ESTABLISHMENT OF AN INCIPIENT NEWELL'S SHEARWATER *PUFFINUS NEWELLI* COLONY ON MAUI

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ABSTRACT

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We report the development of a colony of threatened Newell's Shearwater *Puffinus newelli* (NESH) at Makamaka'ole, West Maui, USA, a successful first undertaking in the Hawaiian Islands. Efforts involved the construction of two predator-proof fenced areas, removal/control of predators, placement of nest boxes, and social attraction using recorded calls and decoys. Initially, one of the management areas was intended for Hawaiian Petrel *Pterodroma sandwichensis* (HAPE) and the other for NESH. Exclosures were completed and mammalian predators were removed in 2013, and social attraction began in 2014. Both species almost immediately began flyovers to inspect speakers and by 2015, they had landed to inspect nest sites. Cameras recorded activity at nests during which individuals showed interest and, in at least one case, competed for the same nest. The first NESH eggs were laid in 2017, by which time HAPE had lost interest. NESH numbers continued to grow, especially after more speakers were added in 2019, when at least one but as many as five NESH chicks fledged. Two main questions arose: 1) What was the source population from which NESH had come, given their near extirpation on Maui? and 2) Why did HAPE, which are abundant in East Maui and on the nearby island of Lāna'i, eventually lose interest? Better understanding the population and behavioral ecology of these species might well inform planning for similar projects elsewhere in Hawai'i.

Key words: Hawaiian Petrel, invasive predators, Maui, nest site competition, Newell's Shearwater, social attraction

INTRODUCTION

The re-establishment or establishment of breeding colonies of severely reduced or extirpated seabird populations through predator control, sometimes followed by chick translocation and/or social attraction, has been a successful management practice for the last 50 years. Indeed, the ~800 efforts to date have involved 100 species (Jones & Kress 2012, Zhou *et al.* 2017; VanderWerf *et al.* 2023). While the majority of projects since the 2010s have dealt with species belonging to the family Laridae, Jones & Kress (2012) reported that ~25% of projects involved procellariids: three used acoustic attraction alone while another 17 projects used acoustic attraction and chick translocation together, chick translocation only, and acoustic attraction accompanied by decoys (see also VanderWerf *et al.* 2023). Herein we summarize a colony establishment effort on the island of Maui in the state of Hawai'i, USA, involving Newell's Shearwater *Puffinus newelli* (NESH), known by its Hawaiian name A'o, and Hawaiian Petrel *Pterodroma sandwichensis* (HAPE), known by its Hawaiian name 'Ua'u. These species are considered Threatened and Endangered, respectively, by the Endangered Species Act (ESA) published by the US Fish & Wildlife Service (DOI 1982). The effort described here provided compensatory mitigation associated with wind energy development on Maui and substantively contributed to species recovery.

We define social attraction as the broadcasting of recorded adult social calls, usually produced at the breeding colony; in some instances, broadcasting included the placement of models or decoys of the respective species. Approximately 300 cases of social attraction are described by Jones *et al.* (2011), who noted that introduced predators first had to be removed from the protected area in the majority of cases, as predation was most often the cause of a seabird species' plight (Towns *et al.* 2011). If full predator eradication is not possible, then fenced exclosures (from which predators have been removed and that they are unable to breach) are necessary to enable the survival of prospecting and breeding birds and their progeny. Among the seabird restoration projects that have been reviewed, some employed only predator removal without social attraction, thereby allowing the seabird populations to recover on their own without the addition of enhanced social cues. Many of these projects tended to be on small islands. Human-constructed "artificial" burrows, which breeding-age and prospecting birds readily utilize, are useful in the early stages of new colony formation.

Both NESH and HAPE populations were greatly reduced on the Hawaiian Islands some 800 years ago following the arrival of humans, who brought with them Pacific or Polynesian Rats *Rattus exulans* and pigs *Sus domesticus*. Subsequently, alien animal predation was augmented by Europeans with introduction of other rat species, cats *Felis catus*, and the Indian Mongoose *Herpestes auropunctatus*. With the addition of habitat change and other anthropogenic factors, many other native Hawaiian bird species were extirpated or severely reduced (Olson & James 1982a, 1982b). This suite of factors stemming from human activities are deemed the main causes behind both the demise of NESH and HAPE (Harrison 1990) and their current status under the ESA. Populations of these cavity-nesting species are very difficult to estimate, especially as their colonies have been relegated to remote, difficult-to-access terrain by the mammalian predators (Ainley *et al.* 2020, Simons & Bailey 2020). These days, NESH number ~28 000 birds (95%

confidence interval (CI) = 18 000–43 000; Joyce *et al.* 2019), with breeders spread among seven islands/islets (~20 600 birds), > 90% of which are on Kaua'i (Ainley *et al.* 2020). The HAPE population numbers ~66 000 birds (20 000–91 000; Joyce *et al.* 2019) nesting among six islands (~12 000 birds), principally on Kaua'i, Lāna'i, and Maui (Simons & Bailey 2020). Pyle & Pyle (2017) estimated that there were about 50 and 1600 pairs of NESH and HAPE, respectively, nesting on Maui in 2017.

To achieve eventual restoration of NESH and HAPE numbers, in accord with their ESA Recovery Plan (DOI 1982), greater emphasis is being placed on specific management actions to address key threats. Efforts for NESH began in 1978/80 at Kilauea Point National Wildlife Refuge, Kaua'i, with the cross-fostering of 90 NESH eggs by Wedge-tailed Shearwaters *Ardenna pacifica*, resulting in 67 fledglings (Byrd *et al.* 1984). In the early 1980s, the US National Park Service began what has proved to be a very successful ungulate and predator control program to protect HAPE nesting areas within Haleakalā National Park (Simons & Bailey 2020). Following the cross-fostering effort, a small NESH colony at Kilauea Point became established but was not discovered until 1997. Since then, a total of 13 chicks are known to have fledged from that colony by 2005 (Zaun & Hawkes 2006, K. Uyehara pers. comm. in Ainley *et al.* 2020). The long-term efforts at Haleakalā National Park are considered an important conservation success story (Carlile *et al.* 2003). Pūlama Lāna'i, a private land and resource management company, has achieved similar predator control success at one of the largest known HAPE breeding colonies, which was rediscovered in 2006 on Lāna'i.

