OWL DEPREDATION AT A RE-ESTABLISHING COLONY OF WHITE-FACED STORM PETREL *PELAGODROMA MARINA*

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ABSTRACT

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We report the depredation by a single Eastern Barn Owl *Tyto javanica delicatula* on prospecting White-faced Storm Petrels *Pelagodroma marina* during the re-establishment phase of a colony on Big Island, off Port Kembla, New South Wales, Australia in 2018. Storm petrels were likely extirpated from this colony 56 years previously when invasive weeds rendered their habitat inaccessible. Restoration of vegetation together with storm petrel call broadcasting, commencing in 2014, resulted in significant increases in prospecting numbers, culminating in breeding (three pairs) in the 2017/18 austral summer season. A significant depredation event (> 59 adults) occurred between August and September 2018, providing a set-back to colony establishment. Previously, barn owl depredation on Big Island had been limited to Silver Gulls *Chroicocephalus novaehollandiae* as prey. However, in the 2018/19 season, the gulls commenced nesting later than usual. The delay appeared to cause the owl to switch target prey. Despite the intense depredation pressure, at least two pairs of storm petrels attempted to breed in the 2018/19 season and 10 birds were trapped and banded at the commencement of the 2019/20 season. Discovery of the mainland roost of the owl was attempted between the two seasons, and its potential death by car strike was investigated. Our findings show that even a single individual predator can have significant impacts on seabird colonies establishing or re-establishing in island environments, especially those under restoration.

Key words: Eastern Barn Owl, colony establishment, owl depredation, White-faced Storm-Petrel

INTRODUCTION

Sixty-five percent of all threatened seabird species—accounting for 165 species in total (Dias *et al.* 2019)—are at risk of extinction from introduced predators, which represents the greatest threat to seabirds globally (Croxall *et al.* 2012). An additional 52 seabird species (14.5%) are at risk of extinction from native species. Imbalances between native predators and island nesting seabirds often occur in the presence of human-induced factors, such as when predators are introduced to islands to which they would not naturally gain access, or in response to habitat alterations on islands that increase the likelihood of predator establishment or harvesting (Priddel & Carlile 1997, Martínez-Gómez & Jacobsen 2004, Harper 2007). With exotic rats *Rattus* spp. introduced to Europa Island off Madagascar, a native Western Barn Owl *Tyto alba* subsisted there on a seasonal diet of Sooty Terns *Onychoprion fuscatus*, reverting to alternate prey (dominated by rats) when terns were not available; extinction of the seabird did not occur in the process (Ringer *et al.* 2015). However, although Ringer *et al.* (2015) found that the Sooty Tern population was affected very little by the depredation pressure, other alternate seabird prey that bred in lower numbers were possibly at risk.

Native avian predators can have significant impacts on breeding seabird populations. Pollet & Shutler (2019) report that two pairs of Great Horned Owls *Bubo virginianus* potentially reduced a significant breeding population (35 000 pairs) of the burrowing Leach's Storm Petrel *Hydrobates leucorhous* on Bon Portage Island, Nova Scotia, Canada by 1% annually over five years. The Pied Currawong *Strepera graculina* was found to be a major predator of adult, cavity-nesting Gould's Petrel *Pterodroma leucoptera* breeding on coastal Cabbage Tree Island, New South Wales (NSW), Australia (Priddel & Carlile 1995). Similarly, the endemic Lord Howe Currawong *S. g. crissalis* impacted all life stages of the tree-nesting White Tern *Gygis alba* on Lord Howe Island (Carlile & Priddel 2015), although the tern colony continued to expand. Also on Lord Howe Island, the Lord Howe Woodhen *Hypotaenidia sylvestris* was observed to extract fledglings from burrows of Providence Petrel *Pterodroma solandri* (Bester *et al*. 2007) and Black-winged Petrel *Pterodroma nigripennis* (O'Dwyer *et al*. 2022) at a rate that did not appear to be detrimental to the seabird's colony viability.

Introduced avian predators arguably have a greater impact on seabird colonies. In the Hawaiian Islands, barn owls (introduced for rodent control) impacted the burrowing Band-rumped Storm Petrel *Hydrobates castro* on Lehua Islet (Raine *et al*. 2020) and also took adults of four burrowing seabird species on Kaua'i (Raine *et al*. 2019). A seven-year study on Kaua'i also found that barn owls were responsible for 4% of recorded depredation events (adults, chicks, or eggs) involving adult Newell's Shearwater *Puffinus newelli* and Hawaiian Petrel *Pterodroma sandwichensis* (Raine *et al*. 2020). On Lord Howe Island, the Australian Masked Owl *T. novaehollandiae* (introduced for rodent control) regularly depredated White Tern adults (Carlile & Priddel 2015). The endemic Weka *Gallirallus australis*, although native to New Zealand, was an introduced predator on Taukihepa Island off southern New Zealand and was found to impact the Sooty Shearwater *Ardenna grisea* (Harper 2007), taking chicks from burrows. At the Farallon Islands, California, USA, native, seasonally resident (winter) Burrowing Owls *Athene cunicularia* took appreciable numbers of Ashy *Hydrobates homochroa* and Leach's storm petrels, as well as Cassin's Auklets *Ptychorampus aleuticus* (Mills 2016), with negative effects on the Ashy Storm Petrel population (Nur *et al*. 2019). Such depredation on established populations of seabirds may, in most cases, be sustainable. However, it is unknown how depredation might impact prospecting species attempting to gain a "foothold" on islands whose seabird populations are under restoration.

