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Hand-rearing and translocation trial of the critically endangered kuaka Whenua Hou (Whenua Hou diving petrel; *Pelecanoides georgicus whenuahouensis*)

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Abstract: The critically endangered kuaka Whenua Hou (Whenua Hou diving petrel, *Pelecanoides georgicus whenuahouensis*) is a burrow-nesting petrel, restricted to breeding in the foredunes of Whenua Hou. The species' recovery is inhibited by ongoing threats such as vessel-based light pollution, interspecific competition, and climate change including storm-induced erosion of fragile breeding habitat and thus, kuaka Whenua Hou would benefit from the establishment of a new colony through translocation. However, translocations of petrels require hand-rearing of pre-fledging chicks on the destination site to reset their philopatric behaviour. We documented a hand-rearing and translocation trial of kuaka Whenua Hou in preparation for future translocations. Ten kuaka Whenua Hou chicks were translocated from natal burrows to nest boxes installed behind the colony, and hand-reared on a bespoke diet of pureed sardines. All hand-reared chicks fledged successfully, with fledging mass similar to naturally-reared chicks and with slightly longer wing lengths. The techniques used highlighted the importance of selection criteria, access to natural growth curves to infer feeding regimes, nutritionally rich diets, and strict hygiene protocols. Our trial provides a knowledge base for future translocations and the establishment of new kuaka Whenua Hou colonies.

Tuhinga whakarāpopoto: He momo tata korehāhā te kuaka o Whenua Hou (*Pelecanoides georgicus whenuahouensis*), he momo ōi e whai rua hei kōhanga, kua mau ki te whakatipu ki ngā tāhuahua kopī o mua o Whenua Hou. Ko te whakarauora o tēnei momo kua whakanguengue i ngā āhuatanga whakaraerae e mau tonu pērā i te pokanga rama, ā rātou ake pakanga ki a rātou me te hurihuri o te āhuarangi, tae noa atu ki te horonga whenua o te pūrei kōhanga marore nō te marangai, ā nō reira, ka whai hua te kuaka Whenua Hou i te whakatūtanga atu o tētahi taiwhenua hou mā te nukunuku kōhanga. Engari, me whakatipu ngā pīrere ki te ringa ki te wāhi e tū ai te kōhanga hou kia ea ai te nuku kōhanga, ā, kia tautuhi anō tā rātou hiahia ki te hoki atu ki te kāinga i whakatipuria kētia rātou. I āta mārama mātou ki te whakamātautau o te whakatipu ā-ringa me te nukunuku kōhanga o te kuaka Whenua Hou kia whakarite ai ki te nukunukunga tūturu e haere ake nei. I nuku kia ngahuru ngā pīpī kuaka Whenua Hou mai i ngā rua i whānau mai ai rātou ki ētahi kōhanga hanga i whakatūria ki muri i te taiwhenua matua, ā, i whakatipuria rātou ki te ringa ki ētahi kai ake o te hārini penupenu. I whai huruhuru pai ngā pīpī katoa, ā, ehara i te rerekē te taumaha o ēnei pīpī i ērā i whakatipuria ki ō rātou ake kōhanga, engari he paku roa ake ngā parirau. I whakamiramira atu ngā tū-āhua i whakamahia i te hiranga o ngā paearu whiri, te whai wāhitanga ki ngā pikinga whakatipu māori kia whakapae tika ai te tikanga whāngai, te whiringa o te kai taioranga me ngā tikanga akuaku mārō. Ka noho tā mātou whakamātautau hei tūāpapa mātauranga ki ngā nukunukunga kōhanga e haere ake nei, me te whakatūtanga o ētahi taiwhenua hou mō ngā kuaka Whenua Hou.