In recent decades, NESH numbers on Kaua'i have continued to decrease, with HAPE only initially following this trend (Raine *et al.* 2017, Ainley *et al.* 2023). Perhaps more importantly, NESH has largely disappeared from other islands (Pyle & Pyle 2017, Ainley *et al.* 2020). As the NESH decline has hastened, the state and federal wildlife agencies entrusted with stewardship of these species (the Hawai'i Department of Land and Natural Resources and the US Department of the Interior) have been developing management strategies and conservation partnerships that are strengthening management capacity. These include the Kaua'i Endangered Seabird Recovery Project (Kaua'i), the Maui Nui Seabird Recovery Project (MNSRP; Maui, Molokai), and Pūlama Lāna'i. Concurrent with these initiatives has been the development of several Habitat Conservation Plans that contain robust programs designed to achieve long-term conservation benefits for NESH and HAPE on Kaua'i and Maui.

When efforts first began to locate as-yet unknown colonies of NESH and HAPE on Maui, Kaheawa Wind Power (one of the largest wind farms in Hawai'i) and the wildlife agencies envisioned that existing colonies of HAPE and NESH could be located and fenced, and that predators could be controlled. This would enable these colonies to flourish at levels above those that occur when protective measures are absent. Field investigations, including radar studies (Cooper & Day 2003) and reports from field biologists, helped inform where audio-visual surveillance was most likely to result in HAPE and NESH detections in the West Maui interior. Surveys ultimately identified several activity hotspots for HAPE, though they were confined to deep valleys and steep, high-elevation terrain; surveys also identified at least one small NESH hotspot. None of these areas was readily accessible or conducive for predator control (i.e., fencing) and long-term management.

In 2007, biologists performing nighttime reconnaissance discovered a site on the windward slope of West Maui at 500–800 m elevation, where HAPE could be observed vocalizing and performing low-level aerial flight displays over a relatively concentrated area along Makamaka'ole Stream (Fig. 1). On an old map, the area was labeled "Ua'u Hill." Nighttime auditory point counts and visual observations later confirmed marked HAPE aerial activity (with an occasional NESH), and that this activity was consistent with colony attendance, at least by petrels (Kaheawa Wind Power II 2011). Trained dogs searched the area and found a few abandoned HAPE nesting cavities. Human searchers later discovered a burrow with associated petrel remains, along with evidence of widespread presence of mongoose. Because the Makamaka'ole site was accessible by vehicle and foot and because researchers could secure landowner approval, it was selected for an attempt to establish viable breeding colonies of both species using predator control and social attraction. Population modeling was used to estimate various success scenarios, including recruitment and population growth rates over more than 20 years.

METHODS

Population modeling

We modeled the effects of mitigation efforts on HAPE using an age-classified (Leslie) matrix population model (Caswell 2001). Modeling was performed using Hood (2010), and R software (RDCT 2009). We projected the number of adult and juvenile HAPE using the mitigation site for a 20-year period from the start of the mitigation for eight different scenarios (i.e., one baseline scenario and seven different mitigation scenarios) to determine the circumstances under which a net recovery benefit could be achieved (H.T. Harvey & Associates 2011a, 2011b). Model projections tracked expected dynamics of the local population, assuming no net emigration or immigration. The mitigation scenarios assumed various increases to annual adult survival rate and reproductive success as a result of proposed predator control, compared to the baseline scenario.
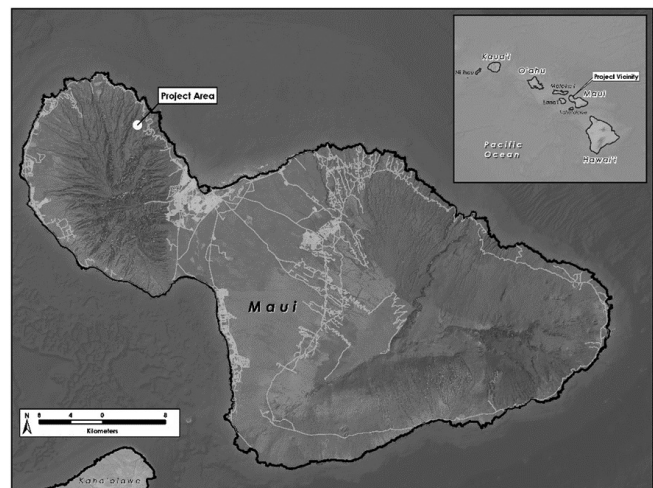
Fig. 1. The island of Maui—second largest of the main Hawaiian Islands, USA—and the location of the Makamaka'ole seabird conservation area (Project Area) in West Maui. The high-elevation areas of Mount Haleakalā in East Maui (the eastern third of Maui) and the much smaller island of Lāna'i to the west (inset) both host large breeding populations of Hawaiian Petrel *Pterodroma sandwichensis*.

In regard to HAPE, the following rates were used for our models, based on the demographic variables in Simons (1984, 1985) and Hodges & Nagata (2001). We assumed an initial population size of no more than several hundred pairs in West Maui (Fig. 2A, 2B), that average first reproduction occurs at six years of age, and that some individuals breed as four- and five-year-olds. No data are available to differentiate survival in the first few years, when immature birds remain mostly or entirely at sea and, thus, survival to age four years remains the same regardless of colony predation. The 600 pairs in the starting population were taken as an estimate of the population that could have been in West Maui, given the level of activity observed (especially relative to NESH) by radar (Cooper & Day 2003) and given the local point counts in the context of how many HAPE nested elsewhere on Maui (*cf.* Simons & Bailey 2020).

