Trail-camera assessment of the fates of Northern Royal Albatross and Northern Buller's Mollymawk chicks: 2021 breeding season, Motuhara

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Department of Conservation, Conservation Services Programme

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Frontispiece. *A well-developed Northern Royal albatross chick (foreground) and an adult parent (behind) showing the subtle differences in plumage, principally the pale edging to the mantle, back and covert feathers of the chick. Such differences can be difficult to see at a distance in trail-camera images*

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Executive Summary

1. This report focuses an analysis of a set of over 174,000 images from 10 trail cameras set up on Motuhara, Chatham Is, in January 2021 to cover five groups of nesting Northern royal albatross | toroa *Diomedea sanfordi* and five Northern Buller's mollymawk | hopo *Thalassarche bulleri platei*.
2. One objective was to produce indices of the number of adults of both species ashore daily in late-January – early-February in relation to time of day, weather conditions and breeding activity, to determine when best to survey these colonies aerially. Other objectives included monitoring a sample of nests to determine nest failure rates and causes (if possible); fledging success; and any behavioural interactions among individuals, including predators/scavengers such as Northern giant petrel | pāngurunguru *Macronectes halli* and brown skua | hākoakoa *Stercorarius antarcticus*.
3. The number of adult Northern royal albatrosses was highest at the end of January and early February, declining sharply as the brood-guard phase ended (5 February–8 March 2021). Early in this period, daily numbers were highest at dawn and dusk and lowest around midday. There was no obvious relationship with the prevailing wind speed or direction, but the sample size was small. The patterns for Northern Buller's mollymawk were similar, where the end of the brood-stage started on 26 January and finished 3 weeks later on 15 February.
4. Of the 62 Northern royal albatross nests monitored, four turned out to be empty, leaving 58 active nests from which 48 chicks apparently fledged (assuming that all 19 well-grown chicks being monitored at one site when the camera stopped function successfully fledged). Fledging took place between 7 September and 4 October 2021, with most birds apparently leaving between 11–17 September.
5. The main cause of failure was toroa chicks dying soon after hatching (3/10 chicks), presumed illness (2/10), and single instances of death apparently from heat stress, cold and wet conditions, and an egg failing to hatch. The cause of death in two other cases could not be determined. Nest failures were concentrated in the brood-guard stage and soon after.
6. A total of 86 Northern Buller's mollymawk nests were monitored, of which 28 proved to be empty but occupied by pairs of birds. From the remaining 58 nests, 39 chicks fledged successfully (*i.e.,* they were all last seen alive during the fledging period). Fledging started on 4 June 2021 and was completed just over a month later on 6 July.
7. Of the 19 nests that failed, one chick died soon after hatching; three eggs failed to hatch; two chick appeared to succumb to heat stress, and two to cold, wet conditions; three appeared sick before they died; and the causes were unknown in the remaining eight. These failures/deaths were spread throughout the chick-rearing period, including two chicks that died during the fledging period.
8. Chicks of both species showed marked behavioural and presumably physiological responses to rising temperatures above 20–25°C, a cause for concern given the prospects of rising temperatures in a warming world.
9. Combining the results with separate but wider, near-simultaneous assessment of the number of nests of both species that had failed up to when the cameras were installed suggests an overall nesting success for Northern royal albatross of 76% and for Northern Buller's mollymawk of 51%. The implications of these are discussed.

Introduction

Northern royal albatross | Toroa *Diomedea sanfordi* and Northern Buller's mollymawk *Thalassarche bulleri platei* | Hopo breed almost exclusively on three privately-owned outlying islands in the Chatham Island archipelago: Rangitautahi (Big Sister) and Te Awanui (Middle Sister) in the Rangitutahi group (The Sisters), and on Motuhara/Motchuhar (The Forty-Fours). Aside from these core populations, there are two tiny outlier populations, one of each species. A small number of Northern royal albatrosses (<1 % of the estimated global total breeding population of around 6,300 pairs) breeds at Pukekura Taiaroa Head, near Dunedin. A proportionately even smaller number of Northern Buller's mollymawk, <0.2 % of the global total breeding population of just under 21,000 pairs, breeds on Rosemary Rock in the Three Kings archipelago, north of New Zealand. The Chatham Islands also support around 17% of the global breeding population of just under 12,000 breeding pairs of Northern giant petrel | Pāngurunguru *Macronectes halli*.

All three islands are challenging to access regularly, making it difficult not only to establish the annual numbers of breeding pairs of these species and track changes in their populations, but also to determine finer details of their breeding cycles. These include as arrival and departure dates at the colonies; the timing and duration of egg laying and the brood-guard stage after the chicks have hatched; the timing and causes of nest failures; the pattern of fledging; and the attendance of failed breeders and non-breeding individuals and pairs at the colony. For the Northern Royal albatross, some details of breeding and breeding success are known from Pukekura Taiaroa Head (Robertson 1993, 1998; Sugishita 2016), but little else.

The aim of this study was to evaluate the usefulness of obtaining images regularly from trail cameras to gain insights into the behaviour and fate of adults and their offspring during the chick rearing period of the Northern Royal albatross and Northern Buller's mollymawk. The following specific tasks were undertaken.

1. Produce indices of the number of adult birds on land daily in relation to weather conditions and seasonal breeding activity, to help optimise the time of day for aerial monitoring of active nests when the number of non-nesting birds is lowest.
2. Determine the outcome of each monitored nest, whether and when a chick fledged or, if the nest failed, the time and apparent cause of failure.
3. Record any other notable events, including occurrences of chicks being fed; aspects of chick behaviour, such as fidelity to site; and interactions with other species, most notably with Northern giant petrel and brown skua | hākoakoa *Stercorarius antarcticus*.

Methods

The study was carried out on Motuhara (The Forty Fours or Bertier), situated at 43.9622° S, 175.8347° W, 42 km east of Rēkohu (Chatham Main I.). Motuhara consist of an 11.5 ha, 60-m high main island with a relatively flat 7.8 ha plateau, and several offshore stacks together covering a further 1.4 ha. All the work in this project was carried out on the main island.

Twelve trail cameras (11 Swift Enduro and one Reconyx Hyperfire 2) were deployed on the island in late-January 2021, 10 (five for each species) overlooking separate groups of nesting Northern royal albatrosses and Northern Buller's mollymawks, and two focusing on nesting Northern giant petrels. Only the data from the cameras aimed at the albatrosses and mollymawks are reported here. Their locations are shown in Fig. 1.

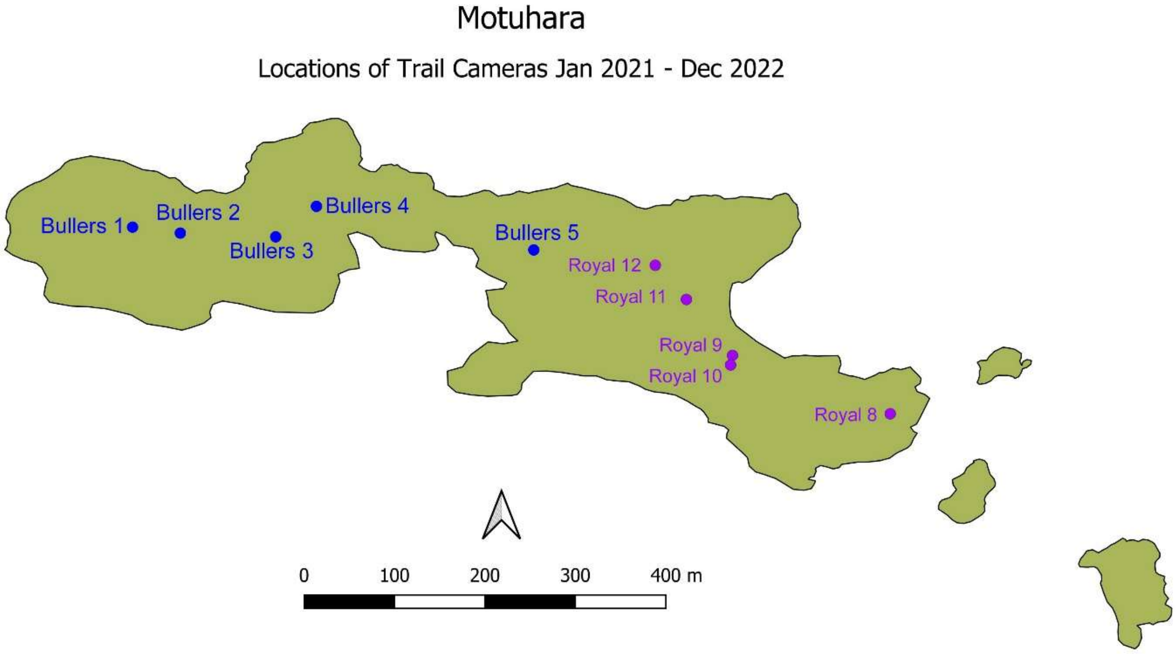

Figure 1. Locations of the trail cameras on Motuhara.

The Swift Enduro cameras were set to take one image every 30 minutes, day and night. The times on the cameras were set at Chatham Is summer time (DST) throughout, equivalent to UCT+13:45. The multi-shot function was turned off. Conversely, the Reconyx Hyperfire 2 camera was set both to take an image every 30 minutes and to respond to significant movement within the camera's field of view, in which case three successive images were taken at 1-second intervals. All images after dark were taken with a flash but the range of these was limited, and little useful information was obtained. Other details of the cameras and their functioning are given in Appendix 1.

Images of each of the five views of each species were analysed visually at the relevant intervals using ImageJ (https://imagej.nih.gov/). This software allows regions-of-interest (ROI) to be marked out on permanent digital overlays so that even when an image from a set is changed, the marked overlay remains in place. This allows the same sites to be viewed across time and for the activity at each to be recorded.

In each field of view, two kinds of regions of interest were drawn: an overall area in which all sites initially occupied by apparently nesting individuals were individually marked and monitored, and all individuals of the focal species, nesting or not, were counted. Any other notable occurrences such as the presence and behaviour of giant petrels or brown skua were also recorded. Examples of two views with marked ROIs are shown in Fig 2. In a few instances, a camera's field of view shifted slightly, either through being bumped or readjusted by MB after set-up or by being buffeted by the wind. In these few cases, the positions of the individual ROIs were adjusted to accommodate the change in view without affecting which sites were being monitored.

We follow the convention used by the Agreement on the Conservation of Albatrosses and Petrels in referring to the nesting season by the year in which the chicks fledged, in this case 2021.