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INTRODUCTION

Seabirds have key ecological roles, serving as indicators of environmental changes in the marine ecosystem and providing important marine-terrestrial linkages such as nutrient transport (Mulder & Keall 2001; Parsons *et al*. 2008; Pizarro *et al*. 2012; Signa *et al*. 2021). However, increased anthropogenic pressures have led to widespread population declines and range restrictions, resulting in seabirds being one of the most threatened taxonomic groups on the planet (Croxall *et al*. 2012; Dias *et al*. 2019). Seabirds are impacted by multiple threats including invasive predators, by-catch in commercial fisheries, habitat degradation, pollution, sea-level rise, and climate change (Taylor 2000a; Baker *et al*. 2006; Jones *et al*. 2008; Dias *et al*. 2019; Rodriguez *et al.* 2019). These threats affect various seabirds in different ways, highlighting the importance of targeted conservation techniques to restore species.

Translocation is an established and effective technique that involves the intentional movement of species from one location to another for conservation or restoration goals (Seddon *et al*. 2007; Seddon 2010). This technique is used to overcome dispersal barriers, reinforce existing populations, re-establish extirpated populations, and increase ranges by establishing new populations (Fischer & Lindenmayer 2000; Gummer 2003; Miskelly & Taylor 2004; Deguchi *et al*. 2011). Translocation techniques have been adapted for many threatened seabirds, including Procellariiformes (tube-nosed seabirds, including petrels) (Miskelly & Taylor 2004; Miskelly *et al*. 2009; Deguchi *et al*. 2011; Piludu *et al*. 2018; VanderWerf *et al*. 2019; Spatz *et al.* 2023). For translocations of petrels, incorporating hand-rearing of pre-fledging chicks at the destination site is required to reset their innate homing instinct (Gummer 2003; Miskelly *et al*. 2009). This has proven to be successful with >100 seabird translocations events successfully implemented around the world (Spatz *et al.* 2023).

The critically endangered kuaka Whenua Hou (Whenua Hou diving petrel, *Pelecanoides georgicus whenuahouensis*) is a recently-described burrow-nesting petrel for which translocation has been identified as an important step to secure its long-term survival (Fischer *et al*. 2018c, 2023). Kuaka Whenua Hou was once widespread with a historical distribution including Rēkohu (Chatham Islands), Rakiura (Stewart Island), and Te Waipounamu (South Island of New Zealand) (Taylor 2000b; Holdaway *et al*. 2003; Wood & Briden 2008; Fischer *et al*. 2017b; Tennyson 2020). Introduction of invasive predators such as rats (*Rattus* spp.) led to multiple local extinctions and the last remaining colony of kuaka Whenua Hou is now found on Whenua Hou (Codfish Island), where the adult population numbers ~200 individuals (Taylor 2000b; Fischer *et al*. 2018b, 2020b). Despite the eradication of invasive predators from Whenua Hou in 2000, pressure from ongoing threats including vessel-based light pollution, interspecific competition for burrows, and climate change including storm-induced erosion of fragile breeding habitat, resulting in direct mortality, is inhibiting kuaka population recovery (Fischer *et al*. 2017a, 2018b, 2020b, 2023).

Translocation of kuaka Whenua Hou may reduce the impact of ongoing threats and thus are key to the long-term survival of the species (Fischer *et al*. 2023). To ensure the future success of kuaka Whenua Hou translocations, a key component, the hand-rearing of chicks, must be tested. While protocols for the closely related common diving petrel (kuaka, *Pelecanoides urinatrix*) and other small petrels exist (Miskelly & Taylor 2004; Gummer & Gardner-Gee 2009; Miskelly *et al*. 2009), it is uncertain whether these protocols are also suitable for kuaka Whenua Hou.

We assessed whether existing hand-rearing protocols developed for kuaka are suitable for kuaka Whenua Hou. To achieve this, we monitored chick survival and condition and aimed to answer the following questions: (1) Do hand-reared chicks fledge at equal to/or better condition than naturally-reared chicks? (2) Do hand-reared chicks have the same fledging phenology as naturally-reared chicks? The development and fine-tuning of hand-rearing techniques for kuaka Whenua Hou chicks is a crucial part of the larger kuaka Whenua Hou recovery programme (Fischer *et al*. 2023). Here, we report on the first test translocation.