With predation active:

- Survival from fledging to age 4 years = 0.27; survival at age > 4 years = 0.80 per annum
- Breeding probability at age ≥ 6 = 0.51 per annum; at age 4–5 years = 0.26 per annum
- Reproductive success at age ≥ 6 = 0.39 per annum; at age 4–5 years = 0.27 per annum

With predators excluded:

- Survival from fledging to age 4 years = 0.27; survival at age > 4 years = 0.93 per annum
- Breeding probability at age ≥ 6 = 0.89 per annum; at age 4–5 years = 0.45 per annum
- Reproductive success at age ≥ 6 = 0.72 per annum; at age 4–5 years = 0.50 per annum

In regard to NESH, the following rates were used based on the demographic variables in Ainley *et al.* (2001) and Griesemer & Holmes (2010), assuming an initial population not exceeding 40 pairs in West Maui (Fig. 2C, 2D). That, too, was a best estimate based on the numbers thought to exist in West Maui (*cf.* Cooper & Day 2003, Ainley *et al.* 2020). Average first reproduction occurs at six years of age, and some individuals breed as three- to five-year-olds; similar to HAPE, no data are available to differentiate survival in the first few years when immature birds remain mostly or entirely at sea, so survival to age four years remains the same regardless of colony predation.
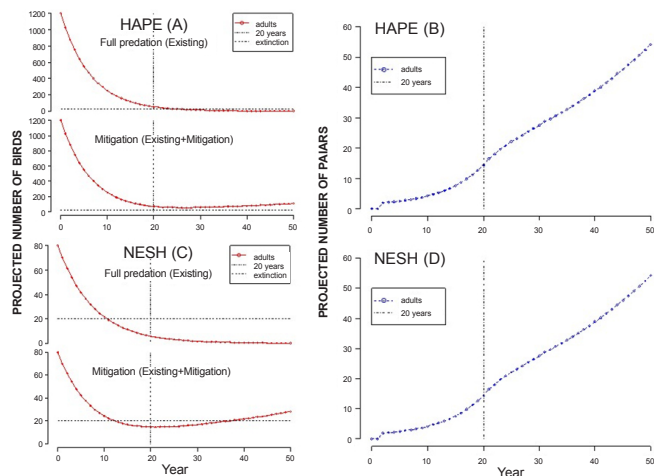
With predation active:

- Survival from fledging to age 1 year = 0.516, at age 2 years = 0.780, at age 3 years = 0.830, at age ≥ 6 years = 0.877 per annum
- Breeding probability at age ≥ 6 years = 0.50; at age 3–5 years = 0.25
- Reproductive success at age ≥ 6 years = 0.30; at age 3–5 years = 0.21

With predators excluded:

- Survival from fledging to age 1 year = 0.516, survival at age 2 years = 0.780, at age at 3 years = 0.830, at age 2 years = 0.890, at age 3 years = 0.905, at age ≥ 6 years = 0.930 per annum
- Breeding probability ≥ 6 years = 0.80; at age 3–5 years = 0.40
- Reproductive success age ≥ 6 years = 0.70; at age 3–5 years = 0.50

Project operation

Two fenced areas, each of about 1.8 hectares (ha, 0.018 km²), were created in 2013 using fencing designed to exclude mammalian predators (Fig. 3). These two exclosures were separated by about 135 m, and within each, we used Tomahawk (Hazelhurst, Wisconsin, USA) cage traps to intercept cats; for mongoose we deployed DOC-200 (Predator Free, New Zealand) traps secured

Fig. 2. Modeled Hawaiian Petrel *Pterodroma sandwichensis* (HAPE) scenarios: A) the mitigation colony with predation is "borrowing" recruits from the existing West Maui population, which is otherwise disappearing; and B) the mitigation colony (now the entire West Maui population) is growing with predation removed and social attraction added. In Newell's Shearwater *Puffinus newelli* (NESH) scenarios, C) the existing West Maui population disappears with predation, and population growth in mitigation colony eventually becomes positive; D) with predation removed and social attraction added, the mitigation colony and West Maui population both grow.

Fig. 3. The two fenced management areas (with Makamaka'ole Valley, Hawaii, USA, in the background) were fenced to exclude predators in 2013/14. Management actions initially focused on establishing separate Newell's Shearwater *Puffinus newelli* (right exclosure) and Hawaiian Petrel *Pterodroma sandwichensis* (left exclosure) colonies.

in boxes designed to avoid non-target species. Snap traps and diphacinone bait grids to control rats were placed 50 m apart throughout the exclosures. Traps were also placed outside the fences to maintain an exclusion buffer.

Nest boxes were fabricated out of marine-grade plywood (*n* = 50 per exclosure) and installed in clusters with no less than 2 m between nest boxes. Locations were selected so that the adjacent slope and aspect to prevailing winds would facilitate birds taking flight (especially NESH; Fig. 4). Custom HAPE and NESH decoys were fabricated (Weta Workshop, New Zealand) and placed in the vicinity of the burrow clusters as an added visual cue, and recorded call loops of both species began broadcasting from the respective exclosures. Recordings mostly of aerial calling were gathered on Kaua'i, Lāna'i, and Maui and stored digitally on standard definition (SD) memory cards. Recordings were played from sundown to sunrise on a Sony Xplod 350W 2/1 channel amplifier (or similar) powered by a solar array and broadcasted through four 30-watt and two 50-watt speaker horns (TOA Electronics, Ltd., Secaucus, New Jersey, USA) spread within each exclosure.