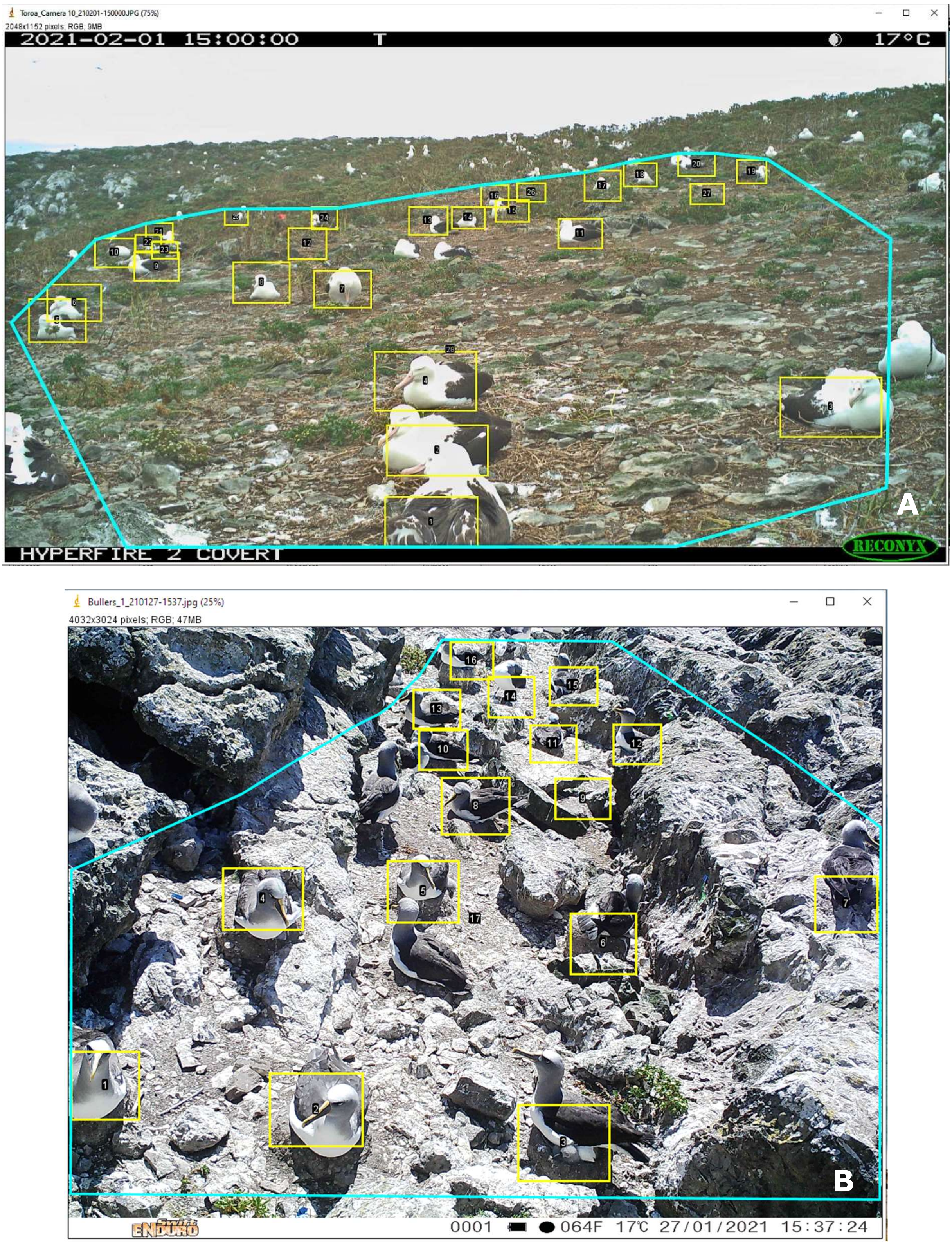

Figure 2. Two fields of view as examples of overall regions of interest (cyan polygons) and monitored individual nests (yellow rectangles): (A) from Northern royal albatross camera 10, Reconyx Hyperfire 2 with a 16:9 aspect ratio, and (B) from Northern Buller's mollymawk camera 1, Swift Enduro with a 4:3 aspect ratio. Note that in these views not all nests turned out to be active at the time. Some birds on nests here are accompanied by their partners, and some other birds are just loafing.

Indices of the number of adult birds ashore

For each overall ROI on each sampling occasion, the number of adult birds present were counted. A distinction was made between an adult brooding a chick (or incubating an egg) or sitting alongside one (guarding), and those not obviously associated with an active nest. For the individual ROIs, the presence or absence of an adult and/or a chick in that site was noted. If two adults were present, with one presumed to be the partner of the other, this was recorded as two birds present at that site. It was generally not possible to classify further those birds not obviously linked to a nest. They could have been individuals in transit to or from a nest elsewhere, or failed breeders, or prospective breeders in search of a partner or a potential nest site. Some were possibly outright non-breeders visiting or resting in the colony.

The total number of adults present within the overall ROI therefore those individuals associated with a nest plus those birds not obviously linked to one. For the purpose of calculating the numbers of additional birds present in each area during daylight hours, this was taken to be the difference between the number of active nests with an adult present and those not actively brooding or guarding a chick (including any partners of sitting birds).

The daily pattern of occurrence of individuals of both species on land was recorded every 30 minutes during daylight hours for the first week of observation (28–30 January to 2–5 February, the dates varying according to when all five cameras for each species were operating concurrently). Thereafter, until the end of the brood-guard stage, daily numbers of adult birds were recorded around solar noon and for one hour each side. After that, the total number of adults was recorded at weekly intervals.

Duration and timing of the brood-guard stage

The exact duration of the brood-guard stage could not be determined because the date when eggs hatched in individual nests was not known. On the few occasions when an incubated egg was visible, this was only at nests where the egg eventually failed to hatch. Adults brood newly hatched chicks tightly. Although there must be occasions when a chick is visible, such as when it is being fed or there is a change-over of parents at a nest, none were seen early enough to indicate that the chick had hatched within the last 24 hours.

The end of the brood-guard stage is conventionally taken to be the first occasion on which a chick is left along at the nest, even if only for a short period (Catry *et al*. 2006. 2010). The date and timing of this event was noted for all chicks of both species. The spread of these end-of-brood-guard dates should give a rough indication of the degree of breeding synchrony in these species. The end of the brood-guard stage is also significant because a chick's exposure to predation or adverse weather increases from then on.

Fate of nests

The attendance of adults at nests, the nest contents (when these could be determined), and the fate of the chicks (or, in a few cases, eggs) were recorded on each sampling occasion. If a chick died or disappeared, we went back through the images to determine what happened and when. Some Northern royal albatross chicks were mobile from an early age, soon after the end of the brood-guard stage, so if a chick was not seen on its nest, it was crucial to determine if it had died or had simply moved. If it had moved, a new ROI was created, linked to the original site, so as to continue following the fate of that chick.

Northern royal albatross chicks were generally highly mobile once their feathers had begun to develop, moving around the study areas and sometimes straying beyond the ROIs, even out of sight. In most cases, the birds returned periodically to their original nests before moving off again. Efforts were made to track these movements by cycling back and forward through successive images at 30-minute intervals to determine what was happening. Nonetheless, these movements created considerable uncertainty both in the eventual fate of individuals and when exactly they fledged, assuming they did. Apart from one observed death of a bird thought to have been an early-returning adult, but which could have been a particularly late-departing fledgling, no deaths were recorded among these older albatross chicks, so they were all assumed to have eventually fledged.

Northern Buller's mollymawk chicks generally remained on their nests until just before fledging. A few moved among nearby empty nests, especially if those appeared taller than their own. These birds were tracked in the same way by cycling back and forth through successive images to establish the likely movements. In the few days before fledging, however, when the young mollymawks were practicing wing-flapping, they moved more often and further, occasionally out of sight. Some appeared to return before leaving permanently; others did not and are assumed to have fledged at that point. That introduces some uncertainty, partly offset here by reporting fledging at weekly intervals.

Weather data

The temperature recorded on the images on each occasion was also noted. These readings may not accurately reflect the temperature of a site generally, depending on whether or not a camera was in the shade. Moreover, the temperature readings recorded on the Reconyx camera images were on average 7 °C higher than those recorded by the Swift Enduro cameras. Some of this may reflect variation in microclimate and exposure but given the narrow range of variation recorded among the other cameras (average 1.6 °C) there may be differences between these trail camera brands in how ambient temperature is assessed. These temperature data should be used circumspectly.

Additional weather data (daily rainfall; maximum and minimum temperature; wind run; 9 a.m. measurements of wind direction and speed; wind gust direction and speed; wet- and dry-bulb temperatures; incoming radiation; and mean sea level and station level pressure) were acquired from the National Climate Database (https://cliflo.niwa.co.nz/) for Chatham Island Aero Automatic Weather Station (network number K98617) situated 54 km away on Rēkohu (Chatham Main) at 43.81676°S, 176.47502°W, the closest continuously monitored weather station to Motuhara.

Daily rainfall and maximum and minimum temperature from the Chatham I. Aero AWS for the period 1/01/2021–30/09/2021 are shown in Fig. 3. Two features are notable: a 4-day period of maximum temperatures above 23°C, 25–28 January, during the end of the brood-guard stage for Northern Buller's mollymawk, and a week-long period at the end of February when daily maximum temperatures were above 22.5°C, followed by a wet spell in early March, around the end of the brood-guard stage for Northern royal albatross.

A wind rose showing the daily vectors for wind direction and wind speed (m/s) at 9 a.m. measured at the Chatham Aero AWS for the period 1/01/2021–31/03/2021 is shown in Fig. 4. The figure emphasises the predominance of wind from the northerly and south-westerly sectors during this period, the period of highest presence of Northern royal albatross and Northern Buller's mollymawk on Motuhara. Peak wind speed (11.1 m/s) and the longest daily wind run (925 km) occurred on 5/02/2021-6/02/2021, with the wind blowing predominantly from the south-east.

