating 'Auckland and Antipodes Island cluster group' females was:

$$\text{Function} = -128.3202 + (\text{HBL} * 1.1664) + (\text{CBD} * -0.1350)$$

HBL = head and bill length and CDB = culmen depth at the base. A negative result from the linear function = 'Auckland Island cluster group' and a positive result = 'Antipodes Island cluster group'.

Head and bill length could not be taken from museum skins so another alternate discriminant analysis was done that could be used on female museum skins. This discriminant analysis differentiated 84.0% 'Antipodes Island cluster group' females from 'Auckland Island cluster group' females after cross validation using culmen length, and wing length (Table 3.49). For the full results of this discriminant analysis see Appendix 3.14.

Table 3.49 Alternate discriminant analysis summary of classification with cross validation between the 'Antipodes Island cluster group' females (n = 10) and 'Auckland Island cluster group' females (n = 15) to use on museum skins. ANICG = 'Antipodes Island cluster group'; AKICG = 'Auckland Island cluster group'.

	Classified in correct 'cluster group'	Classified in other 'cluster group'	% correctly classified
ANICG females	9	1	90.0
AKICG females	12	3	80.0
Total	21	4	**84.0**

This alternate linear discriminant function for differentiating 'Auckland and Antipodes Island cluster group' females was:

$$\text{Function} = -161.5171 + (\text{CL} * 1.0033) + (\text{WL} * 0.2841)$$

CL = culmen length and WL = wing length. A negative result from the linear function = 'Auckland Island cluster group' and a positive result = 'Antipodes Island cluster group'.

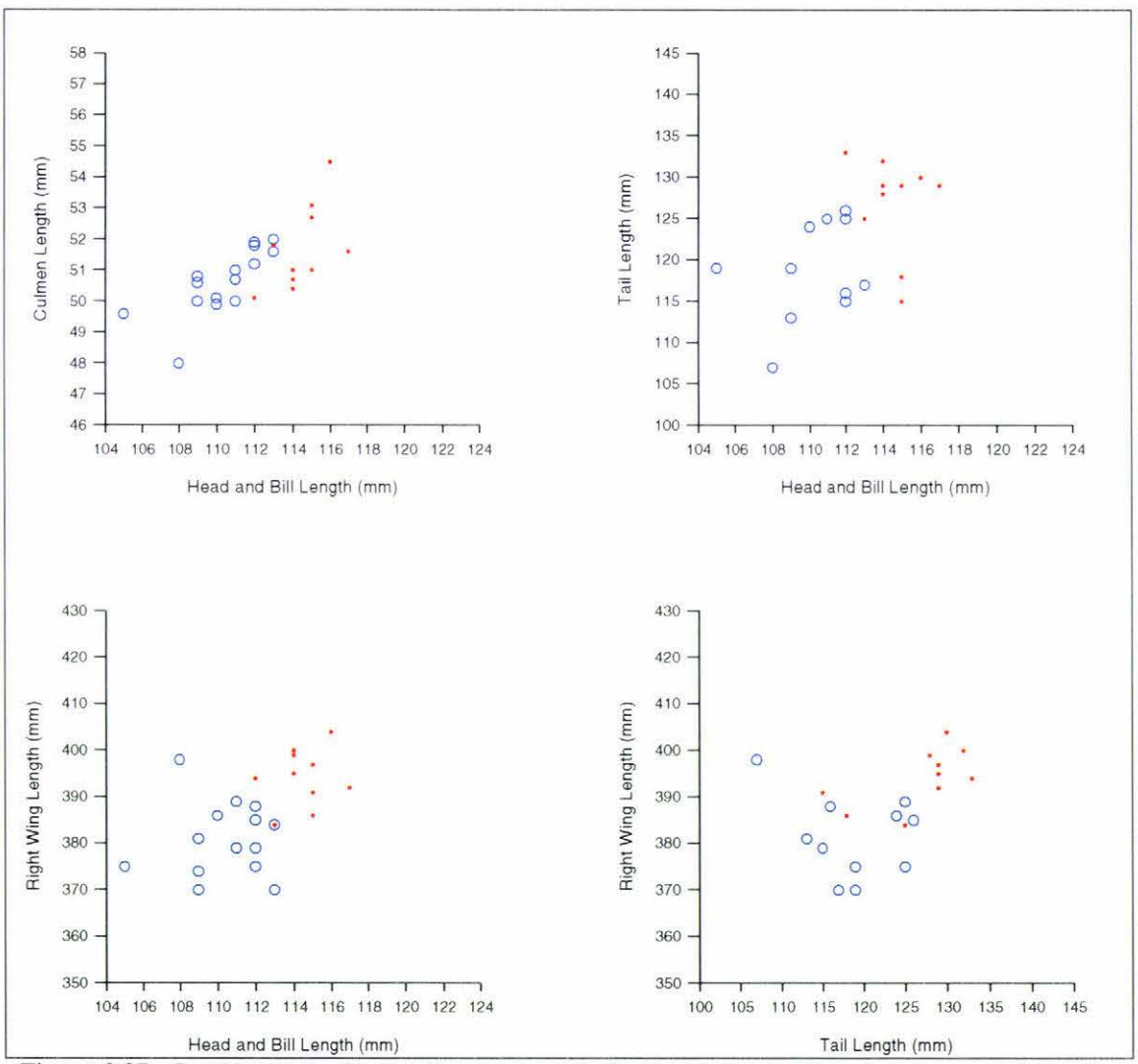

Figure 3.27 Combinations of external measurements for the 'Antipodes Island cluster group' females and 'Auckland Island cluster group' females showing the 'Antipodes Island cluster group females are larger in all external measurements than the 'Auckland Island cluster group' females but with some overlap. Red dots = 'Antipodes Island cluster group' females (n = 10); and blue circles = 'Auckland Island cluster group' females (n = 16). Sample sizes differ on each graph due to measurements unable to be taken from some specimens.

'Auckland and Antipodes Island cluster group' males and females

Combinations of external measurements showed the 'Antipodes Island cluster group' males to be larger than the 'Auckland Island cluster group' females with very little or no overlap between measurements (Figure 3.28).

Combinations of external measurements showed the 'Antipodes Island cluster group' females to be of similar size, or slightly larger, to the 'Auckland Island cluster group' males with a large amount of overlap between measurements (Figure 3.29).

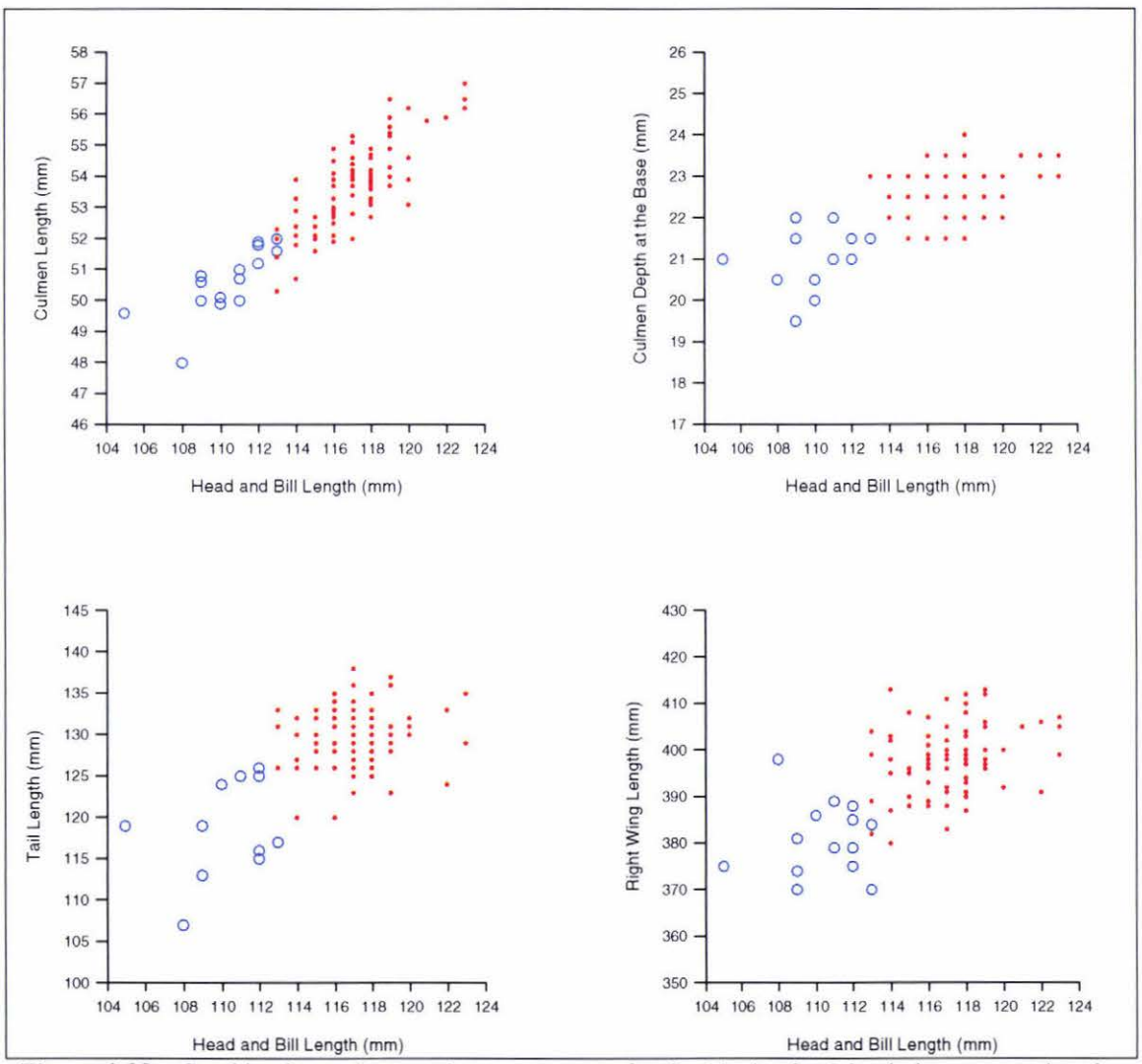

Figure 3.28 Combinations of external measurements for the 'Antipodes Island cluster group' males and 'Auckland Island cluster group' females showing the 'Antipodes Island cluster group males are larger in all external measurements than the 'Auckland Island cluster group' females with very little or no overlap. Red dots = 'Antipodes Island cluster group' males (n = 95); and blue circles = 'Auckland Island cluster group' females (n = 16). Sample sizes differ on each graph due to measurements unable to be taken from some specimens.

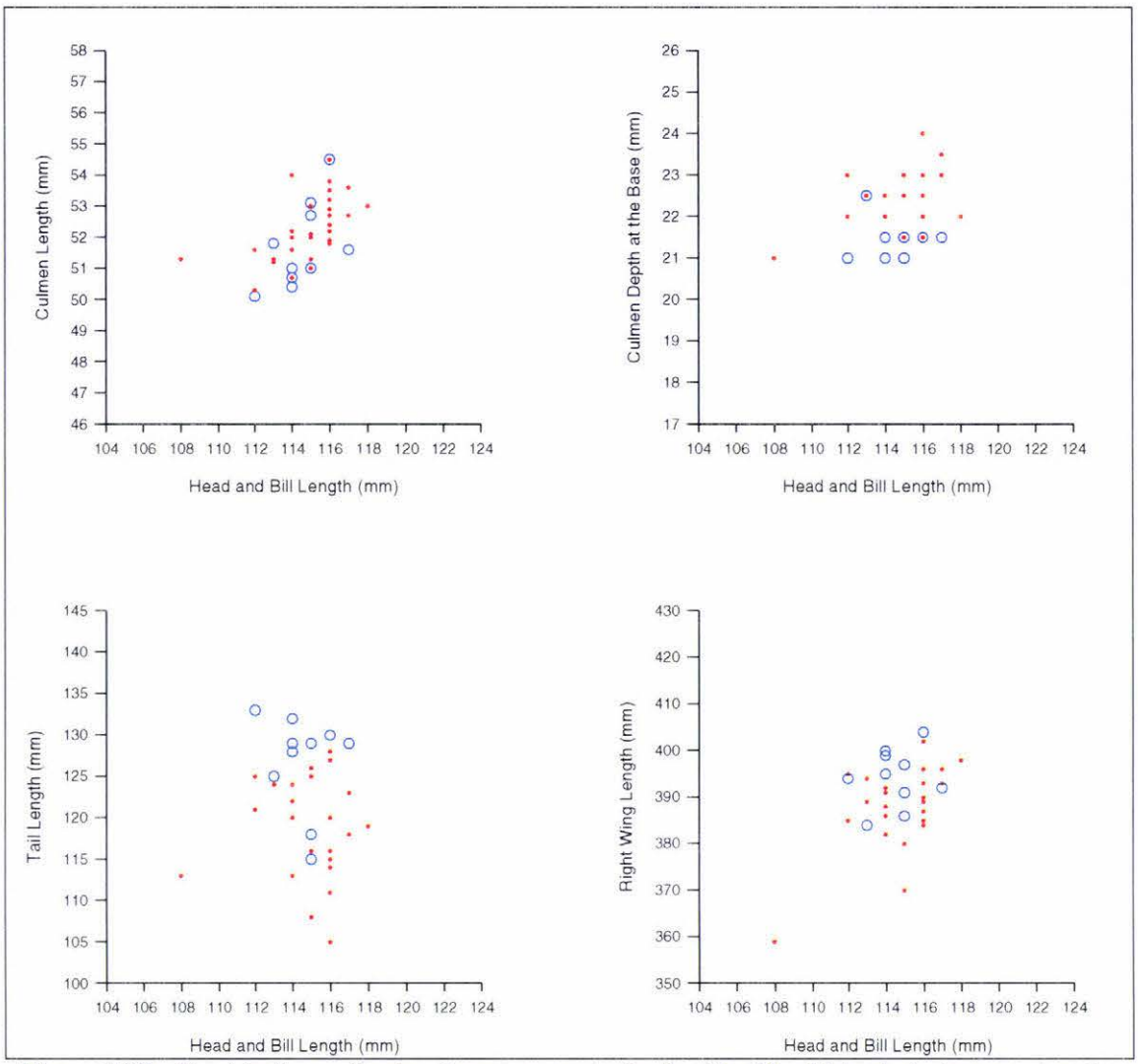

Figure 3.29 Combinations of external measurements for the 'Auckland Island cluster group' males and 'Antipodes Island cluster group' females showing the 'Antipodes Island cluster group females are of similar size in all external measurements to the 'Auckland Island cluster group' males with a large amount of overlap. Red dots = 'Auckland Island cluster group' males (n = 29); and blue circles = 'Antipodes Island cluster group' females (n = 10). Sample sizes differ on each graph due to measurements unable to be taken from some specimens.

3.3.7 Comparison of 'cluster groups' to white-chinned petrel museum skins

The best functions for differentiating 'Auckland and Antipodes Island cluster group' males and 'Auckland and Antipodes Island cluster group' females were tested on the 58 white-chinned petrel museum skins (section 3.3.2 on museum skin measurements). The museum skins were collected from the Auckland Islands (n = 8 males, 2 females), the Antipodes Islands (n = 3 males, 2 females including the type specimen *Procellaria aequinoctialis steadi*), Campbell Island (n = 1 male and 2 females), from breeding islands in the South Indian Ocean (n = 1 male, 2 females), from breeding islands in the South Atlantic Ocean (n = 1 male, 3 females), and from museum skins collected at sea off the coast of Chile (n = 14 males, 14 females). However five specimens were of

unknown sex and not included in the following analyses. Also measurements were unable to be taken on five male skins and five female skins and were therefore not included in the following analyses.

The best function for discriminating 'Auckland and Antipodes Island cluster group' males used culmen length and tail length (as described in section 3.3.6 under the heading 'Auckland and Antipodes Island cluster group' males). This function was tested on male museum skins from breeding populations and birds caught off Chile to determine if they related closest in size to 'Auckland or Antipodes Island cluster group' males.

All six male museum skins from the Auckland Islands, both male museum skins from breeding islands in the South Indian and South Atlantic Oceans, and 11 of the male museum skins caught off Chile each had negative values from the discriminant function, as shown in Table (3.50), which indicates they were all related closest in size to the 'Auckland Island cluster group' males.

Table 3.50 Results of the best discriminant function for 'Auckland and Antipodes Island cluster group' males using culmen length and tail length applied to male white-chinned petrel museum skins from breeding island populations at the Auckland Islands (n = 6); Antipodes Islands (n = 3); from the South Indian Ocean (n = 1); from the South Atlantic Ocean (n = 1); and birds caught off Chile (n = 12). CL = culmen length; TL = tail length. * = the type specimen *Procellaria aequinoctialis steadi*.

	CL (mm)	TL (mm)	Function Value
Auckland Island	52.0	114	-7.0469
	52.3	117	-4.9899
	51.9	124	-0.9929
	53.0	122	-1.4156
	49.8	124	-2.5252
	53.4	121	-1.7364
Antipodes Island	55.9	131	6.2148
	53.3	124	0.0287
	56.1	124	2.0719*
South Indian Ocean	51.0	120	-4.1004
South Atlantic Ocean	52.0	120	-3.3707
Caught off Chile	52.4	113	-7.3677
	53.0	113	-6.9299
	51.5	108	-11.088
	51.0	126	-0.4242
	50.8	124	-1.7955
	52.4	121	-2.4661
	50.8	125	-1.1828
	51.7	119	-4.2023
	52.2	115	-6.2883
	51.4	120	-3.8085
	51.0	116	-6.5512
	53.7	126	1.5460

The three male museum skins from the Antipodes Islands and one male museum skin caught off Chile had positive values from the discriminant function, as shown in Table 3.50, which indicates they relate closest in size to the 'Antipodes Island cluster group' males.

The best function for discriminating 'Auckland and Antipodes Island cluster group' females used head and bill length as one of the measurements. Head and bill length could not be taken from museum skins so an alternate discriminant function was used to test female museum skins. The second alternate discriminant function (as described in section 3.3.6 under the heading 'Auckland and Antipodes Island cluster group' females) used culmen length and wing length. This function was tested on female museum skins from breeding populations to determine if they relate closest in size to 'Auckland or Antipodes Island cluster group' females.

The two female museum skins from the Auckland Islands, two females from breeding islands in the South Indian Ocean, three females from breeding islands in the South Atlantic Ocean, one female from Campbell Island, and eight females caught off Chile each had negative values from the discriminant function, as shown in Table 3.51, indicating they relate closest in size to 'Auckland Island cluster group' females.

The two female museum skins from the Antipodes Islands, one female from Campbell Island, and one female caught off Chile both had positive values from the discriminant function, as shown in Table 3.51, which indicates they relate closest in size to the 'Antipodes Island cluster group' females.

The type specimen *P. a. steadi* (function value = 2.0719) collected from the Antipodes Islands is closest in size to Antipodes Island white-chinned petrels museum skins and in turn to 'Antipodes Island cluster group' males (Table 3.50).

The type specimen *P. a. mixta* (a male) was collected at sea in the South Atlantic Ocean 300 miles north of Cape Town. The 'Auckland and Antipodes Island cluster group' male descriminant function was tested on this individual to determine it related closer to 'Auckland or Antipodes Island cluster group' males. The function value for this specimen was -3.8375 which indicates it is closest in size to 'Auckland Island cluster group' males, and in turn to Auckland Island, South Atlantic and South Indian

Ocean museum skins. However, because the specimen was caught at sea it was difficult to relate it to either the South Atlantic population or the South Indian population based on size. Another parameter needs to be found to discriminate the Auckland Island, South Atlantic and South Indian Ocean populations.

Table 3.51 Results of the second alternate discriminant function for 'Auckland and Antipodes Island cluster group' females using culmen length and wing length for female white-chinned petrel museum skins from breeding island populations at the Auckland Islands (n = 2); Antipodes Islands (n = 2); Campbell Island (n = 2); from the South Indian Ocean (n = 2); from the South Atlantic Ocean (n = 3); and birds caught off Chile in the South East Pacific Ocean (n = 9). CL = culmen length; WL = wing length.

	CL (mm)	WL (mm)	Function Value
Auckland Island	52.1	381	-1.0187
	49.1	363	-9.1415
Antipodes Island	51.4	393	1.6884
	51.3	389	0.4517
Campbell Island	50.9	380	-2.5064
	53.1	388	1.9730
South Indian Ocean	50.9	380	-2.5064
	49.8	382	-3.0415
South Atlantic Ocean	51.4	375	-3.4254
	50.8	382	-2.0385
	48.7	379	-4.9971
Caught off Chile	50.2	381	-2.9244
	48.0	393	-1.7218
	48.0	388	-3.1423
	51.0	380	-2.4061
	50.7	380	-2.7070
	52.3	378	-1.6704
	49.0	360	-10.0941
	49.5	383	-3.0583
	52.4	386	0.7027

One hundred percent of Auckland Island museum skins related closest to the 'Auckland Island cluster group' and 100 % of Antipodes Island museum skins related closest to the 'Antipodes Island cluster group' (Table 3.52). These results suggest that the 'Auckland Island cluster group' and the 'Antipodes Island cluster group' are related to the respective breeding island populations at the Auckland and Antipodes Islands (Table 3.52).

Also 100 % of the South Atlantic and Indian Ocean and 90.5 % of the birds caught off Chile related closest to the 'Auckland Island cluster group' which indicates they are all of a similar size (Table 3.52). These results suggest two groups of white-chinned petrels, the larger sized white-chinned petrels related to the Antipodes Islands, which includes the *P. a. steadi* type specimen, and possibly Campbell Island, and the smaller sized white-chinned petrels related to the Auckland Islands and breeding populations in the South Atlantic and South Pacific Oceans. The white-chinned petrels caught off Chile seem mostly related to the Auckland Islands than the Antipodes Islands.

Table 3.52 Percent of white-chinned petrel museum skins from breeding populations at the Auckland Islands (n = 8), Antipodes Islands (n = 5), Campbell Island (n = 2), South Indian Ocean (n = 3), South Atlantic Ocean (n = 4), and white-chinned petrels caught off Chile (n = 21) which related closest to the 'Auckland Island cluster group' and the 'Antipodes Island cluster group'.

	'Auckland Island cluster group' (%)	'Antipodes Island cluster group' (%)
Auckland Island Skins	100.0	0.0
Antipodes Island Skins	0.0	100.0
Campbell Island Skins	50.0	50.0
South Indian Ocean Skins	100.0	0.0
South Atlantic Ocean Skins	100.0	0.0
Birds Caught off Chile	90.5	9.5

3.3.8 'Chatham Rise and Puysegur Point cluster groups'

The best functions for discriminanting 'Auckland and Antipodes Island cluster group' males and females were tested on white-chinned petrels caught further away from breeding islands to give an indication as to where adult birds go during the breeding season, i.e. the 'Chatham Rise cluster group' and the 'Puysegur Point cluster group'.

The 'Chatham Rise cluster group' consisted of 257 white-chinned petrels (35.5% of 'the white-chinned petrel sample'), 208 adult males and 49 adult females. The ratio of adult males to females in the 'Chatham Rise cluster group' was 4:1. Plate 3.9 shows the location of the 'Chatham Rise cluster group' and where the individual birds were caught.

The 'Puysegur cluster group' consisted of 224 white-chinned petrels (31.0% of 'the white-chinned petrel sample'), 181 adult males and 43 adult females. The ratio of adult males to females in the 'Puysegur Point cluster group' was also 4:1. Plate 3.10 shows the location of the 'Puysegur Point cluster group' and where the individual white-chinned petrels were caught.

The best function for differentiating 'Auckland and Antipodes Island cluster group' males used culmen length and tail length (as shown in section 3.3.6 under the heading

'Auckland and Antipodes Island cluster group' males). This function was tested on the 208 males in the 'Chatham Rise cluster group' and the 181 males in the 'Puysegur Point cluster group' to determine how many related closest to the 'Auckland or Antipodes Island cluster group' males. One hundred and ninety-five of the 'Chatham Rise cluster group' males and 166 of the 'Auckland Island cluster group' males had both culmen length and tail length measured.

Eighty-one 'Chatham Rise cluster group' males and 108 'Puysegur Point cluster group' males had a negative result from the discriminant function which indicated they related closest in size to the 'Auckland Island cluster group' males. One hundred and fourteen 'Chatham Rise cluster group' males and 58 'Puysegur Point cluster group' males had a negative result from the discriminant function which indicated they related closest in size to the 'Antipodes Island cluster group' males.

The best function for differentiating 'Auckland and Antipodes Island cluster group' females used head and bill length, culmen depth at the base and wing length (as shown in section 3.3.6 under the heading 'Auckland and Antipodes Island cluster group' females).

This function was tested on the 49 females in the 'Chatham Rise cluster group' and the 43 females in the 'Puysegur Point cluster group' to determine the number that related closest to the 'Auckland or Antipodes Island cluster group' females. Forty-four of the 'Chatham Rise cluster group' females and 38 of the 'Puysegur Point cluster group' females had head and bill length, culmen depth at the base and wing length measured.

Eighteen 'Chatham Rise cluster group' females and 31 'Puysegur Point cluster group' females had a negative result from the discriminant function which indicates they are closest in size to the 'Auckland Island cluster group' females.

Twenty-six 'Chatham Rise cluster group' females and seven 'Puysegur Point cluster group' females had a positive result from the discriminant function which indicates they are closest in size to the 'Antipodes Island cluster group' females.

