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Original Research Article

Maximising success: Translocation does not negatively impact stress reactivity and development in petrel chicks

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ABSTRACT

The order Procellariiformes, or albatross and petrels, face declining populations and many species hold threatened species status. Translocations of petrel chicks are increasingly recognised as a powerful conservation tool with multiple benefits: restoring species to their former range, restoring lost land-sea ecological linkages and 'spreading the risk' for threatened species. However, translocations are stressful events for chicks. Petrel chicks are able to perceive and respond to stressors from hatching at a level comparable to adults. Consequently, if chronic stress is induced in petrel chicks by translocation, it may result in energy divergence away from growth and condition, with potentially ongoing negative effects throughout the birds' lives. The aim of this research was to define how translocation impacts stress reactivity and development in petrel chicks and to use this information to guide best-practice for petrel translocations.

Mottled petrels (*Pterodroma inexpectata*) are a target for major translocation-restoration programmes across New Zealand. We measured total corticosterone from mottled petrel chicks at regular intervals coinciding with key translocation events from two groups: one that underwent translocation according to current best practice (Translocation group), and a group that remained in the natal colony (Control group). Growth, weight and fledging parameters of the Translocation group were compared against a multi-year source colony average. We found there was no difference in stress reactivity between Translocation and Control chicks, or development between Translocation and chicks at the source colony. Petrel translocation practitioners may proceed in the knowledge that current practices did not induce a state of chronic stress or alter stress reactivity in mottled petrel chicks, and therefore are unlikely to negatively impact post-fledging survival, and their capacity to establish viable colonies. However, we caution that these results may not apply to other petrel species with different life-history strategies to mottled petrels, and encourage testing in a wider range of species.

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1. Introduction

The Procellariiformes order of seabirds, or albatross and petrels, are threatened with rapidly declining populations, predominately the result of human-driven factors (Croxall et al., 2012; Phillips et al., 2016). In particular, burrow-nesting petrels have largely been extirpated from many of their breeding sites due to the presence of introduced mammalian predators and large-scale land-use changes (Phillips et al., 2016). The loss of burrow-nesting petrel colonies not only impacts species at the population level, but it also lowers terrestrial biodiversity and ecosystem complexity due to the role petrels play as ecosystem engineers at their breeding sites (Smith et al., 2011; Orwin et al., 2016). To remedy this, translocations are increasingly recognised as a powerful conservation tool that return petrels to protected sites within their former range, whilst restoring lost land-sea ecological linkages, and spreading the risk for species threatened by localised catastrophe (Miskelly et al., 2009).

Due to the philopatric nature of petrels, translocations should occur before chicks have imprinted on their natal colony (Miskelly et al., 2009; Gummer et al., 2014). The mechanisms by which petrels imprint on their natal colony are not understood, but it appears to occur during the period immediately prior to fledging when chicks emerge from their burrow at night to strengthen their flight muscles and shed down (Warham, 1996). Current best practice states that chicks should be translocated a maximum of several days prior to the youngest age at which they could be expected to emerge, but not so young that a prolonged reliance on artificial food is required to sustain their developmental trajectories, i.e. typically four weeks prior to peak fledging period (Miskelly et al., 2009; Gummer et al., 2014). Thus, the majority of petrel translocations result in chicks being individually housed and provisioned for several weeks until they fledge [e.g., (Miskelly et al. (2009); Binder et al. (2013); Sagar et al. (2015))]. Considerable research has been undertaken to improve the chances of translocation success, including artificial diet and housing modification [e.g., (Bell et al. (2005); Miskelly et al. (2009))]. However, very little is known about how translocation impacts petrel chicks during (pre-translocation monitoring, transport) and after (feeding regimes, handling, novel environment) the event, and whether this affects their lifetime fitness and ability to establish viable colonies.

Petrel chicks are able to perceive and respond to stressors from a young age [e.g., Adams et al. (2005); Quillfeldt et al. (2009)], by activating the hypothalamic-pituitary-adrenal (HPA) axis to trigger production of the glucocorticoid stress hormone corticosterone [CORT (Wingfield and Romero, 2001)]. Whilst short-term elevation of CORT is beneficial to an individual's survival, repeated exposure to a stressor can result in long-term or altered activation of the HPA axis, termed chronic stress [reviewed in Wingfield et al. (1998), Sapolsky et al. (2000b), Wingfield and Romero (2001)]. Therefore, petrel chick translocations, which are sustained over a period of weeks, may induce a state of chronic stress and could result in altered developmental trajectories and stress responsiveness (Dickens et al., 2009, 2010). Chronic stress during early life has the potential to incur life-long negative effects on an individual's performance including condition, reproductive efforts and survival (Sapolsky et al., 2000b), which may translate into reduced effectiveness or failure of translocation programmes. Indeed, 'stress' is often cited as a cause of wild bird translocation failure, though empirical evidence to support this notion, particularly in petrels, is lacking (Dickens et al., 2009, 2010). To address this, we measured the stress response of mottled petrels [kōrure; *Pterodroma inexpectata*; IUCN threat status: near threatened (IUCN, 2016)] that were undergoing translocation.