To monitor initial visitation of nest sites by HAPE and NESH, we placed an array of toothpicks across each nest box entrance and monitored them frequently for signs of disturbance; i.e., we took scattering or displacement of toothpicks as an indicator of birds exploring the burrow entrance. After a site exhibited several toothpick displacements, often accompanied by guano, a motion-triggered infrared game camera (Reconyx, Holmen, Wisconsin, USA) was positioned within a few meters of the nest box entrance and programmed to record three to five digital images per triggering event (Fig. 5). Images were stored on time- and date-stamped digital SD cards; each image was viewed individually to score the species, number of birds, visitation frequency, general activities, and behavior (Fig. 6). Such a procedure has since been used effectively to monitor activities and breeding success of montane, burrow-nesting seabirds like NESH and HAPE (Raine *et al.* 2022, Raine & Sprague 2022).

Fig. 4. View overlooking the southwestern portion of the Exclosure B management area on Maui, Hawai'i, USA, where the majority of the nest boxes were initially installed to facilitate colonization by Hawaiian Petrel *Pterodroma sandwichensis*; the watershed through which Makamaka'ole Stream flows is visible in the background.

Fig. 5. Game camera images of a Newell's Shearwater *Puffinus newelli* (NESH, left) and Hawaiian Petrel *Pterodroma sandwichensis* (HAPE, right) on Maui, Hawai'i, USA, using the same uluhe fern cavity on different but nearly overlapping nights in August 2017. Below the photos is the corresponding record of visitation at an adjacent nest box (B-22). Date boxes filled by black (NESH) or blue (HAPE) indicate nights of visitation.

RESULTS AND DISCUSSION

Modeling

In HAPE scenarios with predation (Fig. 2A), the existing West Maui population disappears, while the mitigation colony "borrows" recruits (emigrants from other colonies) and persists. With predation removed and social attraction added (Fig. 2B), the mitigation colony (having shifted to become the hub of the West Maui population) grows. In NESH scenarios with predation (Fig. 2C), the West Maui population disappears and population growth in mitigation colony eventually becomes positive. However, with predation removed and social attraction instituted (Fig. 2D), both the mitigation colony and West Maui population grow.

Response of petrels and shearwaters

HAPE and NESH both initially showed interest in the acoustic playbacks within days of the start of broadcasting in March 2014. During the weeks that followed, both species called and swooped over speakers (typical of mate attraction/formation behavior), followed eventually by landing to visit nearby nest boxes. In 2017,
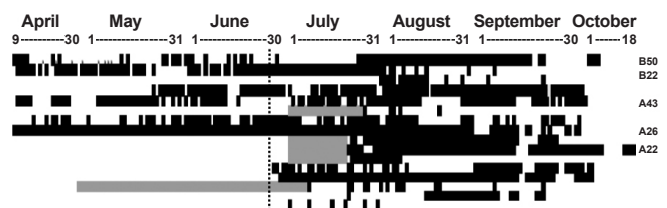
Fig. 6. Activity of Newell's Shearwater *Puffinus newelli* in nest boxes on Maui, Hawai'i, USA, during 2019, as recorded by trail cameras (i.e., comings and goings, mostly). Dates of visitation represented by black were sensed by camera; consecutive nightly visitations become a horizontal bar. Gray shading indicates visitation, as detected by periodic guano and disturbed toothpicks prior to camera deployment. The dotted vertical line indicates when additional speakers were added. Labeled nest boxes on the right indicate those having evidence of a chick.

individuals from both species attempted to improve a natural cavity inside a stand of uluhe ferns *Dicranopteris linearis* (Fig. 5). Groves of uluhe are typical nesting understory in many other HAPE and NESH nesting locations, though such xeric landscapes are used by HAPE as well (Troy *et al.* 2016, Young *et al.* 2019, Ainley *et al.* 2020, Simons & Bailey 2020). It seems plausible that HAPE and NESH may have been competing for the same nest sites: although both species were still observed flying and vocalizing over the management area after 2017, HAPE no longer investigated natural cavities or nest boxes. After 2017, only NESH were documented visiting nest boxes and recorded laying eggs in them beginning in 2017/18; Table 1).

A petrel, apparently *Bulweria* spp., was the first seabird seen in the game cameras in 2014. In 2017, rather unexpectedly, a pair of this species shared interest with NESH in one of the nest boxes, where both species eventually laid eggs. Of interest, the *Bulweria* egg was laid during the winter preceding the arrival of NESH. Laying at the time called into question the actual species involved; Bulwer's Petrel *Bulweria bulwerii* is not known as a winter breeder in Hawai'i, though the *Bulweria* spp. do nest during winter elsewhere (Howell & Zufelt 2019). In 2019, NESH again ejected this pair of petrels, pushing their egg aside. Despite their shared space, the alleged Bulwer's Petrels occupied this favored nest box (B-50) each season (Table 1, Fig. A1).

During the initial few years of the project, NESH eggs were laid but broke or rolled out of the nest box and down the tunnel. We surmised that some eggs could have been laid within the long (2 m) tunnels, rather than in the nest box. On the other hand, inadequate attempts at nesting can be a function of the inexperience of new recruits (known in many seabird species; Brook 1990, Warham 1996), which most of these birds may well have been. Nest box

intrusions by competitors can also lead to lost eggs. Physical conditions of the nest environment might also be important, but our monitoring indicated that the box environment was not an issue. No strong evidence established that any chicks were produced during these early years. In 2019, prior to the arrival of NESH or HAPE, efforts were made to reduce the potential for egg breakage by replacing the river stones initially used for box drainage with pea gravel and some minimal grassy substrate. This seemed to reduce apparent egg breakage. In 2021, the remaining river stones were removed to a depth of ~5 cm and the bottom of the box was filled with sand to a level approximating the tunnel entrance; the contents of each, collected prior to substrate refurbishment, was returned to the respective nest box (PCSU 2022).