MATERIALS & METHODS

Study site

The only extant kuaka Whenua Hou colony is found on Whenua Hou, located 3 km off the west coast of Rakiura, Aotearoa (New Zealand; Fischer *et al*. 2017a, 2018b). All kuaka Whenua Hou burrows are confined to a small 20 m wide strip of sand dunes (0.018 km^2) located within Waikoropupū (Sealers Bay; 46.766°S, 167.645°E). The test translocation site (Fig. 1) was located in the back dunes behind the main colony (Fischer *et al*. 2018b). This site was chosen because of its distance from the springtide line (18 m), its central location in respect to the rest of the kuaka Whenua Hou colony, the absence of active burrows, the absence of known archaeological sites (Fischer & Tucker 2020), and its accessibility.

Chick collection

A total of 10 kuaka Whenua Hou chicks were located in their natal burrows using a burrowscope (Sextant Technologies, Wellington) and subsequently collected by hand. Shallow burrows <80 cm depth

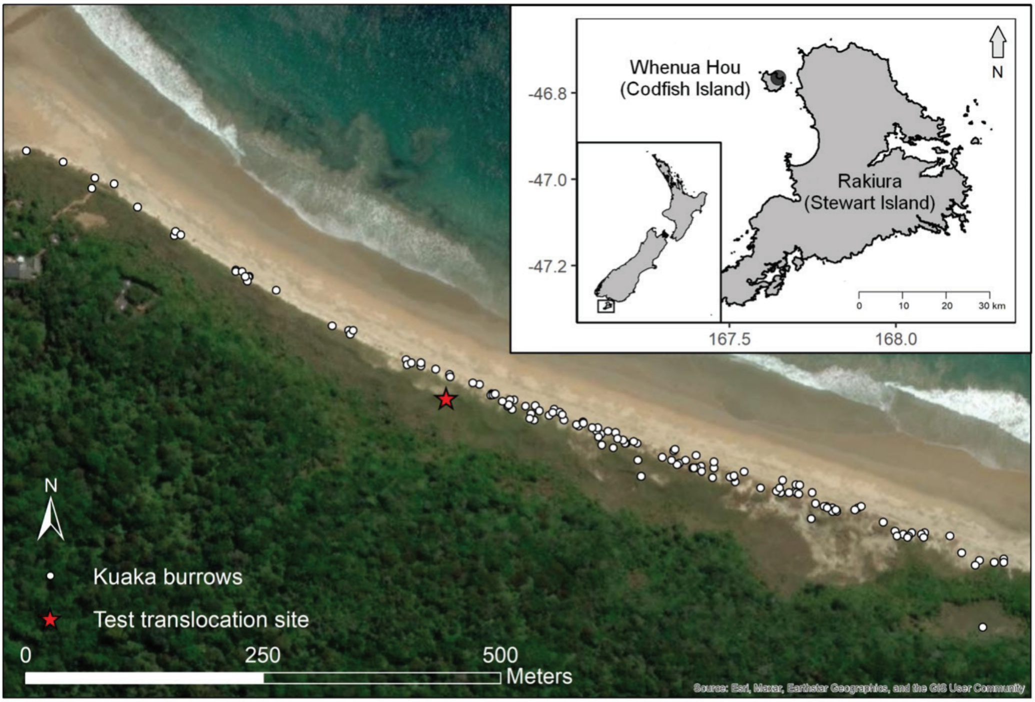

Figure 1. Location of the test translocation site, in relation to kuaka Whenua Hou (*Pelecanoides georgicus whenuahouensis*) burrows, within the dunes of Waikoropupū (Sealers Bay), Whenua Hou

were targeted for easy extraction. Additionally, burrows more at risk of erosion from future storm events were favoured. Criteria for translocation candidates were adapted from Fischer *et al*. (2021). Specifically, chicks were selected if they exhibited a wing length of 100–110 mm and a mass of >130 g, which in combination indicated healthy chicks at 10–7 days before fledging (DBF; Fischer *et al*. 2021). Suitable fledglings were transported in cloth bags to nest boxes (20–400 m; transportation time <5 min). Chick collection commenced on the 28 December 2022 with two chicks transferred to burrows, followed by five chicks on 29 December, and the final three chicks on 30 December.