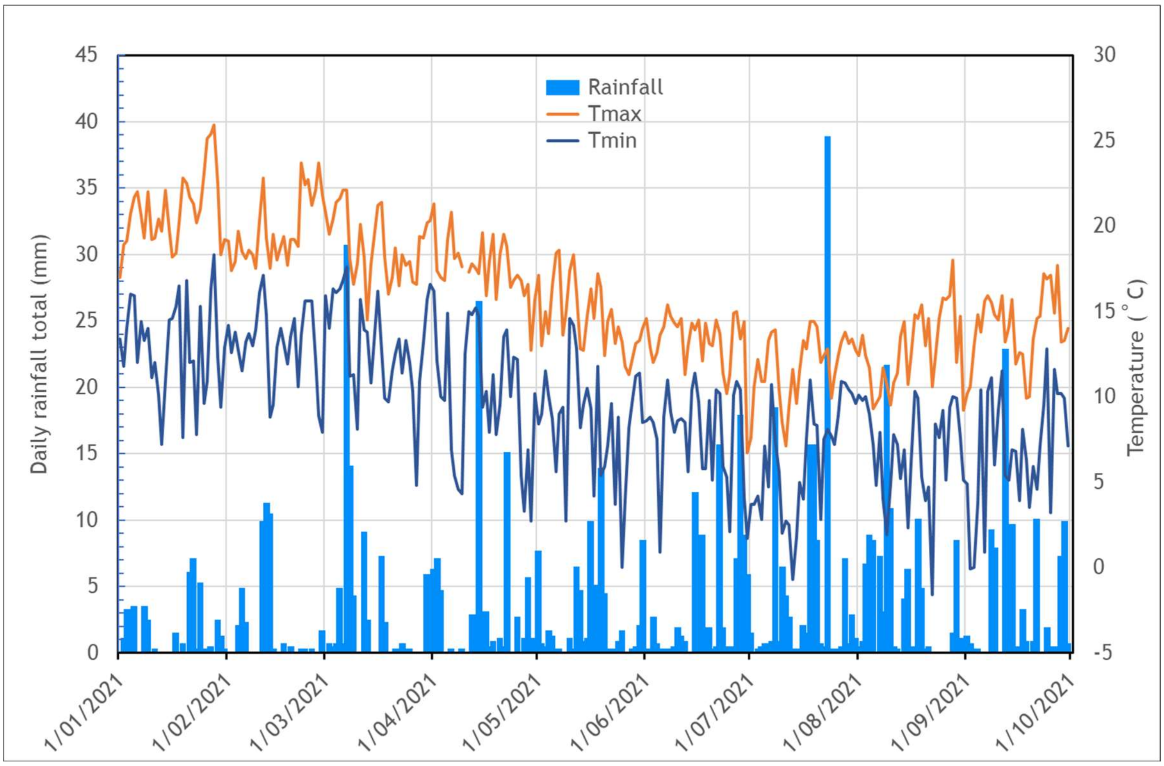

Figure 3. Daily rainfall (mm) and maximum and minimum temperature (°C) recorded by Chatham Aero AWS for the period 1/01/2021–30/09/2021.

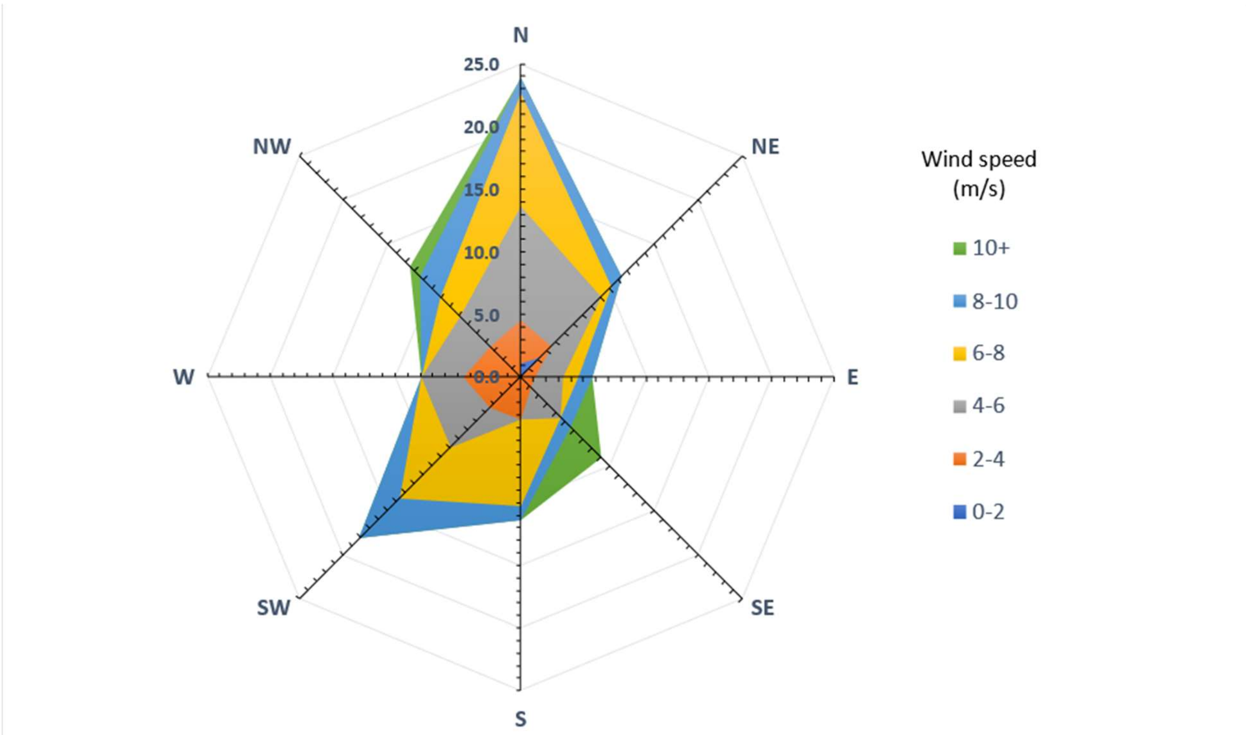

Figure 4. Wind rose for the period 1 January–31 March 2021 showing the daily vectors for wind direction and wind speed (m/s) at 9 a.m. measured at the Chatham Aero AWS.

Response to high temperatures

Towards the end of February, a period when afternoon temperatures reported on the camera images regularly exceeded 25°C, many chicks of both species were seen exhibiting signs of apparent heat stress. Closer examination revealed a graded response, ranging from birds initially just opening their bills, presumably increasing respiration rate and intensifying evaporative cooling, through to the chicks adopting an upright posture, often orientating towards the sun with head and neck extended and the gape fully opened, apparently gular fluttering. At the extreme, some chicks just curled up. In the case of Northern Buller's mollymawk chicks some had their necks and heads hanging over the nest rim. These postures were noted, where possible, but differentiating them consistently was difficult because of variations in the birds' positions.

Accordingly, a selection of clearly visible chicks at each of the five sites for both species were scored in a binary fashion (0 = no sign of heat stress; 1 = bird showing some sign of heat stress: bill open, gular fluttering, curled up) against the temperature recorded on the images. The percent of chicks showing some sign of heat stress was then calculated at each 1°C temperature interval. The surface incidence angles of incoming solar radiation between 10h00 and 18h00 during this period averaged 48.3° (daily range, 35.5°–67.0°).

Results

Northern royal albatross | Toroa

Presence of adults

The number of adult Northern royal albatrosses recorded on the ground was highest at the start of observations, declining sharply once the end of brood-guard phase was initiated (Fig. 5). Thereafter, the numbers present were low and intermittent, mostly comprising adults visiting their chicks, presumably to feed them. These visits were invariably short, lasting less than 30 minutes (*i.e.,* the same adult was seldom seen in successive images).

The number of adults started to increase from the end of September, accelerating in early October (Fig. 5). This reappearance of adults overlapped with the departure of the last fledging chicks, sometimes making it difficult to distinguish between the two. This adds further uncertainty to the precise timing of fledging, already ambiguous because of the chicks' tendency to wander around the area, making it difficult to track individuals until they fledged.

The data shown in Fig. 5 come from counts made around solar noon (13:12–13:48). At least initially, during the late incubation and brood-guard stages, extra birds visited the areas, many if not most of them non-breeding birds. Numbers rose during the late afternoon and evening declined slightly overnight, then further during the day to a minimum around midday (Fig. 6).

Much day-to-day variation in the numbers of these extra birds is apparent. Some of this could have been due to some combination of wind strength and direction. The high numbers recorded on 30/01/2021 and 31/01/2021 were days with average or below-average wind runs for the period, both from the south. Conversely, the low numbers recorded on 2/02/2021 were on a day with a strong south-easterly wind (9 a.m. wind speed at Chatham Aero AWS recorded as 10.3 m/s and a daily wind run of 789 km, equivalent to a daily average wind speed of 8.6 m/s). Extending this assessment further was complicated by the gradual drop in numbers of adults overall as the end of the brood-guard stage began.

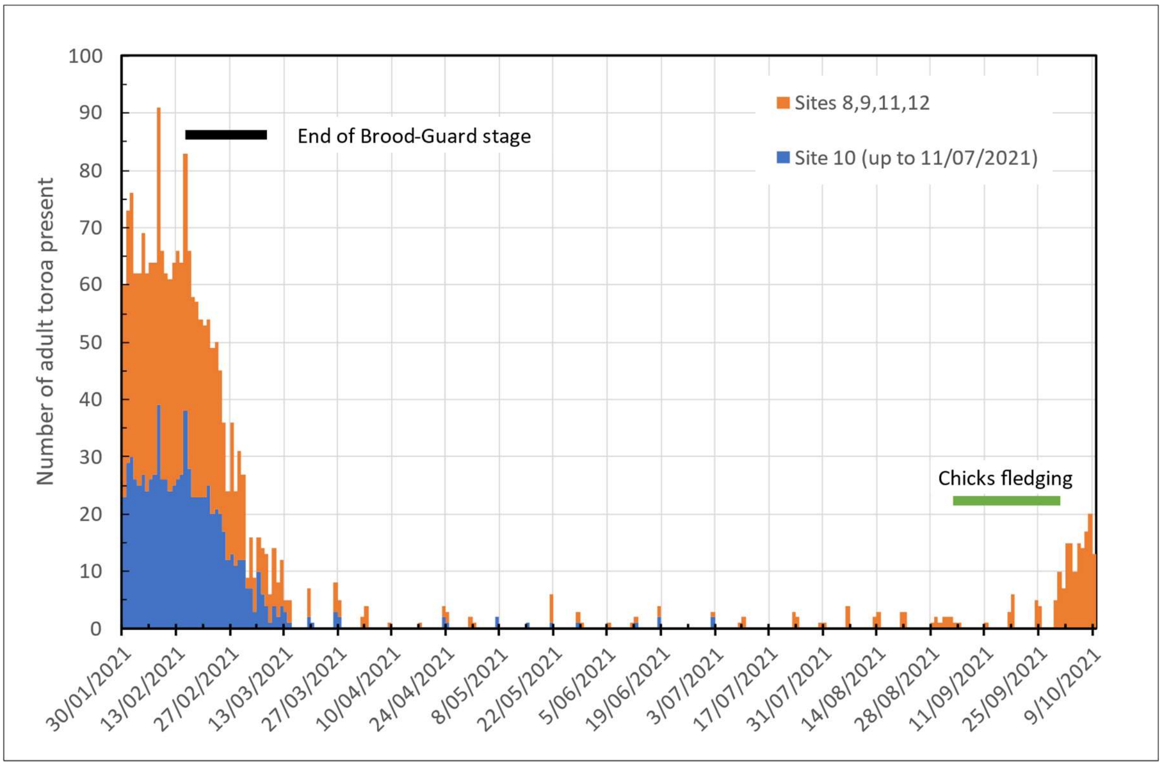

Figure 5. Total numbers of both breeding and non-breeding adult Northern royal albatross present around solar noon at five sites monitored by trail cameras. Site 10 was monitored by a Reconyx camera, which stopped operating just after midnight on 12/07/2021. The remaining sites were monitored by Swift Enduro cameras, which continued functioning until at least 9/10/2021.