In the restoration of seabird colonies, the natural habits of species for prospecting and recruitment play a significant role in their ability to establish or re-establish in newly available habitat (Becker & Bradley 2007). If source populations are within 25 km of a restoration site or the island has a small extant population that has withstood depredation or habitat alteration, then passive recovery in restored habitat (removal of predators or impediments to nesting) is more likely (Buxton *et al*. 2013). As part of restoration efforts, wildlife can be deliberately manipulated using techniques such as translocation or social attraction (Jones & Kress 2012), which can be combined with providing artificial habitat (Priddel & Carlile 1995). However, Buxton *et al*. (2013) suggested that the most influential factors affecting recruitment in seabirds is density-mediated social attraction (Doligez *et al*. 2003), habitat copying (Parejo *et al*. 2006), and competition for nest sites (Schippers *et al*. 2011). Notably absent in these restoration studies is any quantification of the potential impact of depredation pressure either by introduced or native predators that can intermittently access islands from mainland populations.

The White-faced Storm Petrel *Pelagodroma marina* is a medium-sized (length 20 cm, wingspan 42 cm; mass 55 g) storm petrel that commonly occurs over neritic and pelagic waters around southern Australia and New Zealand (Marchant & Higgins 1990). The species is considered to be of "Least Concern" internationally (BirdLife International 2022). In NSW on Australia's east coast, White-faced Storm Petrels are known to return to islands in August (this study) and commence incubation of their single egg in late September (Carlile *et al*. 2015). Chicks fledge in late January and February (Carlile *et al*. 2020). Until the early 1960s, they bred on Big Island (34°29′24″S, 150°55′42″E), part of the Five Island Nature Reserve (FINR), spread over two discrete areas (Fig. 1). However, they disappeared entirely from Big Island by the early 1970s (Gibson 1976). The nearest extant White-faced Storm Petrel colony to Big Island, from which emigration may assist