Artificial nest boxes

Chicks were individually housed in the back dune behind the main colony, in customised artificial nest boxes following an existing design specific to this species (Fischer *et al*. 2018a). Ten multi-level nest boxes were installed in October 2022 with mana whenua at ~60 cm underground (Fig. 2). The nest boxes were built from 12 mm plywood, with a design consisting of an open-bottom brood chamber (25 x 25 x 15 cm), insulating sand layer (25 x 25 x 5 cm) with an insulated access hatch (10 x 15 x 5 cm), an access shaft (25 x 25 x 40 cm) and external access door (30 x 30 x 1.2 cm). To mimic dark natural tunnels, artificial nest box tunnels were inserted with a curved profile and reinforced with Novacoil© piping (length = ~150 cm; diameter = 11 cm). As an additional insulation measure, sandbags (83 x 48 cm) were placed on top of external access doors (Miskelly *et al*. 2009; Fischer *et al*. 2018a). Tunnel entrances were initially obstructed with wooden blockades to facilitate chicks acclimating to surroundings and prevent premature fledging. Blockades were removed based on chick condition and behaviour, on average 4.9 days (range: 3–7 days) after chick transfer.

Hand-rearing chicks

Fledglings were hand-reared following protocols developed for the closely related common diving petrels (kuaka, *Pelecanoides urinatrix*) (Miskelly & Taylor 2004; Gummer & Gardner-Gee 2009; Miskelly *et al*. 2009). Initial feeding of chicks did not commence until the day after extraction of chicks from natal burrows to reduce stress. Fledglings were fed a pureed sardine diet prepared by blending sardines (two 106 g tins of Brunswick sardines in soya oil and one 106 g tin of Pams sardines in soya oil, with excess oil removed), 210 ml of cooled pre-boiled water, 60 ml of Melrose Omega fish

Figure 2. Installation process of customised artificial nest boxes, for translocated kuaka Whenua Hou (*Pelecanoides georgicus whenuahouensis*) chicks in the back dunes of Whenua Hou. Photographs: Johannes Fischer.

oil + Vitamin D and one crushed Mazuri® Vitazu™ Small Bird Supplement with Vitamin A tablet. This mixture was delivered via 14 Fg Jorvet PVC feeding tubes cut down to 70 mm x 4.66 mm and fed to chicks once daily. Chicks were fed at the Whenua Hou field station, rather than directly at the test translocation site to allow for strict hygiene practices following best practice guidelines for burrow-nesting petrels (Gummer & Gardner-Gee 2009; Gummer *et al*. 2014). Chicks were transported from the test translocation site to the field station in transfer boxes with ice packs to reduce heat stress. Feeding portions were designed to mimic natural feeding regimes, but finetuned to individual chick growth, and thus smaller portions were delivered as chicks neared fledging. On average, chicks were fed 8.65 ml (range: 3–20 ml) portions of the pureed sardine diet, but on occasion, chicks close to fledging were fed small portions of fish oil only, on average 4.3 ml (range: 2–5 ml) to avoid weighing them down, while still providing them with additional energy to fledge. Kuaka Whenua Hou chicks were hand-reared an average of nine days before fledging (range: 5–12 days).

Targets considered for optimum fledging condition included meeting or exceeding mean natural fledging mass: 112.1 g (range: 90–130 g; mean adult mass: 124 g, excluding masses collected during chick-rearing period) and mean natural fledging wing length: 113.6 mm (range: 110–119 mm; mean adult wing length 120 mm). Hand-reared chicks were measured daily using a wing ruler for wing length (flattened wing cord; mm) and an electronic scale for mass (g) prior to feeding. Naturally-reared chicks were mostly handled and measured only once during banding within ~two weeks prior to fledging. Direct mass comparisons showed that Pesola (used in previous seasons' mass measurements of naturally-reared chicks) and electronic scales performed equally well and thus, no confounding factors were introduced due to the use of two different measuring tools. To assess fledging phenology all nest boxes, as well as natural burrows with previously banded chicks, were monitored daily using stick palisades placed at tunnel entrances to record fledging activity of chicks until fledging had occurred.