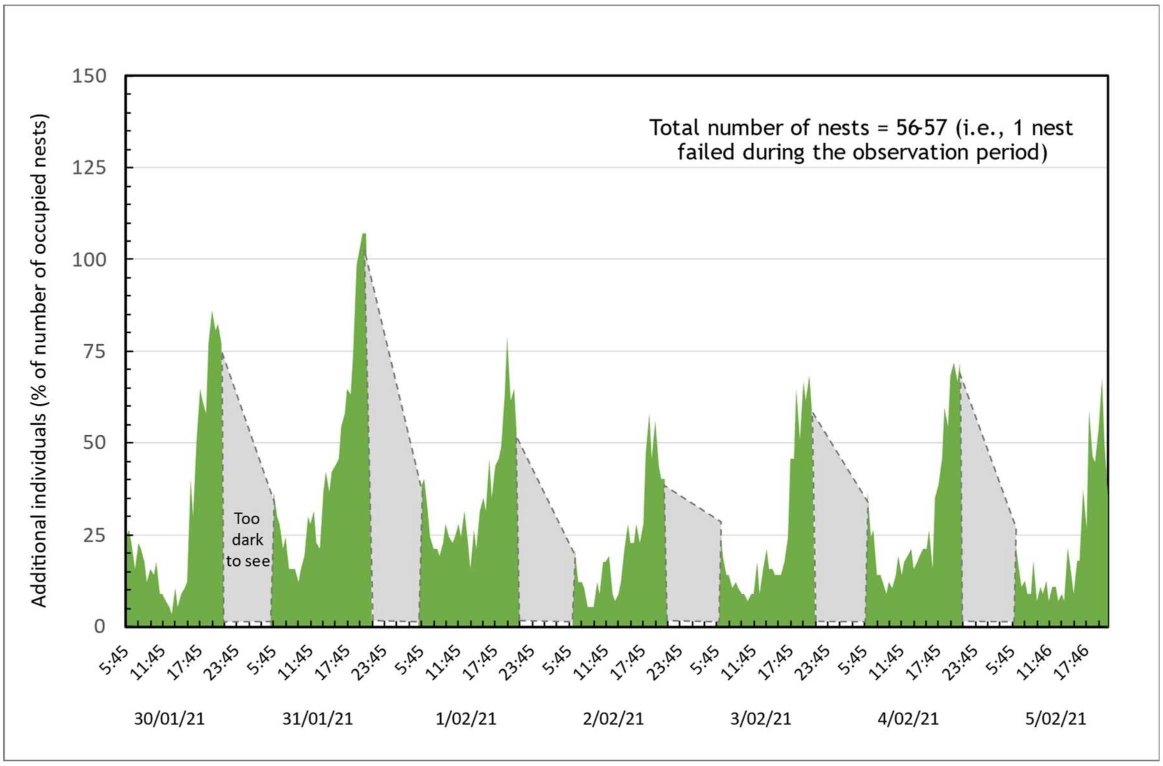

Figure 6. Daily variation in the number of additional Northern Royal Albatross—birds on land but not on nests, all five monitoring areas combined—on Motuhara, late January-early February 2021.

End of brood-guard stage

The first chick was left alone on 15/02/2021 and the last two on 8/03/2021, a spread of 22 days, normally distributed around a mean of 25/02/2021 (Fig. 7). About a third of pairs (32%) left abruptly within a day. The others returned intermittently for up to 11 days to brood or guard their chicks (average 5 days). During this transitional period, chicks were on their own, on average, 56% of the time (range 11–96%), with one or very occasionally two adults present, either brooding or guarding the chick the rest of the time (44%, range 4–89%). This continued, if intermittent, presence at a nest after the end of the brood-guard stage enabled parents to shelter their chicks against inclement weather. For example, in early March during a spell of wet weather, chicks that were not brooded soon became sodden. One chick died during this wet period, and the wet weather may have caused the death of two others, but these were all at difficult-to-see distant nests. The dates of the end of the B-G stage and the duration of the transitions were uncorrelated.

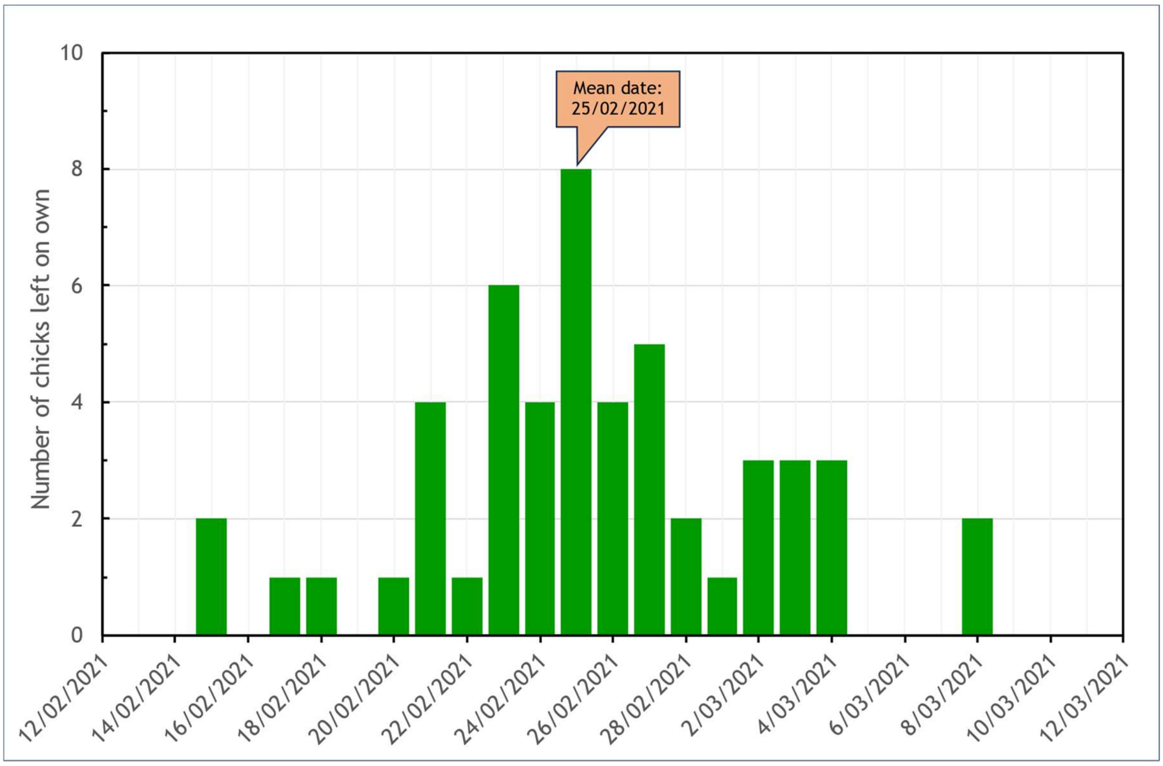

Figure 7. End of brood-guard stage in Northern royal albatross on Motuhara during the 2021 breeding season. The date refers to the first occasion when the chick was left alone, even if only briefly.

Chick-rearing and fledging

Northern royal albatrosses were still incubating eggs or brooding recently hatched chicks when the cameras were installed. Overall, 62 pairs were monitored during this study, of which four (6%) turned out eventually to be sitting on empty nests, or ones that had failed before the cameras were set up. Of the remaining 58 active nests, 23 were being monitored by the Reconyx camera. This stopped working on 11 July 2021, at which point 19 of the original 23 chicks were still alive. No certain deaths among chicks were recorded from this date onward among the 29 chicks alive and being monitored by the other four cameras: all fledged. Assuming therefore that all 19 chicks under observation through the Reconyx camera also survived to fledging, 48 Northern royal albatross chicks overall apparently fledged (83% fledging success).

Among the causes of nest failure, one was due to abandonment of an unhatched egg towards the end of February, when the brood-guard stage was ending at other nests. Three chicks died while still very small, so presumably soon after hatching. Four other chicks died suddenly, one following a wet spell, one during an extremely hot spell (the temperature recorded on the Reconyx camera rose from 24°C to 40 °C in just 5 hours), and two where the chicks looked sick before they died, both with soiled faces. The causes of mortality of the remaining four chicks are unknown because these chicks were distant. One of these had wandered a short distance away from its nest before it died, but it is unclear if this had any bearing on its subsequent death. At least one of its parents was present some time before and after it died, so hunger-induced movement seems unlikely.

We do not know the eventual fate of the 19 chicks that were alive in the area covered by the Reconyx camera when it stopped functioning on 7/07/2021. We assume that they all fledged successfully, based on the absence of any mortality among the 29 chicks being monitored through the other cameras after early July and fledging. Fledging dates are therefore known only for these latter chicks but, even then, these are approximate. We cannot assign a precise departure date to any particular chick because of the birds' habit of wandering widely during the pre-fledging period (including outside chicks straying into the monitored areas).

Matters were further complicated by reappearance of adult toroa before fledging was complete. Fledglings on the point of departure were barely distinguishable from adults at a distance, other than by using tentative behavioural cues, such as persistent preening and an upright 'sitting-on-tarsus' posture.

The approximate departure dates of fledglings was therefore based on daily changes in 'roll calls' of the number of chicks present each day in each area, excluding, where possible, the chicks suspected to have come from outside the area. Lumped into weekly intervals, these are shown in Fig. 8, along with information on the timing of nest failures. The few failures that were recorded were concentrated at the start of the fledging period, during and immediately after the brood-guard stage.

Response to rising temperatures

On hot days, when ambient temperatures exceeded ~20°C, chicks showed increasing signs of heat stress. The general response of young toroa chicks to rising ambient temperatures, is shown in Fig. 9. The response was graded, with increasing numbers of chicks opening their bills, presumably panting, as temperature rose beyond 20°C, gradually transitioning to assumed gular fluttering with wide open gapes along with an upright posture. Above 35°C, some chicks just curled up, presumably an extreme response to heat loading brought on by increasing difficulty in maintaining evaporative heat loss.