Mottled petrels are a far-ranging endemic medium-sized gadfly petrel that historically were widespread throughout mainland New Zealand [Fig. 1A (Taylor, 2000; Worthy and Holdaway, 2002)]. Due to predation pressures from introduced mammals and habitat loss, mottled petrels are now mainly found on predator free-offshore islands (Fig. 1), with the breeding stronghold found on Whenua Hou/Codfish Island (Taylor, 2000; Scott et al., 2009). Owing to the widespread historical distribution of mottled petrels and an accessible breeding population on Whenua Hou, they are a target species for conservation programmes across the country, with the aim of restoring mainland breeding colonies of this species to their former range, and as a means of re-establishing lost land-sea linkages to promote ecosystem recovery (Sagar et al., 2015). Typical of many petrel species undergoing translocation, mottled petrels are synchronous, densely colonial breeders that are a burrow-nesting, semi-precocial species with slow growth and an extended chick-rearing period [for more detail see Methods (Miskelly et al., 2009; Sagar et al., 2015)].

Using mottled petrels as a model for other commonly translocated petrel species, the objective of this study was to determine the extent of stress experienced during translocation. The specific aims of this study were: 1) to compare initial and stress response CORT levels in translocated mottled petrel chicks exposed to current best practice translocation protocols with control chicks that remained at the natal colony; and 2) to examine whether translocation activities altered mottled petrel chick growth and fledging condition compared to chicks that remained in the natal colony. We hoped that our research could determine whether there were any potentially detrimental effects of current best practice translocation protocols, as inferred by their stress state, growth and condition, which could alter the capacity of mottled petrel chicks to survive, thrive and establish viable new colonies. With the results of this study, we hoped we could make recommendations for reducing stress and improving the successful conservation management of this, and other at-risk petrel species.

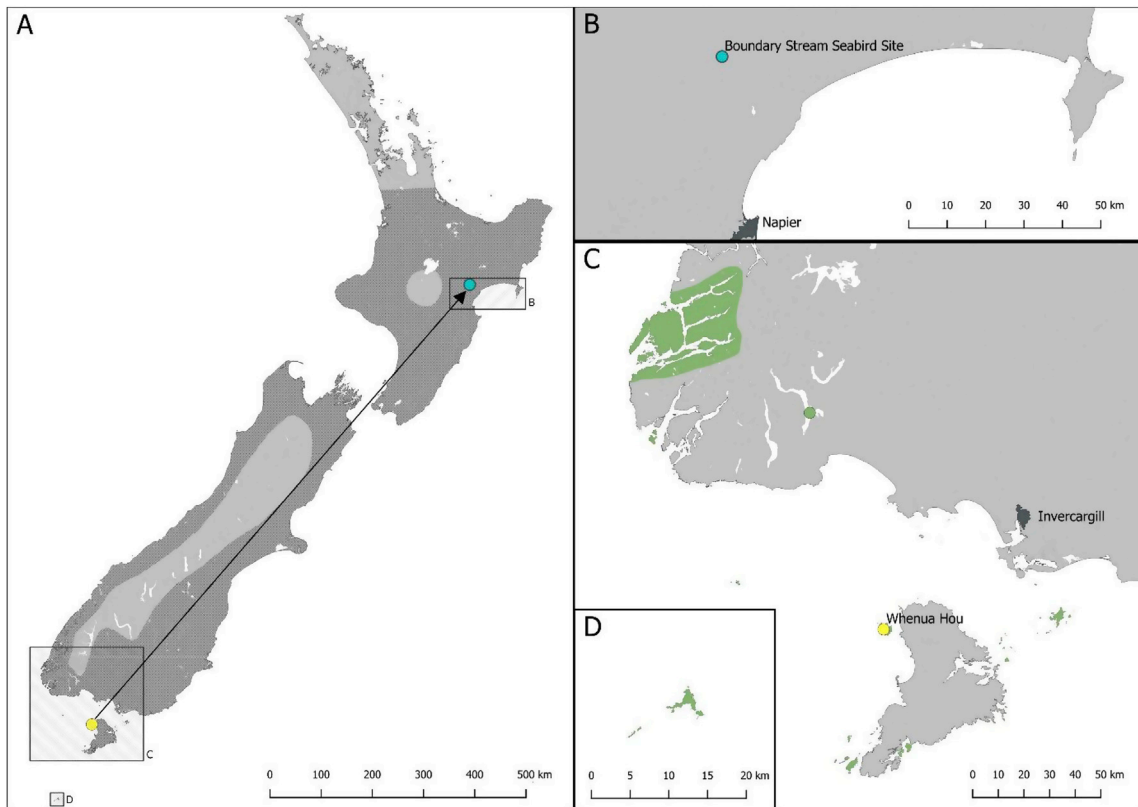


Fig. 1. (A) Historic range of mottled petrel (kōreure; *Pterodroma inexpectata*) in dark grey; (B) translocation site at Maungaharuru/Boundary Stream, north of Napier; (C,D) present day range of mottled petrels indicated by green shading in (C) Fiordland, islands around Rakiura/ Stewart Island and (D) the Snare Islands. The yellow point indicates the source population for translocations at Whenua Hou/Codfish Island and the line running from yellow point to blue point at the translocation site at Maungaharuru/Boundary Stream indicates the distance between the two sites (approx. 1200 km). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2. Methods

2.1. Study species and sites

Typical of burrowing procellariiforms, mottled petrels are synchronous breeders, with one pair occupying a nest chamber, laying a single egg per breeding attempt and exhibiting bi-parental care (Warham et al., 1977). Chicks possess dense down on hatching and are brooded for as little as 2 h, before being fed large meals (average 80 g) by both parents at average interval of every six days throughout the chick-rearing period (R. L. Sagar unpub. data). Mottled petrel growth follows a typical gadfly petrel pattern: chicks gain weight up to a peak far exceeding mean adult weight (up to 220%; R. L. Sagar unpub. data), before rapidly losing weight as they approach fledging. Feather and skeletal growth (in this study characterised by wing chord length) increases in a parabolic manner, before reaching an asymptote as chicks approach fledging (Sagar et al., 2019). Chicks typically fledge at 95–105 days old, following an average emergence period of five days (Sagar et al., 2015). Mottled petrels are considered semi-precocial and are able to mount an adult-level stress response from hatching (Sagar et al., 2019).