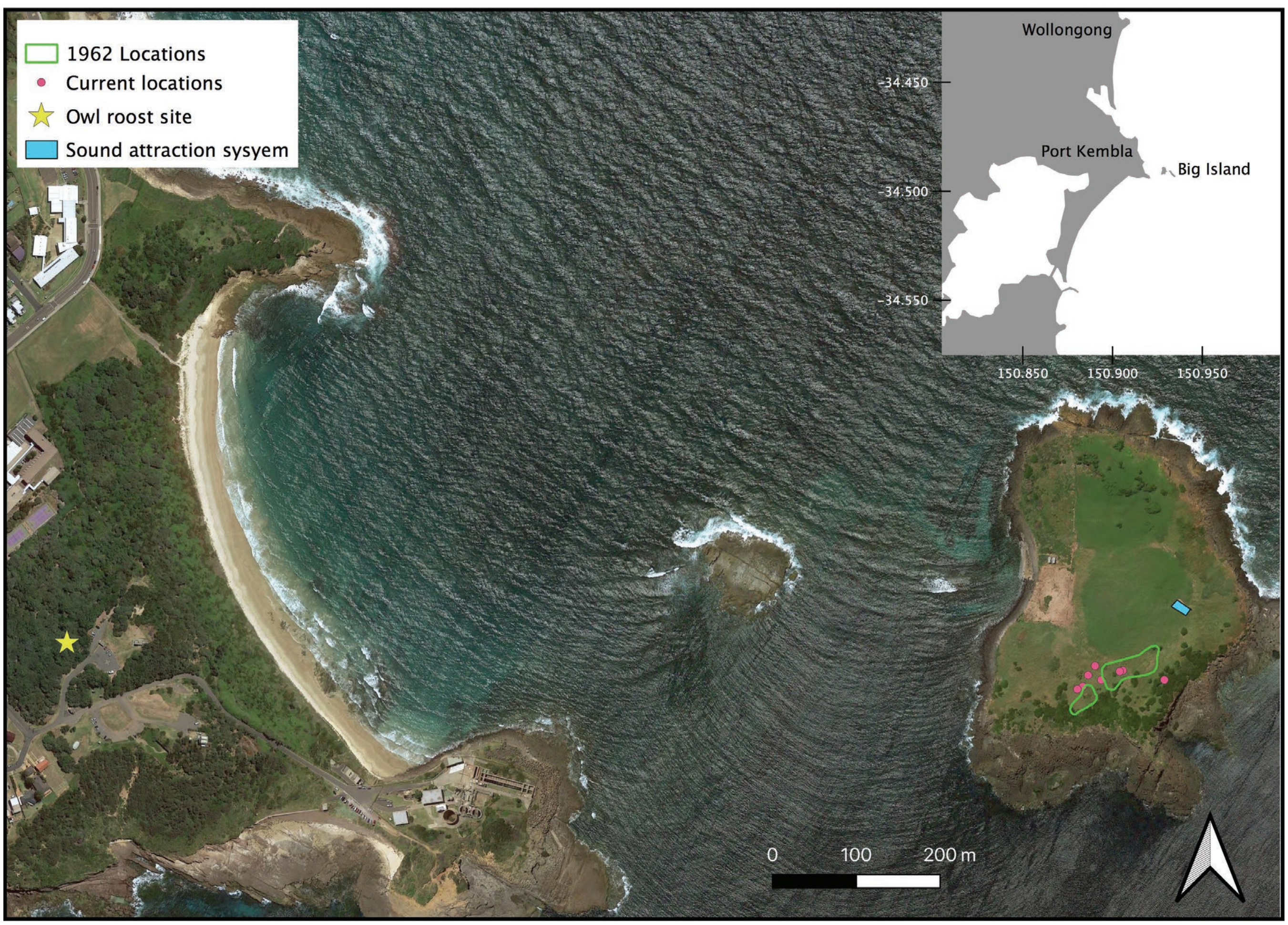

Fig. 1. Map of Big Island adjacent to Hill 60 on the New South Wales coast, Australia, showing the location of historical White-faced Storm Petrel *Pelagodroma marina* colonies (outlined), current breeding burrows (circles), location of the sound-attraction system (rectangular block), and location of a Eastern Barn Owl *Tyto javanica delicatula* roost (star).

recolonisation, is within the FINR on Flinders Islet (34°27′23″S, 150°55′46″E), which is 3.5 km to the north. At Flinders Islet, 50 pairs of White-faced Storm Petrels are known to breed (Lloyd & Carlile 2019). The largest colony in NSW—with over 500 pairs—is 155 km south at the Tollgate Islands (35°44′S, 150°15′E) (Carlile *et al*. 2015). Prior to this study, the most recent direct observations of White-faced Storm Petrels on Big Island were made in September and October 2014 during Little Penguin *Eudyptula minor* surveys (Carlile *et al*. 2017). At this time, up to six birds were recorded flying over and landing in locations previously known for their nesting. Nearby areas that were cleared of invasive grass at the time (see below) showed no signs of activity that would be consistent with storm petrel burrowing attempts.

The Eastern Barn Owl *Tyto javanica delicatula* (hereafter Barn Owl) is a common native nocturnal raptor found over much of Australia. Within the greater Sydney region, this species is uncommon but persists despite the loss of principal nesting habitat to urbanisation (Kavanagh 2004); however, it is probably underreported because it is not listed as a threatened species under state legislation. While it is most commonly associated with eruptions of mice in western NSW where a consistent source of prey is available, it also persists in coastal cities for extended periods, albeit in low numbers (Mo 2019).

Big Island vegetation restoration activities commenced in April 2014 (Mills 2014) with the explicit aim of enabling the White-faced Storm Petrel to re-establish a breeding colony there (Carlile *et al*. 2017). The approaches used were similar to those applied in the Seabird Habitat Restoration Project on Montague Island (36°15’03”S, 150°13’37”E) off the NSW south coast (Pacey 2013). Over six years, specific zones of weed infestation on Montague Island (amounting to 20 ha [0.2 km^2]) were treated with herbicide and, after the bulk of the vegetative matter was either burnt or broken down, native seedlings were planted at high densities. The result was additional seabird species establishing colonies on the island (Pacey 2013, Carlile *et al*. 2020).

This paper presents: 1) the prospecting and breeding activity of White-faced Storm Petrels on Big Island during the 2016–2019 breeding seasons; 2) the recorded presence of a Barn Owl at the colony, and the prevalence of their known prey on the island; 3) evidence of depredation of storm petrels; and 4) attempts to discover the individual owl responsible for depredation at the colony using stable-isotope analysis (SIA) as confirmatory evidence of linkage.

METHODS

Big Island is managed by the New South Wales National Parks and Wildlife Service (NPWS) for the protection of seabirds (NSW NPWS 2005). The island is located 500 m from the coast near the industrial city of Wollongong (Fig. 1. inset). The low-lying 20-ha island has 54% vegetation cover dominated by the exotic grass Kikuyu *Pennisetum clandestinum*, the woody weeds Mirror Bush *Coprosma repens*, and Bitou Bush *Chrysanthemoides monilifera* ssp. *rotundata*, as well as extensive mats of invasive scrambling Morning Glory *Ipomoea cairica* (Mills 2014). The island supports nine species of breeding seabirds and waterbirds (Carlile *et al*. 2017).

In June 2016, a 150 m^2 area of Kikuyu Grass and the Morning Glory were treated with herbicide in an area where White-faced Storm Petrels had been seen landing in 2014 (see below). After the initial vegetation had turned brown, the area was covered with overlapping sheets of 75 mm × 55 mm galvanised reinforced mesh; side mesh enclosed the soil to a depth of 400 mm along the outer edges (to reduce conspecific incursions; see Carlile *et al*. 2020) (Fig. 2). Twenty modified 220-mm-high Rainbird® valve boxes, designed for lawn sprinkler systems, were buried as artificial storm petrel nesting chambers within the sprayed, meshed area. Expanding foam was sprayed onto the inner roof of each valve box to insulate against radiant heat, and an artificial turf flap covered the lid to aid in recovery of any subsequently buried units. The boxes were connected to 65-mm-diameter perforated drainage pipe with a cloth to filter soil/sand, forming tunnels approximately 800 mm in length to the ground surface (Fig. 2 insert). The area was then planted with a native shrub, Seaberry Salt Bush *Rhagodia candolleana*, as well as ground covers known to occur in White-faced Storm Petrel colonies on other NSW islands (Priddel *et al*. 2012, Carlile *et al*. 2015). A New Zealand Department of Conservation solar-powered sound-attraction system (Miskelly & Taylor 2004) was installed and commenced broadcasting White-faced Storm Petrel ground calls during nocturnal periods for the duration of the storm petrel breeding season (September to February) annually from August 2016.