The variability in the data probably reflects a more complex thermal environment than one simply indexed by the temperature recorded on the images, especially given that the Reconyx camera seemed to record higher temperatures than the four Swift cameras. Differences in orientation and exposure to the prevailing winds among the sites could also have been a factor.

Heat stress may have been the cause of at least one death, a chick that died on 27/02/2021, one of the hottest days recorded, when ambient temperature reach 40°C at 16h30 (although the chick died before then, when the recorded temperature was only 28°C).

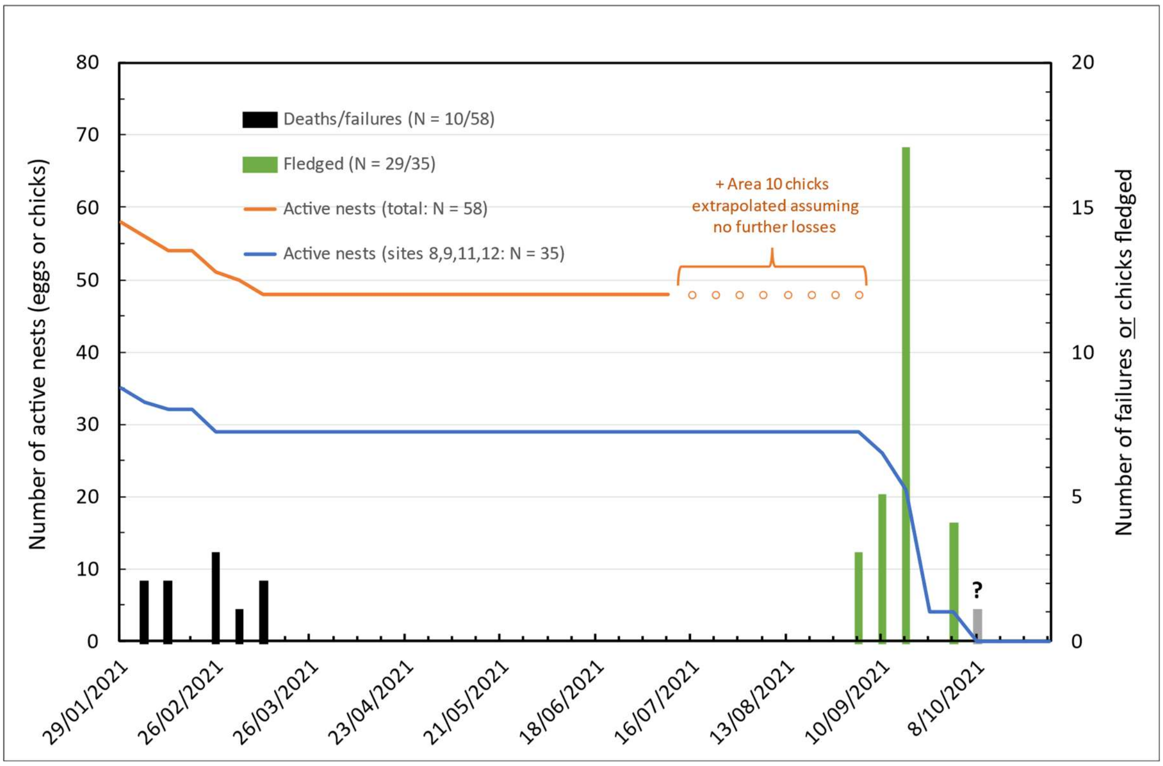

Figure 8. Fate of Northern Royal Albatross nests and chicks during the chick-rearing period on Motuhara during the 2021 nesting season. The question mark signifies one death that could have been a fledgling or, alternatively, a returning adult. It wasn't possible to distinguish the two.

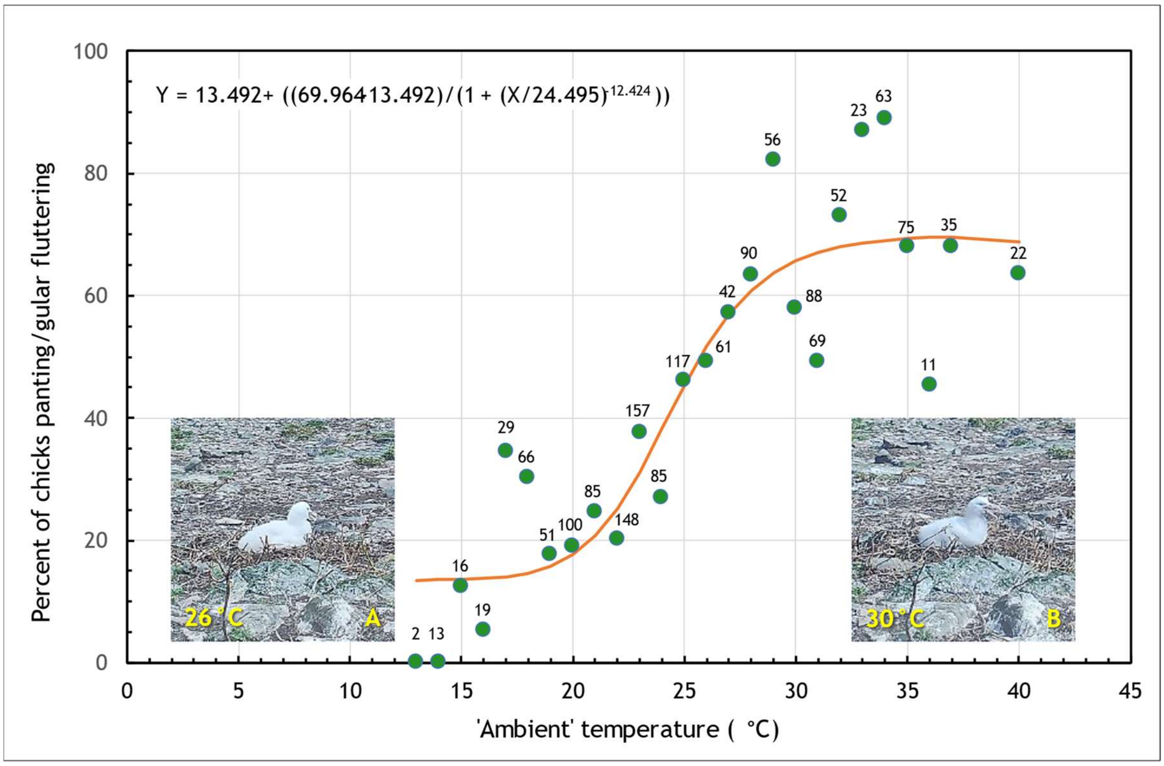

Figure 9. Response of 36 Northern royal albatross chicks to rising ambient temperature, indexed as the percent of chicks panting (A) or gular fluttering (B) at each recorded temperature (1575 observations overall; sample sizes at each temperature are shown on the graph). The line describing the shape of the overall relationship is a Four-Parameter Logistic Regression (4PL) curve. This curve is symmetric around its inflection point (24.5°C; AAT Bioquest 2023).

Northern Buller's mollymawk | Hopo[1]

Presence of adults

As with the Northern royal albatross, the numbers of hopo were highest at the start of the study in late January, when most nesting birds were brooding chicks (Fig. 10). Once the end of the brood-guard stage was underway, the numbers of birds present declined sharply, before rising again in early October as adults returned. In contrast to toroa, however, many non-breeding mollymawks, or those that had failed earlier in their nesting attempt, remained at these sites, occupying empty nests or sitting alongside a bird on one.

Of the 86 nest sites marked for monitoring during this study, 28 (33%), proved to be empty, although they were occupied by one or more birds at some stage. Attendance at these empty nests was more than coincidental. On average, the nests were occupied by one or both birds 65% of the time (S.D. ± 17%, range 8–89%), with single birds accounting for 76% of the occasions on which the nest was occupied. The average duration of stay, from the start of observations (31/01/2021) onwards, was 58 days (range 6–120 days). Three of these birds left late, on 22/05/2021 (2) and 29/05/2021 (1), respectively (Fig.10).

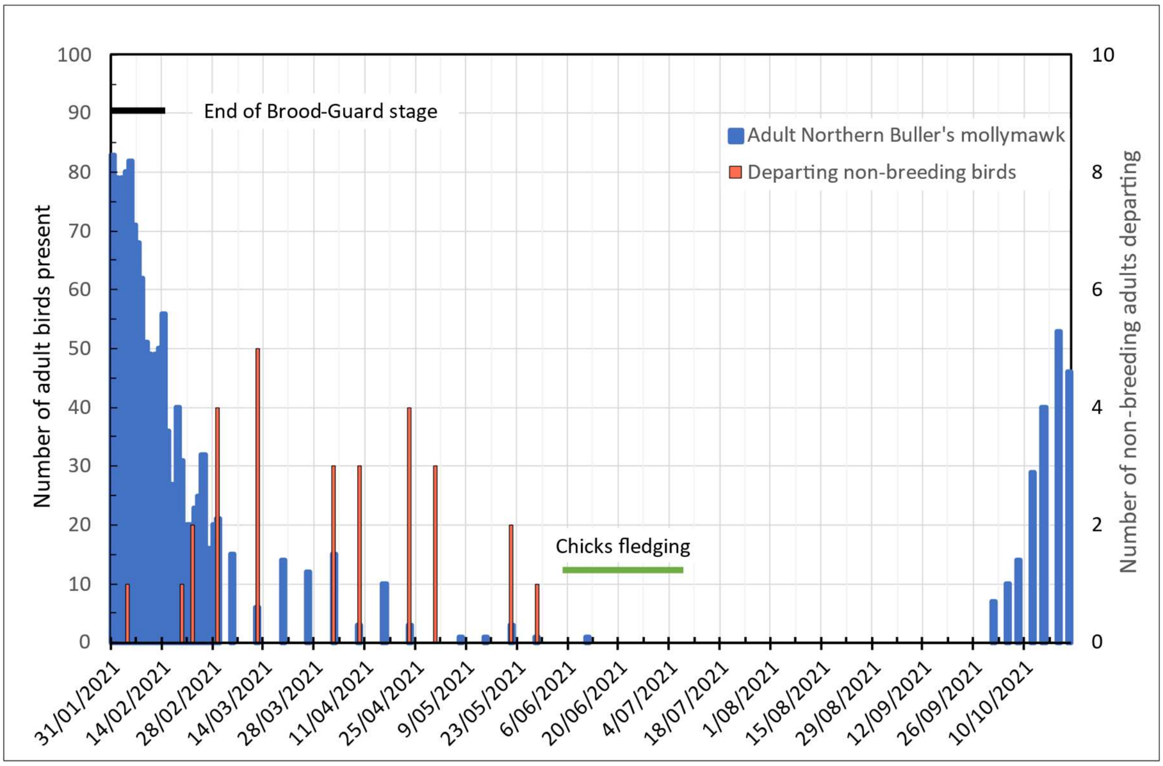

Figure 10. Presence of both breeding and non-breeding adult Northern Buller's mollymawks at five sites, all monitored by Swift Enduro trail cameras. Counts from all five sites combined started on 31/01/2021. Not all cameras were functioning before that. The non-breeding birds were ones that were present at empty nests, perhaps ones that failed earlier. The departure of these birds was taken to be the day after they were last seen at their nest. The counts of adults returning to the monitored areas in October 2021 are incomplete because one of the trail cameras stopped working on 5/10/2021.

