The breeding biology of northern white-faced storm petrels (*Pelagodroma marina maoriana*) and results of an in-situ chick translocation

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Abstract As ecosystem engineers, petrels are integral to ecological restoration schemes seeking to restore land sea nutrient pathways. Yet the current ranges of many petrel species are vastly reduced due to marine and terrestrial threats. Chick translocation is a demonstrated management tool for establishing seabird populations but is dependent on detailed knowledge of species breeding biology. We studied the breeding biology of white-faced storm petrel (*Pelagadroma marina maoriana*) on Burgess Island, Hauraki Gulf, northern New Zealand, and undertook an onsite chick translocation to investigate the efficacy of current petrel translocation practices for this relatively small species. During our study, breeding extended from August 2011 to February 2012 with hatching occurring on 6 December ± 1.2 days, a chick rearing period of 68.1 ± 0.9 days and fledging on 12 February ± 1.2 days. There was no desertion period by provisioning adults and burrow emergence began 2–6 nights before fledging. Chick growth was typical of Procellariiformes with chick mass (mean = 66.2 ± 1.7 g) peaking at 12.2 ± 1.7 days before fledging. There was no age-related change in the nightly probability of provisioning (0.54) or meal mass (mean = 7.8 ± 0.3 g). Translocated chicks fed a sardine puree diet for 11–20 days before fledging had significantly lighter fledging weights than a control group of adult provisioned chicks, but did not differ in wing length or the duration of burrow emergence before fledging. Our data suggest that translocations of white-faced storm petrel using supplementary feeding of chicks may be possible using slightly modified current feeding practices and could provide an option for expanding populations of endangered storm petrels.

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Keywords storm petrel; chick growth; Mokohinau Islands; provisioning; translocations

INTRODUCTION
Following the removal of invasive predators, seabirds are recognised for the unique role they can play in the ecological restoration of habitats via their importation of marine nutrients and the modification of soils through burrowing (Mulder *et al.* 2011). Accordingly, these terrestrial-marine ecological linkages are now being re-established through the translocation of seabirds to establish new or previously lost populations (Miskelly *et al.* 2009; Jones 2010). Methods for the translocation of burrowing seabirds typically rely on moving known age chicks prior to their emergence from natal burrows, before chicks imprint on their natal colony

(Carlile *et al.* 2003). Such techniques are dependent on an understanding of chick provisioning rates, and chick growth rates up to fledging, to enable artificial feeding of translocated chicks that closely mimics provisioning by breeding adults.

The white-faced storm petrel (*Pelagodroma marina maoriana*, hereafter WFSP) is an abundant small procellariform found in temperate and tropical waters of the Atlantic, Indian and Pacific Oceans (Marchant & Higgins 1990). In New Zealand, WFSP breed in dense colonies on islands free of introduced predators (Ismar *et al.* 2014) and are one of the country's most abundant seabirds with over 1 million breeding pairs (Robertson & Bell 1984). Despite this abundance, knowledge of WFSP breeding biology in New Zealand is restricted to a single study site from a southern New Zealand population (Richdale 1965). Given that the breeding behaviour of seabirds can differ significantly across latitudinal gradients (Rayner *et al.* 2008; Rayner *et al.* 2010) it is likely that breeding parameters for WFSP differ in the north of the country.

This study aimed to provide detailed information on the breeding biology of WFSP in northern New Zealand, with the goal of informing translocation of this species as a model for other endangered storm petrel taxa. In particular, we sought to: 1) describe the species' breeding chronology; 2) quantify chick provisioning: feeding frequency and meal size; 3) quantify chick growth; 4) describe emergence behaviour during fledging; and 5) undertake an *in-situ* chick translocation, a first for any storm petrel species, to trial the utility of current translocation methods on storm petrels.

MATERIALS AND METHODS
Study site and study establishment
This study was conducted on Burgess (Pokohinu) Island (35° 54′ S, 175° 07′ E, 56 ha), of the Mokohinau Islands group, in the Hauraki Gulf north of Auckland, New Zealand (Fig. 1). Burgess Island was extensively modified by fire and livestock following the establishment of a lighthouse in 1883. The removal of staff and livestock following the automation of the lighthouse in 1981, and eradication of the Pacific rat (*Rattus exulans*) by the New Zealand Department of Conservation 1990, has led to a recovery of the island's avifauna, particularly seabirds including WFSP (Ismar *et al.* 2014).

