

Buffering artificial nest boxes for Procellariiformes breeding in exposed habitats: investigating effects on temperature and humidity

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Abstract The tendency of various species, including many Procellariiformes, to breed in sub-terrestrial burrows, complicates breeding biology studies. Artificial nest boxes facilitate detailed data collection, but may alter the buffering capacity of natural burrows, especially when these nests are exposed to direct sunlight (e.g., in non-forested habitats). We tested the buffering capacity of artificial nest boxes, equipped with additional insulating features, *ex-situ* in a non-forested sand dune in New Zealand. Specifically, we compared daily temperature (°C) and relative humidity (%) means, minima, and maxima between artificial nest boxes, Procellariiform burrow replicas, and ambient conditions sourced further inland using linear mixed effects models (LMMs), followed by *post-hoc* tests. Differences between artificial nest boxes and replicas were non-significant ($P > 0.05$). Our results thus showed that the applied insulating features were sufficient to retain the buffering capacities expected in natural burrows, even in exposed habitats such as sand dunes. Hence, we encourage the use of insulated artificial nest boxes in breeding biology studies targeting burrowing Procellariiformes (and other sub-terrestrially breeding species) in non-forested areas.

Fischer, J.H.; Chambon, J.; Debski, I.; Hiscock, J.A.; Cole, R.; Taylor, G.A.; Wittmer, H.U. 2018. Buffering artificial nest boxes for Procellariiformes breeding in exposed habitats: investigating effects on temperature and humidity. *Notornis* 65 (1): 35–41.

Keywords artificial nest boxes; breeding biology; insulation; relative humidity; seabirds; South Georgian diving petrel; temperature

INTRODUCTION

Breeding biology studies, investigating breeding phenology, growth curves, and breeding success among other parameters, are key to understanding patterns in (avian) behavior, demographics, and population dynamics (Xiao *et al.* 2016). For

endangered species, understanding their breeding biology is also crucial to conservation management (Armstrong & Reynolds 2012). Many bird species breed in tree cavities (Maziarz *et al.* 2017), rock crevices (Ropert-Coudert *et al.* 2004; Kelsey *et al.* 2015), or sub-terrestrial burrows (Warham 1990; Fischer *et al.* 2017), and this behavior can limit studying their breeding biology considerably. In New Zealand, a large number of seabirds,

Received 7 August 2017; accepted 24 September 2017

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especially smaller Procellariiformes, breed in burrows (Warham 1990; Taylor 2000a, b).

Various techniques have been developed to study the sub-terrestrial breeding biology of burrowing Procellariiformes (e.g., Warham 1990, Lyver *et al.* 1998, Zangmeister *et al.* 2009, Taylor *et al.* 2012, Fischer *et al.* 2017). Techniques to study breeding biology in burrowing Procellariiformes can be non-invasive or invasive, vary in the level of detail in the data collected, and have technique-specific limitations. A non-invasive, simple technique to study activity of birds and occupancy of burrows are stick palisades, sometimes referred to as lattice sticks (Zangmeister *et al.* 2009); this method, however, is prone to false positives (Taylor *et al.* 2012). Recently, Radio Frequency Identification (RFID) readers, which consist of RFID readers and antennas corresponding with RFID tags on (or in) birds, have been used (Zangmeister *et al.* 2009; Taylor *et al.* 2012; Fischer *et al.* 2017). A third method is the instalment of remote cameras at burrow entrances (Taylor *et al.* 2012; Dilley *et al.* 2015). However, these cameras may not always accurately capture the activities of small Procellariiform species either due to the speed at which some species enter/exit their burrows or due to model-specific camera settings (Fischer *et al.* 2017). Another method is the use of burrow scopes, allowing assessment of breeding biology parameters (e.g., hatch dates/rates and fledge dates/rates) directly from the brood chamber (Lyver *et al.* 1998). An invasive technique is the instalment of artificial nest boxes (either as new nest sites, or within existing burrows) (Warham 1990; Priddel & Carlile 1995; Miskelly *et al.* 2009). The advantage of nest boxes is that a wide range of breeding biology parameters can be accurately measured with high temporal resolution (e.g., chick growth curves and daily provisioning rates; Sagar *et al.* 2015) as brood chambers can be easily accessed (Miskelly & Taylor 2004; Miskelly *et al.* 2009).