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[1] Northern Buller's mollymawk is known at *toroa* in te reo Māori, a name that is applied to several albatross and mollymawk species, including the Northern royal albatross. Here we use the Moriori name for the mollymawk, *hopo*, to distinguish it from the royal albatross, which is more widely and commonly referred to as *toroa*.

The pattern of occurrence of adults during the day was similar to that of toroa, with numbers lowest around midday, then rising to a maximum at dusk before falling slightly overnight, then more rapidly towards the following midday (Fig. 11). There was no obvious association between the numbers of birds ashore and any simple weather variable. The highest number present (57 on 29/01/2021 and 55 on 31/01/2021) occurred on days of moderate wind (7.9 and 6.8 m/s from the SW and S octants, respectively).

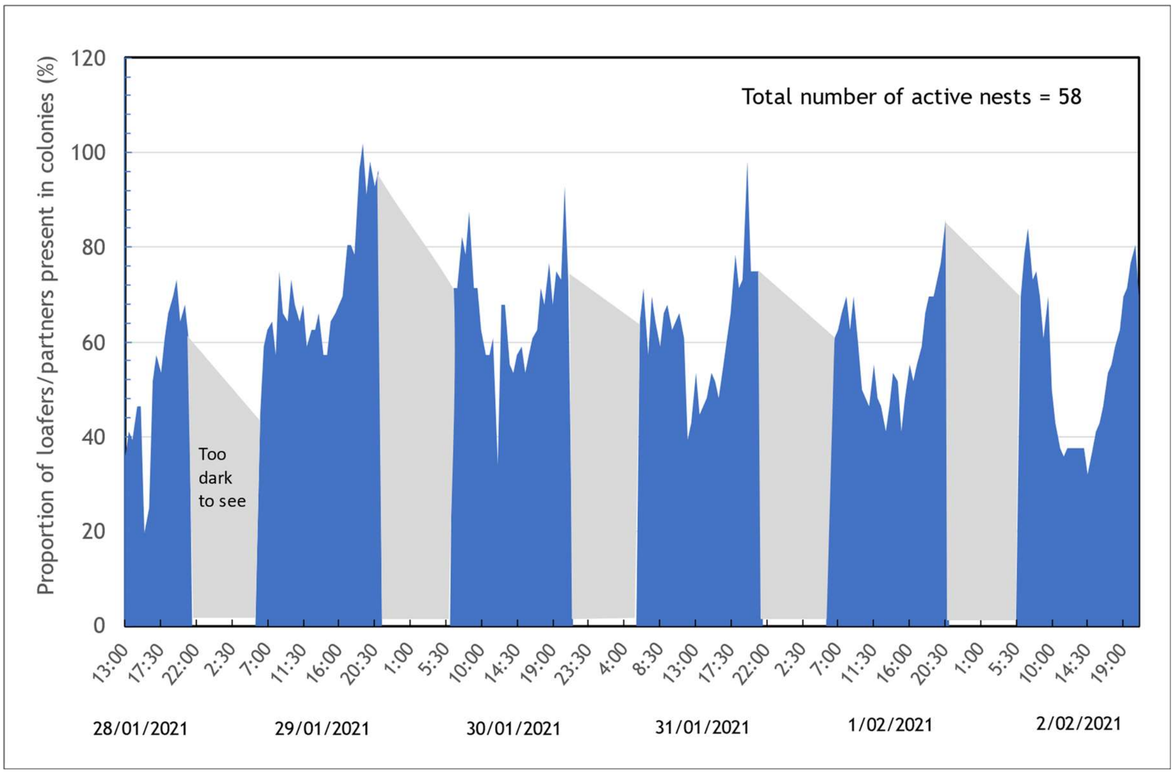

Figure 11. Daily variation in the number of additional Northern Buller's Mollymawk, expressed as a percentage of those not on active nests, Motuhara, late-January - early-February 2021.

End of brood-guard stage

The end of the brood-guard stage started soon after the first cameras were installed, with two small chicks being left alone in the afternoon on 26/01/2021 (one only briefly: ~30 minutes). Both were being closely brooded immediately before that. The last chick left alone was on 15/02/2021, 21 days after the first (Fig. 12). The distribution of these departure dates overall was slightly positively skewed, with a median date of 8/02/2021.

More than half of the departures (54%) were concluded within a day, with 37% not being seen again until much later. A further 44% of nesting birds returned periodically for 2–6 days to brood (38%) or sit alongside their chick, guarding it (16%). Two parents were present together at the nest on only 6% of these occasions. For the remainder of these transitional periods the chicks were on their own (46%). One pair brooded (98%) or guarded (0.4%) their chick for 12 days after leaving it alone initially. Overall, this chick was left alone on only 3 of the 246 occasions (1.2%) on which it was monitored during this period. When it ended, the parents' departure was abrupt. As with toroa, the dates of the end of the B-G stage and the duration of the transition periods were uncorrelated, although the two earliest pairs that stopped brooding/guarding had the longest transition periods.

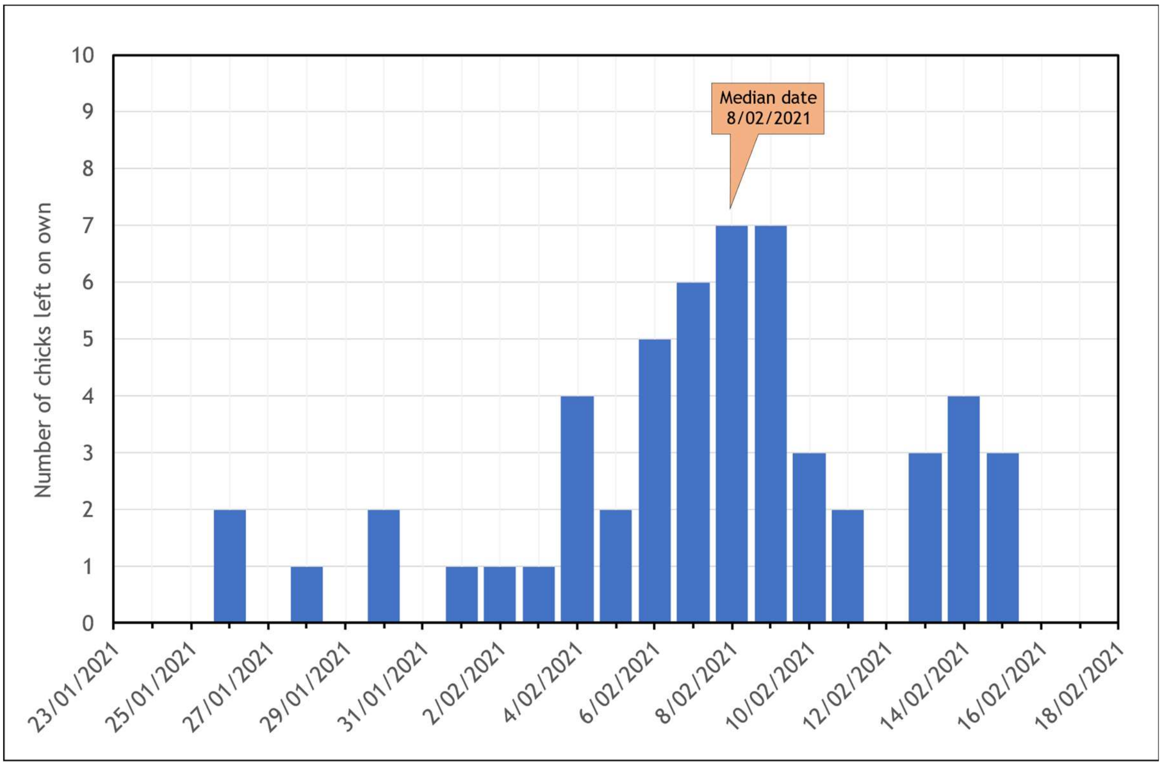

Figure 12. End of brood-guard stage in Northern Buller's mollymawk on Motuhara during the 2021 breeding season. The dates are the first occasions when individual chicks were left alone, even if only for an hour or two.

Chick-rearing and fledging

Of the 58 active nesting pairs present at the start of observations, 39 successfully fledged a chick (67% fledging success). Of the 19 that failed, one involved the carcass of a young chick lying in the nest at the start of observations. At least one parent was present on this nest on 44% of 321 occasions up to 23/02/2021, when it was last seen on the nest. Two birds were present together on 28% of these occasions. The chick is assumed to have died soon after hatching, the cause unknown.

Three nests contained incubated eggs that eventually failed to hatch and were kicked out by the nesting birds. One of the eggs was first seen outside the nest on 28/01/2021 but had been incubated up to then. A pair continued to occupy this nest for almost another month until 26/02/2021. The eggs at the other two nests were eventually abandoned (kicked out of the nests) on 13/02/2021 and 22/02/2021, respectively, when most other nests contained unattended chicks.

Two chicks apparently died of heat stress, one on 28/01/2021, when the camera-recorded mid-afternoon temperature reached 35°C. The other chick died overnight on 4/03/2021 when the chick, sitting in full sunlight, looked heat-stress (gular fluttering), although the camera-recorded temperature was only 20°C (but then this camera was in the shade). Other possible weather-related deaths were of chicks that died on 7/03/2021 and 1/7/2021, during and following particularly wet spells, respectively. Three chicks looked unwell before they died, one in late-February (it looked underdeveloped); one in mid-May; the other in mid-June. The causes of mortality of the other chicks are unknown.

The timing of these failures was spread throughout the fledging period (Fig. 13), in contrast to those of toroa, which occurred when the chicks were still young and covered with down. Five deaths occurred after mid-May when the chicks were already well feathered and, in the case of two of these, they died after others had already begun to fledge. Whereas one of these had ragged-looking underbody plumage, which may suggest some sickness, the other bird looked fine until it just flopped over and died.