During the course of this study, three trips were made to Burgess Island during the spring and summer of 2011/2012. The first trip was undertaken during 11-20 September 2011 to establish study burrows. This trip coincided with the WFSP burrow prospecting phase and timing was based on prior field observations and available literature (Marchant & Higgins 1990). A study site, with high densities of WFSP, was selected on the northern headland of Burgess Island (Ismar *et al.* 2014). Burrows were identified by their small size and marked using labelled tags at the tunnel entrance and a coloured stake with reflective tape. Where suitable, access lids were installed above the nesting chamber to minimise stress for chicks being removed and damage to burrows.

Between 7–21 December 2011, study burrows were checked for occupancy and eggs candled to determine fertility. Subsequently, all eggs were 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 was stopped. Burgess Island is closed to researchers in October and November for traditional harvest of grey-faced petrel (oi, *Pterodroma macroptera gouldi*) and as a result we were unable to establish laying dates for this population. Laying dates were subsequently back-calculated from hatching dates based on an incubation period of 50 days from southern WFSP (Richdale 1965). The timing of our December trip also meant a proportion of chicks hatched prior to our arrival and we subsequently back-calculated hatching dates for these chicks by subtracting the mean chick rearing duration for known age development group chicks (see below) from their fledging dates.

We occupied the study site to study chick rearing between 9 January and 27 February 2012. On arrival study chicks were assigned to one of three groups: 1) development group: chicks of known age (hatched during our 7–21 December trip) for whom mass was recorded daily and morphological measurements taken every four days to quantify chick provisioning and growth; 2) translocation group: chicks of unknown age (hatched prior to commencement of our 7–21 December trip) selected for a trial in-situ translocation (see below); 3) control group: chicks of unknown age (hatched prior to commencement of our 7–21 December trip) measured on three to four occasions throughout the study as a control against handling impacts in the development group.

Chick growth and provisioning
To quantify provisioning and growth rates, chicks from the development group were weighed daily between 0800 h and 1230 h using 100 g or 300 g Pesola scales to the nearest 0.5 g and had wing chord measurements taken (flattened and straightened) using a ruler to ±0.5 mm every four days. Measuring frequency was increased to every second day once wing length reached 120 mm as chicks approached fledging (Gangloff & Wilson 2004).
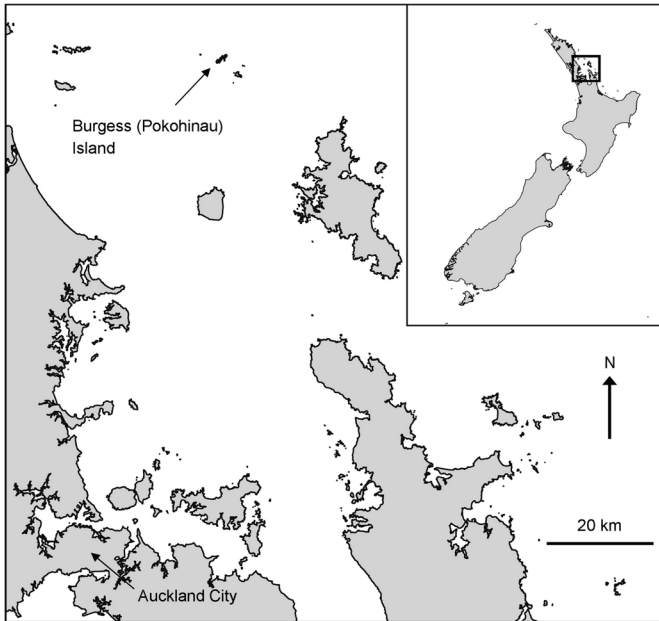
Fig. 1. Location map of Burgess Island, Hauraki Gulf.

Control group chicks were first weighed and measured in December, a second time in early January when individuals were allocated into study groups, and lastly when each chick was predicted to be approximately 1 week away from fledging based upon growth rate data for known age chicks in the development group. Some chicks were less developed than expected when handled for the third time and were measured again if they had not fledged within 1 week. After the third measurement, control chicks were checked daily for fledging by gently sliding a hand into the burrow to briefly determine the presence/absence of the chick.