In 2019, the number of speakers was doubled and placed at wider intervals within the nest box clusters, as the birds appeared to be attracted to nest boxes near speakers. In addition, decoys were periodically repositioned to minimize potential site-specific adversarial response by prospectors (i.e., avoidance of conflict). The first offspring were also produced in 2019 (Fig. A2). Visitation and activity data gathered from the game cameras and visual inspections of nest boxes indicated that eggs were laid and that chicks likely fledged from one or more nest boxes (Fig. 6). Although only one chick was photographed in its nest box, three to four other nest boxes contained thick mats of downy feathering, eggshells, and fragments of membrane; lengthy periods of parental attendance and visitation were consistent with provisioning (Fig. A3). Nest box cameras recorded birds with visible tufts of down emerging from entrances to display and exercise wings. Lastly, the feeding of a chick by its parents at the entrance was recorded in at least one nest box (A-22; Fig. A4), with the same chick exercising its wings a few days before apparent departure (Fig. A5). Eleven of the other pairs used nest boxes for most of the season. We surmise, based on observations from 2019, that some chicks remain in the long tunnels during the day, rather than inside the boxes themselves, while awaiting food visits from parents. Thus, our decision to avoid undue disturbance to new breeders by not continually opening nest boxes may have been overly conservative relative to assessing our goals. Since 2021, the new breeding site at Makamaka'ole has produced at least one successful NESH fledgling annually. At least 24 nest boxes have received active visitation, mostly in exclosure A but expanding into exclosure B. In 2022, researchers identified a female sex-biased recruitment pattern among NESH sampled at nesting sites inside the management area (Learned *et al.* 2023).

Recommendations

Although the new nesting colony has been exhibiting steady growth, mostly in accord with modeling results (at least for NESH), maintaining the basic management protections is essential to ensure continued colony growth. Ongoing management and maintenance are required to ensure the fences remain fully functional, along with monitoring and trapping to ensure the exclosures remain predator-free. At ~600 m elevation, the project area is exposed to steady trade winds, which deliver salty marine air upslope and through the area (most pronounced in February to September), hence the corrosion of the metal fencing. Heavy rains and moist marine air descend upon the area during the winter months. To address serious maintenance needs, several sections of meshing along with some fence posts were replaced prior to the beginning of the 2020 breeding season, and these types of repairs and maintenance actions have continued.

TABLE 1
Summary of nest box activity during years when acoustic broadcast combined with decoys were used to attract Newell's Shearwater *Puffinus newelli* (NESH) and Hawaiian Petrel *Pterodroma sandwichensis* (HAPE), on Maui, Hawaii, USA, 2013–2019

Year	Exclosure A			Exclosure B		
	Nests visited	No. eggs	Max. no. chicks	Nests visited[a]	No. eggs	Max. no. chicks
2013	0	0	0	0	0	0
2014	0	0	0	1	0	0
2015	0	0	0	1	0	0
2016	1	0	0	4[b]	0	0
2017	3	3	0	3[b]	1	0
2018	5	2	0	5[b]	2	0
2019	14	3	3	2	3	2

[a] A species of dark *Bulweria*-like petrel, the first seabird observed exploring the artificial burrows in 2014/15, continued to be present each season thereafter, eventually displaced each season by NESH (Kaheawa Wind Power 2020, H.T. Harvey & Associates 2020)

[b] A single NESH fledgling was produced in each of 2021 and 2022 (PCSU 2022, MNSRP pers. comm.)

We recommend four actions that may improve the performance of this incipient colony and that are relevant to similar efforts elsewhere in Hawai'i:

First, rebuild and modify the design of many of the original and weathered nest boxes, and shorten the entrance tunnels from 2 m to perhaps 70 cm. This shorter tunnel would be more consistent with some other social attraction projects (e.g., Bell *et al.* 2005) and with the actual nest passage dimensions of most NESH and HAPE nests (e.g., Ainley *et al.* 2020, Simons & Bailey 2020). In Australian efforts, the tunnels are long enough only to exclude light (≤ 70 cm; N. Carlile pers. comm.).

Second, expand the acoustic attraction capacity by adding and repositioning speakers to focus on areas targeted by first-time, prospecting birds and to reduce competition for nesting sites. At the same time, rather than adding more boxes, begin digging "starter" burrows so that nest boxes may eventually not be necessary (N. Carlile pers. comm.).

Third, broadcast recordings from only the courtship to early chick periods, which is the portion of the season when pairs are forming and potential recruits would be scouting (Warham 1996). We suggest this because, notwithstanding normal competition for nest sites, the cameras recorded periods of hyperactivity and some apparent aggression among birds exhibiting interest in the same nest box, especially in the vicinity of the larger (50-watt) speakers. It is possible that continuing to play recordings beyond the courtship-early chick period could amplify territoriality, thus discouraging some individuals. MNSRP biologists (pers. comm.) were also concerned about this issue; they did not include audio playback of calls of NESH in 2020 and 2021 but they did play recorded HAPE calls.

Fourth, our data do not indicate whether the decoys affected the recruitment or behavior of seabirds visiting the site, in that cameras never documented shearwater/petrel interaction with the decoys. In general, as a visual cue, they are considered a valued element of some social attraction and restoration projects (VanderWerf *et al.* 2023).

Questions remaining

Some tantalizing questions have arisen. First, why did HAPE, after exhibiting initial interest in nest boxes and cavities then continuing some aerial visitation of the site thereafter, eventually cease interest in actually nesting? After all, HAPE are very abundant in East Maui and nearby Lāna'i, and thus the probability of recruitment would seem to be high.