Data analysis

To assess the success of the trial, growth curve (mass and wing length) and phenology data of hand-reared and naturally-reared chicks (pre-existing datasets 2017–2022) were compared. Specifically, differences in fledging mass and wing length (i.e. at DBF = 0) between hand-reared (n = 10 individuals) and naturally-reared chicks (n = 216 individuals) were compared using t-tests. Linear models (LMs) were fit to growth curve data during the last 12 DBF to investigate the effect of the translocation on kuaka Whenua Hou chick mass loss and wing growth. These models included a fixed effect of DBF and translocation status (i.e. hand-reared or naturally-reared) as well as an interactive effect between both. The first day following chick translocation was excluded for each translocated chick, as development during the first day these was not controlled by hand-rearers. To compare differences in fledging phenology (i.e. timing of DBF = 0) between hand-reared (n = 10 individuals) and naturally-reared chicks (n = 125 individuals), fledging dates were initially transformed into a numerical variable (i.e. days since 31 December) and then, a non-parametric Wilcoxon test was performed to address non-normal parameter distributions. All statistical analysis and graphical visualisations were completed using Program R (R Core Team 2020; version 4.1.3).

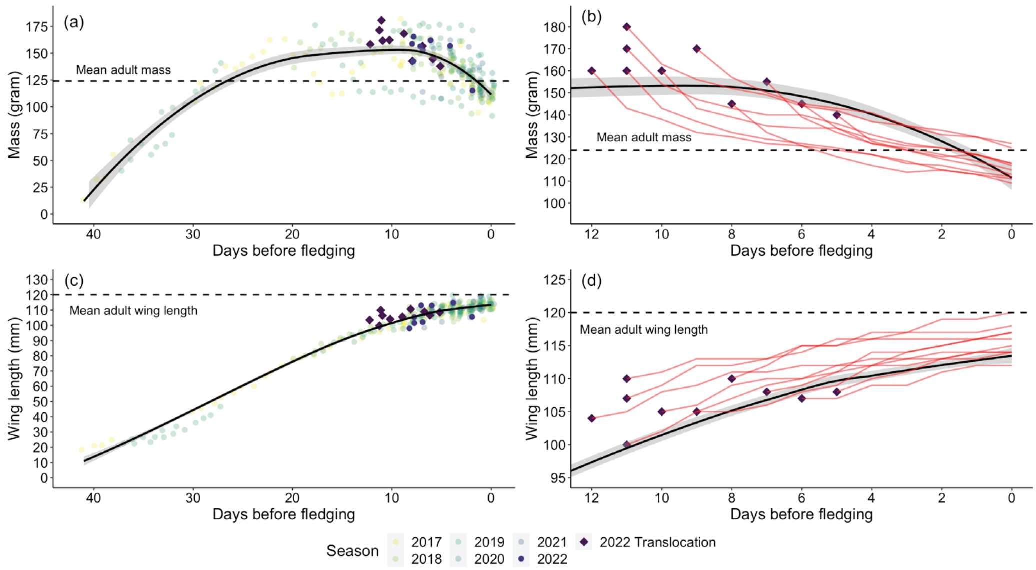

Figure 3. (a) Kuaka Whenua Hou mass growth curves of naturally-reared chicks, (b) mass trajectories of individual translocated chicks, (c) naturally-reared chick growth curves of wing length, (d) and wing length growth trajectories of individual translocated chicks. Mean mass growth curves of naturally-reared chicks are illustrated by locally estimated scatterplot smoother (LOESS) curves (black lines).