The instalment of artificial nest boxes, however, may negatively affect the study species if environmental variables inside brood chambers change. For example, nest box placement can reduce the buffering capacity of the soil surrounding the brood chamber. This may result in either reduced or elevated temperatures. Reduced temperatures can increase parental costs of thermoregulating eggs or nestlings (O'Connor 1975; Haftorn & Reinertsen 1985), or increase the risk of hypothermia. Increased temperatures can lead to hyperthermia of chicks or incubating birds (Ropert-Coudert *et al.* 2004; Kelsey *et al.* 2015). Hyperthermia may occur in seabirds, such as Procellariiformes, as they are often adapted to cold water temperatures through insulating plumage and fat layers (Ropert-Coudert 2004). Additionally, reduced buffering capacity can also affect the humidity inside the brood chamber,

potentially resulting in egg desiccation (Kelsey *et al.* 2015). Reduced buffering effects are most prevalent in unshaded nest boxes exposed to direct sunlight (Warzybok & Bradley 2010; Kelsey *et al.* 2015). Most burrowing Procellariiform species in New Zealand breed in forested areas (Taylor 2000a, b), but some species exhibit habitat preferences for non-forested areas (Fischer *et al.* 2018). Such species would be particularly vulnerable to negative effects from elevated temperature and reduced humidity in brood chambers caused by nest box placement, and thus additional measures to prevent this may be required.

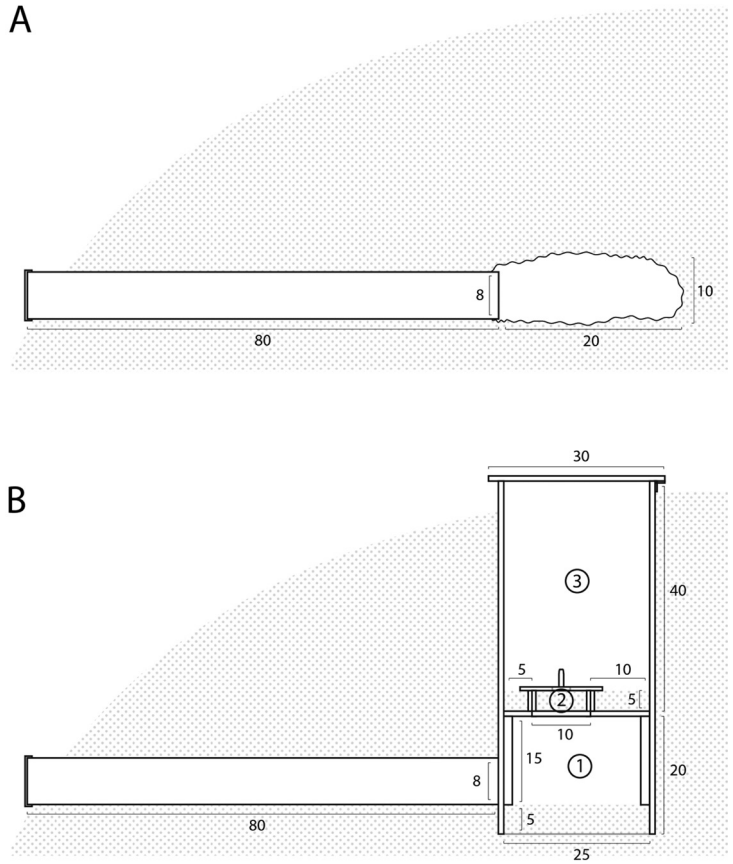
To test the buffering capacities of artificial nest boxes designed for Procellariiform species breeding in open or exposed habitats, we compared brood chamber variables (temperature and relative humidity) inside Procellariiform burrow replicas, with variables inside nest boxes, as well as with ambient variables.

MATERIALS AND METHODS

Study design

To analyze the effects of artificial nest box placement on brood chamber variables, without impacting nesting Procellariiformes, we built Procellariiform burrow replicas ($n = 5$). For the design of these replicas, we used data from South Georgian diving petrel (*Pelecanoides georgicus*) burrows on Codfish Island (Whenua Hou), New Zealand (Fischer unpub. data). This species prefers non-forested foredunes in New Zealand (Taylor 2000b; Holdaway *et al.* 2003; Wood & Briden 2008; Fischer *et al.* 2018). Replicas were hand-dug and consisted of an 80 cm long tunnel with an 8 cm diameter (Fischer *et al.* 2017, 2018) (reinforced by polyvinyl chloride, VC, downpipe to allow retrieval of monitoring devices and prevent collapse) and a brood chamber mimicking natural conditions (approximately 20 x 15 x 10 cm; Fig. 1A). We also designed artificial wooden nest boxes ($n = 5$), suitable for small Procellariiformes, such as the South Georgian diving petrel, with additional insulation to cope with potential environmental fluctuations in non-forested areas. We used information from Miskelly & Taylor (2004), Miskelly *et al.* (2009) and Gummer *et al.* (2014) for our design and added additional insulating measures. Our nest boxes were custom-built using 12 mm plywood and consisted of various stories: 1) a brood chamber (25 x 25 x 15 cm) with an open bottom to retain the draining capacities of soil; 2) an insulating sand layer (25 x 25 x 5 cm) with an equally insulated access hatch (10 x 15 x 5 cm); and 3) an access shaft (25 x 25 x 40 cm) with an access door (30 x 30 x 1.2 cm) (Fig. 1B). As a final insulating measure, we placed sand bags on top of the access doors (Miskelly *et al.* 2009). Nest boxes also had 80