This study was undertaken during late mottled petrel chick-rearing, April 2014 and 2017. The source population for translocated chicks was on Whenua Hou/Codfish Island (46°46'22"S, 167°37'6"E; Fig. 1), 3 km west of Rakiura/Stewart Island and the translocation site was located approx. 1200 km north in the Boundary Stream area, 50 km north of Napier, New Zealand (39°5'43"S; 176°48'15"E; Fig. 1). Whenua Hou is a predator-free nature reserve and is the global breeding stronghold of mottled petrels, with an estimated 160 000 + breeding pairs (Scott et al., 2009). The 2.9 ha translocation site at Maungaharuru/Boundary Stream area lies within a predator-proof fence, which lies within a much greater area (800 ha) subjected to continuous predator control (Saunders and Norton, 2001). Burrows at the mottled petrel colony on Whenua Hou were marked with numbered stakes and fitted with a wooden lid that allows access to the nest chamber. At the translocation site chicks were individually housed in numbered plywood artificial burrows (Fig. 2), as described in Gummer et al. (2014).



Fig. 2. Mottled petrel chicks (*Pterodroma inexpectata*) loaded into carry boxes ready for transport (left) and settled in individual nest boxes at the translocation site (right).

2.2. Experimental design and translocation protocol

Burrows at the source colony on Whenua Hou were marked during March (2014 and 2017) if they contained an accessible chick. Due to the synchronous nature of mottled petrel breeding seasons and known development patterns, the window for translocating the highest number of chicks within a suitable age/size range fell early within the second week of April, though the actual date was dictated by logistical and weather constraints.

All chicks ($n = 40$) were handled for the first time when weighed and measured one week before translocation. Chicks were carefully removed from the nest by hand and allowed to settle for up to 1 min to minimise the risk of defensive regurgitation, a typical gadfly petrel response to predators (Warham, 1996). Chicks were then placed in a cotton bag, weighed (± 5 g) and had their wing chord length (flattened, straightened; ± 1 mm) measured (Sagar et al., 2015). If chicks fell within the required wing chord length and weight range for translocation [reviewed in Mitchell (2017)] an initial blood sample was collected (see below). Chicks were left enclosed in a dark coloured cotton bag on the ground next to their burrow and a second stress response blood sample was taken 25 min after chick extraction from the nest.

Following the first weigh, measure and blood sample, chicks were randomly allocated into treatment groups (Table 1): Translocation ($n = 10$ in 2014; $n = 10$ in 2017) and Control ($n = 10$ in 2014; $n = 10$ in 2017). Each group underwent the same subsequent blood sampling regime (Table 1), though the Translocation group underwent translocation activities as detailed below, while the Control group remained in the natal burrow at the source colony. All chicks were re-measured two days prior to translocation day. Chicks that fell within adjusted weight and wing chord length parameters on this day were translocated (Translocation group: $n = 7$ in 2014; $n = 10$ in 2017) or continued in the Control group in their natal burrow ($n = 7$ in 2014;

Table 1

Handling and blood sampling regimes for mottled petrel chicks (*Pterodroma inexpectata*) that were randomly assigned to the Control group (remained in the natal burrow; $n = 7$ in 2014; $n = 10$ in 2017; total $n = 17$) or the Translocation group (underwent translocation from Whenua Hou/Codfish Island to Maungaharuru/Boundary Stream; $n = 7$ in 2014; $n = 10$ in 2017; total $n = 17$) during 2014 and 2017 seasons.

Day	Translocation group activity	Control group activity	Blood sampling schedule (Control & Translocation groups)
-7	First weigh and measure + blood collection	First weigh and measure + blood collection	Initial blood sample < 4 min +25 min 'stress response' sample
-6	Undisturbed in natal burrow	Undisturbed in natal burrow	
-5	Undisturbed in natal burrow	Undisturbed in natal burrow	
-4	Undisturbed in natal burrow	Undisturbed in natal burrow	
-3	Undisturbed in natal burrow	Undisturbed in natal burrow	
-2	Second weigh and measure	Undisturbed in natal burrow	
-1	Undisturbed in natal burrow	Undisturbed in natal burrow	
0	Translocation Day + rehydration + blood collection	Weigh and measure + blood collection	Initial blood sample < 4 min
1	First feed, weigh and measure at translocation site + blood collection	Weigh and measure + blood collection	Initial blood sample < 4 min +25 min 'stress response' sample
2	Undisturbed in nest box	Undisturbed in natal burrow	
3	Undisturbed in nest box	Undisturbed in natal burrow	
4	Feed, weigh, measure	Undisturbed in natal burrow	
5	Undisturbed in nest box	Undisturbed in natal burrow	
6	Undisturbed in nest box	Undisturbed in natal burrow	
7	Feed, weigh, measure + blood collection	Weigh and measure + blood collection	Initial blood sample < 4 min +25 min 'stress response' sample

$n = 10$ in 2017). If chicks did not meet the weight or wing chord length selection criteria, they were returned to the natal burrow and not selected for the translocation programme, or for continuation in this study.