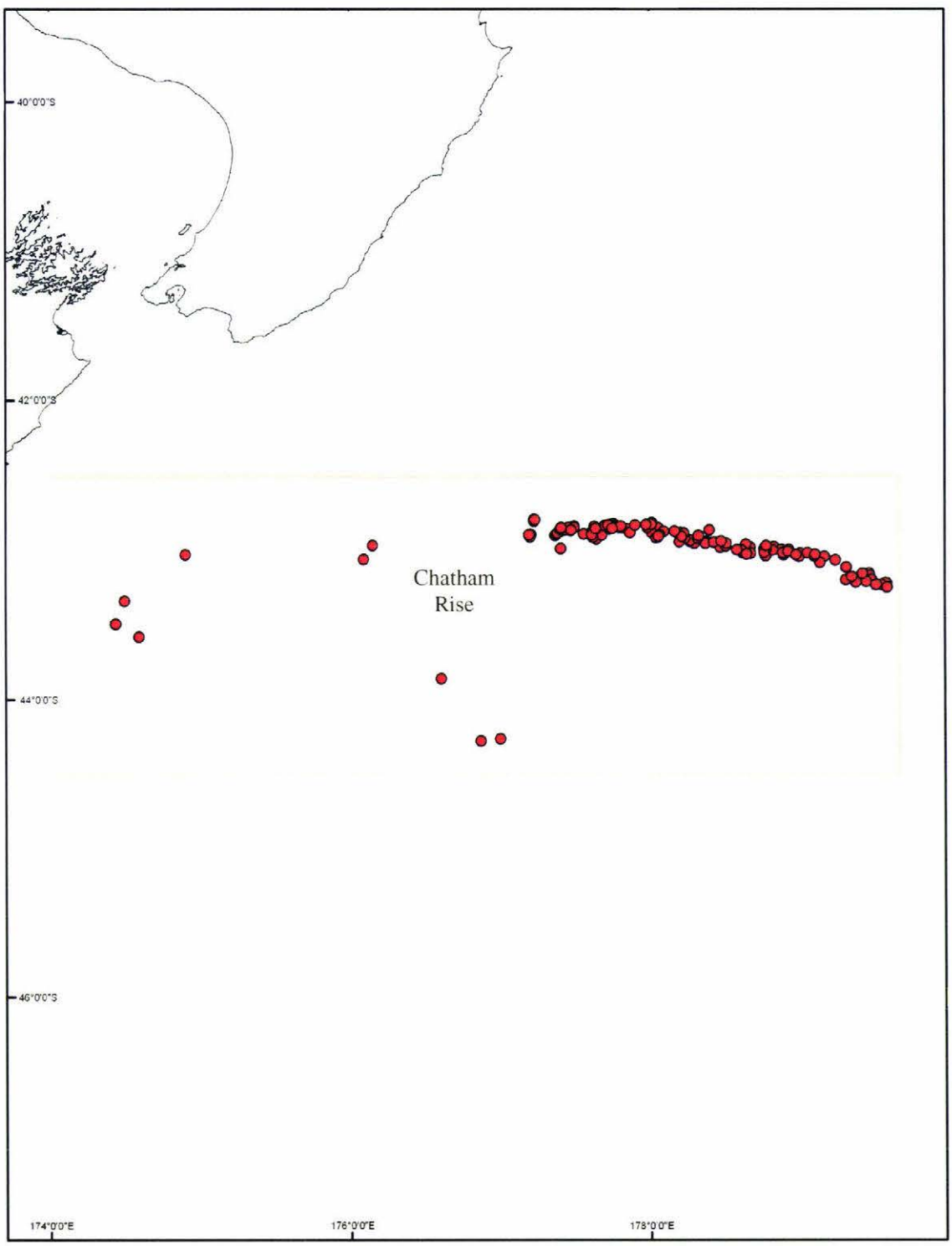

Plate 3.9 Map of the location of the 'Chatham Rise cluster group', and where the 257 adult white-chinned petrels were caught between November and March.

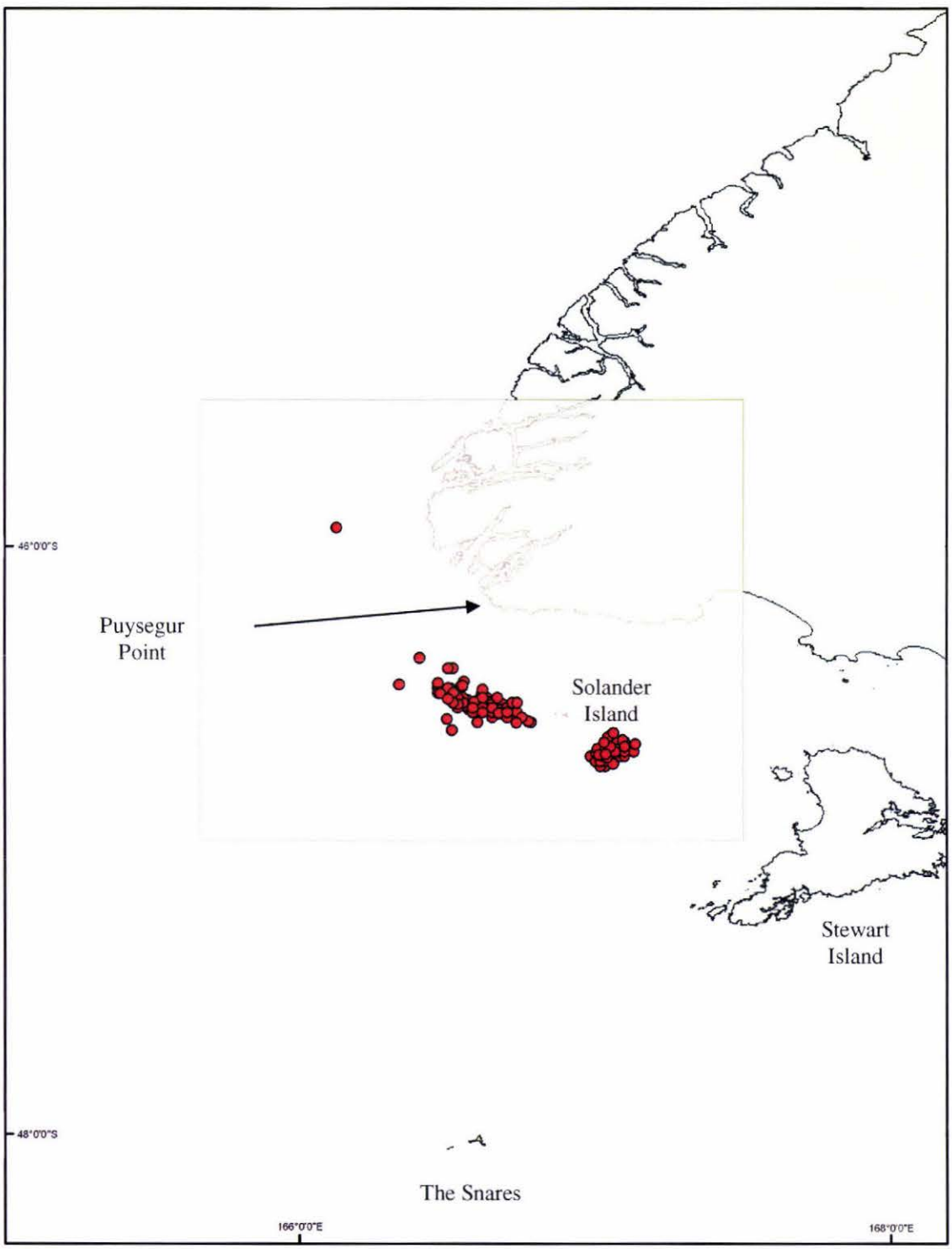

Plate 3.10 Map of the location of the 'Puysegur Point cluster group', and where the 224 adult white-chinned petrels were caught between November and March.

Fifty-nine percent of the 'Chatham Rise cluster group' relate closest to the 'Antipodes Island cluster group' and 41% relate closest to the 'Auckland Island cluster group' (Table 3.53). Sixty-eight percent of the 'Puysegur Point cluster group' relate closest to the 'Auckland Island cluster group' and 32% relate closest to the 'Antipodes island cluster group' (Table 3.53).

Table 3.53 Percent of white-chinned petrels in the 'Chatham Rise cluster group' and the 'Puysegur Point cluster group' which related closest to the 'Auckland Island cluster group' and the 'Antipodes Island cluster group'.

	'Auckland Island cluster group' (%)	'Antipodes Island cluster group' (%)
'Chatham Rise cluster group'	41.0	59.0
'Puysegur Point cluster group'	68.0	32.0

3.3.9 White-chinned petrels caught at the end of the breeding season

No adult white-chinned petrels were caught outside the breeding season between June and August. Therefore to give an indication of what white-chinned petrels are in New Zealand waters during the non-breeding adult birds caught at the end of the breeding season in April and May were compared with the 'Auckland and Antipodes Island cluster groups'. These petrels could also give an indication where birds from Antipodes Island and Auckland Islands go during the non-breeding season.

Twenty-nine adult bycatch white-chinned petrels were caught at the end of the breeding season between April and May within the New Zealand EEZ, of which 17 were adult males and 12 adult females. Four males were caught off the Auckland Islands, two off the Antipodes Islands, five on the Chatham Rise, five on the Pukaki Rise, and one off Fiordland. Nine females were caught on the Chatham Rise and three were caught off the Auckland Islands.

The best function for differentiating 'Auckland and Antipodes Island cluster group' males (as shown in section 3.3.6 under the heading 'Auckland and Antipodes Island cluster group' males) was tested on the 17 adult male white-chinned petrels. However, four males had neither culmen nor tail lengths measured, two off the Auckland Islands and two on the Pukaki Rise, and were not included.

Two males caught off the Auckland Islands, two caught off the Antipodes Islands, four caught on the Chatham Rise, and three caught on the Pukaki Rise all had positive values from the discriminant function indicating they were more closely related in size to the 'Antipodes Island cluster group' males. One male caught on the Chatham Rise and one caught off Fiordland had negative values from the discriminant function indicating they were more closely related in size to the 'Auckland Island cluster group' males.

The best function for differentiating 'Auckland and Antipodes Island cluster group' females (as shown in section 3.3.6 under the heading 'Auckland and Antipodes Island cluster group' females) was tested on the 12 adult females. One female caught on the Chatham Rise did not have a head and bill length measurement and was not included.

Table 3.54 Percent of bycatch white-chinned petrels caught at the end of the breeding season between April and May off Antipodes Island (n = 2), off the Auckland Islands (n = 5), on the Chatham Rise (n = 13), on the Pukaki Rise (n = 3), and off Fiordland (n = 1) which related closest to the 'Auckland Island cluster group' and the 'Antipodes Island cluster group'.

	'Auckland Island cluster group' (%)	'Antipodes Island cluster group' (%)
Off the Auckland Islands	20.0	80.0
Off Antipodes Island	0.0	100.0
On the Chatham Rise	7.7	92.3
On the Pukaki Rise	0.0	100.0
Off Fiordland	100.0	0.0

Eight adult females caught on the Chatham Rise and two caught off the Auckland Islands all had positive values from the discriminant function indicating they were more closely related in size to the 'Antipodes Island cluster group' females. One female caught off the Auckland Islands had a negative value from the discriminant function indicating they were more closely related in size to the 'Auckland Island cluster group' females.

Table 3.54 shows the percent of white-chinned petrels caught at the end of the breeding season between April and May that relate to the 'Auckland and Antipodes Island cluster groups'. All but three birds caught at the end of the breeding season

related closest in size to the 'Antipodes Island cluster group', including birds caught near the Auckland Islands (Table 3.54).

3.3.10 Non-adult white-chinned petrels

As shown in section 3.3.4 (adult and non-adult white-chinned petrel external morphology), non-adult white-chinned petrels were no different in size to adults. Thirty-one non-adults were caught during the breeding season between October and March, distribution shown in Plate 3.3, of which 25 were males and six females.

The best function for differentiating 'Auckland and Antipodes Island cluster group' males (as shown in section 3.3.6 under the heading 'Auckland and Antipodes Island cluster group' males) was tested on the 25 non-adult males to determine which individuals relate closest to the 'Auckland or Antipodes Island cluster group' males. Two non-adult males, one caught on the Chatham Rise and one off Antipodes Island, did not have culmen length measurements and were not included.

Nineteen non-adult males caught off Antipodes Island and one caught on the Pukaki Rise had positive values from the discriminant function indicating they were more closely related in size to the 'Antipodes Island cluster group' males. One male caught off Antipodes Island and two caught on the Pukaki Rise had negative values from the discriminant function indicating they were more closely related in size to the 'Auckland Island cluster group' males.

The best function for discriminating 'Auckland and Antipodes Island cluster group' females (as shown in section 3.3.6 under the heading 'Auckland and Antipodes Island cluster group' females) was tested on the six non-adult females to determine which individuals relate closest to 'Auckland or Antipodes Island cluster group' females.

Two non-adult females caught off Antipodes Island and one caught on the Chatham Rise had positive values from the discriminant function indicating they were more closely related in size to the 'Antipodes Island cluster group' females. Two non-adult females caught off Puysegur Point and one caught on the Chatham Rise had negative values from the discriminant function indicating they were more closely related in size to the 'Auckland Island cluster group' females.

Table 3.55 shows the percent of non-adult white-chinned petrels that relate to the 'Auckland and Antipodes Island cluster groups'. Almost all non-adults caught off Antipodes Island were of similar size to the 'Antipodes Island cluster group' and those caught close to the Auckland Islands, off Puysegur Point and on the Pukaki Rise, were all of similar size to the 'Auckland Island cluster group' (Table 3.55).

Table 3.55 The percent of non-adult bycatch white-chinned petrels caught off Antipodes Island (n = 22), on the Chatham Rise (n = 2), on the Pukaki Rise (n = 3), and off Puysegur Point (n = 2) which related closest to the 'Auckland Island cluster group' and the 'Antipodes Island cluster group'.

	'Auckland Island cluster group' (%)	'Antipodes Island cluster group' (%)
Off Antipodes Island	4.5	95.5
On the Chatham Rise	50.0	50.0
On the Pukaki Rise	66.6	33.4
Off Puysegur Point	100.0	0.0

4

DISCUSSION

4.1 INTRODUCTION

The main aim of this thesis was to determine if white-chinned petrels *Procellaria aequinoctialis* in New Zealand waters comprise a single taxon. Presently the literature suggests that all breeding populations of the white-chinned petrel are a single global taxon *P. aequinoctialis*. However, morphological characteristics of white-chinned petrels caught as bycatch in New Zealand waters indicate there may be more than one taxon (Robertson, C.J.R. *pers. comm.*). This chapter discusses the results from analyses of morphology of white-chinned petrels in the following sections: 4.2 measurement error between two observers; 4.3 sample size; 4.4 white-chinned petrel external morphology; 4.5 white-chinned petrel taxonomy; and 4.6 white-chinned petrel internal morphology.

4.2 MEASUREMENT ERROR BETWEEN TWO OBSERVERS

Morphometric variables are used to infer statistical differences about biological phenomena, such as age, sex and phylogeny (Lougheed *et. al.* 1991). Morphological measurements need to be accurate and repeatable. Morphometric data are, however, derived from measurements that vary in precision (Yezerinac *et. al.* 1992) (that is precision of the observer and precision of the measurement), therefore a reliable set of methods for making and recording each measurement is needed. This in turn allows future researchers to use those exact same techniques.

Most research involves a single observer collecting all measurements from all individuals and determining their own observer error (Lougheed *et al.* 1991; Yezerinac *et al.* 1992). There are only a few publications where multiple observers

have taken a range of morphological measurements from the same set of individuals (Evans 1964; Johannesson 1967; Nisbet *et al.* 1970). In my study I compared 10 head, bill and bodily measurements of a sample of 723 white-chinned petrels with measurements taken from the same individuals by 'the Laboratory' to determine if two separate observers using the same measuring techniques can obtain similar results with little error.

These results clearly indicate that two observers can collect a set of external measurements from a sample of white-chinned petrels and obtain very similar results with little error. Therefore, provided the same measuring techniques are used and repeated, multiple observers can relatively accurately collect similar data from the same sample of individuals. Statistical tests for each measurement showed significant differences between most of 'the Laboratory's' and my measurements. On the whole, they only picked up minute differences in technique, and were therefore biologically insignificant, i.e. that is differences not indicated by biological variation. Nisbet *et al.* (1970) also found significant differences between observers measuring wing length on a series of white-throated sparrows *Zonotrichia albicollis*, however they were slight differences in technique and also concluded they were biologically insignificant.

The most accurate and repeatable measurements were culmen length, bill least depth and head and bill length. The percentage of overall variation for these measurements was between 0.8-2.1 %, indicating only a very small difference in measuring by 'the Laboratory' and myself. The likely reason these were the best measurements was they tended to be structures that were well defined, with very little flexibility, and do not show seasonal differences. These measurements can be taken from all specimens during anytime of the year and are not likely to be damaged.

A measurement technique error was discovered when measuring tarsometatarsus length resulting in the medial length of the right tarsometatarsus being measured and the lateral length of the left tarsometatarsus being measured. This showed that the average medial measurement of the tarsometatarsus is 0.9 mm longer than the average lateral measurement for white-chinned petrels. This was discovered to be a handedness error as both observers were right handed and using the left hand found the opposite results. This emphasises the importance of recording exactly how each

measurement was taken and that handedness does influence how measurements are taken. Apart from this technique error, tarsometatarsus length was repeatable but not as accurate. I consistently measured both right and left tarsometatarsi 0.5 mm longer than 'the Laboratory'. Tarsometatarsus length was also rounded to the nearest millimetre which influenced the measurement error between observers, i.e. two measurements of the same tarsometatarsus could be 65.4 and 65.6 mm and after rounding the difference would be 1.0 mm, rather than the actual difference of 0.2 mm.

Measurements of non-skeletal parts, wing length and tail length, are noted for having seasonal differences due to moult and wear. However, these measurements can be accurately and consistently taken if seasonal differences are noted and individuals showing signs of wear or moult are not included in analyses. The percentage of overall variation for wing length was 0.5 % and for tail length was 2.4 % indicating only small amounts of error or a big sample size. Marchant and Higgins (1990) note that experienced measurers tend to take longer maximum chord lengths of the wing. However, as the least experienced measurer, I tended to slightly over measure maximum chord length. Nisbet *et al.* (1970) found that four observers measuring the flattened chord of the wing of the same sample of white-throated sparrows got standard errors of the differences between observers between 0.039 and 0.052 mm, and also that their most experienced measurer had the shortest overall measurements, as found in this study for wing length.

Measurement error as a percent of the average length of each measurement gives a more accurate indicator of the accuracy and repeatability of each measurement and showed that measurements, such as wing length, with a large measurement error in millimetres had a small measurement error as a percent of the mean. Clearly time taken to learn how to correctly take measurements and learn defined character landmarks is important in reducing measurement error.

Nisbet *et al.* (1970) suggest three sources for discrepancies between measurements for two observers measuring the same specimens: error by one observer; error by the other observer; and variation in the object being measured. All these sources of error are related as the more variation in the object being measured the likeliness that there will be more error by one or both observers. Contributions of all three sources of error

are different for all measurements. For this study bill measurements such as culmen length, head and bill length, and bill least depth incur less error due to variation in object being measured because their methods for measuring are more fixed than measurements such as tail and wing length, and would therefore incur less error by one or both observers.

Another source could be error caused be the first observer altering the object being measured. For this study error due to object alterations by the first observer would be greater for wing and tail measurements rather than bill measurements because wing and tail feathers could be easily stretched or damaged by the first observer.

Assessing measurement error between multiple observers was important as it assessed the accuracy of both observers in measuring several external measurements. It also showed clearly that using the same measuring techniques it was possible to accurately collect two sets of measurements from a sample of white-chinned petrels by two observers that were very similar, though some measurements, e.g. culmen length and bill depth, were easier to collect than others, e.g. skull width, culmen depth at the base and culmen width at the base.

The high level of concordance between my measurements and those of 'the Laboratory' allowed me to combine other measurements of study skins to create a larger sample and in turn get the obtained results.

4.3 SAMPLE SIZE

The 944 white-chinned petrels were caught and killed as fisheries bycatch within the New Zealand Exclusive Economic Zone (EEZ) between October 1996 and September 2003 provided an excellent sample to look at New Zealand white-chinned petrel taxonomy. With the addition of 117 study skins, I had a large morphological database with which to examine the *Procellaria aequinoctialis* taxon.

Seven-hundred and twenty-three bycatch white-chinned petrels were used in this study as these were the only ones available out of the sample of 944; the rest either

had been disposed or were in museums. The reason a large sample was used was because I wanted to collect data from all available specimens and since all the literature had been looked at then all the birds had to be looked at as well. Also all white-chinned petrels study skins in New Zealand and from as many museums overseas were examined in the short time available to make sure all white-chinned petrel specimens available were used to provide taxonomic information.

The main aim of this thesis was to determine if white-chinned petrels *Procellaria aequinoctialis* in New Zealand waters comprise a single taxon. The large sample of 723 fisheries bycatch white-chinned petrels (called 'the white-chinned petrel sample') used in this thesis was considered an unbiased random sample of the New Zealand white-chinned petrel population. The sample consisted of white-chinned petrels of different age, sex and location and was used to look at morphological characteristics to determine if they comprise a single taxon.

My results indicate there are two taxa of white-chinned petrels in New Zealand waters, the smaller sized Auckland Island white-chinned petrels and the larger sized Antipodes Island white-chinned petrels. Further, my results suggest that globally there are two white-chinned petrel taxa, the smaller sized *aequinoctialis* taxon comprising the Auckland Island, South Indian and South Atlantic populations, and the larger sized *steadi* taxon comprising the Antipodes Island and most likely the Campbell Island populations. These results were obtained only because of the large sample of bycatch white-chinned petrels, and the large sample of study skins.

'The white-chinned petrel sample' consisted of 95.7 % adults and 4.3 % non-adults. It was important to have measured a selection of non-adults to determine if they differed in size from adult white-chinned petrels. If a smaller sample size of 500 had been used then it is likely only 4 % (ca. 20) would be non-adults. If a sample size of 100 or 50 had been used then it is likely only four or two individuals would be non-adults, too few to make comparisons between adults and non-adults.

'The white-chinned petrel sample' also consisted of 79.9 % males and 20.1 % females (a ratio of 5:1 males), of which 76.4 % were adult males and 19.3 % adult females. Even with a large sample size of 723 only 20.1 % were females indicating that a large

sample size was important in being able to collect females for this study. A smaller sample size of 100 or 50 birds would have only included 20 or 10 females, or maybe none at all, making comparisons between males and females, and in turn adult males and females very difficult or impossible. Males were generally larger than females; however there was a large selection of males and females of similar size, particularly males caught near the Auckland Islands compared with females caught near Antipodes Island. Using a smaller sample size may have reached different conclusions.

The small 'Auckland and Antipodes Island cluster groups' caught near the Auckland and Antipodes breeding islands were only discovered after plotting the location of all 723 bycatch birds on a map of the New Zealand EEZ. 'The Auckland Island cluster group' consisted of only 6.2 % of the total sample (29 males and 16 females) and 'the Antipodes Island cluster group' 14.5 % of the total sample (95 males and 10 females). The large sample size of 723 birds enabled me to compare these two clusters of white-chinned petrels and relate them to study skins of individuals from the Auckland and Antipodes Islands and in turn reach the conclusion that my results suggest two white-chinned petrel taxa in New Zealand waters. Using a smaller sample size of 100 or 50 birds could miss one or both of the 'clusters' of birds and therefore would not have been able to indicate which breeding population the bycatch birds were most likely from, and therefore reach the conclusions that my results suggest. Also had the sample size been any smaller then if both cluster groups were found it would be likely they would have been comprised entirely of males, making the assessment of new taxa difficult.

Measuring all the study skins that were available and combining C.J.R. Robertson's study skin measurements with mine was important in reaching the above conclusions. The combined total of 117 study skins only included 29 skins from breeding islands, of which included 11 from the Auckland Islands and six from Antipodes Island. These were then compared with the 'Auckland and Antipodes Island cluster groups' to see if they related in size to the skins, which in turn reached the conclusions that my results suggest. These results would not have been reached if the bycatch and study skin sample sizes were smaller.

4.4 WHITE-CHINNED PETREL EXTERNAL MORPHOLOGY

This section discusses white-chinned petrel external morphology in relation to the two main aims of this thesis: the first to determine if white-chinned petrels in New Zealand waters comprise a single taxon; and to determine if white-chinned petrels in New Zealand waters fit the proposition of a global white-chinned petrel taxon. This section is divided into seven sections which provide answers to the above aims: 4.4.1 museum skins; 4.4.2 'the white-chinned petrel sample'; 4.4.3 adult and non-adult white-chinned petrels; 4.4.4 adult male and female white-chinned petrels; 4.4.5 'Auckland and Antipodes Island cluster groups'; 4.4.6 New Zealand white-chinned petrel taxa; and 4.4.7 global white-chinned petrel taxa.

4.4.1 Museum Skins

The initial comparison of external measurements of white-chinned petrel study skins from the Auckland, Antipodes and Campbell Islands, and breeding islands in the South Indian and Atlantic Oceans showed the Antipodes Island study skins were significantly larger in most external measurements than all other breeding island study skins except the Campbell Island skins. The external measurements that showed the most significant size differences were average culmen length (54.0 mm ± 0.94, n = 6), left wing length (395.3 mm ± 5.36, n = 4) and tail length (125.3 mm ± 2.56, n = 4). The Antipodes Island study skins were only exceeded in size by the tail length of the Campbell Island skins (126.0 mm ± 3.46, n = 3), but were greater in size of culmen length and wing length.

In comparison, the Auckland Island and South Indian and Atlantic Ocean skins all had smaller average culmen, wing and tail lengths. Birds from these three locations were of a smaller size. The average culmen length varied between (50.7-51.7 mm), left wing length between (378.1-382.0 mm) and tail length between (118.6-120.0 mm). The white-chinned petrel study skins caught off Chile also related closest in size to the Auckland Island and South Indian and Atlantic Ocean skins.

The area of white on the chin varied in size between individuals of all breeding island skin populations. However, the average area of white on the chin was larger for the

South Indian Ocean study skins, but with overlap between the standard deviations of all breeding island study skin populations. There were also no study skins from South Indian Ocean breeding islands without white chins. The average white chin area was relatively similar for the Auckland, Antipodes and Campbell Island and South Atlantic Ocean breeding island study skins. The Auckland, Antipodes and Campbell Island study skins were the only locations with white chins under 50.0 mm^2, with one skin from the Auckland Islands, one from Campbell Island without a white chin and two skins from Antipodes Island with a trace of a white chin (< 5.0 mm^2). The study skins results indicate New Zealand white-chinned petrels have on average the smallest white chins of any breeding population.

Mathews' (1912-13) type specimen of the subspecies *Procellaria aequinoctialis steadi*, the New Zealand white-chinned petrel, was collected from Antipodes Island. Based on the specimen's size, it fits with the other study skins from Antipodes Island.

4.4.2 'The white-chinned petrel sample'

'The white-chinned petrel sample' was found to be caught in five main locations; along the Chatham Rise, on the Bounty Platform, on the Pukaki Rise, off the Auckland Islands, and off Puysegur Point. These five locations are generally related to underwater shelves where the concentration of food is higher and consequently it is here where high concentrations of birds and fisheries vessels interact (Brothers *et al.* 1999). 'The white-chinned petrel sample' was caught during the breeding season between September and May, with the highest concentration caught in November during the egg laying and incubation period where one parent is sitting on the egg and the other is foraging. Many were also caught between January and March, during the chick rearing period when both parents are out at sea foraging.

The general description of 'the white-chinned petrel sample' is consistent with published descriptions (Murphy 1936; Oliver 1955; Serventy *et al.* 1971; Imber 1985b; Marchant and Higgins 1990; Warham 1990), except black lines along the maxillary unguis have preciously not been mentioned and black at the bill tip is seen in most individuals which was also only noted in a few publications (Serventy *et al.* 1971; Imber 1985b). Another common feature on almost all bycatch white-chinned

petrels, and not noted in any publication, was moulting on the bill plates. Most individuals had some moulting on the bill plates which was indicated by flaking layered patches on the bill. The moulting parts of the bill were generally a pale yellow colour and the newly moulted plates were white, which could indicate the variation in bill colour noted in most publications (Murphy 1936; Oliver 1955; Serventy *et al.* 1971; Imber 1985b; Marchant and Higgins 1990; del Hoyo *et al.* 1992). Moulting of black on the bill plates was consistently black.