Fig. 1. Side view of a Procellariiform burrow replica (A) and an artificial nest box for Procellariiformes with additional insulation (B). In both, the tunnel is solidified with a PVC down pipe (length = 80 cm; diameter = 8 cm). The nest box consists of various stories: 1) a brood chamber (25 x 25 x 15 cm) with an open bottom, 2) an insulating sand layer (25 x 25 x 5 cm) with an insulated access hatch (10 x 15 x 5 cm), and 3) an access shaft (25 x 25 x 40 cm) with an access door (30 x 30 x 1.2 cm).



cm entry tunnels with an 8 cm diameter (reinforced by PVC downpipe).

We installed the Procellariiform burrow replicas and artificial nest boxes in a non-forested dune (Castlecliff, Whanganui, New Zealand; 39°55'37" S, 174°57'54" E) to test for differences in temperature and relative humidity between the 2 treatments (replicas vs. nest boxes). We installed the 5 replicas and 5 nest boxes along a 100 m transect, while alternating between treatments, with 10 m between samples. We placed both treatments at a depth of 60 cm, mirroring conditions on Codfish Island (Fischer unpub. data). We ensured that on-site conditions were comparable among all samples (e.g., the entire transect was located 20 m from the spring tide line, plant cover was extremely limited with spinifex (*Spinifex sericeus*) as the only species present, and all slopes were facing southwest).

Data collection

To measure temperature and relative humidity, we placed iButton loggers (DS1923 Hydrochron; Maxim

Integrated Products Inc. 2011) in brood chambers of burrow replicas and artificial nest boxes during the austral summer (27 January to 26 March 2017) when the potential influence of sun exposure was likely most extreme (Cooper 1958). iButton loggers can record air temperature between -20°C and 85°C with an error of $\pm 0.5^\circ\text{C}$ and relative humidity between 0% and 100% with an error of $\pm 5\%$ (Maxim Integrated Products Inc. 2011). We ensured that logger instalment conditions were comparable between treatments (e.g., installation height within brood chambers was 5 cm) by building plywood logger stands for replicas. This also prevented the clogging of humidity sensors by sand. We programmed loggers to record temperature and relative humidity every 20 minutes.

We compared conditions inside brood chambers of both Procellariiform burrow replicas and artificial nest boxes with ambient conditions. Due to a limited number of available iButton loggers, we sourced hourly temperature and relative humidity data from Spriggens Park, Whanganui

Table 1. Averages of daily means, minima, and maxima \pm standard error for variables measured during 56 days in late summer in brood chambers of Procellariiform burrow replicas ($n = 5$) and artificial nest boxes ($n = 5$), as well as for ambient conditions (sourced from CliFlo). *** indicates $P < 0.001$.

Parameter		Replica	Nest box	Ambient
Temperature (°C)	Mean	22.23 \pm 0.95	21.96 \pm 0.94	17.94 \pm 1.74 ***
	Minimum	22.08 \pm 0.97	21.77 \pm 0.96	14.36 \pm 2.34 ***
	Maximum	22.34 \pm 0.95	22.16 \pm 0.93	21.93 \pm 2.25
Relative humidity (%)	Mean	84.28 \pm 17.33	90.67 \pm 8.36	77.71 \pm 7.90
	Minimum	83.49 \pm 17.50	89.42 \pm 9.17	61.58 \pm 11.53
	Maximum	84.97 \pm 17.10	91.63 \pm 7.87	90.39 \pm 6.31

(approximately 5 km further inland from the study site) (CliFlo; <http://cliflo.niwa.co.nz>).

