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**The breeding biology of northern white-faced storm  
petrels (*Pelagodroma marina maoriana*) and a feeding trial  
in preparation for translocation, New Zealand**

A thesis presented in partial fulfilment of the requirements for the degree of  
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**Plate 1.1 Captured in paint - a white-faced storm petrel foraging in the Hauraki Gulf, New Zealand. Photograph by Neil Fitzgerald. Artist: Thomas Young.**

## ***Abstract***

As keystone species and ecosystem engineers, petrels are integral to ecosystem restoration. However, many petrel breeding populations are currently reduced from their former ranges due to marine and terrestrial threats. Consequently, seabird translocation is now a rising species management tool for establishing/re-establishing colonies. The goals of this study were to investigate the expansion of translocation from medium sized *Pterodroma* and *Puffinus* species to much smaller storm petrels and to generate customised translocation protocols for white-faced storm petrels (*Pelagodroma marina maoriana*). This project aimed to 1) monitor and measure chick growth, 2) quantify chick provisioning: feeding frequency and meal size, 3) describe emergence periods and fledging morphology, and 4) undertake a mini-translocation to trial current petrel feeding practices on this relatively small species and outline a suitable artificial feeding regime. The breeding biology of a northern white-faced storm petrel (WFSP) population was monitored during the breeding season of 2011/2012 on Burgess Island, Hauraki Gulf. Results were compared with a southern WFSP population from previous research.

Northern WFSP bred one month earlier than southern populations and fledged at smaller weights and sizes. Chick rearing was longer (68 days) than expected and burrow emergence began 2–6 nights before fledging. Growth patterns generally aligned with Procellariiform chick development. Mean overnight provisioning masses delivered to chicks by parents were similar between northern and southern populations (7.8 g and 6.4 g respectively), however mean feeding rates were lower in the north (57.1% of monitored nights vs. 71.7%). Periods of fasting were longer than expected, frequently lasting 4–7 days. This low provisioning rate may reflect limited prey availability; possibly from the concurrent La Niña-Southern Oscillation climate. Stable isotope analysis of adult blood showed an increase in  $\delta^{15}\text{N}$  between burrow prospecting and chick rearing phases; indicating a shift in trophic level potentially due to a behaviour change in adult foraging or prey availability. Analysis of  $\delta^{13}\text{C}$  shows WFSP potentially foraging at greater ranges than expected.

During the feeding trial, a 10 Fg x 70 mm PVC crop tube was used to successfully feed chicks until fledging. Chick weight was maintained on a daily 7–8 ml regime of sardine puree diet. This research shows that WFSP are suitable candidates for translocation operations. Future translocations of northern WFSP are recommended to transfer chicks at 10 days before fledging, selected by criterion of wing lengths ranging from 120.9–129.7 mm and weights greater than 55 g. Translocation management should consider population variability due to

environmental and climatic fluctuations, and also latitudinal gradients as factors influencing temporal planning and chick selection.

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**Plate 1.2** The wonderful volunteers who together made this project a success.

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# Chapter One

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## INTRODUCTION

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### 1.1.0 Introduction

#### 1.1.1 Biology of Procellariiformes

There are 359 known species of seabirds worldwide, distributed throughout tropical, subtropical, temperate, sub-Antarctic and Antarctic regions (Taylor, 2000a). The order Procellariiformes is an ancient group recognised in fossil records from over 35 million years ago (Onley & Scofield, 2007). They are thought to have descended from a single ancestor, one likely shared by Sphenisciformes, which are commonly known as penguins (Warham, 1990). *Procella* is Latin for storm, tempest or gale (Brooke, 2004). Aptly named, Procellariiformes are a distinctive pelagic group dispersed worldwide, which use specialist aerial locomotion and oceanic winds to find food resources across oceans (Warham, 1990). Despite their large biomass and cosmopolitan distribution (Warham, 1996), Procellariiformes, with 125 species, represent just over one percent of the world's avian diversity (Onley & Scofield, 2007). There are four recognised families: Diomedidae (albatrosses), Procellariidae (gadfly petrels, shearwaters and allies), Hydrobatidae (storm petrels) and Pelecanoididae (diving petrels) (Brooke, 2004; Marchant & Higgins, 1990).

Size varies considerably between species, from the least storm petrel (*Halocystena microsoma*) weighing just 19.5 g to the royal albatross (*Diomedea* sp.) at 8700 g. Most petrels are pelagic by nature, and regardless of size they can travel thousands of kilometres over oceans as a result of various biological adaptations (Taylor, 2000a; Warham, 1990). For example, average body temperatures are lower for petrels at 38 °C compared to other avian groups at 41 °C, thus conserving energy. In addition petrels can drink salt water and expel excess sodium chloride through nasal gland excretion (Warham, 1996, 1990). Petrels are highly efficient flyers, using updrafts, slope and dynamic soaring to exploit wind energy (Warham, 1965). There are many different flight modes between species, but all species are adapted for various aspects of pelagic life (Warham, 1965, 1990). The distribution of petrels depends on life history stages, distribution of food resources and the location of safe breeding habitats (Warham, 1965, 1990). Some species are migrational (Warham, 1990). Distances travelled are variable and some species follow specific routes circumnavigating the globe, while others follow shorter or multi-directional dispersal routes; all are driven by factors such as temperature and resource abundance (Schreiber, 2002).

Petrels are K-strategist breeders, exhibiting low reproductive productivity and high survival rates (Brooke, 2004; Marchant & Higgins, 1990). Life cycles are long relative to their size

and many petrel species reach ages of 20+ years, with some surviving to 40 years, for example the Laysan albatross (*D. immutabilis*) and sooty albatross (*Phoebastria fusca*) (Taylor, 2000a; Warham, 1996). Petrels are colonial breeders, generally located in naturally predator free areas on offshore islands, coastal cliffs or inland hills with varying levels of vegetation (Brooke, 2004; Marchant & Higgins, 1990; Warham, 1990). The majority of Procellariiform species nest in burrows dug underground, with some surface nesting (25% of species) or using rock crevices (4% of species) (Warham, 1990). The densities of nests and burrows can be characteristically high, for example the medium sized sooty shearwater (*Pterodroma griseus*) has densities of 1.9 /m<sup>2</sup> and 1.2 /m<sup>2</sup> in meadow and forest habitat, respectively (Warham & Wilson, 1982). White-faced storm petrels (*Pelagodroma marina*) burrow at densities of 2–4 /m<sup>2</sup> (Gillham, 1963).

Most petrel species are highly philopatric, meaning that they show a high rate of natal site fidelity (Warham, 1990). Juveniles spend several years at sea before reaching sexual maturity and returning to breeding colonies. The age at which chicks return is relative to species' size and life expectancy, with larger species returning later than smaller ones (Brooke, 2004; Taylor, 2000a; Warham, 1990). For example, wandering albatross (*D. exulans*) return on average at five to six years of age and common diving petrels (*Pelecanoides urinatrix*) as early as just one year of age (Croxall, Rothery, Pickering, & Prince, 1990; Richdale, 1965). It may then take several years before breeding commences; the short-tailed shearwater (*Puffinus tenuirostris*) for example exhibits a three-year interval between returning to the colony and first breeding (Brooke, 2004).

The breeding chronology varies over latitudinal range for different species. With some exceptions of winter breeders (North Pacific albatrosses), petrels nesting in polar regions are generally obligate summer breeders, temperate regions often see spring-summer nesting and in tropical species laying may occur over many months (Warham, 1990). Most petrel species breed annually, with some larger species breeding biennially, and they generally hold high fidelity rates for both nest sites and partners (Warham, 1990; Brooke, 2004). Pairs of breeding petrels do not however mate for life and there seems to be a positive relationship between pair bonds and species' size (Warham, 1990). Breeding site tenacity is linked with mate tenacity and varies between species, for example during a second breeding season of fairy prions (*Pachyptila turtur*) 74% of 237 birds were found using the same burrow, however by the fourth season just 26% of the 23 found remained in the original burrow (Warham,

1990). In comparison, of 1288 Laysan albatrosses, just 10 individuals had shifted nests over a three year period, of which eight of the birds had swapped partner (Fisher, 1976).

Petrels generally only come ashore to breed and provision chicks. Most activity is during dusk and hours of darkness, however some species come ashore during the day. This is likely to be related to predation pressures, whereby large species are at less risk and so can exploit daylight hours, but those more vulnerable species follow nocturnal behaviours for protection (Brooke, 2004). The incubation period of Procellariiformes is exceedingly long. Storm petrels incubate over approximately 40 days, this is the shortest Procellariiform incubation period but is still twice as long as that of the domestic chicken (Brooke, 2004). In comparison the incubation time for albatrosses is approximately 80 days (Brooke, 2004). All Procellariiformes have a clutch size of one egg and both parents incubate and provision young (Warham, 1990). Chicks are regarded as semi-precocial. Chicks are left alone soon after hatching but are then fed at intervals by regurgitation (Marchant & Higgins, 1990; Warham, 1990). Chick rearing periods can be from 45 to 278 days in length depending on the species and body size (Warham, 1990). Once chicks fledge they are then independent and fend for themselves, and in many species fledglings depart immediately on long migrations (Marchant & Higgins, 1990).

Procellariiformes are characterised morphologically by their hooked bills and raised tubular nostrils (Marchant & Higgins, 1990). Highly developed olfactory bulbs in the brain suggest that petrels have exceptional abilities to detect scent, which probably enables them to locate highly dispersed food resources (Brooke, 2004). Petrels have a distinctive musky odour; it is thought that nesting away from mammalian predators makes this identifiable smell of low risk (Brooke, 2004). The distinguishing scent combined with highly developed olfactory senses may work as a cue for returning birds to natal colonies and/or the identification of individuals (Marchant & Higgins, 1990). Despite the predominant pelagic nature of petrels, many species are at risk from perils from both terrestrial and marine environments.

### *1.1.2 Threats to seabirds*

Current threats to seabirds are mostly due to anthropogenic sources affecting both land and sea environments. Croxall, *et al.* (2012) recognises 199 pelagic seabird species, of which over half are recognised as threatened and 21% considered endangered or critically endangered. This threatened status of seabirds has increased rapidly over recent decades

(Croxall, *et al.*, 2012). Marine threats include interactions with fishing operations such as long lining, entanglement and ingestion of anthropogenic debris, pollutant contamination, and disruptions to food webs caused by commercial fisheries (Baker, Gales, Hamilton, & Wilkinson, 2002; Croxall, *et al.*, 2012). The primary terrestrial pressure to seabirds is from exotic invasive predators threatening breeding colonies globally. In addition, habitat destruction and human disturbance are also major threats (Baker, *et al.*, 2002; Croxall, *et al.*, 2012; Taylor, 2000a). Invasive species pose the most severe danger for threatened seabirds, affecting 73 species (75% of all threatened seabird taxa) and human disturbance affects 26 species (27%)(Croxall, *et al.*, 2012). Forty species are impacted by fisheries bycatch (41%), a further 30 species (31%) are affected by pollution, and 23 (24%) by hunting and trapping (Croxall, *et al.*, 2012).

Given the migrational nature of many Procellariiform species, conservation management should ideally be consistent across international borders. The United States, Chile, Mexico, Canada, Australia and New Zealand are the top six countries for seabird abundance, with New Zealand, Chile and the United States also topping the tally for endemism and threatened species (Croxall, *et al.*, 2012). It is important that countries whose jurisdiction covers seabird breeding and foraging areas take responsibility of conservation protection for the species, for example by implementing regional and global networks of Important Bird Areas and Marine Protected Areas (Croxall, *et al.*, 2012). North America, while identified as a significantly important region, has restricted designated protected coastlines because of commercial development and human recreation (Croxall, *et al.*, 2012).

### *1.1.3 New Zealand*

Considered the seabird capital of the world, the New Zealand archipelago consists of thousands of islands stretching across 3000 km (Tennyson & Martinson, 2006) and encompasses various climatic environments, from the subtropical regions of the northern Kermadec Islands to the sub-Antarctic conditions of Campbell Island in the south (Taylor, 2000a). With no predatory land mammals present in pre-human times, New Zealand had a high rate of avian diversity, with many bird species filling mammalian niches (Tennyson & Martinson, 2006). This isolation from terrestrial mammals and the vast surrounding ocean habitat enabled the most diverse seabird community in the world to evolve, with New Zealand and Antarctica being the only continental areas in which petrels breed (Brooke, 2004; Taylor,

2000a). Numerous remote offshore islands offer secure breeding habitat for more seabird species than does any other region. Such sites are supplemented by the southern ocean; a rich feeding ground supporting massive seabird populations (Tennyson & Martinson, 2006). Worthy and Holdaway (2002) suggest that before human settlement New Zealand would have been the breeding region for hundreds of millions, perhaps billions, of petrels.

#### 1.1.4 Threats to New Zealand seabirds

Twenty-six percent of New Zealand's native avian fauna has become extinct over the past 800 years and while seabirds have fared much better than land and freshwater counterparts, with just one probable extinction, the Scarlett's shearwater (*Puffinus spelaeus*), most species have suffered huge population reductions (Tennyson & Martinson, 2006). Predator-free offshore islands are now the remaining refuges for many Procellariiform species (Robertson & Bell, 1984).

Approximately half (47) of the surviving seabird taxa breeding in New Zealand are considered threatened, and 12 are classified as either critically endangered or endangered (Taylor, 2000). The demise of New Zealand seabirds is attributable to both historic and modern day anthropogenic threats; the primary impact driver being the introduction of mammalian predators, particularly Pacific rats and cats (Bellingham *et al.*, 2010; Taylor, 2000a; Tennyson & Martinson, 2006). Adult seabirds and unattended chicks left in burrows are vulnerable to invasive predators (Marchant & Higgins, 1990; Taylor, 2000a) and as 35 of 53 introduced mammalian species have become established in New Zealand as feral populations, the impact on seabirds has been significant (Parkes & Murphy, 2003). The Pacific rat, kiore (*Rattus exulans*), along with dogs, reached New Zealand with the first Polynesian settlers (Taylor, 2000a) and consequently 27 avian species became extinct, including the Scarlett's shearwater (Tennyson & Martinson, 2006; Worthy & Holdaway, 2002). With European settlement the introduction of ship rats (*Rattus rattus*) and cats (*Felis catus*) as well as Norway rats (*Rattus norvegicus*), stoats (*Mustela ermine*), pigs (*Sus scrofa*) and ferrets (*Mustela furo*) also had strong negative consequences for naïve indigenous fauna (Taylor, 2000a; Tennyson & Martinson, 2006).

In addition to predation, New Zealand seabirds have also been affected by the loss of suitable breeding habitats. Introduced herbivores disturb seabird populations by destroying habitat, trampling nests, reducing nest coverage and increasing rates of erosion (Taylor, 2000a).

Habitats have also been lost as a result of landscape modification by invasive plant species, coastal development and high rates of human activity (Taylor, 2000a). After disturbance events such as fire and browsing animals, vegetation can become dense and weedy, thus altering the physical characteristics of the habitat required for some seabird species (Taylor, 2000a). For example, boxthorn (*Lycium ferocissimum*), transported to islands by European starlings (*Sturnus vulgaris*) and other land birds, are dense and have stiff thorns, which are known to snare and kill breeding petrels (Cox, Taylor, & Mason, 1967; Taylor, 2000a). Other threats to New Zealand seabirds include commercial and cultural harvesting, fisheries, and pollution such as plastic debris, oils, heavy metals, and other contaminants such as pesticides, fertilisers and effluent run-off (Taylor, 2000a).

#### 1.1.5 Current situation

Of New Zealand's offshore islands, 158 of the 735, equivalent to 2162 ha, are known to have remained free from mammalian colonisation (Parkes & Murphy, 2003). This coupled with developing eradication projects on islands mean they remain a stronghold for extant seabird breeding colonies. Despite the anthropogenic impacts, New Zealand is one of the top 10 countries worldwide for seabird abundance; it is a centre for endemism and has over twice the number of threatened species than does any other country (Croxall, *et al.*, 2012). Leading the global tally for seabird diversity, New Zealand has 84 breeding species of which 42% (35 species and 49 taxa) are endemic (Taylor, 2000a). However, dangerous and exotic pests continue to press New Zealand borders, and with currently small, fragmented and degraded habitats the risk to remaining extant populations remains high (Tennyson & Martinson, 2006). An optimistic sign for New Zealand conservation is the recent rediscovery of the New Zealand storm petrel (*Fregetta maoriana*) in 2003; this was last sighted over 100 years ago (Brooke, 2004; Tennyson & Martinson, 2006).

#### 1.1.6 Ecological importance of petrels

In New Zealand, the significance of petrels within the unique insular ecosystem may never be accurately described. The sheer number of petrels which once bred on the North and South Islands would have been the most significant component of New Zealand avifauna (Worthy & Holdaway, 2002). Such large colonies influenced terrestrial environments and during pre-human times, seabirds had a greater impact on the terrestrial environment than did any other

vertebrate group (Worthy & Holdaway, 2002). Seabird colonies supply nutrients to soils, transferred from the marine environment, and are essential for biodiversity and ecosystem function (Jones, 2010; Worthy & Holdaway, 2002). Well recognised as ecosystem engineers, seabirds affect both physical and chemical aspects of their terrestrial environments by altering soil nutrients and the terrestrial food chains, as well as by allogenic engineering of their physical habitat (Bancroft, Roberts, & Garkaklis, 2005; Crooks, 2002; Durrett & Mulder, 2011; Hawke, Holdaway, Causer, & Ogden, 1999; Markwell & Daugherty, 2002).

Terrestrial food chains are directly affected by the biomass of seabirds: adults are predated on by, for example, kea (*Nestor notabilis*) and in the past by laughing owls (*Sceloglaux albifacies*) (Worthy & Holdaway, 2002). In addition, at the base of the terrestrial food chain, guano, broken eggs and dead chicks provide nutrients to invertebrates and microorganisms (Worthy & Holdaway, 2002). The removal of seabirds from an ecosystem, for example by rat predation, has cascading ecosystem effects on below-ground organisms, plant nutrients, and biomass (Fukami *et al.*, 2006). For example, Mulder & Keall (2001) show that on Stephens Island, between 4 and 50 g/m<sup>2</sup> of guano was deposited weekly by fairy prions and that high levels of soil phosphorus and low pH levels were positively correlated with burrow density. Markwell and Daugherty (2002) show increased abundances of invertebrates and lizards with the presence of seabirds on islands in the Marlborough Sounds, and that the nutrients from seabirds were also found within tissues of plants and other animals. It is understood that on small islands soils are affected by the cessation of petrel populations and it is probable that the massive reduction of mainland Procellariiform colonies has resulted in significant changes in mainland vegetation (Worthy & Holdaway, 2002). The nutrient enriched sites from former pre-European seabird colonies on mainland New Zealand contain nutrients such as nitrogen, phosphorus and cadmium at levels equivalent to superphosphate agricultural fertilisers (Hawke, *et al.*, 1999).

Seabird colonies also physically affect vegetative communities by burying and trampling seeds and seedlings and altering microclimates (Grant-Hoffman, Mulder, & Bellingham, 2010). For example, burrows of wedge-tailed shearwaters (*Puffinus pacificus*) provide thermally suitable microhabitats for the amphibious snake (*Laticauda saintgironsi*) in New Caledonia (Lane & Shine, 2011). Tuatara (*Sphenodon punctatus*), a predatory reptile endemic to New Zealand, are also known to co-inhabit petrel burrows (Dawbin, 1949; Pierce, 2002; Warham, 1990). Wedge-tailed shearwater colonies in Western Australia chemically and physically engineer soils, thus affecting plant growth and local ecology (Bancroft, *et al.*,

2005). The vegetation within the shearwater colony was shorter and less dense, with double the area of bare soil than non-colonised sites. Moreover, within the colony plants showed greater rates of germination, phytometer productivity was significantly higher and greenhouse experiments showed cuttings grown in colony soil had 537% foliage mass and 337% root mass than cuttings grown in non-colony soil (Bancroft, *et al.*, 2005). The undoubted contribution that seabirds have to terrestrial ecosystems is significant and Jones, *et al.* (2010) suggests that active seabird restoration from extirpated sites may be able to promote and increase ecosystem recovery.

#### *1.1.7 Procellariiform translocation*

As the role of seabirds as ecological drivers in terrestrial systems becomes increasingly understood (Jones & Kress, 2012; Markwell & Daugherty, 2002; Miskelly, Taylor, Gummer, & Williams, 2009; Mulder & Keall, 2001), seabird restoration projects are being implemented worldwide (Jones & Kress, 2012). Examples where petrels naturally recolonise a site after total extirpation are rare (Miskelly, *et al.*, 2009), this is primarily because of high levels of natal site philopatry (Warham, 1990). Methods of restoring seabird populations include the use of decoys, acoustic vocalisation playback and/or translocation (Jones & Kress, 2012). Translocations are defined as the movement of animals from one area to a free release in another with the intention of establishing, re-establishing or augmenting existing populations (IUCN, 1987; IUCN SSC Species Survival Commission, 2012). Translocation is a powerful conservation tool employed to manage environments; it can greatly benefit biological systems (IUCN, 1987) and assist the preservation of threatened species (Priddel, Carlile, & Wheeler, 2006). Translocations are essential for utilising suitable and available island habitat as natural sanctuaries (Armstrong & McLean, 1995); a particularly important conservation tool within New Zealand as much native flora and fauna is still in decline.

Translocation is most suitable for petrel species which 1) exhibit high philopatric tendencies, 2) where chicks do not require post-fledging care, and 3) when a nearby source colony is not available (Jones & Kress, 2012). Due to the strength of natal site fidelity expressed in Procellariiformes it is critical that translocation methods ensure transferred chicks imprint on their release sites (Gummer, 2003). Such methods are relatively invasive, requiring downy chicks to be removed from parental care, transported and hand reared until fledging at the new location (Jones & Kress, 2012). In New Zealand at least 16 Procellariiform translocations

have been implemented in the past 25 years (predominantly in the most recent decade) and detailed translocation protocols are becoming well established (Gummer & Adams, 2010; Gummer & Gardner-Gee, 2009; Gummer, Taylor, Collen, Ward-Smith, & Mitchell, 2012). Miskelly *et al.* (2009) describe a series of translocation trials for eight non-threatened seabird species aimed at developing techniques which may be later used for the management of more endangered petrels. The trials were generally successful and in some cases birds are known to have returned to the translocation site and bred successfully (Miskelly, *et al.*, 2009; Priddel, *et al.*, 2006). Diet and hygiene practices are becoming well understood (Gummer & Gardner-Gee, 2009; Miskelly, *et al.*, 2009), a single sardine-based diet has been shown to be nutritionally suitable for many seabird species regardless of their size, phenology or natural diet (Miskelly, *et al.*, 2009).

To support the current knowledge of translocation protocols and optimise project success it is vital to establish 1) the best stage of chick development for translocation, 2) which individuals have reached suitable condition for translocation, and 3) how best to provision translocated chicks artificially. Selecting appropriate chicks requires a good understanding of species specific breeding biology: chick development patterns and feeding frequency (Gangloff & Wilson, 2004). Understanding when best to remove nestlings from their natal site may also rely on knowledge of breeding chronology as well as plumage development and patterns of burrow emergence (Priddel, *et al.*, 2006). Such detailed data will promote the overall success of the translocation and ensure the welfare of translocated nestlings.

### 1.2.0 White-faced storm petrels

#### 1.2.1 Taxonomy and distribution

The white-faced storm petrel (*Pelagodroma marina maoriana*) is known to Māori as Takahikare-moana, meaning ‘dancing on the waves’. Endemic to New Zealand this sub-species is considered abundant, at low risk and of least conservation concern (Taylor, 2000b). Storm petrels are the smallest seabird group (Marchant & Higgins, 1990) with 21 species within two subfamilies, Oceanitinae and Hydrobatinae (Warham, 1990). White-faced storm petrels belong to the family Oceanitinae, which comprises five genera and seven species all of which are distributed in the southern hemisphere (Warham, 1990). There are six sub-species of white-faced storm petrel (Brooke, 2004) of which three are common to pelagic and inshore waters of Australasia: *P. m. dulciae* which breeds south on east coasts of Australia, *P. m. albiclunis* thought to potentially breed on the Kermadec Islands and *P. m. maoriana* which breeds within the New Zealand archipelago (Marchant & Higgins, 1990) (Plate 1.3). The remaining three, *P. m. marina*, *P. m. hypoleuca* and *P. m. eadesi*, breed on islands in the Atlantic Ocean (Brooke, 2004).

*Pelagodroma marina maoriana* (WFSP) breed on 23 islands off New Zealand’s North, South, Stewart, Chatham and Auckland Islands (Taylor, 2000b). The estimated total breeding population is more than one million pairs (Robertson & Bell, 1984) and the largest breeding colony is found on Rangatira Island in the Chatham group, with an estimated 840,000 breeding pairs (West & Nilsson, 1994). Outside of breeding, WFSP migrate to tropical eastern Pacific regions during the austral winter (Imber, 1994; Taylor, 2000b).

#### 1.2.2 Morphology

*Pelagodroma marina* are distinctive because of their facial patterns, particularly long legs and characteristic flight patterns, they are medium sized, weighing 40–70 g and are 18–21 cm in length with a wing span of 42–43 cm (Brooke, 2004; Marchant & Higgins, 1990) (Plate 1.3).



**Plate 1.3** A foraging white-faced storm petrel observed in the Hauraki Gulf Marine Park, Auckland, New Zealand. Photograph by Abe Borker.

### *1.2.3 Foraging*

WFSP generally forage over the continental shelf (Marchant & Higgins, 1990; Taylor, 2000b) and have distinctive feeding behaviours. In light winds they glide slowly using both feet to push off the water surface every few seconds in a hopping motion (Marchant & Higgins, 1990) (Plate 1.3). Foraging may be solitary, but when in close proximity to breeding sites WFSP are more frequently observed in small groups or loose flocks and often in association with fairy prions (Marchant & Higgins, 1990). Aerial and contact-dipping methods are used for foraging and less frequently surface-seizing and surface plunging. Diet is based on pelagic crustaceans, small fish and surface plankton (Brooke, 2004; Marchant & Higgins, 1990). Imber (1981) showed 70% of the diet of Chatham Island WFSP was composed of crustaceans: barnacles, Copepods, Stomatopds, Mysidaceans, Amphipods, Euphsausiids and Decapod larvae.

#### 1.2.4 Threats

Given their small size, WFSP are extremely vulnerable to introduced predators, for example cats, all rat species, mustelids, dogs and pigs (Taylor 2000b). Several hundred WFSP were killed by colonising Norway rats on the Noises Islands in 1959–1960 (Cunningham & Moors, 1985) and the population on the Cavalli Islands was thought to have become locally extinct due to feral pigs (Millener, 1980). Other threats to WFSP include anthropogenic disturbance by the trampling of burrows, which are often dug in soft friable soils (Taylor, 2000b), and the larval nematode (*Distomum filiferum*), a natural threat to WFSP. On the Chatham Islands WFSP become suspended and entangled in vegetation after their legs become bound by the tough fibrous material of the nematode (Claugher, 1976; Nilsson, Kennedy, & West, 1994). In 1970 it was estimated that 200,000 WFSP (from a population considered at the time greater than one million) perished in this way (Claugher, 1976).

#### 1.2.5 Breeding biology and life history

The life span of *P. marina* is not specifically known, however the oldest recorded individual was 16 years old from the Mud Islands of Australia (Menkhorst, Pescott, & Gaynor, 1984). WFSP are summer breeders, and like all Procellariiformes they lay a single egg for which incubation is shared by both parents in alternating four-to five-day incubation shifts (Richdale, 1965). Colonies are usually located on flat areas with shallow and friable soil (Marchant & Higgins, 1990). Burrows are dug into relatively shallow ground at densities recorded to 1.5 /m<sup>2</sup> and 2–4 /m<sup>2</sup> (Gillham, 1963; Brooke, 2004). Birds return to colonies around six to seven weeks prior to laying (Brooke, 2004). Incubation is thought to be around 50 days, after which chicks are brooded for one to two days and are then left unattended with parents returning to provision them night (Richdale, 1965). Both parents provision the chick for which visitation by each sex may be on the same or different nights, and chick rearing varies between 54.8 and 60 days (Campos & Granadeiro, 1999; Richdale, 1965; Underwood & Bunce, 2004). Pre-breeding birds probably return to colonies for the first time at around three years old (Menkhorst, *et al.*, 1984), two to three years before breeding (Marchant & Higgins, 1990).

### ***1.3.0 Purpose of this research***

The historical abundance of petrels in New Zealand, their contributions to terrestrial environments and the diverse threats affecting seabird species worldwide, highlight the importance of petrels within ecological scale conservation projects. Seabird restoration by means of translocation is currently recognised as a valuable and necessary conservation tool for ecological restoration.

Petrel translocations in New Zealand have thus far focused on medium sized *Pterodroma* and *Puffinus* species. However, there is potential to extend the conservation scope of translocation practices to small Procellariiformes, such as storm petrels. White-faced storm petrels are good candidates for translocation because of their local abundance (which allows for accessibility to colonies), as well as their relatively short maturation time until first breeding. They also have reduced breeding distributions from pre-human times and there is scope to restore extirpated populations (Taylor, 2000b). In addition, a latitudinal variation in breeding chronology has been predicted for WFSP across New Zealand (Taylor 2000b). The breeding timetable and biology of WFSP from a southern population was studied in detail during the 1940s by L. E. Richdale on Whero Island, but until the current study there is little information available for northern WFSP populations.

This project aims to understand the crucial breeding dynamics of WFSP, with emphasis on key aspects necessary for translocation. Miskelly, *et al.*, (2009) used common petrel species to generate practices for analogue and more endangered taxa. Likewise WFSP have the potential to provide important information relevant to the conservation of the critically endangered and data deficient New Zealand storm petrel (*Fregetta maoriana*).

#### ***1.4.0 Aims and objectives***

The aim of this research is to collate species specific information required for the successful translocation of WFSP. Data will be collected from a northern population and compared with the work of Richdale (1943a, 1943b, 1944, 1965) on southern birds to generate guidelines to aid future translocation initiatives for the species.

The objectives for this research are to:

- I. Quantify adult provisioning behaviour by measuring feeding frequency and meal size to describe chick feeding regimes, and to examine diet using stable isotope analysis.
- II. Quantify the development of WFSP chicks through focused growth studies during the chick rearing period using regular morphometric measurements. Data will be collated to calculate and describe growth rates and plumage development throughout the chick rearing period.
- III. Describe chick fledging by investigating emergence behaviours and fledging morphology.
- IV. Conduct a small scale feeding trial, adapting and using currently tested techniques for hand rearing seabirds along with concurrent *in-situ* population data, to guide artificial feeding regimes and morphological targets.

### ***1.5.0 Thesis structure***

#### *Chapter 1- Introduction*

The biology of Procellariiformes is introduced, as well as their role within ecosystems and the practice of translocation as a seabird management tool. Seabirds within the context of New Zealand and white-faced storm petrels are also reviewed. The framework of this project is outlined with research purpose and aims.

#### *Chapter 2 – Study site and methods*

The history and current state of the research study site, Burgess Island, is described. Detailed accounts of the field methods used for all data chapters are grouped into an overall methods section. Brief method summaries are then given within subsequent chapters. The purpose of this is to minimise repetition throughout chapters. However, details of statistical analysis are customised within individual chapters.

#### *Chapter 3 – Chick growth and development*

This chapter investigates: 1) northern WFSP population breeding chronology, 2) hatching morphology of chicks, 3) growth and development of wing length, tarsus length, bill length and plumage, 4) fledging morphology and 5) chick emergence behaviours prior to fledging. Statistical analyses are described and the baseline information is compared to literature on southern WFSP populations. This chapter identifies morphological traits indicating chick age and provides insight into the timing of significant breeding stages for this species. Implications and recommendations to future WFSP translocations are outlined.

#### *Chapter 4 – Chick provisioning and diet*

This chapter investigates: 1) provisioning frequencies delivered to chicks, 2) overnight feeding masses, and 3) stable isotope analysis on adult blood and chick feather tissues. As in Chapter 3, statistical analysis and comparisons with southern populations are also described. Understanding baseline chick provisioning and diet is important in order to identify dietary requirements to help shape species specific artificial feeding regimes.

#### *Chapter 5 – Feeding trial*

The mini-translocation of WFSP is described. The use of artificial feeding practices and an artificial diet is examined as well as suitable feeding regimes, meal sizes and target fledging morphology. Statistical methods are outlined. Data is presented to inform and identify limitations and important elements for WFSP translocation protocols. This chapter ties in the

importance of understanding natural rates of chick growth and provisioning to the practical considerations needed for translocation.

*Chapter 6 – Summary*

Chapter 6 identifies the key findings from each chapter and concludes with relevant discussion points. Final recommendations to future translocation initiatives of WFSP are made as well as considerations for future research.

*Appendix*

Additional information of necropsy reports, permits and feeding trial methods are presented. Additional supplementary information is provided on the attached CD. This information includes: raw data from Radio Frequency Identification Readers and Passive Integrated Transponders measuring chick emergence, and individual feeding regimes of meals delivered artificially to feeding trial chicks.



**Plate 1.4 BS1 within a week of fledging.**

# **Chapter Two**

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## **STUDY SITE AND METHODS**

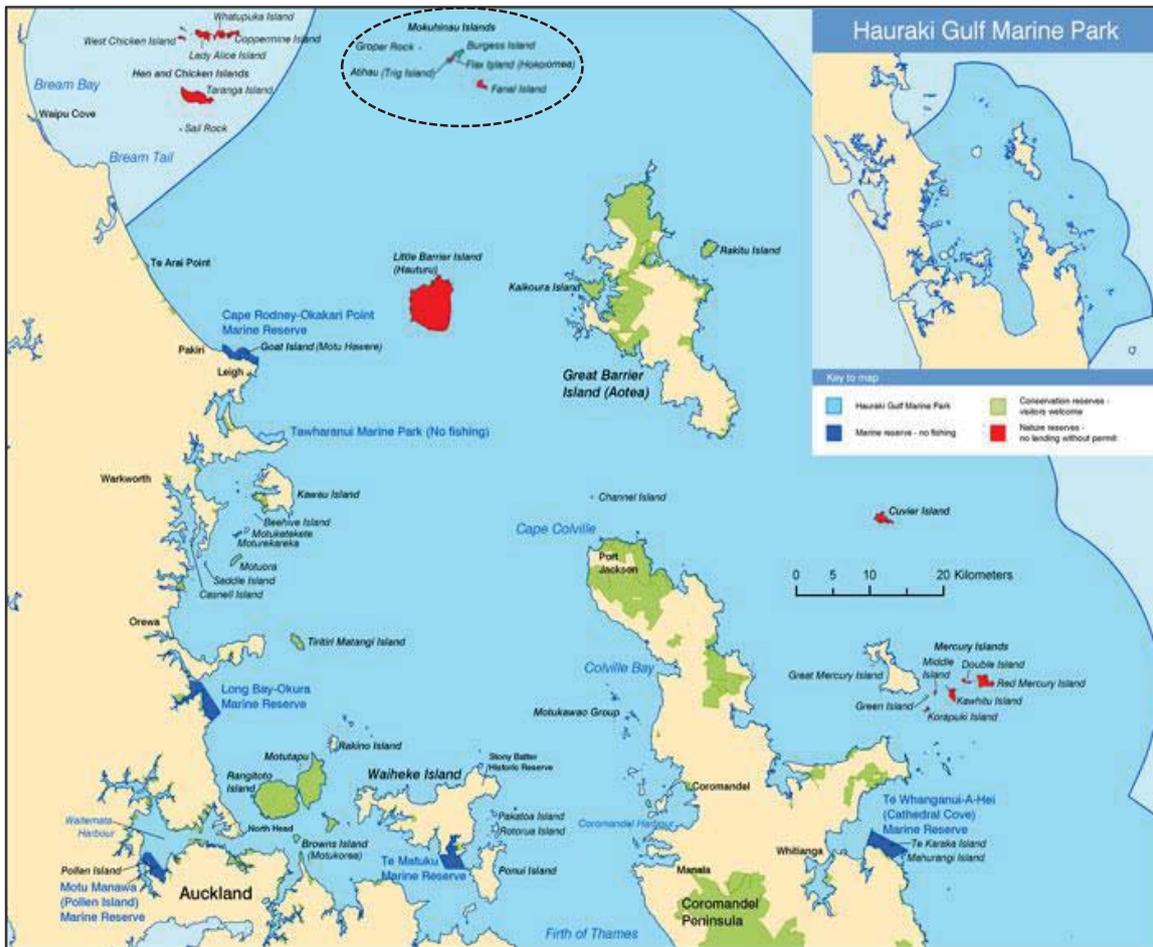
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### 2.1.0 Study Region and Site

#### 2.1.1 The Hauraki Gulf

The Hauraki Gulf is located on the north east coast of New Zealand's North Island. The region is of national significance owing to the inter-relationships of islands, catchments and marine waters providing life supporting capacity to ecosystems and social communities (Hauraki Gulf Marine Park Act, 2000). Many islands within the gulf for example; Hauturu (Little Barrier), Great Barrier and the Mercury Islands have high proportions of native vegetative cover (Hauraki Gulf Forum, 2011). This available habitat along with the proportion of islands (43%) which are free of introduced herbivorous and predatory pests, provide refuges for rare and endemic flora and fauna (Hauraki Gulf Forum, 2011). These include iconic species, for example; kakapo (*Strigops habroptilus*), takahe (*Porphyrio hochstetteri*), little spotted kiwi (*Apteryx owenii*), North Island saddleback (*Philisternus carunculatus rufusater*) and tuatara (*Sphenodon punctatus*). Within the gulf are marine habitats which range between 5–>100 m in depth and the bays, inlets and harbours are valuable for commercial fisheries, recreation, and encompass four marine reserves (Hauraki Gulf Forum, 2011; Ministry of the Environment, 2005). Mainland areas surrounding the Hauraki Gulf were one of the first places of human settlement in New Zealand (Hauraki Gulf Marine Park Act, 2000). Currently 40% of mainland bays adjacent to the gulf are urbanised and intensively or moderately developed. Many developed catchments are of great economic importance (Hauraki Gulf Forum, 2011), for example, Auckland City and the Ports of Auckland.

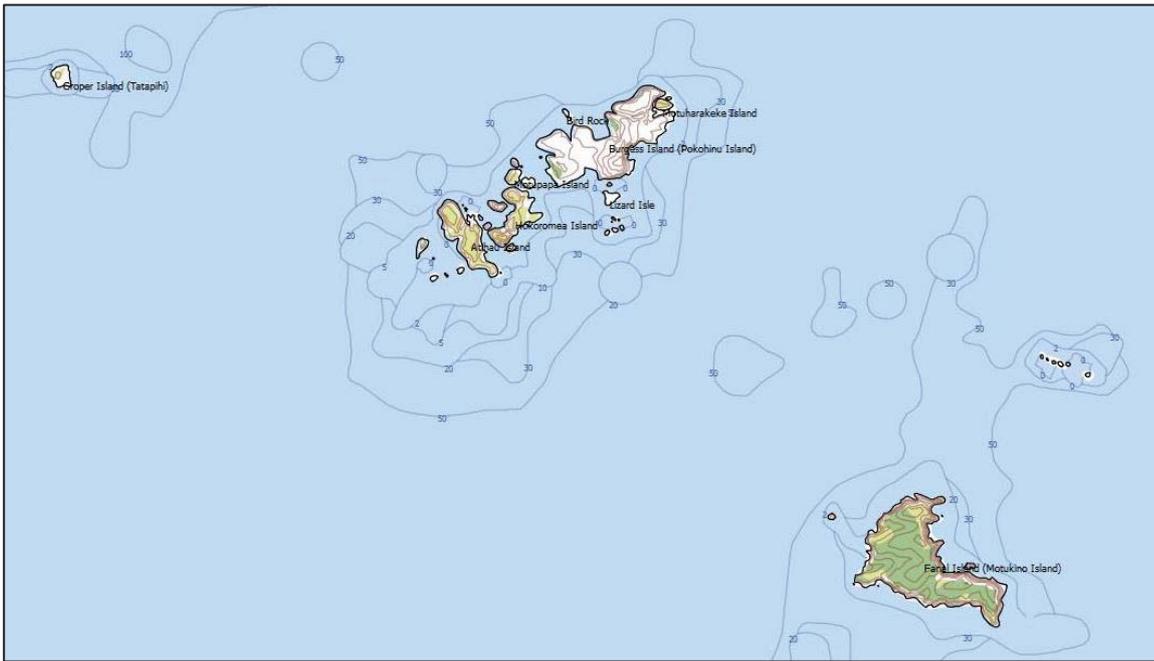
In 2000 the Hauraki Gulf, Waitemata Harbour, Firth of Thames and the east coast of the Coromandel Peninsula were designated as the Hauraki Gulf Marine Park (Map 2.1). The park is administered under the Hauraki Gulf Marine Park Act, 2000. Its purpose is to protect local natural and historic features, to integrate marine and terrestrial management while incorporating public residence, local commerce and relationships with tangata whenua (Ministry of the Environment, 2012).



**Map 2.1** The location and area of the Hauraki Gulf Marine Park in relation to Auckland City. Protected areas are highlighted: marine reserves (blue), conservation reserves (green) and nature reserves (red). The black perforated circle identifies the Mokohinau Island group. Map from the Department of Conservation (n.d.a)

### 2.1.2 The Mokohinau Islands

The Mokohinau Islands are located 110 km north east of Auckland City on the fringes of the Hauraki Gulf at 35° 54' South, 175° 07' East (Maritime New Zealand, n.d.; McFadden & Greene, 1994) (Map. 2.1). This island group is made up of approximately 12 islands with scattered reefs and islets (Gillham, 1960). The group extends from Groper Rock in the north-west to Fanal Island (73 ha) 10 km in the south-west. In between is a belt of islands including Burgess Island (56 ha), Maori Bay Island (10.6 ha), and Trig Island (15 ha) (Berben, McCrone, Creese, & Ballantine, 1988; McFadden & Greene, 1994) (Map 2.2). The Mokohinau Islands are a part of a 210 km rhyolitic volcanic chain stretching from the Coromandel Peninsula to Northland's east coast and probably became active four million years ago with the centre of activity occurring around Burgess Island (Berben, *et al.*, 1988).