RESULTS

Fledging condition

All 10 hand-reared kuaka Whenua Hou chicks survived the trial and fledged at average mass and with above average wing lengths (Fig. 3). Hand-reared chicks exhibited similar fledging mass as naturally-reared chicks (mean ± SE: 116.5 ± 1.85 g vs 112.1 ± 2.03 g for hand-reared and naturally-reared, respectively; t_{27} = -1.41, p = 0.17; Fig. 3). However, hand-reared chicks fledged with a slightly longer wing lengths than naturally-reared chicks (115.7 ± 0.75 mm vs 113.6 ± 0.53 mm for hand-reared and naturally-reared, respectively; t_{28} = -2.35, p = 0.03). Mass loss was influenced by DBF (LM estimates ± SE; R^2 = 0.42, $F_{2,301}$ = 73.62, $p < 0.001$; β = 3.92 ± 0.30, $p < 0.001$), whereas the translocation treatment and interaction showed no impact (β = -3.31 ± 3.10, p = 0.29, β = -0.85 ± 0.59, p = 0.15 for translocation status and the interaction, respectively). In other words, modelled daily mass loss of chicks was approx. 4 g/day and no discernible effect of the translocation was evident. Wing growth was influenced by DBF, translocation status, and the interaction between both (R^2 = 0.61, $F_{3,300}$ = 157.3, $p < 0.001$; β = -1.19 ± 0.06, $p < 0.001$, β = 1.62 ± 0.66, p = 0.02, β = 0.39 ± 0.13, p = 0.002 for DBF, translocation and their interaction, respectively). In other words, wing growth for naturally-reared chicks was approx. 1.2 mm/day, while wing growth for hand-reared chicks was approx. 1.6 mm/day, resulting in longer wings at fledging.

Fledging phenology

All hand-reared kuaka Whenua Hou chicks successfully fledged within the anticipated ~2-week period, between 4–11 January 2023, with a mean fledging date of 8 January (Fig. 4). Timing of fledging for hand-reared chicks was slightly earlier on average compared to naturally-reared chicks,

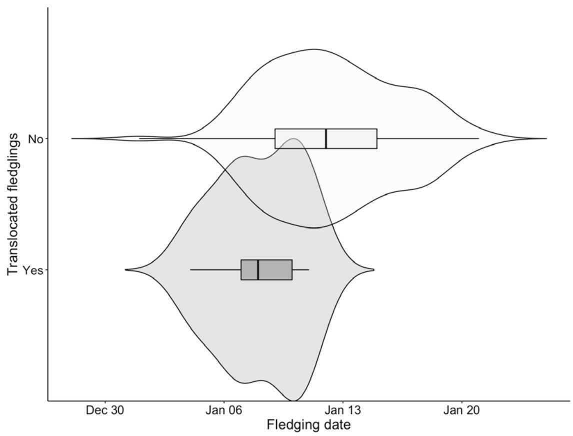

Figure 4. Kuaka Whenua Hou phenology of translocated fledglings and the six-year average of naturally-reared fledglings displayed as violin plots. The width of the plots represents the density of the data, while the box plot illustrates the interquartile range and median, depicted as the solid black line.

with the multiyear average having a mean fledging date of the 12 January (Wilcoxon test, W = 1019, $p < 0.001$).

DISCUSSION

Our study demonstrated that existing hand-rearing protocols developed for kuaka are indeed suitable for future kuaka Whenua Hou translocations. All translocated kuaka Whenua Hou chicks survived and fledged at equal, or better, condition when compared to naturally-reared chicks. Specifically, fledging mass for both groups were similar, while hand-reared chicks exhibited slightly longer wing lengths (Fischer *et al.* 2021). A potential reason for this may be that our hand-rearing diet facilitated faster wing growth and/or that daily feeding allowed additional wing growth, compared to the pre-fledging fasting that naturally-reared chicks experience.

Our trial was successful and can inform future translocations, provided some key deviations from previous protocols are accounted for. Similar to kuaka feeding protocols (Miskelly & Taylor 2004; Miskelly *et al*. 2009), kuaka Whenua Hou chicks were fed daily. However, it should be noted that we aimed to mirror natural mass loss trajectories and thus reduced feeding portions when necessary. This contrasts with kuaka feeding portions which were constant and much larger (8.65 ml on average for kuaka Whenua Hou vs 25–27.2 g for kuaka; Miskelly & Taylor 2004; Miskelly *et al*. 2009). However, it should be noted that our diets were more nutritionally rich due to the additional fish oil used, allowing us to mimic natural petrel diets and deliver smaller portions (Jensen 2021).