Data analysis

Preliminary relative humidity readings indicated high humidity levels (>70%) for extended periods of time. As this can result in inflation of the recorded data, we calibrated relative humidity readings for temperature and saturation drift following Maxim Integrated Products Inc. (2011). This calibration used the 20-minute raw sampling rates to provide hourly calibrated sampling rates. Therefore, we also matched the temperature sampling rates to the calibrated relative humidity sampling rates (hourly). Following calibration, we removed the first 48 hours from every dataset to allow local conditions to settle post installation (Maziarz *et al.* 2017). We arcsine transformed relative humidity data to conform to the normal distribution. We then calculated daily (0000-2300 h) means, minima, and maxima of recorded values (Maziarz *et al.* 2017). This resulted in 56 daily means, minima, and maxima, which we used to analyze differences between Procellariiform burrow replica, artificial nest box, and ambient conditions. Specifically, we analyzed temperature and relative humidity differences using linear mixed-effects models (LMMs) with temperature/relative humidity as response variable, the treatment (replica/nest box/ambient) as explanatory variable, and individual replicas/nest boxes as random intercept. We then tested for significance ($P < 0.05$) using Tukey-HSD *post-hoc* tests.

We used MatLab (version 9.0.0; Mathworks Inc. 2016) for iButton calibrations (Maxim Integrated Products Inc. 2011). All other statistical analyses were conducted in program R (version 3.2.4; R Development Core Team 2016), using the nlme (Pinheiro *et al.* 2017) and multcomp (Hothorn *et al.*

2008) packages. For visualizations of daily variable fluctuations and variable changes over time, we used the ggplot2 package (Wickham 2009).

RESULTS

The Procellariiform burrow replicas and artificial nest boxes exhibited strong buffering capacities, with no signatures of daily variation (e.g., no temperature peak around 1200 h, as seen in ambient measurements) and only limited temperature variations over time (Table 1, Fig. 2A and 2B). No significant differences between replicas and nest boxes were detected for daily temperature means, minima and maxima ($P = 0.636$, $P = 0.606$ and $P = 0.812$, respectively). Differences between the ambient temperatures and replicas, as well as differences between ambient temperatures and nest boxes were significant for daily means and minima ($P < 0.001$ for all comparisons), while differences in daily temperature maxima were non-significant (replica vs. ambient $P = 0.702$; nest box vs. ambient $P = 0.896$). Temperature means and minima in replicas and nest boxes were on average higher than ambient measurements.

The Procellariiform burrow replicas and nest boxes also showed strong relative humidity buffering capacities, with no signatures of daily variations (e.g., no humidity low around 1200 h as seen in ambient measurements) and only limited fluctuations over time (Table 1, Fig. 2C and 2D). No significant differences in relative humidity between replicas and artificial nest boxes (daily means $P = 0.696$, daily minima $P = 0.748$ and daily maxima $P = 0.642$), replicas and ambient conditions (daily means $P = 0.731$, daily minima $P = 0.210$ and daily maxima $P = 0.954$), or nest boxes and ambient conditions (daily means $P = 0.441$, daily minima $P = 0.089$ and daily maxima $P = 0.972$) were detected.