Second, where did all the NESH come from? NESH are many times less prevalent than HAPE in the Makamaka'ole area, at least judging from the relative intensity of calling and the frequency of fly-bys observed for both species at night during the breeding season (Kaheawa Wind Power II 2011, G. Spencer pers. obs.) as well as from earlier radar surveys (e.g., Cooper & Day 2003). Given the relatively high abundance of HAPE, it does not appear likely that sex-biased response (i.e., recruitment prevalence dominated by just one sex) would be involved, as it is in some other procellarids (Brook 1990). If sex-biased recruitment was occurring, then it would more likely be exhibited by the less abundant NESH (Brook 1990). MNSRP (PCSU 2022), based on observations in 2020 and

2021, postulated that the occurrence of multiple eggs in some burrows might indicate that breeding-age NESH establishing nest sites at Makamaka'ole were often young and predominantly female birds. This was confirmed in 2022 by Learned *et al.* (2023). There could well be a greatly unbalanced sex ratio favoring females in the remnant West Maui NESH population, given the much higher predation of males by mammalian predators, likely owing to males' markedly greater ground time while engaging in burrow-making and pair formation behavior (e.g., Brook 1990, Warham 1996).

Third, are HAPE and NESH actually compatible in a one-colony setting? If so, what are the most important mechanisms to consider? These observations may be useful and may inform similar conservation management actions elsewhere in Hawai'i, where efforts are being undertaken to attract one or both of these species to predator-free management areas to promote colony establishment. Indirect evidence suggests that NESH and HAPE may not be compatible in close breeding proximity. For instance, where both species populate the razor-back ridges of the Nāpali region of Kaua'i, HAPE tend to nest on the ridge crests while NESH nest on the adjacent slopes below (Ainley & Holmes 2011, Troy *et al.* 2016). That difference appears to be more than just a function of aerodynamic abilities, HAPE (a gadfly petrel) being a much more adept flyer than NESH (Spear & Ainley 1997a, 1997b). There could well be some social tension affecting respective habitat choices, similar to what is exhibited in other species. For example, Wedge-tailed Shearwaters are notorious for excluding other procellarids (N. Carlile pers. comm.), and that may be why NESH are absent from near-coast habitats, despite NESH fledglings having been cross-fostered by Wedge-tailed Shearwaters (B. Zaun & K. Uyehara in Ainley *et al.* 2020). Bulwer's Petrels are easily displaced by NESH at Makamaka'ole, a behavior also consistent with this pattern.

Another important consideration is that many of the HAPE flying over Makamaka'ole probably associate with birds from Lāna'i and/or the Haleakalā area on Maui, both of which are within ~40 km of Makamaka'ole. Together, these two sites represent two-thirds of the world HAPE population, i.e., several thousand breeding pairs (Pyle & Pyle 2017). The few HAPE still breeding in the West Maui Mountains likely interact extensively at sea with Haleakalā and Lāna'i birds. During the breeding season, evening assemblages of HAPE form in the channel waters between Maui and Lāna'i before birds ascend to their nesting colonies (Ainley & Spencer pers. obs.). If prospective West Maui recruits are included, the significant numbers of Lāna'i HAPE within these assemblages might well attract potential HAPE recruits away from West Maui, perhaps negatively affecting HAPE recruitment capacity at Makamaka'ole. In other words, the Lāna'i and Haleakalā populations, by the power of their high densities and activities, could arguably constitute a seductive force that attracts HAPE away from the small population of West Maui. Apparently, the increasingly consistent calls produced by NESH at Makamaka'ole have been attracting the interest of more NESH recruits, from wherever they might originate.

CONCLUSIONS

On the basis of the criterion offered by Jones & Kress (2012), in which the laying of eggs in two consecutive years represented restoration success, the Makamaka'ole project clearly has advanced on a successful track. In accord with initial modeling, particularly for NESH, the scenario and progression described here were on track: "founding" within a couple of years and then measurable

growth before 10 years had passed. The question of where all the NESH came from can be considered if there was a "floating" portion of the population, which is a common characteristic of any cavity-nesting seabird species: a portion of breeding-age individuals look for but cannot find suitable nesting sites, with mature non-breeders dominating the population (Warham 1996). While the overall trajectory of the NESH at Makamaka'ole thus far does conform to the initial modeling, which assumed initial recruitment of immigrants, the sudden increase in breeding birds with the addition of more speakers in 2019 was nothing less than spectacular for this threatened seabird species. This unexpected influx, for whatever reason, has been seen in other seabird artificial colony projects (e.g., Duarte-Canizales *et al.* 2021, Jan *et al.* 2021), but NESH are thought to be very uncommon (i.e. near extirpated) on Maui (Pyle & Pyle 2017). It would seem that a number of breeding-age individuals, both NESH and HAPE, were awaiting their chance to recruit somewhere on Maui, but they may have been deterred by dense predator presence or other limiting factors. It was clear in the early days of this project that the density of predators, especially Indian Mongoose, was (and continues to be) incredibly high in the area, though this is no longer the case within the exclosures. Calling broadcast from the ground was apparently enough to convince both species, and especially NESH, to attempt nest establishment rather than simply flying past. A residual pool dominated by NESH females would explain the almost-immediate positive reaction to call playbacks. Resolving the importance of many poorly understood factors affecting seabird demography (e.g., degree of philopatry) and the success of seabird colony establishment or re-establishment in Hawai'i continues to present challenges for management actions involving HAPE and NESH. For now, we know that NESH colony establishment is achievable through a combination of predator exclusion and social attraction.

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REFERENCES

AINLEY, D.G. & HOLMES, N. 2011. *Species Accounts for Three Endemic Hawaiian Seabirds on Kaua'i: Hawaiian Petrel, Newell's Shearwater and Band-rumped Storm Petrel.* Unpublished Report. Honolulu, USA: US Fish & Wildlife Service.