**Map 2.2. The Mokohinau Island Group. Map generated by Chris Gaskin.**

Isolated on the outskirts of the Hauraki Gulf, the Mokohinau Islands have records of diverse fauna and particularly large numbers of nesting seabirds (Bellingham, 1980; de Lange, Cameron, & Taylor, 1995; McCallum, 1980b, 1980a). There is no direct evidence that Maori permanently occupied any of the islands, however annual visits were made where vegetation was burned and northern mutton birds (grey-faced petrel; *Pterodroma macroptera gouldi*) harvested in considerable numbers (Elser, 1978; McFadden & Greene, 1994). For example, in 1945, 3500 grey-faced petrels were observed being taken from the island group over a 10 day period (Buddle, 1947). Customary rights to harvest grey-faced petrels are still exercised by Ngati Rehua under the Grey-Faced Petrel (Northern Muttonbird) Notice 1979, pursuant of section six of the Wildlife Act 1953.

The Mokohinau Islands were colonised by kiore (*Rattus exulans*) which were eradicated in 1990 (McFadden & Greene, 1994) and the islands are currently free of introduced predators. The kiore eradication was a successful pilot project for large scale aerial broadcasting of poison bait, aimed at developing methodology and design for future eradications (McFadden & Greene, 1994). All of the Mokohinau islands are now managed by the Department of Conservation and classified as nature reserves, with the exception of Burgess Island, which is classified as a scenic reserve and open to public landing. Currently the Mokohinau Islands are inhabited by endangered and endemic fauna, including the mokohinau skink (*Cyclodina*

*mokohinau*), robust skink (*Cyclodina alani*) and mokohinau stag beetle (*Geodorcus ithaginis*) (Department of Conservation, n.d.b).

### 2.1.3 Burgess Island

Burgess Island is the second largest of the Mokohinau group at 56 ha (McFadden & Greene, 1994). Made of rhyolitic and andesite rock, sheer cliffs surround most of the island and descend 100 m below the sea surface (Fleming, 1950). A light house was established 1883 and the island was then continuously occupied by lighthouse keepers until the lighthouse became automated in the 1970's (Department of Conservation, n.d.b; Elser, 1978; Maritime New Zealand, n.d.). Resident lighthouse keepers grazed stock (cattle, goats, pigs and sheep) and vegetation was controlled by periodic burning approximately every three years (Gillham, 1960). Vegetation on the Mokohinau Island group is now depleted and grossly modified with only 112 native plant species remaining (Elser, 1978). The burning events on Burgess Island left only pohutukawa (*Metrosiderous exelsa*) and ngaio (*Myoporum laetum*) as the remaining large woody plants. In addition rushes, sedge (*Scirpus nodosus*) and bracken (*Pteridium esculentum*), *Muehlenbeckia complexa* as well as rank grass and buffalo grass (*Stenotaphrum secundatum*) (Elser, 1978; McFadden & Greene, 1994). Currently the mokohinau gecko (*Dactylocnemis mokohinau*) and moko skink (*Oligosoma moco*) are observed in noticeably high abundance on Burgess Island (pers. obs.). There are nine known seabird species breeding on the Mokohinau group, seven of which are Procellariiformes with their nesting burrows on Burgess Island (Ismar, Taylor, Gaskin, & Rayner, 2012). Other significant avian species which reside on Burgess Island include, but are not limited to, bellbirds (*Anthornis melanura*) and red crowned kakariki (*Cyanoramphus novaezelandiae*).



Plate 2.1 a) The sheer cliffs of Burgess Island (photograph by Sarah Wells). b) A mokohinau gecko on a pohutukawa flower (photograph by Neil Fitzgerald). c) A moko skink on Burgess Island (photograph by Dylan van Winkle).

White-faced storm petrels (*Pelagodroma marina maoriana*) breed in abundance on Burgess Island, particularly on the northern headland (Map 2.3). This area of Burgess Island was inaccessible to most stock animals except for goats (Gillham, 1960). Elser (1978) recorded an abundance of sedge, maiden hair (*Adiantum aethiopicum*) and broadleaf poa (*Poa anceps*) on the northern headland. The area is now currently predominantly bracken, *Muehlenbeckia* and sedge. In addition to white-faced storm petrels (WFSP), diving petrels (*Pelecanoides urinatrix*) and grey faced petrels also breed in relative abundance on the northern headland together with fewer numbers of sooty shearwaters (*Puffinus griseus*) and black-wing petrels (*Pterodroma nigripennis*).



**Map 2.3** The white-faced storm petrel colony on the northern headland of Burgess Island is highlighted by the red circle. The location of artificial nest boxes for feeding trial birds is depicted by the yellow circle. Map from the Department of Conservation.

## **2.2.0 Methodology**

### *2.2.1 Study site establishment*

During the course of this study three trips were made to Burgess Island during the spring and summer of 2011/2012. The timing of the visits was decided using anecdotal observations of the focal population as well as known breeding data from a southern WFSP colony on Whero Island. To establish a sample of study burrows for subsequent work, the first trip was conducted to coincide with the burrow prospecting phase of the WFSP breeding cycle from 11–20 September, 2011.

*Identifying burrows:* The northern headland of Burgess Island (Map 2.2) was thoroughly searched and potential burrows identified. WFSP burrows were characterised as being smaller than those of diving petrels, particularly with signs of fresh digging and/or fresh nest material. To minimise burrow damage, searching was mostly limited to areas of the colony which could be easily accessed from rock margins. When this was not possible the ground was thoroughly searched for burrows of any size to determine bare ground for paths and thus mitigate disturbance or harm to non-target species. All burrows thought to belong to WFSP were marked for later location and identification using labelled tags at the tunnel entrance and a brightly coloured stake with reflective tape (Plate 2.2). The colony was also visited at night to locate prospecting adults actively accessing and digging out tunnel entrances.



**Plate 2.2 White-faced storm petrel burrows along a rock margin on the northern headland of Burgess Island identified with fluoro coloured and reflective poles.**

*Burrow access:* Where suitable, study access lids were installed above the nesting area of burrows by digging a small fist sized hole. Ideally the hole was positioned in the bird access tunnel just prior to the nest chamber. This reduced the chances of any loosened soil debris falling on the chick and ameliorated stress to the chick when the study lid was removed. The access hole was then covered over using a 200 x 200 mm piece of 15 mm ply wood and covered with dirt and vegetation to prevent the exposed wood from overheating the burrow interior. Study lids were only added to burrows with enough structural integrity to sustain being penetrated and where tunnels were too long and convoluted for alternative access. This method made removing chicks easier and more efficient, thus mitigating excessive stress for chicks and damage to the burrow (Campos & Granadeiro, 1999).

*Colony access:* A path through the colony was labelled, allowing safe access between burrows without trampling any of the chambers or tunnels. Some WFSP burrows in the pathway were deliberately destroyed to prevent eggs being laid and subsequent harm coming to adults or chicks.

### 2.2.2 Chick hatching

To ascertain the hatching dates for study chicks, occupied burrows were identified and monitored from 7–21 December, 2011. Each previously marked burrow was checked for

occupancy and all the eggs located were candled to determine fertility. All the eggs were then checked daily for hatching by gently sliding a hand under the incubating adult to feel for the presence of an egg or chick. Initially adults were banded when the eggs were first located; this however caused nest desertion and consequently the above method was used to minimise adult disturbance. If un-incubated eggs were cold but looked viable when candled, they were monitored for one week to see if incubation resumed. WFSP eggs may still be viable after temporary desertion and have been recorded to hatch successfully after being unattended for four days (Richdale, 1965).

During the post-brooding phase hatchling mass, tarsus (minimum) and bill length (tip to culmen) measurements were recorded. Wing lengths of the newly hatched chicks were too small to measure precisely. Knowing the specific ages of focal chicks by attaining hatch dates was preferred for this research. However, insufficient burrow numbers were found with un-hatched eggs and consequently chicks of unknown age were recruited into the project. These unknown age chicks were also weighed and measured (tarsus and bill).

At no point during this study were chicks handled in the rain or in any situation that would risk their down becoming wet. Searching for new burrows and un-hatched eggs continued throughout the December field trip to maximise the number of chicks of known age recruited into the project.

### *2.2.3 Study groups*

The main data collection period was undertaken over seven weeks from 9 January until 27 February, 2012. Upon arrival in early January, all known chicks were weighed, measured (wing, tarsus and bill in accordance with the New Zealand Bird Banders Manual) and allocated into one of four study groups; development, feeding trial, control and telemetry. Allocation of individuals into these study groups was based on chick age, accessibility of burrows and ease of removing chicks, plus the relative requirements for each particular study group under the following criteria:

- **Development group:** Chicks of known age. The mass of the chicks in this group was recorded daily and the other measurements (wing, tarsus, bill, plumage) were taken very four days to quantify chick growth and provisioning rates.

- Feeding trial group: Chicks of unknown age. 10 of 15 potential chicks were selected for a mini translocation and fed artificially using provisioning methods based on current seabird translocations.
- Control group: Chicks of unknown age. The control group was handled for measuring on a maximum of four occasions throughout the study. This group was later compared to the development study group which were handled daily. Control group chicks were generally selected from burrows that were not suitable for frequent access (unstable and/or shallow in the soft friable soils).
- Telemetry trial: Chicks of unknown age. The 15 chicks in this group each had one parent fitted with a radio transmitter. The impact of this transmitter was to be assessed for each chick. Due to technical problems, only the growth and provisioning data obtained from the chicks has been reported.

#### *2.2.4 Measuring procedures*

Wing measurements (mm) were taken as straightened wing chord using a wing ruler. With straightened primary feathers, not crossed or bent, the measure is taken from the top of the wing while in resting position (fully folded) and the alula straightened in line with the longest primary feather. The straightened wing chord is the length from the carpal joint to the tip of the longest primary feather (Melville, 2011).

For seabirds, bill length is usually measured from the feather line to the tip of the bill (Melville, 2011). Because downy chicks lacked the necessary plumage, lengths were taken from the culmen. Callipers were used to measure the length from the tip of the bill to the longest point where the upper mandible and skin met.

Minimum tarsus length was measured using callipers. Measurements were taken with the tarsus at right angles to the tibia and the foot at right angles to the tarsus (Melville, 2011). The required length was between the foot and the notch of the intertarsal joint or 'knee' (Melville, 2011).

### *2.2.5 Chick growth*

To quantify chick growth (and provisioning rates) all chicks from the development and telemetry groups were weighed daily between 0800 h and 1230 h using 100 g or 300 g pesola scales to the nearest 0.5 g. Each chick had a designated bag for hygiene reasons. To calculate net chick mass all bags were weighed daily to account for soiling and changes in ambient moisture.

Morphological development was quantified by measuring the chicks every four days following their daily weighing. Measurements of tarsus (minimum) and bill length (exposed culmen) were taken using callipers ( $\pm 0.1$  mm) and wing length (flattened and straightened wing chord) using a ruler to ( $\pm 0.5$  mm) (Gangloff & Wilson, 2004; Peck & Congdon, 2005). Measuring frequency was increased to every two days once wing length reached 120 mm as chicks approached fledging (Gangloff & Wilson, 2004). Increasing measuring frequency improved the detail of chick morphology descriptions at the time of fledging. All measurements were taken at least twice and the average value used (to minimise measuring error).

Descriptions of plumage were also recorded as down loss and feather growth. Chick down was described as the percentage loss ( $\pm 5\%$ ) from the original total from the head, back, wing and chest/belly. In addition, prominent white facial plumage was qualitatively described as feathers emerged and established above the bill, behind the eye and completed growth. All qualitative down and plumage accounts were made by a single observer during the entire study period to avoid observer bias of subjective descriptions.

### *2.2.6 Fledging*

Fledging was assumed successful when chicks were considered developed enough to have fledged and their burrows were found empty during the day and there were no signs of predation (Priddle & Carlile, 2009). The burrows of fledglings were checked repeatedly for two more consecutive days after departure to ensure chicks did not return. Monitoring of emergence and fledging periods was conducted using Radio Frequency Identification Readers (RFID) and Passive Inductive Transponder (PIT tags). PIT tags were attached externally to chicks when their wing lengths reached approximately 110 mm and/or when the chicks were thought to be near to one week from fledging. PIT tags were attached to one of the central tail

feathers with a small length (2 cm) of narrowly trimmed light weight first aid tape. PIT tags were fixed to the tape using superglue and once the glue was dry, the tape was wound around the base of the selected tail feather (Plate 2.3a). This method prevented the tag falling off before the chick fledged and the weak adhesive of the tape allowed the tag to drop off soon after fledging. Circular copper wire aerials (approximately 10 cm in diameter) bound with insulation tape were set up around burrow entrances and connected to an RFID reader and a 12 volt battery (Plate 2.3b). RFID readers were set to automatically activate from 1700 h to 0900 h to conserve battery power. For aerials with a 10 cm diameter, we found that approximately 55 rotations of wire were needed to generate the required frequency range of 132000-136000 Hz. RFID readers were required to be spaced 3 m apart to avoid interference between radio signals. Distance restrictions and the target developmental stage of chicks determined which individuals were monitored. To maximise the sample size, chicks from both the development and telemetry groups were used.



**Plate 2.3 a) A PIT tag being attached to the tail of a white-faced storm petrel chick. Photograph by Dylan Van Winkle. b) A copper aerial surrounds a burrow entrance along with connected RFID reader and battery. Photograph by Marleen Baling.**

### 2.2.7 Controls

Control birds were chicks generally selected from burrows that were difficult to access. This group was weighed and measured three times (maximum of four) using the same measurement and descriptive protocols for monitoring the development group during the focal period (see method 2.2.4). The first time chicks were handled was during December when all birds were first identified, a second time in early January when individuals were re-measured and allocated into study groups, and lastly when each chick was expected to be approximately one week away from fledging. The estimated fledging dates were calculated using wing

lengths recorded in early January and the approximate growth rate of regularly monitored birds. Some chicks were less developed than expected when handled for the third time and were measured again if they had not fledged within one week. Outside of these handling events the control group was not disturbed, until after the third measuring event after which they were checked daily until fledging. This involved gently sliding a hand into the burrow to check for presence/absence of the chick.

### 2.2.8 Chick provisioning

Using the daily weighing regime outlined in section 2.2.5, meal sizes and feeding frequencies, as provisioned by WFSP parents, were calculated for the development and telemetry group chicks. This was done using changes in overnight chick weight (Rayner, Hartill, Hauber, & Phillips, 2010) and taking into account mass loss through respiration and excretion (Phillips & Hamer, 2000).

Parental feeding was assumed to take place soon after dark (approximately 12 hours between weighings). Chick body mass lost due to respiration and excretion between the times of parental feeding and chick re-weighing was therefore calculated as 50% of the mean overnight weight loss of chicks known to have gone un-fed, as per Rayner, *et al.* (2008). A feeding event was therefore identified when a chick increased in mass or when the overnight mass change was less than the 50% weight loss value (thus accounting for meals smaller than the expected overnight metabolic weight loss). Individual meal sizes for were calculated as the sum of the overnight change in mass (g) and the 50% weight loss value.

Unfed chicks were identified using burrow gates (painted toothpicks) erected at the entrances of focal tunnels to detect parental visits. Undisturbed gates identified which chicks had not been provisioned that night. However, a disturbed gate did not necessarily indicate a feeding event and this was further verified using the above weight change methodology.

Unfed chicks which dropped below approximately 40 g in mass often became unresponsive when handled and cool to touch. This has previously been described as a state of inertia or torpor (Boersma, 1986; Richdale, 1943b; Warham, 1990). Handling of individuals in this state was avoided so as to not cause excessive stress or heat stress as chicks would be dehydrated due to lack of provisioning. If burrow gates were standing for any undernourished chicks (in or near a state of torpor) the chick was not disturbed for that day and if the gates

had shifted chicks were felt by hand for evidence of provisioning. In most cases if previously unresponsive, chicks which had been fed became animated when touched and as often large amounts of food had been delivered their extended stomachs could be easily felt.

#### 2.2.8 Stable isotopes

Ratios of stable isotopes  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  were analysed to investigate the foraging ecology of diet and foraging distribution for WFSP (Bond & Jones, 2009; Kelly, 2000; Quillfeldt, Bugoni, McGill, Masello, & Furness, 2008; Quillfeldt, McGill, & Furness, 2005). Tissues synthesising at different rates can provide temporal insight into foraging, for example blood reflects the diet over a period of 12–15 days and feathers the diet at the time of growth (Bearhop, Waldron, Votier, & Furness, 2002; Dalerum & Angerbjorn, 2005). Blood samples were taken from adult WFSP captured on the colony surface at night during December, January and February visits. Only birds located outside of the focal colony were used to avoid influencing the provisioning of focal chicks. A volume of  $< 50 \mu\text{L}$  of blood was extracted for stable isotope analysis from the tarsal vein by a small puncture using a 29 gauge syringe and blood was collected via a capillary tube. The blood was smeared onto a slide and once dried preserved with a methanol bath. Chick feathers were also taken to compare chick/adult metabolisms and tissue synthesis over the same period as blood collection. The tenth covert feather from the chick's wing was collected by snipping the feather as close to the base of the shaft as possible with scissors. Feathers were stored individually in a labelled paper envelope until analysed.

Lipids have less  $\delta^{13}\text{C}$  through fractionation of pyruvate to acetyl coenzyme A (Bond & Jones, 2009). Therefore it has been recommended that lipids be removed from heavy lipid tissues before stable isotope analysis (Hobson & Clark, 1992; Kelly, 2000). However, as there is some uncertainty based on the literature as to the necessity in removing lipids in seabird blood samples (Bearhop, *et al.*, 2002; Bond & Jones, 2009; McKenzie, 2011), this procedure was not carried out. Blood slides were dried overnight at approximately  $55^\circ\text{C}$  and then 0.001 g (0.0005–0.0015) was scraped into a tin capsule (McKenzie, 2011). Feather samples were washed in a solution of 2:1 Chloroform and Methanol for a minimum of one hour. After surface contaminants were removed, the feathers were rinsed twice in distilled water for 20 minutes at a time and then dried overnight at  $55^\circ\text{C}$  (Becker & Beissinger, 2006; Wunder, Kester, Knopf, & Rye, 2005). Once dry, feathers were cut into fragments and 0.002 g

(0.0018–0.0024) placed into a tin capsule. Samples were sent to the University of California at Berkeley for analysis by method of combustion, evaluating C and N contents (% dry matter) as well as C and N stable isotope ratios using elemental analyser/continuous flow isotope ratio mass spectrometry. An ANCA/SL elemental analyser (Sercon, Cheshire, UK) and a Finnigan MAT DeltaPlus XL mass spectrometer (Thermo Scientific, Bremen, Germany) were used.

To compare variation between the growth development, provisioning, fledging morphology and behaviour between male and female chicks, two to three full body feathers from the nape of chick's necks were plucked for DNA sexing. Samples from each individual chick were stored separately in an envelope and sent for analysis at Massey Universities Equine parentage and Animal Genetics Services Centre. Gender analysis was done using methods of PCR-H as per (Norris-Caneda & Elliott, 1998) (Houston, M., pers. comm.).

### *2.2.9 Feeding trial*

*Chick selection:* To replicate a scenario similar to translocation, chicks were removed from their natal burrows with parental provisioning and hand reared until fledging using current artificial provisioning techniques. Without known hatching dates for all focal chicks, the timing of the feeding trial was planned based on expected fledging times modelled from hatchling morphology. These selected dates were slightly underestimated and consequently the oldest/more developed chicks were most suitable for the trial. From 15 potential chicks, of approximately the same age (10–14 days away from fledging estimated by wing length), 10 which readily accepted the artificial diet and crop tube were recruited into the trial. The feeding trial was run by an onsite veterinarian.

To ensure that the chicks would tolerate being crop fed and accept the artificial diet they were fed at least once at their natal burrow site prior to transfer to artificial burrows. Any individuals which did not respond well to more than one feed and showed signs of significant distress, e.g. regurgitation, were omitted from the trial.

*Chick transfer and artificial burrows:* Once the ten suitable chicks were selected they were transferred from their natal sites to artificial burrows at a different location approximately 700

m away (Map 2.2). Chicks were transported by hand in a partitioned cat carrier box along with some of their nesting material to allow them to acclimatise to the new burrows.

Artificial burrows were constructed specifically to accommodate WFSP. Burrows measured 200 mm<sup>3</sup> and were constructed of plywood 15 mm thick with a removable lid. A 70 mm diameter x 250–300 mm plastic drainage tube was used as a burrow tunnel (the tube lengths were specifically less than 500 mm enabling any chicks that became stuck to be easily reached by hand). The burrows were dug into the ground therefore reducing the inside volume which was seen as being more spacious than natal burrows (thus following advice from the overseeing veterinarian) (Plate 2.4a). Burrows were placed in shaded areas, for example under thickets of *Muehlenbeckia*, to prevent overheating and to provide protection against rain (Plate 2.4b). Burrow lids were covered with extra vegetation and/or sun reflective covers on particularly hot days. The location of the artificial burrows was near to the research hut for hygiene purposes when transporting food and also close to suitable take off points for fledging chicks.



**Plate 2.4 a) Interior and open floor of artificial burrows used in white-faced storm petrel trial translocation. b) The artificial burrow design used to house transferred white-faced storm chicks selected for the artificial feeding trial. Photographs by Kay Clapperton.**

*Artificial diet:* Chicks were provisioned on a puree of Brunswick sardines in soya oil (106 g), fresh sterilised water (70 ml) and Mazuri seabird vitamin tablets (1/3 of tablet). This diet was slightly modified from a diet previously trialled on eight other petrel species with differing dietary niches and was recommended as an effective general food for burrowing Procellariiformes (Miskelly, Taylor, Gummer, & Williams, 2009). Water ratios were increased from 60 ml to 70 ml and Mazuri vitamin tablets were added on the advice of seabird

experts G. Taylor and H. Gummer (pers. comm.). Strict hygiene protocols were observed when preparing and delivering food (Gummer & Bishop, 2004; Gummer & Gardner-Gee, 2009), see Appendix V and VI. All water used in the puree was boiled for a minimum of 3 minutes for sterilisation. To prevent yeast and bacterial growth equipment was sterilized before food preparation and between individual feeds with Chlorhexidine. The food was prepared daily immediately prior to chick feeding with any unused food purees being discarded (Gummer & Adams, 2010; Taylor, G., pers. comm.).

*Feeding apparatus:* Crop tubes of different materials and sizes were trialled to identify those most appropriate and accommodating for the relative small size of WFSP. Crop tubes were too long (490–390 mm) and were shortened to 70 mm discarding the end distal to the syringe adapter. Full length tubes were impractical to handle and the length would have allowed the food to cool too much before reaching the chick (Mitchell, C. pers. comm.). The cut ends of modified tubes were quickly passed through a flame to soften the edges.

*Provisioning and meal regimes:* The feeding techniques used had been employed successfully in previous petrel translocation projects (Gummer & Gardner-Gee, 2009; Miskelly, *et al.*, 2009; Gummer & Adams, 2010). Chicks were fed by inserting food puree directly into the proventriculus using a crop tube in which 60 mm of the tube was inserted down the oesophagus and 10 mm was left extending from the tip of the bill. Two people were present at all times; one person restraining the chick while the other operated the syringe and controlled the chicks upper mandible, extending the neck up and outwards at approximately a 45° angle. If chicks expressed any signs of regurgitation or distress whilst being fed, the crop tube was carefully removed and the chick left to settle before further feeding attempts were made.

Using a working system incorporating literature and opportunistic concurrent data from naturally provisioned *in-situ* chicks, feeding regimes, meal sizes and target fledging weights were generated. As the chicks recruited into the feeding trial were the most developed of all the focal birds, there were no congruently aged *in-situ* chicks for direct comparison. Subsequently feeding regimes and meal sizes were based on available literature and the expertise of the veterinarian overseeing the trial. The wing length and weight was measured daily for each chick and meal sizes determined accordingly. Trial meals of diluted versions of the puree were given to the chicks as their first 2–3 feds, at their natal burrows as well as the

artificial burrows after transfer. These meals consisted of 70 ml of water per tin of sardines given at quantities of 2–3 ml. Meal sizes were reduced if chicks showed signs of high weight increases over a 24 hour period as this may indicate food being ingested too quickly for digestion and accumulation in the digestive tract (Gummer & Gardner-Gee, 2009).

*Unblocking burrows:* To prevent chicks leaving their burrows before they were ready, burrow tunnels were blocked using shade cloth. Without concurrent information on chick emergence from *in-situ* birds, it was difficult to know when to remove blockades. The criteria to determine when a chick was most likely to begin emerging and leave the burrow was based on changes in the chick's feeding and alertness behaviour together with wing length (when measurements reached approximately 135 mm). Chicks which became reluctant to feed and restless to handle and exhibited wing lengths exceeding 145 mm were considered to be imminent of fledging. This criterion was established after the most developed chick was allowed to emerge when the wing length reached 151 mm. The chick emerged on the first night following the removal of the blockade, and fledged the following night. Fledging may have occurred earlier if the blockade had been removed sooner.

All chicks were banded before blockades were removed. Burrow gates (stick palisades) were erected at the tunnel entrances to monitor chick emergence. Fledging was assumed to have been successful when burrows were found empty for two consecutive days and there were no signs of predation.

### ***2.3.0 Statistical analysis***

Specific details of statistical analysis are covered within each chapter. Overall, data were analysed using Minitab 16 (Minitab Inc., 2010) and Excel 14.0 (Microsoft Corporation, 2010) as well as CurveExpert and Jmp 10 (SAS Institute Inc.) for linear and logistic modelling of growth rates. Wing length growth was linear during the period of this study. Linear regression models fit better than logistic models and met the assumptions of normality (Table 3.1). The mean growth of wing length was statistically different for telemetry and development chicks ( $3.0 \pm 0.1$  mm/day and  $2.7 \pm 0.1$  mm/day;  $t = 3.00$ ,  $df = 24$ ,  $p = 0.01$ ). However, the measuring accuracy was 0.5 mm and therefore the small difference between groups was of no biological significance. The two groups were combined for additional analysis. Mean values  $\pm$  standard error are shown for all data with additional median values  $\pm$  standard deviation non-parametric data. All interval plot graphs show standard error.



**Plate 2.5 The Maritime NZ hut and home for the summer.**

# **Chapter Three**

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## **CHICK GROWTH AND DEVELOPMENT IN RELATION TO TRANSLOCATION**

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### 3.1.0 Introduction

#### 3.3.1 Procellariiformes and conservation

Procellariiformes (albatross, shearwaters and petrels) are distributed across oceans worldwide (Warham, 1990). However, over 30% of the world's seabirds are globally threatened or endangered and in New Zealand alone 47 taxa are considered threatened (Taylor, 2000a). Population declines are the result of marine and terrestrial anthropogenic impacts, and in particular invasive predators affecting breeding colonies (Croxall, *et al.*, 2012). For example, Procellariiform breeding colonies in New Zealand are significantly depleted from pre-human times because of the introduction of Pacific rats (*Rattus exulans*) and cats (Bellingham, *et al.*, 2010, Taylor, 2000a, Tennyson & Martinson, 2006).

There are important ecological considerations to the conservation of the world's seabirds. Procellariiformes are considered as keystone species and drivers of terrestrial systems, contributing to soil composition and food web interactions (Bancroft, Roberts, & Garkaklis, 2005; Hawke, Holdaway, Causer, & Ogden, 1999; Markwell & Daugherty, 2002; Worthy & Holdaway, 2002). The role of seabirds within ecological restoration is therefore now widely recognised.

#### 3.1.2 Seabird restoration ecology and translocation

The scientific discipline of restoration ecology emerged during the late 20<sup>th</sup> century and supporting theory has developed over the past decade (Comin, 2010). Ecological restoration is an important component of conservation work worldwide, and is augmented by projects involving seabird restoration (Jones & Kress, 2012; Taylor, 2000a). Jones and Kress (2012) identified 128 active seabird restoration projects worldwide, employing three different strategies: translocation, decoys and acoustic playback. Translocation is used to actively manage seabird populations, creating restoration opportunity by repatriating colonies and establishing new populations (Jones & Kress, 2012). Seabird translocation is a relatively new conservation method in New Zealand (Gummer, Taylor, Collen, Ward-Smith, & Mitchell, 2012), with only 17 seabird chick translocation projects identified between 1954 and 2008 (Miskelly, Taylor, Gummer, & Williams, 2009).

Seabird translocations are best suited to species that display naturally high rates of philopatry, those which do not require post-fledging care and that provision chicks with whole fish or

regurgitated meals (Jones & Kress, 2012). Albatross and petrels are therefore good examples of highly translocatable species. However, translocating Procellariiformes (petrels, shearwaters and albatross) can be challenging because it is invasive, labour intensive and expensive (Jones & Kress, 2012). Due to the intrinsic philopatry (high natal site fidelity) displayed by Procellariiformes (Brooke, 2004; Serventy, Gunn, Skira, Bradley, & Wooller, 1989; Warham, 1990), individuals must be translocated before they imprint on their natal site (Warham, 1990). This requires transporting chicks that are still dependent on parental provisioning from their natal burrows and supplementing them artificially until fledging at the translocated site (Jones & Kress, 2012). Imprinting is thought to occur near the end of chick rearing and during the chick emergence period (Serventy, 1967). The emergence period is when burrow-nesting chicks begin to explore outside their nest chamber during night hours and return to the burrow during the day (Serventy, 1967; Warham, 1990). The total number of nights in which chicks emerge is variable between species, individuals and sites (Gummer, Taylor, Collen, Ward-Smith, & Mitchell, 2012). For example, Simons (1985) described the emergence period of the Hawaiian dark-rumped petrel (*Pterodroma phaeopygia sandwichensis*). The chick began leaving the burrow two to three weeks prior to fledging, exploring a 10 m radius around the burrow and potential take-off points. In comparison diving petrels (*Pelecanoides urinatrix*) emerge for only one or two nights before fledging (Richdale, 1965; Miskelly & Taylor, 2004).

Miskelly and Taylor (2004b) describe the restoration of petrel populations as being extraordinarily difficult. The artificial rearing of transferred nestlings may result in reduced fledging success and high nestling mortality (Priddle & Carlile, 2001). For example, a translocation of fluttering shearwaters (*Puffinus gavia*) had a 38% fledging failure due to food poisoning (Bell, Bell, & Bell, 2005). During a three year project translocating 239 common diving petrels (*Pelecanoides urinatrix*), 51% of chicks failed to fledge (Miskelly & Taylor, 2004b). In this case, mortality resulted primarily from food poisoning, candidiasis and hypothermia (Miskelly & Taylor, 2004b). Protocols for translocating petrels are developing, with advancements in feeding techniques and hygiene, and a greater knowledge of breeding biology. Consequently, the rates of high fledging failure decreased to 4.5% in subsequent years (Miskelly & Taylor, 2004a; Miskelly, *et al.*, 2009).

When selecting suitable candidates for translocation it is important to know the estimated fledging period of the species and to select birds of similar age and in good condition. Having a sound understanding of basic breeding ecology, such as chick growth, plumage

development, and emergence behaviours of the target or a closely related species, will increase the probability of translocation success (Gangloff & Wilson, 2004; Miskelly, *et al.*, 2009; Priddle & Carlile, 2001). Provisioning information, such as meal size and feeding frequency, is also important for refining translocation techniques to ensure and maintain the health of hand-reared chicks (Gangloff & Wilson, 2004; Priddle & Carlile, 2001).

### 3.1.2 White-faced storm petrels

White-faced storm petrels (*Pelagodroma marina*) belong to the sub-family Oceanitinae, of the family Hydrobatidae, and are considered by the IUCN Red List as of “Least Concern” (Birdlife International, 2012). There are six subspecies of *P. marina* breeding on islands around Australasia and the Atlantic Ocean. *Pelagodroma marina maoriana* (specifically referred to here as WFSP) is endemic to New Zealand (Brooke, 2004; Marchant & Higgins, 1990; Taylor, 2000b) and breeds on islands around mainland North and South Islands, Chatham and Auckland Islands (Taylor, 2000b). The most detailed research on WFSP was collected from a southern population on Whero Island during the breeding seasons between 1940 and 1945 by L. E. Richdale (Taylor, 2000b). There is relatively little known about northern WFSP populations.

WFSP are one of the smallest Procellariiformes, averaging 47 g (Richdale, 1965). Breeding takes place during the austral summer, however the chronology is thought to vary with latitude (Richdale, 1965; Taylor, 2000b). For southern WFSP on Whero Island breeding begins during November and continues through to March. Adults return to colonies six to seven weeks prior to laying (Brooke, 2004) and most hatching occurs early January, ranging from late December to early February (Richdale, 1965). However, over five observed breeding seasons of southern WFSP, a variation in hatching dates was recorded, with 10.6 days separating early and late seasons from the mean (Richdale, 1965).

Procellariiformes generally lay a single egg per breeding season and a replacement egg after nest failure is uncommon (Warham, 1990). Storm petrels are known to lay large eggs relative to their size, at almost one third of their body weight (Warham, 1990). For WFSP, the incubation period lasts for approximately 50 days (Richdale, 1965); this is similar to the Australian white-faced storm petrel (*P. m. dulciae*), which incubate on average for 51.7 days, and Atlantic white-faced storm petrels (*P. m. hypoleuca*) for 53.7 days (Campos & Granadeiro, 1999; Underwood & Bunce, 2004). Incubation is shared by both parents with

each sitting for durations averaging four to five days (Richdale, 1965). This period of nest attendance per parent during incubation is relatively long compared to other storm petrel species, for example European storm petrels (*Hydrobates pelagicus*) and Wilson's storm petrels (*Oceanites oceanicus*) each incubate for two to three days at a time (Beck & Brown, 1972; Brooke, 2004).

Like many other Procellariiform species, *P. marina* is prone to temporary nest desertion and eggs can consequently withstand considerable periods of chilling (Marks & Leasure, 1992; Richdale, 1965; Warham, 1990). Richdale (1965) reports WFSP eggs being left unguarded for four days with incubation resuming just two days prior to successful hatching. This resistance of eggs to chilling is not uncommon among Procellariiformes and helps to buffer any lag periods that occur between parents when swapping incubation shifts (Warham, 1990). Records of Wilson's storm petrels from the South Shetland Islands of Antarctica show that eggs can still successfully hatch after being left unattended for 35% and 58% of the total incubation period, even though the ambient temperature of burrows can drop by approximately 10 °C in the absence of an incubating adult (Pefaur, 1974).

Southern population WFSP chicks are reared for 50 days before fledging in mid-February through to early April (Richdale, 1965). No parental care is given post fledging, as in all Procellariiformes, and it is likely that chicks migrate as adults do to regions of the eastern Pacific during austral winter (Imber, 1982; Marchant & Higgins, 1990; Spear & Ainley, 2007).

### 3.1.3 Purpose of the study

Seabird translocations to date have been predominantly conducted on small and medium-sized petrel species (Miskelly, *et al.*, 2009). WFSP provide an opportunity to investigate the potential to expand current translocation methods to even smaller petrel species. WFSP are good potential candidates (as are all Procellariiforms) as they fulfil the requirements for seabird translocation: they are highly philopatric, they do not require post-fledging care and they provision young with regurgitated meals. In addition, WFSP also breed in accessible locations and are not threatened, thus making them good a study species for exploring and extrapolating translocation methods. Expanding translocation prospects to storm petrels increases the potential of restoration possibilities for ecosystems and extirpated populations of small-sized petrels. This is especially important for potential management options for related

threatened species such as the newly rediscovered and data deficient New Zealand storm petrel (*Fregetta maoriana*).

There is comparatively little known about the breeding biology of northern WFSP relative to the southern population on Whero Island. There is an abundant population of WFSP on Burgess Island of the Mokohinau Group, in the Hauraki Gulf. This WFSP colony provides an opportunity to gather information from a northern population and compare it with Richdale's earlier work (1943a; 1943b; 1944; 1965). The breeding biology information from both latitudinal spectrums will provide better baseline knowledge to develop translocation prospects and protocol for this species.

### **3.2.0 Aims and objectives**

The aim of this chapter is to quantify chick development of northern WFSP during the chick rearing period and compare their growth with the existing information on southern populations. This information will provide important insights into the stages of chick growth and developmental characteristics, which may aid in identifying suitable chicks for future translocation projects. There are four main objectives:

- I. Describe the breeding timetable for the Mokohinau population of WFSP from the time of adult prospecting through to chick fledging. Basic incubation and hatchling data will be also described.
- II. Collect baseline data on the development of phenotypic characteristics and assess these characteristics as potential indicators of chick age. Focused studies of chick weight, wing length, bill length and tarsus length will be used to monitor chick development and to quantify morphological advancement throughout chick rearing to fledging.
- III. Describe the plumage development of chicks to supplement predictions of chick age.
- IV. Describe fledging behaviours and monitor burrow emergence behaviour by chicks prior to fledging to outline potential imprinting timeframes.

### **3.3.0 Field methodology**

As described in detail in Chapter 2 (sections 2.2.4 to 2.2.6), the growth of northern WFSP chicks has been quantified using the breeding colony on Burgess Island, of the Mokohinau Group.

Chicks from the development and telemetry groups (section 2.2.3) were weighed daily between 0800 h and 1230 h to monitor individual daily weight changes and growth.

Measurements of wing length (straightened,  $\pm 0.5$  mm) and tarsus (minimum,  $\pm 0.1$  mm) and bill length (exposed culmen,  $\pm 0.1$  mm) were collected every four days (Gangloff & Wilson, 2004; Peck & Congdon, 2005). Measuring frequency was increased to every two days once wing length reached 120 mm as chicks approached fledging (Gangloff & Wilson, 2004).

Plumage descriptions were recorded at the same time that morphometric measurements were taken. Plumage was described as percentage down loss of the wing, chest/belly, back, and head, and the development of characteristic white facial plumage. All qualitative observations were made by the same person during the study.

Chicks from the control group were weighed and measured using the above methodology two times during the focal chick growth monitoring period; once at the beginning of January and again when they were estimated to one week away from fledging (section 2.2.7). After the second measure chicks were checked daily for fledging. The development of control birds were later compared with the growth of chicks frequently handled.

Chick emergence periods were identified using Radio Frequency Identification Readers (RFID) and Passive Inductive Transponder (PIT) tags. Tags were attached externally to the base of a central tail feather using glue and first aid tape at approximately one week prior to fledging. Radio frequency receivers were set up around the burrow entrance to detect emerging chicks.

### **3.4.0 Statistical analysis**

All analyses were conducted using CurveExpert Professional 1.6 and the statistical package Jmp 10. Linear and logistic models were fitted to wing, bill and tarsus data, with individual as the co-variate. Models were compared using  $r^2$  and AICc values and the residuals were plotted and checked for normality.  $Y$  values included wing length and tarsus length, and  $x$  values were days before fledging (DBF) as age was generally unknown. To correctly fit the models, DBF values were first transformed by subtraction from 70 (average fledging age) and then the models run per chick. Group growth rates were then determined, accounting for individual variation, by using the mean of pooled individual data using the methods of Grim (2006).

The data on adult visits to nests monitored with radio telemetry is not included in this thesis due to technical errors affecting the results. However, the chicks from these nests were also measured and included in development estimates.

As hatch dates were not collected for all chicks, their age is described as days before fledging (DBF). When chick measurements are grouped by days (DBF), individuality is accounted for by using mean values for each chick. Considering the large sample sizes data generally conformed to normality. Mean values  $\pm$  standard error are presented. Descriptive statistics and data analysis were carried out using Minitab 16 (Minitab Inc., 2010) statistical software and Excel 14.0 (Microsoft Corporation, 2010). Two sample t-tests were used to compare morphological variation between male and female WFSP chicks. The overall down loss for individual chicks was calculated as the mean loss from all body sections (head, wing, back, chest/belly).

### 3.5.0 Results

#### 3.5.1 Growth of development vs. telemetry chicks

Linear regression models fitted wing growth better than logistic models and met the assumptions of normality (Table 3.1). The mean growth of wing length was statistically significant between telemetry and development chicks ( $3.0 \pm 0.1$  mm/day and  $2.7 \pm 0.1$  mm/day;  $t = 3.97$ ,  $df = 24$ ,  $p = 0.01$ ). The accuracy of wing measurements was 0.5 mm and while the results are statistically significant, the small differences are unlikely to be of biological consequence.