Provisioning frequency and mass for development chicks were calculated using changes in overnight chick weight (Rayner *et al.* 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 before weighing). 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 unfed. A feeding event was identified when a chick increased in mass or when the overnight mass change was less than the 50% weight loss value. Individual meal sizes were calculated as the sum of the overnight change in mass (g) plus the 50% weight loss value. The probability of nightly provisioning by both parents was calculated using

the methodology of Klomp & Furness (1992). In brief 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. Unfed chicks were identified using burrow palisades (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 methodology.

Fledging behaviour
Monitoring of emergence and fledging was conducted using Radio Frequency Identification Readers (RFID) and Passive Inductive Transponder (PIT tags) (Taylor *et al.* 2012). PIT tags were attached to 10 chicks when their wing lengths reached approximately 110 mm ~2 weeks from fledging. Tags were attached to one of the central tail feathers with bandage tape and fixed using superglue. Circular copper wire aerials (approximately 10 cm in diameter) were set up around burrow entrances and connected to an RFID reader and a 12 volt battery. Readers were programmed to read for tags every 0.1 seconds between dusk and dawn. This set up allowed for accurate time stamp data to be collected on the exit and entry behaviour of chicks without observer disturbance (Taylor *et al.*

2012). Fledging was assumed to be successful when chicks were considered developed enough to have fledged and their burrows were empty for at least two consecutive days (Priddel & Carlile 2009).

In-situ translocation

To replicate a translocation scenario, 10 WFSP chicks were removed from their natal burrows and hand reared until fledging in wooden artificial burrows constructed of 15 mm thick plywood with a 70 mm diameter plastic drainage tube as a burrow tunnel. Artificial burrows, placed in shaded areas under vegetation to prevent overheating, were approximately 800 m from the source colony.

Using a working system incorporating concurrent data from development group chicks, feeding regimes, meal sizes, target fledging weights were approximated. Without known hatching dates for these chicks, the timing of the feeding trial (considered approximately 2-3 weeks away from fledging) was based on expected fledging times modelled from wing measurements of known development group chicks. 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 prior to transfer to artificial burrows. Subsequently, 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). Strict hygiene protocols were observed when preparing and delivering food. Equipment was sterilised before food preparation and between individual feeds with chlorhexidine. Food was prepared daily immediately prior to chick feeding, and unused food purees discarded. Chicks were fed by inserting food puree directly into the proventriculus using a 70 mm crop tube. Feeding frequency and meal sizes were established based on observed data from development group chicks.

To prevent chicks leaving their burrows before they were ready, burrow tunnels were blocked temporarily. Blockades removed when chick wing length reached 110 mm. All chicks were banded before blockades were removed. Stick palisades were erected at the burrow 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.

Statistical Analysis

Spearman rank correlations were used to test for a relationship between provisioning probability and meal mass versus days before fledging. Kruskal-Wallis tests were used to examine differences in overnight provisioning quantities between development chicks, and Mann-Whitney U tests for differences in fledging weight, wing length and emergence period duration between development and translocation groups. A linear model was fitted to wing growth data for each chick with DBF (days before fledging) as a predictor that was first transformed by subtraction from 70 (average fledging age). Group growth rates were determined, accounting for individual variation, by using the mean of pooled individual data (Grim 2006) and development and control growth rates compared using Mann-Whitney U tests. All analyses were conducted using JMP® 11.2.0 (© 2015 SAS Institute) at a level of significance of $\alpha = 0.05$.

RESULTS

During our December field study we located 58 unhatched eggs and 50 hatched chicks. Of unhatched eggs, 41.2% ($n = 21$) hatched successfully and 72.0% of chicks (52 of 71 chicks in total) survived to fledging at the end of the study, or 42.7% of all known active burrows (found containing an egg or chick). In January, we allocated 16 and 13 chicks randomly into the development and control study groups. Of these 93.8% ($n = 15$) and 100% survived to fledging respectively.

Breeding timetable

Adults first return from migration in September and egg laying peaked on approximately 17 October. Hatch date for development group chicks was 13 December ±1.1 days ($n = 16$, range = 7–21 December) with an extrapolated population hatch date, based on the mean chick-rearing duration of known-age chicks (68 days), of 6 December ± 1.2 days ($n = 44$, range = 22 November – 21 December). The chick rearing period was 68.1 ± 0.9 days ($n = 15$, range = 62–73 days) with chicks fledging on 12 February ± 1.2 days ($n = 43$, range = 30 January – 2 March).