The activity of White-faced Storm Petrels on Big Island was assessed nocturnally by: (1) observing prospecting birds overflying a traditional nesting area (Fig. 1), (2) trapping overflying birds using an 18 m × 3 m mist net placed adjacent to the area being prospected, and (3) investigating ground calls within suspected burrows. Suspected burrows were identified by fresh soil piles outside of holes < 6 cm in diameter. Diurnal surveys for prospecting and breeding burrows were carried out using a burrowscope (EMS2015 Gopher Tortoise Camera System, Environmental Management Services, Canton, Georgia, USA). Artificial burrows were searched periodically for remnant nesting material, storm petrel feathers, or their guano deposits. Birds captured through mist-netting were fitted with an Australian Bird and Bat Banding (ABBBS) metal ring, each with an identifying number, and were then released.

Any seabird carcasses and the remains of body parts within the vicinity of the historical breeding sites were collected for later examination to determine minimum numbers of impacted individuals. Remains were identified as owl kill by the minimal traces of muscle and connective tissue on either single wings or pairs joined by damaged sternum and disarticulated single legs. Remains or partial remains of heads were rarely found within regurgitated pellets. Where possible, tarsus and wing chord measurements to the nearest 0.1 mm from single leg and wing items were used to collate total individual birds from multiple remains collected from owl feeding perches. Each collection was individually bagged and removed for later analysis. Silver Gulls *Chroicocephalus novaehollandiae* were discounted as potential predators by the high level of tissue removal, unlike remains from known gull scavenging. Additionally, there is no record of Silver Gulls killing storm petrels either at the study site or another well studied colony where both species cohabit (Underwood & Bunce 2004).

Barn Owl observations were made during diurnal periods when searches of potential habitat disturbed an adult owl from roosting sites and, during nocturnal periods, when owls were occasionally intercepted when potentially searching for prey. At these times, photographic records were made to assist in identification of the species. Indirectly, owl activity was determined from previous sites of potential diurnal perches and nocturnal sites where dismemberment