A crucial observation made during this study was the importance of access to existing natural growth curves when inferring feeding regimes. Petrels can be hand-reared on a universal artificial diet (Miskelly *et al*. 2009), which we used in this trial. However, species from the same genus may exhibit different mass loss strategies prior to fledging. Kuaka Whenua Hou tend to fledge below mean adult mass, while kuaka fledge at or above adult mass (Miskelly *et al.* 2009; Fischer *et al.* 2021), an important difference that must be accounted for during hand-rearing. These differences in mass loss strategies are evident in other seabird species pairs. Yelkouan shearwater (*Puffinus yelkouan*) and providence petrels (*Pterodroma solandri*), fledge below adult mass (Binder *et al*. 2013; Piludu *et al*. 2018), while closely-related Manx shearwaters (*Puffinus puffinus*) and ōi (grey-faced petrels; *Pterodroma gouldi*), respectively, fledge at similar or above adult mass (Hamer & Hill 1997; Ramos *et al*. 2003; Miskelly *et al*. 2009; Eizenberg *et al*. 2021). Pre-fledging mass recession (increasing chick mass gain, peaking above adult mass, followed by pre-fledging mass loss) is common in Procellariiformes (Gray & Hamer 2001), but the reason for fledging below adult mass is unknown. Possible functions could include inducing fledging or optimising wing loading, which is important for manoeuvrability and catching prey (Morbey *et al.* 1999; Wright *et al*. 2006; Goodpaster & Ritchison 2014). Yet, fledging at higher mass is often correlated with increased post-fledging survival (Perrins *et al*. 1973). A possible reason for kuaka Whenua Hou exhibiting lighter fledging mass may be that extra mass prevents fledging and limits a chicks ability to fly (Perrins *et al*. 1973; Sagar & Horning 1998; Mauck & Ricklefs 2005). Lack of pre-fledging emergence behaviour in kuaka Whenua Hou (Fischer *et al*. 2021) may also limit the ability to fledge at higher mass, as emergences allows for flight training of wing muscles, and without this training, lower mass may be necessary for liftoff (Yoda *et al*. 2016). The underlying drivers of mass loss strategies of individual species requires further investigation.

Our findings indicated that hand-reared chicks fledged earlier than naturally-reared chicks. However, this difference may be an artifact of collection timing and selection criteria. Specifically, our criteria (wing length = 100–110 mm, mass >130 g), which we applied in late December, may have caused the earlier cohort to be favoured (Fischer *et al*. 2021). Regardless, kuaka Whenua Hou chicks can fledge earlier than the mean fledging date. Additionally, chicks need to be hand-reared for a sufficient amount of time to enable the resetting of their homing instinct, as required for any future translocation off island (Gummer 2003; Miskelly *et al*. 2009). Kuaka Whenua Hou chicks were hand-reared for a sufficient period (5–12 days), based on results from previous kuaka translocations during which translocated chicks returned to the destination site (Mana Island) after being present for 2–3 days before fledging only (Miskelly & Taylor 2004; Miskelly *et al*. 2009). Our study thus reinforces that our selection criteria were appropriate for future translocations.

Following this successful test translocation, we recommend taking the next step in the kuaka Whenua Hou recovery process and translocate kuaka Whenua Hou to a new site. Only ~200 kuaka Whenua Hou remain on Whenua Hou. Furthermore, the ongoing impacts of environmental changes, storm-induced erosion of breeding habitat, competition for burrows, and vessel-based light pollution are inhibiting population recovery (Fischer *et al*. 2017a, 2020b, 2021). The establishment of a new colony through translocation is crucial for the long-term survival of this species and our successful trial paved a way forward to achieving this key goal.

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