Average measurements of 'the white-chinned petrel sample', including culmen length, wing length, tail length, and tarsometatarsus length fit within range of published measurements of New Zealand white-chinned petrels (Warham and Bell 1979; Marchant and Higgins 1990; Warham, J. *pers. comm.*) (also see Appendix 4.1). The area of white on the chin was a variable character within 'the white-chinned petrel sample' with 18 individuals with no white chin patch and a further 11 with only a trace of white on the chin. Individuals without white on the chin were still considered white-chinned petrels as their head, bill, and bodily measurements, as well as the general description, were consistent with 'the white-chinned petrel sample' and with published measurements and descriptions (Marchant and Higgins 1990) (Appendix 4.1).

The average size of 'the white-chinned petrel sample' white chin patch related closest in size to New Zealand and South Atlantic study skins rather than the Indian Ocean skins with large white chins. The average white chin area was relatively small and similar to other birds described in the New Zealand region, which also included individuals without white on the chin (Oliver 1955; Warham and Bell 1979; Imber 1985b; Warham 1990). There were a few bycatch individuals with large white chins that had white extending onto the face similar to Indian Ocean birds. Seventy percent of the bycatch sample had some black feathering indispersed with the white chin giving the white chin a speckled look making it look smaller and harder to see, which would make identification difficult at sea.

'*Dark line scores*', '*Unguis scores*' and '*Nail scores*' were not based on location as the different scores were found throughout all the main locations; along the Chatham Rise, on the Bounty Platform, off the Auckland Islands, and off Puysegur Point. Also

nostril shape does not seem to be related to the location of 'the white-chinned petrel sample'.

Also the culmen, right wing, and tail lengths of birds caught between October and December were not significantly longer than the corresponding lengths during January and March which indicated that white-chinned petrel wing and tail lengths do not differ significantly in length over the breeding season.

4.4.3 Adult and non-adult white-chinned petrels

The external morphology of adult and non-adult white-chinned petrels was explored and it was found that non-adults do not differ in size from adult white-chinned petrels. This is possible as when petrels fledge they are fully grown in size with adult plumage which makes it difficult to identify age classes at sea. The average area of white on the chin for non-adults was not significantly different in size to the average area of adults indicating white-chin size is relatively constant between age classes in New Zealand waters. However it is possible that the non-adult petrels in this sample could be from breeding populations outside the New Zealand EEZ, as little is known on non-adult white-chinned petrel dispersal after fledging before they return in seven to ten years as adults.

Initially dark lines on the maxillary unguis were thought to indicate non-adult birds; however there does not seem to be any correlation between age and '*Dark line score*' as a higher percent of non-adults had no dark lines on the bill and only slightly more non-adults had a '*Dark line score*' of 3. Four of the five nostril shapes were found in the non-adult sample indicating that nostril shape is not related to age.

4.4.4 Adult male and female white-chinned petrels

The lack of sex-linked plumage differences makes it difficult to identify sexes of Procellariiformes in the field (Ryan 1999). Size differences based on external measurements is a method that has been used to sex numerous bird species, including Antarctic petrels *Thalassoica antarctica* (Lorentsen and Røv 1994), Balearic shearwaters *Puffinus mauretanicus* (Genovart *et al.* 2003), Cory's shearwaters

Calonectris diomedea (Lo Valvo 2001), and white-chinned petrels *Procellaria aequinoctialis* (Ryan 1999).

There was a ratio of 5:1 adult males to females in 'the white-chinned petrel sample' indicating males are more likely to be caught and killed by interactions with fishing vessels. There are at least two reasons for this skew in sex ratio. First, males are larger than females and are more aggressive at getting baited hooks around fishing vessels. Second, males and females feed in different parts of the ocean. Based on the location of 'the white-chinned petrel sample', females are caught in the same locations as males, only in smaller numbers, and maybe the reason is that males are more aggressive at getting baited hooks.

The average area of white on the chin of adult males was significantly larger than that of adult females (a feature not noted in any published descriptions of the taxa); however, there were individual males and females with small and large white chins. A higher percentage of males had a white chin patch greater than 100 mm^2 (52.2 %) compared with females (23.7 %), but this could be due to the uneven sample sizes of males and females and there might be a greater number of females with larger white chins in the New Zealand population, however they were not in the sample.

Bill descriptions and nostril shapes of adult males and females were similar indicating that the amount of black on the bill and nostril shape are not sex related.

Based on external measurements, males are significantly larger than females; however, there was considerable overlap between smaller males and larger females. The average head, bill, and bodily measurements of adult males and females fit within the range of published measurements of male and female white-chinned petrels (Murphy 1936; Warham and Bell 1979; Hall 1987; Marchant and Higgins 1990; Ryan 1999) (Appendix 4.1).The best combinations of external measurements that show size differences between males and females were head and bill and culmen length, head and bill and culmen depth at the base, and culmen depth at the base and bill least depth.

These external measurements are generally a good indicator of bird size and have been used along with wing length to sex other bird species, particularily using discriminant analysis (Lorentsen and Røv 1994; Ryan 1999; Lo Valvo 2001; Genovart *et al.* 2003). Bill least depth head and bill length and wing length seem to be the best measurements to sex Procellariiformes (Lorentsen and Røv 1994; Ryan 1999; Lo Valvo 2001; Genovart *et al.* 2003). Ryan (1999) could correctly sex 95% of white-chinned petrels killed by longline fishing around the Prince Edward Islands by discriminant function using culmen length and bill depth at the base, which are also measurements which show size differences between male and female white-chinned petrels within the New Zealand EEZ.

I found a large overlap between the measurements of small males and large females, indicating there could be more than just a difference between males and females. Perhaps small and large males and females are from different locations at sea. This possibility is explored in the next section.

4.4.5 'Auckland and Antipodes Island cluster groups'

As mentioned in section 4.3, sample size was important as it allowed 'clusters' to be compared, in particular the two groups of birds caught close to the Auckland and Antipodes breeding islands. Sample sizes for both the 'Auckland and Antipodes Island cluster groups' were reasonably small compared with the overall 'white-chinned petrel sample' and would most likely not been found had the overall sample been any smaller. Also the sex ratio within each 'cluster group' was strongly male biased, particularly in the 'Antipodes Island cluster group' where there were almost ten times more adult males than females. Berrow *et al.* (2000) mention that petrels are likely to forage closer to breeding grounds during the breeding season, especially those with dependent young, therefore it was logical to only select adult petrels caught close to the Auckland and Antipodes Islands to represent each of the two populations.

The 'Antipodes Island cluster group' was significantly larger in most external measurements than the 'Auckland Island cluster group'. Discriminant analysis showed the best external measurements for differentiating between the two cluster groups were head and bill length, tarsometatarsus length and tail length. Head and bill length has been shown to be a good differentiator for size, particularly for sexing birds

where one sex is larger in size than the other (Lorentsen and Røv 1994; Genovart *et al.* 2003). Tarsometatarsus length and head and bill length have both been shown to be good discriminators between geographical locations of species, for example, bill measurements and tarsometatarsus length were used to separate the Tristan albatross form of the wandering albatross (presently called *Diomedea dabbenena*) from the wandering albatross *Diomedea exulans* (Cuthbert *et al.* 2003). Also bill measurements and tarsometatarsus length show variation in morphometry of geographical populations of black-browed albatross *Diomedea melanophrys* and grey-headed albatross *Diomedea chrysostoma* (Waugh *et al.* 1999).

The significant difference between 'Auckland and Antipodes Island cluster group' tail and wing lengths was at first considered to be difference due to feather wear over the breeding season as the 'Auckland Island cluster group' was collected between January and March, whereas the 'Antipodes Island cluster group' was collected between October and February. Comparison of tail and wing lengths of the 'Antipodes Island cluster group' between October and December and January and March showed both wing and tail length to not be significantly different between the two periods. Therefore feather wear for white-chinned petrels is small over the breeding season and the fact that the 'Antipodes Island cluster group' have significantly longer tail and wing lengths is not explained by feather wear as far as I can tell. Reasons for longer wings and tail could be due to different feeding strategies or island terrain where burrows are constructed.

There was no significant difference between the average white chin patch area indicating white-chin size is relatively constant between the 'Auckland and Antipodes Island cluster groups' with the only main difference being the 'Antipodes Island cluster group' had almost twice as many individuals with a white chin area between 100 to 200 mm^2. However, white chin area is in general a variable character and within the New Zealand EEZ does not seem related to age, sex or 'cluster group' location.

The 'Auckland Island cluster group' had twice as many individuals with dark lines on the maxillary unguis, however the 'Antipodes Island cluster group' had on average

slightly darker bill tips based on '*Nail*' and '*Unguis scores*'. Bill descriptions were not strong components for differentiating the two 'cluster groups'.

Principal component analysis of the 'Auckland and Antipodes Island cluster groups' explained almost 70 % of the variation between the groups with the first three components, which generally related to a size difference between the two 'cluster groups'. Principal component scores showed general groupings of 'Auckland and Antipodes Island cluster group' males and females (Figure 3.22) which warranted further investigation.

'Antipodes Island cluster group' males were significantly larger in most external measurements than 'Auckland Island cluster group' males and discriminant analysis differentiated 93 % males of the 'Antipodes Island cluster group' versus the 'Auckland Island cluster group' using culmen length and tail length. Also the 'Antipodes Island cluster group' females were significantly larger in most external measurements than 'Auckland Island cluster group' females and again discriminant analysis differentiated 92 % females of the 'Antipodes Island cluster group' versus the 'Auckland Island cluster group' using head and bill length, culmen depth at the base and wing length. These results indicate that a few individuals in each 'cluster group' relate closer in size to the opposite 'cluster groups' and that there is some amount of interaction between the two groups. Again these measurements are consistent with those used in separating sexes and geographical groups of other Procellariiformes (Lorentsen and Røv 1994; Waugh *et al.* 1999; Cuthbert *et al.* 2003; Genovart *et al.* 2003).

These results suggest two different sized groups of white-chinned petrels in New Zealand waters based on 'cluster group' location, with the 'Antipodes Island cluster group' being significantly larger than the 'Auckland Island cluster group'. There is a difference in white-chinned petrel size within the New Zealand EEZ, but is it possible to relate the 'cluster groups' to breeding populations to determine if there are more than one taxa of white-chinned petrel in New Zealand waters? The only option available was to compare external measurements of the 'Auckland and Antipodes Island cluster group' males and females with measurements from male and female study skins from the Auckland and Antipodes Islands using discriminant analysis.

4.4.6 New Zealand white-chinned petrel taxa

The New Zealand white-chinned petrel population is comprised of individuals from breeding populations at the Auckland, Antipodes and Campbell Islands. The general description of New Zealand white-chinned petrel sample, as previously mentioned, is consistent with published descriptions (Murphy 1936; Oliver 1955; Serventy *et al.* 1971; Imber 1985b; Marchant and Higgins 1990; Warham 1990) in that they have a uniform sooty black plumage with black legs and feet. The bill is a white to pale yellow colour depending on the amount of moult on the bill plates, with black on the naricorn around the nostrils, on the culminicorn, along the mandibular sulcus and at the bill tips. The average area of white on the chin of 'the white-chinned petrel sample' is also consistent with published accounts of New Zealand white-chinned petrels, including the small percent which lack a white chin (Oliver 1955; Warham and Bell 1979; Imber 1985b; Warham 1990).

The external morphology of Auckland, Antipodes and Campbell Island study skins showed the Antipodes and Campbell Island birds were significantly larger than the Auckland Island birds. These results support those obtained on the 'Auckland and Antipodes Island cluster groups' that suggest there are two groups of white-chinned petrels, based on external morphology, within the New Zealand EEZ.

Based on the results of comparing external measurements of the 'Auckland and Antipodes Island cluster groups' to study skins from the Auckland and Antipodes Islands the conclusion was reached that the Auckland Island skins all related closest in size to the 'Auckland Island cluster group' and therefore could be most likely from the Auckland Island population. The Antipodes Island skins also all related closest in size to the 'Antipodes Island cluster group' and were most likely from the Antipodes Island population. Small study skin samples sizes may influence the results; however they were all the skins available to draw conclusions from

Therefore within the New Zealand EEZ there are two groups of white-chinned petrels based on morphological characteristics, the 'Auckland and Antipodes Island cluster groups', which can be related to breeding populations at the Auckland and Antipodes Islands. Average head, bill, wing, tail, and tarsometatarsus measurements of study

skins from New Zealand offshore islands from the National Museum of New Zealand (Te Papa Tongarewa, Wellington) measured by Marchant and Higgins (1990) (Appendix 4.1) fit within the range of 'Auckland and Antipodes Island cluster group' measurements and were most likely the same study skins I used. The skins Marchant and Higgins (1990) measured, five male and four female, would have included birds from the Auckland and Antipodes Islands and probably Campbell Island, however as the individual specimen numbers are not known it was impossible to compare individual specimen measurements from each island between Marchant and Higgins (1990) and my measurements.

Published measurements of white-chinned petrel study skins from Antipodes Island (Mathews 1912-13; Warham and Bell 1979) (Appendix 4.1) showed that average culmen length 52.5-56 mm and tail length 122-127 mm fit within the range of Antipodes Island skins I measured and in turn the 'Antipodes Island cluster group'. A small sample of live white-chinned petrels from Antipodes Island measured by Warham and Bell (1979) (Appendix 4.1) between January and March 1969 had large wing and tail lengths comparable to Antipodes skins I measured and the 'Antipodes Island cluster group', which also indicates there are other published measurements which support the results of this research.

Only a single live female white-chinned petrel has been measured from the Auckland Islands (date unknown) (Bailey and Sorensen 1962) (Appendix 4.1) which for all measurements except tarsometatarsus length was more closely in size to Antipodes Island skins and live birds, and the 'Antipodes Island cluster group'. However a single specimen for comparison is not sufficient, as this could be an abnormally large bird from the Auckland Islands and not a true representation of the overall population. Also there was no description of how the measurements on this specimen were taken and this could be the reason for these abnormally large measurements on this female. This individual could be a young female originally from Antipodes Island and therefore indicates interbreeding between the Auckland and Antipodes Island populations. In general the study skins from the Auckland Islands I measured all conform to smaller size white-chinned petrels, which in turn are the same size as the 'Auckland Island cluster group'.

Also only a single male white-chinned petrel has been measured from Campbell Island, during February 1943, (Bailey and Sorensen 1962) (Appendix 4.1) and all measurements were extremely large comparable to the large Antipodes Island skins I measured and the 'Antipodes Island cluster group'. The measurements of this specimen were larger than measurements I took of Campbell Island skins, but do suggest the Campbell Island population is related closest in size to the Antipodes Island population.

Virtually nothing is known on New Zealand white-chinned petrel biology and the breeding cycle to give any indication that there are differences other than morphology between the Auckland and Antipodes Island populations. Serventy *et al.* (1971) claim that the breeding cycle of New Zealand white-chinned petrels are 'apparently earlier than the more southern breeding populations', however they do not give any evidence for this claim. A small amount of information is known on white-chinned petrel breeding biology at Antipodes Island (Warham and Bell 1979; Imber 1983) based on observations of burrows including females found incubating eggs in February as well as chicks found in burrows in February. However there have been no seasonal studies of white-chinned petrels breeding at the Auckland or Antipodes Islands, so no comparisons can be made between the breeding cycle at each location in New Zealand.

Dispersal of white-chinned petrels from the Auckland and Antipodes Islands during the breeding season is unknown in the New Zealand region. Published results of satellite tracked white-chinned petrels in the South Atlantic and Indian Oceans showed that they travel vast distances up to 2190 km from the breeding islands, and tend to travel to close coastal shelves near breeding islands (Weimerskirch *et al.* 1999; Berrow *et al.* 2000). Therefore during the breeding season white-chinned petrels from breeding islands in the South Atlantic and South Indian Oceans stay within those respective Oceans and are not likely to travel to the New Zealand region of the South Pacific. Few publications show distribution of white-chinned petrels at sea in New Zealand EEZ (Fleming 1950; Vooren 1973), the best would be the fisheries bycatch between 1996 and 2003 (Bartle 2000; Robertson 2000; Robertson and Bell 2002a, 2002b; Robertson *et al.* 2003a; Robertson, C.J.R. *pers. comm.*). There are however

no publications of known distribution of Auckland and Antipodes Island white-chinned petrels in New Zealand waters.

The 'Chatham Rise and Puysegur Point cluster groups' included adult white-chinned petrels caught further from breeding grounds at the Auckland and Antipodes Islands during the breeding season. These 'cluster groups' showed some dispersal of adults during the breeding season where fisheries vessels were operating between 2000 and 2003. The Chatham Rise is located between Banks Peninsula and the Chatham Islands, New Zealand, and is geographically closest to Antipodes Island, whereas Puysegur Point is located off the bottom of the South Island, New Zealand, and is geographically closest to the Auckland Islands.

A larger percent of the 'Chatham Rise cluster group' (59 %) related closest in size to the 'Antipodes Island cluster group' and only a small percent (32 %) of the 'Puysegur Point cluster group' related closest in size to the 'Antipodes Island cluster group'. Also a large percentage (68 %) of the 'Puysegur Point cluster group' related closest in size to the 'Auckland Island cluster group' compared with only 41 % of the 'Chatham Rise cluster group' related closest in size to the 'Auckland Island cluster group'. These results suggest that in general white-chinned petrels forage close to breeding islands during the breeding season, where Antipodes Island birds are more likely to forage along the Chatham Rise than to forage further away off Puysegur Point and Auckland Island birds are more likely to forage off Puysegur Point than on the Chatham Rise.

The Antipodes Island birds that forage off Puysegur Point would pass close to the Auckland Islands and this could influence interbreeding between the two populations, as would intermingling at sea off Puysegur Point and Chatham Rise. However, Auckland Island birds that forage on the Chatham Rise would not be likely to pass close to Antipodes Island.

The dispersal of adult white-chinned petrels from the Auckland and Antipodes Islands during the non-breeding season is unknown in New Zealand waters. Unfortunately there were no adults caught during the non-breeding season between June and August, so to give some indication of whether Auckland or Antipodes Island birds are in New

Zealand waters during the non-breeding season birds caught at the end of the breeding season between April and May were compared with the 'Auckland and Antipodes Island cluster groups'. Clearly almost all adult white-chinned petrels caught within the New Zealand EEZ between April and May related closest in size to the 'Antipodes Island cluster group' and in turn Antipodes Island birds. Only three were related in size to the 'Auckland Island cluster group' and two were caught close to the Auckland Islands.

The results from comparison of the 'Auckland and Antipodes Island cluster groups' to birds caught off Chile showed that almost all (90.5 %) related closest in size to 'Auckland Island cluster group' white-chinned petrels. A majority of the Chile white-chinned petrels were caught during the non-breeding season which suggests Auckland Island birds may travel to the west coast of South America outside the breeding season. Several publications note white-chinned petrels are common along the west coast of South America along the Humboldt Current (Murphy 1936; Jehl 1973), particularly at the end of the breeding season and into the non-breeding season from April onwards (Jehl 1973). The white chin size of individuals recorded off the west coast of South America is relatively small, and on average the same size as New Zealand white-chinned petrels (Mathews 1912-13; Murphy 1936), which indicates white-chinned petrels off the west coast of South America are likely to be New Zealand birds, and in particular Auckland Island birds.

These results suggest Antipodes Island white-chinned petrels stay within the New Zealand region during the non-breeding season and the Auckland Island white-chinned petrels go outside the New Zealand region, and as shown above, Auckland Island white-chinned petrels most likely go to Chile during the non-breeding season.

The movements of non-adult white-chinned petrels from breeding islands worldwide are unknown. Newly fledged white-chinned petrels spend a period of seven to ten years at sea before returning to breeding grounds, and have the ability to frequent all the southern oceans during this time. Therefore non-adults in New Zealand waters could be from any breeding population worldwide. The small sample of non-adult bycatch white-chinned petrels was caught during the breeding season between November and March. These birds all had small white chins well below the average

white-chin size for Indian Ocean white-chinned petrels which indicates these non-adults are most likely not from breeding populations in the South Indian Ocean.

There is also no indication in the literature that the white chin size increases with age or changes during annual moult as this has not been researched. As previously mentioned, non-adult size is the same as adult white-chinned petrel size and within the New Zealand region there is a mixture of non-adults relating in size to both the 'Auckland and Antipodes Island cluster groups'. Non-adults caught close to the Auckland and Antipodes Islands tended to relate closer in size to each respective 'cluster group'. These results indicate Antipodes Island sized non-adults were most likely from Antipodes Island, however the smaller sized non-adults could be from the Auckland Islands or maybe South Atlantic breeding populations.

Therefore, the results suggest that within New Zealand EEZ there are two white-chinned petrel taxa based on external morphology that can be related to breeding populations; the smaller sized white-chinned petrels which comprise the Auckland Island population, and the larger sized white-chinned petrels which comprise the Antipodes Island population (and relate closest to the *P. a. steadi* taxa), and possibly the Campbell Island population. If this is the case then serious issues need to be raised about the status of both populations, especially in relation to white-chinned petrel bycatch in New Zealand where they are the most numerous bycatch species caught. The New Zealand white-chinned petrel international status of vulnerable needs to be re-evaluated taking into account the likelihood there are two taxa in New Zealand waters.

4.4.7 Global white-chinned petrel taxa

Globally, white-chinned petrel males are on average larger than females (Ryan 1999) which is consistent among the Procellariiformes (Lorentsen and Rov 1994; Lo Valvo 2001; Cuthbert *et al.* 2003; Genovart *et al.* 2003). However, within the New Zealand EEZ size differences go beyond just male and female differences as shown in section 4.4.6 above on New Zealand white-chinned petrels where the Antipodes Island population are larger in size than the Auckland Island population based on comparison of the 'Auckland and Antipodes Island cluster groups' with study skins

from the Auckland and Antipodes Islands. If this is the case, where do the South Indian Ocean and South Atlantic Ocean populations fit in size with the New Zealand populations?

The comparison of the 'Auckland and Antipodes Island cluster groups' with study skins from breeding populations in the South Indian and Atlantic Oceans showed that all skins from breeding populations in the South Indian and Atlantic Oceans related closest in size to the 'Auckland Island cluster group' and in turn Auckland Island skins. These results suggest the Auckland Island population and breeding populations in the South Indian and Atlantic Oceans are all of a similar size based on average external measurements of study skins from those populations.

Published measurements of white-chinned petrel skins from South Georgia in the South Atlantic Ocean had average culmen, wing and tarsometatarsus lengths the same size as skins from breeding islands in the South Atlantic Ocean, and therefore Auckland Island skins and the 'Auckland Island cluster group' (Murphy 1936) (Appendix 4.1). Tail lengths of skins from South Georgia were on average slightly longer than skins I measured from the South Atlantic Ocean, but were not as long as average tail lengths of skins from Antipodes Island or the 'Antipodes Island cluster group' (Murphy 1936) (Appendix 4.1). Average culmen, wing and tarsometatarsus lengths of live birds from South Georgia were all slightly larger than the averages from the same measurements taken on skins from South Georgia (Hall 1987) (Appendix 4.1), which could be due to shrinkage of skins over time or slightly different measurement techniques, as Murphy (1936) does not mention how his measurements were taken. This further supports the notion that white-chinned petrels from breeding islands in the South Atlantic Ocean are the same size as white-chinned petrels from the Auckland Islands based on external measurements.

Published measurements of average culmen, wing and tarsometatarsus lengths of white-chinned petrel skins from the Kerguelen Islands in the South Indian Ocean (Falla 1937; Hall 1987; Marchant and Higgins 1990) (Appendix 4.1) fit with the general size of skins from breeding islands in the South Indian Ocean I measured. These measurements in turn fit closer with Auckland Island skins than Antipodes Island skins and therefore the 'Auckland Island cluster group'. Published average tail

lengths of Kerguelen Island skins (Falla 1937) (Appendix 4.1) were larger than those of skins from breeding islands in the South Indian Ocean I measured and closer in size to Antipodes Island skins I measured. However this is only one out of four measurements that does not fit the general trend and therefore the published measurements of Kerguelen Island skins (Appendix 4.1) are of a similar size to South Indian Ocean skins and Auckland Island skins I measured.

Published measurements of live white-chinned petrels from the Crozet Islands and Marion Island in the South Indian Ocean had average culmen, wing, tail and tarsometatarsus lengths similar in size to skins from breeding islands in the South Indian Ocean I measured (Rand 1954; Mougin 1970; Jouventin *et al.* 1985; Marchant and Higgins 1990) (Appendix 4.1).

The only exception was culmen lengths of Marion Island live birds (Rand 1954; Marchant and Higgins 1990) (Appendix 4.1) were slightly larger than measurements taken from South Indian Ocean skins, similar to culmen lengths of live birds from South Georgia, which could be due to shrinkage of culmen on skins or that culmen lengths shrink more over time than other appendages. This size difference in culmen lengths could also be due to measurement technique as the Marchant and Higgins (1990) specimens from Marion Island were measured by M. De L. Brooke (unpubl. cited in Marchant and Higgins 1990) and his technique is not mentioned. Moreover, they are the specimens with the largest culmen lengths in the South Indian Ocean.

The specimens measured by Rand (1954) all have culmen lengths within the range of other Indian Ocean white-chinned petrels except one individual with a culmen length of 55 mm which could be just an abnormally large individual and caused the average culmen length to be quite large (Appendix 4.1).

Therefore published measurements of white-chinned petrels (particularly skins) from breeding islands in the South Atlantic and Indian Oceans further support the notion that the Auckland Island and breeding islands in the South Indian and Atlantic Oceans are similar in size based on external morphology and are also smaller in size than Antipodes Island and Campbell Island white-chinned petrels.

The breeding cycle of white-chinned petrels in the South Atlantic Ocean is known from research done at South Georgia (Hall 1987) and in the South Indian Ocean by research done at Kerguelen Island (Weimerskirch *et al.* 1989), Crozet Islands (Mougin 1970; Jouventin *et al.* 1985) and Prince Edward and Marion Islands (Brooke 1986; Marchant and Higgins 1990). The timing of the breeding cycle of white-chinned petrels in the South Indian Ocean is very similar to the timing of the breeding cycle in the South Atlantic Ocean with arrival at breeding grounds in early to mid September, egg laying early November to mid December, hatching early to late January, and fledging early April to early May (Mougin 1970; Jouventin *et al.* 1985; Brooke 1986; Hall 1987; Weimerskirch *et al.* 1989; Marchant and Higgins 1990).

From what is known of the timing of the breeding cycle at Antipodes Island it seems the Antipodes Island white-chinned petrels may have a slightly later breeding season than South Indian and Atlantic Ocean season as hatching in the Indian and Atlantic Ocean has been noted for being no later than 28th January (Jouventin *et al.* 1985; Hall 1987; Weimerskirch *et al.* 1989) whereas a female at Antipodes Island was noted to be incubating an egg on 1st February that hatched about the 6th or 7th of February (Warham and Bell 1979). However, the timing of Antipodes Island white-chinned petrels breeding cycle cannot be discerned from a single observation. More information is needed on New Zealand white-chinned petrel breeding biology, particularly from the Auckland and Antipodes Islands, before comparisons can be made between breeding populations in the South Atlantic, Indian and Pacific Oceans.