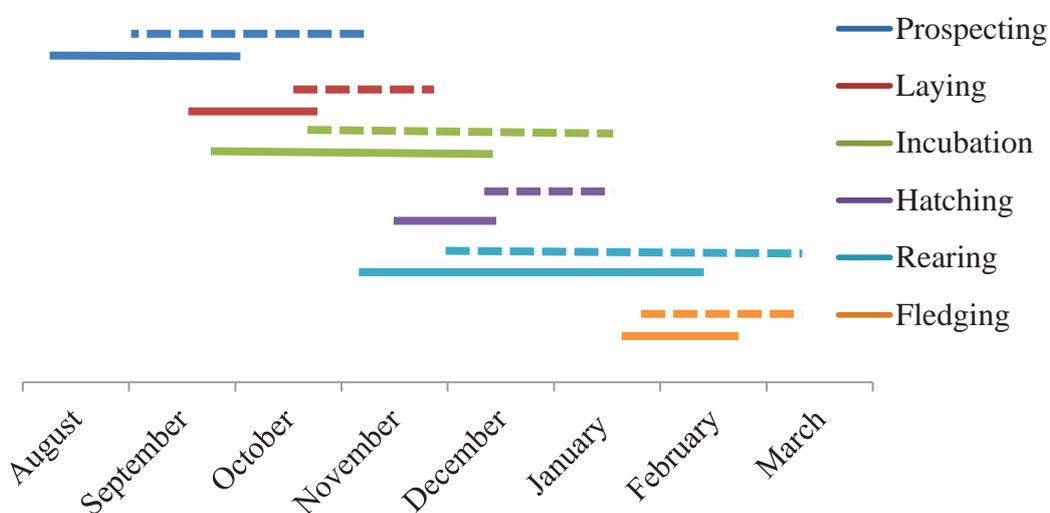
**Table 3.1 Linear model fit for wing length growth for two test groups (telemetry and development). Residuals from each linear regression model conformed to normality.**

Group	Model	R <sup>2</sup>	AICC	Normality
Development	<b>Linear</b>	<b>0.96</b>	<b>576</b>	<b>yes</b>
	Logistic	0.90	713	no
Telemetry	<b>Linear</b>	<b>0.92</b>	<b>387</b>	<b>yes</b>
	Logistic	0.94	407	no

Chick weight and wing length at the time of fledging did not vary statistically between development and telemetry groups. The mean fledging weights of development and telemetry groups were  $49.6 \pm 0.8$  g ( $n = 12$ , range: 45.5–54.5) and  $48.6 \pm 1.1$  g ( $n = 14$ , range: 42–55), respectively ( $t = 0.72$ ,  $df = 22$ ,  $p = 0.48$ ). Mean wing length at fledging for the development group was  $148.5 \pm 0.8$  mm ( $n = 13$ , range: 143.3–159.5) and  $148.3 \pm 1.3$  mm ( $n = 13$ , range: 141.0–159.5) for the telemetry group ( $t = 0.13$ ,  $df = 20$ ,  $p = 0.9$ ). Considering the relatively small differences in wing growth and the absence of variation between wing lengths and chick weight between groups at fledging, it is apparent that fitting radio tags to one parent per adult WFSP pair did not significantly affect the provisioning and growth of the respective chick. Consequently the data from the telemetry group has been merged to supplement data collected from the development group.

## 3.5.2 Breeding chronology

Figure 3.1 shows the breeding chronology for both northern Burgess Island and southern Whero Island populations. Southern birds in general breed approximately one month later than northern populations. During September 2011, WFSP were observed prospecting and digging burrows. Based on the incubation period of 50 days for southern WFSP (Richdale, 1965), the laying period for the Burgess Island WFSP population is expected to have occurred in mid- to late October.



**Figure 3.1** The breeding timetable for a population of northern white-faced storm petrels (solid lines), from burrow prospecting to chick fledging ( $n = 44$ ). The duration of prospecting and laying are estimated based on anecdotal observations. Dashed lines indicate the breeding chronology of southern populations on Whero Island, as recorded by Richdale (1965).

The breeding timetable of *P. marina* subspecies is shown in Table 3.2. On Burgess Island, WFSP hatching occurred over a period of about 30 days. The mean known hatch date, from observed hatchlings, was 13 December  $\pm$  1.1 days ( $n = 16$ , range: 7–21 December) and an extrapolated population hatch date, based on the mean chick rearing duration of known-age chicks (68 days) and fledging dates, was 6 December  $\pm$  1.2 days ( $n = 44$ ). The earliest chick was estimated to have hatched on 22 November and the last record was observed on 21 December. The observed chick rearing period was 68.1  $\pm$  0.9 days ( $n = 15$ , range 62–73). This is the longest recorded for WFSP or other *P. marina* subspecies (Table 3.2). The earliest

chick fledged on 30 January and the last on 2 March; observed fledging occurred over 32 days and the mean fledging date was 12 February  $\pm$  1.2 days (n = 43).

**Table 3.2 The duration in days that *P. marina* chicks hatch, are reared and fledge between populations of different sub-species, as well as mean dates for hatching and fledging (standard error).**

Population	Mean hatching date (hatch period)	Duration of chick rearing	Mean fledging date (fledging period)
<b>Burgess Is.</b>	<b>6 Dec <math>\pm</math>1.2 (30)</b>	<b>68 (62-73)</b>	<b>12 Feb <math>\pm</math> 1.2 (32)</b>
Whero Is. (Richdale, 1965)	5 Jan $\pm$ 0.5 (29-42)	57.4 (52-67)	Unknown (est 23-40)
Mudd Is. (Underwood & Bunce, 2004)	24 Dec $\pm$ 0.8 (18)	54.8 (50-70)	17 Feb $\pm$ 1.7 (31)
Selvagem Grande Is. (Campos & Ganadeiro, 1999)		60.3 (55-67)	

### 3.5.3 Survivorship

Within a few days of our arrival at the colony (7 December 2011), burrows containing 50 hatchlings were located and an additional 58 nests were located with unhatched eggs, of these, 21 eggs successfully hatched (41.2%) (Table 3.3).

The overall mortality rate of chicks was 21% (n = 15). Three deaths occurred within one week of hatching and a further five within the first three weeks after hatching. Another two chicks died two weeks prior to fledging. The remaining five chicks were lost between the December and January visits.

Of the focal chicks recruited into this chapter (n = 44, for chick selection see Chapter 2.2.3) at the beginning of January, 98% successfully fledged; there was one mortality (Table 3.3). The death of the chick remains undetermined after necropsy at Wildbase, Massey University. For this entire study a total of 52 chicks are thought to have fledged successfully. This number of fledglings represents 47.7% of all known active burrows (found containing an egg or chick, n = 108) and 72.2% of all hatchlings (n = 71) (Table 3.3).

**Table 3.3 Summary of the survival success of white-faced storm petrels' nests during 2011-2012, from eggs to chick fledging and respective test groups. Values in brackets are percentage values. Unknown failures are eggs and chicks that were lost or disappeared without confirmation of death.**

Group	n	Survived (%)	Known failure (%)	Unknown failure (%)
Number of eggs (hatching)	58	21 (36.2)	26 (44.8)	11 (18.9)
Number of chicks (fledging)	71	52 (72.2)	15 (21)	4 (5)
<b>Total active burrows</b>	<b>108</b>	<b>52 (48)</b>	<b>41 (38)</b>	<b>15 (14)</b>
Development group	16	15 (93.8)	1(6.2)	
Telemetry group	15	15 (100)	0	
Control group	13	13 (100)	0	
<b>Total chicks recruited into study</b>	<b>44</b>	<b>43(98)</b>	<b>1(2)</b>	

#### 3.5.4 Hatchling morphology

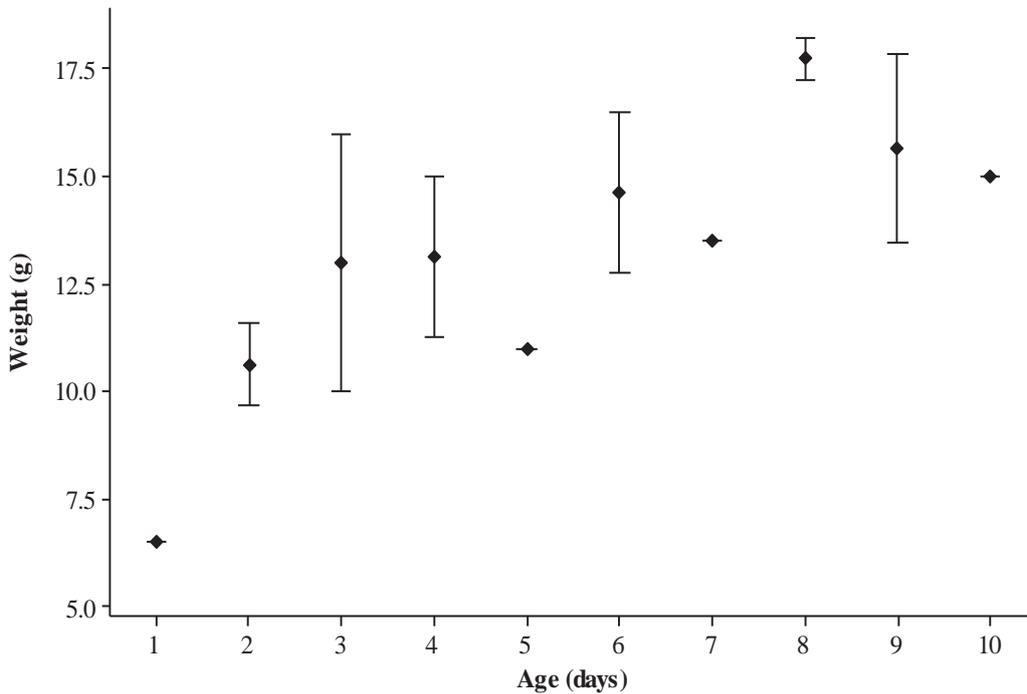
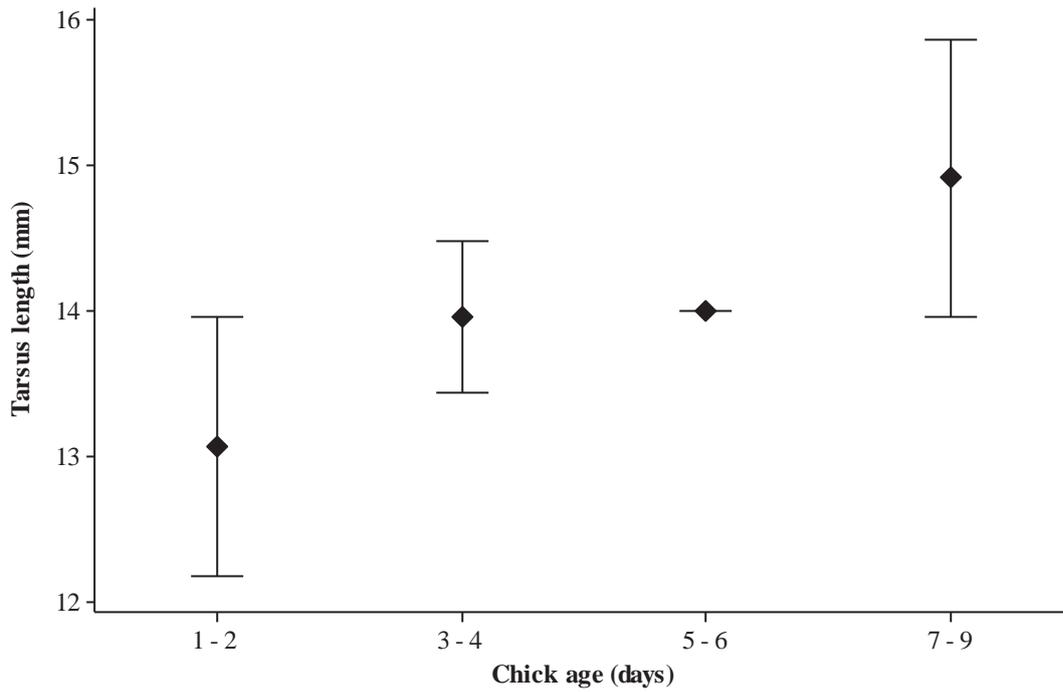
Chicks were covered in grey down at hatching (Plate 3.1). Our observations agree with (1965), that only a single down was grown in contrast to other Procellariiform chicks, which develop a second layer (Warham, 1990). At the time of hatching chicks have a pink bald patch on their crown, the skin then turned grey at one to two weeks of age. The bill and tarsus were dark grey and feet had a pink tinge.

Adult WFSP were recorded staying with their chick during daylight hours inconsistently over the first week after hatching and up to nine days of age. However, chicks were frequently recorded as unattended by the parents in the burrow one day after hatching (70%, n = 7). An adult was in the majority of cases back with the chick on the second day (71%, n = 5). The egg tooth was generally lost within one week of hatching.



**Plate 3.1 a) A young downy white-faced storm petrel chick soon after losing the egg tooth. Photograph by Megan Young. b) A white-faced storm petrel chick having the tarsus measured. The tinge of pink colouration is visible in the chick's foot. Photograph by Abe Borker.**

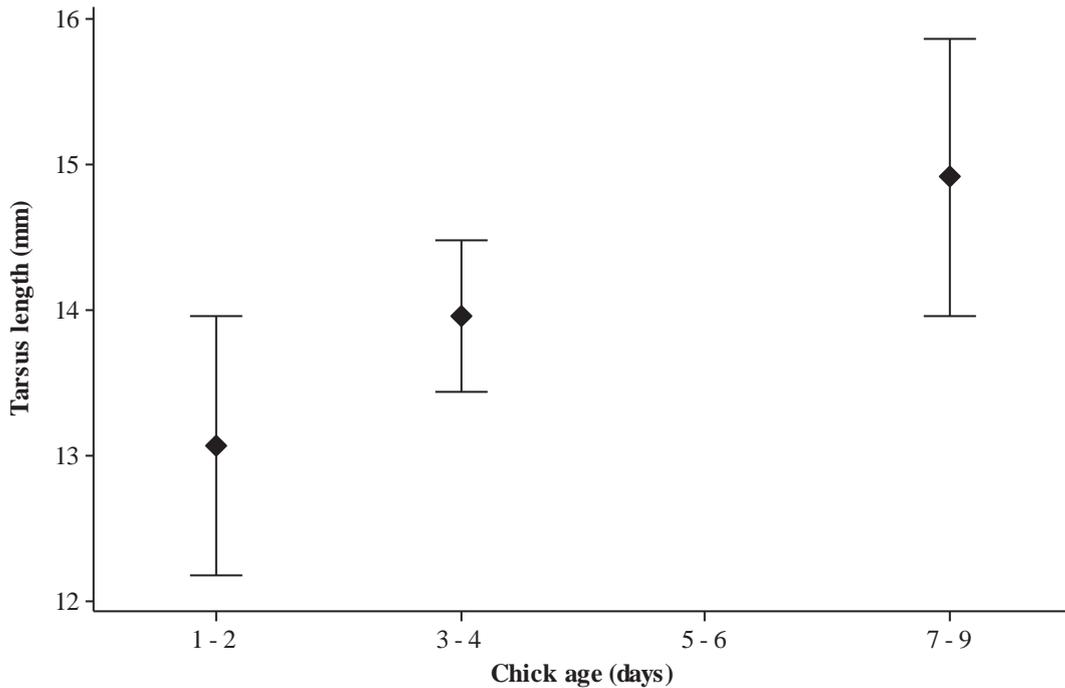
On the first and second days after hatching chicks weighed  $9.8 \pm 1.1$  g ( $n = 5$ , range: 6.5–12.5). At eight to 10 days chicks had increased to an average weight of  $16.6 \pm 0.9$  g ( $n = 8$ , range: 13–20). Although not addressed in detail, Richdale (1943a) mentions that chicks on Whero Island weigh approximately 9 g at hatching. Changes of chick weight over time are shown in Figure 3.2.



**Figure 3.2 Mean weight increase (with standard error bars) for white-faced storm petrel chicks (n = 14, range per day 1–7) during the first ten days of age.**

The tarsus length of hatchlings, ranging from one to five days in age, was  $13.6 \pm 0.2$  mm (n = 10, range: 12.3–14.1). Growth during the first nine days was steady, reaching a maximum

length of 15.6 mm (Figure 3.3). Re-measuring was done opportunistically, when time and conditions allowed and when chicks were not being brooded. Consequently, intervals between measurements are inconsistent and vary between individual chicks. Measurements of chick wing lengths within one week of hatching were too difficult to measure and deemed too imprecise for analysis.



**Figure 3.3 Mean tarsus length (with standard error bars) for white-faced storm petrel chicks (n = 11, range per day 4–5) from ages one to nine days.**

Defining the culmen length for hatchlings was difficult and it is likely to have been overestimated partly due to the inexperience of the researcher. The mean bill length during the first four days of age was  $12.2 \pm 0.5$  mm (n = 8, range: 10.8–14.2). Initial measurements were incorrect and hence excluded from the analysis, the bill size is likely to be nearer to a mean length of  $10.7 \pm 0.1$  mm (n = 6, range: 10.5–10.9).

### 3.5.5 Control group

The daily handling of development group chicks did not affect their growth. There was no significant difference in the growth rate of wing length between test and control groups; as the value for test birds was within the upper and lower limit confidence intervals for the control

group (Table. 3.4) ( $t = -0.05$ ,  $df = 42$ ,  $p = > 0.05$ ). The difference between daily growth rates of both groups was less than the measuring accuracy of 0.5 mm and is likely due to the level of instrument precision. Individual variation could not be accounted for with control chicks as sample sizes for each individual were too small, consequently all the control data were pooled.

**Table 3.4 Results from a linear regression model show the variation in wing length growth rates for control and test birds with 95% upper and lower confidence intervals. There was no significant difference between the groups ( $t = -0.05$ ,  $df = 42$ ,  $p = > 0.05$ ).**

Group	Growth rate	Lower CI (95%)	Upper CI (95%)
Control (n=18)	2.8	2.83	2.95
Test (n= 28)	2.9	2.86	2.94
<b>Difference</b>	<b>0.01</b>		

### 3.5.6 Chick morphology

#### Growth rates

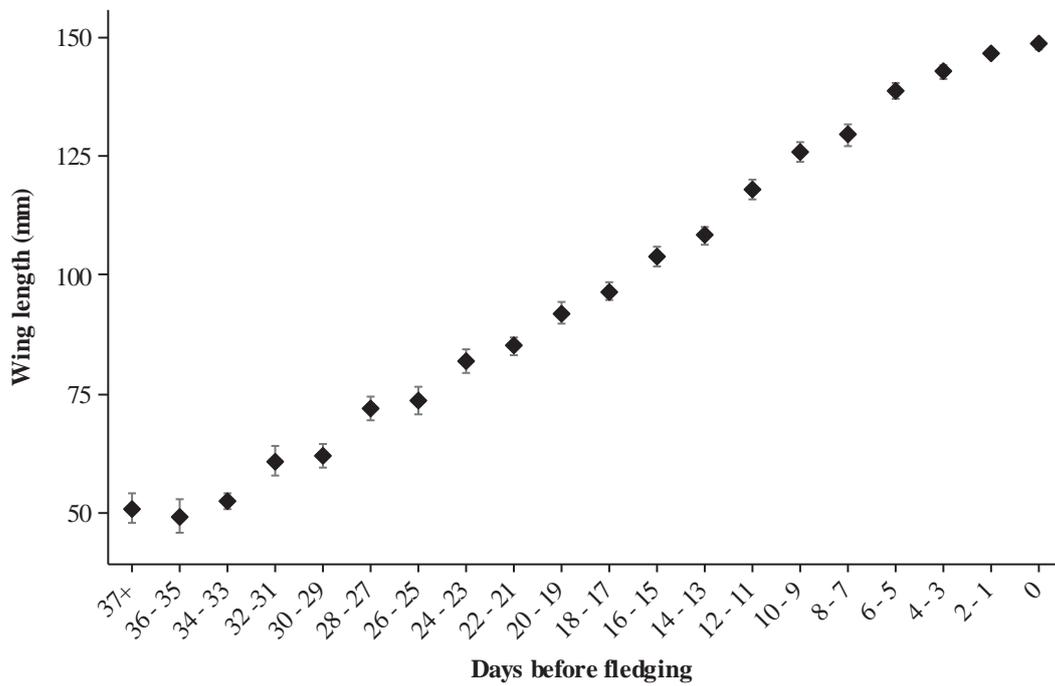
Wing length and tarsus growth rates are shown in Table 3.5. Wing growth was linear, increasing by 2.86 mm/day. Bill length has been excluded because precise measures were difficult to obtain consistently in the field throughout the study. Weight was variable (Figure 3.9) and had a limited fit to the models.

**Table 3.5 Growth values from linear (wing length), logistic (tarsus) and Gompertz (weight) models. Bill lengths were considered problematic and too difficult to precisely measure in the field. Values are combined for control and test chicks: mean daily growth rates,  $r^2$ , AICc and 95% confidence intervals**

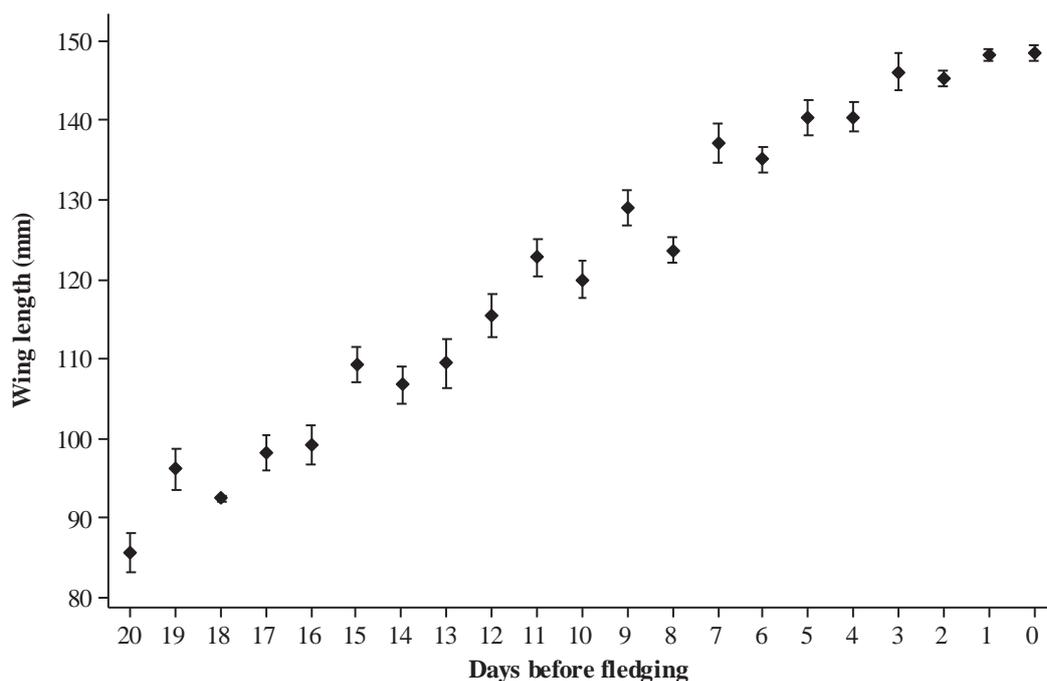
Measure	$R^2$	AICc	Growth rate	Lower CI	Upper CI
Wing (mm)	0.96	387	2.86	2.73	2.97
Tarsus (mm)	0.95	416	0.45	0.32	0.57
Weight (g)	0.38	240	0.7	0.02	0.17

*Wing development*

Wing length increased at an almost linear rate during the focal period (Figure 3.4). Chicks fledged with wing lengths averaging  $148.8 \pm 0.8$  mm ( $n = 27$ , range: 141–159), which is less than adult length (93.6%): 158.6 mm (Richdale, 1944). Recorded wing lengths were smaller than those on Whero Island, where WFSP chicks fledged with average wing lengths of 156.5 mm (range: 147–167) (Richdale, 1944). Figure 3.5 gives a detailed account of wing growth during the final 20 days before fledging.



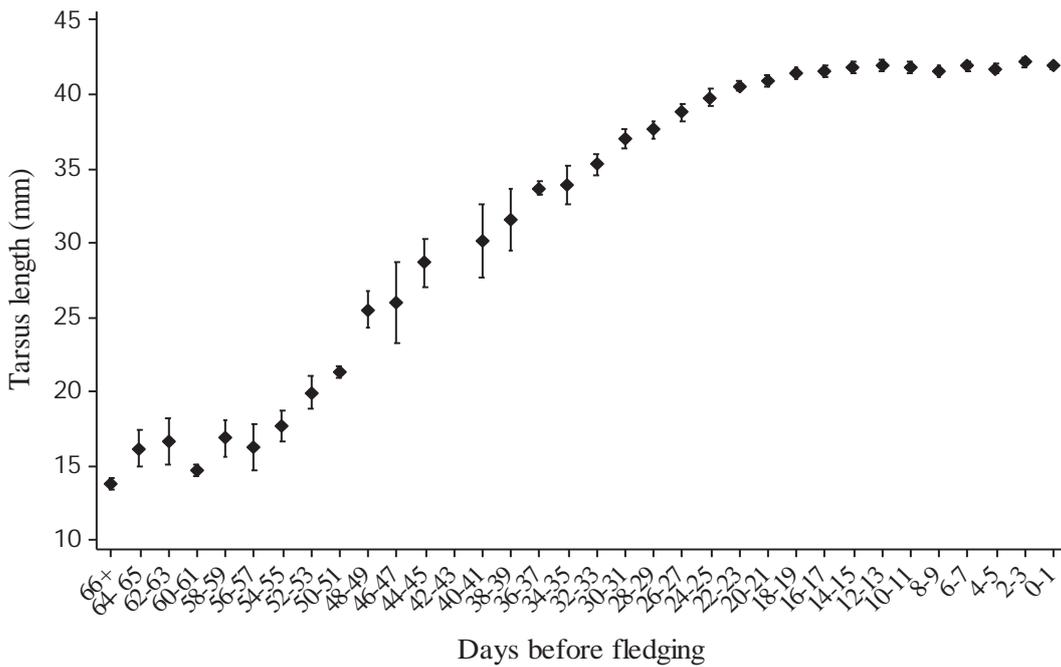
**Figure 3.4** Mean wing length for white-faced storm petrel chicks ( $n = 28$ , range per day 5–19) shown relative to days before fledging. Error bars represent standard error.



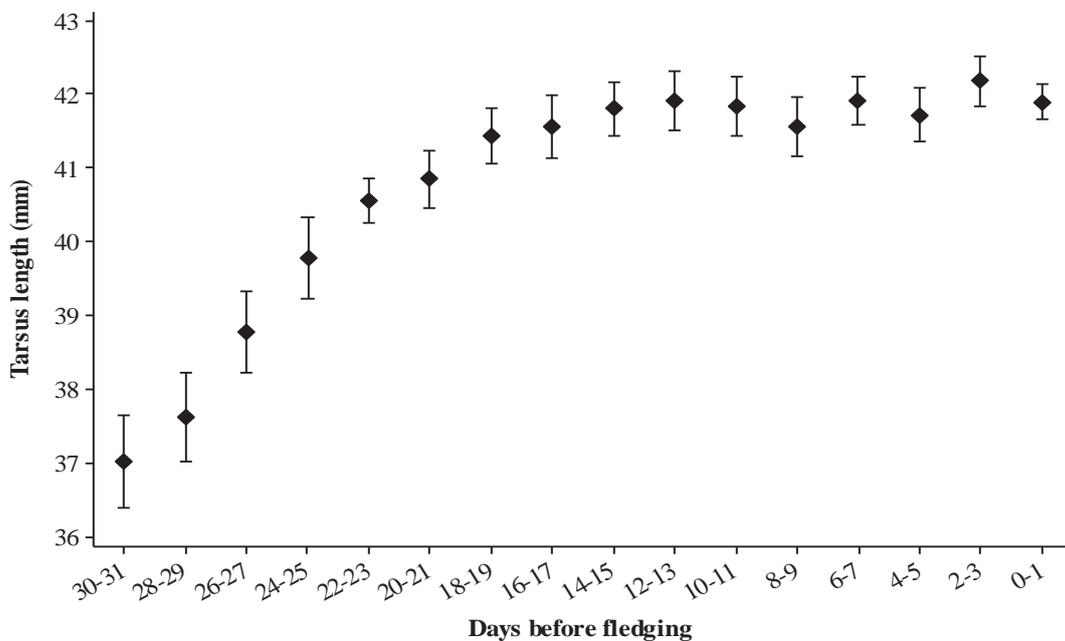
**Figure 3.5** Average wing lengths (with standard error bars) for white-faced storm petrel chicks. Overall 28 chicks measured (daily 2–12) from 20 days before fledging until departure.

### *Tarsus development*

Chick tarsus growth was rapid from about 56 DBF until the asymptote was reached at approximately 12 - 13 DBF (Figure. 3.6). Chicks fledged with a mean tarsus length of  $41.8 \pm 0.2$  mm ( $n = 31$ , range: 39.4–44.3), compared to a full adult tarsus length of 42.1 mm ( $n = 46$ , range: 39.0–45) (Imber, 1984). Figure 3.7 shows data for the last 30 DBF, providing detail on tarsus length as chicks approach fledging.



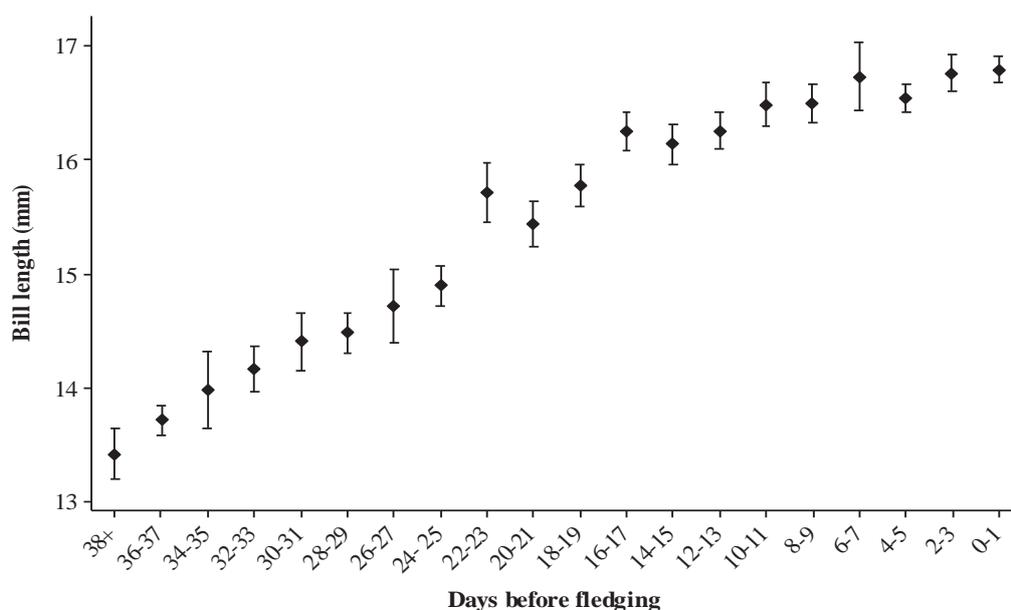
**Figure 3.6** Development of tarsus length (error bars show standard error) of white-faced storm petrel chicks (n = 28, range per day 2–20) during the chick rearing period, relative to days before fledging.



**Figure 3.7** Mean tarsus length for white-faced storm petrel chicks (n = 28, range per day 9–20) during the last three weeks of the chick rearing period prior to fledging. Error bars show standard error.

*Bill length*

Bill length increased consistently throughout the chick rearing period, reaching an asymptote at approximately seven days before fledging (Figure 3.8). Chicks fledged with bill lengths averaging  $16.7 \pm 0.1$  mm ( $n = 31$ , range: 15.6–18.1). This figure is slightly greater (104%) than the full bill length of adults of 16.1 mm recorded by Richdale (1944) and 15.8 mm ( $n = 42$ , range: 14.6–17) by Imber (1984). This difference may be accounted for within precision measures, however Southern Whoero Island WFSP fledged with bill lengths lower again, averaging 15.33 mm (range: 14–16.5) (Richdale, 1944).

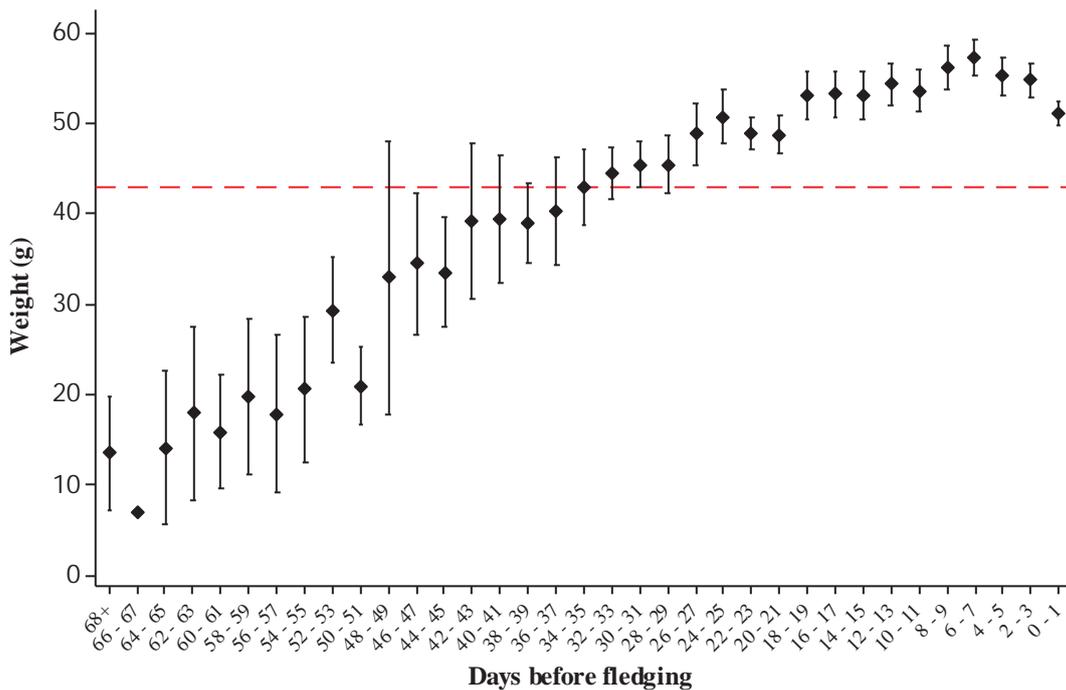


**Figure 3.8** Mean bill length for white-faced storm petrel chicks ( $n = 28$ , range per day 1–20) during the chick rearing period. Error bars represent standard error.

*Weight*

Changes in chick weight over time are shown in Figure 3.9. On average chicks reached the adult weight of  $43.4 \pm 0.7$  g ( $n = 58$ , range: 30–55) at 35 DBF. On Whoero Island adults were heavier, averaging 47.2 g ( $n = 100$ , range: 40–62) (Richdale, 1944). The greatest peak weight

reached by chicks was 87 g at 17 DBF. The average peak weight was  $66.2 \pm 1.7$  g ( $n = 25$ , range: 49–87), which is 153% of mean adult weight. Individuals reached maximum weight at different times during the rearing process, ranging between 0 and 29 DBF. The mean time was at  $12.2 \pm 1.7$  days ( $n = 25$ ) before fledging. The average weight lost from peak to fledging weight was  $16.7 \pm 1.5$  g ( $n = 25$ , range: 0–34.5); one chick reached its heaviest weight of 49.5 g on the day it fledged.



**Figure 3.9** The mean weight of white-faced storm petrel chicks ( $n = 30$ , range per day 3–30) during chick rearing. Error bars show standard error. The red dashed line shows mean weight of adult white-faced storm petrels, measured across the breeding season (2011/2012) on Burgess Island.

The average fledging weight for chicks was  $49.5 \pm 0.7$  g ( $n = 25$ , range: 42–55), equivalent to 114% of mean adult weights ( $43.4 \pm 0.7$  g,  $n = 58$ ). Chicks on Whero Island fledged at weights slightly higher but more variable, averaging 51.8 g (range: 35–68) (Richdale, 1944). Figure 3.10 shows chick weights during the last 20 days before fledging.

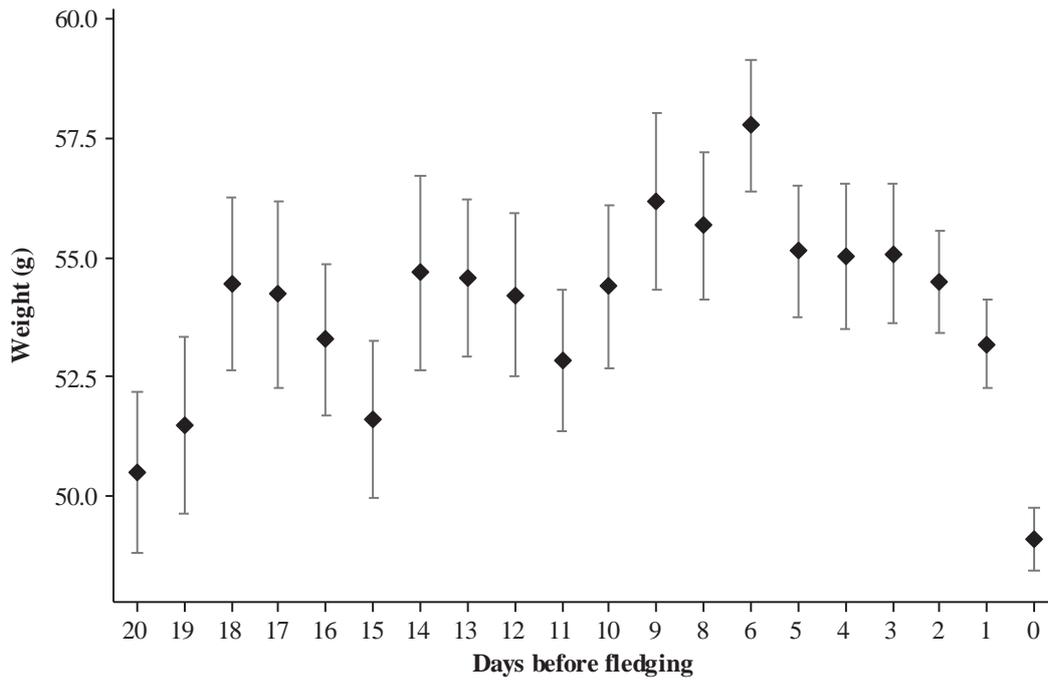


Figure 3.10 Mean chick weight (with standard errors) for white-faced storm petrels' (n = 30, range per day 28–24) during the last 20 days before fledging.

### 3.5.7 Sexual variation

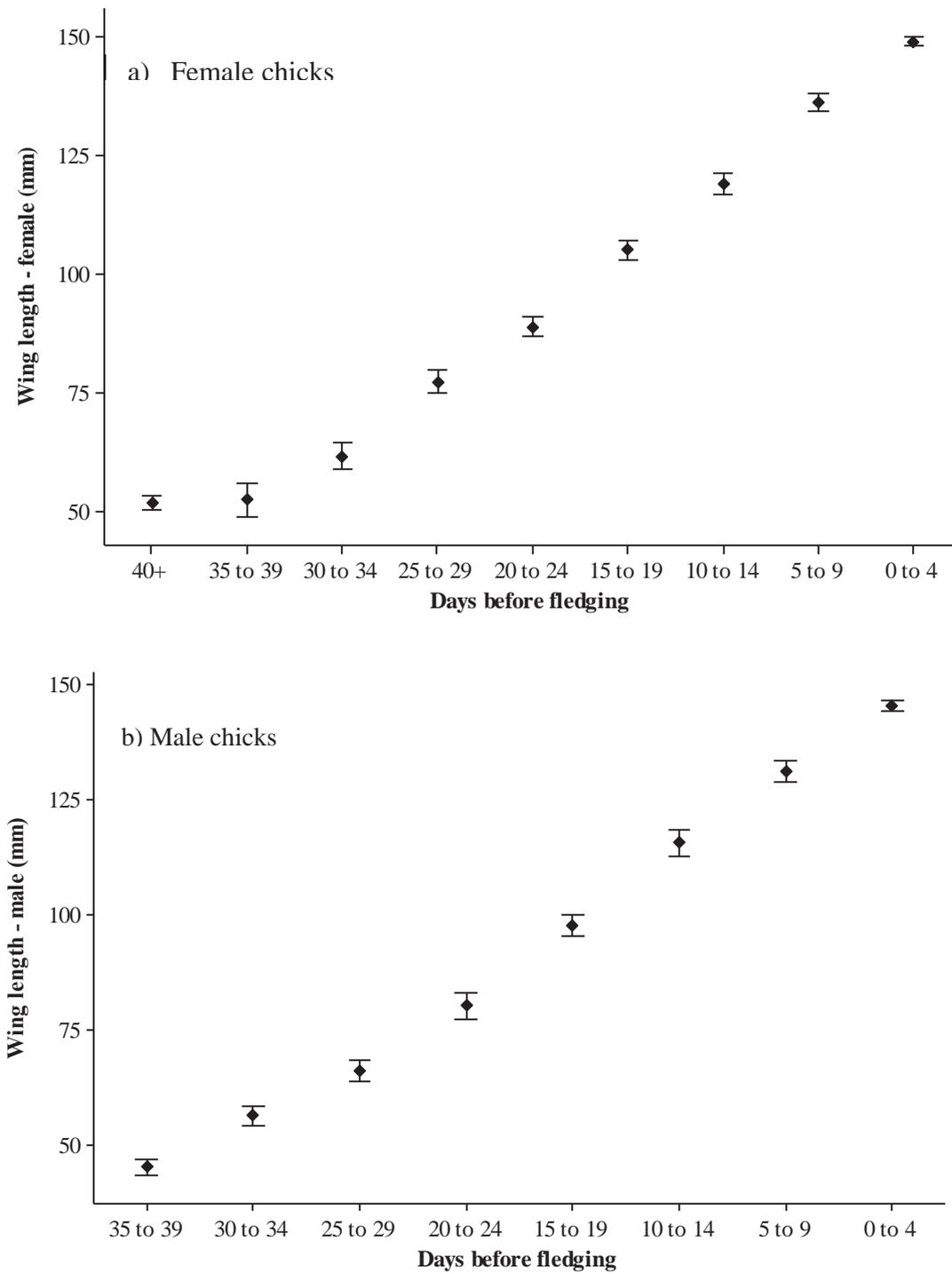
Growth rates as calculated using Gompertz models for weight, wing and tarsus were similar for males and females (Table 3.6).

Table 3.6 male (n = 7) and female (n = 10) growth rates for weight, wing and tarsus measurements using Gompertz growth curve models.