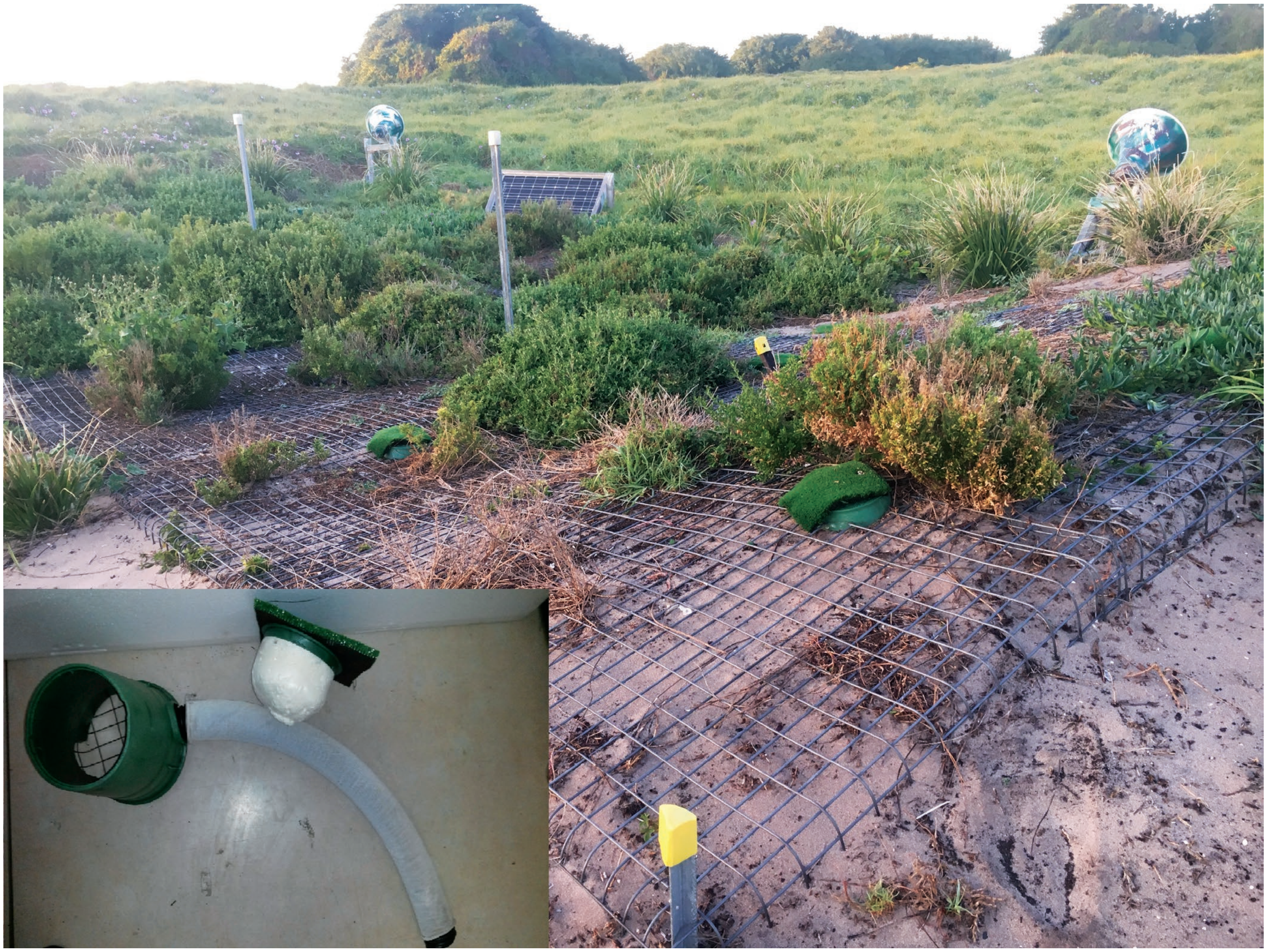

Fig. 2. White-faced Storm Petrel *Pelagodroma marina* sound attraction on Big Island, New South Wales, Australia with solar panel and stadium speakers (facing away). The ground cover in the background is a one-metre-thick blanket of invasive Kikuyu Grass *Pennisetum clandestinum*. Insert shows modified valve box with mesh floor, tunnel, and insulated lid.

of prey occurred, as indicated by the recovery of the remains of seabird carcasses and regurgitated pellets at these sites.

Recovery of a deceased Barn Owl in close proximity to the storm petrel colony provided material for chemical analysis of its feathers to assess whether the bird had been feeding on the storm petrels of Big Island. Stable-isotope analysis (SIA) can provide a clear relationship between the carbon and nitrogen isotope signals and a birds' diet during the keratanisation of new feather pulp (Shealer 2002). Garthe *et al*. (2016) found that the proportion of diet that an individual consumes, either marine or terrestrially derived, gives elevated δ^{13}C values (in blood) with elevated marine foraging, whereas δ^{15}N are elevated with a high trophic level diet (invertebrates to vertebrates). Three emergent feathers and one recently-erupted flight feather was prepared for SIA using standard techniques (Bontempo *et al*. 2014), and muscle samples were prepared before measurement. Isotope ratios were measured using a continuous-flow isotope ratio mass spectrometer, with analyses conducted by the Environmental Analysis Laboratory, Southern Cross University (Lismore, Australia). Stable isotope abundances values were expressed in δ-notation as the deviation from standards in parts per thousand.

RESULTS

Investigations of prospecting birds

On the evening of 20 September 2016, a maximum of 10 White-faced Storm Petrels were seen in the air at any one time, including two birds found on the ground calling within a tangle of recently sprayed Bitou Bush and Kikuyu Grass. A single bird was intercepted on the surface and placed (unbanded) in an artificial breeding burrow at the sound attraction site (Fig. 1) to introduce it to this newly available habitat. Two trapping sessions in the 2017/18 season consisted of mist netting on 20 September 2017, which caught 11 birds (all placed within available artificial habitat), and on 07 February 2018, which caught two birds that were banded and released. In mid-September in the 2018/19 season, two 1.5-h mist-net sessions over two nights failed to catch a storm petrel, although one was seen flying nearby on the first night. On 10 January 2019, a single 1.0-h mist-net session failed to trap any storm petrels and none were observed. Finally, during the 2019/20 season on 20 September, 10 individuals were banded and released in a 2.0-h trapping session, but a follow-up session on 24 January 2020 involving a single hour of mist-netting failed to trap any overflying storm petrels and no storm petrels were observed.

Confirmation of breeding burrows

In September of the 2017/18 season, three pairs of White-faced Storm Petrels were found calling at night from within freshly dug burrows (Fig. 1). By January 2018, eight burrows were excavated in the same area, with five showing recent activity and two containing storm petrel chicks. No artificial burrows were in use at the sound-attraction site throughout the season.

Early in the 2018/19 breeding season the island was visited overnight in August and a further five new active burrows were found and marked. Two additional excavated burrows were located in September. However, these 15 total burrows were reduced by four when they were enlarged by Wedge-tailed Shearwater *Ardenna pacifica*, making them unavailable to the storm petrels. In January 2019, a single new burrow was marked but only five of the 13 available burrows retained unobstructed entrances. The remainder were filled with sand and covered by weed growth. On examination, one burrow contained an abandoned egg and the other contained a well-developed storm petrel chick with emerging adult tail feathers. Again, no artificial burrows were in use or showed signs of visitation at the sound attraction site.

Finally, diurnal checks in September of the 2019/20 season found no new burrows and only three previously active burrows that were open with signs of fresh digging. By January, only a single burrow showed fresh digging with two burrows that were enlarged by shearwater excavation. At the sound-attraction site, no artificial burrows were in use. However, two natural burrows had been excavated (350 mm and 200 mm in length) through the mesh in front of one of the broadcast speakers. The shallower burrow contained an adult White-faced Storm Petrel.