AINLEY, D.G., PODOLSKY, R.R., NUR, N., DEFOREST, L.N. & SPENCER, G.C. 2001. Status and population trends of the Newell's Shearwater on Kaua'i: Insights from modeling. *Studies in Avian Biology* 22: 108–123.

AINLEY, D., SCHNEIDER, S. & SPENCER, G. 2023. Disparate decadal trends in Kaua'i seabird populations. Possible effects of resource competition and anthropogenic impacts. *Marine Ornithology* 51: 47–54.

AINLEY, D.G., TELFER, T.C., REYNOLDS, M.H. & RAINE, A.F. 2020. Newell's Shearwater (*Puffinus newelli*), version 2.0. In: RODEWALD, P.G. (Ed). *Birds of the World*. Ithaca, USA: Cornell Lab of Ornithology. doi:10.2173/bow.towshe2.01

BELL, M., BELL, B.D. & BELL, E.A. 2005. Translocation of Fluttering Shearwater (*Puffinus gavia*) chicks to create a new colony. *Notornis* 52: 11–15.

BROOK, M. 1990. *The Manx Shearwater*. San Diego, USA: Academic Press.

BYRD, G.V., SINCOCK, J.L., TELFER, T.C., MORIARTY, D.I. & BRADY, B.G. 1984. A cross-fostering experiment with Newell's race of Manx Shearwater. *Journal of Wildlife Management* 48: 163–168.

CARLILE, N., PRIDDEL, D., ZINO, F., NATIVIDAD, C. & WINGATE, D.B. 2003. A review of four successful recovery programmes for threatened, sub-tropical petrels. *Marine Ornithology* 31: 185–192.

CASWELL, H. 2001. *Matrix Population Models: Construction, Analysis, and Interpretation, 2nd Edition*. Sunderland, USA: Sinauer Associates, Inc.

COOPER, B.A. & DAY, R.H. 2003. Movement of the Hawaiian Petrel to inland breeding sites on Maui Island, Hawai'i. *Waterbirds* 26: 62–71.

DOI (DEPARTMENT OF THE INTERIOR). 1982. *Recovery Plan: Newell's Shearwater and Dark-rumped Petrel*. Portland, USA: Department of the Interior, US Fish & Wildlife Service.

DUARTE-CANIZALES, A., MÉNDEZ-ROSAS, L., FERNÁNDEZ-ROBLEDO, A., ROLDÁN-OLVERA, E., MÉNDEZ-SÁNCHEZ, F. & HERNÁNDEZ-MONTOYA, J. 2021. *Restoration Actions for the Conservation of Guadalupe Murrelet (Synthliboramphus hypoleucus) on Guadalupe Island, México.* Abstract presented at the 3rd World Seabird Conference, 04–08 October 2021, online. https://worldseabirdconference.com/program/

GRIESEMER, A. & HOLMES, N.D. 2010. *Population modeling for Newell's shearwaters for HCP and Recovery Planning.* Unpublished report. Lihue, USA: Kaua'i Seabird Habitat Conservation Plan.

HARRISON, C.S. 1990. *Seabirds of Hawaii: Natural History and Conservation.* Ithaca, USA: Cornell University Press.

HODGES, C.S.N. & NAGATA, SR., R.J. 2001. Effects of predator control on the survival and breeding success of the endangered Hawaiian Dark-rumped Petrel. *Studies in Avian Biology* 22: 308–318.

HOOD, G. 2010. *PopTools Version 3.2.0.* Accessed at http://www.cse.csiro.au/poptools/index.htm on 03 March 2011.

HOWELL, S.N.G. & ZUFELT, K. 2019. *Oceanic Birds of the World: A Photo Guide*. Princeton, USA: Princeton University Press.

H.T. HARVEY & ASSOCIATES. 2011a. *Newell's Shearwater Population Modeling – Growth of Mitigation Colony at Makamaka'ole, West Maui and Growth in a Possible Project in East Maui, Addendum 4*. Final Report. Kihei, USA: First Wind, Environmental Affairs, Kaheawa Wind Power LLC.

H.T. HARVEY & ASSOCIATES. 2011b. *Hawaiian Petrel Population Modeling*. Final updated report. Kihei, USA: First Wind, Environmental Affairs, Kaheawa Wind Power, LLC.

H.T. HARVEY & ASSOCIATES. 2020. *Makamaka'ole Seabird Mitigation Project*. 2019 Final Report. New York, USA: TerraForm Power.

JAN, P.-L., BARBRAUD, C., JENOUVRIER, S. & DIVOKY, G. 2021. *How sea ice processes and climate fluctuations affect the demography an Arctic diving seabird?* Abstract presented at the 3rd World Seabird Conference, 04–08 October, online. https://worldseabirdconference.com/program/

JONES, H.P. & KRESS, S.W. 2012. A review of the world's active seabird restoration projects. *Journal of Wildlife Management* 76: 2–9. doi:10.1002/jwmg.240

JONES, H.P., TOWNS, D.R., BODEY, T., ET AL. 2011. Recovery and restoration on seabird islands. In: MULDER, C.P.H., ANDERSON, W.B., TOWNS, D.R. & BELLINGHAM, P.J. (Eds). *Seabird Islands: Ecology, Invasion, and Restoration*. Oxford, UK: Oxford University Press.