Measure	Sex	R <sup>2</sup>	AICc	Growth Rate	SE	Upper CI	Lower CI
Weight	Male	0.42	244	0.12	0.06	0.25	0.001
	Female	0.43	212	0.22	0.08	0.38	0.05
Wing	Male	0.99	58	0.04	0.01	0.07	0.05
	Female	0.98	46	0.03	0.003	0.04	0.03
Tarsus	Male	0.66	33	0.08	0.04	0.15	0.01
	Female	0.39	22	0.12	0.01	0.14	0.1

*Wing length*

The mean wing lengths at fledging for female and male chicks was  $151.1 \pm 1.3$  mm ( $n = 11$  range: 144.3–159.5) and  $147.8 \pm 0.8$  mm ( $n = 7$ , range: 144.6–150.5), respectively. The variation between the two groups is statistically significant ( $t = 2.18$ ,  $df = 14$ ,  $p = <0.05$ ) (Figure 3.11). Sexually dimorphic size variation in wing length is recognised amongst adult *P. marina* (Marchant & Higgins, 1990) (Table. 3.7). Wing growth parameters of male and female chicks are shown in Table 3.6, there was no significant difference in the growth rates of wings between male and female chicks ( $t = 1.83$ ,  $df = 16$ ,  $p = 0.085$ ) (Figure 3.11).



**Figure 3.11 a & b** Average wing lengths (with standard error bars) for female ( $n = 10$ , daily range 2 - 10) and male ( $n = 7$ , daily range 3–7) white-faced storm petrel chicks during the chick rearing period. Variation between groups was statistically significant at the time of fledging ( $t = 2.18$ ,  $df = 14$ ,  $p < 0.05$ ). The slope of growth was not statistically different between sexes ( $t = 1.83$ ,  $df = 16$ ,  $p = 0.08$ )

**Table 3.7 Variation in morphological traits of wing, tarsus and bill length of male and female white-faced storm petrel chicks at fledging from Burgess Island and adults collected from museum skin collections (Marchant & Higgins, 1990). The current study (Burgess Is.) is in bold font. Mean values  $\pm$  SE**

	Female	Male
<u>Wing length (mm)</u>		
<b>Burgess Is.</b>	<b>151.1 <math>\pm</math> 1.3 (n = 10, range: 144.3 - 159.5)</b>	<b>147.8 <math>\pm</math> 0.8 (n = 7, range: 144.6 - 450.5)</b>
Imber (1984)	156.8 $\pm$ 1.4 (n = 17, range: 148 - 173)	155.0 $\pm$ 2.44 (n = 10, range: 145 - 167)
<u>Tarsus length (mm)</u>		
<b>Burgess Is.</b>	<b>42.6 <math>\pm</math> 0.3 (n = 11, range: 40.8 - 44.3)</b>	<b>41.4 <math>\pm</math> 0.8 (n=7, range: 41.3 - 42.5)</b>
Imber (1984)	41.2 $\pm$ 0.42 (n = 19, range: 38.3 - 44.2)	41.2 $\pm$ 0.5 (n = 13, range: 37.6 - 44.5)
<u>Bill length (mm)</u>		
<b>Burgess Is.</b>	<b>17.09 <math>\pm</math> 0.2 (n = 11, range: 16.2 - 18.1)</b>	<b>16.4 <math>\pm</math> 0.2 (n = 7, range: 15.6 - 17.3)</b>
Imber (1984)	16.1 $\pm$ 0.8 (n = 19, range: 14.7 - 17.8)	15.9 $\pm$ 0.18 (n = 13, range: 14.2 - 17.9)

### *Tarsus*

The mean tarsus length for female WFSP fledglings was  $42.6 \pm 0.3$  mm (n = 11, range: 40.8–44.3) and males  $41.4 \pm 0.8$ mm (n = 7, range: 41.3–42.5) (Table. 3.6). The variation between sexes was statistically significant ( $t = 2.84$ ,  $df = 15$ ,  $p = <0.05$ ). Tarsus lengths of female and male WFSP on Burgess Island were greater than those described by Imber (1984) (Table 3.7). Tarsus growth rates for male and female chicks showed a similar Gompertz curve, however mean female tarsus lengths were 1.7 mm longer than those of males at 39–35 DBF at the start of the study (Figure 3.12). The growth rates of males and female chicks were not significantly different (Table 3.6;  $t = 1.18$ ,  $df = 16$ ,  $p = 0.25$ ).

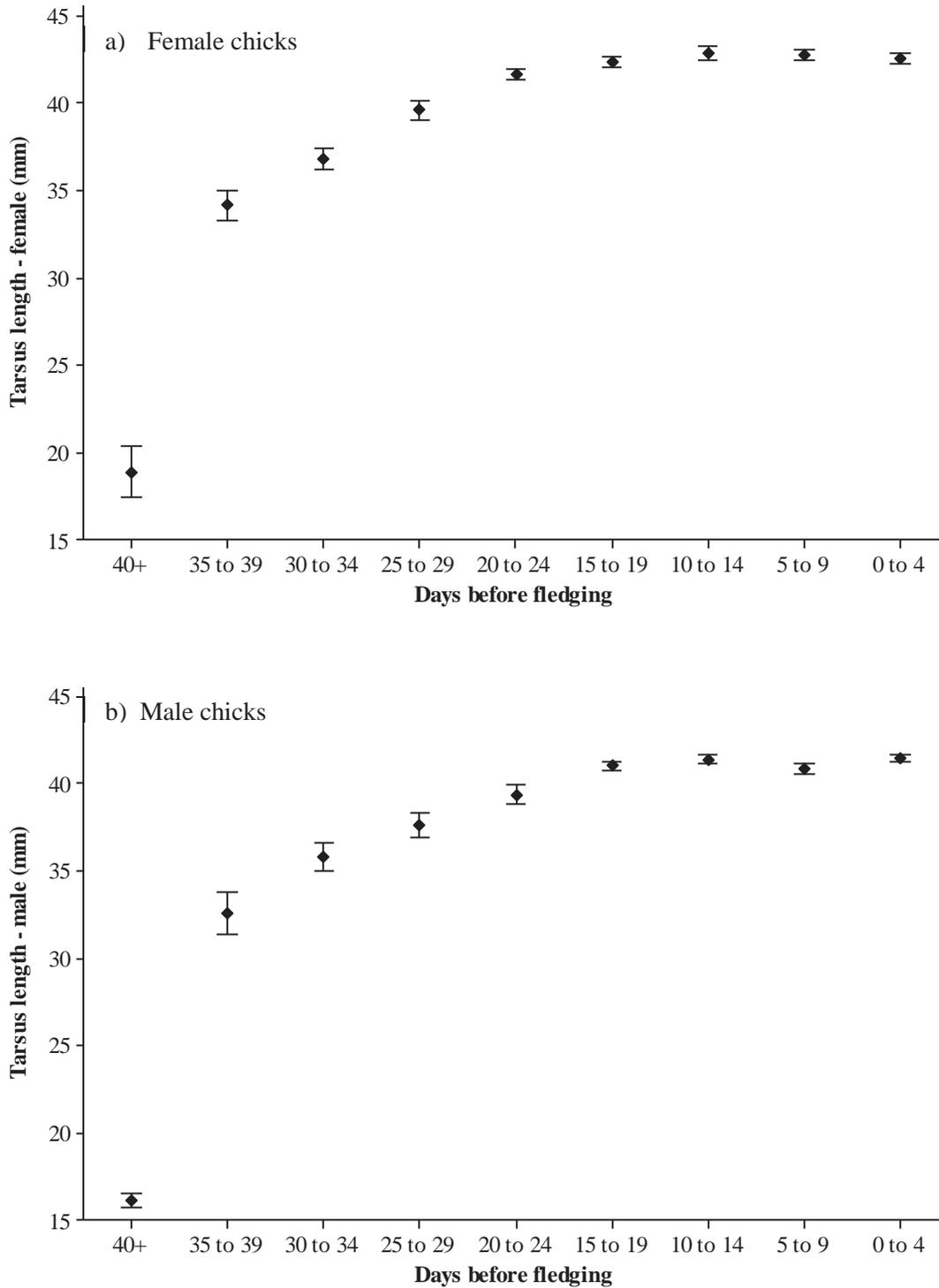


Figure 3.12 a & b Tarsus growth for female (n = 11, daily range 2–11) and male (n = 7, daily range 3–7) white-faced storm petrel chicks during the chick rearing period to fledging. Error bars represent standard errors. There was no significant variation in the slope between sexes ( $t = 0.18$ ,  $df = 16$ ,  $p = 0.25$ ).

*Bill*

Bill growth rates showed similar trends in both sexes (Figure 3.13). Female and male WFSP chicks fledged with mean bill lengths of  $17.09 \pm 0.2$  mm ( $n = 11$ , range: 16.2–18.1) and  $16.4 \pm 0.2$  mm ( $n = 7$ , range: 15.6–17.3), respectively (Figure 3.13). The variation between sexes was statistically significant ( $t = -2.58$ ,  $df = 12$ ,  $p = < 0.05$ ). Although consistent with Imber's (1984) findings (Table 3.6), the reliability of this result is low due to sample size and measurement errors. Due to challenges in accurately measuring bill length consistently the growth has not been modelled for male and female chicks.

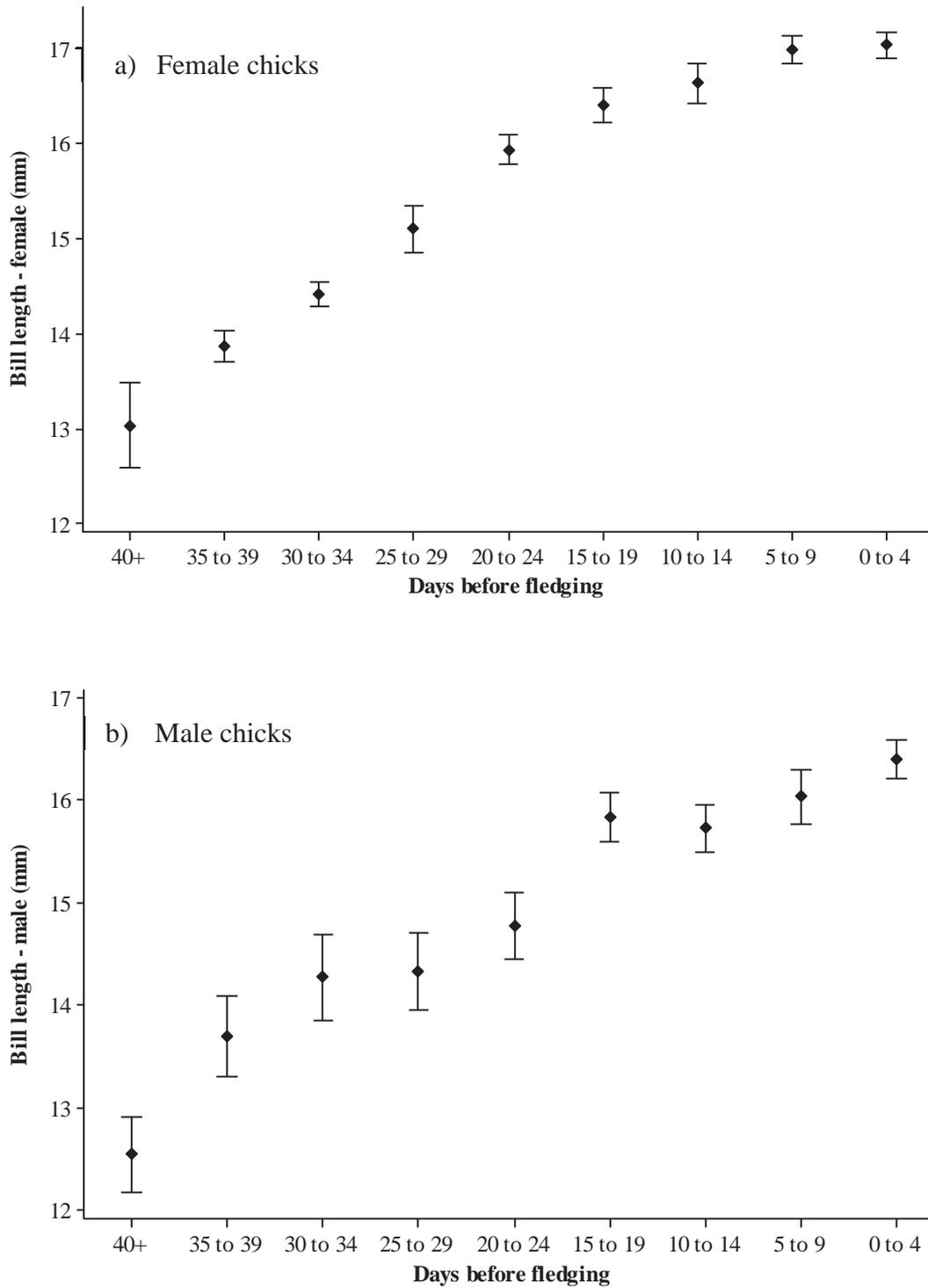
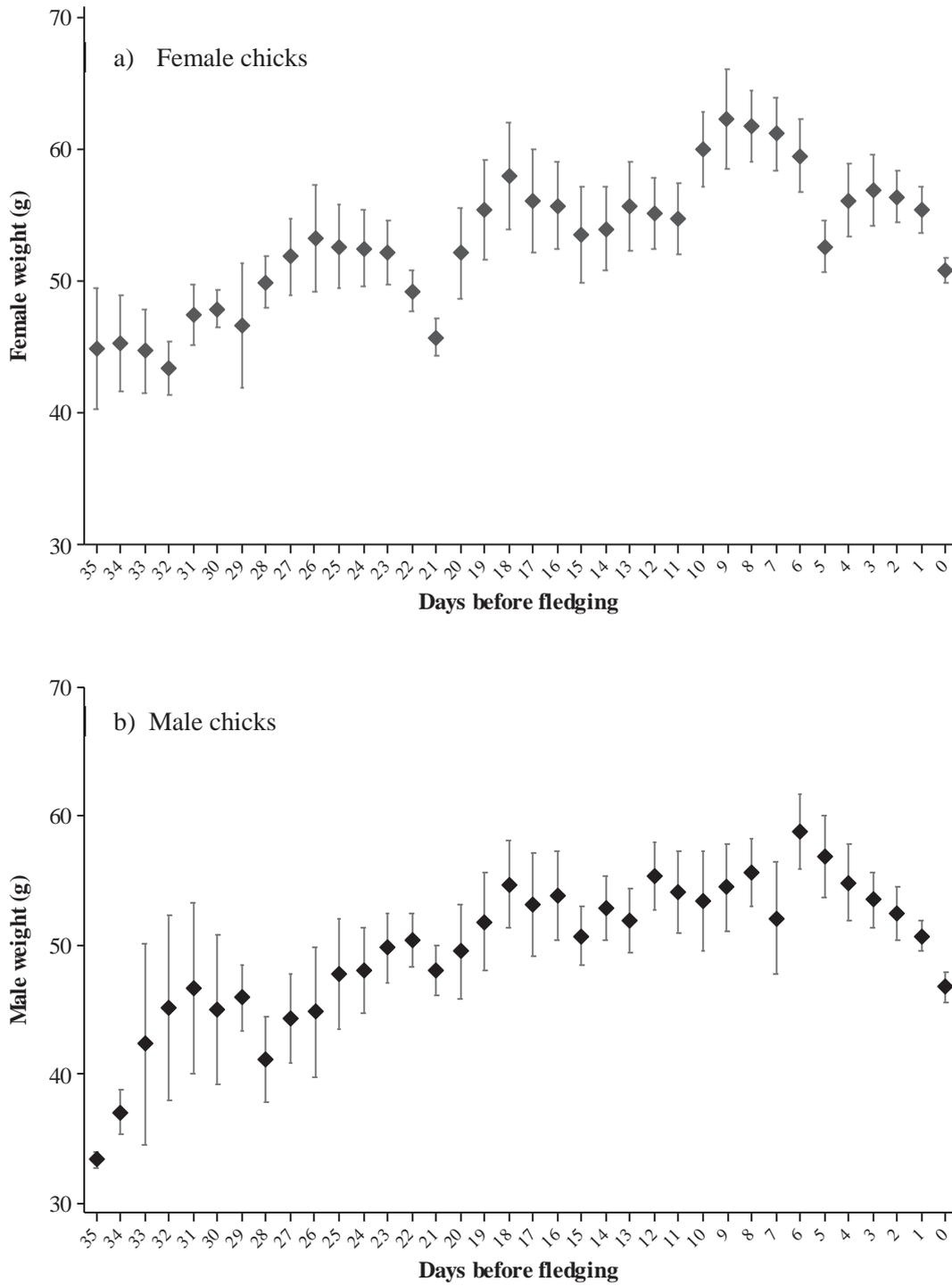


Figure 3.13 Mean bill length (with standard error) of a) female (n=11, daily range 2–11) and b) male (n = 7, daily range 3–7) white-faced storm petrel chicks over the period of chick rearing until fledging.

*Weight*

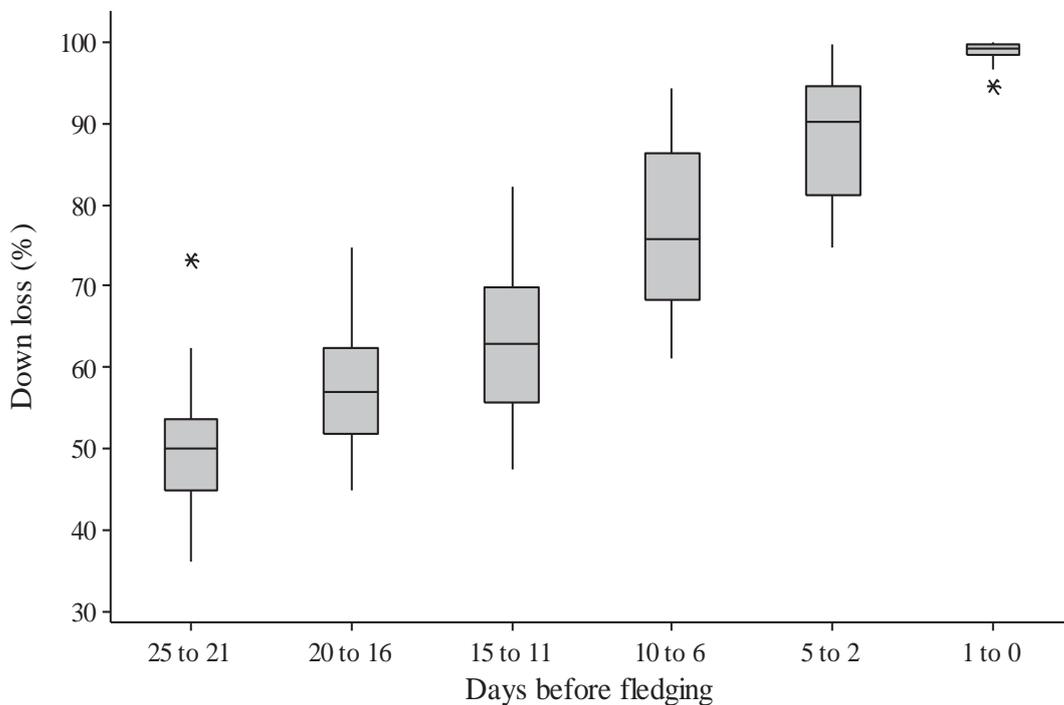
At the time of fledging, female and male WFSP chicks did not differ statistically in weight ( $t = -1.83$ ,  $df = 10$ ,  $p = 0.97$ ). Female chicks averaged  $50.9 \pm 0.9$  g ( $n = 11$ , range: 45.5–54.5) and males averaged  $47.9 \pm 1.4$  g ( $n = 7$ , range: 42–55). Growth rates using Gompertz models are shown in Table 3.6. There was no significant difference in the growth of chick weight between male and female chicks ( $t = 0.89$ ,  $df = 16$ ,  $p = 0.89$ ) (Figure 3.14).



**Figure 3.14** Mean chick weight over the duration of chick rearing for both a) female ( $n = 11$ ) and b) male ( $n = 7$ ) white-faced storm petrel chicks. Error bars show standard error. There was no significant difference in growth rate of sexes ( $t = 0.89$ ,  $df = 16$ ,  $p = 0.89$ ).

3.5.8 Plumage

By the time chicks had reached 20–25 DBF the median proportion of down loss (mean value of combined body sections) was 49% (n = 26, range: 36–73) (Figure 3.15). At time of fledging, chicks had lost on average 99% (n = 26, range: 94.5–100) of down. Some individuals fledged with no down at all and others with varying traces. The most down remaining on a chick was 5.5% and this was predominantly on the head and chest.



**Figure 3.15 Median percentage down loss for white-faced storm petrel chicks (n = 26) relative to development as days before fledging.**

At 25–21 DBF the mean down loss on the wings of focal chicks was 72% (n = 26). At this stage of development, wings had lost more down compared to the chest (63%), back (20%) and head (42%) (Table 3.8). Down loss of the head was difficult to gauge due to the natal bald patch found on the chick’s crown.

**Table 3.8 Mean percentages of down loss for white-faced storm petrel chicks (n = 26) at five day intervals for individual body segments. Combined values are the average of individual body sections.**

DBF	Wing	Chest	Back	Head	Combined
25 to 21	72	63	20	42	63
20 to 16	79	70	26	54	70
15 to 11	85	73	35	62	74
10 to 6	91	82	51	85	82
5 to 2	97	87	75	98	87
1 to 0	100	98	98	99	98

One

of the most distinctive growth stages of chicks is the development of white facial plumage (Plate 3.2). White feathers emerge first just above the bill at  $23 \pm 0.7$  days (n = 21, range: 16–32). Soon after, white feathers begin to develop behind the eye at  $18 \pm 0.7$  DBF (n = 22, range: 12–24). Full white facial plumage was fully established at approximately  $11 \pm 0.7$  DBF (n = 20, range: 8–16). White tips on primary feathers (Plate 3.3) were also distinctive features of development and began to emerge at  $25 \pm 0.8$  DBF (n = 23, range: 1–32).



**Plate 3.2** White facial plumage development of white-faced storm petrel chicks. Chick A) plumage at 21 days before fledging, white feathers emerge above the bill. Chick B) white plumage progresses around the back of the eye at 14 DBF. Chick C) fully established white facial plumage and Chick D) the plumage of the head near to fledging at 2 days prior to fledging.



**Plate 3.3** A white-faced storm petrel chick with white tips on the primary wing feathers.  
Photograph by Dylan van Winkle.

### 3.5.9 Emergence

The average number of nights that chicks emerged from their burrow before fledging was  $3.1 \pm 1.4$  nights ( $n = 10$ ), this ranged from two to six nights. Eight out of ten chicks left their burrow for the last time between 20:49 h and 23:24 h, the other two chicks did not return to their burrows after 03:26 h and 03:43 h, respectively. Chicks were never observed more than two meters away from their burrow entrances. However, these observations were opportunistic and the distances travelled by chicks when emerging were not specifically measured.

RFID readers detected chick presence at the entrance of the burrow; chicks began emerging from their burrows soon after dark (20:00 h and 21:00 h) and would be active (near burrow entrance, entering or exiting) for an average of 6 h 30 min. Times of activity varied from one minute to 10 h 39 min.

### 3.6.0 Discussion

#### 3.6.1 Control group and the effects of handling

The lack of biologically significant variation between the wing growth of control and development groups suggests there is minimal impact from regular handling of chicks. As the hatch dates for control birds were not known, the duration of chick rearing and most morphometric measurements could not be compared. The mean fledging weight of the development group was similar to that of southern chicks on Whero Island, also suggesting only minimal effects on chick condition from frequent handling. The variation between the means of northern and southern populations (2.3 g) is to some extent explained by Bergmann's rule (Feldhamer, Drickamer, Vessey, Merritt, & Krajewski, 2007).

Defensive reactions such as regurgitating oils and stomach contents in response to handling, as recorded for some Procellariiform species, may have negative effects on chick growth and body mass (Carey, 2009; Warham, 1990). When WFSP chicks were initially handled small amounts of oil were sometimes visible around the bill, possibly from stress related regurgitation. However, this was not common and once regular monitoring commenced in January the presence of oil was rare. I conclude, the frequent handling of WFSP chicks is unlikely to be detrimental to fledging condition. This finding is consistent with the evidence from literature that frequent handling has little or no discernable effects to chick growth and quality (Carey, 2009). Saffer, *et al.* (2000), for example, showed that no effects were found between groups of short-tailed shearwater (*Puffinus tenuirostris*) chicks disturbed at low, medium and high frequencies. In contrast, Gangloff and Wilson (2004) found that in Pycroft's petrel chicks (*Pterodroma pycrofti*), control birds were significantly heavier than study birds late in chick development. However, they note that shorter wing length of control birds may indicate that they were younger than the study chicks.

WFSP chicks which were monitored regularly appeared to become habituated to handling. Although resistance from removal from the burrow was common, once chicks were in the hand they were generally calm and sometimes peeped quietly. This peeping was similar to the sounds made by chicks being provisioned by adults. A few chicks remained relatively aggressive, being less passive to handle, biting and trying to escape restraint. In contrast, when control unhabituated birds were handled, struggling was intense and frequent and chicks were also aggressive.

### 3.6.2 Survivorship

The overall success of active nests in this study, from egg to fledging, was 48%. This is within the range of expected success rates for small burrowing petrels (40–50%) as outlined by Warham (1990). Nest failure during the egg stage was generally more common than during chick rearing, as reported by Brook (2004) and Warham (1990). The cause of mortality of young chicks that died prior to the commencement of focal monitoring in January was unknown. However, young chicks may die from starvation and hypothermia (Phillips & Hamer, 1999). Boersma (1986) reports 75% of fork-tailed storm petrel (*Oceanodroma furcata*) mortalities occurring before 10 days of age. The low impact of handling chicks is reflected in the fledging success of both development and control chicks; that had just one individual die during this study. The chick was found dead a few metres away from its natal burrow. A post mortem at the Institute of Veterinary, Animal and Biomedical Sciences at Massey University could not detect a cause of death. For the necropsy report see Appendix II.

Small Procellariiformes, and particularly storm petrels, are known to be sensitive to disturbance during incubation, with effects such as reduced reproductive success, burrow shifts, divorce rates and long term effects on lifetime reproductive success (Blackmer, Ackerman, & Nevitt, 2004; Carey, 2009; Warham, 1990). Incubating adult WFSP were initially removed from burrows and banded when active nests were found, however some eggs were consequently deserted and adults were therefore no longer handled. A study on the effects of handling Leach's storm petrel (*Oceanodroma leucorhoa*) showed that weekly handling reduced hatching success by 50% and daily handling by 56% compared to controls (Blackmer, *et al.*, 2004). Marks and Leasure (1992) reported hatching success at 33% in Tristram's storm petrel (*O. tristrami*) and this high rate of failure was attributed to adult desertion (either permanent or temporary) resulting from researcher disturbance. In this study, hatching success was similar to ours at 36%. Including all known chicks (hatching post and prior to researcher arrival) the overall hatching success increases to 64%. The slightly lower rate of hatching after the commencement of regular monitoring suggests researcher disturbance may have been a compromising factor. However, there may also be a bias towards higher egg failure rates after researcher arrival because of infertile eggs, as well as a seasonal trend in success.

To minimise disturbance I suggest that egg/chick presence be checked by gently sliding a hand under the incubating adult rather than complete removal. The short length of WFSP

burrows means that manual hand checking is effective in terms of time and accuracy. Marks and Leasure (1992) used similar methodologies on Tristram's storm petrels, however they removed the eggs when checking. The authors reported adults quickly re-settling upon the returned eggs. Burrow scopes may be an option to monitor hatching, however probing under an incubating adult to check for egg/chick presence can damage the adult and/or offspring (Lyver *et al.*, 1998).

### 3.6.3 Breeding chronology

This is the first detailed study of WFSP breeding in the northern regions of New Zealand. The latitudinal variation between southern populations on Whero Island and northern birds on Burgess Island appears to be approximately one month, with breeding beginning earlier in the north. The breeding timetable of northern birds reported in this study is consistent with the brief literature described by Cunningham and Moors (1985) for WFSP on Maria Island of the Noises Group in the Hauraki Gulf. The authors described WFSP incubating during late November/early December and that most chicks had fledged by 3 March. On Whero Island, hatching was observed in early January by Richdale (1965) and in early December in this study on Burgess Island. In southern populations the spread of hatching is protracted, ranging from 29 to 42 days between seasons (Richdale, 1965), and is estimated at approximately 30 days on Burgess Island. The timing of fledging reflects this takes one month on Whero Island (Richdale, 1944) and over 32 days on Burgess Island.

The synchronicity of breeding varies between Procellariiformes (Warham, 1990); asynchronisation is common in the laying of storm petrels and one month periods of unsynchronised hatching have been recorded in grey-faced petrels (*Pterodroma macoptera gouldi*), wedge-tailed shearwaters (*Puffinus pacificus*) and Hutton's shearwaters (*Puffinus huttoni*) (Brooke, 2004; Cuthbert & Davis, 2002; Warham, 1990). Other Procellariiformes however, such as great shearwaters (*Puffinus gravis*), sooty shearwaters (*Puffinus griseus*) and short-tailed shearwaters, have more tightly synchronised breeding. These latter species are more restricted by temporal limitations of migration and the utilisation of food resources peaking between southern and subarctic waters during austral and northern summers (Cuthbert, 2005; Warham, 1990).

The latitudinal variation in WFSP breeding timetables would influence the planning of translocation proposals depending on the chosen source population. When breeding is

asynchronous, it may be difficult to collect enough individuals of the same age in a single transfer. Additional transfers two to three weeks apart may be necessary. In addition, the timing of chick hatching in southern populations varies between years. Over five breeding seasons a variance of 10.6 days from the mean was recorded between earliest and latest seasons (Richdale, 1965). Making reconnaissance trips to the source population several weeks prior to transfer to gauge the extent of variation in breeding timetables and chick development would help identify and overcome such temporal limitations.

The chick rearing period observed on Burgess Island was longer than the recorded duration for southern WFSP and other sub-species by an average of 10.6 days (Table 3.2). It is not known whether this extended duration is representative of a normal season or whether it is abnormal and in response to an external variable such as food supply or climate. Chick rearing periods are generally not uniform because chicks are influenced by varying microclimates and provisioning rates (Warham, 1990). A study done on grey-faced petrels in the Hauraki Gulf during the same year (2011) also reported an atypically extended chick rearing period, with 22 days between observed and expected means. Grey-faced petrel chicks were provisioned with lower than previously recorded meal masses and were consequently stunted in growth and in poor condition at the time of fledging (Dunn, 2012). Dunn (2012) suggests the effects on oceanic productivity resulting from a mild-medium La Niña of the El Niño-Southern Oscillation (ENSO) phenomenon that season may be a relevant factor. Another aspect of oceanic climate is the Interdecadal Pacific Oscillation (IPO). IPO is a phenomenon which has long term influence over the ENSO cycle affecting climate variability and surface temperatures (NIWA, n.d.; Salinger, Renwick & Mullan, 2001). Ainley & Hyrenbach (2010) show that Pacific Decadal Oscillation (North American reference to IPO) is significantly correlated with oceanic upwelling and population trends in various seabird species. In addition, Pacific Decadal Oscillation is known to affect the diet of common murre chicks (*Uria aalge*) (Parish & Zador, 2003).

Another factor possibly relevant to the extended duration of chick rearing is the recent recovery of this population following the eradication of kiore (*Rattus exulans*) on Burgess Island in 1990 (McFadden & Greene, 1994). Young breeding Procellariiformes are often associated with patterns of low provisioning and consequently slow growth rates, a trend that is exaggerated with limited food resources (Brooke, 2004; Sydeman, Penniman, Penniman, Pyle, & Ainley, 1991). WFSP were historically recorded as abundant during the late 1800s and then not present at all on Burgess Island post kiore colonisation (McCallum, 1980;

Sandager, 1889). It was assumed that any storm petrel breeding attempts failed due to kiore predation (McFadden & Greene, 1994). The current WFSP density on Burgess Island suggests a rapid population increase during the past 18 years (Gaskin, C., pers. comm.; pers. obs.). Therefore the extended chick rearing period may be partially explained by relatively young and inexperienced breeders from the recent population expansion, as well as seasonal fluctuations of food availability; thus suggesting that some disparity in breeding chronology may be expected in future breeding seasons.

#### 3.6.4 Chick development

The growth of wing and tarsal lengths for WFSP chicks were congruent with expected patterns of general Procellariiform development (Cuthbert, 2005; Gangloff & Wilson, 2004; Quillfeldt & Peter, 2000; Underwood & Bunce, 2004; Warham, 1990). Wing growth increased at a linear rate from approximately 32 DBF, making it a good predictor of chick age, as described by Gangloff and Wilson (2004) and Gummer and Gardner-Gee (2009). Wing length has been used in conjunction with specified weight criteria to select diving petrel chicks for translocation (Gummer & Gardner-Gee, 2009). Neither Whero Island nor Burgess Island WFSP chicks attained full adult wing length before fledging (Richdale, 1965). As expected, tarsus length increased steadily and reached adult length approximately two weeks prior to fledging.

Chick weight is inherently more variable than other morphological traits because stomach contents are generally changeable and often in a pre-absorptive state (Warham, 1990). The weight growth pattern for Procellariiform chicks is generally sigmoidal with a peak that drops to the adult asymptote (Warham, 1990). This pattern is observed in a range of Procellariiformes where peak weights, depending on the species, exceed adult mass by 10–70% (Booth, Minot, Imber, & Fordham, 2000; Brooke, 2004; Cuthbert, 2005; Phillips & Hamer, 2000; Warham, 1990). The peak weights attained by storm petrels are relatively high, exceeding adult weights by 40–70% (Warham, 1990). WFSP chicks observed in this study reached on average 156% of adult weight ( $43.4 \pm 0.7$  g) at  $67.5 \pm 1.8$  g ( $n = 28$ ), however the timing of this peak varied between chicks relative to DBF, thus skewing the population growth from expected patterns. In comparison, the subspecies *P. m. dulciae* from the Mud Islands, Australia, reached mean peak weights of  $79.7 \pm 0.4$  g (SE,  $n = 21$ ), at 140.5% of adult mass ( $57 \pm 4.9$  g (SD)). The pattern of pre-fledging weight loss of *P. m. dulciae* is more

distinct than that of WFSP, with a prominent drop in mean chick weight in the final week before departure (Underwood & Bunce, 2004). WFSP descended in weight over just three days to reach fledging weights (Figure 3.10).

Mauck and Ricklefs (2005) suggest that for Leach's storm petrels, pre-fledging weight loss is triggered by the attainment of full wing development and that fledging occurs once chicks reach a weight light enough to sustain flight. They also highlighted the role of parental provisioning on the rate at which chicks reach full development and the duration of pre-fledging mass loss relative to the nutritional state of the chick. Therefore, abnormal food provisioning may explain the unsynchronised attainment of peak mass and lack of a distinctive weight loss phase in WFSP chicks. In addition, Dunn (2012) suggests that the variance in wing growth between individual grey-faced petrel chicks may indicate that growth spurts are directly proportional to short term provisioning.

Undernourished chicks generally follow normal growth patterns and only those which are extremely starved have stunted growth (Harris, 1966). Dunn (2012) also observed extended chick rearing periods as well as stunted growth in grey-faced petrels on other islands in the Hauraki Gulf during the same year as this study. This occurred from nutritional deficiencies resulting from small meal sizes. An example similar to this occurred within the focal WFSP: one chick from this study, which went frequently unfed, had small wings which seemed less rigid and fragile. This chick was of unknown age but fledged much earlier than expected.

### *3.6.5 Burrow emergence*

The emergence periods for WFSP were longer than expected, averaging  $3.1 \pm 1.4$  nights and ranging from 2 to 6 nights. Richdale (1944) reported WFSP emerging on the night of fledging or one night prior. It is possible that Richdale was only reporting chicks completely leaving their burrows, and excluding those sitting at the tunnel entrance. The mechanisms of imprinting at the time of emergence are unknown (Warham, 1990), but it could be assumed that chicks sitting at tunnel entrances are initialising philopatric learning. The identification of chick emergence behaviours beginning earlier than one to two nights before fledging is important for the planning and management of translocations. If chicks were to be transferred assuming an emergence period which is shorter than the true duration, chicks could have already imprinted on their natal site, thus jeopardising translocation success.

Some focal chicks were observed sitting above ground at night as well as climbing and moving around the immediate areas outside of their burrows. One chick was seen entering an empty burrow near to its own (less than half a metre away) and remaining inside for periods up to approximately 10 minutes. The chick was observed moving between its own burrow and this vacant one several times. For this reason burrows of presumably fledged chicks were checked over three consecutive days and exact fledging dates could only be assumed.

RFID readers and PIT tags were generally useful technologies for monitoring emergence periods. The sensitivity of aerials set up around the burrow entrance was such that they would detect a PIT tag approximately 5 cm away. As the PIT tags were attached to the base of focal chicks' tails, the tag would be recorded when the chicks' head was approximately in line with the aerial and not when the chick had completely exited the burrow. A 2–3 m distance was required between RFID readers to prevent interference between signals. Because of this, some chicks could not be monitored when neighbouring burrows had chicks at the same developmental stage. Regardless of the limitations, this technology was more reliable and informative than the traditional method of burrow gates (Gangloff & Wilson, 2004). During this study burrow gates moved too easily in the soft soils and could be disturbed by visiting adults or other emerging chicks. I consider that RFID and PIT tag technology would be a worthwhile investment for the investigation of chick emergence for seabird taxa being translocated for the first time, and particularly for rare or threatened species.

### *3.6.6 Morphology for translocation selection*

The earliest emergence recorded for a WFSP chick was six days prior to fledging. To minimise the health risks associated with translocation, chick transfers should be for the minimum period required for imprinting at the new site, while avoiding any unnecessary additional days of artificial feeding. It is therefore recommended that WFSP being selected for translocation are transferred at approximately 10 days prior to fledging. This time allows three days to block burrows (preventing premature emergence) and for chicks to acclimatise to the new location and artificial burrows (Gummer, *et al.*, 2012).

Using wing length as the primary indicator of age, the upper and lower quartile ranges (120.9–129.7 mm) of wing lengths at 9–11 DBF is a suitable target collection guide; aiming to collect chicks with wings as close to the average length ( $124.6 \pm 1.6$  mm) as possible.

Weight is not as good an indicator of age, however at 9–11 DBF chicks weighed on average  $53.8 \pm 1.4$  g ( $n = 28$ , range: 40–68.8). Chicks which are lighter than the expected fledging weight ( $49.5 \pm 0.7$  g) should not be selected for translocation. Moreover, chicks will lose weight during the transfer (Gummer, *et al.* 2012) and therefore target weights at collection should be at least 50 g, and ideally  $>55$  g.

Chicks at 9–11 DBF still retained approximately 30% of their total down, but it would be expected that chicks would have almost fully developed white facial plumage at this age. The average time that full white facial plumage was established was  $11 \pm 0.7$  DBF, ranging from 8 to 16. Therefore, the white feathering of the face is a better indicator of age than is down loss.

### 3.6.7 Variation between sexes

The variation of wing, tarsus and bill lengths between male and female WFSP chicks was slightly more exaggerated than was found in other studies. Literature suggests females are generally slightly larger in storm petrels, particularly in regards to wing length (Marchant & Higgins, 1990; Warham, 1990). The SE variations observed within this study are explained by the small sample sizes of ten female and seven male chicks. Growth patterns suggest that the variation in wing length between sexes is evident from early on in chick development. At 35–39 DBF female wing lengths were already 7 mm longer than were male wing lengths. The statistically significant variation in tarsus length found between sexes has not been found in other studies. The mean tarsus lengths were 41.2 mm for both male ( $\pm 0.5$  SE) and female ( $\pm 0.4$  SE) WFSP as reported by Marchant and Higgins (1990) from National Museum of New Zealand skins. In addition, the variation in tarsus length between sexes for *P. m. dulciae* is slightly different, with 0.8 mm between means Marchant & Higgins, 1990). The significant variation in this study is again likely due to small sample sizes. The same outcome is reflected in bill length, which is significantly longer in females than males. This variation was not supported by museum specimens reported by Marchant and Higgins (1990).

Marked sexual dimorphism in Procellariiformes is generally not pronounced, although there is often variation in male and female body dimensions, sexing is difficult (Warham, 1990). Using DNA sexing methods can be costly and time consuming (Taylor, G., pers. comm.). Therefore, the sex of chicks may not be determined prior to translocation and equal sex ratios are assumed by pseudorandom selection of chicks.

*3.6.8 Limitations of the study*

Not knowing the hatch dates of all focal chicks was a significant limitation which affected various aspects of this study, particularly the methodology of comparing treatment groups. In addition to the late arrival to the colony during the hatching period (due to access restrictions), ascertaining hatch dates was also difficult owing to the sensitivity of adult birds to disturbance and the potential for nest abandonment. The rate of egg desertion was not quantified, however anecdotally fewer adults abandoned incubation (either permanently or temporarily) if the eggs were detected without adult removal from the nest.

Physically checking burrow tunnels and artificial access holes daily had a significant and negative toll on the integrity of burrow structure. Effects were exacerbated by the soft friable soil and shallow nature of WFSP burrows. Tunnels became widened and in some cases collapsed. The chamber roofs of particularly shallow burrows also eroded and would occasionally collapse. The states of burrows after the completion of the study are shown in Appendix I. Burrows insulate nests and protect occupants from weather extremes (Warham, 1990). The widening of tunnels is likely to affect internal microclimates by allowing more light into nest chambers and altering ambient temperatures. Nest temperature has a significant influence on chick survival and also affects chick energy requirements (Drummond & Leonard, 2010; Obst & Nagy, 1993). Marks and Leasure (1992) suggest that burrow damage, through widened and eroded tunnels, may indicate burrow instability and prompt adult storm petrel abandonment.

Implementing study lids for access to nest chambers was particularly beneficial in avoiding damage to the burrow entrance and also minimising the stress and/or duration of accessing chicks. However in some cases, due to the shallow depth of the nest chambers and the friable soil, study holes could not sustain prolonged penetration and consequently some chamber roofs eroded as the hole expanded with repeated access. Damage was alleviated by using plywood to reinforce tunnel and chamber roofs. The colony was very exposed to the sun and consequently any burrows reinforced with plywood needed to be shaded to prevent burrows overheating. This was done using cut vegetation and reflective covers. While no chicks perished prior to fledging from impaired burrows, the extent of damage was significant enough that most focal burrows would not be reusable in the following breeding season.