On translocation day chicks were removed from the natal burrow at day-break (approx. 06:30 h) and placed in an individual compartment (two chicks per box; Fig. 2) of a carry-box lined with non-slip mat. Individual nesting material was placed in the box with each chick to help anchor chicks to their nest-box at the translocation site. Once all chicks were collected they were carried up to 700 m along a track to the helicopter pad, where they were loaded into a B3 Type Squirrel Helicopter and flown 20 min to Invercargill Airport (46°24'44"S; 168°18'46"E). Chicks were transferred into a Piper PA31 Navajo plane and flown 5 h north to Napier Airport (39°27'59"S; 176°52'21"E). The aeroplane cabin temperature was held at 14 °C (approx. temperature of natal burrow; R.L. Sagar unpub. data) and boxes were placed in a single layer with gaps between to allow air circulation. Following arrival at Napier Airport, chicks were transferred into a B3 Type Squirrel Helicopter and flown 30 min to the translocation site at Maungaharuru/Boundary Stream. During 2017, the helicopter was unable to land at the translocation site at Maungaharuru/Boundary Stream, and chicks were transferred to a four wheel drive truck and were driven the final 9 km to the site on a gravel road.

On arrival at the translocation site (approx. 17:30 h) all chicks underwent a health assessment and were provided 50 mL rehydration fluid (Compound Sodium Lactate Intravenous Infusion B.P., Baxter Healthcare Pty Ltd, NSW, Australia) via crop tube before being relocated to their individual nest boxes (Fig. 2). The longest time between removing a chick from the natal burrow and placing it into the nest box at the translocation site was 16 h (Mitchell, 2017). Access to the nest-box tunnel was restricted for the first three days to ensure chicks settled and did not wander. The blockade was then removed to allow chicks to emerge *ad libitum* as they progressed towards fledging. Chicks were weighed, had wing chord length measured and were fed the first two days following translocation, then weighed, measured and fed every third day thereafter [Table 1; see (Sagar et al., 2015)]. Chicks were banded during the second or third handling event. Feeding regimes were only adjusted if chick condition or growth did not follow expected trajectories. All chicks fledged within one month of translocation. Translocation group weight and wing chord growth, emergence and fledging parameters were compared against a multi-year (2014–2017; $n = 58$) average of mottled petrel chick weights and wing chord lengths from the source population (R. L. Sagar unpub. data). The chicks from the multi-year study were weighed and measured every three days and had habituated to handling from a young age (Sagar et al., 2019) and therefore provided an additional control against blood collection and the late-stage intensive handling associated with Translocation group.

To quantify chick emergence, stick palisades were erected in entrance of the burrows of Translocation and Control chicks. Any natal burrow found to have more than one entrance had a stick palisade placed in each entrance. Each time sticks were found to be displaced, they were re-erected. Displaced sticks were assumed to either indicate a visit from a parent (Control chicks only), or a chick emerging. Emergence of chicks was confirmed by the presence of down in the burrow tunnel and/or around the burrow entrance, and multiple, consecutive nights of stick displacement. Once emergence was detected for individual chicks, burrows were checked daily for the presence/absence of the chick by lifting the access hatch to observe the chick. A chick was deemed to have fledged if the nest and the burrow were found empty and the chick was known to have been fully feathered, in reasonable health and to have had been emerging prior to its disappearance. Burrows were checked for three days following a presumed fledging event to confirm that chicks had permanently left the nest.

2.3. Blood sampling procedures, sample storage and hormone assay

During all blood sampling events initial blood samples were taken within 4 min of the investigator approaching the nest and the time was started when the investigator was 2 m from the burrow to minimise potential disturbance from footsteps. Initial blood sample collection times (mean = 3 min 25 s; min. = 1 min 31 s; max. = 4 min) were longer than the recommended <3 min (Romero and Reed, 2005) due to the need to avoid the defensive regurgitation many chicks exhibited, and as cold conditions reduced blood flow in the chicks' extremities, which made obtaining initial blood samples difficult. Accordingly, we have used the term 'initial', as opposed to 'baseline' sample, see Sagar et al., 2019 for further detail. Blood samples (0.05 mL–0.1 mL) were collected by puncturing a tarsal vein with a 27-gauge needle and collecting blood in heparinised capillary tubes (0.05 mL; Sarstedt, Numbrecht, Germany). Chicks were then weighed and measured (see above) and left enclosed in a dark cotton bag on the ground close to their burrow before the second 'stress response' sample was collected from the opposite tarsal vein as the first sample 25 min after sampling was initiated. Sampling was performed during 13:30–20:30 h. The number of blood samples at each time-point varied as blood samples could not reliably be collected from chicks during each attempt due poor weather hampering sampling efforts and/or poor blood flow.

Immediately following collection, all blood samples were transferred to 0.3 mL lidded heparin-lined vials (Sarstedt, Germany) and stored upright at approximately 10 °C until centrifugation. Blood samples were centrifuged at 2000 rpm within 6 h of collection, after which plasma was decanted into new 0.5 mL lidded vials (Eppendorf, Germany) and stored upright at -20 °C until hormone assays were undertaken, except during overnight cold transport (approx. 4 °C) from the sampling sites to the laboratory at the University of Auckland, New Zealand.