Therefore these results suggest that New Zealand white-chinned petrels do not fit the proposition of a global white-chinned petrel taxon. The results also suggest that globally there are two taxa of white-chinned petrels based on solely on external measurements of bycatch birds and study skins: the smaller sized white-chinned petrels the Auckland Island, the South Indian Ocean and the South Atlantic Ocean populations; and the larger sized white-chinned petrels which comprise the Antipodes Island, and most likely, the Campbell Island populations.

The white chin size of South Indian Ocean white-chinned petrels are noted for being relatively large with some individuals with white extending onto the side of the face (Mathews 1912-13; Falla 1937; Sinclair *et al.* 1997). Could this be a feature for

distinguishing the South Indian Ocean population from the South Atlantic Ocean and Auckland Island populations? The Auckland Island and South Indian Ocean populations have individuals with large white chins, however not to the same extent and consistency as the South Indian Ocean birds and this could indeed be a feature to distinguish the Auckland Island and South Atlantic Ocean populations from the South Indian Ocean populations.

Also since the white-chinned petrels caught off Chile relate closest in size to the 'Auckland Island cluster group' and therefore the Auckland Island and South Indian and Atlantic Ocean skins, it seems likely they could be from either the Auckland Islands or South Atlantic Ocean population rather than the South Indian Ocean populations based on white chin size. Godman (1907-10) also reported the white chin size of an Auckland Island female resembled that of birds from Chile.

4.5 WHITE-CHINNED PETREL TAXONOMY

This section discusses the results found in this thesis with the current taxonomy of the white-chinned petrel. The first part reiterates the present techniques for describing taxa, then the problems with white-chinned petrel taxonomy, followed by how the taxonomic history of white-chinned petrels relates to my results, and finally how many taxa are found in New Zealand waters and how many global white-chinned petrel taxa there are with taxonomic names to back them up.

There is continuing controversy on how species should be discriminated and this has been labelled as the 'species problem' (Mayr and Ashlock 1991; Mayr 1996). Within the 'species problem' argument there are two further problems: first, which species concept to use; and second, how to apply this concept in the differentiation of species (Mayr 1996). The most readily accepted species concept used presently is the biological species concept; however both the typological species concept and the evolutionary species concept are still used by researchers although not universally recognised as the best species concepts (Mayr and Ashlock 1991; Mayr 1996).

Mayr and Ashlock (1991) and Mayr (1996) recommended that species should not be recognised solely on morphology, as mentioned under the typological species concept, but rather on a combination of morphological, molecular, behavioural, and ecological data using the biological species concept. Linnaeus in the eighteenth century based his entire classification on morphological characteristics with some cognisance of geographical location. These were the only data available to him, and his system of classification is still in use today. For several species, particularly the Procellariiformes including the white-chinned petrel, there is very little molecular, behavioural, and ecological information on each population so the biological species concept cannot be used. Until these become available, the only option is to use morphological characteristics to describe species taxa using the typological species concept.

Type specimens and study skin collections in museums are important in classifying species taxa as they provide actual representations of each species taxa to show visual characteristics that differentiate closely related species (Mayr and Ashlock 1991). Type specimens should still be used in the classification of species taxa, where available, and those taxa without a designated type specimen should have one designated.

The designated white-chinned petrel type specimen (Linnaeus 1758) is no longer in existence making comparisons between it and the Auckland and Antipodes Island populations and breeding populations in the South Indian and Atlantic Oceans impossible. This reiterates the need for a good type specimen when classifying taxa.

The current status of the white-chinned petrel suggests a single global taxon *Procellaria aequinoctialis* with the spectacled petrel a separate species *P. conspicillata* (Ryan 1998; Ryan and Moloney 2000). The New Zealand checklist (Turbott 1990) lists the white-chinned petrel as sub species *P. a. aequinoctialis* and spectacled petrel as sub species *P. a. conspicillata* under the species *aequinoctialis*. The spectacled petrel is currently considered a separate species (Ryan and Moloney 2000) and therefore the New Zealand checklist needs updating. However, there has been much debate over the taxonomic status of the white-chinned petrel since Linnaeus first described the genus and species in 1758. this is highlighted in the

taxonomic history section 1.7 of the introduction. This indecision shows the need for a good white-chinned petrel description and type specimen with a set of measurements that define the species taxa and the need for good ecological data from all breeding populations, particularly from the New Zealand region.

There are several instances in the white-chinned petrel taxonomic history section 1.7 that need further discussion: the locality of the type specimen and where it is now, the multiple genera described for the white-chinned petrel, the usage of the term 'white-chinned petrel', and the variation in white-chin size and the multiple number of sub species described.

The type location as designated by Linnaeus (1758) was the Cape of Good Hope; however this was based on the description of 'The Great Black Peteril' by Edwards (1747) who mentioned with uncertainty that it was collected from the seas about the Cape of Good Hope. Edwards (1747) description did not include any mention of white feathering on or around the throat area, unless it was overlooked and in that case would have been quite small. Based on current knowledge that individuals in the South Indian Ocean have the largest white chins, it seems unlikely that Edwards specimen was from the Cape of Good Hope. It is therefore likely that Linnaeus never saw the actual specimen as he would have noted any peculiarities such as white feathering on the chin and throat area.

Gray (1840) further showed that Linnaeus' *Procellaria* was in fact *P. aequinoctialis* and designated this as the type which therefore meant Edwards' (1747) bird was the type specimen and the Cape of Good Hope is the type location. The Edwards (1747) bird is no longer in existence so there is no actual type specimen available to make comparisons.

Mathews (1912-13) was the first to mention that based on white chin size the type locality should be the South Atlantic Ocean near South Georgia or the Falkland Islands rather than the Cape of Good Hope. Mathews (1912-13) lists the *aequinoctialis* sub species as the South Atlantic form of the white-chinned petrel. Dabbene (1923) followed on from Mathews (1912-13) and changed the Linnaeus (1758) white-chinned petrel type locality from the Cape of Good Hope to South

Georgia, but did not reassign a neotype. Marchant and Higgins (1990) list the Linnaeus (1758) type locality as South Georgia based on Dabbene (1923), but there is still no actual type specimen.

The difficulties of naturalists working in the field of ornithology during the eighteenth and nineteenth centuries were shown with the number of genera described for the white-chinned petrel. The original genus described by Linnaeus (1758) for the white-chinned petrel was *Procellaria*. All petrels described were initially placed within the genus *Procellaria* which caused problems as groups such as storm petrels and gadfly petrels were different in size and shape from the original *Procellaria* petrels. This caused rearrangement of petrel genera in 1853 resulting in *P. aequinoctialis* being moved to a separate genus *Majaqueus* Reichenbach (1853), rather than moving all other species out of the *Procellaria* genus.

Gray (1840) showed the type for *Procellaria* was *P. aequinoctialis* so that by 1912 *M. aequinoctialis* was changed back to *P. aequinoctialis* and all other species within the *Procellaria* genus were removed. Also in 1890 a further genus was introduced, *Cymatobolus* Reichenow (1890), but this name was based on a specimen that was later shown to be a white-chinned petrel. This example shows the difficulties in classification where naturalists are working in different parts of the world where communication between researchers was impossible.

The name 'white-chinned petrel' has only been used since 1879 (Salvin 1879) and the name does not encompass individuals without white chins. Another name used by Murphy (1936) is 'shoemaker' based on the call the birds make from their burrows. Perhaps this is a better name to use rather than 'white-chinned petrel'.

The first description of a white-chinned petrel (Edwards (1747) classified by Linnaeus (1758)) did not include any mention of white feathering on the chin or throat area. Since individuals with white chins were discovered in 1769, there has been controversy over the classification of white-chinned petrels based on white chin size. Both Solander in 1769 (Mathews 1912-13) and Forster in 1772 (1844) who first described white-chinned petrels with a white chin patch gave them separate names *Procellaria fuliginosa* Solander and *P. nigra* Forster. Forster (Hoare 1982) also

mentions '*aequinoctialis*' is an improper name for the species. All three names *P. aequinoctialis*, *P. fuliginosa*, and *P. nigra* are of the same species even though the original description lacks a white chin and since Linnaeus (1758) description of *P. aequinoctialis* is the oldest it is the authority making the other two synonyms.

Gould (1844) described two variations in white chin size; those individuals with a patch of white on the chin and throat area, and those with a white chin patch that extends onto the head and face and around the eyes. Gould (1844) distinguished the two forms as separate species, *Procellaria aequinoctialis* and *P. conspicillata* Gould. This has caused further controversy with the classification of white-chinned petrels and split ornithologists into two groups; those that consider the white-chinned petrel and spectacled petrel as separate species or sub species (Bonaparte 1856; Coues 1864; Giglioli 1870; Mathews 1912-13; Rowan *et al.* 1951; Turbott 1990; Ryan 1998; Ryan and Moloney 2000) and those that consider them a single species with a large amount of variation in white chin size through the whole population (Sharpe 1879; Salvin 1896; Buller 1905; Godman 1907-10; Loomis 1918; Dabbene 1923; Oliver 1930; Murphy 1936; Falla 1937). This makes it difficult to determine who is correct when classifying white-chinned petrels, but some of Mathews (1912-13) research may make more sense of it.

Perhaps the biggest advocator for splitting white-chinned petrels into separate sub species based on white chin size and location was G. M. Mathews (1912-13). Mathews (1912-13) suggested five sub species: *P. aequinoctialis aequinoctialis*, South Atlantic Ocean petrels with small white chins; *P. a. mixta*, South Indian Ocean petrels with large white chins; *P. a. conspicillata*, spectacled petrels; *P. a. brabournei*, petrels with small white chins found off the coast of Chile; and *P. a. steadi*, New Zealand white-chinned petrels with small white chins. Mathews (1912-13) pointed out that the original type locality described by Linnaeus (1758) was most likely from the South Atlantic, near South Georgia or the Falkland Islands rather than the Cape of Good Hope based on white chin size. Mathews (1912-13) also had type specimens for two of his sub species, *P. a. mixta* a bird caught at sea in the South Indian Ocean, and *P. a. steadi* a bird collected from Antipodes Island. The Antipodes Island type specimen was important for this thesis as it allowed comparison between a type specimen and skins from Antipodes Island as well as the 'Antipodes Island cluster

group'. Mathews (1912-13) five subspecies are no longer valid but results from this research may indicate the *P. a. steadi* type may be valid for the Antipodes population, though not based on white chin size but rather on body size.

The splitting of the spectacled petrel *Procellaria conspicillata* as a separate species by Ryan (1998) and Ryan and Moloney (2000) based on that they breed at one location Inaccessible Island, they have unique plumage of white on the head around the eyes, are smaller in size than the general *P. aequinoctialis*, they breed earlier than *P. aequinoctialis*, and they are 'vocally distinct from white-chinned petrels'. This leaves the white-chinned petrel as its own separate species; however as results of this thesis show this may not be the case.

As previously mentioned, my results suggest two taxa of white-chinned petrels in New Zealand waters that can be related to breeding populations based on external morphology; the smaller sized individuals from the Auckland Islands, and the larger sized individuals from Antipodes Island. Furthermore, my results also suggest that globally there are two taxa of white-chinned petrels based on external morphology; the smaller sized petrels from the Auckland Islands and breeding populations in the South Atlantic and Indian Oceans, and the larger sized petrels from Antipodes Island and most likely Campbell Island.

As previously mentioned, Mathews (1912-13) suggested five sub species of white-chinned petrel based on white chin size and location. These sub species are no longer in use; however the sub species described as the New Zealand white-chinned petrel *P. a. steadi* had a type specimen that was from Antipodes Island. This specimen had bill and bodily measurements within the range of other Antipodes Island skins and the 'Antipodes Island cluster group'. The measurements of the *P. a. steadi* type specimen are significantly larger than measurements of Auckland Island skins, South Atlantic and Indian Ocean skins, and the 'Auckland Island cluster group'. This suggests that perhaps Mathews was right in that New Zealand white-chinned petrels, or more appropriately, the Antipodes Island population, were different in size to all other white-chinned petrel populations even though his original discriminating features were not quite correct. In other words, the *steadi* taxon can be linked to the Antipodes

Island population and perhaps all other white-chinned petrels should come under the *aequinoctialis* taxon.

The analysis of morphological characteristics suggests there are two taxa of white-chinned petrel in New Zealand waters related to breeding populations at the Auckland and Antipodes Islands: the smaller sized white-chinned petrels from the Auckland Islands and the larger sized white-chinned petrels from Antipodes Island.

Furthermore, these results also suggest that globally there are two taxa of white-chinned petrel based on external morphology: '*aequinoctialis*', the smaller sized white-chinned petrels from the Auckland Islands and breeding populations in the South Atlantic and Indian Oceans; and '*steadi*', the larger sized white-chinned petrels from Antipodes Island and most likely Campbell Island.

There are several albatross taxa within the New Zealand region where breeding populations can be separated by morphological characteristics. The shy albatross *Thalassarche cauta* (Gould) has several populations that are morphologically different, but breed within 1000 km of each other (Robertson and Nunn 1998). These populations are different enough to warrant separate species status and include: *T. steadi* Falla, New Zealand white-capped albatross; *T. salvini* (Rothschild), Salvins albatross; and *T. eremita* Murphy, Chatham Albatross (Robertson and Nunn 1998).

The wandering albatross taxa *Diomedea exulans* Linnaeus has two morphologically and ecologically distinct taxa within the New Zealand region: *D. gibsoni* Robertson and Warham, which breed at the Auckland Islands; and *D. antipodensis* Robertson and Warham, which breed at the Auckland Islands (Robertson and Nunn 1998). The Antipodes Island wandering albatross are noted off the coast of Chile whereas the Auckland Island wandering albatross are more circumpolar in distribution (Robertson, C.J.R. *pers. comm.*), which seems to be opposite to the Auckland and Antipodes Island white-chinned petrel distribution.

In despite of what Mayr and Ashlock (1991) and Mayr (1996) suggest about describing taxa based on the biological species concept, it seems that in this thesis

there is a case to argue as to some extent the aims were answered using only morphological characteristics based on the typological species concept.

Within the suggested '*aequinoctialis*' white-chinned petrel taxon, which includes the Auckland Island white-chinned petrels and petrels from breeding islands in the South Indian and Atlantic Oceans, there seems to be a differentiation in white chin size. The South Indian Ocean white-chinned petrels have by far the largest white chins and this could be a morphological character to look at for differentiation between populations within the '*aequinoctialis*' taxon.

4.6 WHITE-CHINNED PETREL INTERNAL MORPHOLOGY

This section just briefly discusses the internal morphology of white-chinned petrels in three sections: 4.6.1 sex and age determination; 4.6.2 testicular development of white-chinned petrels (results in Appendix 3.15); and 4.6.3 white-chinned petrel internal organ descriptions (results in Appendix 3.15).

4.6.1 Sex and age determination

Sex and age determination of white-chinned petrels was consistent with other Procellariifomes and other bird species in that the males had a pair of testes located at the anterior end of the kidneys and the females a single ovary on the left side anterior to the left kidney.

All bycatch white-chinned petrels were sexed, where possible, by examination of the gonads. Age of individuals was estimated as either adult or non-adult based on gonad size, condition of the brood patch, moult condition and date of capture. Non-breeding adults could not be differentiated from breeding adult so they were grouped together as adults. Adult males were easily identifiable as the testes were a relatively large round or oval shape ranging up to 3350.9 mm^3 and could not be mistaken for any other organs. Adult male testis size increased at the beginning of the breeding season from September to November which coincided with mating and the pre laying exodus (Marchant and Higgins 1990). Once eggs are laid in mid November (Mougin 1970;

Warham and Bell 1979; Imber 1985b; Jouventin *et al.* 1985; Hall 1987; Marchant and Higgins 1990; del Hoyo *et al.* 1992) testis size starts to recedes and by January the average testis size is back to less than 200 mm^3.

Non-adult males were characterised by very small 'rice grain shaped' testes that could easily be mistaken for adrenal glands which are located slightly anterior to the testes and are similar in size. Careful identification made sure this did not happen. Only 25 non-adult males were caught as bycatch and they were all caught towards the end of the breeding season in February and March. Non-adult testis size was consistent between February and March and was still smaller in volume than adult testes that had receded.

Adult females were also easily identified by the location of the ovary and the size of the follicles on it. A thick convoluted oviduct also aided identification and occasional adult females caught between September and December had developing follicles up to 44 mm in diameter which aided in identification. The development of follicles is consistent with mating and the pre-laying exodus at the start of the breeding season (Marchant and Higgins 1990). Some adult females with developing follicles on the ovary in late November and December, after the egg laying period, were considered to be developing secondary egg to be used if the first egg fails.

Only six non-adult females were caught in the bycatch sample and these were more difficult to identify than the adults as the ovary itself was quite small and the oviduct very thin and straight and difficult to see. These non-adult females had no developing follicles and all were the same size.

4.6.2 Testicular development of white-chinned petrels

The reproductive state of white-chinned petrel testes was examined to determine if there is a relationship between stage of spermatogenesis and testis volume. Gartrell (2002) showed that for male swift parrots *Lathamus discolour* there were five stages of testicular development based on development of spermatogenic tubles; quiescence, spermatagonial multiplication, spermatocyte division and elongation, regression and rehabilitation. Between November and February all five stages of development were

also found in white-chinned petrels. Testis volume was smallest in stage 1, clearly larger in stages 2 and 3, receding in stage 4, and back to the smallest size in stage 5.

An explanation of this is that in stage 1 the ratio of seminiferous tubule to interstitium tissue within the testes was even and the testis size was relatively small, however in stages 2 and 3 there is more seminiferous tubule than interstitium tissue indicating an increase in tubular cells within the seminiferous, which in turn reflects the larger testis volume of stage 2 and 3 which coincided with the start of the breeding season in November. Sperm were also seen during stage 3 when the testes were large which coincided with mating at the start of the breeding season in November. In stage 4 there is still more seminiferous tubule than interstitium, however there is less organisation of the tubular cells within the seminiferous tubules and they are breaking down and shrinking. This explains the left testis volume at stage 4 being greater than stage 1 but less than stages 2 and 3. In stage 5 the ratio of seminiferous tubules to interstitium is back even which indicate the seminiferous tubules have shrunk back to their original size, and this is indicated by the left testis volume of stage 5 being similar to the left testis volume of stage 1. Stages 4 and 5 occur between December and February where testis size is receding back to non-breeding size.

Clearly this shows a relationship between stage of spermatogenesis and testis volume over time, where sperm are only present in the large stage 3 testes during November, which happens to be when mating takes place for white-chinned petrels. After mating the male has no need to keep producing sperm so the seminiferous tubules break down and the testes recede (stages 4 and 5 and eventually stage 1), which occur between December and February.

4.6.3 White-chinned petrel internal organ descriptions

Internal organs including the heart, small intestine, liver and gall bladder, and kidneys were measured and a fat score taken to determine if there were any differences between adults and non-adults, males and females. Comparison between organ size and an external measurement indicator for overall body size would be the best approach to analyse these data, however time constraints made this impossible to do.

Nearly three quarters of 'the white-chinned petrel sample' had a fat score between 1 and 2 indicating that most birds were low on fat reserves and since these birds were caught during the breeding season it seems most were caught at the beginning of a foraging trip after spending time in the burrow. It is likely these birds thought the fisheries vessels an easy source of food rather than foraging themselves. There were significant differences in fat scores between adults and non-adults, and adult males and females. Non-adults had a significantly lower fat score than adults which could indicate adults are more proficient at foraging and collecting food than non-adults. Adult males had a slightly higher fat score than adult females which could indicate males are more proficient at foraging or females spent more time in the burrow and deplete there fat reserves more than males.

Bile in the gall bladder is used to break down fat reserves to use when a bird is not feeding. Therefore gall bladder size would increase with increased production of bile when breaking down fat reserves. These fat reserves would be used when white-chinned petrels are incubating eggs and rearing chicks when they are spending long periods of time away from the sea. Gall bladder length was only slightly negatively correlated with fat score which indicated gall bladder length was longer for low fat scores. This indicates that as white-chinned petrels start using up fat reserves more bile is produced increasing the gall bladder size.

Heart measurements, small intestine length, liver weight and kidney measurements showed similar sizes between adults and non-adults indicating non-adults are the same size as adults. Adult males were generally larger in all internal organ measurements than adult females, which indicates males are larger in size than females, which is also shown with external measurements. Overall more analysis needs to be done on size of white-chinned petrel internal organs and relate it to an overall body size indicator.

5

CONCLUSIONS

This chapter discusses the main conclusions drawn from this thesis in four sections: 5.1 measurement error between two observers; 5.2 sample size; 5.3 white-chinned petrel external morphology; and 5.4 white-chinned petrel taxonomy. The chapter finishes with a probable taxonomy for white-chinned petrels based on a typological species concept.

5.1 MEASUREMENT ERROR BETWEEN TWO OBSERVERS

The comparison between 'the Laboratory' and my measurements clearly showed very little measurement error between the two observers, and the small amount of error was biologically insignificant. The most accurate and repeatable external measurements with the least amount of error between observers were culmen length, bill least depth and head and bill length. These measurements tended to be of structures that were well defined with little flexibility. Wing length and tail length also had only a small amount of error between observers and could be accurately measured if seasonal differences such as moult and feather wear were noted. Thus, if the same measuring techniques are used, data from two or more observers can be pooled and used in comparative studies. This was important as it allowed me to combine my study skin measurements with those of C.J.R. Robertson.

5.2 SAMPLE SIZE

A large sample size was the most important factor in reaching the conclusion that the results suggest two white-chinned petrel taxa in New Zealand waters. Without the large sample of 723 bycatch white-chinned petrels it would have been likely that adult

birds caught near the Auckland and Antipodes Islands would have been missed and not included in the sample. Therefore comparisons between the 'Auckland and Antipodes Island cluster groups' and study skins from the Auckland and Antipodes Islands could not have been made and the above conclusion reached.

5.3 WHITE-CHINNED PETREL EXTERNAL MORPHOLOGY

The initial comparison of average study skin external measurements showed the Antipodes and Campbell Island skins were significantly larger in most measurements than Auckland Island skins and study skins from breeding islands in the South Indian and Atlantic Oceans. Also the average area of white on the chin of study skins from breeding islands in the South Indian Ocean was significantly larger than the average area of all other populations. Measurements of study skins from breeding islands were also important as this was the only means of linking the 'Auckland and Antipodes Island cluster groups' to breeding populations.

The 'Antipodes Island cluster group' was significantly larger in most external measurements than the 'Auckland Island cluster group'. Discriminant analysis showed 'Antipodes Island cluster group' males could be differentiated from 'Auckland Island cluster group' males using culmen length and tail length, and 'Antipodes Island cluster group' females could be differentiated from 'Auckland Island cluster group' females using head and bill length, culmen depth at the base and wing length. The size and shape of the white chin patch varied throughout the 'Auckland Island cluster group' and the 'Antipodes island cluster group' and was a poor characteristic for discriminating between the two cluster groups.

Antipodes and Campbell Island study skins related closest in size to 'Antipodes Island cluster group' and Auckland Island study skins related closest in size to 'Auckland Island cluster group', which suggested both 'cluster groups' were from each respective breeding island population. Also study skins from breeding islands in the South Indian and Atlantic Oceans related closest in size to the 'Auckland Island cluster group'. The *P. a. steadi* Mathews type specimen for the New Zealand white-

chinned petrel also related closest in size the 'Antipodes Island cluster group' and Antipodes Island skins.

More than half of the 'Chatham Rise cluster group' related closest in size to the 'Antipodes Island cluster group' and Antipodes Island skins, and most of the 'Puysegur Point cluster group' related closest in size to the 'Auckland Island cluster group' and Auckland island skins. This indicated that during the breeding season white-chinned petrels tend to forage close to breeding islands.

Nearly all white-chinned petrels caught at the end of the breeding season in April and May related closest in size to the 'Antipodes Island cluster group' and Antipodes Island skins which indicated that Antipodes Island birds were likely to stay in New Zealand waters during the non-breeding season and that Auckland Island birds leave the New Zealand Exclusive Economic Zone (EEZ) during the non-breeding season. Comparison of the 'Auckland and Antipodes Island cluster groups' with birds caught off Chile showed the Chile birds related closest in size to the 'Auckland Island cluster group'. This suggested that Auckland Island birds may go to Chile during the non-breeding season.

The main conclusion reached from the results suggests that, based on morphological characteristics, there are two taxa of white-chinned petrels in the New Zealand EEZ: the smaller sized white-chinned petrels from the Auckland Islands; and the larger sized white-chinned petrels from Antipodes Island, and possibly Campbell Island (which include the *P. a. steadi* Mathews type specimen).

The results also suggest that, globally, there are two taxa of white-chinned petrels based on morphological characteristics: the smaller sized white-chinned petrels from the Auckland Islands and breeding islands in the South Atlantic and Indian Oceans; and the larger sized white-chinned petrels from Antipodes Island, and possibly Campbell Island. Further, white-chinned petrels off Chile are likely to be from the Auckland Island breeding population or South Atlantic Ocean breeding populations.

5.4 WHITE-CHINNED PETREL TAXONOMY

The current white-chinned petrel status suggests a single global taxon *Procellaria aequinoctialis* Linnaeus with the spectacled petrel a separate species *P. conspicillata* Gould. However the conclusions reached in this thesis suggest that, based on morphological characteristics, within the New Zealand EEZ there are two groups of different sized white-chinned petrels, one from the Auckland Islands and the other from Antipodes Island, and that globally these are representations of two groups of white-chinned petrel related to different breeding locations. As shown in the discussion, the *P. a. steadi* type specimen described by Mathews (1912-13) fits with the description of Antipodes Island white-chinned petrels. Therefore it was logical to suggest '*steadi*' as the taxon name for the larger sized Antipodes and Campbell Island white-chinned petrels. For the smaller sized Auckland Island and South Atlantic and Indian Ocean white-chinned petrel taxon the original name '*aequinoctialis*' should be used as it refers to the taxon originally described by Linnaeus in 1758.

The main conclusion reached by this thesis is that within the New Zealand EEZ there are two taxa of white-chinned petrel based on external morphology: '*aequinoctialis*', the smaller sized white-chinned petrels from the Auckland Islands; and '*steadi*', the larger sized white-chinned petrels from Antipodes Island and most likely Campbell Island.

The secondary conclusion reached by this thesis is that globally there are two taxa of white-chinned petrel based on external morphology: '*aequinoctialis*', the smaller sized white-chinned petrels from the Auckland Islands and breeding populations in the South Atlantic and Indian Oceans; and '*steadi*', the larger sized white-chinned petrels from Antipodes Island and most likely Campbell Island.

In future, white-chinned petrel behavioural, ecological, molecular and morphological data will need to be collected for individuals from all breeding populations, particularly in New Zealand. This information should be combined with morphological characteristics described in this thesis to provide a better taxonomic classification of white-chinned petrels globally.