### **3.7.0 Conclusion and recommendations**

The breeding chronology, growth and fledging morphology for WFSP chicks from a northern population on Burgess Island have been described and compared with a southern population using the research of Richdale (1943a, 1943b, 1944, 1965). The following recommendations are presented and should be incorporated into future translocation protocols of WFSP and subsequent research.

- The most useful morphometric assessment for determining the age of WFSP chicks is wing length. Used in conjunction with this, chick mass is also a good indication of body condition. It is recommended that WFSP chicks being translocated from northern populations (in the geographic vicinity of Burgess Island) are transferred at approximately 10 DBF. At this age, target wing length should be as close to 124.5 mm as possible, ranging between 120.9 and 129.7 mm, and chick mass should be in excess of 55 g.
- Translocation management should consider seasonal variability of environmental and climatic conditions and the subsequent effects of these on the duration of chick rearing, chick condition and fledging morphology. Future research investigating such relationships may provide a better predictive inference for translocation planning.
- The latitudinal variation of breeding timetables between Burgess Island and Whero Island populations is estimated at one month. This study also indicates that Burgess Island birds take approximately 9 days longer to fledge. This chronological difference must be incorporated into translocation planning for the timing of chick selection and transfer.
- Translocating WFSP chicks from Burgess Island would be difficult owing to the differing ages (approximately one month) of accessible chicks. Locating enough chicks of the correct age within this colony would be extremely difficult without high levels of disturbance and destruction to occupied burrows. Prospecting and collecting chicks for translocation must be done with immense care and vigilance in order to minimise burrow destruction and harm to adults and/or chicks.
- Many of the focal burrows were highly modified and collapsed from repeated researcher access during this study. Consequently, many are unlikely to be reusable by breeding

WFSP in subsequent years. The WFSP colony on Burgess Island is therefore unsuitable for repeated studies of intensive monitoring using methodology similar to this project. Studying the subsequent breeding success and behaviours of adult WFSP pairs after such invasive burrow disturbance would however be valuable to understanding of the overall research effects. The effects of widened tunnels and internal nest chamber erosion from researcher disturbance on burrow microclimates should also be investigated opportunistically.

- Incorporating control groups into research to test the effects of handling focal birds is important in order to understand short and long term effects, as well as reducing and connecting study biases (Carey, 2009). It is recommended that future studies continue to test the effects of regular handling.
- Disturbing adults incubating eggs increases the risk of nest desertion and subsequent negative effects on hatching/breeding success. The handling of incubating adults should be minimised and occasions treated with great sensitivity.



**Plate 3.4 A white-faced storm petrel chicks less than one week old showing the egg tooth.**

# Chapter Four

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CHICK PROVISIONING AND ITS  
RELATIONSHIP TO  
TRANSLOCATION

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#### 4.1.0 Introduction

##### 4.1.1 Procellariiformes and translocation

Seabirds have become a focal point of many conservation projects as they are affected by significant global threats such as invasive non-native predators, habitat loss and impacts of commercial fisheries (Baker, Gales, Hamilton, & Wilkinson, 2002; IAPC 5, 2012; Jones & Kress, 2012). There are 346 species of seabirds recognised worldwide, of which 28% are considered to be globally threatened and 5% critically endangered (Croxall *et al.*, 2012). The role of seabirds within terrestrial ecosystems is well understood: soils become enriched with deposits of guano, regurgitated matter, failed eggs and chicks (Hawke, Holdaway, Causer, & Ogden, 1999; Worthy & Holdaway, 2002). Vegetative communities are physically altered by burrowing and the trampling and removal of vegetation (Bancroft, Roberts, & Garkaklis, 2005; Durrett & Mulder, 2011; Grant-Hoffman, Mulder, & Bellingham, 2010; Warham, 1996). Seabirds are therefore integral components of ecological restoration. The order Procellariiformes comprises the albatross, shearwater and petrel families. Distributed worldwide Procellariiform numbers and biomass make them the most successful of the seabirds (Warham, 1996), despite significant population declines due to anthropogenic related threats (Baker, *et al.*, 2002; Warham, 1996).

A principal factor in petrel conservation is the preservation of breeding sites free from introduced predators. Consequently, predator control is an important and reoccurring conservation objective (Carlile, Priddel, Zino, Natividad, & Wingate, 2003; Taylor, 2000). Complementing this approach, translocation is a management tool that may be used to establish new populations when new or restored habitats become available. Translocation is now used globally for various taxa and most recently this includes Procellariiformes (Jones & Kress, 2012; Miskelly, Taylor, Gummer, & Williams, 2009; Seddon, Armstrong, & Maloney, 2007). Procellariiformes display a high degree of philopatry (Warham, 1990) and this strong natal site fidelity is thought to develop during the chick emergence period prior to fledging (Serventy, 1967). Consequently, translocation is difficult and relatively invasive, requiring the transfer of pre-fledgling downy chicks which have not yet imprinted on their natal colony (Jones & Kress, 2012). Translocated chicks, which would otherwise be dependent on parental provisioning, consequently require hand-rearing until fledging (Miskelly, *et al.*, 2009). Understanding the life history, developmental biology and provisioning biology of the focal species is important for the selection of suitable nestlings to optimise fledging success (Gangloff & Wilson, 2004; Miskelly, *et al.*, 2009).

Previous translocations of petrels have removed chicks from natal burrows at approximately 1–6 weeks before expected fledging (Gummer & Gardner-Gee, 2009; Miskelly & Taylor, 2004a; Priddle & Carlile, 2001) and there is an increased risk of fledging failure and mortality with artificial provisioning (Priddle & Carlile, 2001). However, the development of techniques to translocate and artificially provision Procellariiform chicks is progressing (Gummer, 2003; Gummer, Taylor, Collen, Ward-Smith, & Mitchell, 2012; Miskelly & Taylor, 2004b; Miskelly, *et al.*, 2009). For example, the fledging success of translocated diving petrels (*Pelecanoides urinatrix*) increased from 49% to 98% with improvements to husbandry and provisioning hygiene (Gummer & Gardner-Gee, 2009; Miskelly & Taylor, 2004a)

#### 4.1.2 Procellariiformes and foraging

Seabirds exploit ocean resources at many trophic levels (Schreiber & Burger, 2002). Procellariiform diet varies between species and includes a variety of food types such as; fish, cephalopods and small marine invertebrates (Marchant & Higgins, 1990; Warham, 1990). Foraging is generally limited to the upper two to three metres of the ocean surface, although some shearwater species have been observed foraging at depths of 20m (Warham, 1990). Feeding styles have been described based on the methods used to acquire food items - surface seizing, for example, is used by 80% of 103 petrel species (Warham, 1996). Other feeding methods include surface diving, pursuit diving, pursuit plunging, dipping and hydroplaning (Warham, 1996).

The spatial distribution and behaviour within the Procellariiformes reflects food supply (Monaghan, 1996; Schreiber & Burger, 2002). Petrels can cover long distances whilst migrating; for example, sooty shearwaters (*Puffinus gresius*) can travel more than 15,000 km over a two to three week period to reach summer feeding grounds (Hedd, Montevecchi, Otley, Phillips, & Fifield, 2012). During chick rearing, petrels forage in closer proximity to their breeding colonies (Warham 1996). The ranges are however likely to be dependent on regional oceanic productivity and food availability (Rayner, *et al.*, 2008; Stahl & Sagar, 2000; Weimerskirch, 2007). The white-chinned petrel (*Procellaria aequinoctialis*) of South Georgia forages on average 610 km from the colony during chick rearing (Phillips, Silk, Croxall, & Afanasyev, 2006) and the maximum recorded range for the cook's petrel (*Pterodroma cookii*) on Cod Fish Island during chick rearing is 836 km (Rayner, *et al.*, 2008).

The life stage of an individual is also important to its spatial locality; for example breeders, non-breeders and recent fledglings are often found in different areas and at different times of the year (Warham, 1996).

Petrels can store sub-dermal fat and stomach oils, which assist with insulation and can be utilised when provisioning opportunity is limited (Warham, 1990). Consequently, petrels can survive for long periods of time without food; an advantage as food can be patchy in concentration and distributed over thousands of kilometres (Warham, 1990; Weimerskirch, 2007). Fat storage also supports fasting adults during long incubation periods; for example, the Galapagos albatross (*Diomedea irrorata*) incubates for 19–22 consecutive days (Harris, 1973) and the medium sized grey-faced petrel (*Pterodroma macoptera gouldi*) sits for an average of 17 days without provisioning (Imber, 1976; Warham, 1990). The digestive tract of petrels is different from other birds in that they have no crop; instead the proventriculus, located at the bottom of the oesophagus, is thick, glandular and folded, forming a large bag. This anatomical feature allows petrels to carry large meals back to their chicks (Brooke, 2004). The oil found in the proventriculus of petrels is very energy rich, with 40 kJ/g compared to 4–8 kJ/g of fresh prey (Brook, 2004). Generally, birds that forage further from the breeding colony return with greater ratios of oil, while those foraging in close proximity deliver more fresh prey (Brooke, 2004).

Procellariiform chicks are provisioned by both parents. Feeding is done soon upon parental arrival at the burrow and for many species adults will return to sea after spending only minutes in the nest (Warham, 1990). The frequency at which chicks are provisioned varies between species as well as with the growth stage of the chick (Warham, 1990). Chicks also have high lipid stores and reach weights often exceeding adult body weight by 40–70% (Warham, 1990; Brooke, 2004). Obesity is a conspicuous feature of chick growth in Procellariiformes and is thought to act as a buffer against inconsistencies in provisioning (Brooke, 2004; Hamer & Hill, 1997; Hamer, Lynnes, & Hill, 1999; Phillips & Hamer, 1999). Chicks, like the adults, can also withstand periods of fasting. This is done by entering a state of torpor characterised by a cold and lethargic appearance (Warham, 1990). For example, fork-tailed storm petrels (*Oceanodroma furcata*) show frequent declines of 10 °C from mean body temperatures of 37.4 °C and in one case a chick was recorded with a body temperature of just 10.6 °C (Boersma, 1986). Chicks cope with fasting by slowing down their metabolism (Ochoa-Acuna & Montevecchi, 2002; Richdale, 1965; Warham, 1990). This ability to cope

with fasting is likely an adaptation in response to widely distributed food resources and irregular provisioning (Boersma, 1986).

#### 4.1.3 White-faced storm petrels

The smallest of the Procellariiformes are the cosmopolitan storm petrels. Storm petrels maintain a pelagic existence except for nocturnal visits ashore to provision chicks during breeding (Marchant & Higgins, 1990). Belonging to the sub-family Hydrobatidae, *Pelagodroma marina maoriana*, commonly known as white-faced storm petrels (specifically referred to as WFSP), are an endemic to New Zealand subspecies.

Observed as either gregarious or solitary at sea, storm petrels forage by picking food items - planktonic crustaceans, molluscs and small fish - from the water's surface (Marchant & Higgins, 1990). The majority of WFSP food is obtained from the uppermost centimetres of the sea surface (Warham, 1990) by employing methods of aerial dipping and contact dipping, pattering and less frequently surface seizing and surface plunging (Marchant & Higgins, 1990). WFSP are recognised for their distinctive flight patterns when feeding as they hop using both feet along the sea surface with horizontally spread wings (Plate. 4.1) (Marchant & Higgins, 1990).

The diet of WFSP analysed from 22 regurgitation samples from birds of the Chatham Islands, comprised predominantly crustaceans and fish, representing 70% and 30% of weight respectively (Imber, 1981). Crustaceans included Copepods (*Calanus tonsus*), two species of Stomatopods, Amphipods (7 species) and, Euphausiids (6 species), as well as immature crabs and Decapod larvae (Imber, 1981). One regurgitation sample collected from WFSP on Whero Island mostly consisted of Euphausiids, possibly squid meat, two lenses and barnacle larvae (Richdale, 1943a). Fish up to 6.5 cm long have been recorded in *P. marina* (Warham, 1990).



**Plate 4.1** White-faced storm petrel showing the distinctive flight patterns when foraging of gliding forwards with both feet extended and hopping along sea surface with horizontally spread wings (Marchant & Higgins, 1990). Photograph by Neil Fitzgerald.

WFSP breed during the austral summer and migrate to tropical eastern Pacific waters during the austral winter (Imber, 1982; Leveque, Bowman, & Billeb, 1966; Spear & Ainley, 2007). Both WFSP parents share incubation, with rotational shifts averaging four to five days (Richdale, 1943b). During this time the incubating bird does not leave the nest nor does the other parent provide provisioning. Chicks are fed by incomplete regurgitation - usually at night by one or both parents, although provisioning may occur during the day while chicks are young and being brooded (Marchant & Higgins, 1990; Richdale, 1965).

#### *4.1.4 Diet - stable isotopes*

Isotopes are different forms of the same element, distinguished by the number of neutrons in the nucleus (Fry, 2006). The stable isotopes of hydrogen, carbon, nitrogen, sulphur and oxygen cycle tightly within organic matter and are of great ecological importance (Fry, 2006). Stable isotopic research has been used to quantitatively describe ecological processes of spatial dispersal and migration, temporal dimensions of diet variation and historical elements

of marine and terrestrial communities (Clementz, 2012; Martinez del Rio & Carleton, 2012; Pauli, Winston, & Ben-David, 2012).

The unit of stable isotopes is most often expressed using the delta ( $\delta$ ) notation:

$$\delta = ((R_{\text{sample}}/R_{\text{standard}}) - 1) \times 1000$$

$R_{\text{sample}}$  and  $R_{\text{standard}}$  represent respective heavy and light isotopes and  $\delta$  is the ratio between the two. Multiplying the ratio by 1000 means that the unit is expressed as parts per thousand (‰) (Kelly, 2000).

The analysis of carbon and nitrogen stable isotopes is useful by providing insight into the diet and trophic relationships of animals and their ecology. This is particularly valuable as unbiased and complete foraging observations of wild animals are difficult to obtain (Kelly, 2000), particularly for pelagic seabirds. The tool of stable isotope analysis is now widely used within seabird research to describe foraging ecology (Bond & Jones, 2009; Inger & Bearhop, 2008; Quillfeldt, McGill, & Furness, 2005).

As nitrogen is sourced from the amino acids of digested protein, the main use of nitrogen stable isotope analysis is to investigate the foraging relationship of an animal and its target trophic levels (Kelly, 2000). For example, it has been shown that chicks of *Pelecanoides geogicus* and *Pelecanoides urinatrix* sympatrically breeding on South Georgia are provisioned with prey from different trophic levels; however this difference was not identified between adults during the moulting season (Inger & Bearhop, 2008). Such analysis is based on evidence that the stable isotope  $\delta^{15}\text{N}$  increases with trophic levels at a predictable rate because  $\delta^{14}\text{N}$  is lost through nitrogenous waste (Kelly, 2000). Tissues are generally enriched with nitrogen isotopes by 1–5% over initial diet compositions (Hobson & Clark, 1992; Michener & Kaufman, 2007; Minagawa & Wada, 1984).

Isotopes of  $\delta^{13}\text{C}$  on the other hand have recognised spatial biogeographic patterns which create gradients across large latitudinal scales (Kelly, 2000). Consequently, pelagic food sources can be distinguishable from inshore food sources as inshore plants are more enriched with  $\delta^{13}\text{C}$  (Fry, 1983; Kelly, 2000; Quillfeldt, *et al.*, 2005).

Biological samples can be taken and tested for levels of stable isotope. Tissues such as blood, feathers or nails can be samples from live animals while more destructive methods sample from muscle, bone collagen or egg albumen (Bond & Jones, 2009; Clementz, 2012;

Quillfeldt, *et al.*, 2005). Isotopes are assimilated into tissues at a rate determined by how fast the consumer absorbs and loses elements (Martinez del Rio & Carleton, 2012) and are fixed when the tissue is synthesised (Hobson & Clark, 1992). The choice of tissue sampling depends on the temporal scale under investigation. Isotopic ratios in blood are replenished at greater rates than other tissues and can be used to examine short-term dietary patterns with a turn over period of 1–2 weeks (Bearhop, Waldron, Votier, & Furness, 2002; Dalerum & Angerbjorn, 2005; Hobson & Clark, 1992). On the other hand, stable isotopes in feathers will not change with time as the isotopic ratio reflects diet at the time of feather growth (moult) (Dalerum & Angerbjorn, 2005). Feather and egg samples were used by Quillfeldt, *et al.* (2005) to show that Wilson's storm petrels (*Oceanites oceanicus*) on King George and South Shetland Islands show a shift in diet from crustaceans to fish during egg development to chick-feeding and moulting and also that spatial changes in foraging coincided with changes in the diet.

#### 4.1.5 Purpose of the study

Many seabird translocations to date, particularly in New Zealand, have been focused on medium-sized *Pterodroma* and *Pelecanoides* species (Miskelly, *et al.*, 2009). There are many conservation benefits to broadening the scope of translocation to smaller species, such as storm petrels. By establishing new populations, opportunities of ecological and population restoration may be expanded. Specific species management plans may be augmented for both the focal species and potentially endangered and/or data deficient sister taxa to which information may be extrapolated. WFSP are good candidates for research because of their abundance and accessibility.

Baseline data describing chick provisioning is important for the generation of artificial feeding procedures and consequently improving translocation outcomes. Understanding the diet and foraging patterns of northern WFSP populations during the breeding season may provide useful insights into the spatial proximity of translocation sites to important food resources as well as changes in chick diet and potential nutritional requirements during the rearing period.

#### **4.2.0 Aims and objectives**

This chapter aims to provide a quantitative description of the provisioning biology of WFSP chicks from a northern New Zealand population (Burgess Island). The data will be compared with the literature of WFSP from a southern population (Whero Island) and will underpin the generation of chick provisioning and growth rate targets for translocation protocols. There are three main objectives:

- I. To describe the provisioning rates of WFSP chicks by monitoring feeding frequency and periods of fasting. Feeding regimes will be quantified and the relationships with chick development explored.
- II. To calculate the quantity of overnight provisioning masses delivered to chicks across the rearing period to develop appropriate meal size guidelines for artificial feeding regimes of translocated chicks.
- III. Stable isotope analysis will be used to understand trophic relationships.  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  will be measured from adult blood and chick feather samples to describe foraging characteristics such as location and trophic levels throughout the breeding season.

### 4.3.0 Methodology

As described in detail in Chapter 2 (section 2.2.5 and 2.2.8), chicks were weighed between 0800 h and 1200 h daily to calculate feeding rates and overnight provisioning masses. Toothpick palisades (burrow gates) were erected at each tunnel entrance after weighing and unfed chicks were identified by undisturbed burrow gates the following morning. Following methods in Rayner, et al. (2008), chick provisioning was assumed to occur soon after dark, approximately 12 hours between chick weighing. Given chick respiration and excretion during this period, provisioning mass was calculated, using 50% of the mean overnight weight loss of unprovisioned chicks summed with individual overnight weight changes of likely fed chicks (Rayner, *et al.*, 2008). The overnight weight loss for unprovisioned chicks was calculated using the negative weight changes of chicks from burrows with gates upstanding overnight and the 50% figure accounted for weight lost after provisioning and before chicks were reweighed. Chicks were considered to have been fed if their overnight weight change was greater than this estimate. As the median collective weight loss was 4.58 g (mean =  $4.64 \pm 0.28$ ) this meant any mass change greater than -2.5 g indicates provisioning. This indicator weight was rounded to the infield weighing accuracy of 0.5 g.

To avoid disturbing adults at the focal nests, blood samples for stable isotope analysis were collected from adults located on the surface outside of the study colony. The reason for this was to minimise potential disturbances to focal chick provisioning. Blood samples were collected during incubation and throughout chick rearing. Samples ( $< 50\mu\text{L}$ ) were collected using a 29 gauge syringe and capillary tube and then smeared onto a slide and preserved with methanol. Feather samples were taken from study chicks which were within one week from fledging to compare the synthesis of feather tissue over the same time period of blood collection.

#### 4.4.0 Statistical Analysis

As detailed in Chapter 3 (section 3.5.1), the chick growth data from two test groups (development and telemetry) was pooled as the variation is not considered to be of biological significance. All chicks referred to in this chapter are the same test chicks described in Chapter 3.

Kruskal-Wallis tests were used to compare weight loss data over time and between chicks. When weight loss data were stratified into weeks, measured as days before fledging (DBF), no significant difference was detected (Kruskal-Wallis = 1.99, df = 6, p = 0.92). Consequently, weight loss has been calculated as a single flat rate throughout chick rearing. In the case of overnight weight loss and feeding probability, individuality is accounted for within analysis by using mean values for individual chicks, as per Grim (2006). Weight loss in relation to time since last feeding was analysed using raw data without accounting for individual variation. The reason for this was the variation in overnight weight loss was likely to be more closely related to the mass of previous mean meal size.

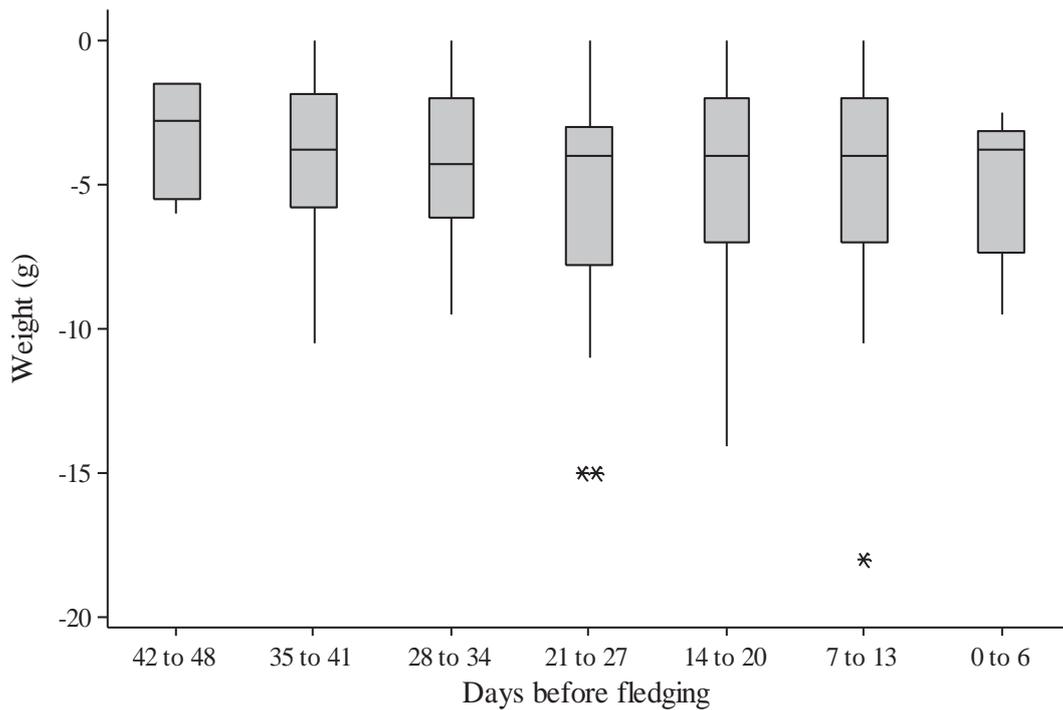
Spearman Rank Correlations were used to test the relationship between meal size and DBF, the duration of chick rearing and the rate at which individuals fasted, as well as chick weight and fasting periods. Fasting periods were quantified and categorised by summing the duration of consecutive fasting nights for each chick. Kruskal-Wallis tests were used to analyse weight loss over weeks, provisioning rates between chicks, provisioning rates of male and female chicks and the change in stable isotope values between months. Mann-Whitney U tests were used to compare stable isotope levels between tissue types as well as adults and chicks. Data are described using mean values and standard error, and where values are non-parametric medians and standard deviations are also shown. Data were analysed using Minitab 16 (Minitab Inc., 2010) and Excel 14.0 (Microsoft Corporation, 2010).

#### 4.5.0 Results

##### 4.5.1 Provisioning rates

Chicks ( $n = 27$ ) were monitored for an average of 32 days ( $\pm 1.47$ , range: 19–44) prior to fledging. During this time 847 chick weights were taken and 445 overnight provisioning events were estimated. Provisioning masses delivered during one versus two parental visits were calculated using the methodology of Ricklefs (1984), and Klomp and Furness (1992). The probability that a parent feeds its chick is  $P$ , the probability that a parent does not feed the chick is  $1 - P$ , the probability of neither parents feeding the chick is  $(1 - P)^2$  and the probability that both feed the chick is  $P^2$ . During the focal period of this study, chicks were recorded as being unfed 45% of the time (371 out of 817); hence  $P = 0.33$ . Therefore the probability of both parents feeding their chick is 0.10 or 10% ( $n = 89$  occasions).

The comparison of overnight weight loss in relation to days before fledging is shown in Figure 4.1. Median weight loss between weeks remains relatively constant, ranging between 2.7 g and 4.3 g. During the earlier stages of development and at fledging the variation between chicks is lower relative to middle stages. The mean ( $\pm$  SE) overnight weight loss for all individual chicks known to be unfed was  $-4.6 \pm 0.3$  g (median  $4.6 \pm 1.5$ ,  $n = 27$ , range: 2.3–8.0). Overall, chicks fed and unfed, lost up to 18 g. Outlying values (Figure 4.1) are likely to occur after chicks were delivered large meals the previous night.



**Figure 4.1** Weekly median values of overnight weight loss of white-faced storm petrel chicks ( $n = 27$ ) as days before fledging (Kruskal Wallis = 1.99,  $df = 6$ ,  $p = 0.92$ ).

The percentage of nights that individual chicks were fed varied from 32% to 79% with a mean of 54.4% (median 55%,  $n = 27$ ) (Appendix III). The mean probability of chicks being fed – calculated as the proportion of chicks fed on a given night during the focal period (last 30 DBF) – was 0.55 (median 0.57,  $n = 30$ , range: 0.16–0.73). There were no clear patterns in provisioning probability (DBF) and rates ranged from 0.23 to 0.83 (Figure 4.2). Feeding probability with time and moon phase showed no discernable patterns (Figure 4.3).

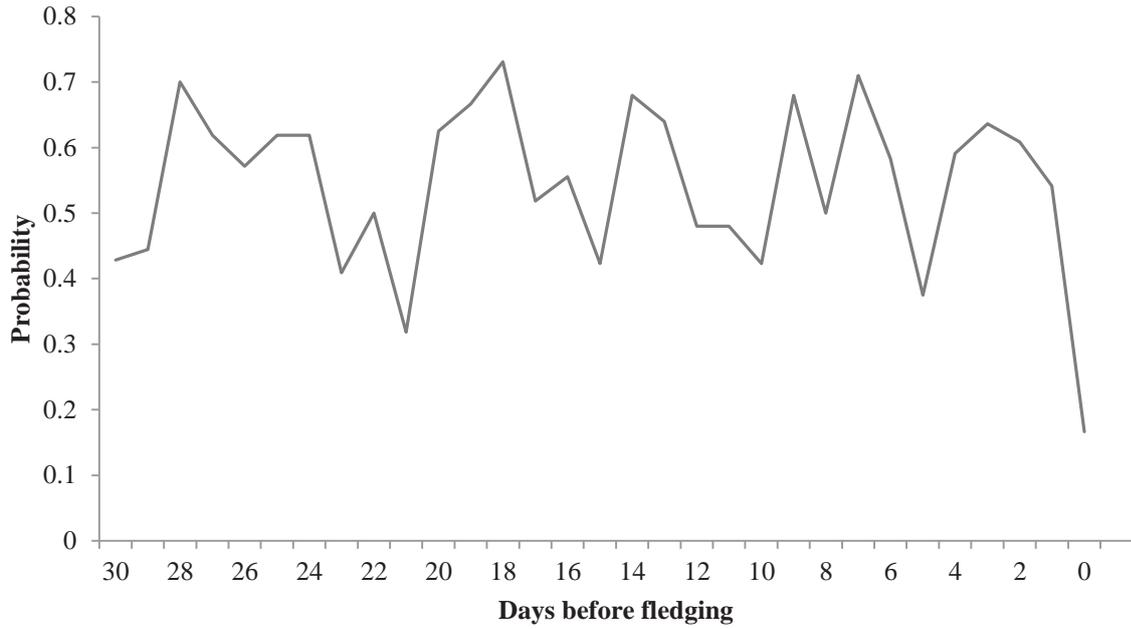


Figure 4.2 The probability of white-faced storm petrel chicks (n = 27) being fed based on their age described as days before fledging.

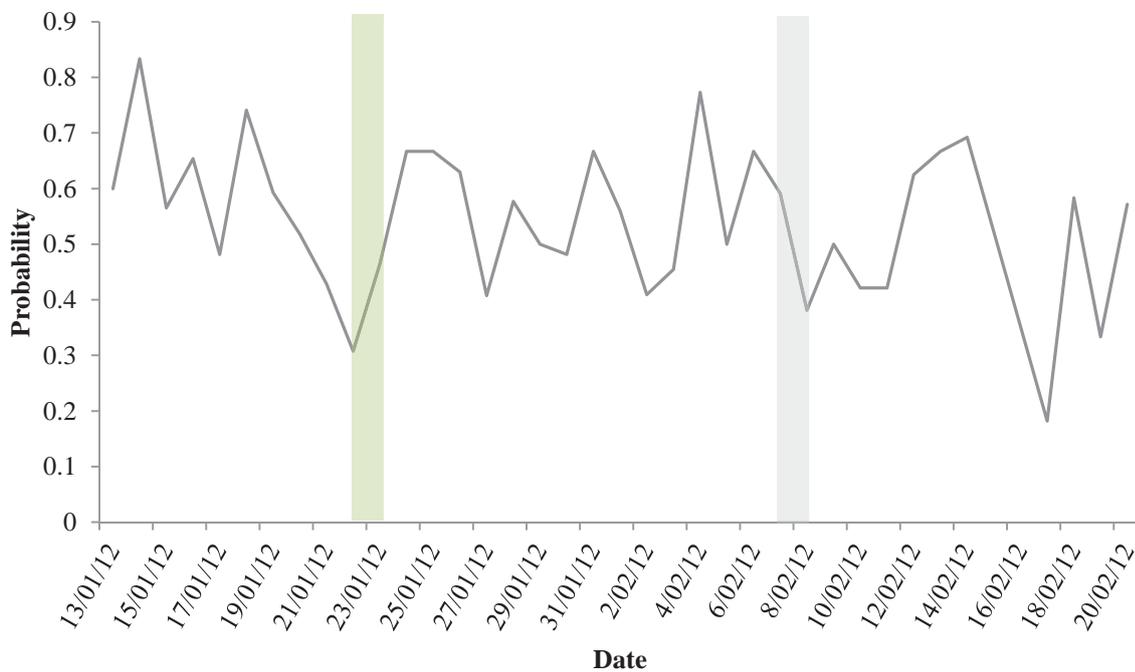


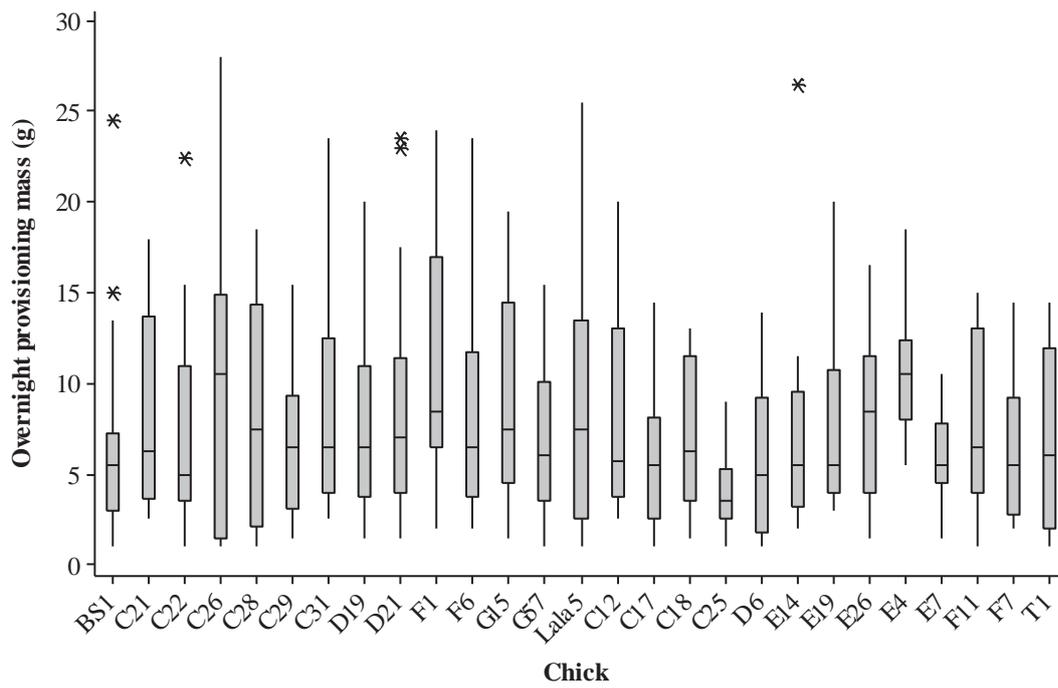
Figure 4.3 The probability of white-faced storm petrel chicks (n = 27) being fed relative calendar date. Green column indicates a new moon and they grey column a full moon.

#### 4.5.2 Meal size

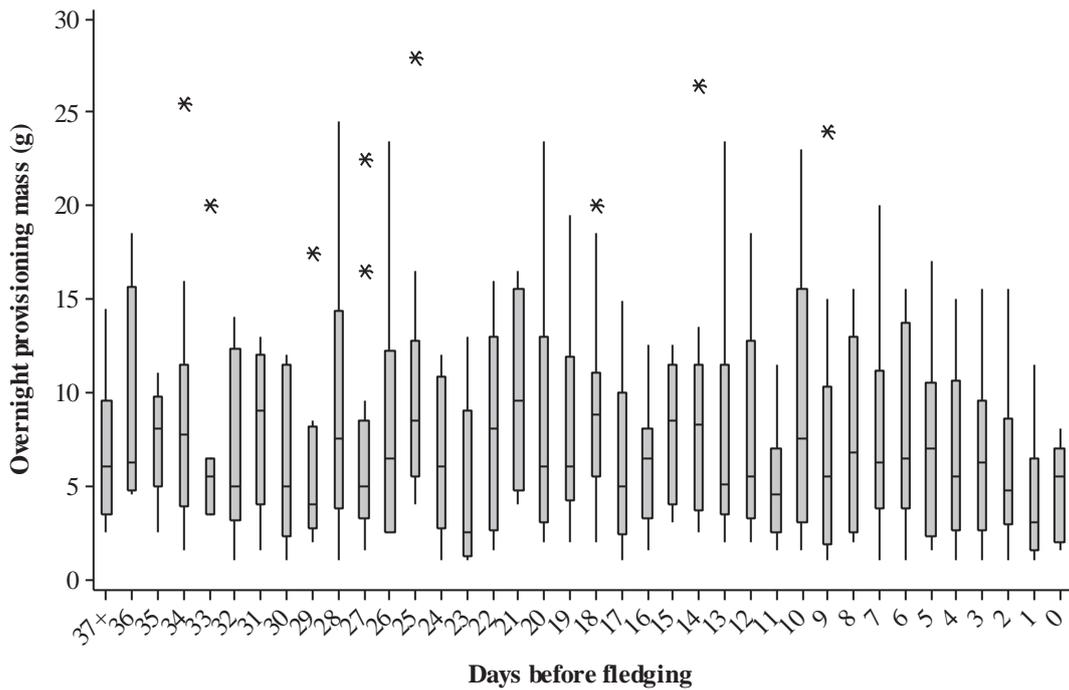
The estimated provisioning masses for all nights when feeding occurred ranged between 1.0 g and 28 g; the mean quantity delivered was  $7.8 \pm 0.3$  g (median  $8.0 \pm 1.53$ ,  $n = 27$ ).

Summaries of overnight provisioning for individual chicks are shown in Figure 4.4; outlying asterisks indicate large overnight provisioning masses delivered by both parents. For the southern population of WFSP chicks on Whero Island mass increase ranged between 0 g to 25 g, (Richdale (1965) used morning and evening weight changes to measure meal size. Due to differences in methodology, meal sizes between northern and southern populations cannot be directly compared). From hatching through to fledging, Whero Island chicks increased in weight each night by an average of  $6.4 \pm 0.3$  g (median  $6.5 \pm 0.0.7$ ,  $n = 8$ , range: 5.1–7.2) (Richdale, 1965).

There were no significant differences in overnight provisioning quantities between chicks (Kruskal-Wallis = 34.85,  $df = 26$ ,  $p = 0.115$ ). Some burrows were observed opportunistically at night being attended by both parents, therefore it is highly likely that outlying points of Figure 4.4 indicate provisioning of two large meals from both parents. There was a very weak correlation between meal size and age ( $r = 0.09$ ,  $p = 0.08$ ) (Figure 4.5) and no significant variation in the average overnight provisioning masses of male and female chicks (Kruskal-Wallis = 0.05,  $df = 1$ ,  $p = 0.82$ ).



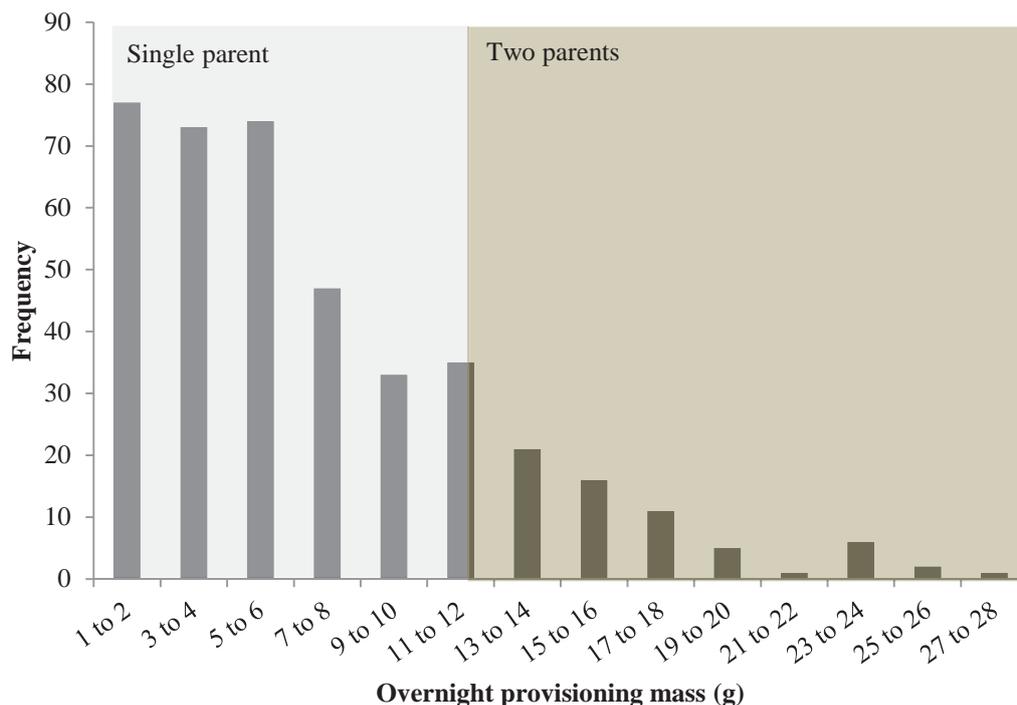
**Figure 4.4** The median overnight provisioning masses for individual white-faced storm petrel chicks ( $n = 27$ ), error bars show 95% confidence intervals. The variation between chicks is not significant (Kruskal-Wallis = 34.85,  $df = 26$ ,  $p = 0.115$ ).



**Figure 4.5** Overnight quantities of food given to white-faced storm petrel chicks (n = 27) relative to time days before fledging. Medians and 95% confidence intervals are shown.

The frequency at which specific food masses were recorded being delivered to chicks is shown in Figure 4.6. The majority of weight increases ranged between 1–2 g. Of all recorded estimated provisioning events (n = 403), 56% were between 1 g and 6 g. The largest provisioning mass projected was 27.5 g. This particular chick weighed just 27 g prior to provisioning, an increase in weight of 54%. On Whero Island the most frequent chick mass increases were between 0–4.9 g and 5–9.9 g; combined these categories represented 62.7% of all recorded feeds (Richdale, 1943a).

From all detected provisioning events 89 were calculated to be provided by two parents. The largest 89 meals delivered to chicks ranged between 11.5 g and 28.0 g (Figure 4.6). The average meal size delivered by a single parent was 5.2 g.



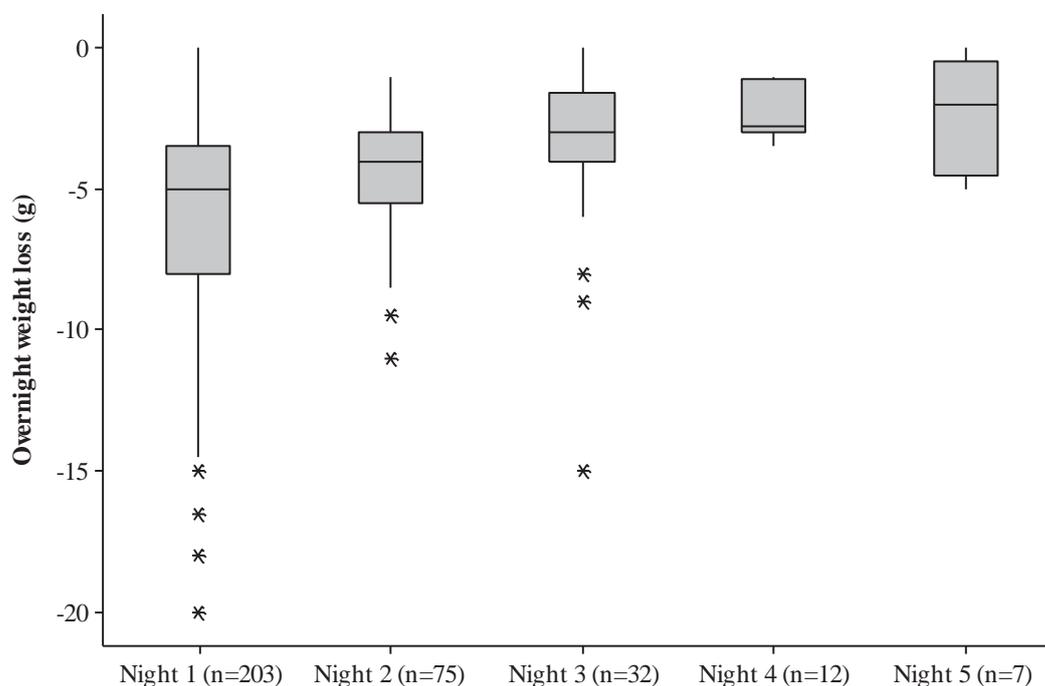
**Figure 4.6** Frequency at which overnight provisioning masses were recorded for white-faced storm petrel chicks ( $n = 27$ ). The light grey area represents meals delivered by one parent and the dark area meals likely shared between two parents.