Total CORT concentration in non-extracted plasma was determined using a commercially available corticosterone enzyme-linked immunosorbent assay (Enzo Life Sciences, catalog no. ADI-901-907). All standards and samples were run in duplicate across six assay plates at 1:40 dilution and total volume of 100 μ L with 1% steroid displacement buffer. Procedures were carried out according to kit instructions, with five serial dilutions of 20 000 pg mL^{-1} CORT standard producing a standard curve from which total CORT was calculated. Plates were run at 405 nm wavelength and intra- and inter-assay coefficient of

variation across all plates was 4.08% and 9.13% respectively. The detection limit of the assay was 0.61 ng mL^{-1} . Differences between individual initial and stress-induced CORT were calculated for each individual as the change between paired initial and stress response CORT samples.

2.4. Statistical analysis

Statistical tests were performed in JMP 13.0.0 (SAS Institute Inc. 2016).

ANOVA was used to test for differences in initial and stress response CORT between translocation years (2014 vs. 2017). No differences between years were detected (initial CORT: $F = 2.41$, $df = 65$, $P = 0.126$; stress response CORT: $F = 0.003$, $df = 71$, $P = 0.986$) and data were pooled to test for differences between groups and sampling events. To evaluate CORT responses in mottled petrel chicks across the sampling period (-7, 0, 1 and 7 days) we used a linear mixed model, with CORT as the dependant variable and sample type (initial vs stress response CORT) and group (Control and Translocation), and the interaction between group and sample type as fixed effects. To account for repeated measures we included chick identification as a random factor. Residuals were tested for normality using Shapiro-Wilks tests. Initial CORT failed to meet the assumptions of normality and therefore data were log-transformed (natural log; \ln). Differences between individual initial and stress-induced CORT between Translocation and Control groups before and after translocation were also evaluated using a linear mixed model, with the relative difference between initial and stress-induced CORT as the dependant variable, and group (Control and Translocation), timing of the sampling relative to translocation (Before and After), and the interaction of these factors as fixed effects. We included chick identification as a random factor. Residuals met the assumptions of normality. In all models, values were analysed by ANOVA with False Discovery Rate (FDR) correction and if the p -value was < 0.05 , a *post-hoc* Tukey's test was applied. Weight and wing chord length were examined as a function of chick age [represented by days before fledging, see Sagar et al. (2015)] and residuals did not meet the assumptions of normality. Accordingly, they were examined by regression analysis with the fixed effects of age and group, and interaction between age and handling group. Again, we accounted for repeated measures of individuals by including chick identification as a random factor. Between-group (Translocation and multi-year average) differences in fledging weight, wing chord length and mean fledging date were examined by one-way ANOVA as residuals were normally distributed. Differences between groups in the number of days chicks emerged for before they fledged were tested by Kruskal-Wallis as they did not meet the assumptions of normality. All data are presented as mean \pm SEM.

3. Results

3.1. Impact of translocation on the stress response of mottled petrel chicks

There was a highly significant effect of time on mean CORT levels, with *post-hoc* tests revealing stress response CORT levels increased above initial CORT levels at all sampling events for both Control and Translocation groups across the sampling period (Fig. 3; adjusted $R^2 = 0.82$; $F(6111.30) = 80.464$, FDR-corrected $p < 0.001$; $\eta^2 = 0.700$). We found no effect of group on mean initial and stress response CORT values at any sampling event (Fig. 3; $F(1111.70) = 0.374$, FDR $p = 0.895$) across the study period. Comparisons of the change in CORT, i.e. the differences between individual initial and stress-induced CORT (Fig. 4; adjusted $R^2 = 0.51$; $F(3,1618.72) = 0.904$; FDR-corrected $p = 0.449$), revealed no significant differences between groups (Fig. 4; $F(1,12.63) = 3.237$; FDR-corrected $p = 0.288$), before and after translocation (Fig. 4; $F(1,33.92) = 0.072$; FDR-corrected $p = 0.790$).

3.2. Impacts of translocation on chick weight, wing chord length and fledging parameters

The weight of Translocation chicks was higher throughout the study period than for chicks from the source colony in the equivalent age range (Fig. 5A; $F(1,842) = 12.694$, $p < 0.001$), though there was no difference between mean Translocation group fledging weight ($350 \pm 5 \text{ g}$) and mean multi-year fledge weights of chicks from the source colony ($336 \pm 4 \text{ g}$; Fig. 5A; $F = 2.408$, $df = 71$, $p = 0.125$). Wing chord length did not differ between Translocation chicks throughout the study period compared to chicks from the source colony in the equivalent age range (Fig. 5B; $F(1,1302) = 0.017$, $p = 0.869$), and there was no difference between mean Translocation group fledging wing chord length ($267 \pm 2 \text{ mm}$) and mean multi-year fledge wing chord length of chicks from the source colony ($266 \pm 1 \text{ mm}$; Fig. 5B; $F = 0.040$, $df = 71$, $p = 0.842$). Translocation chicks emerged for an average of 7 ± 1 nights, which was not different to chicks at the source colony, which emerged for an average of 9 ± 1 nights ($\chi^2(1) = 1.080$, $p = 0.299$). Translocation chicks fledged earlier ($29 \text{ April} \pm 4 \text{ nights}$) than chicks at the source colony, though not significantly so ($2 \text{ May} \pm 5 \text{ nights}$; $F = 5.210$, $df = 71$, $p = 0.255$).