Provisioning and growth

Development chicks were monitored from early January for 32 ± 2.5 days (range = 19 –44) prior to fledging. The probability of nightly provisioning for these chicks was 0.55 (range = 0.16–0.73) with no significant correlation between provisioning probability and DBF (Fig. 2). Chicks were recorded as being unfed on 45% of nights (371 out of 817 nights total, $P = 0.33$) and we thus calculated the probability of both parents feeding their chick on a given night as 0.10 ($n = 89$ occasions). The mean overnight weight loss of unfed development chicks was -4.6 ± 0.3 g (median = 4.6 ± 1.5 g, $n = 27$, range = 2.3–8.0 g).

There was no significant correlation between provisioning mass and days before fledging (Fig. 3). The mean overnight meal mass provided to chicks was 7.8 ± 0.3 g (range = 1.0–28 g), although provisioning mass frequency was dominated (56%
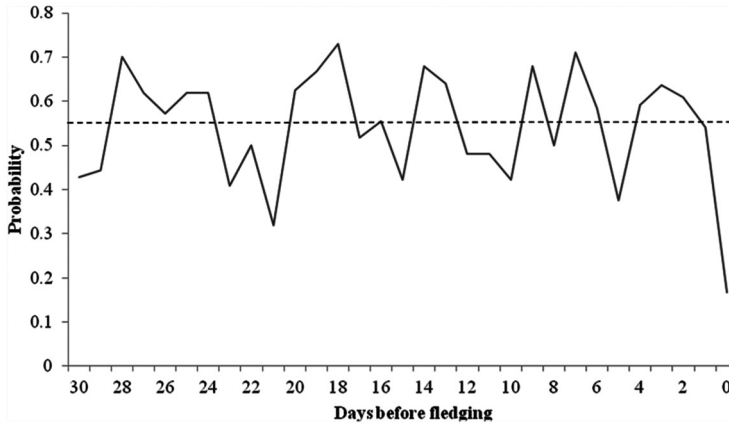
Fig. 2. Nightly provisioning probability for white-faced storm petrel chicks from 30 days before fledging. Mean value shown by dashed line.
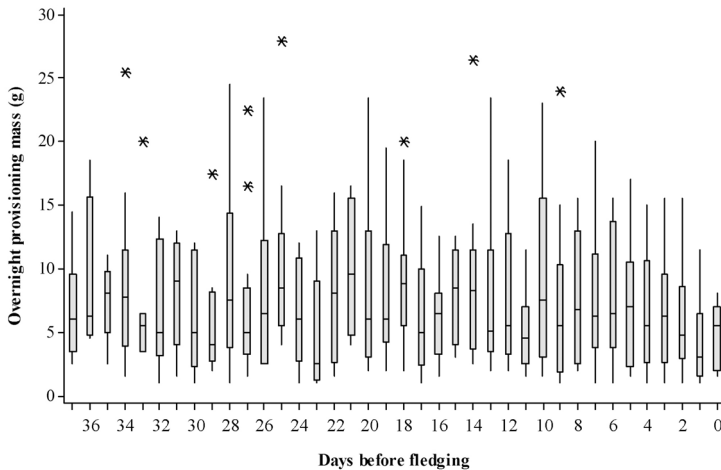

Fig. 3. Overnight meal mass provisioned to white-faced storm petrel chicks relative to days before fledging. Medians and 95% confidence intervals are shown. Asterisks are outliers representing provisioning by both adults on the same night.

of 403 events) by meals between 1-6 g (Fig. 4). From all detected provisioning events, 89 were calculated to be provided by 2 parents and ranged between 11.5–28 g. One chick fed a 28 g meal had a single-night weight increase of 54%.

The mean mass of development chicks peaked at 66.2 ± 1.7 g (153% of mean adult weight of 43.4 g) at 12.2 ± 1.7 days prior to fledging and then declined to a fledging mass of 49.5 ± 0.7 g (114% of mean adult weight) (Fig. 5). Wing chord growth of development chicks was linear, increasing by 2.9 mm/day with chicks fledging with wing lengths of 148.8 ± 0.8 mm (93.6% of mean adult wing length of 158.6 mm) (Fig. 6). There was no significant difference in wing chord growth between the development and control chick groups (both 2.9 mm/day).