#### 4.5.3 Fasting

Chicks frequently had nights without apparent provisioning, ranging from two to seven consecutive days. Fasts of four days or longer were experienced by 52% of chicks ( $n = 14$ ). There was no correlation between the rate at which chicks went without food and the duration of their rearing period (Spearman rank correlation = 0.02,  $n = 14$ ). Chicks which fell below approximately 40 g when fasting were prone to becoming inert and lifeless, a torpid state (as described by Warham (1990). Richdale (1943b) reported a more extreme state, in which chicks became cold to touch, with shut eyes, stiff wings and violently shivering. Recovery however occurred when the chicks were warmed.

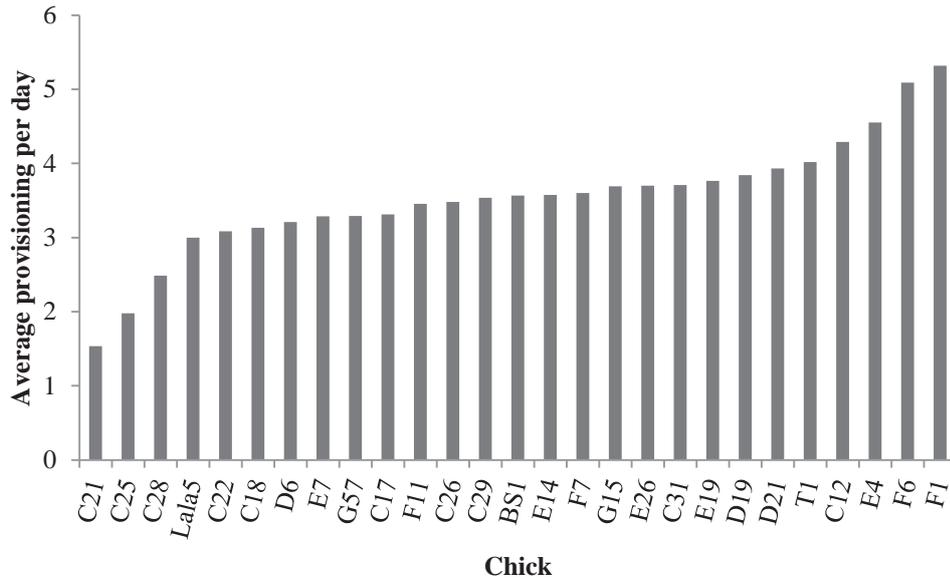
There is an inverse correlation between the number of nights fasted and mean chick weight loss (Spearman rank correlation = 0.63,  $p < 0.001$ ). Chicks lost the most weight on the first night they were not provisioned at a mean rate of  $-5.9 \pm 0.2$  g (median  $-5.0 \pm 3.5$ ,  $n = 203$ ). The rate of loss reduced with the duration of the fasting period to a mean value of  $2.4 \pm 0.8$  g (median  $-2.0 \pm 2.1$ ,  $n = 7$ ) on day five (Figure 4.7). The outlying asterisks in Figure 4.7 are likely the result of large mass/water declines following large food intakes from meals provisioned by both adults. The amount of overnight weight lost in unfed chicks was

significantly different between the number of nights since previously fed (Kruskal-Wallis = 49.13,  $df = 4$ ,  $p = <0.001$ ).



**Figure 4.7** Median values of weight lost by white-faced storm petrel chicks ( $n = 27$ ) over the duration of fasting length. The difference between groups is statistically significant (Kruskal Wallis = 49.13,  $df = 4$ ,  $p = <0.001$ ).

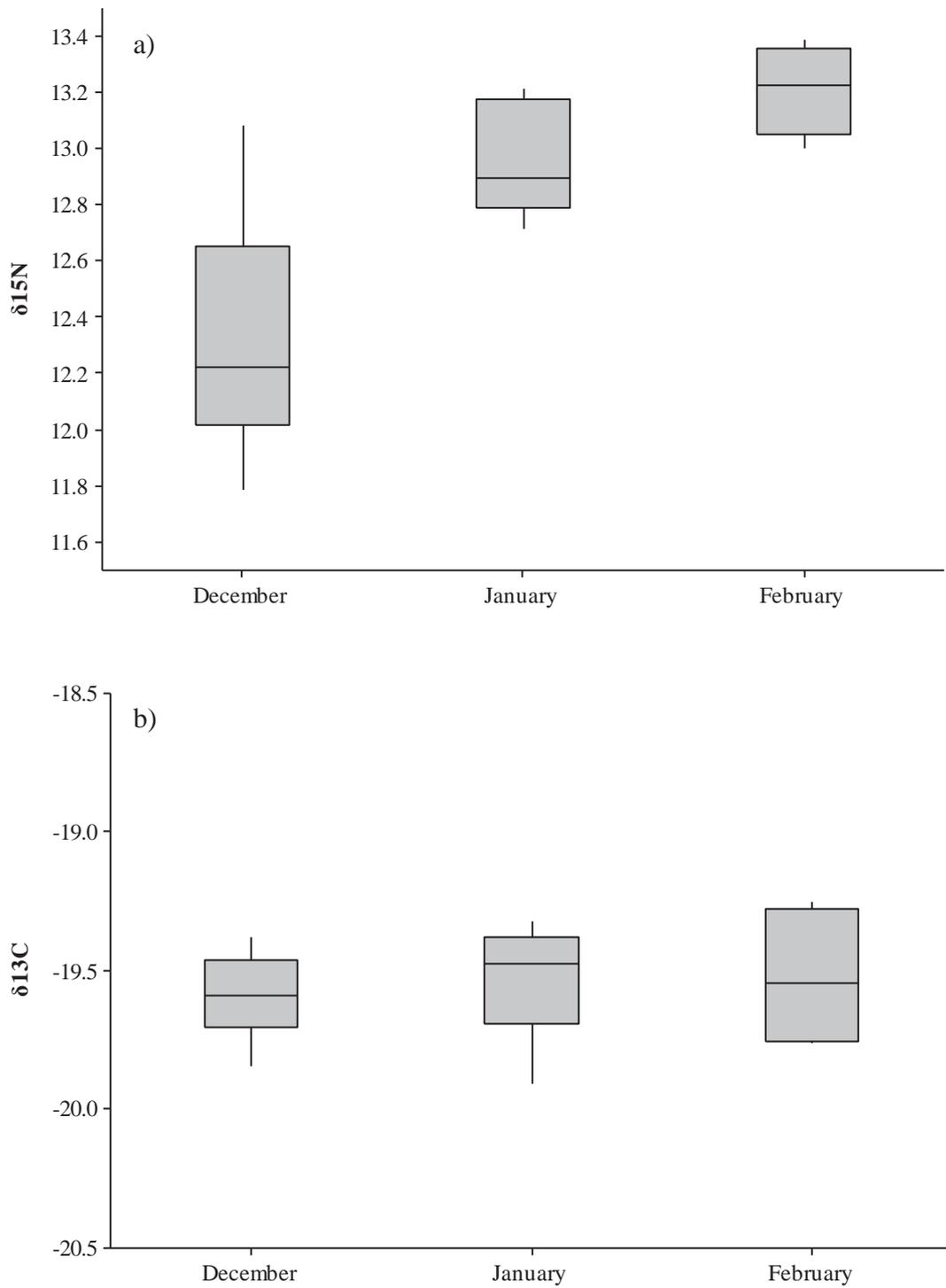
Figure 4.8 shows the total apparent mass provided to each chick divided by the total number of times weighed (fed and unfed). The overall apparent mass provided to chicks spread across all days is reasonably uniform among individuals, with 74% of chicks ( $n = 20$ ) receiving masses equivalent to 3.0 - 4.0 g/day. The mean for all birds is  $3.5 \pm 0.2$ g/day (median  $3.6 \pm 0.8$ ,  $n = 27$ , range: 1.5–5.3). A similar pattern was observed on Whero Island with little variation between provisioning mass per chick when fasting periods and individual meal sizes removed; chicks received an average of  $4.1 \pm 0.2$  g/day (median  $4.9 \pm 0.7$ ,  $n = 16$ , range: 2.6–5.0) (Richdale, 1943b).



**Figure 4.8** The overall mass of food provisioned to white-faced storm petrel chicks divided by the total number of days they were monitored for, showing an equivalent daily quantity regardless of frequency and duration of fasting.

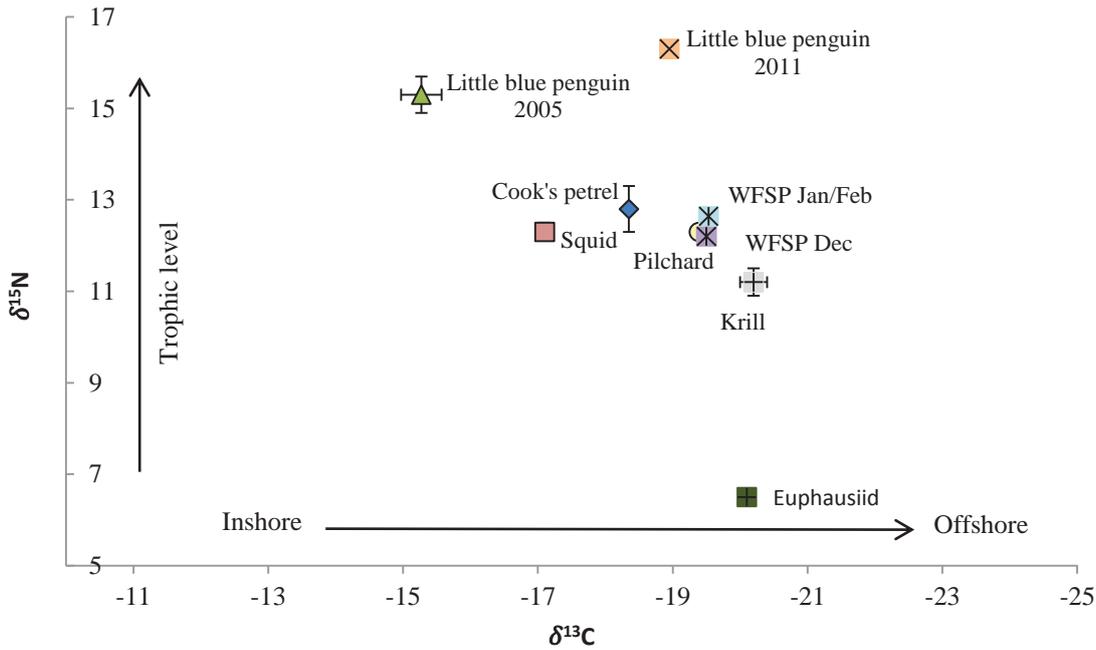
#### 4.5.4 Stable isotopes

Isotopic ratios of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  in adult WFSP blood samples during the months of December 2011, January and February 2012 are shown in Figure 4.9. The variation of  $\delta^{15}\text{N}$  between the months is statistically significant (Kruskal-Wallis = 16.48,  $df = 2$ ,  $p < 0.001$ ). Values for  $\delta^{13}\text{C}$  do not vary significantly between months (Kruskal-Wallis = 0.96,  $df = 2$ ,  $p = 0.62$ ). The mean value for December was  $-19.60 \pm 0.04$  ( $n = 14$ , range:  $-19.85$ – $-19.25$ .) for January  $-19.54 \pm 0.20$  ( $n = 8$ , range:  $-19.91$ – $-19.32$ ) and for February  $-19.53 \pm 0.13$  ( $n = 4$ , range:  $-19.76$  –  $-19.25$ ).



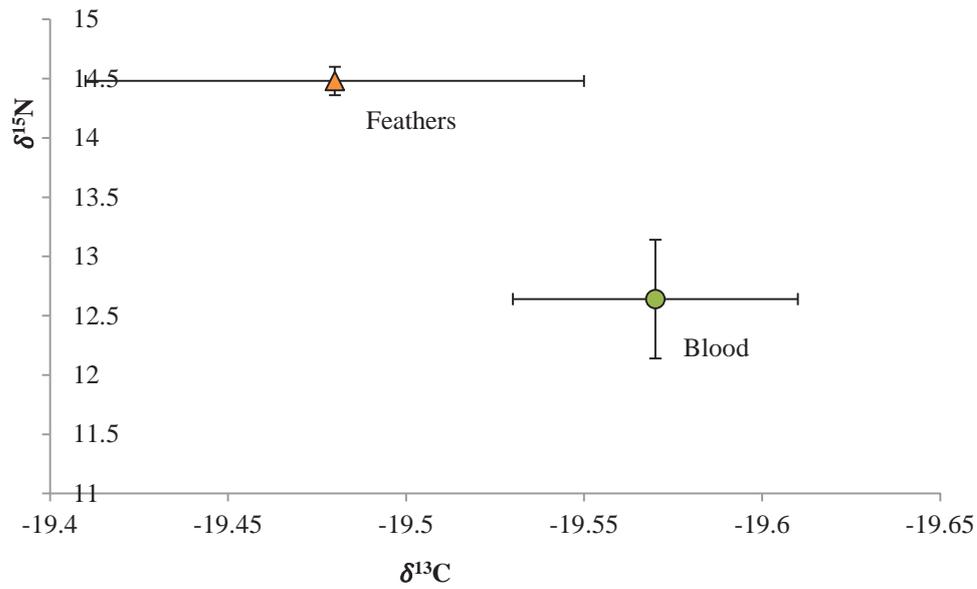
**Figure 4.9 a & b Median stable isotope values for  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  for white-faced storm petrels during December, January and February, 2011/2012. Values of  $\delta^{15}\text{N}$  are significantly different between months (Kruskal Wallis = 16.48, df = 2, p = <0.001) however values of  $\delta^{13}\text{C}$  are not (Kruskal Wallis = 0.96, df = 2, p = 0.62).**

Stable isotopic ratios of cook's petrels and little blue penguins (*Eudyptula minor*) also breeding in the Hauraki Gulf, as well as examples of prey species, relative to WFSP are shown in Figure 4.10. WFSP appear to forage at similar trophic levels to cook's petrels, with  $\delta^{15}\text{N}$  at similar levels to pilchards and squid.



**Figure 4.10** Mean stable isotope ratios (showing standard errors) of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  for white-faced storm petrels in relation to cook's petrel (Rayner *et al.*, 2008), little blue penguins 2005 ( $n = 63$ ) (Geurts, 2006) and 2011 (McKenzie, 2011) as well as example prey species of pilchards (McKenzie, 2011), Euphausiids and copepods (Thompson & Furness, 1995), krill and squid. Squid and krill samples are from Californian waters, in and around the Gulf of Farallones (Sydeman, Hobson, Pyle, & McLaren, 1997).

There was a distinct shift in the fractionation of  $\delta^{15}\text{N}$  between blood (adult) and feather (chick) tissue samples (Figure. 4.11). The mean value of heavy nitrogen for feathers of WFSP chicks was  $14.48 \pm 0.12$  ( $n = 5$ ), this being  $\delta^{15}\text{N}$  1.84 above mean blood values. The difference between the groups was statistically significant (Mann-Whitney  $U = 145$ ,  $p = <0.001$ ). However, the variation between carbon levels overlapped and were not significant (Mann-Whitney  $U$  test,  $p = > 0.05$ ), the mean value for feather samples was  $-19.48 \pm 0.07$  ( $n = 5$ ).



**Figure 4.11** Mean isotope ratios of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  between blood samples of adults white-faced storm petrels ( $n = 23$ ) and feather samples of white-faced storm petrel chicks ( $n = 5$ ), showing standard errors. The variance between the two groups for  $\delta^{15}\text{N}$  is statistically significant (Mann-Whitney  $U = 145$ ,  $p = <0.001$ ), however not significant for  $\delta^{13}\text{C}$ .

#### 4.6.0 Discussion

##### 4.6.1 Feeding frequency and probability

The proportion of nights in which individual WFSP chicks were provisioned over the study period was lower than that recorded on Whero Island by a difference of 17.3% ( $n = 8$ ) (Richdale, 1965). Differences in the methodology used to identify feeding events may account for this variation. Richdale (1965) considered a chick to have been fed when the morning weight was  $-0.5$  g or more than the previous night's weight. In this study, evening weights were not made and provisioning was considered to have occurred when overnight weight changed (from the previous morning) by less than 50% of mean overall weight loss of known unfed chicks (2.5 g), thus accounting for respiration and defecation (Rayner, *et al.*, 2008). Young Procellariiform chicks are generally fed small meals frequently (Warham, 1990). This study quantified provisioning rates after chicks were approximately three weeks old. The difference in the time periods covered may account for the observed lower overall feeding rate of the current study. Provisioning was recorded as unknown when chicks went un-weighed for various reasons (rain/torpor) and/or feeding could not be determined. Such unknown events were excluded when calculating proportion of nights provisioned. The apparent provisioning probability observed in WFSP chicks (mean = 0.54) during this study was much lower than those reported for other storm petrel species. For example fork-tailed storm petrels have feeding probabilities ranging from  $0.7 \pm 0.6$  /day ( $\pm$  SD,  $n=100$ ) to  $1.1 \pm 0.7$  /day ( $\pm$  SD,  $n=92$ ) recorded over two consecutive years (Simons, 1981). Wilson's storm petrel chicks were fed on 93% of nights, of which 68% were single feeds from one parent and 25% were meals from both parents (Quillfeldt & Peter, 2000).

In petrels, chicks are fed more frequently during the first half of chick development with the rates declining towards fledging (Gangloff & Wilson, 2004; Warham, 1990). In Pycroft's petrel chicks (*Pterodroma pycrofti*) there are four distinct stages of declining provisioning probabilities, with the final three descents occurring during the final three weeks prior to fledging (Gangloff & Wilson, 2004). In this study the probability of WFSP chicks being provisioned on a given night relative to their age (DBF) showed no apparent pattern or correlation. Richdale (1965) showed the proportion of unfed night's increases from 32% at 1–13 DBF to 40% and 68% at 8–5 DBF and 4–1 DBF respectively.

Procellariiform chicks, especially storm petrels, can withstand long fasting periods (Warham, 1990) and irregular chick provisioning is not uncommon among storm petrels (Ricklefs, Day,

Huntington, & Williams, 1985). The growth of WFSP seems resilient to irregular feeding as the periods some focal chicks from this study went without provisioning (up to seven days) were much greater than expected from literature case studies. For example, southern WFSP chicks on Whero Island frequently went without provisioning for one to two days and only occasionally three to five days (Richdale, 1943b). Wilson's storm petrels are fed on 93% of nights (Quillfeldt & Peter, 2000). During this study the frequency and duration at which WFSP chicks fasted did not affect their overall development or fledging morphology. As this study was over a single season, it cannot be determined if the rate of fasting is typical of this population. Variation in nestling periods is considered to be related to variation in parental provisioning (Mauck & Ricklefs, 2005; Warham, 1990) and the long fasting periods found may explain the longer chick rearing period (68 days) than on Whero Island (Richdale, 1965).

For the purpose of translocation, variation in fasting may affect the suitability of individuals for transfer selection. However, regardless of the fasting periods, when averaged out over time the quantity of food provisioned was uniform between most chicks (Figure 4.9). This suggests that the mass of food delivered compensates for periods of fasting (as proposed by Richdale, 1943a). Therefore, chicks which seem underweight may have fasted for a few days and re-weighing at a later date may help to increase number of those transferrable

The lower than expected provisioning rates and extended durations of fasting, of the 2011-2012 WFSP breeding season may be due to seasonal conditions and it is difficult to extrapolate from a single years results. Oceanic phenomena such as the warming effects of El Niño-Southern Oscillation (ENSO) influence marine resources and trophic flows by altering nutrients, plankton and other prey species abundance (Surman & Nicholson, 2009; Wolff, Ruiz, & Taylor, 2012). Seabirds are regarded as upper trophic level indicators of marine productivity (Surman & Nicholson, 2009) and the influence of ENSO can affect seabird breeding success, reproductive output and distribution (Jaksic, 2004; Surman & Nicholson, 2009; Wolff, *et al.*, 2012). For example, dark-rumped petrel chicks (*Pterodroma phaeopygia*) show slower growth rates and latent fledging dates during ENSO (Cruz & Cruz, 1990). The peak weights achieved by chicks are smaller and attained later than chicks of non ENSO seasons (Cruz & Cruz, 1990). Although less well documented, La Niña-Southern Oscillation (LNSO) conditions also affect sea currents and food availability; altering the breeding chronology of little blue penguins (*Eudyptula minor*) (Perriman, Houston, Steen, & Johannesen, 2000) and reduced observations and of *Oceanodroma*, *Pterodroma* and *Puffinus* species (Bjorksteadt *et al.*, 2011; Ribic, Ainley, & Spear, 1992). Mild to medium LNSO

conditions were experienced in New Zealand over the summer of 2011-2012 following strong LNSO conditions of 2010-2011 (NIWA, 2010, 2011). Dunn (2012) suggest LNSO effects contributed to the observed stunted growth rates and low provisioning rates of grey-faced petrels breeding in the Hauraki Gulf during the 2011 breeding season. Similarly, WFSP provisioning biology may also be similarly affected by LNSO climatic conditions.

#### 4.6.2 Overnight provisioning masses

Nightly provisioning masses for northern and southern WFSP populations were similar. Average meal sizes for southern WFSP chicks were reported by Richdale (1943a; 1965) to be slightly smaller than in this study by an estimated 18%. However, Richdale's methodology was to weigh chicks morning and night, and it is not clear how this methodology affects meal size data, although Richdale suggests his methodology generates slightly less than actual meal size weights. Storm petrels are thought to deliver meal sizes at approximately 15–20% of their body weight (Brooke, 2004; Croxall, Hill, Lidstonescott, Oconnell, & Prince, 1988). The relative meal sizes for WFSP chicks recorded in this study were consistent with this: average meal sizes (8 g) represented 19% of mean adult weight (43.4 g).

The ranges in overnight weight change were also similar for northern and southern populations, with chicks increasing their overnight weight by a maximum of 28 g and 25 g respectively. One chick, from Burgess Island, had a 54% overnight weight increase. Demonstrating the maximum food intake capability of chicks; presumably resulting from large meals being delivered by both parents. The average size of meals delivered to chicks may provide an indication of how much chicks can readily digest. The rate at which natural and artificial diets are digested may however vary, this is important as continuous overfeeding during translocation, delivering more food than can be digested, can be fatal for chicks. Food accumulation in the proventriculus can cause infection from bacterial and/or fungal growth and also regurgitation of excess food may result in aspiration (Gummer, *et al.*, 2012).

Understanding the feeding biology of WFSP is important in developing translocation protocols. However, due to the rapid weight loss of chicks due to water loss, respiration and excretion, measuring meal size is considered difficult (Warham, 1990). The average daily weight loss of unfed chicks in this study was estimated to be 4.6 g/day. It was assumed that a fed chick would still lose 2.5 g during the course of the night due to respiration and excretion and that any weight change larger than -2.5 g indicated provisioning. Brooke (2004) found

that weight loss is however not consistent and is greatest shortly after provisioning; this is supported by results reported here for WFSP (Figure 4.7). In hindsight, the methodology used in this study was not ideal and future studies should use methods that more accurately quantify changes in weight loss. Due to the limitations of the methods, there was no way to distinguish between provisioning events with small meals and chicks whose metabolism and weight loss deviated from the estimated rate. Therefore, apparent provisioning rates and meal size data should be interpreted with caution. It should be noted that the considerable decrease in sample size for weight loss relative to days since last feeding was exacerbated because chicks entering states of lethargy/torpor were not handled, so as to minimise further stress. Hence, chicks were less likely to be weighed the longer they fasted. In addition, using burrow gates to identify unfed chicks and calculate weight loss was limited because gates moved easily in the soft soils and the combined potential for interference from other adults, emerging chicks or other fauna (moko skinks, *Oligosoma moco*) meant that gates were often disturbed even when the focal chick was not provisioned.

#### 4.6.3 Stable isotopes – trophic level and fractionation

Blood samples taken from adult WFSP during December, when birds were prospecting burrows, were significantly lower in  $\delta^{15}\text{N}$  than during chick rearing (January/February), however there was no change in  $\delta^{13}\text{C}$ . This suggests the birds shift their diet by trophic level but not their foraging location. Consumers tend to be enriched in  $\delta^{15}\text{N}$  relative to their diet by a fractionation factor of 1–5‰ (Hobson, Piatt, & Pitocchelli, 1994; Michener & Kaufman, 2007; Williams, Buck, Sears, & Kitaysky, 2007). Fractionation is thought to occur during the absorption of nitrogen isotopes from the diet and conversion to amino acids and other compounds (Minagawa & Wada, 1984). Fractionation is species specific and varies between tissues (Martinez del Rio & Carleton, 2012). The upwards shift in heavy nitrogen in WFSP blood, between burrow prospecting and chick rearing phases, is <1% and probably indicates a partial shift in prey ratios of differing trophic levels. Possibly to a higher proportion of fish or cephalopod prey from a greater crustacean based diet (Figure 4.10). This may be due to temporal differences in available prey (Rayner, *et al.*, 2008) and perhaps in relation to concurrent LNSO conditions. Alternatively fish may provide a more suitable diet for chick provisioning (Harding *et al.*, 2008). Previous blood stable isotope analysis of WFSP from Burgess Island during the breeding season of 2010/2011 also showed an increase in  $\delta^{15}\text{N}$

from early breeding stages in October and during chick provisioning and fledging in January (Ismar, S., pers. comm.).

Euphausiids are a known prey species of WFSP (Richdale, 1943a). Euphausiid isotope nitrogen ratios vary with geographic location, with reported levels of  $\delta^{15}\text{N}$  of 6.5 from SW (44°S, 176°W) of the Chatham Islands, New Zealand (Thompson & Furness, 1995) and at approximately 10.5 from Barkley Sound, BC, Canada (Hobson, *et al.*, 1994). Considering a ~1-5% enrichment factor (Hobson & Clark, 1992; Michener & Kaufman, 2007; Minagawa & Wada, 1984) and the reported mean values  $\delta^{15}\text{N}$  of WFSP (12.3 - 13.04), it appears likely that WFSP are mixing their diet with prey from a higher trophic level, for example, fish and/or cephalopods. Pilchards from the Hauraki Gulf for example, have reported values of  $\delta^{15}\text{N}$  of 12.2 (McKenzie, 2011), squid records range from  $\delta^{15}\text{N}$  of 8.2 - 10.2 in Australian waters (Cherel, Hobson, & Weimerskirch, 2000) to 12.3 near California (Sydeman, *et al.*, 1997). The diet of Wilson's storm petrels during three breeding seasons showed a heavy reliance on krill: 81-91% of the diet between years was crustacean (64-78% krill) and 20-36% fish (Quillfeldt, 2002). During these years the  $\delta^{15}\text{N}$  in feather samples of Wilson's storm petrel chicks' was  $10.5 \pm 0.2$  in 1999 and  $11.1 \pm 0.3$  in 2000 (Quillfeldt, *et al.*, 2005). These lower  $\delta^{15}\text{N}$  values relative to WFSP potentially suggests a higher rate of foraging on fish by WFSP. Previously recorded WFSP regurgitation samples, taken during February and March of the Chatham Island breeding season, showed proportions (quantified visually) of 70% crustaceans and 30% fish (Imber, 1981). The range of  $\delta^{15}\text{N}$  between species may be accounted for by variation resulting from resource partitioning, different fractionation rates between the species, and/or fractionation during the synthesis of different tissues sampled; blood and feathers.

#### 4.6.4 Stable isotopes - feather samples

There were significantly higher  $\delta^{15}\text{N}$  levels found in chick feathers compared to adult blood tissue (Figure 4.11). There are several possible explanations for this difference. Firstly the blood collected was not from the adults of focal chicks. In addition, fractionation between blood and feather samples, chick versus adult metabolisms as well as individual nutritional states.

Samples record diet at different time scales; for example, feathers are formed in the winter and blood is formed 12–15 days prior to sampling (Bearhop, *et al.*, 2002; Dalerum & Angerbjorn, 2005; Evans Ogden, Hobson, & Lank, 2004). Chick feathers may assimilate nutrients from the egg and would incorporate stable isotopic signatures from the maternal diet during egg formation (Bond & Jones, 2009). The stable isotopic values within certain sample types are reflective of not only source elements but also processes of fractionation (Dalerum & Angerbjorn, 2005; Martinez del Rio & Carleton, 2012). Feathers, bone and skin tend to be more enriched than most tissues (Kelly, 2000). In a study by Quillfeldt, Bugoni, McGill, Masello, & Furness (2008) five Procellariiform species showed consistently higher values of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  in feathers compared to blood tissues. This pattern, of greater heavy nitrogen in feather samples, was recorded in both adults and chicks and is likely to be due to differences in tissue metabolism (Quillfeldt, *et al.*, 2008). The difference between  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  observed in this study may therefore be explained largely by metabolic differences between the tissues. Other factors must also be considered, for example; differences in adult and chick metabolisms and physiological states, lipid content and focal species biology (Bond & Jones, 2009).

Ideally samples from parents and chicks would be taken for direct comparison, however in this study chicks were not blood sampled because of the potential changes to their development. The relationships of stable isotope values between tissue type and life stages must be interpreted with caution as the factors which affect isotopic ratios between adults and chicks are difficult to account for due to potential metabolic differences and potential bimodal foraging strategies of parents (Bond, *et al.*, 2010; Harding, *et al.*, 2008; Williams, *et al.*, 2007). For example, little auk chicks (*Alle alle*) show consistently lower  $\delta^{15}\text{N}$  in blood than adults. The differences are thought to result from either a shift in diet being provisioned to chicks versus that consumed by adults or other complexities within chick blood during growth (Harding, *et al.*, 2008). No definite conclusions can be made regarding the foraging strategies or influence of adult/chick metabolism to  $\delta^{15}\text{N}$  fractionation in the current WFSP data, however the variation should be considered when interpreting results.

Fractionation processes are dependent on many variables and stable isotope results must be interpreted with caution. Food deprivation can lead to enriched  $\delta^{15}\text{N}$  in body tissues (Michener & Kaufman, 2007; Williams, *et al.*, 2007). Therefore the observed fasting periods and lower than expected rate of provisioning of WFSP chicks may have influenced  $\delta^{15}\text{N}$

values in chick feathers. Moderate levels of food restriction result in decreased levels of  $\delta^{15}\text{N}$  and  $\delta^{13}\text{C}$  for tufted puffins (*Fratercula cirrhata*) and decreased  $\delta^{15}\text{N}$  of growing rhinoceros auk chicks (*Cerorhinca monocerata*) (Sears, Hatch, & O'Brien, 2009; Williams, *et al.*, 2007). Obtaining species specific fractionation factors involves testing animals with isotopically known diets and monitoring over various times relative to tissue synthesis and turnover rates of stable isotopes (Michener & Kaufman, 2007). This would be particularly difficult for this migratory and pelagic species.

#### 4.6.5 Stable isotopes – distribution

WFSP are expected to forage within the Hauraki Gulf and have been observed doing so (Gaskin, C. pers. comm.; pers. obs.). However the spatial distributions of  $\delta^{13}\text{C}$  shown by Rayner, *et al.* (2008) indicate that expected carbon values in the Hauraki Gulf are approximately  $-18.5\text{‰}$ , which is comparatively higher than WFSP blood at  $-19.6\text{‰}$ . This may indicate a wider foraging area for this WFSP population. Understanding locations of preferred foraging activity may provide insight into areas geographically suitable as recipient translocation sites.

#### **4.7.0 Conclusion and recommendations**

##### *4.7.1 Provisioning regimes*

This study has focussed on WFSP chick provisioning biology, presenting information on feeding frequency, meal size and insight into the complexities of diet and stable isotope analysis. WFSP chicks on Burgess Island were fed at a rate lower than expected based on Whero Island WFSP populations (Richdale, 1943b); the overall proportion of nights that individual chicks went unfed and the duration of consecutive fasting nights were higher than recorded from the southern population. The probability of a chick being fed on any given night relative to its age was also lower than observed in southern populations of WFSP and other storm petrel species (Quillfeldt & Peter, 2000; Simons, 1981). The size of meals delivered to chicks, measured as overnight provisioning mass, were consistent with expected values. It would appear that adult WFSP were having to spend more time foraging, possibly at greater distances, to obtain sufficient meal masses. It may also be concluded that WFSP will prioritise time investment into collecting adequate meal sizes rather than making more frequent visits ashore with smaller portions. However, the mild to medium LNSO climatic conditions, in play during the breeding season in this study, may have affected the abundance and distribution of the WFSP's food resources. An even greater drop in provisioning was observed in breeding populations of grey-faced petrels in the Hauraki Gulf during the same 2011 season to which LNSO conditions are considered a driving/contributing factor (Dunn, 2012). It is recommended that future WFSP research considers and compares the role of current climatic conditions and generates a range of seasonal provisioning rates relative to chick growth.

In relation to translocation, variation in provisioning frequency may affect the rates of chick development. Consequently, seasonal variation in feeding rates will influence the timing of expected fledging and morphological target indicators for translocation selection.

Provisioning information is highly valuable for planning artificial feeding regimes. Although the digestion rates of different diets will vary, the average and most frequent meal sizes ( $7.8 \pm 0.3$  g or 3.0–4.0 g/day) quantified in this study provide a guideline to suitable meal sizes that chicks can digest at regular and frequent rates.

Precisely identifying meal sizes was difficult owing to the variable nature of chick metabolism and inconsistencies of weight loss over time. An assumption was made that any weight loss less than 2.5 g indicated provisioning. Therefore chicks which decreased in

weight by 0–2.4 g were considered to have been fed, this is a conservative approach and takes into account variation in weight loss by individuals and time elapsed since last fed.

Consequently, provisioning rates and meal sizes may be slightly over- and/or underestimated.

It is recommended that future methods could test this assumption by using more periods of frequent weighing, for example, at three-hour intervals as done by Gangloff and Wilson (2004), to identify temporal changes in metabolism and the precision of calculating weight loss from a single daily weighing.

#### *4.7.2 Stable isotopes*

Values of  $\delta^{15}\text{N}$  between December and February showed a significant increase. The change is perhaps due to a shift in the ratio of prey consumed at different trophic levels, and best explained by a greater intake of fish compared to crustaceans. The alteration may be attributable to prey choice in adults, or overall prey availability, to which the mild to medium LNSO conditions at the time of this study may have had an influence.

Isotopic values of  $\delta^{13}\text{C}$  suggest WFSP may be foraging at more offshore locations. Because of the small size of WFSP, tracking their spatial movement with geolocators or GIS tags is not possible. Prey sampling within the outer Hauraki Gulf and continental shelf areas near Northland may provide a better insight to the divergence of WFSP foraging. For the purpose of translocation, identifying foraging grounds may help to identify suitable sites for the establishment of new populations. Such areas may complement historical WFSP distributions (Worthy & Holdaway, 2002). Additionally, by factoring in the sea spatial distributions of WFSP into translocation planning, opportunities of local attraction to the new site may be increased.



**Plate 4.2 Lala 5 with a protruding stomach after a large meal.**

# Chapter Five

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## FEEDING TRIAL FOR ARTIFICIAL PROVISIONING

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### 5.1.0 Introduction

#### 5.1.1 Translocation of Procellariiformes

Conservation translocation are considered by the International Union for the Conservation of Nature to be the deliberate movement of organisms intended to create measureable benefits to populations, species or ecosystems and not limited to the aid of translocated individuals (IUCN, Species Survival Commission, 2012). Humans have been moving animals between geographic areas for centuries, for reasons of aesthetics and game hunting, and more recently for conservation, i.e. biodiversity preservation and/or restoration (Armstrong & Seddon, 2007; Green, 1997; Griffith, Scott, Carpenter, & Reed, 1989). Many conservation translocations were initiated during the 1970s and 1980s but had high rates of failure (Armstrong & Seddon, 2007; Griffith, *et al.*, 1989). In response, the field of reintroduction biology emerged, calling for more rigorous scientific and strategic methods to be applied to translocation efforts (Seddon, Armstrong, & Maloney, 2007). Translocation is now a powerful tool for the conservation management of environments and threatened species (IUCN, 1987; Priddel, Carlile, & Wheeler, 2006). For example, the black robin (*Petroica traversi*) population of the Chatham Islands, New Zealand, was reduced to just five individuals in 1976, including only one female. Through translocation and intensive management, numbers had increased to 254 by 1999 (Department of Conservation, 2001a). The first seabird translocation project was pioneered in 1973 when 954 Atlantic puffins (*Fratercula arctica*) were moved successfully from New Foundland to Eastern Egg Rock Island in Maine (Kress, 1998).

Procellariiformes (albatross, petrels and shearwaters) are considered drivers of terrestrial systems and ecological engineers. In particular, burrow-nesting species manipulate colonies through both autogenic and allogenic processes as marine nutrients are transferred to land and physical disturbances affect terrestrial ecology (Bancroft, Roberts, & Garkaklis, 2005; Crooks, 2002; Durrett & Mulder, 2011; Hawke & Newman, 2007; Markwell & Daugherty, 2002; Roberts, Duncan, & Wilson, 2007). In pre-human New Zealand, petrels would have made the greatest contribution to avifauna biomass, breeding in colonies numbering hundreds of millions (Worthy & Holdaway, 2002). Hawke, *et al.* (1999) show that in New Zealand, historical seabird breeding sites from pre-European times (300–700 years ago) still have significant concentrations of nitrogen, phosphorus and cadmium, which have enriched soils to levels equivalent of modern-day superphosphate fertilisers. Miskelly, *et al.* (2009) highlighted the urgency to develop conservation management techniques for burrow-nesting petrels, to improve species' recovery and promote their role within ecological processes. The

first seabird restoration efforts began in the early 1970s and now techniques to encourage colonisation are being applied worldwide (Jones & Kress, 2012).

Conservation management is a necessity for many species experiencing significant declines resulting from anthropogenic impacts (Baker, Gales, Hamilton, & Wilkinson, 2002). Croxall, *et al.* (2012) recognises 21% of 199 pelagic seabird species as endangered or critically endangered. Threats that negatively affect Procellariiformes are both terrestrial and marine based. Primary causes of decline include predation from invasive predators, degradation of nesting habitat, interactions with fishing operations and pollution (Baker, *et al.*, 2002; Croxall, *et al.*, 2012). The Chatham Island taiko (*Pterodroma magentae*), considered to once have been the most abundant species on Chatham Island, has now less than 150 individuals. This great decline is attributed to predation by non-native mammals and loss of habitat (Department of Conservation, 2001b). The management plan for the Chatham Island taiko includes translocation to establish additional breeding populations (Department of Conservation, 2001b). Trials to develop techniques were first run using grey-faced petrels (*Pterodroma macoptera gouldi*) and Pycroft's petrels (*Pterodroma pycrofti*) as surrogate species (Miskelly, Taylor, Gummer, & Williams, 2009). One Chatham Island taiko chick was translocated in 2006, eight in 2007 and 13 in 2008; the fledging success for these chicks was 100% (Miskelly, *et al.*, 2009).

### 5.1.2 Complications of Procellariiform translocation

Procellariiformes exhibit K-selected life-history traits, with low intrinsic rates of reproduction, and naturally high degrees of philopatry, consequently recolonisation of extirpated breeding sites will be slow (Miskelly, *et al.*, 2009; Warham, 1990). This strong natal site fidelity complicates translocation attempts and transfer techniques must ensure focal animals imprint on the translocation site (Priddle & Carlile, 2001; Warham, 1990). How and when chicks imprint and develop philopatry is unclear (Priddle & Carlile, 2001), although the process is thought to occur sometime during the chick emergence period prior to fledging (Miskelly & Taylor, 2004; Serventy, 1967). Consequently, translocation requires the transfer of pre-fledgling downy chicks still reliant on parental food provisioning (Jones & Kress, 2012) and that therefore must be artificially fed until fledging.

The provisioning of burrow-nesting petrels is labour intensive and involves hand-feeding using crop tubes to deliver pureed food directly into the proventriculus (Miskelly, *et al.*,

2009). Removing dependant chicks increases the requirements of general care as well as the risk of mortality (Priddle & Carlile, 2001). For example, during a translocation of 239 common diving petrels (*Pelecanoides unrinatrix*) to Mana Island, New Zealand, only 49% of chicks survived to fledge and food poisoning and candidiasis were thought to be the leading causes of mortality (Miskelly & Taylor, 2004). Renal failure and gastrointestinal related problems have also been reported in translocated grey-faced petrels close to fledgling (Miskelly, *et al.*, 2009).

In addition to the health risks, the translocation of seabirds is intensive and expensive and, depending on the species, fledglings may spend 2–11 years at sea before returning to breed. It took eight years after the translocation of 940 Atlantic puffins before the first birds, five pairs, returned to nest on Eastern Egg Rock Island (Kress, 1998). The common diving petrel translocation to Mana Island comprised 118 fledglings of which 20 returned to the translocation site at ages ranging from one to five years (Miskelly & Taylor, 2004). Conservation gains are therefore slow to accrue (Warham, 1990), as it is the return of chicks to the transfer site and the establishment of a viable population determining translocation success.