Barn Owl observations and seabird depredation on Big Island

Direct observations of the Barn Owl on Big Island were made in September 2014 (Carlile *et al*. 2015) when it was flushed from two separate roosts on consecutive days. The fresh remains of Silver Gull wings were also found at these sites. At dusk on 14 August 2018, a single owl was observed flying onto Big Island from the direction of Hill 60 (34°29′27″E, 150°55′09″S), 1 km west (Fig. 1). Within 30 min, it was also seen flying within the vicinity of the known storm petrel breeding burrows and perching atop a nearby Mirror Bush. A photographic record was made that confirmed the owl species observed earlier, also confirming that it was an adult. During the two days of the owl's visit to the island, fresh remains of nine White-faced Storm Petrels, identified by their pairs of wings, were recovered either at the known prospecting site or nearby. In September 2018, during nocturnal observations, a single adult Barn Owl was again seen perching atop Mirror Bush adjacent to the known breeding burrows, confirmed by inspection of a photograph. On this occasion the remains of 50 White-faced Storm Petrels (both dried and fresh) were recovered from the prospecting site, the sound-attraction site, and at several probable feeding perches in nearby Mirror Bush. Thirteen regurgitated owl pellets were found during September 2018, and all contained White-faced Storm Petrel remains. Indirect evidence of owl activity was found in January 2019 when the remains of two Silver Gull juveniles were found within a tall Mirror Bush; it was estimated that several weeks had passed since they had been depredated. No further storm petrel remains were located during this visit despite checking previous sites of recovery. In the 2019/20 season, two nights of observations on Big Island failed to detect any owl species hunting on the island. No remains of depredated storm petrels were found during the 2019/20 season despite checks at previous sites where remains had been recovered.

At the time of the significant depredation on storm petrels, as observed on 14–15 August 2018, Silver Gulls were found to have landed on the eastern end of the island and commenced landing on the western shore during these two days. Therefore, egg laying would not be expected for a subsequent 15–19 d (Smith & Carlile 1992), placing their commencement of incubation a month later than would normally be expected. This delay in breeding was the likely catalyst for the Barn Owl to shift its foraging attention, if it was a seasonal visitor to the island, to the less numerous storm petrels (see Discussion).

Barn Owl occurrence on nearby mainland sites

In August 2016, on the adjacent mainland, a single adult Barn Owl was found roosting in vegetation near the summit of Hill 60 (P. Lynch pers. comm.), which was suitable diurnal habitat (9.5 ha [0.095 km^2] of coastal woodland surrounded by commercial and residential areas) (Fig. 1). In January 2019, a six-person-hour search of potential owl roost sites on Hill 60 failed to find a Barn Owl in residence, but recent owl-depredation remains (~2 months old) of a juvenile Silver Gull indicated some usage of the area. It is likely that heavy rainfall in the months preceding the search broke down any owl pellets and that the lapse of time allowed for the scavenging of prey remains by feral animals.

On 05 April 2019, an opportunistic but uncommon discovery of a road-killed, non-breeding adult Barn Owl was made on the side of a major freeway 7 km northwest of Hill 60 (34°27′28″E, 150°51′21″S). Four erupting or recently replaced flight feathers were sampled because it was suspected that the individual could have been responsible for the depredation events on Big Island. To ensure comparative data to a Barn Owl that likely had a fully terrestrial-derived diet, four similar feathers were sampled from a road-kill Barn Owl on 17 May 2019 near the town of Berry (34°46′35″E, 150°41′00″S). This location, 38 km to the southwest of Big Island, is also 38 km northeast of the seabird colonies on Bowen Island (35°07′08″S, 150°46′09″E; Lane 1976). Dried muscle tissue was extracted from the remains of two White-faced Storm Petrels from Big Island. These samples were combined to establish a marine SIA signal that reflected that their food resource was derived exclusively from foraging within the marine environment (Table 1). The four sampled feathers from each Barn Owl recorded similar $\delta^{13}C$ and $\delta^{15}N$ isotopic values, indicating that their diets were likely composed of similar prey items at the time of feather formation prior to their eruption as flight feathers in the proceeding months. The elevated nitrogen values indicate a terrestrial prey base. In contrast, the nitrogen values established in muscle extracted from the White-faced Storm Petrel remains recovered on Big Island were lower, indicating a marine diet in these petrels and also suggesting that this species was unlikely to have been a prey item for the owls.