Fledging behaviour

Chicks with PIT tags first emerged from their burrow 3.1 ± 1.4 nights (*n* = 10, range = 2–6 nights) prior to fledging and subsequently emerged nightly after that. Chicks began emerging from their burrows soon after dark (2000 h and 2100 h) and would be active (near the burrow entrance, entering or exiting) for an average of 6 h 30 min (range = 1 min – 10 h 39 min). Eight out of 10 chicks left their burrow for the last time between 2049 h and 2324 h, the other 2 chicks did not return to their burrows after 0326 h and 0343 h respectively. Some chicks were opportunistically 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

Fig. 4. Frequency distribution of overnight meal masses for white-faced storm petrel chicks (*n* = 16). Light grey area represents larger meals considered to have been provided by two parents (refer to Methods).
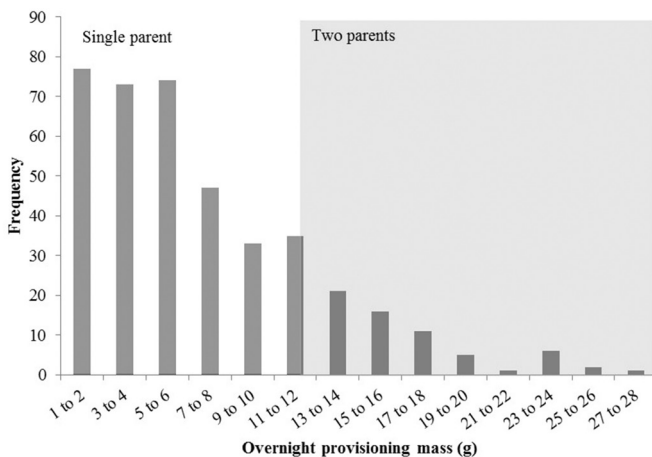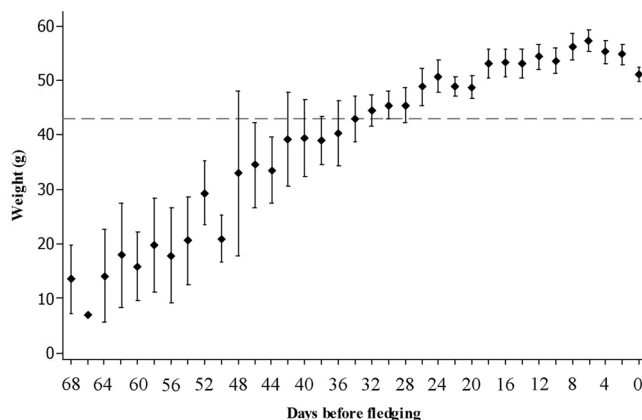

Fig. 5. Weight of white-faced storm petrel chicks (*n* = 16) during the chick rearing period relative to days before fledging. The dashed horizontal line shows mean weight of adult white-faced storm petrels, measured across the breeding season.

burrow near its own (0.5 m away) and remaining inside for periods up to 10 minutes. The chick was observed moving between its own burrow and this vacant one several times.

Translocation

The 10 translocation chicks were given 1 or 2 3.5g introductory meals at their natal burrow to ensure that they would accept the artificial diet and subsequently translocated and artificially provisioned for 16.6 ± 0.9 days (range = 11-20 days). A total of 150 collective meals and a gross mass of 1028 ml of puree were provisioned to these chicks. Chicks were provided an average daily meal mass of 7.5 ± 0.1 ml (range = 3.5–9 ml) with a daily adjustment of 1–2 ml greater or less allocated on an individual basis to promote weight gain or loss and achieve target fledge weight.