4. Discussion

4.1. Impact of translocation on stress responsiveness, weight and growth of mottled petrel chicks

This study provides the first empirical evidence that current best practice translocation techniques for petrels (Miskelly et al., 2009; Gummer et al., 2014) do not alter stress responsiveness, condition or growth in mottled petrel chicks. Mottled

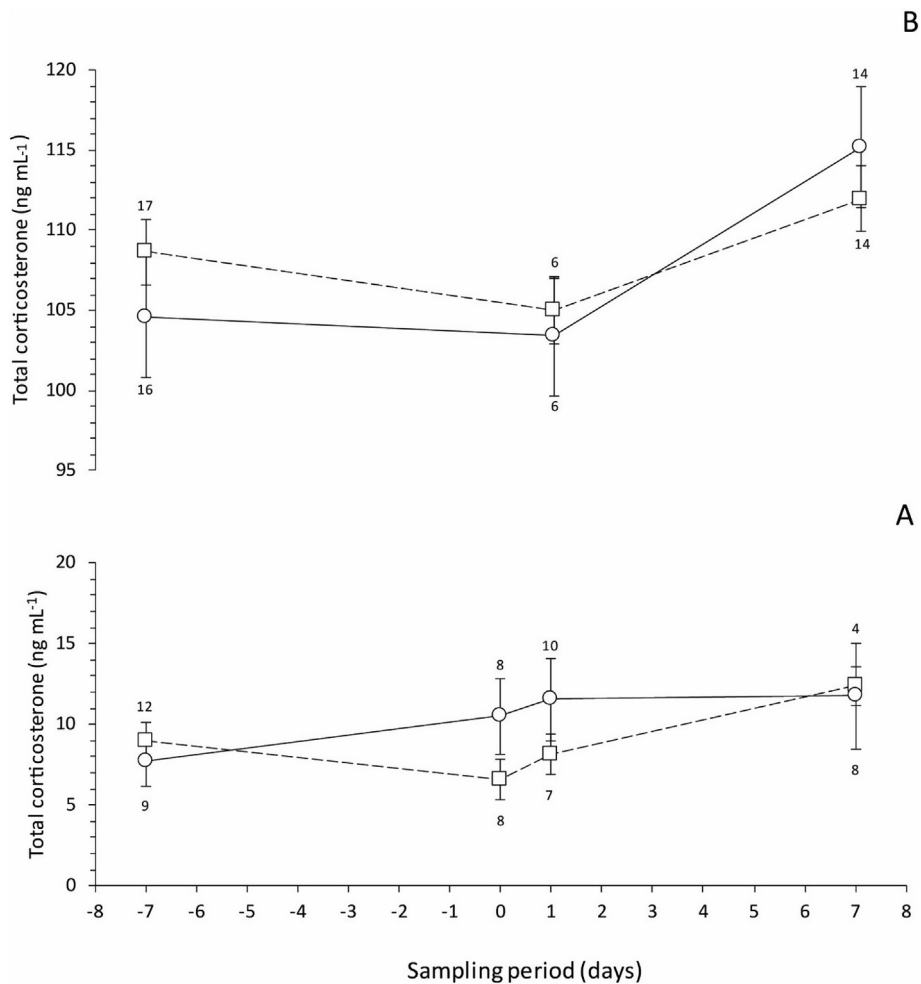


Fig. 3. Mean (\pm SEM) initial (A) and stress-induced (B) total corticosterone levels (ng mL^{-1}) in two groups of mottled petrel (*Pterodroma inexpectata*) chicks: Translocation chicks underwent translocation (○) whilst Control chicks remained in the natal burrow at the source colony (□). Translocation occurred on Day 0, sampling events on Day -7 relate to pre-translocation measures and sampling events on days 1 and 7 relate to activities associated with post-translocation care. Numbers denote sample size for each group (Control and Translocation) at each sampling point.

petrel chicks in both Control and Translocation groups were capable of mounting a stress response that compared to an adult response (Sagar et al., 2019), further confirming that mottled petrels are capable of responding to stressors as nestlings. The capacity of mottled petrels to respond to stress as nestlings is comparable to grey-faced petrel (*Pterodroma macroptera gouldi*) chicks (Adams et al., 2008), a species of medium-large gadfly petrel, that is commonly included in translocation programmes in New Zealand (Miskelly et al., 2009; Gummer et al., 2014).

No differences between Control and Translocation group initial CORT levels were detected, nor did initial CORT levels change between sampling events for either group. The same trend was observed for stress response CORT levels, with stress response CORT increasing to similar levels at each sampling event. Additionally, the relative change in CORT (i.e. the difference between initial and stress response CORT) was consistent between groups, both before and after translocation. These findings indicate that handling events, prolonged transport and rehousing in a novel environment as part of standard petrel translocation practices did not result in physiological traits (elevated baseline glucocorticoid hormones or reduced capacity to mount a CORT response to handling) in mottled petrel chicks that are associated with chronic stress in animals (Sapolsky et al., 2000b; Dickens et al., 2010). This conclusion is further supported by the lack of negative impact on Translocation group weights and wing chord growth. It is well recognised that there is often high intra- and inter-individual variation in CORT measures, that occur as a result of both extrinsic and intrinsic factors (Williams et al., 2008; Bonier et al., 2009; Will et al., 2014; Taff et al., 2018). Accordingly, we concede that the small sample size in this study in conjunction with possible individual variability in CORT responses may mask true differences between groups. However, our models described the majority of the variation in analyses, and our before-after-control-impact experimental design increases our confidence that the observed trends in stress reactivity and condition in this study are likely to be real. However, we encourage further testing with larger sample sizes in a wider range of petrel species to confirm this finding.