DISCUSSION

Prospecting and breeding birds

The similar numbers of prospecting storm petrels seen or trapped near the Big Island colony site before and after the high depredation

TABLE 1
Stable-isotope analysis of Eastern Barn Owl *Tyto javanica delicatula* feathers from two specimens collected in 2019 on the mainland adjacent to Big Island, New South Wales, Australia, and White-faced Storm Petrel *Pelagodroma marina* muscle tissue from depredated specimens collected in 2018 from Big Island

Species	Sample date	Location	Average total carbon (% δ^{13}C TC[a])	Average total nitrogen (% δ^{15}N TN[a])
Eastern Barn Owl	04 Apr 2019	Wollongong	44.3	14.7
			43.3	14.3
			42.9	14.3
			42.6	14.0
Mean (+ SD[b])			43.3 (0.77)	14.3 (0.26)
Eastern Barn Owl	17 May 2019	Berry, NSW	46.4	14.8
			47.3	15.0
			45.8	14.6
			45.7	14.5
Mean (+ SD[b])			46.3 (0.73)	14.7 (0.22)
White-faced Storm Petrel	Sep 2018	Big Island	51.6	11.7

[a] TC = total carbon; TN = total nitrogen
[b] SD = standard deviation

in 2018 indicates that the attractiveness of the area of breeding has not been diminished. The presence of these birds—which could also be part of a larger regional ”floating” population (Ford *et al*. 2021)—may also relate to habitat quality at their original colonies, which could be driving their search for new colonies that can provide better quality habitat and less competition for breeding sites (Kildaw *et al*. 2005). Further, the addition of the sound-attraction site and associated artificial burrows and mesh-protected restoration area should detect the continued presence of the storm petrels in this area, despite their current lack of use of the burrows provided. Excavated burrows may be the preferred habitat of the species; alternatively, the artificial burrows that retain higher ambient temperatures than natural burrows during diurnal periods are unacceptable for breeding. The latter issue may necessitate refinement in the design of artificial burrows, which is currently being investigated to reduce thermal inertia. The recovery of storm petrel remains within the established sound-attraction site and the evidence of burrow establishment in this study was not unexpected. Camera monitoring of storm petrels found strong responses to vocalization broadcasts and recordings of birds entering and attending several artificial nest sites near broadcast speakers on Santa Cruz Island, California (McIver *et al*. 2011).

If White-faced Storm Petrels on Big Island behave similar to northern hemisphere storm petrels as they colonise islands, we expect a constant influx (within limits) to the colony (Fowler 2002, Tasker 2002); therefore, both the current breeding pairs and the sound broadcasting should continue to attract wandering prebreeders. Indeed, the number of wanderers has been substantial, as found for Ashy Storm Petrels at the Farallon Islands, California (Nur *et al*. 2019). However, it is possible that the high observed depredation may lead to abandonment of the Big Island site, as was found with Ashy Storm Petrels after high depredation by Spotted Skunk *Spilogale gracilis amphiala* at Santa Cruz Island, California (McIver *et al*. 2011). At that colony, after depredation of 32 adults or prospecting birds associated with 14 known nests, only two nests were active in the following season; thereafter, storm petrels were absent despite other nearby sub-colonies (McIver *et al*. 2011).

While the depredation of White-faced Storm Petrels on Big Island by a suspected single Barn Owl limited breeding in the 2018/19 season compared to the previous season, some individuals did manage to breed successfully. Their success was probably due to the swamping of the potential prey (Darling 1938) by the more numerous prospecting birds on the surface, as total remains recovered far outnumbered known burrows. Burrowing seabirds that are either without partners or of pre-breeding age (prospecting birds) are more likely to remain above ground for longer periods at breeding colonies (Mougeot *et al*. 1998, Mougeot & Bretagnolle 2000), a behaviour that would increase their chance of depredation.

Had the owl depredation not occurred at the Big Island colony in 2018, we suspect that the storm petrel colony may have expanded significantly following first breeding. On Montague Island, a new colony grew to over 100 active burrows in five years (Carlile *et al*. 2020). Similar rates of colony establishment were documented on Fisher Island in Bass Strait over three years. Brothers (1981) found that from six prospecting burrows in the first year, the colony had expanded to 25 burrows with eggs in the second year and 64 burrows with eggs in the third year. Based on the number of bird remains recovered on Big Island in August–September 2018 (59 adults), it is likely that a similar high rate of colony establishment—from the initial two successful breeding attempts from 15 excavated burrows—may have occurred here had the owl not intervened.

In addition to predator pressure on the establishing colony, the loss of burrows to the larger conspecific shearwaters may make a secure colony in our project area more difficult to sustain. The 25% loss of the initial burrows during the 2017/18 season to the burrowing actions of Wedge-tailed Shearwaters is similar to that found in a new colony of White-faced Storm Petrels on Montague Island (Carlile *et al*. 2020). The addition of the mesh-habitat (see Methods and Fig. 2), which restricts larger shearwaters, provides one mechanism to minimize the disturbance of excavated burrows. While active restoration continues at Big Island, any areas cleared of invasive weed cover will prove attractive to prospecting shearwaters, as was seen during the 2014 seabird surveys (Carlile *et al*. 2017). This may attract and concentrate shearwater prospecting efforts away from the establishing storm petrel colony.

Barn Owl interactions

The Barn Owl is a relatively uncommon species on the eastern seaboard of NSW, but numbers appear to spike in the austral spring (Barrett *et al*. 2003). They are known to concentrate their hunting activities to just after dark and just before dawn (McLaughlin 1994), a pattern that brings them into direct contact with storm petrels moving to and from burrows at their island colonies. On Big Island, the addition of a sound-attraction system playing amplified calls of storm petrels may have provided further attraction for the owl to forage. A call playback system installed to attract Newell's Shearwaters on Kaua'i to a mist net succeeded in attracting a Barn Owl to perch on the net poles (D.G. Ainley pers. comm.).