There was a significant difference in the mean fledging weights between translocation (*mean* = 43.2 ± 0.9 g, range = 40–47 g) and development groups (*mean* = 49.5 ± 0.7 g, range = 42–55 g) (Mann-Whitney U = 51, p = <0.001; Fig. 7) that were not significantly different at the beginning of the trial. There was no significant difference in fledging wing lengths (translocation: *mean* = 150.4 ± 1.3 mm, range = 143.5–155 mm; development: *mean* = 148.8 ± 0.8 mm, range = 143.2–159.5 mm; Fig. 8) or emergence times (translocation: *mean* = 3.5 ± 0.6 nights before fledging, range = 3–7 nights; development: *mean* = 3.1 ± 1.4 nights prior to fledging, range = 2–6 nights) between groups.
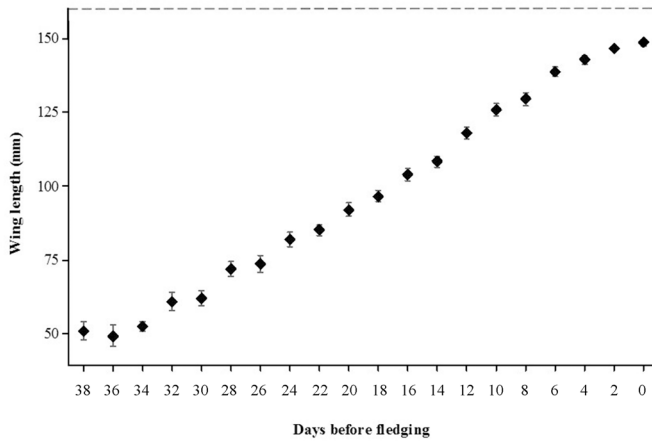
Fig. 6. Wing length of white-faced storm petrel chicks (*n* = 16) during the chick rearing period relative to days before fledging. The dashed horizontal line shows mean wing length of adult white-faced storm petrels, measured across the breeding season.
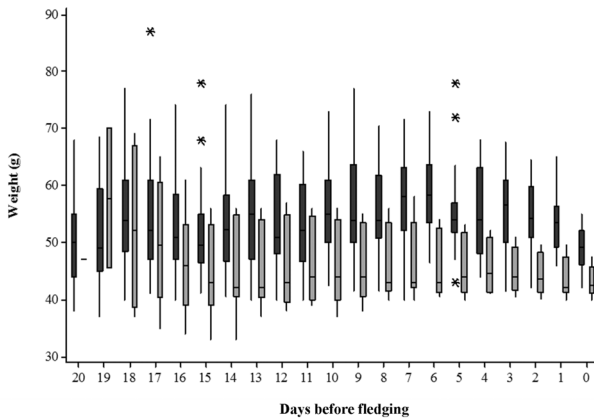

Fig. 7. Weights of white-faced storm petrel chicks for the translocation group (light grey bars, *n* = 9) and development group (dark grey bars, *n* = 16) during translocation experiment. Box plots show median values, error bars (95% confidence intervals) and asterisks represent outliers.

Nine of the 10 chicks included in the translocation study are presumed to have fledged successfully based on their wing length and absence from burrows for two days with no sign of predation. One chick was found with a fractured tibia and 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 occurred during handling. One translocated chick was recaptured near its natal burrow, 800 m from the translocation site, in October 2016 (when nearly 5 years old).

DISCUSSION
This study provides a detailed account of the breeding biology of WFSP from hatching to fledging in northern New Zealand. Overall breeding success (48%; egg to fledging) was consistent with other small burrowing petrels (40–50%; Warham 1990), however our initial handling of incubating birds during study establishment resulted in some nest abandonment reflected in the low hatching success of study nests (41%). Extreme sensitivity to handling, during incubation in particular, is common in storm petrels (Marks & Shawne 1992; Blackmer *et al.* 2004) and our subsequent method of feeling gently under incubating birds for an egg proved a suitable alternative from which birds did not abandon the nest. Only 1 chick died from both developmental and control groups; it was found several metres from its burrow and a veterinary post mortem was unable to establish the cause of death.