Behavioural, ecological and molecular information were not available for the analysis in this thesis, so the taxa proposed here are based solely on a typological species concept. A likely taxonomy for white-chinned *Procellaria* petrels based on the typological species concept, taking into account the spectacled petrel is a separate species *P. conspicillata*, is:

'*aequinoctialis*' Linnaeus 1747	- locations -	Auckland Islands
P. fuliginosa Solander		- South Georgia
P. nigra Forster		- Falkland Islands
		- Kerguelen Islands
		- Crozet Islands
		- Prince Edward Islands
'*steadi*' Mathews 1912-13	- locations -	Antipodes Island
		- Campbell Island

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APPENDICES

Appendix 1.1

George Edwards. 1747. *A Natural History of Birds*, Part. II. G. Edwards, London. p. 89, pl. 89. Following the scanned copy of the plate is an accurate reproduction of the original manuscript.

(89)

The great BLACK PETERIL.

THIS Bird is about the Bigneſs of a *Raven*; the Bill, from the Corner of the Mouth to the Point, is three Inches long; from the Forehead to the Point but two Inches; the Wing when cloſed is near 15 Inches long: It is of Kin to the *Albatroſs* laſt deſcribed, yet I cannot pronounce it abſolutely of the ſame Genus; the Shape of the Bill is much the ſame with that, but a great deal leſs in Proportion, and the Noſtrils placed together on the upper Part of the Bill; the Legs and Feet are alſo like thoſe of the laſt deſcribed, except that this hath a little Spur, or Claw, where other Fowls have the hind Toe, which Spur riſes immediately from the Heel.

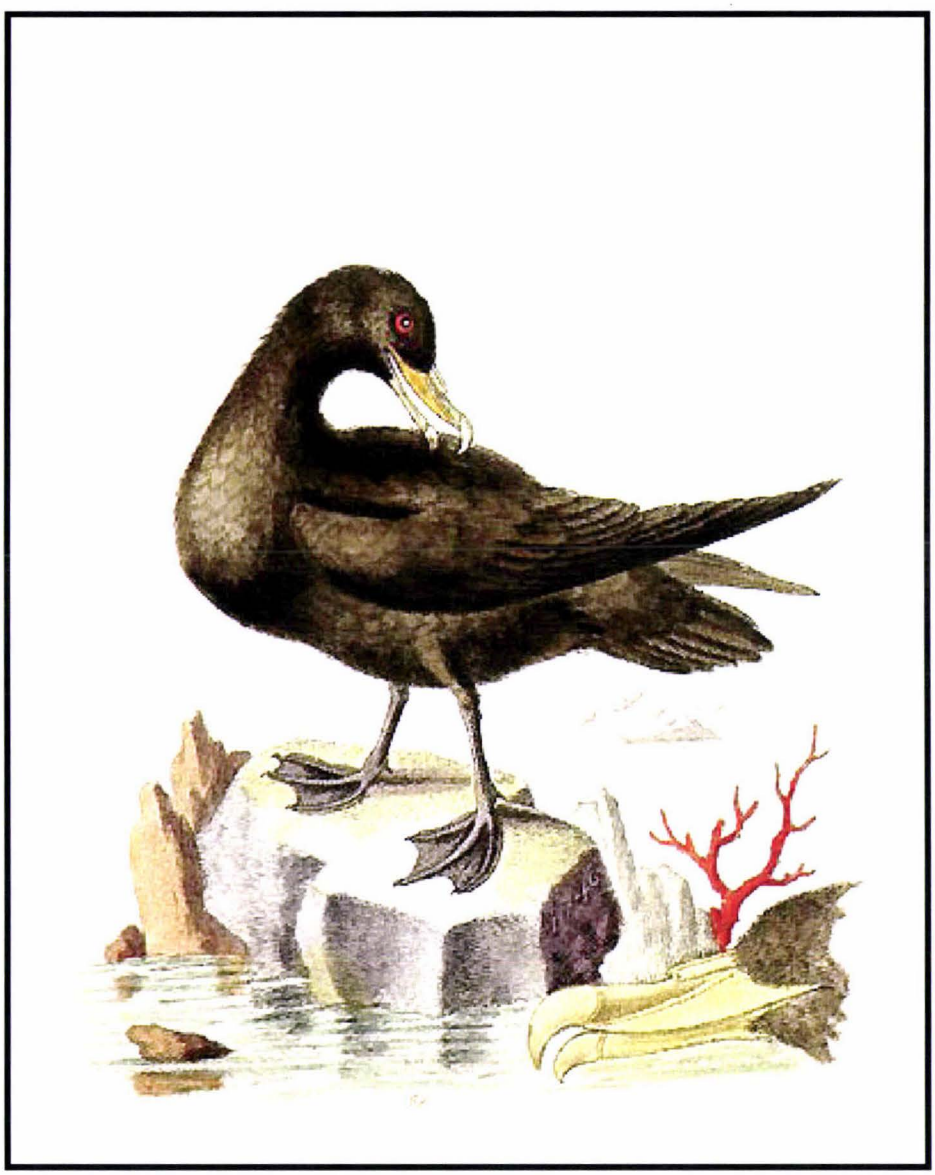
The Bill is of a Yellow Colour, not very bright, but might be more lively perhaps when the Bird was living; the Noſtrils ſeem to be carried on in two Tubes or Pipes joined together, which proceed from the Forehead, and paſs about one third Part of the Length of the Bill on its upper Part, with two Openings forward; the Bill is creaſed or furrow'd, and pretty much hooked at the Point, all which may be better conceived from the lower Figure than from Deſcription, the Bill being there drawn of its natural Bigneſs: It is ſhaped in general pretty much like a *Sea-Gull*; the Wings when cloſed reaching farther than the Tail; the Plumage all over the Body is the ſame, without the leaſt Variety of Shade, it being of a very ruſty Black, or blackiſh Brown; the Legs and Feet were near of the ſame Colour, or a little more inclining to Fleſh, reſembling the Colour of an *Ethiopian*'s Skin: Its Claws are Black; it hath a little Claw or Spur riſing out of the Heel immediately, and not by a Toe, for it hath no Sign of a back Toe; the Figure expreſſes a Claw on each Foot; the outer Sides of all the Toes are webb'd, as in the *Albatroſs*.

This Bird was ſent me to draw by Mr. *Benjamin Cowel*; it came with the *Albatroſs* by an *India* Ship, ſo that I am of Opinion it is from the Seas about the Cape of *Good Hope*: I could not gather any more certain Account of its Place. In looking over a ſmall Tract entitled, *a Voyage to* St. Kilda, the moſt remote of all the Weſtern Iſlands of *Scotland*, by M. *Martin*, Gent. *London* 1698, I find the Figure of a Bird agreeing exactly with this in the Shape of its Bill, and the back Claw is very juſtly expreſſed in the Print, tho the Deſcription calls it a back Toe; it ſeems to be of the ſame, or very near the Size of the Bird here deſcribed, but of different Colours; it being greyiſh White on the upper, and purely White on the under Side: But what confirms me moſt that theſe two Birds are of the ſame Tribe or Family, is the Opinion of Dr. *James Monroe*, Fellow of the College of Phyſicians, and Phyſician of *Bethlem* Hoſpital, who, happening to ſee my Drawing, ſaid he remembered a Bird in the Voyage to *St. Kilda*, called the *Fulmar*, that agreed with mine; and told me, at the ſame Time, he had ſeen the *Fulmar*, and drew the Figure of it for the Plate in the Book when he was a young Lad. See the Figure and Deſcription of the *Fulmar* in the Voyage to *St. Kilda*, *Pa.* 55, where the Author ſays, "he "picks his Food out of the Backs of living Whales." This Manner of Feeding may ſhew us that Nature hath fitted every *Animal* according to his appointed Way of Life; for the hooked Bill muſt be moſt commodious to take out the ſlimy Subſtance that gathers and is lodged in the Fiſh's Skin; and the Claw or Spur on the Heel, which is placed very low, may be deſigned to give the Bird a more firm Standing, to feed on the ſlippery Side or Back of a Fiſh, without which the Bird might be blown from her Place, becauſe there generally prevails a pretty ſtrong Wind in the open Sea: But I ſhall always ſubmit ſuch Opinions and Reaſonings to the Experience of the more knowing. I believe this Bird hath never been deſcribed.

L *The*

Plate 89 'The Great Black Peteril' from George Edwards. 1747. *A Natural History of Birds*, Vol. II. G. Edwards, London. p. 89, pl. 89.

The great BLACK PETERIL



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George Edwards. 1747. *A Natural History of Birds*, Vol. II. G. Edwards, London. p. 89, pl. 89.

The great BLACK PETERIL

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Appendix 1.2

Disclaimer - Every effort has been made to reproduce accurately the original manuscript.

Description of the genus *Procellaria* and description of *Procellaria aequinoctialis*.

Caroli Linnæus 1758. *Systema Naturæ*, 10th edition. L. Salvii, Holmiae. p. 131-132.

64. PROCELLARIA. *Roſtrum* edentulum, ſubcompreſſum : Mandibulis aequalibus : ſuperiore apice adunca ; inferiore apice compreſſo - canaliculata.
Nares cylindro ſupra baſin roſtri decumbente, truncato.
Pedes palmati : ungue poſtico ſeſſili absque digito.

aequinoctialis. 2. P. fuſca immaculate, roſtro flavo.
Peteril magna nigra *Edw. Av.* 89. t. 89.
Habitat ad Cap. b. Spei.

Translation of Caroli Linnaeus 1758 *Systema Naturae* 10th edition. p. 131-132 on the genus *Procellaria* and *Procellaria aequinoctialis*. Latin translated into English by Rev. Michael Blain.

64. PROCELLARIA. *The bill* is used for eating, lower mandible is suppressed or pulled in : Both mandibles are even, flush : the upper mandible has a hooked tip ; the lower mandible is suppressed - with a small groove or 'canal' running down it.
nostrils are in a cylinder and rest on top of the bill at its base, and are cut back (truncate).
The feet are palmed (webbed?) : hind toe has no claw and when the bird is standing it does not touch the ground.

aequinoctialis. 2. This species is uniformly dark coloured, with a golden yellow coloured bill.

The Great Black Peteril *Edw. Av.* 89. t. 89.

Habitat is the Cape of Good Hope.

Appendix 1.3

Disclaimer - Every effort has been made to reproduce accurately the original manuscript.

Description of *Procellaria aequinoctialis*

Caroli Linnæus 1766. *Systema Naturæ*, I, L. Salvii, Holmiae. p. 213.

aequinoctialis. 4. P. fuſca immaculata , roſtro flavo, pedibus fuſcis.
Sterna major fuſca humile volitans. *Brown. jam.* 482.
Puffinus capitis b. ſpei. *Briſſ. Av.* 6. *p.* 137.
Avis diomedea. *Redi diſſert.* 1674. *Amſtel.*
Peteril magna nigra. *Edw. Av.* 89. *t.* 89.
Habitat ad Cap. b. Spei.
Narium tubus conſtat cylindris duobus diſtinctis parallelis.

Translation of Caroli Linnaeus 1766 *Systema Naturae* I, page 213 on *Procellaria aequinoctialis*. Latin translated into English by Rev. Michael Blain.

aequinoctialis. 4. This species is uniformly dark coloured, with a golden yellow coloured bill, the feet are a dark colour.
Large dark coloured bird that flies close to the ground. *Brown. jam.* 482.
Puffin from the Cape of Good Hope. *Briſſ. Av.* 6. *p.* 137.
Avis diomedea. *Redi diſſert.* 1674. *Amſtel.*
The Great Black Peteril. *Edw. Av.* 89. *t.* 89.
Habitat is the Cape of Good Hope.
Nostril tubes sit together as two distinct cylinders that are Parallel.

Appendix 1.4

Disclaimer - Every effort has been made to reproduce accurately the original manuscript.

Type description of *Procellaria aequinoctialis steadi*

Gregory M. Mathews. 1912-13. *The Birds of Australia*, Volume 2. Witherby and Co., London. p. 113-114

Order PROCELLARIIFORMES *Family* PROCELLARIIDAE.

No. 94.

PROCELLARIA AEQUINOCTIALIS STEADI.

NEW ZEALAND WHITE-CHINNED PETREL.

PROCELLARIA AEQUINOCTIALIS STEADI, subsp. n.; Antipodes Island, New Zealand.

Majaqueus aequinoctialis Buller, *Trans. New Zeal. Inst.*, 1892, Vol. XXV., pp. 62, 80, 1893; Hutton, *ib.*, 1894, Vol. XXVII., p. 177, 1895; Buller, *Suppl. Birds New Zeal.*, Vol. I, p. 109, 1905; Godman, *Monogr. Petrels*, p. 169, 1908 (pars).

Adult male. General colour above sooty-black with brown edges; interramal space only more or less white; "Bill with sides of the upper mandible and the tubes blue, the culmen and unguis black, the lower edge of the lower mandible flesh-colour; legs and feet black" (Hutton). Total length 510 mm.; culmen 56, wing 388, tail 122, tarsus 67.

Adult female. Agrees in colouration and size.

Young. According to Hutton, identical in colouration.

Nest. "Breeds in holes made in the side of a slope, these holes being hollowed out into a circular chamber at the end" (Hutton).

Egg. "White" (*id.*).

Breeding season. "December" (*id.*).

I have included this subspecies in the Australian List, as there is a specimen in the British Museum, supposed to come from Tasmania, which is undoubtedly the Antipodes Island breeding bird. It is a bird which could be reasonably suspected to be

driven as far north as Tasmania, and from the general Australian records of *Majaqueus aequinoctialis* I cannot conclude whether *P. a. conspicillata* is always intended. The inclusion of this bird will draw attention to the fact that such a race may be met with. What can be the *Majaqueus aequinoctialis* of Hull (*Proc. Linn. Soc. N.S.W.* 1909, Vol XXXIV., p. 649, 1910) recorded as a visitor to the seas adjacent to Lord Howe Island? As a synonym is given *Majaqueus gouldii* Hutton, of Ramsay. Ramsay could surely never have intended *P.a. conspicillata* by this identification, and he most probably intended *Pterodroma macroptera gouldi* which is an altogether different bird. It will be seen how difficult it is to deal with the existent Australian records of birds of this order.

Captain Hutton* writing of this Petrel found breeding on Antipodes Island, observes that: "All the birds on this breeding station had white chins, and none had any white markings on the face. The legs and feet are black. The bill, when fresh, had the sides of the upper mandible and the tubes blue, the culmen and unguis black, the lower edge of the lower mandible was flesh-colour".

"The old birds were sitting on fresh-laid eggs in December, while in the following May the young birds were fully fledged, although still in their nests. These young birds had the plumage in every respect similar to that of the adult".

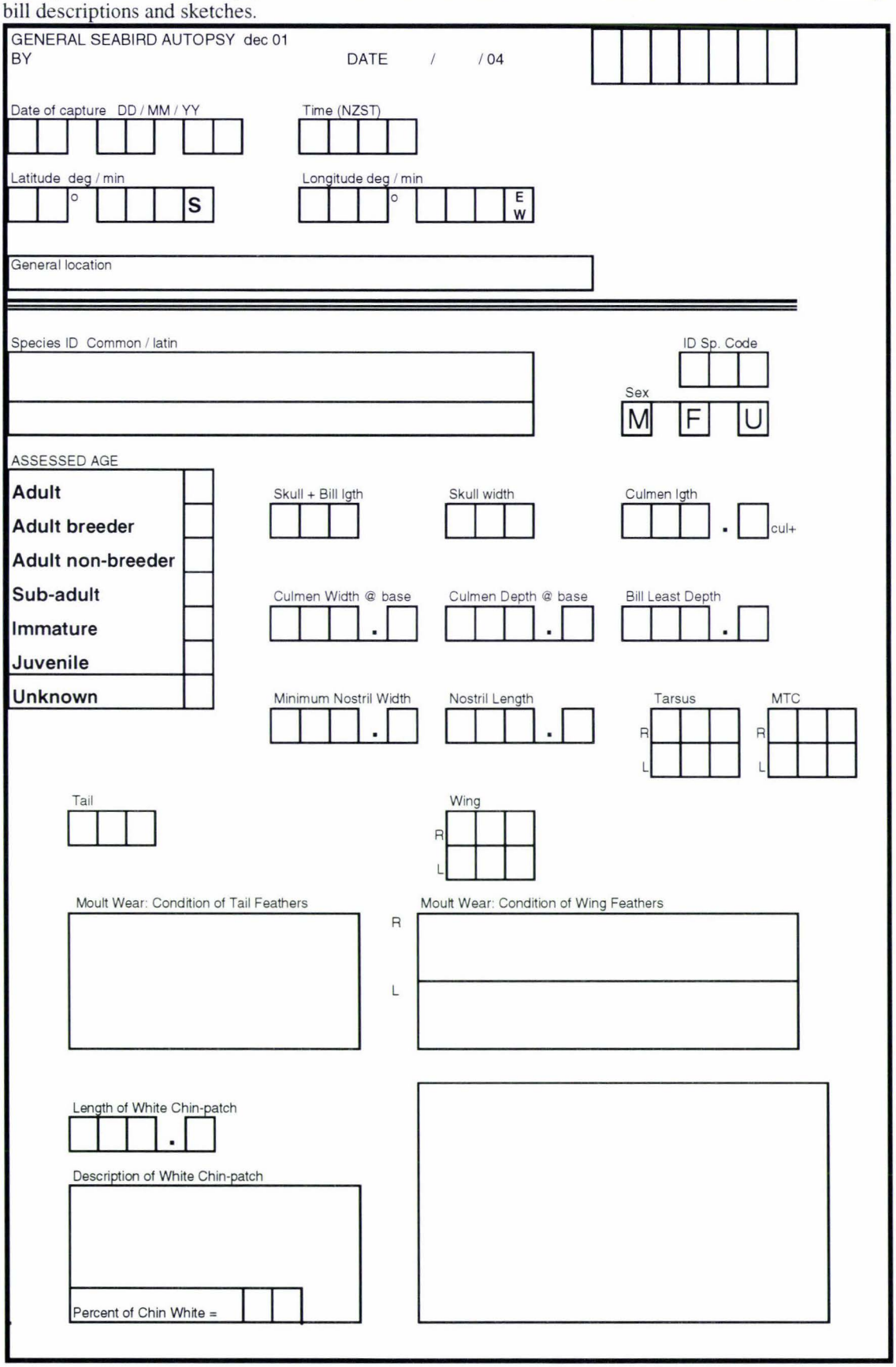
The bird figured in White's *Journ. Voy. New South Wales*, p. 252, Pl. 1790. as *Procellaria fuliginosa* appears to be the form frequenting the Cape seas, but as White says absolutely nothing about where he observed or procured it we cannot, of course, decide anything. The constancy in measurements of these birds is again noticeable when breeding birds are examined. Six specimens from the Auckland and Antipodes Islands in the Rothschild Museum give the wing-measurement as 382, 382, 382, 384, 386 mm., the sixth moulting. The specimens in the British Museum are between the extremes, being 383, 385.

NOTE – Forster described *Procellaria nigra* (*Descr. Anim.*, ed. Licht., p. 26. 1844) from a specimen apparently like my *P.a. mixta*. His name was however proposed as a substitute name for Linne's *P. aequinoctialis*. I have treated it as such, and not as recognisable as a different name to be used for a different race. The type-locality of Forster's *P. nigra* would therefore be Falkland Islands.

* *Trans. New Zeal. Inst.* 1894. Vol. XXVII., p. 177, 1896.

Appendix 2.1

Examples of the three autopsy sheets used to enter the data onto. The third sheet was used for entering bill descriptions and sketches.



GENERAL SEABIRD AUTOPSY dec 01
BY DATE / / 02

Length of Right Ventricle . Width of Heart .

Length of Small Intestine Weight of Small Intestine .

Description of Heart

Weight of Heart .

Description of Small Intestine

Length of Right Lobe of Liver .

Length of Left Lobe of Liver . Weight of Liver .

Description of Right Lobe of Liver

Description of Left Lobe of Liver

L Length of Testes . L Width of Testes .

R Length of Testes . R Width of Testes .

L Description of Testes

L Weight of Testes .

R Description of Testes

R Weight of Testes .

L Length of Kidneys . L Weight of Kidneys .

R Length of Kidneys . R Weight of Kidneys .

L Description of Kidneys

R Description of Kidneys

Fat score

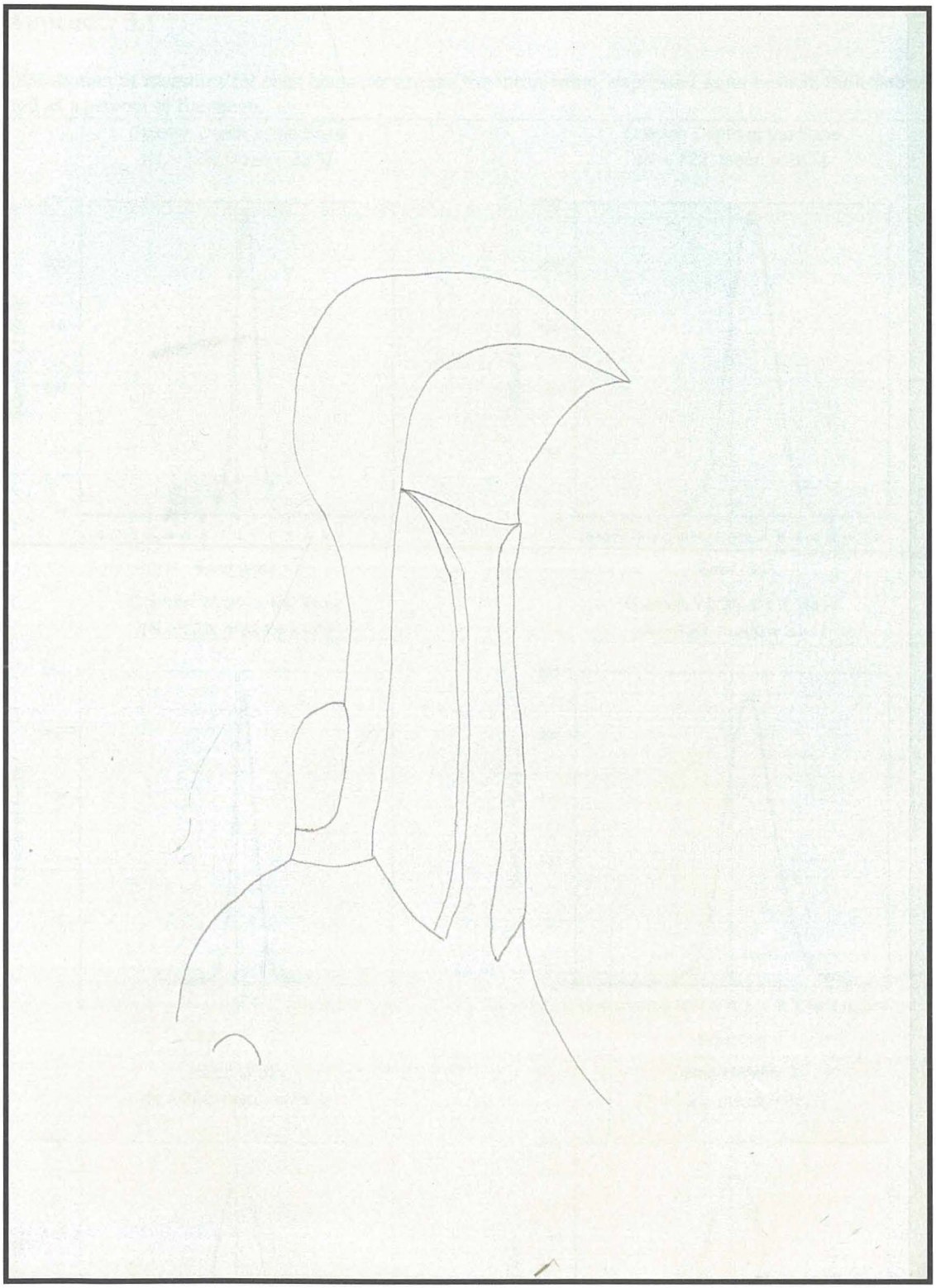
1 2 3 4 5 U

NOTES

Length of Gall Bladder .