### 5.1.3 Developing and refining species specific protocols

Small scale translocation trials are a useful technique for the development of best practice protocols and methods. Gould's petrels (*Pterodroma leucoptera leucoptera*) were restricted to breeding on Cabbage Tree Island in Australia (Priddel, Carlile, & Wheeler, 2006a); in 1995 a successful trial translocation of 30 chicks was made by transferring individuals from natal burrows to different areas on the island and artificially provisioning them until fledging. Provisioning was done by placing pieces of whole fish into the oesophagus (Priddle & Carlile, 2001). Subsequently, as a result of the success of the trial, 200 Gould's petrel chicks were transferred over two years (1999 and 2000) to Boondelbah Island, and from these 98% of chicks successfully fledged. Three years later, 10 translocated chicks had returned and produced six known fledglings (Priddel, *et al.*, 2006a).

After initial failure there has been an increase in fledging successes from 49% to 97–100% successive translocations of various species, owing largely to improved husbandry techniques (Miskelly, *et al.*, 2009; Miskelly & Taylor, 2004; Priddle & Carlile, 2001). Such improvements s the rinsing of feeding apparatus in Chlorhexidine solution between chicks

minimised the risk of candidiasis (Miskelly & Taylor, 2004; Miskelly, *et al.*, 2009). Miskelly *et al.* (2009) conducted trial translocations and tested attraction techniques on eight non-threatened burrowing petrel species with the purpose of learning and developing protocols. These trials saw six of the eight species fledge at rates greater than 90%, with 61% and 80% for the remaining two species. The authors collected information on the basic breeding ecology of focal species: hatching dates, meal provisioning frequency, meal size, chick growth, emergence behaviour and fledging information. Chicks were collected at ages considered to be between zero and six weeks away from fledging and provisioned on a range of test diets. The authors found that a diet of pureed Brunswick sardines and water was the most suitable nutrition for all trialled species, regardless of their natural diet, with all fledglings leaving in good condition. Adjustments of additional Mazuri seabird vitamin tablets and greater water ratio have since been made to the standard sardine diet; the increased water content is aimed at reducing kidney failure related issues and gout (Gummer & Gardner-Gee, 2009). MAZURI Exoite Animal Nutrition, owned by PMI Nutrition, design, test and manufacture animal diets. The feeding procedure using crop tubes and strict hygiene protocols are outlined by Miskelly, *et al.* (2009) and Gummer & Gardner-Gee (2009), see Appendices V and VI.

#### 5.1.4 White-faced storm petrels

New Zealand white-faced storm petrels (WFSP), *Pelagodroma marina maoriana*, are an endemic New Zealand subspecies. The estimated national population size of this species is more than one million pairs, with a breeding range covering 23 offshore islands (Robertson & Bell, 1984). Southeast Island/Rangitara Island in the Chatham Island group is considered the largest WFSP population, with approximately 840,000 breeding pairs (Taylor, 2000). WFSP breed during the austral summer and migrate to the eastern Pacific during winter months (Imber, 1982; Marchant & Higgins, 1990; Richdale, 1965). Like all Procellariiformes, WFSP lay a single egg, and incubation and chick provisioning is shared by both parents. There are six sub-species within *P. marina* (Brooke, 2004), weighing between 40 g and 70 g and having wing spans of 42 – 43 cm (Marchant & Higgins, 1990). The natural diet of *P. marina* consists of pelagic crustaceans, small fish and surface plankton (Marchant & Higgins, 1990). Few observations have been made on the stomach contents of WFSP although Richdale (1943b) investigated one regurgitated stomach sample from a parent bird. It contained mostly

Euphausiids, potentially small portions of squid meat, two lenses and one barnacle cypris larva.

WFSP are a suitable candidate species for translocation as their abundant population size makes colonies and numbers more accessible. In addition, fledgling WFSP reach their first breeding age relatively quickly, in approximately three years (Menkhorst, Pescott, & Gaynor, 1984). This means that translocation success/failure and colony establishment can be more rapidly identified. Moreover the restoration of WFSP populations provide an opportunity to increase the scope of translocation to other Hydrobatidae species (subfamilies Hydrobatinae and Ocenaitinae), the smallest seabird group (Marchant & Higgins, 1990), for which translocation has so far not been accomplished.

#### 5.1.5 Purpose of study

The purpose of this research was to investigate the efficacy of current translocation protocols, which have been developed for medium sized Procellariiformes, mostly *Pterodroma* and *Puffinus* spp., in the translocation of a storm petrel species, the WFSP. Extending translocation protocols to storm petrels may allow populations to be established or re-established in their historic geographical ranges and thus reinstate their keystone roles within terrestrial ecosystems (Miskelly & Taylor, 2004). As storm petrels are considered cosmopolitan in all oceans (Warham, 1990), translocation protocols developed on WFSP would refine current techniques that would be transferable to other related taxa and thus augment available conservation management tools.

### 5.2.0 Aims and objectives

The aim of this study was to conduct an experimental translocation of WFSP within Burgess Island in order to trial current meal provisioning techniques, artificial diet composition and feeding regimes on this small species. There are two main objectives:

- I. To identify suitable crop tube sizes for feeding WFSP chicks and test the suitability of the currently described sardine based artificial diet with this species.
- II. To compare the response of chicks being provisioned experimentally on an artificial diet to naturally *in-situ* reared chicks. Feeding regimes and guidelines for artificial provisioning based on described target fledging morphology; wing length and weight will be developed.

### 5.3.0 Methods

As described in detail in Chapter 2, section 2.2.9, 10 chicks were selected to undergo an experimental translocation and artificial provisioning feeding trial. The oldest known chicks were selected based on wing length and their acceptance to being artificially fed with a crop tube. All 10 focal chicks were transferred to artificial burrows set up on the same island. Chicks were then provisioned on a diet of pureed Brunswick sardines, sterilised water and Mazuri seabird vitamin tablets. All chicks were weighed and wing lengths measured daily; feeding regimes were then based on daily chick weights. Chick emergence was monitored using burrow gates erected at the entrance of burrow tunnels.

*In-situ* chicks from the focal birds' natal colony (development test group from Chapters 3 and 4) were monitored to determine their fledging morphology (weight and wing lengths), and the feeding regimes (meal size and frequency) provided naturally by their parents. Overnight provisioning masses for *in-situ* chicks were quantified over their last 20 days before fledging (DBF) to reflect the same period of chick rearing as the selected feeding trial (FT) birds. Meal size calculations accounted for weight loss through respiration and excretion by adding 50% of the mean overnight weight loss from all unfed chicks to overnight weight changes of those potentially provisioned.

#### 5.4.0 Statistical analysis

Owing to the small sample size of FT birds ( $n = 9$ ), non-parametric tests were applied in the analyses of these data. Box plots and median values with standard deviation are displayed for FT morphometric and overnight provisioning data. Mean and standard error values are also displayed for further detail and as comparative data to *in-situ* birds from previous chapters, which are described as parametric. Spearman Rank correlations were used to investigate the relationship between provisioning probability and overnight provisioning masses with days before fledging. The morphological variation between FT and *in-situ* groups at fledging for wing length and weight were tested using Mann-Whitney U tests.

Chick age is described as days before fledging (DBF). Data describing meal size, provisioning probability and weight loss were calculated using the mean value of individual chick averages to account for variation between individuals, as per Grim (2006). The calculation of emergence periods excluded one chick that was blocked from emerging for too long and thus the true emergence date could not be accurately determined. All analyses were conducted using Minitab 16 statistical software (Minitab Inc., 2010) and Excel 14.0 (Microsoft Corporation, 2010).

### 5.5.0 Results

#### 5.5.1 Chick selection

The wing lengths of chicks recruited into the artificial provisioning trial ranged from 88 to 119 mm, with a mean of  $101.8 \pm 3.8$  mm (median  $98.8 \pm 12.2$ ,  $n = 10$ ). The weights of these selected chicks on the day of their first artificial feed at their natal site (before feeding) ranged between 37 g and 69 g, with a mean of  $49.5 \pm 3.0$  g (median  $46.5 \pm 9.4$ ,  $n = 10$ ). For weight and wing lengths per chick see Appendix IV.

#### 5.5.2 Feeding apparatus

Three available types of crop tubes were trialled:

- 10 Fg x 49 cm PVC
- 10 Fg x 39 cm rubber
- 14 Fg x 39 cm rubber

The larger 14 Fg rubber tube was passed into the proventriculus without complication, however on review it was considered to be too large relative to the size of the chick. Three chicks were fed once only with this tube size, of which one bird accepted the entire feed, the second had some difficulties (unsettled behaviour, spilling food, excessive vocalisation), requiring two attempts and the third chick also had difficulties, subsequently the last portion of the meal was delivered using a smaller 10 Fg PVC tube.

The 10 Fg rubber tube was too small. The internal lumen of the tube was too narrow to attach to the syringe hub after the tube length had been adjusted. Therefore this type of tube was not trialled.

The 10 Fg PVC tube was successfully used to provision chicks throughout the trial (Plate 5.1). Modifications to the tubes were however necessary, see Chapter 2, section 2.2.9.



**Plate 5.1** A white-faced storm petrel chick is fed a diluted version of a sardine based puree for the first time at the natal colony site. Photograph by Kay Clapperton.

### 5.5.3 Feeding regimes

Chicks were fed two 3.5 g introductory feeds of diluted sardine puree. At least one feed was given at their natal burrow to ensure they would accept food, and another after being transferred to their artificial burrow. A total of 12 chicks were trial fed: one chick did not feed well with artificial provisioning and thus was not selected; a second chick that did feed well was replaced with a more suitable older chick because of its proximity to fledging. Ten chicks were inducted into the trial, and the nine chicks which fledged were artificially provisioned for an average of  $16.6 \pm 0.9$  days ( $n = 9$ , range: 11–20). A total of 150 collective feeds and a gross mass of 1028 ml of sardine puree were provisioned to these chicks after they were transferred to artificial burrows. After the two standard small diluted meals, chicks were fed daily with an average meal mass of  $7.5 \pm 0.1$  ml ( $n = 123$ ), ranging from 3.5 to 9 ml. A meal size of 7–8 ml per day was adequate to keep chick weight constant. Daily adjustments of 1–2 ml greater or less were allocated on an individual basis to promote weight gain or loss and achieve target fledge weights. Chick weight at the time of collection, basic provisioning information and fledging weights for all FT chicks are shown in Table 5.1. For individual chick feeding regimes and weight changes see additional data CD.

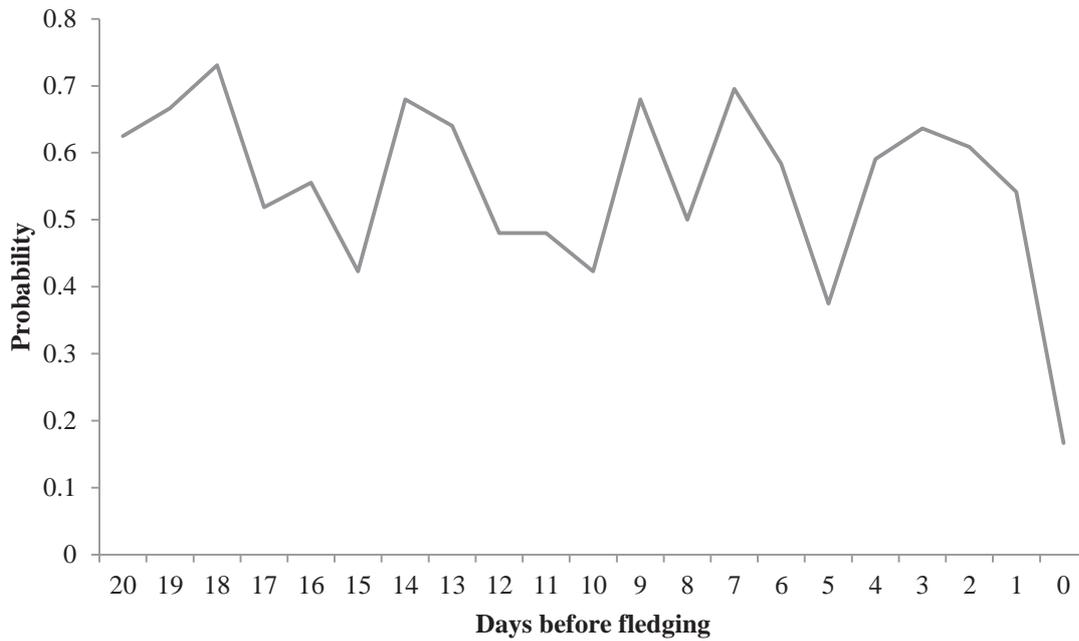
**Table 5.1 Average meal sizes of feeding trial chicks. Days in trial represents the number of days that chicks were provisioned on the artificial diet. Data do not include the first small introductory feeds (3.5 g) that all chicks received at their natal colony prior to being selected for the experiment.**

Chick	Collection weight (g)	Days in trial	Mean meal size (ml $\pm$ sd)	Minimum (ml)	Maximum (ml)	Fledge weight (g)
1	45.5	19	7.94 $\pm$ 0.73	6.0	9.0	45.0
3	46.0	16	7.47 $\pm$ 0.92	5.0	8.0	42.0
4	59.0	17	7.46 $\pm$ 0.92	5.0	8.0	47.5
5	47.0	20	7.11 $\pm$ 1.24	5.0	9.0	47.0
6	42.0	14	8.00 $\pm$ 1.00	6.0	9.0	40.0
7	43.0	17	7.91 $\pm$ 1.34	3.5	9.0	41.5
8	37.0	18	8.38 $\pm$ 1.39	3.5	9.0	40.5
9	50.0	11	7.15 $\pm$ 1.05	6.0	9.0	43.0
10	69.0	18	6.68 $\pm$ 1.14	5.0	9.0	44.5

On 17.6% of feeding events chicks did not feed well ( $n = 38$ ); regurgitating or seeming distressed, and requiring the feeding tube to be removed and the chicks left to settle. In such instances the feeding tube was inserted a second (76%,  $n = 29$ ) or third time (21%,  $n = 8$ ), and in one case a fourth time (3%,  $n = 1$ ). The average number of times that individual chicks needed to be fed more than once per sitting was  $4.2 \pm 0.6$  (median  $4 \pm 1.7$ ,  $n = 9$ , range: 3–8). This is an estimated 25% of the average number of times individual chicks were provisioned artificially. Nevertheless chicks were always eventually provisioned with a suitable quantity of food.

#### 5.5.4 Provisioning of *in-situ* chicks

During the last 20 DBF *in-situ* chicks ( $n = 27$ ) were naturally provisioned 256 times collectively by their parents. *In-situ* chicks were fed on average every second night, with an overall mean provisioning probability of  $0.5 \pm 0.02$  ( $n = 27$ , range: 0.3–0.8). There was little to no significant correlation in the probability of feeding relative to DBF ( $r = 0.279$ ,  $p = 0.2$ ). 77% of chicks ( $n = 20$ ) were not provisioned on their last day in the burrow, as the probability drops to 0.2 on the final day before fledging (Figure 5.1).



**Figure 5.1** The probability of *in-situ* white-faced storm petrel chicks ( $n = 27$ ) being provisioned according to days before fledging ( $r = 0.279$ ,  $p = 0.2$ ).

The average overnight provisioning mass for *in-situ* chicks during their last 20 DBF was  $7.4 \pm 0.3$  g ( $n = 256$ , range: 1–26.5). Of all overnight provisioning masses, 55% of meals ranged between 2 and 7 g (Figure 5.2). The size of meals is significantly correlated with DBF ( $r = 0.148$ ,  $p = 0.02$ ) (Figure 5.3). Outlying asterisks show nights when both parents delivered large meals to their chick.

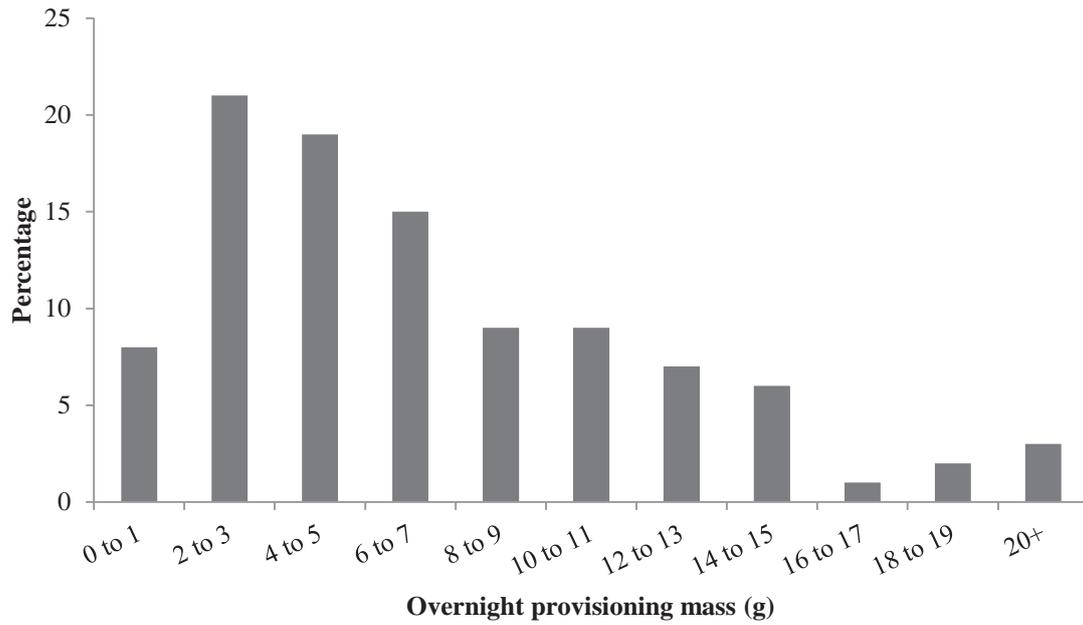


Figure 5.2 Overnight provisioning masses of *in-situ* provisioned white-faced storm petrel chicks (n = 27).

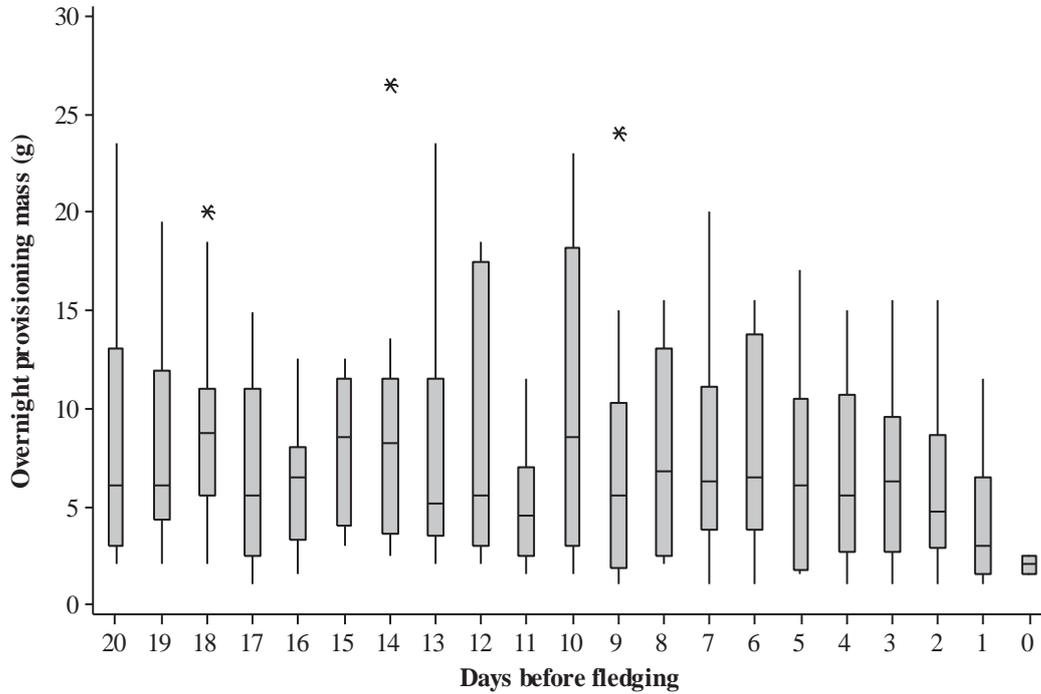


Figure 5.3 Overnight provisioning masses for *in-situ* white-faced storm petrel chicks (n = 27) relative to days before fledging ( $r = 0.148$ ,  $p = 0.02$ ).

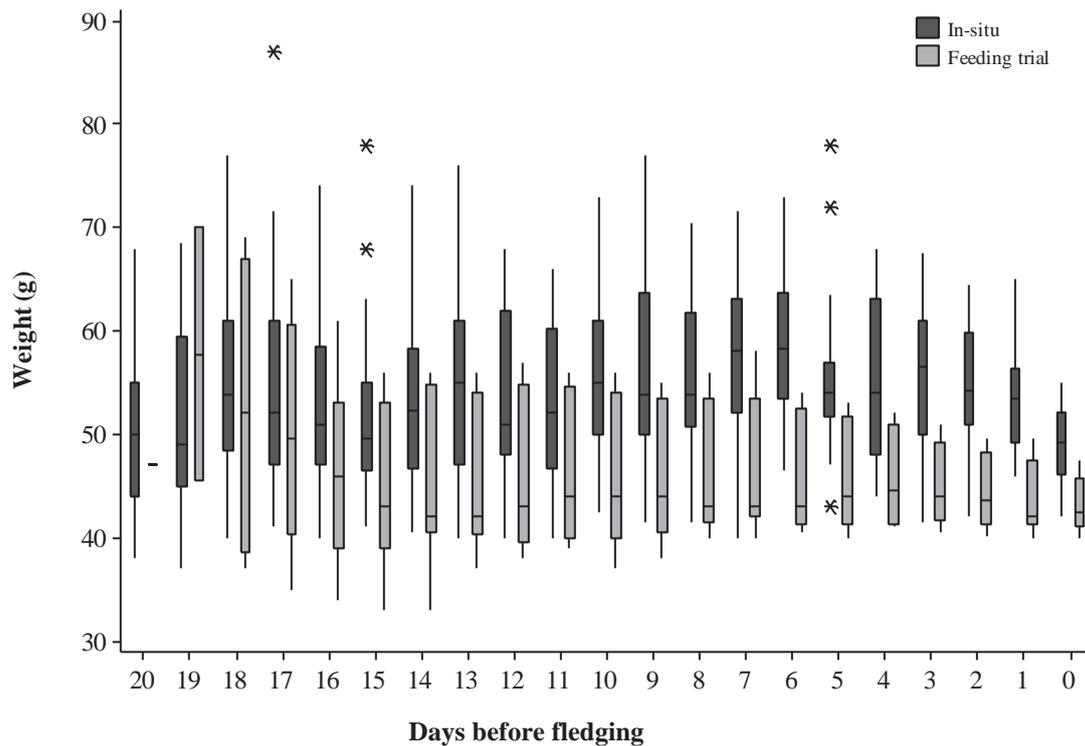
#### 5.5.5 Fledging survival

Nine out of the 10 chicks recruited into the study are presumed to have fledged successfully based on their wing length and absence from burrows for two days with no sign of predation. The one mortality was due to injury. This chick was found in its artificial burrow with a broken leg on the second day after transfer. The break was a tibia/femur fracture to the left leg (Mitchell, C., pers. comm.) and the chick was euthanised by the onsite veterinarian with a lethal injection of pentobarbitone. The cause or timing of the injury was unknown but is likely to have been due to handling.

#### 5.5.6 Fledging weight

There was a significant difference in the mean fledging weights between control (*in-situ*) and experimental (FT) groups (Mann-Whitney U = 51, p = <0.001). FT chicks fledged at an average weight of  $43.2 \pm 0.9$  g (median  $42.5 \pm 2.7$ , n = 9, range: 40–47) and *in-situ* chicks at  $49.5 \pm 0.7$  g (median  $49.5 \pm 3.5$ , n = 25, range 42–55). However, the range between the groups was not dissimilar at the beginning of the trial (Figure 5.4). Outlying values for *in-situ* chicks are most likely indicative of nights when chicks were provisioned large meals by both parents.

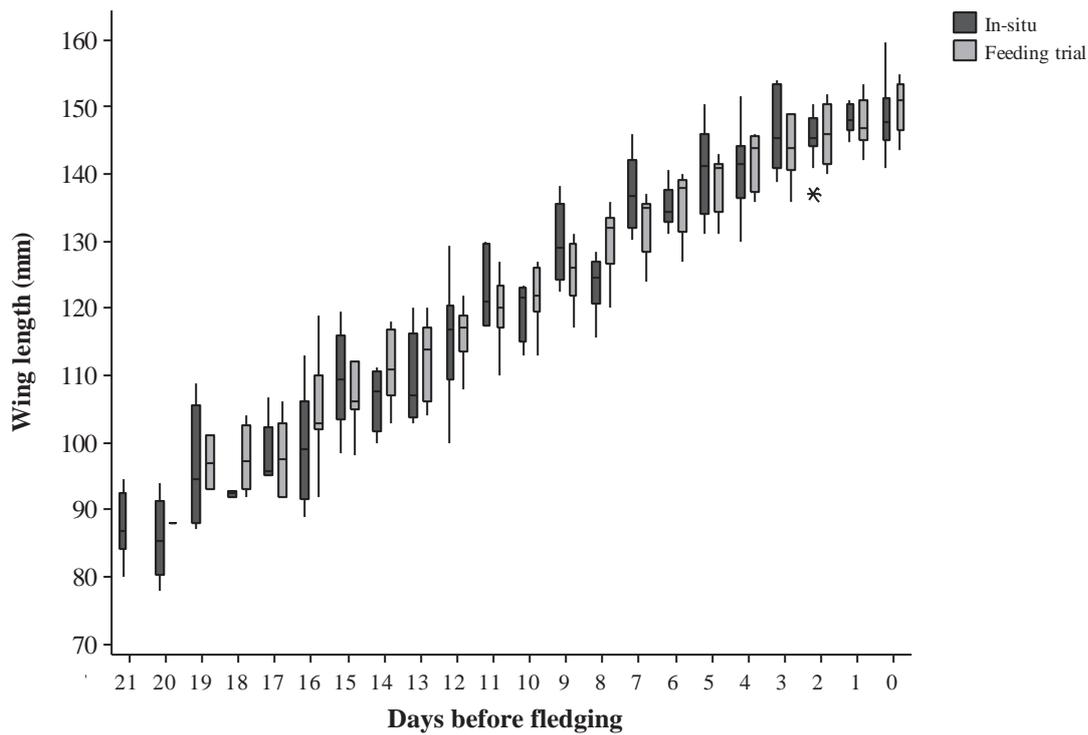
The weights of *in-situ* chicks, during the equivalent duration of the feeding trial (20 DBF), increased to a maximum peak average weight of  $64.6 \pm 1.4$  g (median  $67 \pm 8.6$ , n = 27, range: 48–87) before dropping an average of  $15 \pm 1.5$  g (median  $13.2 \pm 7.7$ , n = 26, range: 0–34.5) prior to fledging. The FT chicks remained at a steady weight and were allocated meal sizes so as to drop an average of  $3.3 \pm 1.5$  g (median  $1.5 \pm 4.5$ , n = 9, range: -1–11) during the last seven days before fledging. Outlying asterisks are indicative of particularly large meals delivered to *in-situ* chicks, most likely by both parents.



**Figure 5.4** The weight of white-faced storm petrel chicks during their last 20 days before fledging for the artificial feeding trial group ( $n = 9$ ) and naturally provisioned *in-situ* group ( $n = 25$ ). There is a significant difference between the two groups (Mann-Whitney  $U = 51$ ,  $p < 0.001$ ).

### 5.5.7 Wing length at fledging

There was no significant difference in the mean fledging wing lengths of FT chicks ( $150.4 \pm 1.3$  mm, median  $151 \pm 3.98$  mm,  $n = 9$ , range: 143.5–155) and *in-situ* chicks ( $148.8 \pm 0.8$  mm, median  $149 \pm 3.98$  mm,  $n = 23$ , range: 143.2–159.5) (Mann-Whitney  $U = 130$ ,  $p = 0.18$ ). Wing lengths for *in-situ* and FT groups increased at similar and linear rates (Figure 5.5). The average growth rate of wing lengths for FT chicks during the trial was  $2.9 \pm 0.2$  mm/day (median  $3.1 \pm 0.5$ ,  $n = 9$ , range: 2.1–3.3). *In-situ* birds, over a similar period of approximately 20 DBF (16–22 depending of available data), showed a very similar growth rate of  $3.0 \pm 0.1$  mm/day (median  $3 \pm 0.3$ ,  $n = 27$ , range: 2.3–3.8).



**Figure 5.5** Wing lengths of white-faced storm petrel chicks fed on an artificial diet (FT,  $n = 9$ ) and naturally provisioned chicks (*in-situ*,  $n = 23$ ) during the last 20 days prior fledging. There is no significant difference between the two groups ( $w = 130$ ,  $p = 0.18$ ).

### 5.5.8 Chick emergence

There is no statistical significance between the emergence times of *in-situ* and FT chicks (Mann-Whitney  $U = 82.5$ ,  $p = 0.59$ ). FT chicks began emerging from their burrows on average  $3.5 \pm 0.6$  nights prior to fledging (median  $3 \pm 1.6$ ,  $n = 8$ , range: 3–7) and *in-situ* chicks at  $3.1 \pm 1.4$  nights prior to fledging (median  $2.5 \pm 1.4$ ,  $n = 10$ , range: 2–6).

### 5.6.0 Discussion

This artificial feeding trial has demonstrated the feasibility of translocating WFSP. Neither the exclusion of parental contact, nor disturbance in removal from natal burrows, nor artificial provisioning affected the fledging success or wing growth of FT chicks. The trial was completed with low mortality rates; fledging success was 90% and the one fatality was not related directly to the artificial diet but to handling issues. All fledglings of the FT group departed with wing lengths equivalent to naturally provisioned chicks. The feeding apparatus and method of delivery were both suitable for WFSP, as was the sardine based diet.

The onsite veterinarian for this feeding trial was concerned about the implications of potential irritations to the throat for such a small species, which can be caused by crop tubes being passed down the oesophagus for an extended period of time (Mitchell, C., pers. comm.). However, no oesophageal irritation was observed in this trial. Despite the relative success of the trial, the inherent risks of artificial feeding should be minimised within management practices by keeping the duration of chick dependency at a minimum (Priddle & Carlile, 2001). The longest duration a WFSP chick was artificially fed in this trial was 20 days; this individual fledged at the same weight as when it was transferred, at 47 g. Given that WFSP appear to emerge from their burrows within one week of fledging, the duration which chicks can tolerate artificial feeding is greater than the time necessary for translocation (approximately 10 days, including a 3-day acclimatisation period as described by Gummer, *et al.*, 2012, see Chapter 3, section 3.6.6).

A significant limitation of this project was the necessity to induct the oldest available chicks into the trial. This was a result of having to predict when to run the trial with birds of unknown ages, as well as the relatively unsynchronised rate of hatching within the colony. Consequently, no previous or concurrent data were available on target fledging or emergence weight and/or wing length for the allocation of feeding regimes and the unblocking of artificial burrows. Such information was collected after the conclusion of the feeding trial and is useful for adjustments to future artificial feeding regimes.

### 5.6.1 Survivorship

The feeding trial is considered to be successful as 90% of chicks survived to fledge. It is unlikely that any of these chicks will be recovered in later years to determine post fledging

survival. This is due to the small number of individuals used in the trial in comparison with the huge population and limited opportunities for future survey effort.

The one chick that was euthanised after injury was moved from its natal site on the morning of 14 January and fed artificially that evening. The injury was discovered on the evening of 15 January when the chick was due to be fed. The chick had been noted as being fidgety and aggressive during its feed on 14 January, suggesting the injury may have already occurred, possibly during transportation. However, no jolting or impact was sustained to the transport box and chicks seemed comfortable inside (Mitchell, C., pers. comm.). From the time of being fed artificially for the first time at the natal site to the identification of the injury, the chick was handled by three people, none of which could identify any incident that may have caused the injury. The opinion of the onsite veterinarian was that the injury may have resulted from leverage of the long tarsi against the tibia/fibula if the leg was in an abnormal position. Two other cases of leg injuries have occurred in translocated grey-faced petrels. In one incident, a tibiotarsal fracture was likely due to handling. However, in the second incident the bird fractured both left and right tibiotarsal bones, and this is thought to have happened outside the burrow during chick emergence (Ward-Smith, T., pers. comm.). There may be a physiological response from the stress of handling, leading to a predisposition of leg injuries. However, no other leg injuries of handled chicks are evident within literature. Regardless of this, extra caution should be taken when handling chicks to ensure their legs are constantly straight and supported.

Another chick was noted as being lethargic for two days (16 days after removal from parental care), with a forward posture and not pressing its weight through its legs like other chicks close to fledging. On the third day a discharge was noticed coming from the chick's left ear which looked reddened; possibly indicating an ear infection or abscess. After the apparent release of discharge, the chick became more active and lively in behaviour and is assumed to have successfully fledged that night.

### *5.6.3 Feeding apparatus*

The 10 Fg PVC crop tube was the most suitable size for WFSP and hence was the primary apparatus used throughout this trial. The 14 Fg tube was considered unsuitable for WFSP as it held the oesophagus open too wide, increasing the risk of spillage and food aspiration (Mitchell, C., pers. comm.).

Crop tubes had to be shortened to 70 mm from their original lengths of 39 cm because the surface area would cause food to cool too quickly, and also because maintaining control of the tube during feeding would be difficult. The closed end of the tubes had to be removed because 1) neither an adaptor nor syringe could be connected directly with the cut tube, and 2) two apertures were located at 15 mm and 33 mm from the distal end of the tube. Consequently the closed area at the bottom of the tube would make adequate cleaning between feeds too difficult and, more importantly, the apertures would release food too far up the oesophagus, increasing risk of regurgitation and aspiration. Extreme caution needs to be taken to ensure the leading edges of the crop tube are smooth so as not to damage the oesophagus. This was overcome by quickly passing the cut end through a flame to soften it. Although this method worked well and meals were successfully delivered, the veterinarian overseeing the feeding trial suggests a 12 Fg rubber tube would be a preferred size for future artificial feeding projects, with a rounded closed end.

Regurgitation during feeding occurred occasionally in some chicks. This problem was mitigated by gently removing the tube from the proventriculus and allowing the chick to settle. The procedure of passing the tube was then repeated until meals were successfully delivered. The risk of food inhalation or irritations to the oesophagus can increase in unsettled chicks with the frequency of passing the tube down the oesophagus. Therefore, artificially feeding chicks at their natal site prior to translocation is important in order to identify chicks that remain settled during feeding, accepting the crop tube and artificial diet. Selecting chicks that feed well improves time efficiency, which is particularly important given the constraints of provisioning many chicks a diet requiring strict hygienic protocols and prompt delivery at a specific temperature.

#### 5.6.4 Feeding regimes and chick weight

The trialled provisioning regime of daily meal sizes of approximately 7–8 ml was sufficient to sustain WFSP chick weights, with daily adjustments to promote weight gain or loss in order to reach target fledging masses. Although artificial chick provisioning is considered to have been successful, FT birds fledged at significantly lighter weights than did *in-situ* birds. The main reason for this was that FT birds fledged before target fledging weights could be determined from *in-situ* birds. By using natural fledging weights as target weights for FT birds, similar fledging masses should be attainable for underweight chicks by increasing meal

size and/or feeding frequencies, if necessary, as chicks approach fledging. Ideally however, chicks will be in excess of fledging weights when they are removed from their natal burrow, therefore weight gain through artificial provisioning would not be necessary. Provisioning chicks more than once a day would not be a desirable option because of 1) the high labour intensity of sterilising equipment and processing meals, 2) the increase in stress to chicks from more frequent handling, and 3) increased chances of health related issues, due to increased feeding attempts, such as irritation of the oesophagus, candidiasis and food regurgitation/aspiration.

Generally in seabird translocation, heavier fledgling weights are considered to increase post-fledging survival (Priddle & Carlile, 2001). Migratory species (such as WFSP) need dense layers of abdominal fat before departure, however, if a chick is too heavy it's flight ability is compromised, particularly as its flight muscles are less conditioned than adults (Gummer, *et al.*, 2012). This was the first feeding trial for the species and the fledging weights for northern WFSP were unknown. Without concurrent *in-situ* comparisons, this study relied on the opinion of the onsite veterinarian, and the concern was that chicks would not fledge if they were too heavy. In addition, if chicks failed to depart, the extended duration of necessary artificial provisioning would increase the potential risk of associated health complications. Therefore, meal sizes were provisioned taking this into account, as well as the natural weight decline common in Procellariiform chicks prior to fledging (Booth, Minot, Imber, & Fordham, 2000; Cuthbert, 2005; Phillips & Hamer, 2000). Consequently, feeding regimes for FT birds were developed so chicks would drop some weight prior to fledging yet fledge at a mass similar to adult weights as reported by Gummer, *et al.* (2012). However, because the species is migratory chicks may fledge with fat stores (Gummer, *et al.*, 2012) that are not yet evident in adults which are still provisioning chicks. Nevertheless, in this study chicks fledged at weights that were considered appropriate at the time, configured by the feeding regime (Mitchell, C., pers. comm.). For future translocation initiatives, we suggest using the fledgling weights of the *in-situ* birds reported in this study as targets for artificially fed chicks from northern populations.

The mean meal size of both groups were very similar, however the FT chicks were fed more regularly than the *in-situ* birds – on a daily basis compared to an average of every second day. The variation in fledging weights between groups therefore suggests that the sardine puree diet may not be as efficient or rich as the chicks' naturally fed crustacean/fish based diet. This difference in diet energetics is predictable as the concentration of food and oil in the

stomach of petrels can be up to 35 times the calorific content of prey (Warham, 1990). This however does not detract from the suitability of the trialled diet for translocation, but compensatory measures such as increased meal size and/or feeding frequency may be required.

#### 5.6.4 Chick growth and fledging

The diet and feeding regimes of FT chicks did not impact on growth rates when compared to *in-situ* chicks. Wing lengths for both FT and *in-situ* groups increased at a steady and similar rate. There was no significant variation between the two groups at the time of fledging, despite the seemingly lower nutritional efficiency of the artificial diet compared with natural provisioning as reflected in body weights. The wing growth trends indicate a nutritional priority is given to wing length at fledging over body condition. It is the structural development (wing length) of chicks which is thought to trigger the onset of pre-fledging weight loss (Mauck & Ricklefs, 2005), again indicating that the attainment of structural targets are prioritised.

Initially, artificial burrows were blocked to prevent unsettled chicks wandering or leaving prematurely, becoming lost or attempting to fledge too early. However, it was uncertain when blockades should be removed and chicks allowed to emerge from burrows naturally. In grey-faced petrels, translocated chicks are blocked from leaving the burrow for at least three days after transfer and until wing lengths reach the known size of emerging chicks. This allows chicks to settle, adjust to changes in temperature and humidity as well as develop their scent within the chamber (Gummer, *et al.*, 2012). A diving petrel translocation initially blocked chicks inside transfer burrows for two days but after that time chicks were observed leaving their burrows during daylight hours. Consequently, chicks were blocked from emerging until they had reached an allocated minimum wing length (Miskelly & Taylor, 2004). As a guideline for the translocation of northern WFSP, blocking of chick emergence should occur for at least three nights after transfer, with emergence allowed only once wings exceed average lengths of  $137.7 \pm 2.4$  mm ( $n = 6$ , range: 130.3–146) (WFSP wing length at seven DBF, the earliest recorded emergence time). Blockading chicks when they are ready to emerge may cause significant stress (Gummer, 2012); therefore chicks should be closely monitored on an individual basis.

The burrow gate method has been used successfully in previous studies (Gangloff & Wilson, 2004; Priddle & Carlile, 2001). In this study, burrow gates were used to determine chick emergence. Burrow gates indicate chicks present in the entrances of burrow tunnels but not necessarily exiting entirely, as sticks would be moved by chicks protruding their head from the tunnel as part of their emergence behaviour. The burrow gates on *in-situ* nests were unreliable because the soil was too friable and the sticks moved easily (Chapter 3). In addition, visiting parents and/or exploring fledglings may disturb sticks, giving an unreliable indication of emergence. This was not a problem for FT chicks as there were no visiting parents, and fewer emerging chicks to disturb gates. Although the method has limitations, using burrow gates is simple and of no financial cost, and is therefore a good way to estimate the activity of chicks, particularly at the transfer site where there is little disturbance from other birds.

### ***5.7.0 Conclusions and recommendations***

This study shows the suitability of current translocation feeding protocols for WFSP. The sardine based diet with vitamin supplements and additional water ratios, 10 Fg PVC apparatus, and feeding methods used in this study all successfully supported the fledging of FT chicks at a rate of 90%. WFSP chicks showed no direct signs of ill health after being artificially fed for up to 20 days. However, with the known health risks associated with translocation, the timing of a transfer should ensure that chicks are not artificially provisioned for periods longer than necessary (Priddle & Carlile, 2001). It is recommended that extreme caution is taken when handling and transporting WFSP. Extra care should be taken to keep chicks, and particularly their legs, in natural positions, considering the relatively long tarsi of the species and the potential leverage on connecting joints and bones.

Although the 10 Fg x 70 mm PVC crop tubes were suitable for feeding artificial diets to this species, it is recommended that a 12 Fg rubber tube would be better suited for WFSP. Additionally, having a closed tube with an opening near the distal end for food delivery would be preferred. Attempts to locate a tube of this description should be made for future feeding projects, however in its absence the described adaptations to the 10 Fg PVC tube are adequate and a suitable substitute.

For northern WFSP, future artificial feeding programmes should use the feeding regimes outlined here to reach target fledge weights of  $49.5 \pm 0.7$  g. By selecting chicks which are naturally at or above target fledge weights, the described feeding regime is suitable to maintain weight and/or make controlled reductions. Trialling artificial provisioning of chicks in their natal sites prior to transfer to identify and exclude chicks which do not feed well is also recommended.