Breeding timetable
The September to February breeding cycle of WFSP from Burgess Island is typical of summer breeding

Fig. 8. Wing lengths of white-faced storm petrel chicks for the translocation group (light grey bars, n = 10) and development group (dark grey bars, n = 16) during the translocation experiment. Box plots show median values, error bars (95% confidence intervals) and asterisks represent outliers.
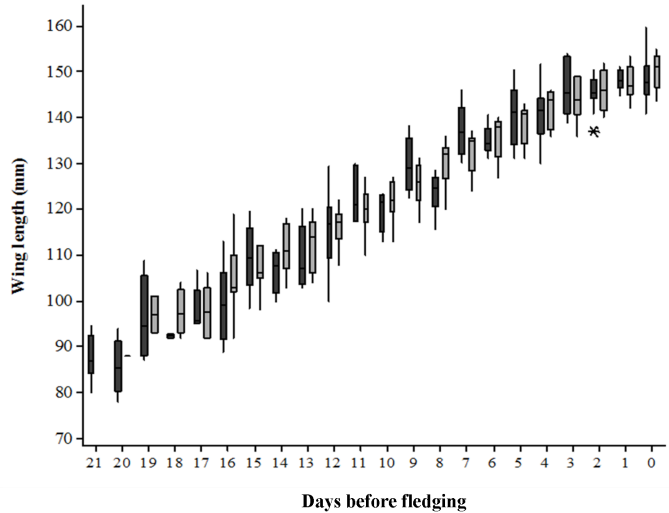
seabirds in the Hauraki Gulf and consistent with the brief description provided by Cunningham & Moors (1985) from Maria Island (located 88 km southwest within the Hauraki Gulf). However, comparison with WFSP breeding on Whero Island in southern New Zealand, suggests a 1 month asynchrony between northern and southern populations. Hatching on Burgess Island occurred in early December compared to early January on Whero, with peak fledging in February compared to March on Whero Island (Richdale 1965). The range of hatching and fledging dates were however similar (hatching approximately 30 days Burgess and 29-40 days Whero; fledging approximately 30 days Burgess and approximately 31 days Whero). Breeding asynchrony is well documented within Procellariform species, particularly those occupying geographically disparate breeding colonies (Friesen *et al.* 2007; Tavecchia *et al.* 2008). Similar to WFSP, northern New Zealand Cook's petrel (*Pterodroma cookii* also breed one month earlier than their southern counterparts (Imber *et al.* 2003) as a result of regional differences in breeding season oceanic productivity and population-specific migratory routes to differing parts of the Pacific Ocean (Rayner *et al.* 2008, Rayner *et al.* 2011). WFSP migrate to the eastern Pacific Ocean during non-breeding but it is unknown if they have population specific migratory destinations (Imber 1984). However, spatial and temporal differences in near colony oceanic productivity likely play a key role in the divergent population-specific breeding timetables of New Zealand WFSP.

Provisioning

The provisioning probability observed for WFSP chicks (0.54) was lower than southern WFSP reported by Richdale (1965) (0.71) supporting the hypothesis that regional difference in oceanography can have large effects on the ability of adults to provision chicks. Fork-tailed storm petrels (*Oceanodroma furcata*) breeding in the Aleutian Islands also showed colony-specific differences in feeding rates (Boersma *et al.* 1980; Simons 1981). In petrels, chicks are frequently fed more often during the first half of chick development, with the rates declining towards fledging (Warham 1990; Gangloff & Wilson 2004). Though, in our study provisioning probability remained consistent in contrast to southern WFSP, where the probability of being provisioned declined markedly in the two weeks prior to fledging (Richdale 1965). It should be noted that in our study we quantified provisioning rates after chicks were approximately three weeks old; potentially biasing our provisioning probability statistic in comparison with studies over the entire chick rearing period.

Storm petrels typically deliver meal sizes of 15–20% of their body weight (Croxall *et al.* 1988; Brooke 2004) and meals received in our study were consistent with these observations (average meal sizes 8 g = 19% of mean adult body mass of 43.4 g) and not dissimilar to southern WFSP (18%) (Richdale 1943b; Richdale 1965). The capacity for chicks to handle extremely large meals was also observed, with 1 chick recording a 54% overnight weight increase, presumably after being provisioned by

both parents. Chicks seemed resilient to long fasting periods of up to 7 days, which were not observed by Richdale (1943a), who noted that southern chicks went without provisioning for 1-2 days and only occasionally 3-5 days. However consistent with the observations of Richdale (*ibid.*), chicks appeared to enter a torpor like state when unfed for extended periods.

Chick growth and fledging

The growth of wing and tarsal lengths for WFSP chicks were consistent with expected patterns of general procellariiform development (Gangloff & Wilson 2004; Cuthbert 2005; Sagar *et al.* 2015); wing growth increased linearly, making it a good predictor of chick age, though chicks did not attain full adult wing length before fledging as observed in southern WFSP chicks (Richdale 1965). As expected, tarsus length also increased linearly, reaching adult length approximately 2 weeks before fledging.