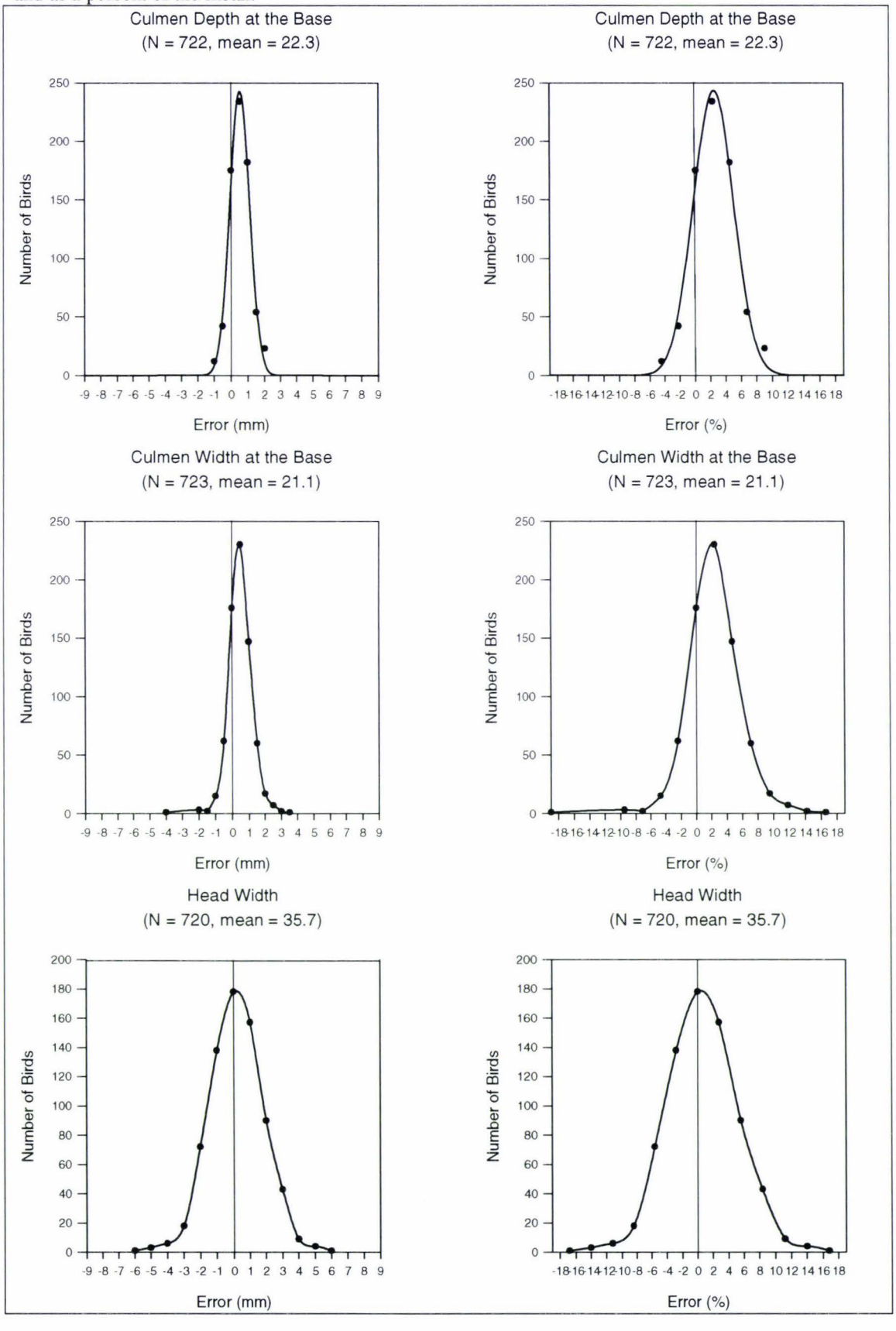
Description of Gall Bladder

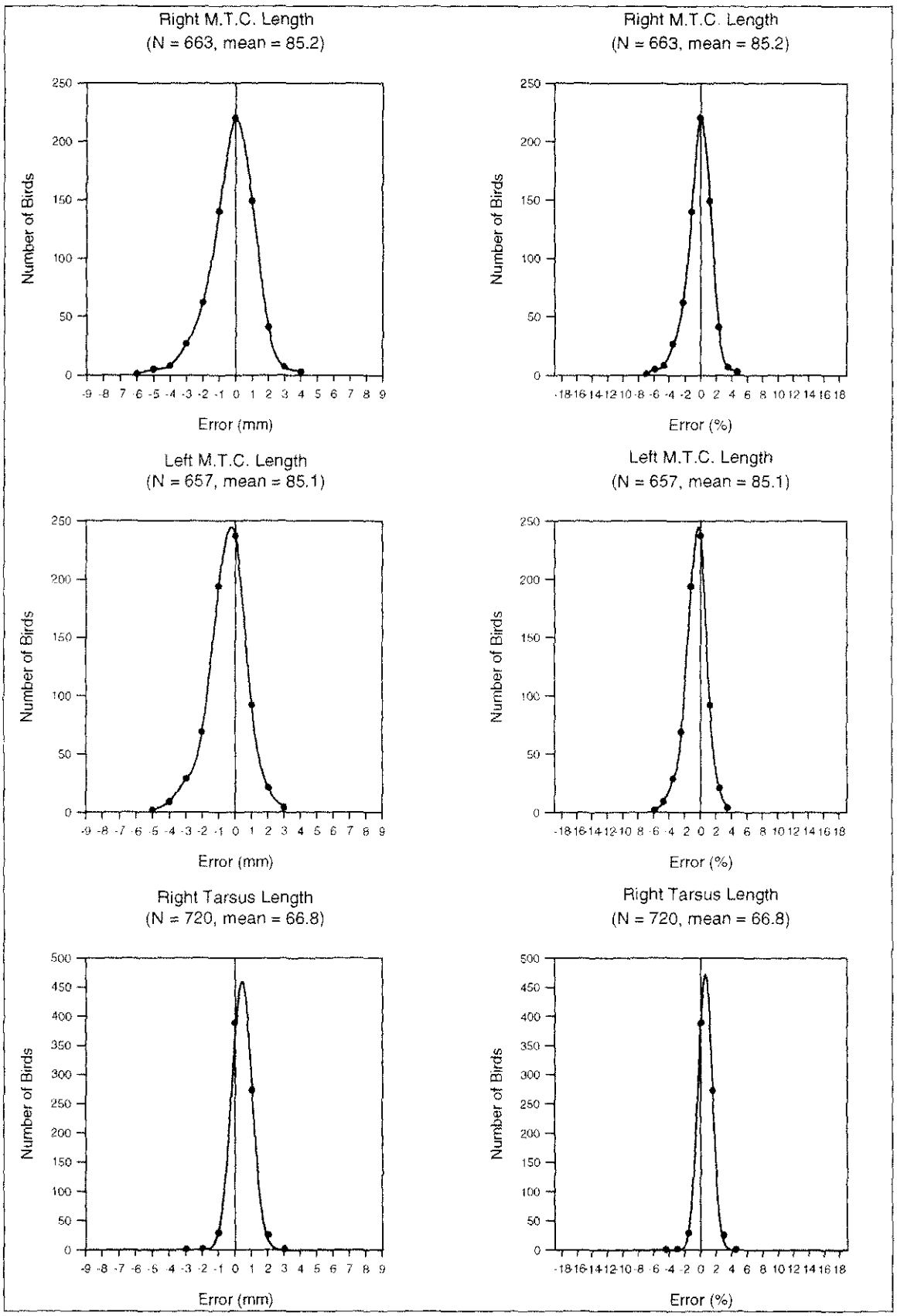
Photos	Disposal	Box

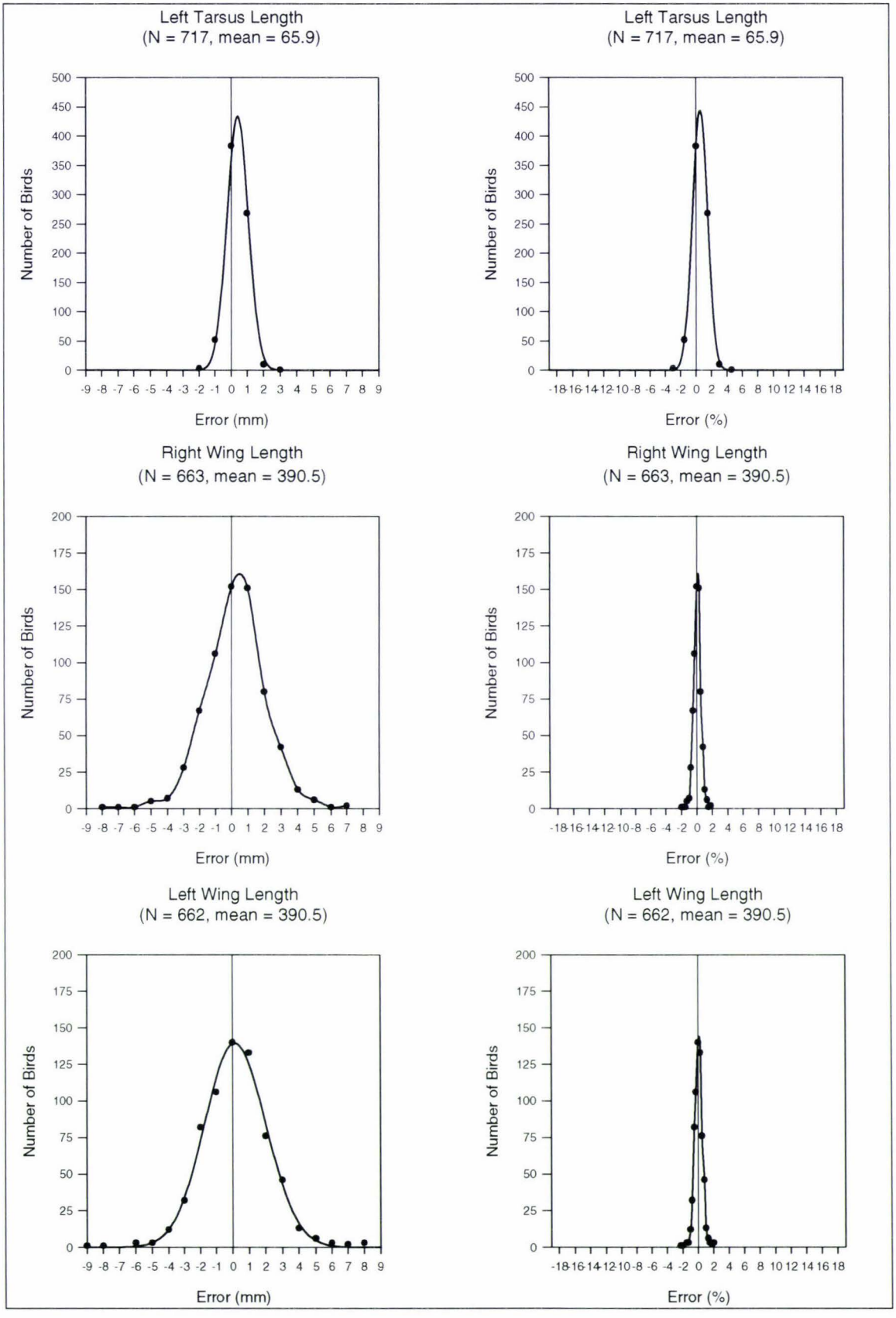


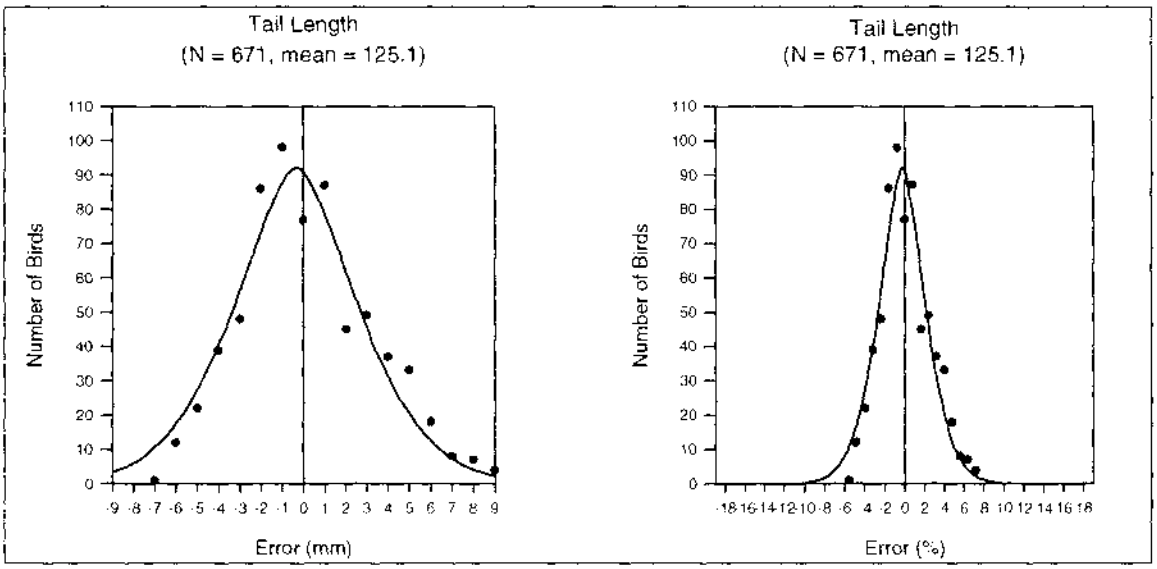
Appendix 3.1

Distribution of measures for each character around the mean value, expressed as an error in millimetres and as a percent of the mean.




Right M.T.C. Length
(N = 663, mean = 85.2)
Number of Birds
Error (mm)
Right M.T.C. Length
(N = 663, mean = 85.2)
Number of Birds
Error (%)
Left M.T.C. Length
(N = 657, mean = 85.1)
Number of Birds
Error (mm)
Left M.T.C. Length
(N = 657, mean = 85.1)
Number of Birds
Error (%)
Right Tarsus Length
(N = 720, mean = 66.8)
Number of Birds
Error (mm)
Right Tarsus Length
(N = 720, mean = 66.8)
Number of Birds
Error (%)


Left Tarsus Length
(N = 717, mean = 65.9)
Number of Birds
Error (mm)
Left Tarsus Length
(N = 717, mean = 65.9)
Number of Birds
Error (%)
Right Wing Length
(N = 663, mean = 390.5)
Number of Birds
Error (mm)
Right Wing Length
(N = 663, mean = 390.5)
Number of Birds
Error (%)
Left Wing Length
(N = 662, mean = 390.5)
Number of Birds
Error (mm)
Left Wing Length
(N = 662, mean = 390.5)
Number of Birds
Error (%)


Tail Length
(N = 671, mean = 125.1)
Number of Birds
Error (mm)
Tail Length
(N = 671, mean = 125.1)
Number of Birds
Error (%)

Appendix 3.2

Principal component analysis of 'the white-chinned petrel sample'.

Output of the principal component analysis of 'the white-chinned petrel sample' using 12 variables.

Eigenanalysis of the Correlation Matrix
550 cases used, 173 cases contain missing values

Eigenvalue	5.0315	1.2714	1.0742	0.9240	0.8568	0.7043	0.5910	0.4876
Proportion	0.419	0.106	0.090	0.077	0.071	0.059	0.049	0.041
Cumulative	0.419	0.525	0.615	0.692	0.763	0.822	0.871	0.912

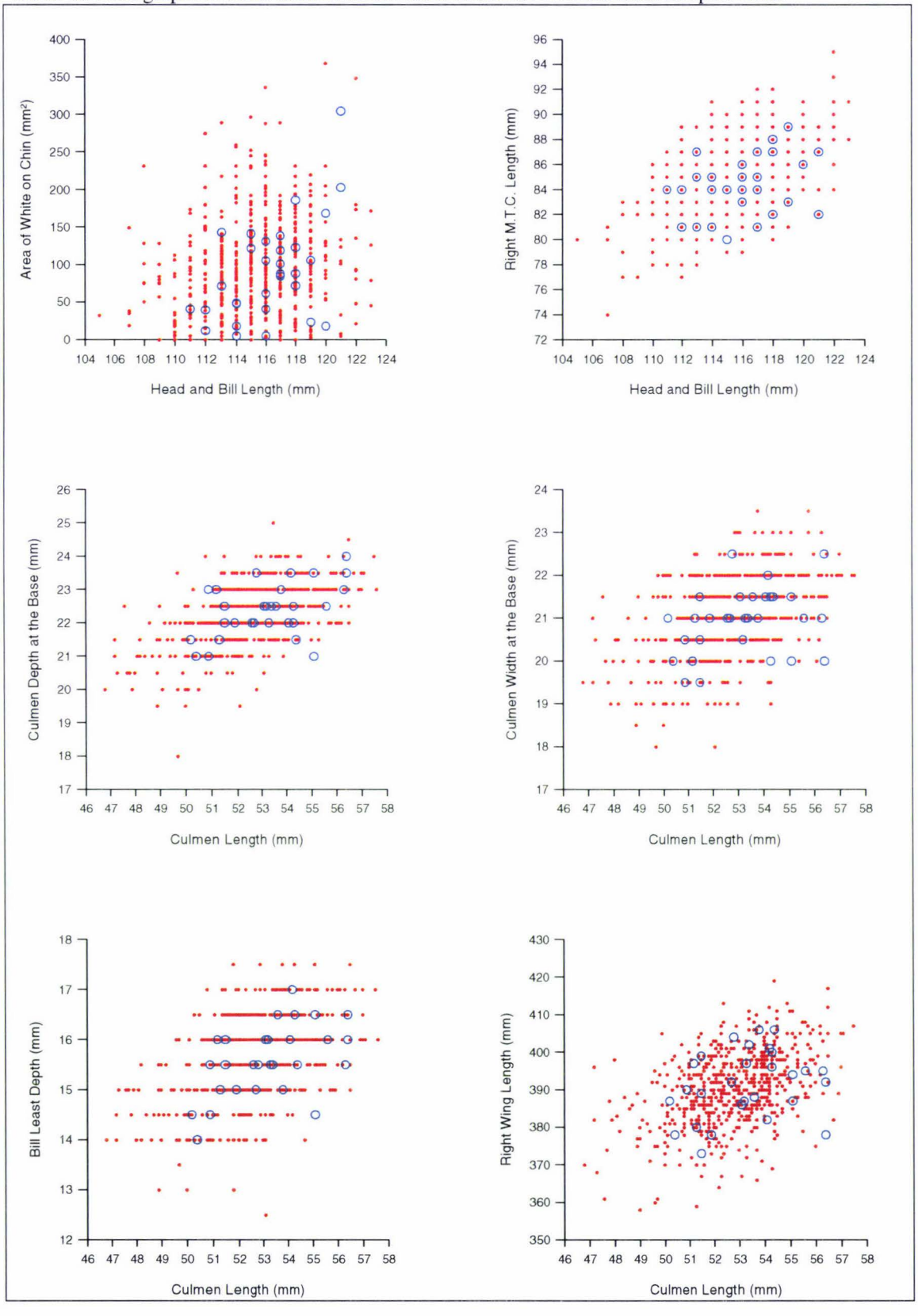
Eigenvalue	0.3484	0.3224	0.2580	0.1305
Proportion	0.029	0.027	0.021	0.011
Cumulative	0.941	0.968	0.989	1.000

Variable	PC1	PC2	PC3	PC4	PC5	PC6
Head + bill length	-0.379	0.054	-0.022	-0.056	-0.257	-0.307
Head width	-0.280	-0.139	0.114	-0.046	0.049	0.705
Culmen length	-0.349	0.036	0.092	-0.061	-0.374	-0.388
Culmen depth at base	-0.349	-0.288	0.043	-0.208	0.036	0.014
Culmen width at base	-0.297	-0.353	0.061	-0.176	0.018	0.264
Bill least depth	-0.312	-0.287	-0.009	-0.314	0.112	-0.247
Minimum nostril width	-0.147	-0.338	0.231	0.592	0.572	-0.286
Nostril length	-0.178	0.091	0.480	0.523	-0.490	0.171
R. MTC length	-0.275	0.078	-0.577	0.310	0.067	0.078
R. tarsus length	-0.312	0.215	-0.435	0.233	0.004	0.087
Tail length	-0.202	0.510	0.408	-0.196	0.392	-0.012
R. wing length (ruler)	-0.286	0.501	0.019	-0.070	0.229	0.048

Variable	PC7	PC8	PC9	PC10	PC11	PC12
Head + bill length	0.351	0.047	0.039	0.033	0.020	-0.749
Head width	0.483	-0.382	-0.079	-0.019	0.028	0.025
Culmen length	0.379	0.048	-0.064	-0.105	-0.077	0.638
Culmen depth at base	-0.365	-0.077	-0.082	0.009	-0.775	-0.049
Culmen width at base	-0.089	0.766	0.097	-0.002	0.274	0.040
Bill least depth	-0.347	-0.484	0.059	0.029	0.535	0.049
Minimum nostril width	0.186	0.030	-0.116	0.046	-0.011	0.005
Nostril length	-0.402	-0.083	0.060	-0.039	0.107	-0.048
R. MTC length	-0.091	-0.029	0.299	-0.617	-0.011	0.027
R. tarsus length	-0.076	0.012	0.084	0.758	0.001	0.135
Tail length	0.009	0.027	0.575	-0.006	-0.076	0.046
R. wing length (ruler)	-0.168	0.112	-0.724	-0.167	0.118	-0.026

Appendix 3.3

Combinations of external measurements for adults and non-adults in 'the white-chinned petrel sample' showing non-adults were similar in size to adult white-chinned petrels. Red crosses = adult white-chinned petrels (n = 691); and blue circles = non-adult white-chinned petrels (n = 31). Sample sizes differ between graphs because some measurements could not be taken from all specimens.



Appendix 3.4

Principal component analysis of adult male and female white-chinned petrels.

Output of the principal component analysis of adult male and female white-chinned petrels in 'the white-chinned petrel sample' using 12 variables.

Eigenanalysis of the Correlation Matrix
519 cases used, 165 cases contain missing values

Eigenvalue	5.0903	1.2565	1.0575	0.9490	0.8442	0.6876	0.5875	0.4796
Proportion	0.424	0.105	0.088	0.079	0.070	0.057	0.049	0.040
Cumulative	0.424	0.529	0.617	0.696	0.766	0.824	0.873	0.913

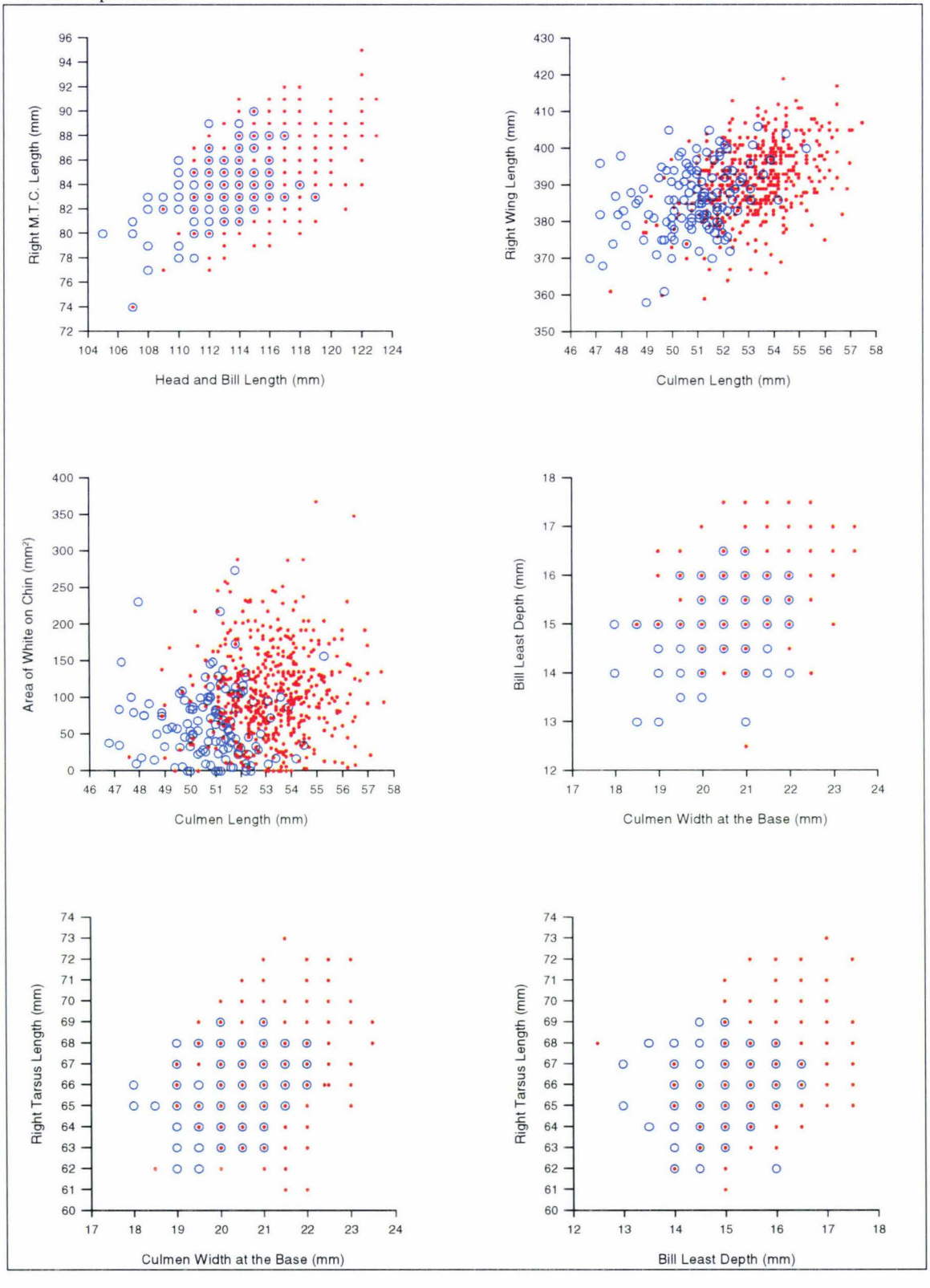
Eigenvalue	0.3510	0.3060	0.2570	0.1338
Proportion	0.029	0.025	0.021	0.011
Cumulative	0.942	0.967	0.989	1.000

Variable	PC1	PC2	PC3	PC4	PC5	PC6
Head + bill length	-0.378	-0.039	-0.000	0.066	0.209	0.342
Head width	-0.284	0.117	0.169	0.029	-0.047	-0.669
Culmen length	-0.348	-0.018	0.114	0.076	0.318	0.440
Culmen depth at base	-0.347	0.290	0.027	0.209	-0.042	-0.048
Culmen width at base	-0.297	0.354	0.081	0.170	0.012	-0.288
Bill least depth	-0.309	0.294	-0.028	0.306	-0.157	0.233
Minimum nostril width	-0.139	0.350	0.126	-0.656	-0.558	0.247
Nostril length	-0.178	-0.084	0.487	-0.506	0.515	-0.117
R. MTC length	-0.280	-0.095	-0.582	-0.272	0.000	-0.102
R. tarsus length	-0.313	-0.227	-0.441	-0.198	0.061	-0.126
Tail length	-0.204	-0.496	0.406	0.145	-0.454	0.015
R. wing length (ruler)	-0.287	-0.502	0.007	0.044	-0.202	-0.038

Variable	PC7	PC8	PC9	PC10	PC11	PC12
Head + bill length	-0.342	-0.056	-0.046	0.064	-0.018	0.751
Head width	-0.512	0.387	0.110	-0.032	-0.040	-0.018
Culmen length	-0.375	-0.050	0.064	-0.105	0.086	-0.632
Culmen depth at base	0.364	0.087	0.062	-0.041	0.774	0.054
Culmen width at base	0.088	-0.757	-0.090	0.024	-0.277	-0.049
Bill least depth	0.351	0.479	-0.041	0.045	-0.534	-0.054
Minimum nostril width	-0.129	-0.054	0.122	0.066	0.026	-0.011
Nostril length	0.396	0.111	-0.073	-0.044	-0.106	0.046
R. MTC length	0.055	0.016	-0.281	-0.637	-0.041	-0.013
R. tarsus length	0.065	0.016	-0.130	0.743	0.038	-0.152
Tail length	0.012	-0.042	-0.558	-0.029	0.063	-0.049
R. wing length (ruler)	0.190	-0.133	0.735	-0.122	-0.107	0.029

Appendix 3.5

Combinations of external measurements for adult male and female white-chinned petrels showing adult males were similar larger in size to adults. Red crosses = adult males (n = 547); and blue circles = adult females (n = 138). Sample sizes differ between graphs because some measurements could not be taken from all specimens.



Appendix 3.6

Principal component analysis of the 'Auckland and Antipodes Island cluster groups'.

Output of the principal component analysis of the 'Auckland Island cluster group' and the 'Antipodes Island cluster group' using 10 variables.

Eigenanalysis of the Correlation Matrix
108 cases used, 42 cases contain missing values

Eigenvalue	4.4955	1.3666	1.0227	0.8823	0.7521	0.4679	0.3764	0.3209
Proportion	0.450	0.137	0.102	0.088	0.075	0.047	0.038	0.032
Cumulative	0.450	0.586	0.688	0.777	0.852	0.899	0.936	0.968

Eigenvalue	0.2072	0.1084
Proportion	0.021	0.011
Cumulative	0.989	1.000

Variable	PC1	PC2	PC3	PC4	PC5	PC6
Head + bill length	-0.407	-0.036	-0.052	0.108	-0.472	0.048
Head width	-0.213	0.355	0.313	-0.686	-0.020	-0.452
Culmen length	-0.362	-0.019	-0.091	0.112	-0.666	-0.125
Culmen depth at base	-0.357	0.327	-0.177	0.159	0.289	-0.162
Culmen width at base	-0.278	0.488	0.133	-0.131	0.070	0.764
Bill least depth	-0.316	0.259	-0.383	0.368	0.316	-0.254
R. MTC length	-0.280	-0.189	0.585	0.287	0.250	-0.191
R. tarsus length	-0.333	-0.324	0.359	0.050	0.117	0.089
Tail length	-0.256	-0.345	-0.464	-0.463	0.186	-0.020
R. wing length (ruler)	-0.313	-0.447	-0.097	-0.170	0.186	0.243

Variable	PC7	PC8	PC9	PC10
Head + bill length	-0.154	-0.062	-0.031	-0.752
Head width	0.068	0.043	-0.216	-0.047
Culmen length	0.163	-0.038	0.075	0.596
Culmen depth at base	0.209	0.423	0.609	-0.081
Culmen width at base	-0.059	0.199	-0.007	0.134
Bill least depth	-0.142	-0.158	-0.578	0.089
R. MTC length	0.117	-0.553	0.208	0.005
R. tarsus length	-0.533	0.545	-0.135	0.180
Tail length	-0.354	-0.352	0.306	0.090
R. wing length (ruler)	0.675	0.151	-0.296	-0.066

Appendix 3.7

Discriminant analysis results for comparing the 'Auckland and Antipodes Island cluster groups'.