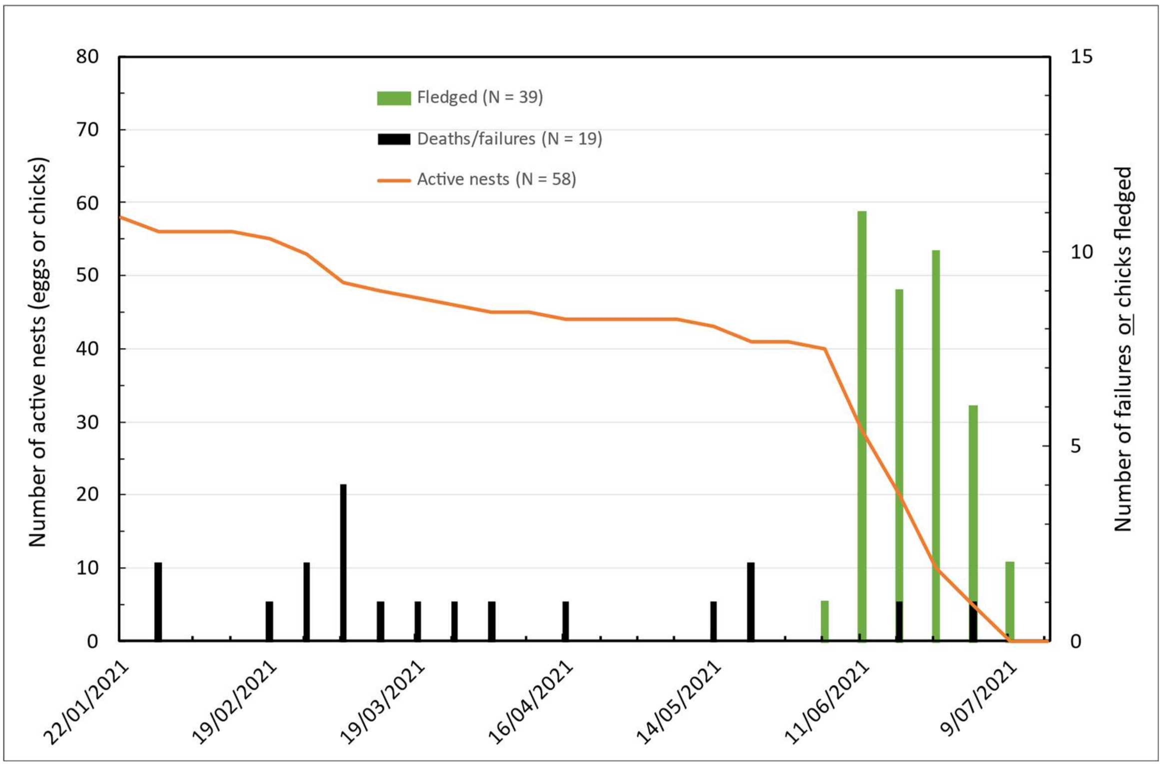

Figure 12. Fate of Northern Buller's Mollymawk nests and chicks during the chicks rearing period on Motuhara during the 2021 nesting season. Tthe vertical bars are not additive.

The first hopo chick fledged on 4/06/2021 and the last just over a month later, on 6/07/2021 (Fig. 13). The precise dates have some uncertainty around them because they represent when the chick disappeared from the field of view of the cameras, which may not necessary be when it flew off the island. By plotting the dates at 7-day intervals, the effect of this uncertainty on the overall pattern is perhaps somewhat reduced.

Response to rising temperatures

Hopo chicks showed a clear response to rising ambient temperatures (Fig. 13). As with toroa, the chicks' response was graded, with birds initially just opening their bills as temperatures rose above 10–15°C (Fig.13, inset A), transitioning to gular fluttering with gapes wide open, necks and heads elevated, and in some cases ruffled plumage at higher temperatures. Above 35°C, some chicks seemed to collapse into a bundle, sometimes with their necks and heads hanging over the nest rim, apparently in extreme distress.

Heat stress may have been the cause of at least two deaths. One chick died on 27/02/2021, when ambient temperature at the site reached 35°C at 17h13, at which point the chick curled up and died. The second died on overnight on 4/03/2021 following a day when the recorded temperature reached 20°C, when the chick was seen in the sun, panting.

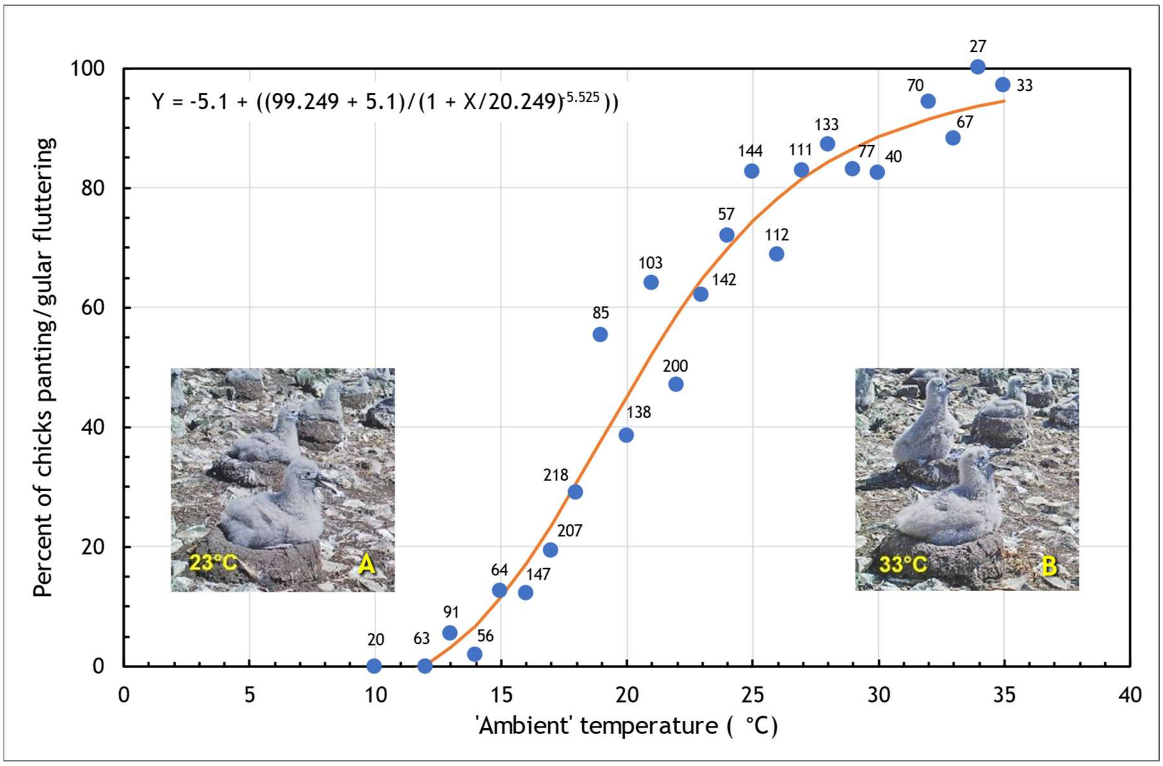

Figure 14. Response of 49 Northern Buller's mollymawk chicks to rising ambient temperature, indexed as the percent of chicks panting (A) or gular fluttering (B) at each recorded temperature (2405 observations overall; sample sizes at each temperature are shown on the graph). The line describing the shape of the overall relationship is a Four-Parameter Logistic Regression (4PL) curve. This curve is symmetric around its inflection point (20.3°C; AAT Bioquest 2023).

Discussion

The analysis of these trail-camera images has provided several insights into the fate of fledglings of both toroa and hopo during the nestling stage. Mortality among toroa fledglings was concentrated around the time when the chicks were small, soon after hatching and just after the end of the brood-guard stage. In contrast, mortality among hopo chicks was spread throughout the nestling period, including some during the fledging period. Whether these are normal patterns or simply a result for a particular year from a small sample size is a question that can only be answered with more data from different years and, ideally, larger sample sizes.

Overall, fledging success for toroa and hopo fledglings was 83% and 67%, respectively. Around the time the cameras were set up in January 2021, one of us (MB) recorded the state of 159 toroa nests found in five 20 * 20-m quadrats (Bell 2022). Of these, 13 (8.2%) had already failed (*i.e.,* survival to the start of the nestling period was 91.8%). Combining the data from these two sources suggests an overall nesting success of 76%. This is higher than that recorded in recent years on Motuhara from an analysis of aerial photographs, 58–67% (Frost 2017, 2019). The small sample size, non-random placement of the cameras, a different method of assessment, and a separate nesting season may account for the difference. This figure should be used cautiously outside the context from which it was derived.

A similar survey of hopo nests inside ten 10 * 10-m quadrats was also carried out in late-January 2021 (Bell 2021). At the time of the survey, 24% of nests had failed; therefore 76% of eggs and chicks survived to that stage. Assuming that these represent survival up to the time that the trail cameras were installed, then overall nesting success can be estimated by combining the data from these two sources: 51% (76% near-hatching success x 67% fledging success). Note that the failure of three eggs to hatch during the trail-camera observations and accounted for here in the calculations of fledging success, would lower actual hatching success and increase fledging success slightly if properly considered in calculating overall nesting success.

Because Northern Buller's mollymawk fledge in mid-winter, there are no prior estimates of overall nesting success for this taxon. For Southern Buller's mollymawk *Thalassarche bulleri bulleri*, breeding on the Snares/Tini Heke and Solander/Hautere islands, Paul Sagar (*in litt*. to Johannes Fischer, 7/05/2023) estimated breeding success (= nesting success for a species that lays one egg) for 16 years over the period 1972–2004 at 72.1% (SD 6.5%, range 57.3–86.3%). This is notably higher than the estimate derived here for Northern Buller's mollymawk. Small same size, non-random positioning of the cameras, and the reliance on having to combine two different methods of assessing hatching success and fledging success, respectively, are all caveats that should be applied to this estimate. It may not be broadly representative.

Some insight into causes of mortality were obtained although, again, the sample sizes are small. For Northern royal albatross, the main mortality events were chicks dying soon after hatching (30%), presumably through illness, judging from the demeanour of the chicks beforehand (20%), and adverse weather (heat stress and cold, induced by becoming sodden during prolonged rain events, each 10%). Egg failing to hatch (10%), and unknown causes of death (20%) made up the balance.

For Northern Buller's mollymawk, the causes were unknown in 42% of occasions; adverse weather (both heat stress and cold, wet conditions) together comprised 21% of the deaths (evenly split between the two); presumed illness and eggs failing to hatch each accounted for about 16% of the deaths; and one chick died soon after hatching (5%).

An analysis of images taken of both species during the last week in February and early March, around the end of the brood-guard stage (toroa) or soon after (hopo), showed many instances of chicks experiencing heat stress. This was a period of notably high air temperatures, both as recorded on the trail-camera images and in the weather data from Chatham Is Aero AWS, generally higher than recorded at other times when the trail cameras were functioning. Heat stress is a known cause of mortality among adult nesting toroa (Robertson 1998, 2001), and has been recorded in other seabirds as well (*e.g.*, Cook *et al*., 2020).