Chick weight is inherently more variable than other morphological traits because stomach contents vary over short time periods (Sagar *et al.* 2015). The weight growth pattern for procellariiform chicks is generally sigmoidal with a peak that drops to adult weight (Warham 1990). In Procellariiformes peak weights, depending on the species, exceed adult mass by 10-70% (Booth *et al.* 2000; Phillips & Hamer 2000; Sagar *et al.* 2015). In our study, peak weights of chicks exceeded adult weights by 40–70%, with chicks reaching on average 153% of mean adult weight (66.2 ± 1.7 g) before losing weight rapidly over the 3 days before fledging. This rapid period of weight loss differed from the study of Underwood & Bunce (2004) who found chicks of *P. m. dulciae* showed a more prolonged drop in peak weight (*mean* = 79.7 ± 0.4 g, 140.5% of adult weight) over a period of a week. The burrow emergence periods for chicks in our study (*mean* = 3.1 ± 1.4 nights, range = 2-6 nights) were longer than observed in southern WFSP, where chicks typically emerge either 1 night before or on the night of fledging (Richdale 1944). However, methodologies may account for this difference. Richdale (1944) used burrow gates of sticks and visual observations to detect chicks leaving burrows, and may have missed those sitting at the tunnel entrance. In our study RFID readers and PIT tags were extremely useful in detecting chicks sitting near or leaving the burrow entrance, presenting an improvement on traditional techniques as reported by Taylor *et al.* (2012).

Translocation trial

Our trial translocation demonstrated the feasibility of translocating storm petrels such as WFSP, which to our knowledge has yet to be conducted under a conservation management scenario. Neither the disturbance in removal from natal burrows, nor artificial provisioning affected the fledging success or wing growth of translocated chicks compared to control group chicks. The trial was completed with low mortality rates; fledging success was high (9/10) and 1 chick was opportunistically recaptured as an adult 4.8 years after the translocation.

The sardine-based diet was sufficient to sustain chick growth and the feeding apparatus used worked well. However, articially-fed chicks fledged at significantly lighter weights than controls. We consider that there are two likely non-exclusive reasons for this discrepancy. First, as data were being collected concurrently on naturally provisioned chicks, we lacked targeted fledging weights for translocated individuals. Our concern was that chicks would not fledge if they were too heavy, and that the resulting extended duration of artificial provisioning would increase the risk of associated health complications such as irritation of the oesophagus from the feeding tube, candidiasis and food regurgitation. Meal sizes were thus calculated to allow chicks to reach a peak weight, with a subsequent weight decline towards fledging at a targeted mass similar to adult weight. In hindsight, data from development chicks indicated that they fledged with considerable fats stores that are not evident in breeding adults. Accordingly, our data on naturally provisioned fledging weights for this species will prove valuable for future translocation initiatives. Second, we targeted mean meal size to be similar to development chicks, but ended up provisioning chicks on a daily basis compared to the average of every second day that was observed for chick in the development group. Variation in fledging weights between groups therefore suggests that the sardine puree diet may not be as nutritious as the chicks' natural diet. This difference in diet energetics is expected, 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 observation 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 in future translocations.

Initially, artificial burrows were blocked to prevent unsettled chicks wandering or leaving prematurely, becoming lost, or attempting to fledge too early. However, it was not clear when blockades should be removed and chicks allowed to emerge from burrows naturally. With translocated grey-faced petrels, chicks were blocked from leaving the burrow for at least 3 days after transfer and until wing lengths reach the known size of emerging chicks (Gummer *et al.* 2012). This allows chicks to settle, adjust to changes in temperature and humidity as well as develop their scent within the chamber. A diving petrel translocation initially blocked chicks

inside transfer burrows for 2 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 3 nights after transfer, with emergence allowed only once wings exceed average lengths of 137.7 ± 2.4 mm ($n = 6$, range = 130.3–146 mm), based on WFSP wing length at 7 DBF (the earliest recorded emergence time). Blockading chicks when they are ready to emerge may cause significant stress; therefore chicks should be closely monitored on an individual basis.

ACKNOWLEDGEMENTS

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