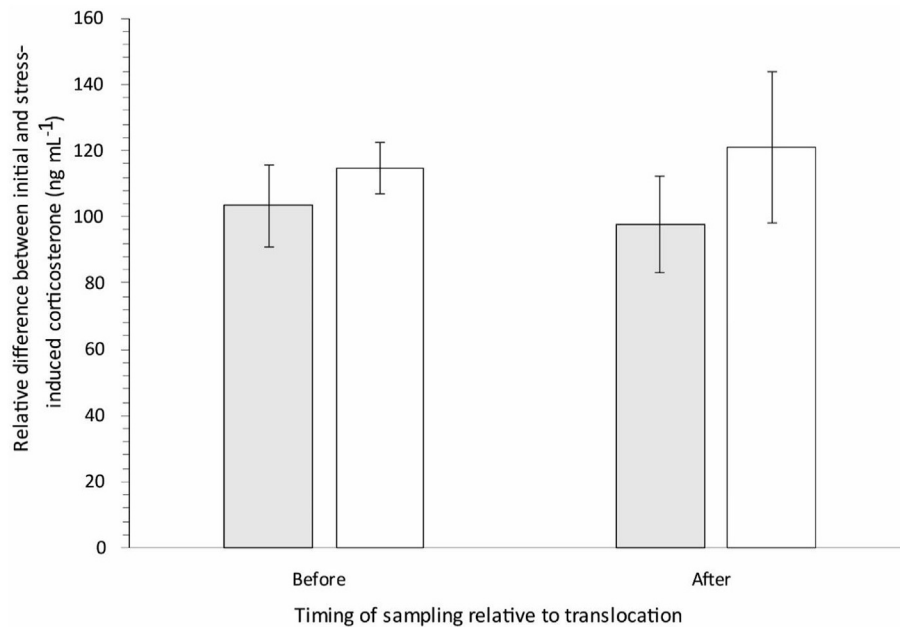


Fig. 4. Mean (\pm SEM) differences between initial and stress-induced total corticosterone levels (ng mL^{-1}) in two groups of mottled petrel (*Pterodroma inexpectata*) chicks: Translocation chicks underwent translocation (grey) whilst Control chicks remained in the natal burrow at the source colony (white).

We hypothesise that mottled petrel chicks may be highly resilient to stress as a means of dealing with extended periods of food deprivation, as relative to their body size, mottled petrel chicks are fed less frequently than other closely related species (Rayner et al., 2008; Sagar et al., 2015). Lowered sensitivity to glucocorticoid hormone activity on growth and condition may be important for this species and others within this taxon that rely on glucocorticoid responses to carry them through long periods between meals. In this study we did not measure corticosterone binding globulin, which has been implicated in regulating the availability of CORT to tissues (Breuner et al., 2013). Future work should aim to examine the mechanisms of CORT uptake in mottled petrel chicks to understand if developmental patterns or stress alters the regulation of CORT and their resilience to its effects on growth and condition. It is possible the selection of high quality individuals may have unknowingly biased our sample of chicks towards those that have a higher resilience to stress (Adams et al., 2005) and may explain why chicks did not display physiological or developmental symptoms of chronic stress in response to translocation activities.

In contrast to our findings, Dickens et al. (2009) demonstrated that a single capture and handling event caused a long-term decrease in stress responsiveness in wild, free-ranging chukar (*Alectoris chukar*), with subsequent translocation activities (captivity and release at a novel site) having additive effects. Causes of chronic stress resulting in translocation failure have been extensively reviewed [e.g. Dickens et al. (2010); Parker et al. (2012); Parker et al. (2015)]. However, petrel translocations differ somewhat to other types of avian translocations that have been discussed in the literature. The life history characteristics of petrels dictate an individualised approach to translocations that reduces the opportunity for exposure to factors that make other avian species vulnerable to chronic stress during and after translocations such as over-crowding, competition, predation risks and limited food availability (Teixeira et al., 2007; Dickens et al., 2010).

Petrel chicks are transported almost immediately after removal from their natal burrow and housed in an individual nest box that closely resemble natural burrows and there are no issues with pro-longed over-crowding or competition for territories that have been implicated in the failure of other avian translocations (Teixeira et al., 2007; Dickens et al., 2010). Petrel translocations selectively target high quality individuals (Miskelly et al., 2009; Gummer et al., 2014) as overall higher chick weights, and especially fledge weights, are strongly associated with post-fledging survival (Sagar and Horning, 1998), which supports the goals of translocation programmes. There is substantial evidence that shows the nutritional status of nestlings influences both baseline CORT and stress reactivity, and nestlings that experience sustained nutritional stress increase their glucocorticoid responses, often leading to reduced lifetime fitness [e.g. (Kitaysky et al. 1999, 2001; Pravosudov and Kitaysky, 2006; Will et al., 2014)]. The selection of petrel chicks with higher overall weights for translocation, and the maintenance of this condition with tailored feeding programmes may reduce the risk of altered stress profiles as a result of nutritional deficiencies, and select for individuals with higher lifetime fitness. The high quality of Translocation chicks explains the discrepancies in weight between these chicks and chicks from the natal colony, as the latter group is representative of the total variation in the population, including lower quality individuals. Condition has been found to not affect growth in mottled petrel chicks (Sagar et al., 2019) and therefore it was not surprising that growth rates did not differ between Translocation chicks and those from the natal colony.