In both species, the response was graded, with emerging heat stress becoming apparent initially through the chicks opening their bills and presumably increasing respiration rate, thereby achieving some measure of evaporative cooling. As temperatures rose above ~25°C, the chicks' response transitioned through to the gape being fully opened, evidently using gular fluttering to achieve greater evaporative cooling. The chicks also oriented themselves towards the sun, thereby reducing their surface area of exposure. Some chicks also appeared to fluff out their natal down, presumably to increase air flow and convective heat loss. A similar range of responses has been noted for the bank cormorant *Phalacrocorax neglectus* (Cook *et al*. 2020). At the extreme, several chicks just curled up: in the case of Northern Buller's Mollymawk, some with their heads hanging over the nest. At least one of these chicks subsequently died.

The T_{50} inflection points of the logistic curves describing the relationship between temperature and percent of birds panting or gular fluttering, 20.3°C and 24.5°C for Northern Buller's Mollymawk and Northern Royal Albatross, respectively, suggest that the larger chicks of the latter species had a greater thermal capacity and so were better able, up to some point, to accommodate rising temperatures. Of course, the temperatures recorded on the trail-camera images are almost certainly different from the operative temperatures being experienced by the chicks. (The operative temperature is one that condenses both microclimate and an organism's morphology into an index of thermal stress: Bakken & Angilletta 2014.) Nevertheless, in spite of this drawback, the overall relationships between recorded temperature and the percent of birds panting at each level well illustrates a pattern of rising heat stress with a hotter environment, however measured. This should raise concerns about the likely impacts of rising temperatures caused by global climate change.

The duration of the brood-guard stage could not be determined for either species because the dates on which the eggs hatched in individual nests was not known. Some eggs of both species had already hatched by the time the cameras were set up. This also means that the spread of egg-laying could not be determined, though the incubation period almost certainly varies among individuals. Nevertheless, the duration of the period over which brood-guarding ended, 22 days in Northern royal albatross and 21 days in Northern Buller's mollymawk, was similar. It serve as a rough guide to the spread of laying dates.

Viewing images at regular intervals provided an opportunity to observe interactions between members of a pair, and between parents and their chicks. The frequency of feeding could not be reliably determined because visits by parents to their chicks were usually less than 30 minutes (parents normally seen in single images only, if at all). Some instances of feeding were seen but not sufficiently often to draw a timeline. Other interactions, such as mutual or unilateral grooming were often seen among pairs, especially non-nesting hopo. This, together with the prolonged presence of individuals and pairs at empty nests, suggests a premium both on maintaining the pair bond and holding on to a nest site. Almost no direct interactions with either giant petrels or skuas were noted, other than when these species were scavenging carcasses (many carcasses went untouched).

The trail cameras were not without limitations. First, as often observed, especially among toroa chicks, the birds' tendency to wander often took them out of view. When a bird reappeared it was assumed that this was the one that had wandered off, but this is not certain. Likewise, when birds were about to fledge, they did not necessarily leave direct from their natal area. This was especially the case for hopo, some of which were nesting in rocky gullies. Thes birds had to leave these gullies, taking them out of view. We do not know if they fledged right away or spent time practising lift-off elsewhere.

Second, the resolution of the cameras (Swift Enduro, 12.2 Mpx; Reconyx Hyperfire, 2.4 Mpx), was adequate for giving broad views of an area, but much less useful for seeing fine detail, especially features at a distance, such as a chick dying or distinguishing between a chick about to fledge and a newly arrived adult, something that proved particularly difficult when adult Northern royal albatrosses returned to the island before the last of the chicks had fledged. The images rapidly became pixellated when magnified, so that the fine details of the pale edging of a juvenile's feathers (see frontispiece), could not be seen. Obviously, there is a trade-off between getting wide views of an area, thereby encompassing a reasonable sample of nesting birds, and having sufficient resolution to be able to discern fine details, with the former clearly being the priority at this stage. Determining some details, if considered important, may need to be explored in other ways.

Third, the Swift Enduro cameras functioned for an impressive 268 days on average (SD 7.1 days, range 253–271 days). This would just cover the entire breeding cycle of Northern Buller's mollymawk (assumed nesting cycle of 235 days) if the cameras were in place and started in early October but would still not cover the breeding cycle of the Northern royal albatross (estimated duration 320 days). Whether deactivating the flash and switching the camera off during the night would extend battery life still has to be tested. Battery capacity may also be adversely affected by low temperatures (there was at least one day when temperatures, at least as measured by the cameras, fell below freezing).

The Reconyx camera stopped working after 163 days. Undoubtedly, part of this was because the motion sensor was switched on, causing the camera to take three successive images at 1-second intervals whenever the motion sensor detected movement within range (30 m, according to the manual). As a result, the camera took 61,055 images, almost seven times as many as the average for the Swift Enduro cameras for the same period. Switching off this function would almost certainly extend the camera's batteries life but by how much is unknown. Conversely, having images triggered by motion within 30 m of the camera could be useful in documenting the frequency with which adults visit their chicks to feed them. This analysis remains to be done. It will require searching through about 48,000 images taken during the first half of the toroa chick-rearing period (mid-March to mid-July).

Recommendations

Despite the labour-intensive work involved in analysing such a large number of images, further years of deploying the cameras are recommended. (Almost 97,000 images are already available to 2022, including 71,000 from the Reconyx camera, many of them capturing motion.) There are also two sets of images covering nesting Northern giant petrels (and a parallel set for 2022) that need to be analysed. These should focus on attendance, which appeared to be highly variable in other images (where it was noted), and overall nesting success.

Analysing the 2022 images sets should indicate to what extent the outcomes seen in 2021 are similar. If they differ, then there is some merit in persisting with the present locations, to build the picture. If they are the same, then some thought should be given to repositioning the cameras so that they are better placed to answer new questions.

Acknowledgements

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References

AAT Bioquest, Inc. (2023, July 27). Quest Graph™ Four Parameter Logistic (4PL) Curve Calculator. AAT Bioquest. https://www.aatbio.com/tools/four-parameter-logistic-4pl-curve-regression-online-calculator.

Bakken, G.S., Angilletta Jnr, M.J. 2014. How to avoid errors when quantifying thermal environments. *Functional Ecology,* **8**: 96–107.

Bell, M. 2021. Motuhara seabird research: field trip report January 2021. Report prepared for the Conservation Services Programme, Department of Conservation. 12 pp.

Bell, M. 2022. Motuhara seabird research: field trip report January 2022. Report prepared for the Conservation Services Programme, Department of Conservation. 12 pp.

Catry, P., Phillips, R.A., Forcada, J., Croxall, J.P. 2006. Factors affecting the solution of a parental dilemma in albatrosses: at what age should chicks be left unattended. *Animal Behaviour*, **72**: 383-391.

Catry, P., Phillips, R.A., Foster, I.P., Matias, R., Lecoq, M., Granadeiro, J.P., Strange, I.J. 2010. Brood-guarding duration in black-browed albatrosses *Thalassarche melanophris*: temporal, geographic and individual variation. *Journal of Avian Biology*, **41**: 460-469.

Cook, T.R., Martin, R., Roberts, J., Häkkinen, H., Botha, P., Meyer, C., Sparks, E., Underhill, L.G., Ryan, P.G., Sherley, R.B. 2020. Parenting in a warming world: thermoregulatory responses to heat stress in an endangered seabird. *Conservation Physiology*, **8**(1): coz109; doi:10.1093/conphys/coz109.

Frost, P.G.H. 2017. Aerial census of Northern Royal Albatross (*Diomedea sanfordi*) fledglings on Rangitatahi (The Sisters) and Motuhara (Forty-Fours), July 2017. Report prepared for the Marine Species and Threats Team, Department of Conservation, Wellington.

Frost, P.G.H. 2019. Aerial surveys of Northern Royal Albatross (*Diomedea sanfordi*) on the Chatham Islands: 2017-2018 Breeding Season. Report prepared for the Marine Species and Threats Team, Department of Conservation, Wellington.

Robertson, C.J.R. 1991. Questions on the Harvesting of Toroa in the Chatham Islands. Science & Research Series No. 35, Department of Conservation, Wellington. 105 pp.

Robertson, C. 1993. Survival and longevity of the northern royal albatross *Diomedea epomophora sanfordi* at Taiaroa Head 1937-93. *Emu* **93**: 269-276.

Robertson C.J.R. 1998. Factors influencing the breeding performance of the northern royal albatross. Pp 46-65 *in* Robertson, G.; Gales, R. (eds) *Albatross: biology and conservation*. Surrey Beatty & Sons Pty Ltd, Chipping Norton.

Robertson, C.J.R. 2001. Effects of intervention on the royal albatross population at Taiaroa Head, Otago, 1937–2001. DOC Science Internal Series, 23, Department of Conservation, Wellington.

Sugishita, J. (2016). *Provisioning and foraging strategies of northern royal albatross (Diomedea sanfordi) at Taiaroa Head/Pukekura, and relationship with fisheries* Doctoral dissertation, University of Otago (Available at https://ourarchive.otago.ac.nz/ handle/ 10523/6241)

Appendix

Table A1. Details of the cameras used in this study and the number of sites occupied by each species marked for observation in the relevant images. The varying number of sites observed reflects the range of those initially occupied by an apparently brooding bird

Camera					Date and time		Duration		Sites
Make and model	Focal species	Aspect ratio	Resolution	No.	Start	End	(days)	Images	observed
Swift Enduro	Buller's mollymawk	4:3	12.19 Mpx	Bullers 1	25/01/2021 17:07	24/10/2021 4:29	271.5	13030	16
				Bullers 2	25/01/2021 17:22	5/10/2021 20:14	253.1	10283	15
				Bullers 3	28/01/2021 11:36	23/10/2021 16:38	268.2	12878	24
				Bullers 4	28/01/2021 12:41	26/10/2021 14:38	271.1	13012	12
				Bullers 5	28/01/2021 12:36	27/10/2021 9:08	271.9	13075	19
Swift Enduro	Northern Royal	4:3	12.19 Mpx	Royals 8	28/01/2021 17:51	26/10/2021 14:55	270.9	13006	3
				Royals 9	29/01/2021 10:53	27/10/2021 1:23	270.6	13002	11
				Royals 11	29/01/2021 14:46	10/10/2021 7:48	253.7	12215	29
				Royals 12	29/01/2021 16:15	26/10/2021 10:44	269.8	12954	3
Reconyx Hyperfire 2	Northern Royal	16:9	2.36 Mpx	Royals 10	29/01/2021 11:26	12/07/2021 12:49	163.6	61055	27