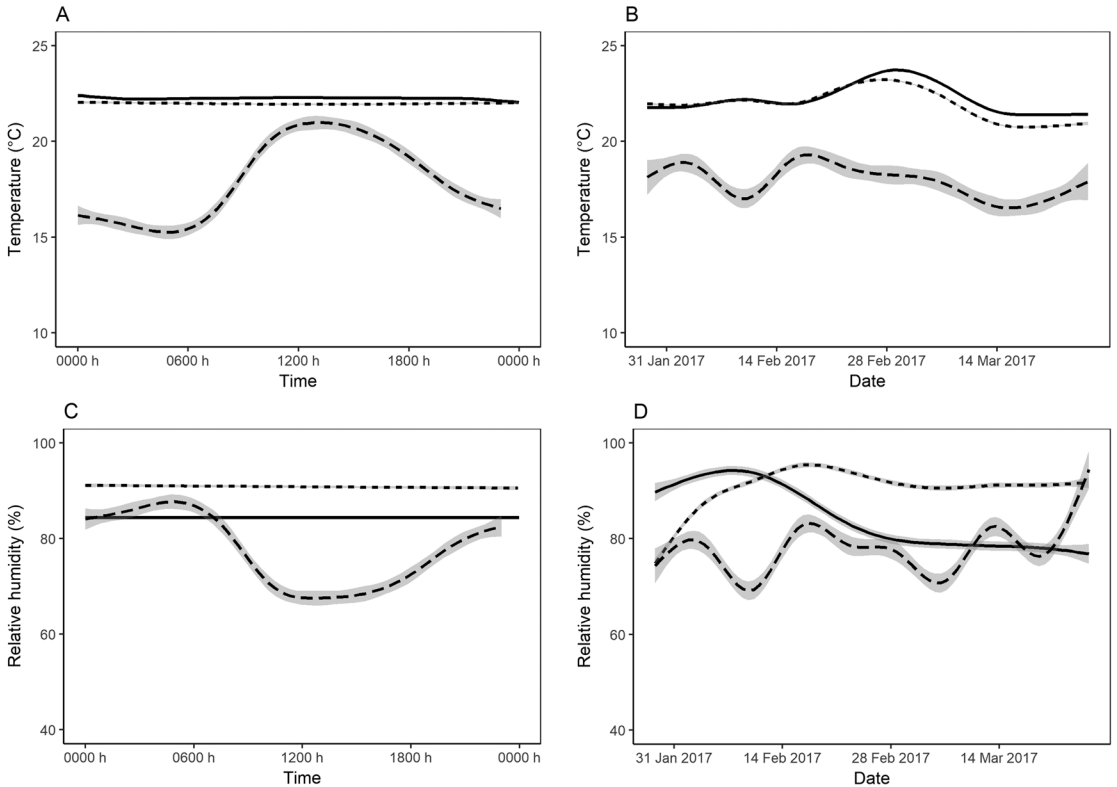


Fig. 2. Locally Estimated Scatterplot Smoothers (LOESS) curves, including 95% confidence intervals (shaded), illustrating the relation between artificial nest box placement and daily temperature change (A), temperature over the duration of the study (B), daily relative humidity (C), and relative humidity over the duration of the study (D). Solid lines = Procellariiform burrow replicas ($n = 5$); double dashed lines = artificial nest boxes ($n = 5$); dashed lines = ambient conditions (sourced from CliFlo).

DISCUSSION

Results from our trial show that artificial nest boxes with additional insulation mimic the brood chamber conditions expected in naturally-dug burrows of Procellariiformes, even for species breeding in exposed habitats. While ambient temperature means and minima were lower than in nest boxes and replicas, these variances were most likely caused by differences between conditions in dunes and conditions further inland. Similarly, the increase in temperature in the nest boxes and replicas in late February and early March, contrasting with the decrease in ambient temperature in the same time period (Fig. 2B), could be explained by local small-scale differences. Compared to temperature, relative humidity showed a greater variation between samples, as well as over time (Table 1, Fig. 2D). Expanding sample sizes would likely give more insights on the

effect of treatments on relative humidity conditions. However, relative humidity conditions remained stable inside brood chambers and no significant differences were detected. Consequently, nest boxes with the applied additional insulating measures can be used to study the breeding biology of burrowing Procellariiformes in non-forested areas without concern to cause egg desiccation, or hypothermia or hyperthermia in eggs, chicks and/or adults.

The brood chamber insulation measures described and tested here, appear fairly easy to apply to many existing artificial nest box designs, and we encourage the incorporation of these measures in contemporary and future studies. Burrowing Procellariiformes are, like most seabirds, a crucial part of many ecosystems due to their ability to facilitate nutrient-cycling between pelagic and terrestrial ecosystems, bioturbation, and seed dispersal (Taylor 2000a, b; Sekercioglu *et*

al. 2004; Lorrain *et al.* 2017). Many of these species are, however, threatened with extinction (Croxall *et al.* 2012; Paleczny *et al.* 2015). Certain conservation strategies, such as reintroductions, rely on detailed, species-specific breeding biology data, illustrating the need for the use of artificial nest boxes (Miskelly & Taylor 2004; Miskelly *et al.* 2009; Sagar *et al.* 2015). Some research projects consist of several hundreds of nest boxes (e.g., Kelsey *et al.* 2015), and thus adaptations to increase insulation quality of these nest boxes may prove laborious and costly. However, climate change prognoses predict rising mean temperatures and increasing temperature extremes (e.g., Blair 2007, Hennessy *et al.* 2007). Therefore, the insulating measures assessed here may prove of high value, not only for studies focusing on burrowing Procellariiform species breeding in non-forested areas, but all studies involving burrowing Procellariiformes, and perhaps even other species outside this family (e.g., other burrowing seabirds such as penguins or alcid; Ropert-Coudert *et al.* 2004; Kelsey *et al.* 2015).

ACKNOWLEDGEMENTS

We are indebted to David Bergin, Graeme La Cock, Stephen Hartley, Nicola Nelson, Sara Treadgold, and the Coastal Restoration Trust of New Zealand for providing valuable insights on our study design. We are also grateful to Whitney Cox and Jake Tessler for assisting with local logistics. Two anonymous reviewers provided helpful comments that improved our manuscript.

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