We did not measure stress responsiveness in mottled petrel chicks immediately following the transport component (up to 16 h) of translocation, and it follows that there may have been an effect on their capacity to respond to stress that was not

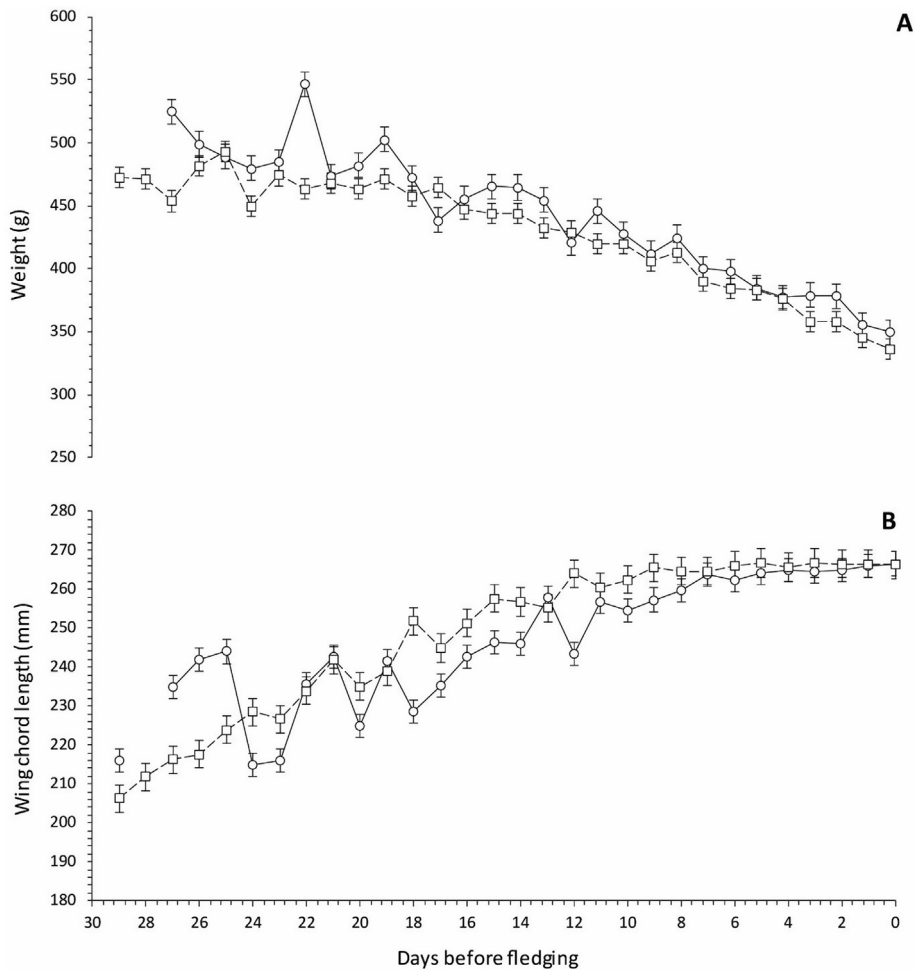


Fig. 5. Mean (\pm SEM) weight (g; **A**) and wing chord (mm; **B**) in mottled petrel (*Pterodroma inexpectata*) chicks that underwent translocation (\circ) or remained in the natal burrow at the source colony (\square).

observed. However, given that initial CORT immediately following transport and both initial and stress response CORT 24 h following transport were comparable to pre-translocation and Control group measures we conclude that if any effect existed it was not sustained. Captive bred grey partridge (*Perdix perdix*) have been shown to recover altered initial CORT levels and stress responsiveness within 33 h of transportation and release (Jenni et al., 2015).

4.2. Conclusions

Despite the popularity of translocations as a conservation tool, few studies have investigated how individual components of translocations impact stress reactivity in wild birds, and this is the first such study in petrels. A successful petrel translocation is two-fold: firstly chicks must fledge in optimal condition to increase their opportunities for post-fledging survival, and secondly, the birds must return to the translocation site several years after fledging and establish a self-sustaining breeding colony (Miskelly et al., 2009). Conservation practitioners may proceed in the knowledge that current practices may adequately manage stress during and after translocation, and promote the best chance of success for mottled petrel translocation programmes. However, the life history characteristics of mottled petrels appear to make them resilient to the effects of CORT. Accordingly, we caution applying our findings to petrel species with different life-history strategies to mottled petrels as these species may exhibit different stress reactivity profiles (Quillfeldt et al., 2009; Fiske et al., 2013; Watson et al., 2016) – hence further investigation across a range of species is warranted. Finally, we suggest that investigating individual, context-dependant variation in stress reactivity profiles and fitness of Translocation mottled petrel chicks may shed light on traits that promote the survival and success of individuals. Furthermore, as colonies establish there is an opportunity to study whether these traits show a level of heritability. Such traits could be tested for in birds as part of future translocation efforts

and would work to promote the overall success of translocation programmes, as well as increase our understanding of the relationship between stress reactivity profiles and fitness in free-living populations.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.gecco.2018.e00508>.

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