Future translocation practices should be conservative and base transfers on a seven day emergence period to ensure selected chicks have not begun imprinting on their natal site. Consequently, the selection of prospective chicks should look to identify individuals estimated to be 10 days away from fledging; thus allowing for a 3 night acclimatisation period. A 10 day target from transfer to fledging would prevent chicks being collected too early and reduce the likelihood of health risks from sustained artificial provisioning. However, when there is uncertainty regarding the age of potential transfer chicks caution should opt for younger birds, considering the observed tolerance of WFSP toward artificial

feeding. Selecting younger chicks will also increase the likelihood of transfer site imprinting and therefore the successful outcome of the translocation.

It is recommended that unblocking of burrows is not done for at least three nights after transfer to allow for acclimatisation (Gummer, *et al.* 2012), and should not be done before wing lengths reach approximately 135 mm. In addition to wing length, the behavioural and plumage indicators (described in Chapter 3, section 3.5.8) should be incorporated and individual chicks considered on a case-by-case basis. Future projects should investigate the likelihood of chicks leaving unfamiliar burrows prematurely and the associated risks of doing so. Post-fledging monitoring is extremely important in future translocations for assessing post-fledging survival, identifying return rates, the timing of return and the location, whether to transfer site or the original natal site.



**Plate 5.2 A white-faced storm petrel chick approximately one week old.**

# Chapter Six

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CONCLUSION

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### 6.1.0 Summary

#### 6.1.1 The importance of seabirds and translocation

Considered drivers of terrestrial systems and ecological engineers, Procellariiformes, in particular burrow nesting species, manipulate terrestrial ecology through the transfer and incorporation of marine nutrients and physical site disturbances to colonies (Bancroft, Roberts, & Garkaklis, 2005; Crooks, 2002; Durrett & Mulder, 2011; Hawke & Newman, 2007; Markwell & Daugherty, 2002; Roberts, Duncan, & Wilson, 2007). Translocation, as a tool for ecological restoration, is an important component of worldwide conservation work for the management of ecosystems and threatened species (Jones & Kress, 2012; Taylor, 2000). Due to the role of Procellariiformes within ecosystems as keystone species and the current number of threatened taxa impacted by marine and terrestrial anthropogenic threats, translocation of seabirds is crucial and offers opportunities to repatriate colonies and establish new breeding populations (Jones & Kress, 2012).

#### 6.1.2 Research outline

New Zealand is a critical and important region for seabirds; with high abundance, endemism and numbers of threatened species (Croxall *et al.*, 2012; Taylor, 2000a). Historically, petrels comprised the greatest component of New Zealand avifauna with numbers in the hundreds of millions (Worthy & Holdaway, 2002). Current petrel breeding colonies are, for the most part, restricted to predator free off shore islands. The translocation of petrels has thus far been restricted to medium sized species, particularly *Pterodroma* and *Puffinus* species. By investigating the expansion of translocation opportunities to smaller Procellariiformes, such as storm petrels, the management options for species and populations as well as ecological restoration prospects may be broadened.

This research has used an endemic species, the white-faced storm petrel (WFSP), *Pelagodroma marina maoriana*, to investigate the prospect of extending translocation protocols to smaller Procellariiform taxa. The aim of this study was to collect baseline breeding data from a northern population of WFSP and compare chick growth and meal provisioning to southern populations described by Richdale (1943a, 1943b, 1944 & 1965), thus supporting the development of translocation protocols for this species. Specifically the objectives were to 1) describe the breeding chronology of northern WFSP populations, measure chick growth and development as well as fledging behaviours to identify chick

morphometric targets for translocation practices; 2) to quantify WFSP chick provisioning by monitoring feeding frequency and measuring meal size as well as describing diet and adult foraging through stable isotope analysis; and 3) undertake a trial translocation, describing the efficacy of current artificial feeding techniques and a pre-described diet on a small number of chicks to identify suitable regimes for future translocation initiatives.

### **6.2.0 Summary of main findings**

#### *6.2.1 Chick growth*

In this study WFSP chicks on Burgess Island hatched on average in early December, but with considerable variation (22 November – 21 December). Chick rearing was longer than expected, averaging  $68 \pm 0.9$  days and chicks fledged mid-February (mean  $12 \pm 1.2$ ). Breeding chronology was approximately one month earlier than southern WFSP populations on Whero Island. The overall breeding success from egg to fledging was 48% (no comparable figure is available for the Whero Island population).

Handling chicks daily had no apparent effect on growth and development. Wing length is the best predictor of chick age and wings grew at an approximately linear rate, consistent with other Procellariiform studies. Northern chicks fledged with wing lengths smaller than southern chicks and at 93.6% of full adult size. Tarsus growth was sigmoidal and reached an asymptote of approximately 42.2 mm at 13 days before fledging. Bill length was likely affected by difficulties in obtaining accurate readings at the time of measurement and therefore, the data may not be accurate in representing typical bill length growth patterns. However average culmen length measurements at fledging were similar to that of Whero Island chicks ( $16.7 \pm 0.1$  mm and 16.1 mm, respectively). Chicks fledged at weights 14% heavier than the average recorded for adult WFSP; departing the nest at  $49.5 \pm 0.7$  g.

The rate of down loss was variable between chicks and the development of white facial plumage was found to be a better indication of proximity to the time of chick fledging. Emergence periods ranged between two and six nights prior to departing the nest, averaging  $3.1 \pm 1.4$  nights.

#### *6.2.2 Provisioning and diet*

Chicks were provisioned on average 54.4% of nights during the 19–44 days prior to fledging. The probability of a chick being fed on any given night was 0.55. These feeding rates are lower than expected for storm petrels, for example, Whero Island chicks were provisioned on 71.7% of nights (Richdale, 1965). In addition northern WFSP chicks frequently fasted for longer durations (four to seven days). No changes in pattern were observed in provisioning rates as chicks approached fledging.

The average quantity of food delivered to chicks overnight (by one or both parents) was  $7.8 \pm 0.3$  g and ranged between 1–28 g. Similarly southern population chicks were provisioned with meals ranging from 0–25 g with a mean quantity of  $6.4 \pm 0.3$  g. The most frequent food masses delivered to chicks on Burgess Island ranged between 1–6 g, these meals representing 56% of all feeds.

Stable isotope analysis of adult blood samples suggest WFSP are foraging on crustacean and small fish species. There was a positive shift in  $\delta^{15}\text{N}$  from December to January/February suggesting a seasonal change and increase in fish-based food items compared to crustaceans/plankton. Feathers grown over the same time period as blood samples were distinctly different in  $\delta^{15}\text{N}$ , thus indicating variation of fractionation between tissue types and/or the metabolism between adults and chicks. Carbon signatures did not vary over time, most likely indicating foraging locations remained consistent.

### 6.2.3 Feeding trial

A 10 Fg x 70 mm PVC crop tube was successfully used to provision chicks artificially over an average  $15.6 \pm 0.9$  days until fledging. Daily meals of sardine puree (see Appendix V) at volumes of 7–8 ml per day sustained chicks at a constant weight. Adjustments of 1–2 ml were sufficient to increase or decrease overnight weight accordingly to achieve target fledging morphology.

Feeding trial chicks fledged with the same wing lengths as naturally reared chicks, however without previously known target fledging weights, feeding trial birds left at significantly lighter masses. The emergence time of feeding trial chicks was on average  $3.5 \pm 0.6$  nights ranging between three and seven nights.

### 6.3.0 Conclusion

The duration of chick rearing was longer than expected and the frequency at which chicks were provisioned was also lower. The overnight quantity of food delivered was similar to that of southern populations; however, the low feeding rates and extended fasting periods suggest that adults may be foraging at distances further from the colony than expected. Evidence of this may be drawn from isotope values of  $\delta^{13}\text{C}$  in adult blood. Results are not consistent with values reported in the expected foraging range within the Hauraki Gulf by Rayner, *et al.* (2010). Deviations from southern rates of feeding may be due to environmental influences such as La Niña-Southern Oscillation (LSNO). Low to medium LNSO conditions occurred during this breeding season and are thought to have also influenced chick provisioning and growth in grey-faced petrels (*Pterodroma leucoptera gouldi*) also breeding in the Hauraki Gulf (Dunn, 2012). The shift in trophic levels indicated by  $\delta^{15}\text{N}$  within WFSP diet may also be a response to LNSO. Stable isotopes of  $\delta^{15}\text{N}$  in adult blood indicate there is an increase in fish-based food items during hatching and chick rearing. Alternatively, this shift may be a change in foraging targets, where adult WFSP seek specific food types to provision chicks.

Overall, the difference in breeding chronology between northern and southern WFSP populations was one month, with the northern population breeding earlier. Other differences in breeding biology include fledging morphology, with northern birds departing at slightly lighter weights and smaller wing lengths. The variation may be explained by cooler southern climates and Bergman's rule. Regardless of the reason, this difference must be accounted for when planning translocations; incorporating latitudinal effects into the timing of transfer and target morphological traits. Chick weight was variable, reflecting infrequent provisioning rates and fasting periods, however it is still a relevant indicator of chick condition. Wing length remains a good predictor of chick age. Together wing length and weight measurements provide an indication of suitable target morphology for identifying chicks of translocatable age.

The trial translocation and hand feeding experiment showed the potential for current translocation practices to be extrapolated to storm petrels. The importance of having target fledging morphology is highlighted, particularly as feeding trial chicks fledged with weights significantly lighter than *in-situ* reared birds. Fledging condition is important for post fledging survival (Priddle & Carlile, 2001). The sardine and Mazuri tablet diet (Appendix V) and practiced feeding regimes appear to be suitable for WFSP. Minor adjustments to

selecting chicks and meal sizes are expected to be adequate in reaching the newly identified target weights.

Chicks appeared to habituate to handling quickly, thus consistent with the non-significant differences in development found between control and handled chicks. Adult disturbance during incubation is likely to be a more important consideration (Blackmer, Ackerman, & Nevitt, 2004; Marks & Leasure, 1992). However, when checking nests for hatching, gently feeling under the adults for the presence of an egg or chick did not appear to disturb the incubating adult. This method should be favoured over handling and removing the parent bird.

#### 6.4.0 Inferences for translocation management

- Chicks selected for translocation should be transferred at approximately 10 days before fledging (DBF). This was calculated using the maximum recorded duration of chick emergence (seven days), as a precautionary measure to minimise the chance of chicks having already imprinted on their natal site, as well as a three-day acclimatisation period as recommended by Gummer, *et al.* (2012).
- At 9–11 DBF wing lengths for Burgess Island chicks ranged between 113–138 mm with a mean length of  $124.6 \pm 1.6$  mm. As a guide, suitable target lengths may fit within upper and lower quartile values 129.7–120.9 mm. For southern populations, target wing lengths will be slightly larger.
- It is recommended that only chicks which exceed target fledging weights are selected for translocation. That way weight needs only to be maintained and weight loss controlled through artificial feeding; a method more suitable than attempting to increase chick weight post transfer. At 10 DBF Burgess Island chicks were a mean weight of  $54.5 \pm 0.9$  g and chicks fledged at  $49.5 \pm 0.7$  g. The stresses of transfer causes chicks to lose weight (Gummer, *et al.*, 2012) and although it cannot be confirmed how much will be lost by WFSP, minimum target collection weights for northern WFSP chicks should be in excess of 55 g, ideally 60 g.
- A 12 Fg x 70 mm rubber crop tube with a closed end and an opening for delivery as far down the distal end as possible is suitable for WFSP chicks. However in the absence of such equipment the adjusted 10 Fg PVC tube used in this trial is an adequate substitute. The diet was suitable and should not be changed without professional advice.
- Initial introductory feeds at the natal nest site to identify chicks which accept artificial feeding is highly recommended. The feeding regime outlined in Chapter 5 and the additional documentation CD should be used to guide future translocations. No adverse effects were observed and it is therefore assumed that the small and diluted introductory meals successfully accustomed chicks to the diet change. Daily meals of 7–8 ml were adequate to maintain chick weight with adjustments of 1–2 ml to promote overnight weight loss or gain to obtain target fledging morphology.

- The natural oils in researcher's hands and frequent handling of chicks daily may affect the waterproofing of chick plumage. It is recommended that future work involving regular monitoring and handling of chicks (of any Procellariiform species) investigates the extent of any effect. This may be imperative to post fledging survival, having dire consequences for translocation outcomes and chick welfare.

### 6.5.0 Recommendations and future research

- The WFSP colony on Burgess Island is a concentration of burrows in soft and friable soil. There is a high likelihood of damage to burrows and chicks when searching for suitable transfer birds. Safely accessing burrows beyond rock margins would be difficult, particularly without a pre-egg laying trip to establish safe paths. Any future work in this colony should be done with minimal personnel to avoid excessive disturbance and early trips to identify safe access within the site. Ideally field staff surveying burrows and extracting chicks would have relatively small hands to mitigate damage to burrow tunnels. In addition, due to the protracted range of hatching (approximately one month) and the limited number of accessible burrows, locating enough chicks of the same age to transfer may be difficult. More than one collection trip is likely to be required.
- For recipient sites of future WFSP translocations, predator control is of paramount importance. Populations of a *P. marina* subspecies breeding in the north Atlantic are heavily affected by mouse predation (Campos & Granadeiro, 1999). The presence of small rodents such as mice must therefore be assessed carefully before planning new WFSP colonies.
- Translocations should incorporate a hypothetico-deductive method and experimental and modelling approaches (Seddon, Armstrong, & Maloney, 2007). Setting up quantifiable goals, ecological purpose and understanding limitations (Seddon, *et al.*, 2007) through planning and post-monitoring evaluation processes are important to optimise learning outcomes for the development of translocation protocols. It is imperative that future WFSP translocations have monitoring to detect post fledging survival through return rates, the age at which birds return and their location; transfer or natal site.
- Seasonal variation in the breeding biology of WFSP may be supported with additional comparisons of varying climatic conditions. Better understanding how petrel populations of the Hauraki Gulf are affected by El Niño and La Niña-Southern Oscillations, may be beneficial for future translocations in terms of planning inter-seasonal timing and identifying chicks in optimal condition.

- WFSP showed a distinctive shift in dietary trophic levels during chick hatching and rearing. This may have been in response to changes in prey availability from general seasonal trends or climatic fluctuations. Investigating the patterns of WFSP diet in future breeding seasons would indicate whether the shift was in response to irregular environmental variation or a reflection of WFSP foraging behaviour. Comparing blood samples from WFSP adults and their corresponding chicks may help to identify if adults are selecting different prey types for their own consumption compared with what is provisioned to offspring. Ideally controlled studies would be set up measuring stable isotope turn over in adults and chicks on a known diet to identify variation in fractionation.
- Until technology updates with smaller and affordable equipment to track WFSP at sea, stable isotope analysis is the best indicator of spatial foraging distribution. Prey sampling within the Hauraki Gulf and continental shelf areas, particularly around the Coromandel, northern Auckland, south west of the Chatham Islands and off the southern east coast of the North Island, may help to better identify where northern breeding WFSP are foraging.

### 6.6.0 Closing remarks

Expanding the scope of Procellariiform translocations to storm petrels, specifically WFSP is a viable management option. This research has shown that WFSP can be successfully provisioned using current translocation methods. Artificial feeding is also sustainable for this species over the 10 days; of burrow emergence prior to fledging.

The ecological qualities of petrels in pre-human New Zealand are largely unknown, as is their marvellous biology, modern environmental relevance and plight of survival against anthropogenic expansion. Out of sight out of mind? Given that seabirds are no longer an obvious component of New Zealand ecology to the recreational bush goer, the foresight of Aldo Leopold is insightful when considering modern attempts at ecological restoration:

*“The last word in ignorance is the man who says of an animal or plant, “What good is it?” If the land mechanism as a whole is good, then every part is good, whether we understand it or not. If the biota, in the course of aeons, has built something we like but do not understand, then who but a fool would discard seemingly useless parts? To keep every cog and wheel is the first precaution of intelligent tinkering.”*

— Aldo Leopold, Round River: From the Journals of Aldo Leopold



**Plate 6.1 Adult white-faced storm petrels returning to provision chicks on Burgess Island.  
Photograph by Abe Borker.**

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*Appendices*

*Appendix I State of focal burrows after chick fledging*



Both the tunnel and chamber roof of this burrow have been completely eroded by researcher disturbance.



The pink stick is one of the burrow gate palisades indicating the entrance of the burrow. The butted end of the ruler shows the eroded tunnel and chamber roof.



Erosion of a tunnel entrance is observable with the butt end of the ruler in the nest chamber.



The butt end ruler shows the tunnel entrance of this burrow. Damage to the tunnel and chamber (on left) is severe.

## Appendix II E13 necropsy report

## Institute of Veterinary, Animal and Biomedical Sciences

## PATHOLOGY REPORT

Submitter's Ref.:	Date Sent: 07/03/2012	Accession No.: 47242
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TO: Megan Young  
Ecology and Conservation Group, Massey University  
Albany  
Auckland

Species: Avian-WL (1)	Sex: Male	Age: 57 Days	Breed: White-faced Storm
ID: E13	At Risk:	Affected:	Dead: 1
Owner: Department of Conservation	Prev. Accn.:	Type: Post Mortem	

## HISTORY

Chick part of a breeding biology study. Was being handled daily for weight and measuring from 14/01/2012 (DOB 16/12/2011). Was handled on the morning of 11/02/2012 and found dead 2 metres from his burrow the same evening. The chick was found outside his burrow on the rocks (abnormal for chick to be outside the burrow during the day).

## GROSS FINDINGS

The bird weighed 60grams and was in good body condition, with plentiful subcutaneous and intracoelomic fat reserves and good pectoral muscle mass. The body was in a moderate-to advanced state of autolysis; maggots has destroyed much of the oral cavity, brain and cervical tissues.

The proventriculus and gizzard contained approximately 20, roughly spherical, translucent-opaque hard objects (5-7mm in diameter), probably fish lenses and/or cartilagenous portions of vertebrate. The proventricular mucosa was diffusely and moderately reddened.

No other abnormalities were noted on gross post mortem.

## PROVISIONAL DIAGNOSIS

Cause of death unknown

## COMMENTS

There was nothing obvious at gross post mortem that might point toward a cause of death. The chick was in good body condition and there was no evidence of trauma.

Approximately 20 roughly spherical, translucent-opaque hard objects (5-7mm in diameter) were found in the proventriculus/gizzard. These are most probably fish lenses and/or cartilagenous portions of vertebrate rather than anything man-made.

Histopathology will be performed on several tissues but advanced decomposition may limit its usefulness.

File Nos.:

Students:

Date:

Pathologist: S A Hunter

Copy to:

*Appendix III Provisioning of individual chicks*

**Table x. Feeding frequencies and proportion of nights fed and unfed for individual white-faced storm petrel chicks are shown. No. nights is the total duration that chicks were monitored for. Total values are described using median and standard deviation values.**

Chick ID	No. Nights	% Prop. Fed (n)	% Prop. Unfed (n)	Unknown
BS1	38	69 (24)	31 (11)	3
C21	44	32 (11)	68 (23)	10
C22	36	55 (18)	45 (15)	3
C26	29	52 (14)	48 (13)	2
C28	40	33 (12)	67 (24)	4
C29	39	57 (21)	43 (16)	2
C31	36	49 (17)	51 (18)	1
D19	33	55 (18)	45 (15)	2
D21	37	53 (18)	47 (16)	3
F1	29	55 (16)	45 (13)	0
F6	35	67 (22)	33 (11)	2
G15	29	52 (15)	48 (14)	0
G57	41	59 (22)	41 (15)	4
Lala5	43	47 (18)	53 (20)	5
C12	24	50 (12)	50 (12)	0
C17	32	63 (20)	37 (12)	0
C18	23	43 (10)	57 (13)	0
T1	28	68 (19)	32 (9)	0

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C25	41	79 (26)	21 (7)	8
D6	31	55 (17)	45 (14)	0
E14	20	50 (10)	50 (10)	0
E19	19	47 (9)	53 (10)	0
E26	28	50 (14)	50 (14)	2
E4	20	55 (11)	45 (9)	0
E7	21	62 (13)	38 (8)	0
F11	34	55 (17)	45 (14)	3
F7	30	57 (17)	43 (13)	0
<b>Overall</b>	<b>32 ± 7.4</b>	<b>55 (range: 32-79)</b>	<b>45 (range: 21-68)</b>	<b>2.00 ± 2.6</b>

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## Appendix IV Feeding trial chick morphology at the time of collection

Burrow number	Band	Natal burrow	Transfer weight (g)	Transfer wing (mm)	Fledge weight (g)	Fledge wing (mm)	First emergence date (pm)	Fledge date (pm)	Emergence period (nights)	Days artificially fed
1	C92593	A4B	43	104	42.5	151	29/01/2012	1/02/2012	3	20
3	C92594	C5	42	112	42	154	27/01/2012	29/01/2012	3	17
4	C92597	C16	53	92	47.5	143.5	26/01/2012	30/01/2012	4	18
5	C92598	E9	70	93	47	153	31/01/2012	2/02/2012	2	21
6	C92595	G19	40	104	40	147	25/01/2012	27/01/2012	2	16
7	C92600	BS8	45	105	41.5	146	28/01/2012	31/01/2012	3	18
8	C92319	C19	35	98	40.5	151	28/01/2012	1/02/2012	4	19
9	C92596	D22	43	122	43	153	23/01/2012	24/01/2012	1	13
10	C92599	D11	65	97	44.5	155	24/01/2012	31/01/2012	7	19
Range			35 - 70	92 - 122	40 - 47.5	143.5 - 155			1 - 7	12 - 20
Average			48.44	103.00	43.17	150.39			3.22	16.89

*Appendix V Methods of food preparation and feeding were based (Gummer & Bishop, 2004).*

Grey-faced petrel chicks on Matakoho-Limestone I. (Dec 2004)  
(H. Gummer and C. Bishop)

Appendix 1

Grey-faced petrel chick food preparation

- 1) Wash hands (with antibacterial soap).
- 2) Boil water for up to four 1 litre thermos flasks (for food-warming baths).
- 3) Make up 8 litres of Johnson's antibacterial solution in small bucket (1 tablet / 2 litres cold water, so 4 tablets/ 8 litres water).
- 4) Clean sink/bench area and wipe over with cloth soaked in antibacterial solution.
- 5) Heat water for cleaning after food preparation (at least two kettles).

Equipment for food preparation:

Blenders / knife / spatula / cold (boiled for >3 mins) water / sardines / food containers

Recipe:

1 (106 g) tin sardines in soya oil (include oil contents)

50 ml cold (boiled > 3 mins) water

*Contents of sardine cans: sardines (89%), soya oil (10%), salt (<1%)*

NB Process a mix of only 3 tins of fish (with 150 ml water) in each batch to prevent strain on blender.

- 6) Place 150 ml cold (boiled > 3 mins) water in blender with 1 tin of fish and liquidize. Add half of second tin (chop fish up in tin) and blend. Add remainder of second tin and blend. Repeat with third tin until smooth. Pour mixture into container - maximum 2 batches (6 tins) per container.
- 7) Place food containers in chilly bin with at least two chilly blocks. Food must be kept cool at the colony site (to prevent contamination) and then warmed just before use.  
NB Keep one container out of chilly bin for first round of feeding.
- 8) Wash out sardine tins in hot, soapy water for disposal.
- 9) Wipe down blender bases with cloth (soaked in antibacterial solution).
- 10) Remove blender blades and rinse out blender etc. before doing two thorough washes (with the petrel washing-up brush) in very hot, very soapy water to remove all oil. Rinse off detergent before placing equipment in bucket of antibacterial solution for the day (minimum soak period 2 hrs).

Grey-faced petrel chicks on Matakoho-Limestone I. (Dec 2004)  
(H. Gummer and C. Bishop)

### Appendix 3

#### Grey-faced petrel chick feeding, measuring and monitoring

A 3-person team is ideal for a full feeding day: one feeder (concentrating on feeding, food temperature, hygiene) and two handlers.

- 1) Wash hands (with antibacterial soap).
- 2) Fill two rinse baths with boiled (>3 mins) water.  
Fill jar with chlorhexidine solution and stabilise (to prevent tipping over with syringes/tubes resting in jar)
- 3) Assemble syringes and crop tubes (hand-tight) and lubricate plunger with smear of castor oil.
- 4) Place first food container in small chilly bin in 1 litre of hot water to warm up.  
Use clean spatula to stir regularly (even temperature).  
Test temperature on wrist: mixture should be *just* warm (cold mix may be rejected by chick; hot mix may damage chick's internal tissues).
- 5) Complete rounds of all occupied burrows to record fence status (emergence behaviour) and check on welfare of all birds before commencing feeds.  
Check nest for signs of regurgitation and that faeces are present and normal (dark brown gritty faeces with white fluidy urates, usually seen on chamber walls).  
NB Don't bother erecting fences at this stage (see 6 below).
- 6) Search all pipes for any missing chicks (two chicks can be found in one burrow) by feeling inside entire length of every pipe with fence recorded as down. Two people can feel inside pipe from each end, or use long soft stick to feel from entrance end. Fences can be restored at this stage, or at the end of all chick processing.
- 7) Process chicks in the following order:  
Extract from burrow (replace lid to keep chamber cool and dry)  
Weigh (to obtain pre-feed or base weight)  
Wing length (right wing) if wing measuring day  
Any other handling (e.g. screening, physical examination)  
Feed (record amount delivered)  
Return to burrow (face chick to back of chamber opposite pipe).  
  
NB No post-feed weight is required as long as it is established that 100 ml of food is 100 g in weight.
- 8) Weigh birds over a surface (to prevent injury if fall from scales). Replace weigh bags as soon as soiled. Keep birds in bags (to keep calm) for wing measuring, removing right wing to measure – straightened and flattened to record maximum wing cord.

Grey-faced petrel chicks on Matakoho-Limestone I. (Dec 2004)  
(H. Gummer and C. Bishop)

- 9) For feeding, load syringe full to an excess of 50 ml, ensuring all air bubbles are removed. The excess allows for up to 10 g to be left in the bottom of the syringe after delivery of 50 g to the chick, important for the sterilising process. Wipe the crop tube with a clean tissue to remove residue food.
- 10) During feeding, the handler holds the chick firmly on a surface with crop (breast area) unrestricted while the feeder inserts the crop tube to the back and side of the throat (to keep airway clear), stretching the head and neck up at all times. Food is delivered in 50 g batches (up to 30 seconds delivery time) which allows chick to rest in between loads. Food delivery stops at the pre-determined amount, or earlier if signs of food coming back up throat. Chick is rested briefly, then carried immediately back to the burrow (not in bag) held in an upright position to prevent any regurgitation incidences.
- 11) After feeding, wipe the crop tube with a tissue and place tube upright in jar of chlorhexidine for a minimum of 2 mins sterilising time. After sterilisation, remove syringe/tube and eject remaining food (<10 g) in syringe – this is important to remove any disinfecting solution that may have soaked into the food in the tube. Rinse the outside (entire length) of tube through two rinse baths. The syringe/tube is now ready to draw up more fresh food (there should be no air bubbles present).
- 12) Keep monitoring food temperature regularly and stir with spatula before drawing up food (the thick part of the mix can settle). Remove from water bath if too warm. Towards the end of each batch, get the next batch out to warm up using a new flask of hot water (takes at least 15 mins). Thoroughly clean spatula before using in the next mix.
- 13) On a full feeding day, the syringe barrels need to be rinsed out and disinfected (fill them with chlorhexidine for minimum 2 mins) and rinse baths replaced at least once during the day (twice if very hot weather). Thoroughly rinse syringes with clean (boiled) water before use again.
- 14) After all feeding is complete, check all fences at burrow entrances are restored. Three thin straight sticks are sufficient, lightly placed in the soil at the entrance so as not to barricade the chicks in!

*Appendix VI Adjustments to food preparation specific to this research (Mitchell, C., pers. comm.)*

1. Wash hands in antibacterial soap and wipe down the prep bench with a Miltons soaked cloth.
2. Blend up food for day – usually the mix was 1 can sardines to 50ml sterilized water plus 1/3 Mazuri tablet (used watery mix for first few feeds)
3. Since we were only doing a few small birds which were close by, we didn't have to worry about cooling down and then reheating the food, but we did need to keep it warm
4. Take food and gear to site, used a hottie and chilly bag to maintain food at right temp (test on inside wrist as for baby bottle)
5. Use 2 syringes to feed, one disinfecting while the other is used. Each syringe has 70mm 10 Fg PVC catheter attached. Syringe removed from disinfectant, excess food ejected from syringe, tube wiped and then rinsed once in each of two boiled water baths (this is done in the same order each time so that the second bath is cleanest).
6. Food drawn up into syringe, tube wiped with tissue, tube passed and chick fed leaving approx 1 ml in syringe.
7. Tube wiped with tissue and replaced in chlorhexidine disinfectant (1:9 dilution).

*Appendix VII. Food preparation clean-up and hygiene*

Grey-faced petrel chicks on Matakoho-Limestone I. (Dec 2004)  
(H. Gummer and C. Bishop)

Appendix 4

Grey-faced petrel chick post-feeding clean-up

- 1) Heat water for cleaning (at least two kettles).
- 2) Wash hands, then remove food preparation equipment (blender jugs etc.) from antibacterial solution that have been soaking over the day in the small bucket. Rinse equipment under cold tap and air dry.
- 3) Pour the antibacterial solution from the bucket into the large chilly bin (ready for soaking the days equipment after washing).
- 4) Discard surplus sardine mixture in the sea (to prevent oiling up drains).
- 5) Rinse all equipment under hot tap to remove bulk of mixture before doing two thorough washes (with petrel washing-up brush) in very hot, very soapy water to remove all oil. Pass hot, soapy water through tube and syringe, then remove tube and plunger for more thorough washing (put dish-wash liquid in syringe barrel and use petrel bottle brush to remove oil residue).
- 6) Rinse off detergent before placing in chilly bin of antibacterial solution (minimum soak period 2 hrs). After sterilising, rinse equipment under cold tap and air dry. Discard the antibacterial solution (recommended to change this every 24 hours); fresh solution is made on the next feeding day.
- 7) Shake out weigh bags and soak in Napisan overnight. Weigh bags from the previous weighing day will need to be rinsed several times and dried.
- 8) Boil water (>3 mins), enough to fill the boiled water container full ready for the next feeding day and to set aside (in a clean/sterilised food container) for use in food preparation on the next feeding day.

## Appendix VIII Research permits

Page 1 of 7



Department of Conservation  
*Te Papa Atawhai*

## High Impact, Research and Collection Permit

National Permit Number: AK-31769-FAU

Her Majesty the Queen, acting by and through the Minister of Conservation (the Grantor) GRANTS to Massey University (the Permit Holder) a Permit under Section 53 of the Wildlife Act 1953 and Sections 49, 57 and 59A of the Reserves Act 1977 subject to the details and conditions listed in Schedule One and Two.

Attach original application form to the approve permit.

### Schedule One

(1) Permit Holder and field assistants involved

Megan Young – the work will be conducted as part of a larger seabird research programme on the Mokohinau Islands with other members of an experienced research team present on the island under separate permits.

(2) Approved activity (including approved quantities) and reasons for undertaking the research

To describe the breeding biology of northern New Zealand white-faced storm petrels (*Pelagodroma marina macriona*) and produce guidelines aiding future initiatives to translocate this species as follows:

1. Quantify chick growth rates with regular measuring and monitoring of fledging behaviour
2. Assess chick provisioning by investigating:
  - a. Adult visitation and chick meal size through daily weighing of chicks and by trialling automated telemetry to record arrival and departure times of parents.
  - b. Meal composition will be analysed using stable isotope analysis of blood samples and the collection of opportunistic stomach samples to identify prey and examination of macronutrient composition.
3. Describe burrow characteristics and density and investigate any correlations with breeding success.

Assessments may also provide an insight into population estimates for the Island.

(3) Approved research /collection methods

Refer to the research methodology included in the research outline attached to this permit.

In summary, 80 study burrows will be established on Burgess Island as follows: 50 for chick development and provisioning studies, 20 for an automated telemetry trial to investigate parental visitation and 30 control burrows. In addition to the 80 proposed study burrows a control group of burrows will be established where adults are not disturbed and chicks are not handled to assess the impacts of the research on the birds. Burrow access will be achieved by the construction of a concealable hole above the nest chamber. This hole allows less stressful (quick) nest monitoring and easy extraction of the chick for measuring therefore reducing stress and preventing damage to the main burrow entrance. Modifications would be sealed using a flat rock or ply wood. Study burrows would be constructed during September before egg-laying.

Training on appropriate bird handling skills will be undertaken with G. Taylor (DoC Banding Office, Wellington) prior to research commencing. Initial site set up will be supervised by the experienced supervisors involved in the project.

(4) Approved Site(s)

Burgess Island Scenic Reserve - Mokohinau (Pokohinu) Islands

(5) **Approved Date(s)**

1 September 2011 to 28 February 2012

**Schedule Two**

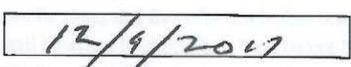
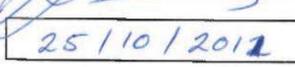
1. The Permittee shall pay the Concession Fee (GST inclusive) of \$Nil, together with the application processing fee deposit in advance to the Grantor in the manner directed by the Grantor.
2. The Permittee shall contact the local Area Manager prior to undertaking the activity in the area, in particular to ascertain any "no-go" areas, which may include areas of concern to tangata whenua. Permission to cross private land shall be obtained from the landowner prior to the conduct of this activity.
3. This Permit does not confer on the Permittee any interest in the Site, nor does it derogate in any way from the rights of the public to use and enjoy the whole or any part of the Site.
4. The Permittee shall indemnify the Grantor against all claims by any person in respect of any injury, loss or damage (including fire damage) caused by or arising out of any act or omission of the Applicant, its servants, agents, contractors, clients or invitees, or otherwise caused as a consequence of its use of the Site or as a result of the conduct of the concession activity.
5. The Permittee shall conduct the activity in a safe and reliable manner and shall comply with all statutes, bylaws and regulations, and all notices and requisitions of any competent authority relating to the conduct of the collecting activity.
  - (a) The Permittee shall prepare a contingency plan for dealing with any mishap that may occur during the operation of collecting activities under this permit, including the recovery of sick or injured persons.
  - (b) The Permittee acknowledges that the Grantor accepts no responsibility for the safety of the Permittee.
6. The Permittee shall not erect or bring onto the Site(s) (or any other land administered by the Grantor) any structure, install any facility, or alter the Site(s) in any way without the prior written consent of the Grantor.
7. The Permittee shall not, unless authorised in writing by the Grantor, interfere with, remove, damage, or endanger the natural features, animals, plants or historic resources in any area administered by the Grantor, or bring any plants or animals to the Landing Site(s), or deposit debris, rubbish, or other dangerous or unsightly matter, or contaminate any body of water. The Applicant shall ensure that its clients and invitees do not carry out any acts prohibited under this clause.
8. The Permittee shall not transfer, sublet, assign or otherwise dispose of the interest granted by this Concession.
9. The Grantor may terminate this Concession if the Permittee breaches any of the terms of this document or if the activity causes any unforeseen or unacceptable effects to the Grantor.
10. The Permittee shall comply with all reasonable notices and directions of the Grantor concerning the activities conducted by the Applicant on land administered by the Grantor. While conducting this activity, the Permittee shall carry this permit with them at all times.
11. Use of aircraft in support of the Concession Activity is subject to separate approval. Vehicles shall only be operated on formed roads.
12. The Permittee shall take all waste and rubbish out of the Site and dispose of it in an environmentally sound manner away from public conservation lands. The Permittee must adhere to the Environmental and Water Care Code while conducting the activity, attached hereto.
13. Samples are to be collected away from tracks, huts, picnic areas or areas of high public use and as far as practicable, out of sight of the public. Wherever practicable, the Permittee shall use access routes to the collection areas that avoid damage to natural features.
14. The Permittee shall not collect samples from biologically sensitive areas, or in such quantities that the taking would unduly deplete the population or damage any other ecological associations.

15. All material collected shall remain the property of the Crown. The Permittee shall comply with any reasonable request from the Grantor or tangata whenua for access to any of the collected samples. Any surplus material is to be stored and the Department of Conservation is to be consulted on ultimate disposal of such material.
16. The Permittee shall not donate, sell or otherwise transfer to any third party any material, including any genetic material, or any material propagated or cloned from such material, collected under this permit, or any information obtained as a result of research done on such material or undertake any other activity with the sample not expressly approved herein; without the written permission of the Grantor in consultation with tangata whenua. Notwithstanding the preceding constraint, the Permittee may publish the results of such research results arising from the collection of the plants.
17. No material collected pursuant to this permit may be used for commercial purposes or patenting of plant varieties or registration of intellectual property rights on any derivatives.
18. Any taxon, which is new to science, shall have holotype specimens and a voucher specimen lodged with a registered New Zealand herbarium, recognised national invertebrate collection or equivalent appropriate collection. The Permittee shall notify forthwith the Grantor and local tangata whenua of any such finds.
19. Where obligations bind more than one person, those obligations shall bind those persons jointly and separately.
20. If requested, the Permittee shall keep the Grantor and tangata whenua informed on the progress of this research. Upon completion of the research, the Permittee shall forward a copy of the research findings, reports and publications to the Grantor's office from where this permit was issued. The Permittee acknowledges that the Grantor may provide copies of these findings to tangata whenua.
21. The Permittee shall comply with the activity provisions on the attached schedule at all times.

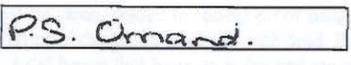
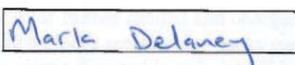
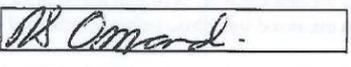
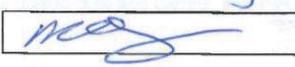
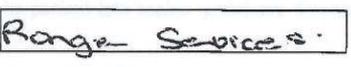
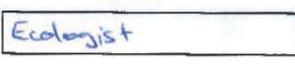
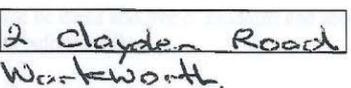
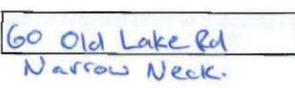
**22. Special Conditions**

1. The Area Manager of the Warkworth Great Barrier Island Area Office is to be notified prior to the research commencing.
2. In addition to the 80 proposed study burrows a control group of burrows shall be established where adults are not disturbed and chicks are not handled to assess the impacts of the research on the birds.
3. Blood sampling shall be from the brachia vein only.
4. Transmitters must be 3% or less of the body weight of the each bird that carries a transmitter.
5. Evidence shall be provided that tail mounts for transmitters are appropriate for storm petrels prior to their use otherwise transmitters must be attached to the upper back feathers between the wings.
6. Petrel tracking activity approved under this permit may only be carried out if prior approval is obtained from the Department of Conservation Animal Ethics Committee for use of proposed tracking devices.
7. A protocol for managing risk and damage to bird burrows, and selecting study nests must be developed in conjunction with Graeme Taylor prior to the research being undertaken, and shall be supplied on request.
8. Access to the Mokohinau Islands is closed during the Oi harvest season (2nd Saturday of November – 7th December each year).
9. The Permit Holder shall comply with the Island Biosecurity Standards for Concession Holders Travelling to DOC managed islands in the Hauraki Gulf included at the back of this permit.
10. All birds must be processed as quickly as possible and then released on site.
11. The Department of Conservation must be informed if any birds are injured during the research. Any birds accidentally killed during the research must be handed into the Department of Conservation and labelled with full details.
12. All research material left on the island must be removed at the end of each study.

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| 13. The Permit Holder(s) must be clearly identifiable off-track.  |
| 14. The Permittee must not impact on any other absolutely protected wildlife, or other research or management activities at a site.   |
| 15. All samples collected are only to be held at Massey University (Albany).  |
| 16. A copy of the research findings and/or any publications produced as a result of the research approved under this permit should be forwarded within 1 year of research completion to the Area Manager for Warkworth Great Barrier Island Area Office and to Ngati Rehua. |

SIGNED by  SIGNED by   
 Dated  Dated   
 Tim Brandenburg, Warkworth Great Barrier Island Area Manager AS APPLICANT

ACTING UNDER DELEGATED AUTHORITY FROM THE MINISTER OF CONSERVATION, whichever is appropriate]  
 ("The Grantor")

In the presence of  In the presence of   
 Witness Signature  Witness Signature   
 Occupation  Occupation   
 Address  Address 

Our ref: AK-29062-FAU

21 December, 2011

Megan Young  
Ecology and Conservation Group  
Institute of Natural Resources  
Massey University  
Albany Campus  
North Shore

Dear Megan,

**Re: Research Permit Variation**

I am writing to inform you that your request to vary the permit for "Describing the breeding biology of northern New Zealand white-faced storm petrels and produce guidelines aiding future initiatives to translocate the species" has been granted. The research permit (AK-31769-FAU) that was issued to you has been amended as follows:

Additional activities are added to section 2 of Schedule One as follows:

1. The sending of blood and feather samples for stable isotope analysis to Berkeley University in the USA.
2. A small-scale feeding trial to identify the appropriate apparatus for feeding white faced storm petrels and to understand the best feeding regimes to mimic natural fledging weights.

Special Condition 15 of Schedule Two is deleted and replaced with the following:

Feather and blood samples may be sent to Berkeley University in the USA for stable isotope analysis provided these samples are destroyed by incineration on site after the analysis is completed and an export permit is obtained. All other samples collected shall only be held at Massey University (Albany).

All the terms and conditions of the original permit AK-29062-FAU are still valid and must be adhered to for the duration of your permit.

Please contact Darcy Liddell on 3074848 if you have any questions.

Yours sincerely,



Tim Brandenburg  
Warkworth Great Barrier Island Area Manager

**Auckland Conservancy**  
Private Bag 68 908, Newton, Auckland 1145, New Zealand  
Telephone 09-307 9279, Fax 09-377 2919