JOYCE, T.R., PITMAN, R.L. & BALLANCE, L.T. 2019. *Estimates of Newell's Shearwater (*Puffinus newelli*) and Hawaiian Petrel (*Pterodroma sandwichensis*) abundance and distribution based on data collected at sea, 1998–2017*. Abstract presented at the 46th Annual Meeting of the Pacific Seabird Group, 27 February to 03 March, Lihue, USA. https://pacificseabirdgroup.org/wp-content/uploads/2019/03/PSG2019_Abstracts.pdf

KAHEAWA WIND POWER. 2020. *Kaheawa Wind Power Habitat Conservation Plan, 2020 Annual Report*. Wailuku, USA: Kaheawa Wind Power.

KAHEAWA WIND POWER II. 2011. *Kaheawa Wind Power II Wind Energy Generation Facility Habitat Conservation Plan*. Wailuku, USA: Kaheawa Wind Power.

LEARNED, J., HAYES, K., ANDERSON, S., ET AL. 2023. *Broadcast playback attracts a female-biased population of Newell's Shearwaters within predator-proof exclosures on Maui*. Presentation at the 50th Annual Meeting of the Pacific Seabird Group, 15–17 February, La Jolla, USA.

OLSON, S.L. & JAMES, H.F. 1982a. Fossil birds from the Hawaiian Islands: Evidence for wholesale extinction by man before Western contact. *Science* 217: 633–635.

OLSON, S.L. & JAMES, H.F. 1982b. *Prodromus of the fossil avifauna of the Hawaiian Islands*. Smithsonian Contributions to Zoology no. 365. Washington, USA: Smithsonian Institution Press.

PCSU (PACIFIC COOPERATIVE STUDIES UNIT). 2022. *Makamaka'ole Threatened and Endangered Seabird Mitigation Project: Exclosures and Artificial Burrows Annual Summary Report*. Honolulu, USA: University of Hawaii.

PYLE, R.L. & PYLE, P. 2017. *The Birds of the Hawaiian Islands: Occurrence, History, Distribution, and Status*. Version 2, 01 January. Honolulu, USA: B.P. Bishop Museum. http://hbs.bishopmuseum.org/birds/rlp-monograph

RAINE, A.F, DRISKILL, S., ROTHE, J. & TRAVERS, M.S. 2022. Evaluating the breeding phenology of the endangered 'A'o (Newell's Shearwater *Puffinus newelli*) on Kaua'i to better focus conservation actions and management decisions. *Bird Conservation International* 33: e35. doi:10.1017/S0959270922000387

RAINE, A.F., HOLMES, N.D., TRAVERS, M., COOPER, B.A. & DAY, R.H. 2017. Declining population trends of Hawaiian Petrel and Newell's Shearwater on the island of Kaua'i, Hawaii, USA. *The Condor* 119: 405–415.

RAINE, A.F. & SPRAGUE, R.S. 2022. Observations of leucistic 'Ua'u (Hawaiian Petrel *Pterodroma sandwichensis*) on Lāna'i, Hawai'i. *Marine Ornithology* 50: 129–131.

RDCT (R DEVELOPMENT CORE TEAM). 2009. *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

SIMONS, T.R. 1984. A population model of the endangered Hawaiian Dark-rumped Petrel. *Journal of Wildlife Management* 48: 1065–1076.

SIMONS, T.R. 1985. Biology and behavior of the endangered Hawaiian Dark-rumped Petrel. *The Condor* 87: 229–245.

SIMONS, T.R. & BAILEY, C.N. 2020. Hawaiian Petrel (*Pterodroma sandwichensis*), version 1.0. In: POOLE, A.F. & GILL, F.B. (Eds). *Birds of the World*. Ithaca, USA: Cornell Lab of Ornithology, doi:10.2173/bow.hawpet1.01

SPEAR, L.B. & AINLEY, D.G. 1997a. Flight behaviour of seabirds in relation to wind direction and wing morphology. *Ibis* 139: 221–233.

SPEAR, L.B. & AINLEY, D.G. 1997b. Flight speed of seabirds in relation to wind speed and direction. *Ibis* 139: 234–251.

TOWNS, D.R., BYRD, G.V., JONES, H.P., RAUZON, M.J., RUSSELL, J.C. & WILCOX, C. 2011. Impacts of introduced predators on seabirds. In: MULDER, C.P.H., ANDERSON, W.B., TOWNS, D.R. & BELLINGHAM, P.J. (Eds). *Seabird Islands: Ecology, Invasion, and Restoration*. Oxford, UK: Oxford University Press.

TROY, J.R., HOLMES, N.D., JOYCE, T., BEHNKE, J.H. & GREEN, M.C. 2016. Characteristics associated with Newell's Shearwater (*Puffinus newelli*) and Hawaiian Petrel (*Pterodroma sandwichensis*) burrows on Kauai, Hawaii, USA. *Waterbirds* 39: 199–204.

VANDERWERF, E.A., KRESS, S., GUZMÁN, Y.B., SPATZ, D.R., TAYLOR, G. & GUMMER, H. 2023. Restoration: Social attraction and translocation. In: YOUNG, L. & VANDERWERF, E. (Eds). *Conservation of Marine Birds*. London, UK: Academic Press.

WARHAM, J. 1996. *The Behaviour, Population Biology and Physiology of the Petrels*. San Diego, USA: Academic Press.

YOUNG, L.C., VANDERWERF, E.A., MCKOWN, M., ET AL. 2019. Evidence of Newell's Shearwaters and Hawaiian Petrels on Oahu, Hawaii. *The Condor* 121: 1–7.

ZAUN, B.J. & HAWKES, M.M. 2006. *Nesting behavior and reproductive success of Newell's Shearwater on Kauai, Hawaii*. Abstract presented at the 33rd Annual Meeting of the Pacific Seabird Group, 15-19 February, Girdwood, USA.

ZHOU, X., CHEN, D., KRESS, S.W. & CHEN, S. 2017. A review of the use of active seabird restoration techniques. *Biodiversity Science* 25: 364–371. doi:10.17520/biods.2016378