Although determining whether the depredation issues on Big Island in 2018 were caused by an individual owl is somewhat problematic, we believe the low number of owl pellets recovered and single bird sightings indicate this to be the case. From a pair of native Barn Owls observed foraging over Boullanger, Escape, and Whitlock islands off the Western Australia coast in one season, 151 pellets were collected, forming the basis of a diet study over one full year (Dickman *et al*. 1991). The owls' diets were investigated and, while remains of introduced House Mouse *Mus musculus* were in 94% of pellets, White-faced Storm Petrels were the most common, non-small mammal remains (19% of pellets sampled; Dickman *et al*. 1991). No other seabirds were represented in the diet despite the availability of colonial surface nesting Bridled Terns *O. anaethetus* (Johnstone & Storr 1998). At a Leach's Storm Petrel colony, significant depredation was observed (4 000 individuals annually; Hoeg *et al*. 2021) that was attributed to just four individual owls (Pollet & Shutler 2019). In this example, the owl nesting or roosting sites were not on the storm petrel island (Hoeg *et al*. 2021) and, similar to this study, the sites where pellet and body part remains were recovered were not reused in subsequent feeding visits by the owls. Notably, a dramatic decrease in depredation occurred on Lehua Islet, Hawaiian Islands, with the removal of just a few Barn Owls (Raine *et al.* 2019).

The isotopic data from this study could not provide a link between the owl collected from the roadkill, 7 km northwest of Hill 60, and the owl that had previously fed on the storm petrels of Big Island. The isotopic samples indicated that the owl from Wollongong foraged on a higher trophic level (indicated by the larger δ^{15}N value) than is encapsulated in the body of the storm petrels on Big Island. Both sampled owls had similar isotopic values for δ^{15}N and δ^{13}C, indicating that they likely had similar diets and were not marine-based at the time the feathers were grown.

If the roosting site of the Barn Owl on Hill 60, identified in 2016, was a habitual place of residence, then the regular targeting of nesting Silver Gulls noted in 2014 (Carlile *et al.* 2017) may have been an annual seasonal resource for this bird. Individuals within predator species have been found to specialise on particular prey items at seabird colonies (Votier *et al*. 2004a). The gulls usually commence breeding activities on Big Island in July (Smith & Carlile 1992), with birds' first landing at the eastern end of the island then spreading over the remainder in the following days before taking up nesting locations. Between 1989 and 1991, the first eggs were laid 12–27 July (Smith & Carlile 1992). However, the late start of gull nesting in the 2018/19 season (late August to early September) may have provided the catalyst for the owl to switch to storm petrel prey, coincident with the storm petrels' increased prospecting for burrows at this location. Barn Owls foraging on islands elsewhere have been found to be flexible predators and will take prey according to availability and profitability (Velarde *et al*. 2007, Ringler *et al*. 2015). Prey switching has also been observed with Burrowing Owls at the South Farallon Islands from introduced House Mice to Ashy Storm Petrels as mouse numbers shrink annually during cooler months (Nur *et al*. 2019). The departure of the owl from Big Island after September 2018, as indicated by the lack of recovered prey remains following this period, may have resulted from more profitable foraging opportunities elsewhere rather than a complete lack of available prey at the island, as Silver Gulls continued to breed for several months after September.

The future impact of the depredation event described herein on colony establishment of the White-faced Storm Petrel on Big Island is unknown. Following the depredation events in 2018, the storm petrels successfully bred, but fewer burrows were occupied in the 2019/20 season, with less successful breeding detected. The sound-attraction site did elicit some burrowing activity in early 2020, but whether this will result in breeding needs to be followed in subsequent seasons. If a Barn Owl is found again in residence on Hill 60 before a breeding season, the relocation of the individual away from the local region (Kenward 1999) would be desirable to improve the possibility for re-establishment of White-faced Storm Petrels on Big Island. Additionally, managers should consider cessation of sound-attraction broadcasting if an owl is known to reside locally. This may reduce the potential for "calling in" an owl predator (Raine *et al*. 2019). The potential for owl depredation at storm petrel or other small burrowing seabird attraction sites will almost always occur when the establishing seabird site is close to sources of introduced or native nocturnal raptors. Forecasting and planning for such eventualities may be a necessary part of mitigation actions if the goals of seabird recovery are to be met.

It is uncertain whether Big Island can regain a storm petrel breeding colony due to the potential multiple threats to colony establishment. Barn Owl depredation pressure on the White-faced Storm Petrel may commence again. Additionally, any weed invasion of the natural burrowing site or the sound-attraction site can render these sites unusable within one or two seasons. An established population of Australian White Ibis *Threskiornis molucca* breeds near to the storm petrel habitat (Carlile *et al.* 2015), and the local foraging of this species is known to cause storm petrel losses at other breeding sites (Underwood & Bounce 2003). This combination of factors may provide too many "knock-on effects" (Votier *et al*. 2004b) to allow successful colony establishment despite attempts to improve the habitat of this species. Future careful monitoring and on-going habitat restoration will be necessary if colony re-establishment of White-face Storm Petrels on Big Island is to succeed.

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