'Auckland Island Cluster Group' = 1
'Antipodes Island Cluster group' = 2

Predictors: Head and bill length; right tarsometatarsus length; and tail length

Cluster Group	1	2
Count	36	92

Total sample = 128, but 22 birds did not have all measurements taken and were excluded

Summary of Classification

	True Cluster Group	
Put into Cluster Group	1	2
1	31	5
2	5	87
Total N	36	92
N correct	31	87
Proportion (%)	86.1	94.6

N = 128 N Correct = 118 Proportion Correct = **92.2%**

Summary of Classification with Cross-validation

	True Cluster Group	
Put into Cluster Group	1	2
1	31	6
2	5	86
Total N	36	92
N correct	31	86
Proportion (%)	86.1	93.5

N = 128 N Correct = 117 Proportion Correct = **91.4%**

Squared distance between 'cluster groups'

	1	2
1	0.00000	6.59011
2	6.59011	0.00000

Linear Discriminant Function for 'cluster groups'

	1	2
Constant	-1332.6	-1440.3
Head and bill length	12.7	13.2
Right Tarsometatarsus length	11.0	10.9
Tail length	4.2	4.6

	Pooled Mean	Mean for Cluster Groups	
Variable		1	2
Head and bill length	115.89	113.36	116.88
Right tarsometatarsus length	67.016	66.00	67.41
Tail length	126.46	118.86	129.43

	Pooled Stdev	Stdev for Cluster Groups	
Variable		1	2
Head and bill length	2.548	3.035	2.334
Right tarsometatarsus length	1.700	2.042	1.549
Tail length	4.585	6.015	3.898

Stdev = standard deviation

Appendix 3.8

Discriminant analysis results for comparing the 'Auckland Island cluster group' males and females.

'Auckland Island Cluster Group' males = 1
'Auckland Island Cluster group' females = 2

Predictors: Head and bill length; and culmen depth at the base

Group	1	2
Count	28	16

Total sample = 44, but 1 bird did not have all measurements taken and was excluded

Summary of Classification

	True Group	
Put into Group	1	2
1	27	0
2	1	16
Total N	28	16
N correct	27	16
Proportion (%)	96.4	100.0

N = 44 N Correct = 43 Proportion Correct = **97.7%**

Summary of Classification with Cross-validation

	True Group	
Put into Group	1	2
1	26	0
2	2	16
Total N	28	16
N correct	26	16
Proportion (%)	92.9	100.0

N = 44 N Correct = 42 Proportion Correct = **95.5%**

Squared distance between groups

	1	2
1	0.00000	6.66075
2	6.66075	0.00000

Linear Discriminant Function for groups

	1	2
Constant	-1728.1	-1586.9
Head and bill length	25.1	24.3
Culmen depth at the base	25.3	23.0

	Pooled Mean	Mean for Groups	
Variable		1	2
Head and bill length	113.23	114.82	110.44
Culmen depth at the base	21.96	22.45	21.09

	Pooled Stdev	Stdev for Groups	
Variable		1	2
Head and bill length	2.024	1.982	2.097
Culmen depth at the base	0.651	0.6286	0.6884

Stdev = standard deviation

Appendix 3.9

Discriminant analysis results for comparing the 'Antipodes Island cluster group' males and females.

'Antipodes Island Cluster Group' males = 1
'Antipodes Island Cluster group' females = 2

Predictors: Head and bill length; head width; culmen depth at the base; and right MTC length

Group	1	2
Count	77	8

Total sample = 85, but 20 birds did not have all measurements taken and were excluded

Summary of Classification

	True Group	
Put into Group	1	2
1	71	0
2	6	8
Total N	77	8
N correct	71	8
Proportion (%)	92.2	100.0

N = 85 N Correct = 79 Proportion Correct = **92.9%**

Summary of Classification with Cross-validation

	True Group	
Put into Group	1	2
1	70	0
2	7	8
Total N	77	8
N correct	70	8
Proportion (%)	90.9	100.0

N = 85 N Correct = 78 Proportion Correct = **91.8%**

Squared distance between groups

	1	2
1	0.00000	8.57340
2	8.57340	0.00000

Linear Discriminant Function for groups

	1	2
Constant	-2547.2	-2377.3
Head and bill length	21.9	21.4
Head width	29.6	28.5
Culmen depth at the base	55.5	51.1
Right MTC length	2.4	2.7

	Pooled Mean	Mean for Groups	
Variable		1	2
Head and bill length	116.94	117.17	114.75
Head width	35.81	35.94	34.63
Culmen depth at the base	22.61	22.74	21.31
Right MTC length	85.46	85.58	84.25

	Pooled Stdev	Stdev for Groups	
Variable		1	2
Head and bill length	2.169	2.221	1.488
Head width	1.056	1.080	0.744
Culmen depth at the base	0.5626	0.5827	0.2588
Right MTC length	2.523	2.562	2.053

Stdev = standard deviation

Appendix 3.10

Discriminant analysis results for comparing the 'Auckland and Antipodes Island cluster group' males (best function).

'Auckland Island Cluster Group' males = 1
'Antipodes Island Cluster group' males = 2

Predictors: Culmen length; and tail length

Cluster Group	1	2
Count	24	83

Total sample = 107, but 17 birds did not have all measurements taken and were excluded

Summary of Classification

	True Cluster Group	
Put into Cluster Group	1	2
1	21	4
2	3	79
Total N	24	83
N correct	21	79
Proportion (%)	87.5	95.2

N = 107 N Correct = 100 Proportion Correct = **93.5%**

Summary of Classification with Cross-validation

	True Cluster Group	
Put into Cluster Group	1	2
1	21	4
2	3	79
Total N	24	83
N correct	21	79
Proportion (%)	87.5	95.2

N = 107 N Correct = 100 Proportion Correct = **93.5%**

Squared distance between 'cluster groups'

	1	2
1	0.00000	7.78100
2	7.78100	0.00000

Linear Discriminant Function for 'cluster groups'

	1	2
Constant	-1117.7269	-1232.5660
Culmen length	27.7287	28.4585
Tail length	9.5919	7.2046

	Pooled Mean	Mean for Cluster Groups	
Variable		1	2
Culmen length	53.47	52.41	53.78
Tail length	127.25	118.67	129.73

	Pooled Stdev	Stdev for Cluster Groups	
Variable		1	2
Culmen length	1.377	1.063	1.452
Tail length	4.253	6.162	3.538

Stdev = standard deviation

Appendix 3.11

Discriminant analysis results for comparing the 'Auckland and Antipodes Island cluster group' males (alternate function).

'Auckland Island Cluster Group' males = 1
'Antipodes Island Cluster group' males = 2

Predictors: Head and bill length; and culmen width at the base

Cluster Group	1	2
Count	28	88

Total sample = 116, but 8 birds did not have all measurements taken and were excluded

Summary of Classification

	True Cluster Group	
Put into Cluster Group	1	2
1	22	21
2	6	67
Total N	28	88
N correct	22	67
Proportion (%)	78.6	76.1

N = 116 N Correct = 89 Proportion Correct = **76.7%**

Summary of Classification with Cross-validation

	True Cluster Group	
Put into Cluster Group	1	2
1	22	21
2	6	67
Total N	28	88
N correct	22	67
Proportion (%)	78.6	76.1

N = 116 N Correct = 89 Proportion Correct = **76.7%**

Squared distance between 'cluster groups'

	1	2
1	0.00000	1.40240
2	1.40240	0.00000

Linear Discriminant Function for 'cluster groups'

	1	2
Constant	-1521.5182	-1572.4441
Head and bill length	21.6694	22.2274
Culmen width at the base	26.0265	25.3775

	Pooled Mean	Mean for Cluster Groups	
Variable		1	2
Head and bill length	116.66	114.82	117.24
Culmen width at the base	21.26	21.32	21.24

	Pooled Stdev	Stdev for Cluster Groups	
Variable		1	2
Head and bill length	2.193	1.982	2.254
Culmen width at the base	0.692	0.656	0.703

Stdev = standard deviation

Appendix 3.12

Discriminant analysis results for comparing the 'Auckland and Antipodes Island cluster group' females (best function).

'Auckland Island Cluster Group' females = 1
'Antipodes Island Cluster group' females = 2

Predictors: Head and bill length; culmen depth at the base; and right wing length

Cluster Group	1	2
Count	15	10

Total sample = 25, but 1 bird did not have all measurements taken and was excluded

Summary of Classification

	True Cluster Group	
Put into Cluster Group	1	2
1	15	0
2	0	10
Total N	15	10
N correct	15	10
Proportion (%)	100.0	100.0

N = 25 N Correct = 25 Proportion Correct = **100.0%**

Summary of Classification with Cross-validation

	True Cluster Group	
Put into Cluster Group	1	2
1	14	1
2	1	9
Total N	15	10
N correct	14	9
Proportion (%)	93.3	90.0

N = 25 N Correct = 23 Proportion Correct = **92.0%**

Squared distance between 'cluster groups'

	1	2
1	0.00000	7.53526
2	7.53526	0.00000

Linear Discriminant Function for 'cluster groups'

	1	2
Constant	-3388.3883	-3609.0997
Head and bill length	24.1895	25.2256
Culmen depth at the base	51.7748	52.2360
Right wing length	7.9047	8.1482

	Pooled Mean	Mean for Cluster Groups	
Variable		1	2
Head and bill length	112.04	110.40	114.50
Culmen depth at the base	21.22	21.10	21.40
Right wing length	386.44	381.27	394.20

	Pooled Stdev	Stdev for Cluster Groups	
Variable		1	2
Head and bill length	1.912	2.165	1.434
Culmen depth at the base	0.626	0.712	0.460
Right wing length	7.207	7.778	6.215

Stdev = standard deviation

Appendix 3.13

Discriminant analysis results for comparing the 'Auckland and Antipodes Island cluster group' females (alternate function).

'Auckland Island Cluster Group' females = 1
'Antipodes Island Cluster group' females = 2

Predictors: Head and bill length; and culmen depth at the base

Cluster Group	1	2
Count	16	10

Total sample = 26

Summary of Classification

	True Cluster Group	
Put into Cluster Group	1	2
1	14	1
2	2	9
Total N	16	10
N correct	14	9
Proportion (%)	87.5	90.0

N = 26 N Correct = 23 Proportion Correct = **88.5%**

Summary of Classification with Cross-validation

	True Cluster Group	
Put into Cluster Group	1	2
1	14	2
2	2	8
Total N	16	10
N correct	14	8
Proportion (%)	87.5	80.0

N = 26 N Correct = 22 Proportion Correct = **84.6%**

Squared distance between 'cluster groups'

	1	2
1	0.00000	4.69732
2	4.69732	0.00000

Linear Discriminant Function for 'cluster groups'

	1	2
Constant	-1922.5396	-2050.8598
Head and bill length	28.5252	29.6917
Culmen depth at the base	32.9399	32.8049

	Pooled Mean	Mean for Cluster Groups	
Variable		1	2
Head and bill length	112.00	110.44	114.50
Culmen depth at the base	21.21	21.09	21.40

	Pooled Stdev	Stdev for Cluster Groups	
Variable		1	2
Head and bill length	1.876	2.097	1.434
Culmen depth at the base	0.613	0.688	0.460

Stdev = standard deviation

Appendix 3.14

Discriminant analysis results for comparing the 'Auckland and Antipodes Island cluster group' females (alternate function for museum skins).

'Auckland Island Cluster Group' females = 1
'Antipodes Island Cluster group' females = 2

Predictors: Culmen length; culmen depth at the base; and right wing length

Cluster Group	1	2
Count	15	10

Total sample = 25, but 1 individual did not have all measurements taken and was excluded

Summary of Classification

	True Cluster Group	
Put into Cluster Group	1	2
1	13	0
2	2	10
Total N	15	10
N correct	13	10
Proportion (%)	86.7	100.0

N = 25 N Correct = 23 Proportion Correct = **92.0%**

Summary of Classification with Cross-validation

	True Cluster Group	
Put into Cluster Group	1	2
1	12	1
2	3	9
Total N	15	10
N correct	12	9
Proportion (%)	80.0	90.0

N = 25 N Correct = 21 Proportion Correct = **84.0%**

Squared distance between 'cluster groups'

	1	2
1	0.00000	4.80478
2	4.80478	0.00000

Linear Discriminant Function for 'cluster groups'

	1	2
Constant	-3194.0175	-3366.3049
Culmen length	36.3717	37.2267
Culmen depth at the base	45.7260	46.4586
Right wing length	9.3844	9.6757

	Pooled Mean	Mean for Cluster Groups	
Variable		1	2
Culmen length	51.12	50.73	51.69
Culmen depth at the base	21.22	21.10	21.40
Right wing length	386.44	381.27	394.20

	Pooled Stdev	Stdev for Cluster Groups	
Variable		1	2
Culmen length	1.211	1.092	1.376
Culmen depth at the base	0.626	0.712	0.460
Right wing length	7.207	7.778	6.215

Stdev = standard deviation

Appendix 3.15

INTERNAL MORPHOLOGY OF WHITE-CHINNED PETRELS

This section shows the results of testicular development of white-chinned petrels and general internal organ descriptions. The relationship between adult left testicular volume (mm^3) and mass (g) was examined using linear regression. Results are expressed as means ± 1 standard error of the mean unless stated otherwise.

1.1 Testicular development of white-chinned petrels

There was a positive relationship between adult left testis volume and mass as shown in Figure 1.1, and described by the linear regression $y = 0.0007x + 0.0251$, where y = testes mass (g) and x = testes volume (mm^3), with $r^2 = 0.827$. Clearly the mass (g) of each left testis correlates to its volume (mm^3), indicating that the measurement of volume based on the length and width of the testes is a valid measure of testis size.

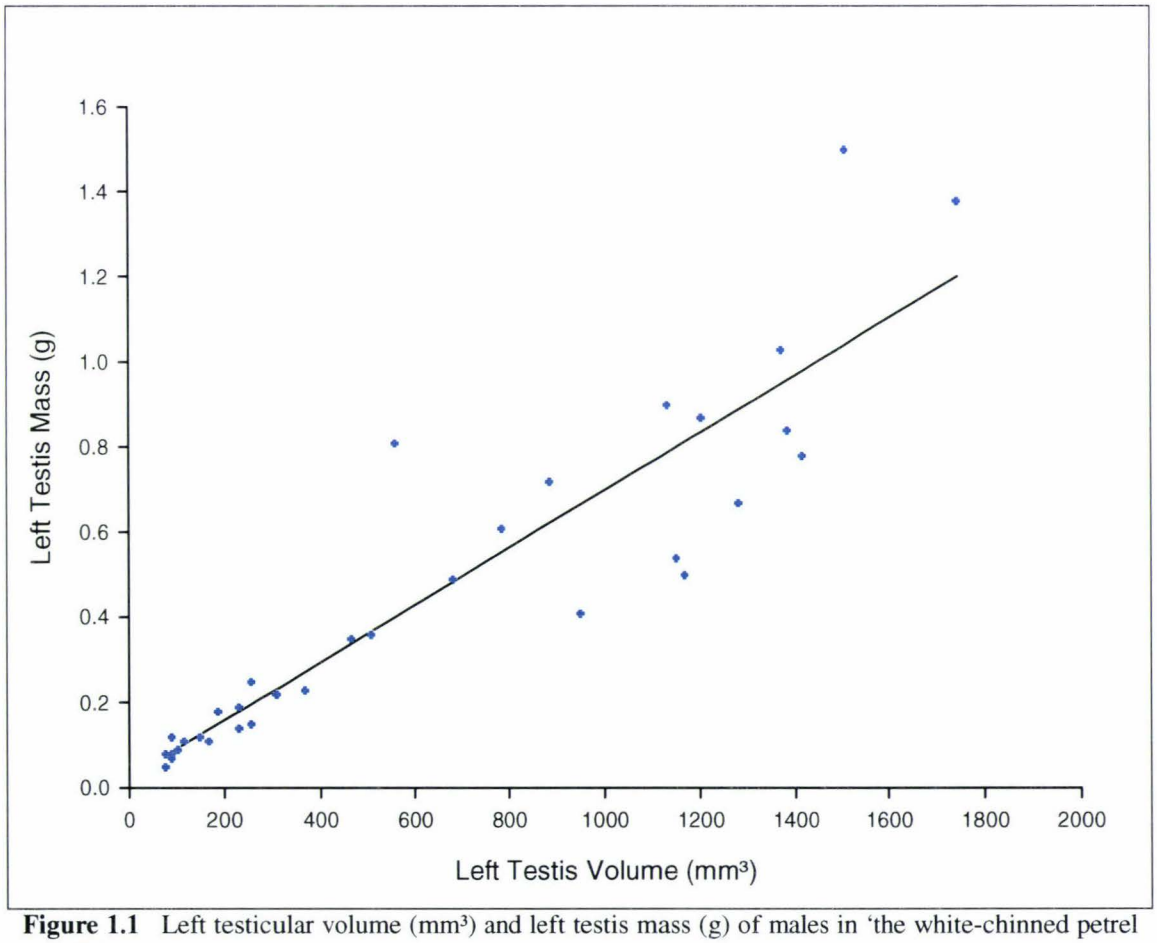


Figure 1.1 Left testicular volume (mm^3) and left testis mass (g) of males in 'the white-chinned petrel sample'.

The reproductive state of white-chinned petrel testes was examined to see if there is a relationship between stage of spermatogenesis and testis volume, and in turn stage of spermatogenesis and testis volume during the breeding season. As shown under the section on sex and age determination above, adult male left testis volume varied in size during the breeding season from being relatively large in September to November, to receding during December, to being relatively small in January to May.

Twenty-five testes from white-chinned petrels were examined, but the testicular tissue was degenerating following severe freezing beforehand and therefore prohibited some fine detail. Results were unattainable from four of the testes because of too much cell degeneration. Eighteen birds were aged as adults and three as non-adults (non-adults all caught in February).

The sample of 21 petrels showed that during the period from November to February testis volume decreased from 1005.27 mm^3 ± 155.17 mm^3 (10) in November, 466.50 mm^3 (1) in December, 104.70 mm^3 (1) in January, to 108.56 mm^3 ± 15.82 mm^3 (9) in February. This result reflects testis volume over time as shown in the section above on sex and age determination. There was a significant difference in left testis volume ($F_{3,17}$ = 10.456, $P < 0.001$, n = 21) within this sample between the period November to February (Figure 1.2), though it is only significant between the months November and February ($P = 4.38^{-5}$) possibly due to small sample sizes in December and January.

There are five stages of testicular development based on development of spermatogenic tubules (ratio of tubule to interstitium and number of tubular cell layers and spermatogenesis): 1) quiescence, 2) spermatagonial multiplication, 3) spermatocyte division and elongation, 4) regression, and 5) rehabilitation as described by Gartrell (2002).

Between November and February all five stages of testicular development were identified in the 21 birds in my sample (Table 1.1 and Plate 1.1). Only one specimen was classed as stage 1 (quiescence), seven as stage two (spermatagonial multiplication), two as stage 3 (spermatocyte division and elongation), one as stage 4 (regression), and seven as stage 5 (rehabilitation).

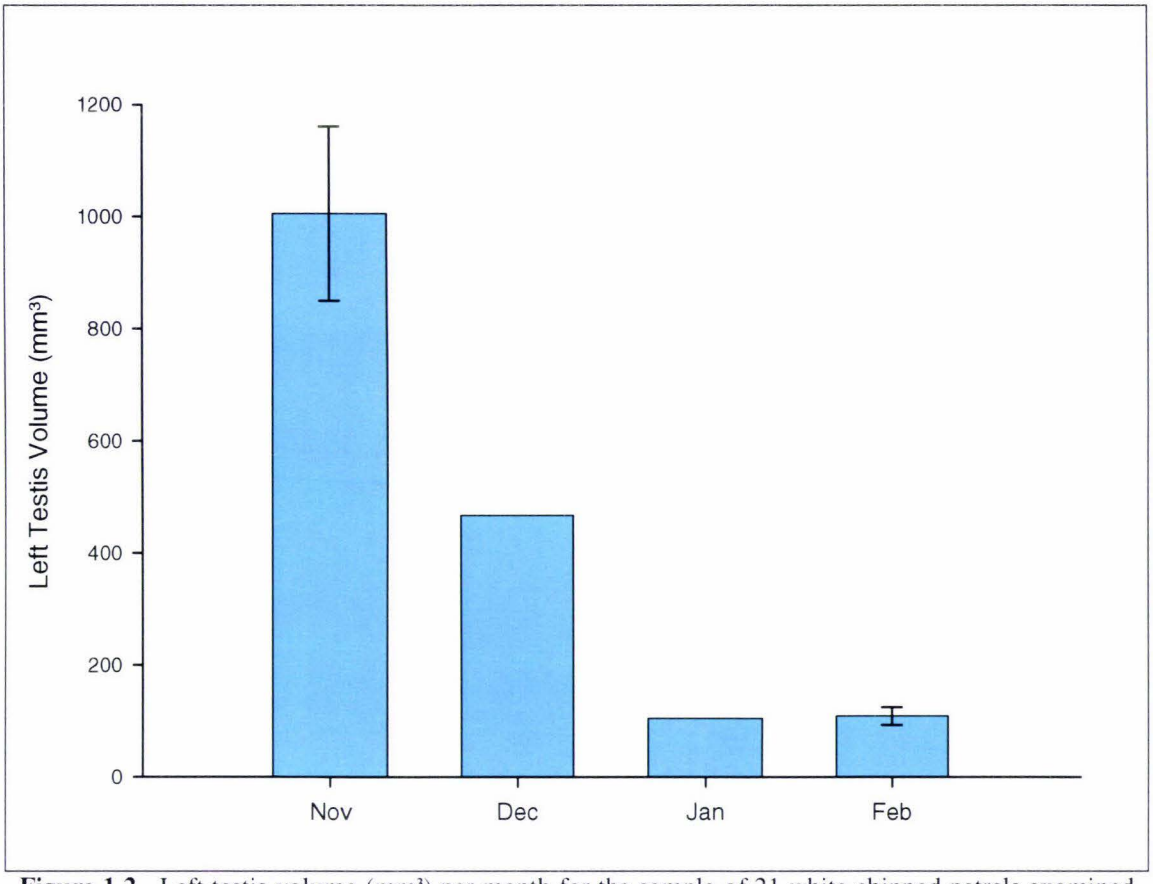


Figure 1.2 Left testis volume (mm^3) per month for the sample of 21 white-chinned petrels examined to look at testicular development. Sample sizes: November, = 10; December, = 1; January, = 1; and February, = 9. Error bars represent ± 1 standard error of the mean.

Average left testis volume of stage 1 was, 119.90 mm^3 ± 37.13 mm^3 (n = 4); stage 2, 1114.84 mm^3 ± 186.03 mm^3 (n = 7); stage 3, 1008.95 mm^3 ± 121.99 mm^3 (n = 2); stage 4, 466.50 mm^3 (n = 1); and stage 5, 119.00 mm^3 ± 19.01 mm^3 (n = 7). Testis volume rose sharply in testicular stage 2 (Figure 1.3) before declining in stages 4 and 5. There was a significant difference ($F_{(4, 16)}$ = 12.563, $P < 0.001$, n = 21) between testicular stage and testis volume. Testicular stages 2 and 3 were significantly larger than all other testicular stages (Figure 1.3).

Table 1.1 Stages of the testicular cycle in white-chinned petrels (n = 21) characterised by interstitial and tubular cells appearance based on Gartrell (2002).

Testicular stage	Tubule (T) to interstitium (I) diameter	Number of tubular cell layers	Spermatogonia cell structure and activity
1. Quiescence	T = I	1-2	Little cytoplasm, no cell division
2. Spermatagonial Multiplication	T > I	2-10	Increased cytoplasmic volume, organised tubular cell progression with larger tubular cells at the edge of the tubule and smaller tubular cells towards the centre of the tubule, no active mitosis seen
3. Spermatocyte division and elongation	T > I	2-10	Spermatogenesis, organised tubular cell progression with larger tubular cells at the edge of the tubule and smaller tubular cells towards the centre of the tubule, no active meiosis seen, but spermatozoa present
4. Regression	T > I	-	No organised tubular cell progression, large tubular cells throughout tubule, no cell division
5. Rehabilitation of the testes	T = I	1-2	Little cytoplasm, no cell division

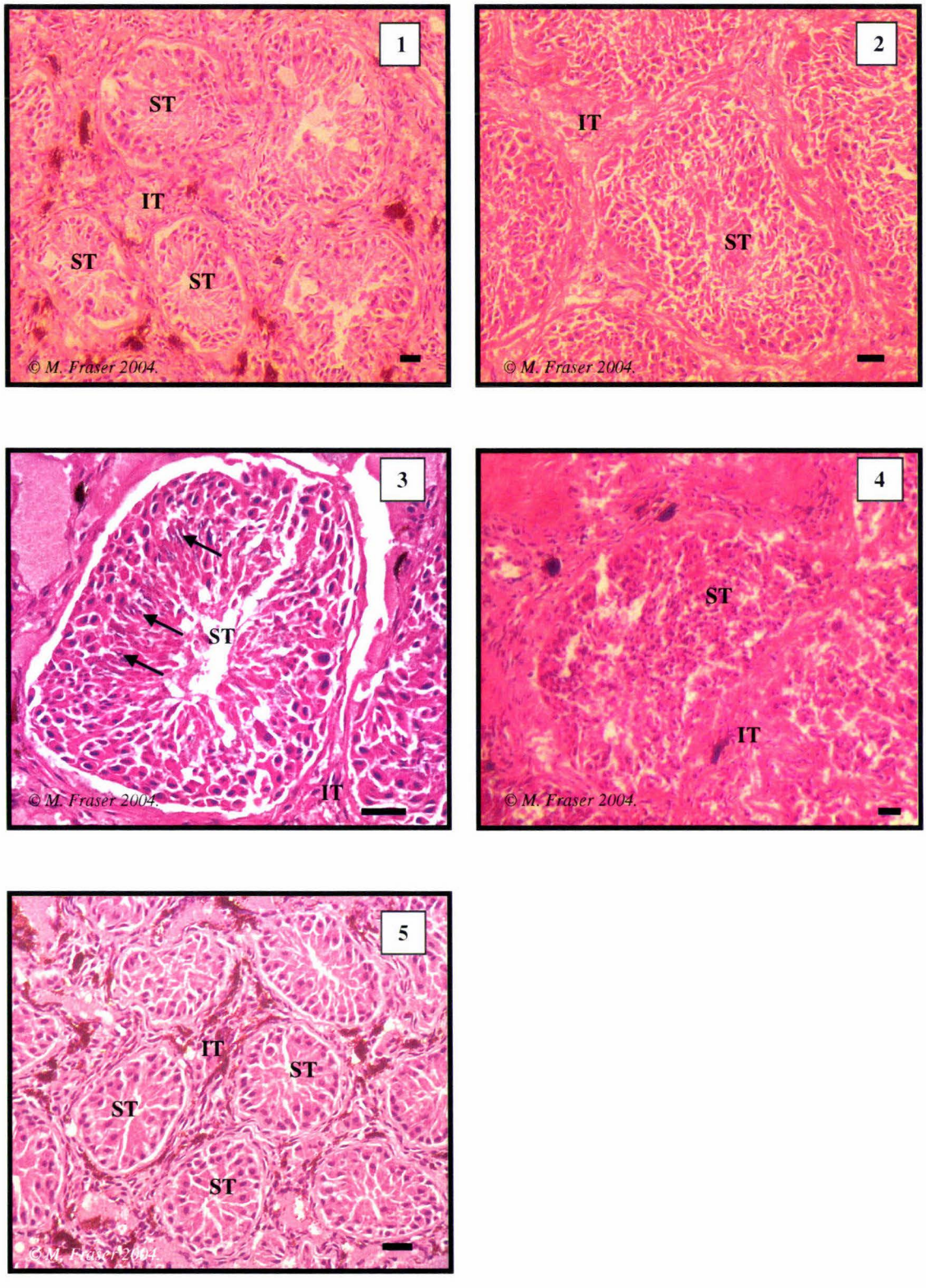


Plate 1.1 Stages of spermatogenesis using histological (haemotoxylin and eosin) techniques. ST indicates seminiferous tubule; IT indicates interstitial tissue; arrows show examples of spermatozoa. Stages: 1 = quiescence; 2 = spermatogonial multiplication; 3 = spermatocyte division and elongation; 4 = regression; and 5 = rehabilitation of the testes. Bars = 10μm.

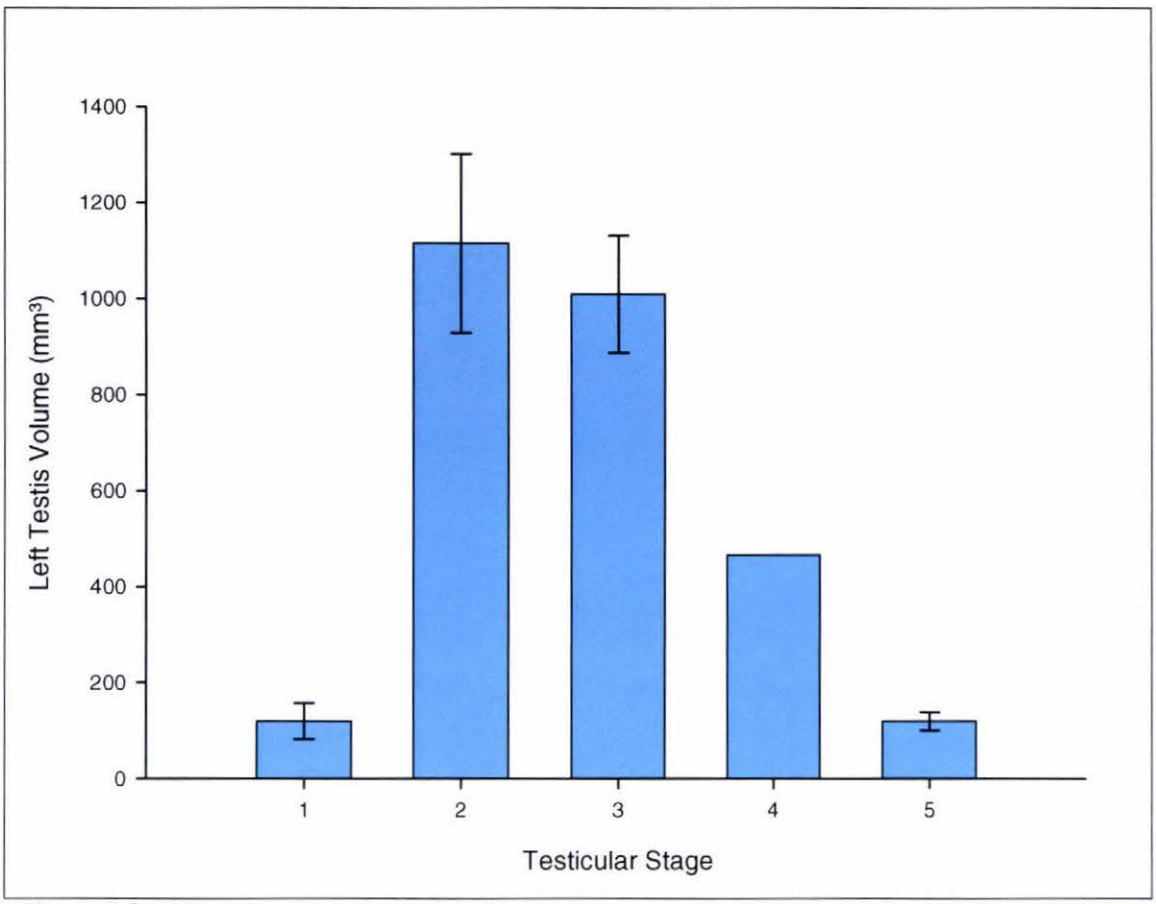


Figure 1.3 The relationship between left testis volume (mm^3) and testicular stage in bycatch white-chinned petrels. 1 = quiescence (n = 4); 2 = spermatogonial multiplication (n = 7); 3 = spermatocyte division and elongation (n = 2); 4 = regression (n = 1); and 5 = rehabilitation of the testes (n = 7). Error bars represent ± 1 standard error of the mean.

The frequency of all five testicular stages varied between November and February, i.e. during the breeding season (Figure 1.4). Stages 1, 2, and 3 were observed in November (n = 10); stage 4 in October (n = 1); stage 5 in January (n = 1); and stages 1 and 5 in February (n = 9). Unfortunately the histological sample did not include any white-chinned petrels caught between September and October, at the start of the breeding season. All three stage 1 birds caught in February were aged as non-adults.

1.2 General Internal Organ Description

This section describes average measurements of white-chinned petrel internal organs to indicate their size, and makes comparisons between adults and non-adults and adult males and females. Internal organ measurements were taken from 34 male and 34 female white-chinned petrels in 'the white-chinned petrel sample'.

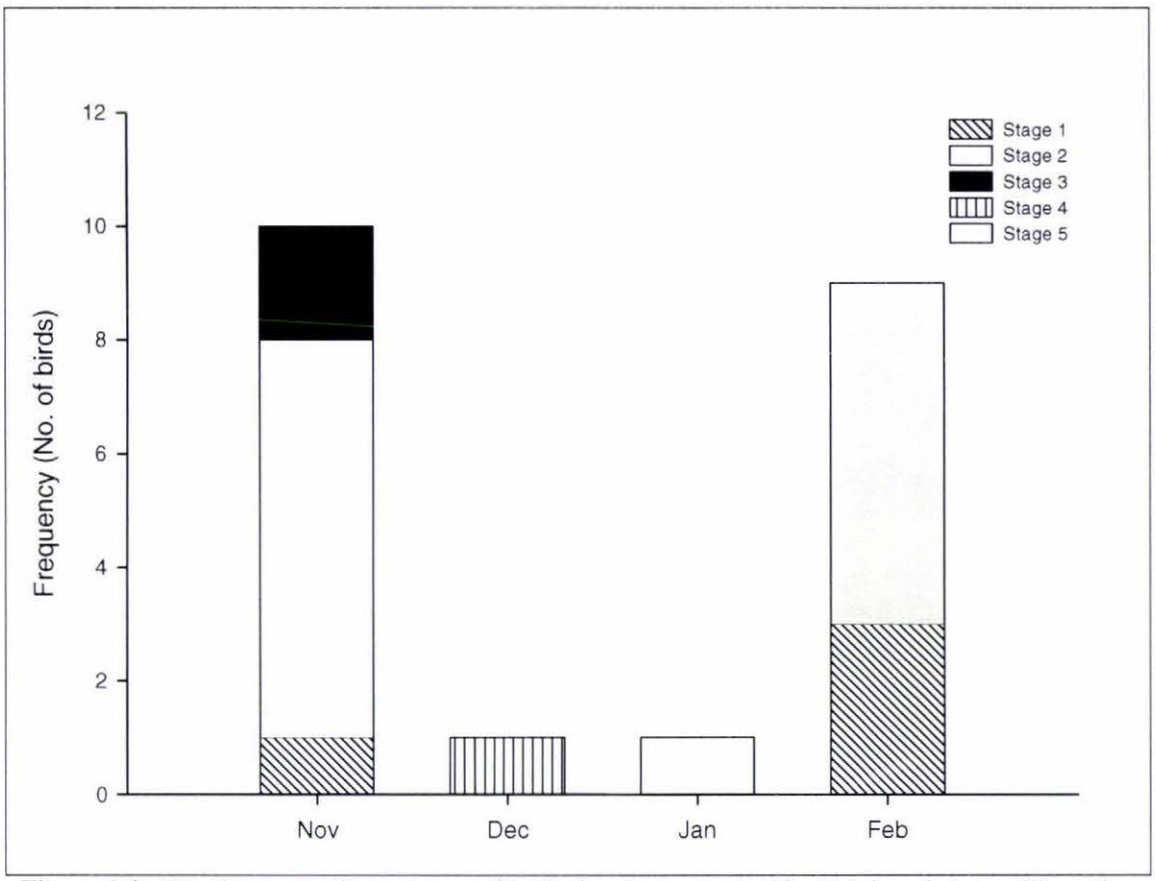


Figure 1.4 The frequency of occurrence of testicular stages assessed by histology between November and February for bycatch white-chinned petrels. Stage 1 = quiescence; stage 2 = spermatogonial multiplication; stage 3 = spermatocyte division and elongation; stage 4 = regression; and stage 5 = rehabilitation of the testes.

Fat Score

Fat score was used to indicate body condition based on the amount of subcutaneous fat, fat on the intestine and fat on the proventriculus and gizzard. The fat scores on average (Table 1.2.) tended to be low for the whole sample (n = 686), adults (n = 655), non-adults (31), adult males (523), and adult females (132). For individuals from which a fat score was taken (n = 686), 401 had a score of 1, 90 a score of 2, 65 a score of 3, 38 a score of 4, and 48 a score of 5. Nineteen also had a score of 1.5, 12 a score of 2.5, 7 a score of 3.5, and 6 a score of 4.5.

Nearly three quarters (73.3 %) of adults and 96.7 % of non-adults had a fat score between 1-2. Also nearly three quarters (71.1 %) of adult males and 80.3 % of adult females had a fat score between 1-2. There was a significant difference in fat score between adults and non-adults ($P < 0.001$), and between adult males and females ($P < 0.001$).

Table 1.2 Average measurements of internal organs taken from 'the white-chinned petrel sample' (n = 723). All Birds = the white-chinned petrel sample (n = 723); FS = fat score; LGB = length of gall bladder; LRV = length of right ventricle; HW = heart width; WH = weight of heart; LSI = length of small intestine; WLG = weight of liver and gall bladder; LRK = length of right kidney; WRK = weight of right kidney; LLK = length of left kidney; WLK = weight of left kidney; SD = standard deviation; SE = standard error; n = sample size. Standard deviations are ± 1 standard deviation of the mean. Standard errors are ± 1 standard error of the mean.

		FS	LGB (mm)	LRV (mm)	HW (mm)	WH (g)	LSI (mm)	WLG (g)	LRK (mm)	WRK (g)	LLK (mm)	WLK (g)
All Birds	mean	2.0	23.94	31.58	34.16	11.21	1364.68	28.16	64.06	5.04	64.67	5.15
	SD	1.27	3.98	2.17	1.68	1.93	129.85	5.12	2.52	0.67	2.74	0.72
	SE	0.05	0.17	0.26	0.21	0.23	15.75	0.85	0.31	0.08	0.33	0.09
	n	686	536	67	67	68	68	36	68	68	68	67
Adults	mean	2.0	24.00	31.54	34.17	11.19	1368.60	27.59	64.07	5.03	64.67	5.13
	SD	1.28	3.94	2.16	1.74	1.98	131.45	4.82	2.59	0.68	2.81	0.73
	SE	0.05	0.17	0.27	0.22	0.25	16.43	0.84	0.32	0.09	0.35	0.09
	n	655	512	63	63	64	64	33	64	64	64	63
Non-adults	mean	1.0	22.58	32.25	34.00	11.66	1301.25	34.45	64.00	5.28	64.75	5.51
	SD	0.46	4.58	2.50	0.00	0.40	89.38	4.61	1.08	0.48	1.32	0.30
	SE	0.08	0.93	1.25	0.00	0.20	44.69	2.66	0.54	0.24	0.66	0.15
	n	31	24	4	4	4	4	3	4	4	4	4
Adult Males	mean	2.0	23.70	32.29	34.94	12.33	1413.94	28.80	63.71	5.11	64.26	5.32
	SD	1.33	3.99	2.05	1.80	2.06	126.16	4.74	2.07	0.65	2.27	0.66
	SE	0.06	0.20	0.37	0.32	0.37	22.66	1.31	0.37	0.12	0.41	0.12
	n	523	412	31	31	31	31	13	31	31	31	30
Adult Females	mean	1.5	25.26	30.81	33.44	10.11	1326.09	26.80	64.40	4.95	65.05	4.96
	SD	0.03	3.49	2.03	1.33	1.14	123.47	4.83	3.00	0.71	3.23	0.77
	SE	0.09	0.25	0.36	0.24	0.20	21.49	1.08	0.52	0.12	0.56	0.13
	n	132	100	32	32	33	33	20	33	33	33	33

Gall bladder length and fat score were slightly negatively correlated (-0.092, n = 686) for 'the white-chinned petrel sample', and for adults (-0.047, n = 655). This means gall bladder length tended to be longer for low fat scores and shorter for high fat scores for all birds and for adults. Non-adults showed a positive correlation (0.378) between gall bladder length and fat score, though the sample size was small (n = 31). Gall bladder length was slightly negatively correlated with fat score for both adult males (-0.021, n = 523) and adult females (-0.073, n = 132).

Heart

The amount of fat at the junction of the atria and right ventricle varied enough to make some measurements unattainable. Forty four petrels had an empty atrium (no blood in it), while 16 had an atrium full of blood. For the whole sample (n = 68) length of the right ventricle varied from 25.0 to 36.0 mm and heart width from 30.9 to 38.5 mm. Heart weight varied from 8.0 to 16.9 g for the whole sample. Heart measures are shown in Table 1.2.

There was no significant difference between adult and non-adult lengths of the right ventricle ($P = 0.528$) and heart width ($P = 0.842$), or heart weight ($P = 0.654$). There were significant differences between adult male and female lengths of the right

ventricle (P = 0.005) and heart widths (P < 0.001). There was also a significant difference in the weight of the heart (P < 0.001) between adult males and females.

Small Intestine

The small intestine varied in general appearance, the amount of fat surrounding the intestine, and how full each small intestine was. Average length of the small intestine is shown in Table 1.2. Overall the small intestine ranged in length from 1028 to 1800 mm (n = 68), a difference of 772 mm. There was no significant difference between adult and non-adult small intestine length (P = 0.318), however there was a significant difference between adult males and females (P = 0.007).

Liver and Gall Bladder

The gall bladder varied in how much bile it contained, and tended to carry some fat if the fat score was above 4. Of 536 measured gall bladders 24.8 % were empty, 18.5 % quarter full, 3.5 % half full, 7.3 % three quarters full, and 45.9 % full. Gall bladder length ranged from 11.0 to 35.0 mm (n = 536) (Table 1.2). There was no significant difference between adults and non-adults gall bladder length (P = 0.088), but there was between adult males and females (P < 0.001).

Because many petrels had a piece of the liver removed, they could not be weighed, but for 36 birds the weight of the liver and gall bladder varied from 20.0 to 39.7 g (Table 1.2). There was a significant difference between adults and non-adults in the weight of the liver and gall bladder (P = 0.024), but not between adult males and females (P = 0.249).

Kidneys

The tri-lobed kidneys were located along the dorsal wall of the abdominal cavity on either side of the backbone. The length of the right kidney varied from 59.0 to 73.0 mm (n = 68), and the weight from 3.8 to 6.5 g (n = 68) (Table 1.2). The length of the left kidney varied from 59.0 to 73.0 mm (n = 68), and the weight from 3.9 to 7.0 g (n = 67) (Table 1.2).

There was no significant difference between adults and non-adults in right kidney length ($P = 0.959$), right kidney weight ($P = 0.472$), left kidney length ($P = 0.953$), or left kidney weight ($P = 0.309$). There was also no significant difference in length of the right and left kidney of adults ($P = 0.213$) or non-adults ($P = 0.414$). There was no significant difference in weight of the right and left kidney of adults ($P = 0.475$) or non-adults ($P = 0.446$).

There was no significant difference between adult males and adult females right kidney length ($P = 0.284$), right kidney weight ($P = 0.369$), left kidney length ($P = 0.260$), or weight ($P = 0.055$). There was no significant difference between the length or weight of the right and left kidney of adult males ($P = 0.324$); ($P = 0.213$). There was also no significant difference between length or weight of the right and left kidney of adult females ($P = 0.403$); ($P = 0.944$).

1.3 References

Gartrell, B. D. 2002. Assessment of the reproductive state in male swift parrots (*Lathamus discolour*) by testicular aspiration and cytology. *Journal of Avian Medicine and Surgery* **16**: 211-217.

Appendix 4.1

Table of published measurements of white-chinned petrels.

Locality	Reference	Month collected	Sex	Wing length (mm ± 1 SD)	Tail length (mm ± 1 SD)	Tarsus length (mm ± 1 SD)	Middle toe and claw length (mm ± 1 SD)	Culmen length (mm ± 1 SD)	Head and bill length (mm ± 1 SD)	Culmen depth at base (mm ± 1 SD)	Culmen least depth (mm ± 1 SD)
South Georgia and South America (skins)	Murphy (1936)	U	M	385 (14) (355-400)	124 (14) (116.3-131.5)	65.6 (14) (60-68.2)	81.1 (14) (78.6-83.7)	51.7 (14) (48.6-55.3)	*	*	*
		U	F	377 (8) (357-383)	123.7 (8) (113-134.1)	63.8 (8) (62.2-66.2)	80.6 (8) (77-84.3)	50.4 (8) (48-51.6)	*	*	*
Valparaiso, Chile (skin)	Falla (1937)	November	M	385 (1)	107 (1)	63 (1)	86 (1)	53 (1)	*	*	*
Bird Island, South Georgia (live birds)	Hall (1987)	September-May	M	396.1 ± 9.0 (26) (397-415)	*	67.0 ± 2.9 (26) (61.5-74.0)	*	53.0 ± 1.2 (26) (50.5-55.2)	*	*	16.4 ± 0.6 (26) (15.1-17.7)
		September-May	F	387.3 ± 7.0 (26) (374-402)	*	63.9 ± 2.4 (26) (60.0-69.0)	*	51.1 ± 1.3 (26) (47.9-53.3)	*	*	15.3 ± 0.6 (26) (14.1-16.4)
Bird Island, South Georgia (all birds - includes unsexed birds)	Hall (1987)	September-May	U	390.7 ± 8.0 (132) (371-415)	*	64.2 ± 3.53 (133) (56-74)	*	52.05 ± 1.7 (133) (47.9-56.7)	*	*	15.6 ± 1.1 (133) (10.9-17.7)
East Island, Crozet Islands (live birds)	Jouventin *et al.* (1985)	U	U	372 ± 11 (30) (350-395)	*	65.0 ± 2.4 (30) (61.0-70.0)	*	52.3 2.0 (30) (47.0-56.0)	*	*	*
Possession Island, Crozet Islands (live birds)	Mougin (1970)	U	U	372 (21) (345-390)	113 (21) (92-131)	64.5 (21) (60.5-67.9)	87.2 (21) (81.2-94.9)	52.1 (21) (49.0-55.5)	*	*	*
Royal Sound, Kerguelen Islands (skin?)	Sharpe (1879)	U	U	381	140	61.0	*	64.7 [8]	*	*	*
Kerguelen Islands (skins)	Falla (1937)	February	M	380 (1)	140 (1)	60 (1)	83 (1)	53 (1)	*	*	*
		February-March	F	378 ± 2.83 (2) (376-380)	129.5 ± 0.71 (2) (129-130)	59.5 ± 0.71 (2) (59-60)	82.5 ± 0.71 (2) (82-83)	51 ± 1.41 (2) (50-52)	*	*	*
At sea 55°S, 55°E (skin)	Falla (1937)	February	F	381 (1)	130 (1)	56 (1)	81 (1)	50 (1)	*	*	*
Kerguelen Islands (skins)	Hall (1987)[4]	U	U	375 (7) (345-381)	125 (7) (108-140)	60.4 (7) (56.0-64.8)	*	51.0 (7) (48.2-53.0)	*	*	*
Kerguelen Islands (skins)	Marchant and Higgins (1990)[5]	U	U	381 ± 14 (14) (345-402)	*	65.7 ± 2.2 (10) (61.8-68.5)	*	52.1 ± 1.5 (13) (50.0-54.4)	*	*	*
Marion Island (live birds)	Rand (1954)	October-April	M	378 ± 2.83 (2) (376-380)	125 ± 4.24 (2) (122-128)	*	*	53 ± 2.83 (2) (51-55)	*	*	*
		October-April	F	370 (3) (365-380)	121 (3) (118-125)	*	*	51 (3) (50-52)	*	*	*
Marion Island (live birds)	Marchant and Higgins (1990)[6]	U	M	378.5 ± 6.43 (25) (367-395)	*	68.3 ±1.66 (27) (64.9-70.9)	*	54.0 ± 1.38 (27) (51.6-57.9)	*	*	*
		U	F	373.2 ± 7.86 (25) (358-387)	*	65.7 ± 1.51 (25) 62.0-68.0)	*	51.4 ± 1.02 (25) (49.7-53.2)	*	*	*
Amsterdam Island	Mougin (1970)[2]	U	U	380 (1)	103 (1)	64.0 (1)	81.0 (1)	49.0 (1)	*	*	*
At sea around the Prince Edward Islands	Ryan (1999)	October-June	M	390.6 ± 7.6 (176) (365-418)	131.4 ± 3.7 (176) (121-141)	67.6 ± 1.7 (176) (62.5-71.8)	*	54.11 ± 1.58 (176) (49.8-59.5)	119.0 ± 2.0 (176) (112.6-125.4)	22.54 ± 0.67 (176) (20.7-24.2)	16.31 ± 0.67 (176) (14.4-18.5)
		October-June	F	385.3 ± 6.2 (36) (370-390)	129.8 ± 3.8 (36) (122-139)	65.8 ± 1.6 (36) (62.0-69.0)	*	51.17 ± 1.68 (36) (46.6-54.6)	115.0 ± 2.4 (36) (108.8-120.4)	20.94 ± 0.62 (36) (19.9-22.3)	14.90 ± 0.67 (36) (13.6-16.0)
Gough Island (skin)[7]	Swales (1965)	U	U	365 (1)	124 (1)	65 (1)	*	52 (1)	*	*	*
Antipodes Island, New Zealand (skin?)	Mathews (1912-13)	U	M	388 (1)	122 (1)	67 (1)	*	56 (1)	*	*	*
Antipodes Island, New Zealand (live birds)	Warham and Bell (1979), Warham, J. *pers. comm.*	January-March	U	401.2[1] ± 9.1 (6)	129.2 ± 3.1 (4)	65.2 ± 2.4 (6)	90.4 ± 3.4 (5)	51.4 ± 0.5 (5)	*	*	*
Antipodes Island, New Zealand (dead birds)	Warham and Bell (1979), Warham, J. *pers. comm.*	U	U	387.6[1] ± 7.0 (7)	125.7 (3)	64.3 ± 1.4 (11)	83.9 ± 3.2 (10)	51.3 ± 1.4 (10)	*	*	*
Antipodes Island, New Zealand (AMNH skins)	Warham and Bell (1979)	February-May	M	382.8[1] ± 5.8 (9)	124.8 ± 3.7 (9)	65.3 ± 2.0 (9)	85.2 ± 2.1 (6)	52.6 ± 2.4 (8)	*	*	*
		February-May	F	376 (3)	127 (3)	64.3 (3)	84.1 (3)	52.5 (3)	*	*	*
Auckland Islands, New Zealand (live?)	Bailey and Sorensen (1962)	U	F	400 (1)	129 (1)	63 (1)	90 (1)	54 (1)	*	*	*
Campbell Island, New Zealand (live?)	Bailey and Sorensen (1962)	February	M	409 (1)	131 (1)	72 (1)	89 (1)	55 (1)	*	*	*
Breeding grounds on NZ offshore Islands (NZMH skins)	Marchant and Higgins (1990)	U	M	387.8 ± 3.76 (5) (381-392)	126.3 ± 5.12 (4) (120-134)	67.9 ± 1.18 (5) (66.1-69.6)	86.6 ± 1.25 (5) (85.1-88.8)	51.9 ± 1.32 (5) (49.6-53.2)	*	*	*
		U	F	390.1 ± 5.77 (4) (384-397.5)	129.0 ± 2.16 (3) (126-131)	66.0 ± 0.13 (4) (65.8-66.1)	84.6 ± 2.09 (4) (82.4-87.9)	50.4 ± 1.38 (4) (48.0-51.5)	*	*	*
Otago Heads, New Zealand (skin)	Falla (1937)	April	M	365 (1)	104 (1)	58 (1)	79 (1)	52 (1)	*	*	*
Chandler Island, New Zealand (skin)	Falla (1937)	May	U	378 (1)	105 (1)	60 (1)	80 (1)	51 (1)	*	*	*
At sea 49°S, 179°W (skin)	Falla (1937)	February	U	*	119 (1)	59 (1)	82 (1)	56 (1)	*	*	*
New Zealand (skins)	Mougin (1970)[3]	U	U	380 (5) (365-400)	110 (6) (104-119)	62.0 (6) (58.0-67.3)	83.1 (6) (79.0-88.2)	52.0 (6) (50.0-56.0)	*	*	*

Notes:

[1]flattened chord

[2]from Paulian (1953)

[3]from Falla (1937)?

[4]from Hall (1900)

[5]from Mougin (1985)

[6]M. De L. Brooke unpubl.

[7]details unknown

[8]measuring technique unknown