# Prioritization of Restoration Needs for Seabirds in the U.S. Tropical Pacific Vulnerable to Climate Change[1]

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**Abstract:** The U.S. Tropical Pacific (USTP) is a globally important area for seabirds with tens of millions of individuals of 32 species breeding in the region. The two greatest threats to breeding seabirds in the USTP are inundation of colonies caused by global climate change and non-native predators. We assessed the status of seabird species breeding in the USTP and which species would benefit most from restoration activities. We scored each species for nine criteria that reflected their extinction risk and vulnerability to climate change and invasive predators, then summed the scores of all criteria to obtain an overall score and ranked the species in terms of overall conservation need. The top five species at risk (in order) were Hawaiian Petrel (*Pterodroma sandwichensis)*, Newell's Shearwater (*Puffinus newelli*), Polynesian Storm-Petrel (*Nesofregetta fuliginosa*), Phoenix Petrel (*Pterodroma alba*), and Black-footed Albatross (*Phoebastria nigripes*). We also assessed 86 locations in the USTP as potential source and restoration sites for seabirds to mitigate the impacts of sea level rise and invasive predators. Some restoration actions are underway for three of the top five species in the USTP, but more actions are needed. Two of the top species (Polynesian Storm-petrel and Phoenix Petrel) occur primarily outside the USTP. Actions within the USTP are needed to complement existing conservation measures underway elsewhere in the Pacific and should be prioritized for future management actions.

**Keywords:** assisted colonization, climate change, invasive predators, managed relocation, sea level rise, seabirds, social attraction, translocation

Seabirds are among the most threatened groups of vertebrates worldwide, with 70% of the 368 species experiencing population declines and up to a third imminently threatened with extinction (Dias et al. 2019). Seabird populations have been substantially reduced by human activities. In their terrestrial breeding habitats, resource extraction, commercial harvest, introduction of invasive species, and anthropogenic increases in predator populations have significant negative impacts (Furness 2003, Jones et al. 2008, Young and VanderWerf 2022). In their marine feeding habitats, fisheries, pollutants, resource extraction, and direct and indirect effects associated with climate change have negatively impacted their populations (Wilcox et al. 2015, Dias et al. 2019, Lieske et al. 2019). Seabirds are one of few groups impacted by both terrestrial and marine threats, which can hamper conservation efforts. Effective conservation depends on targeting species and habitats of greatest importance and most immediate risk. Prioritizing species and habitats in greatest need of conservation interventions can help to ensure that limited conservation resources are allocated towards

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the groups and locations at highest risk (Buxton et al. 2016, McGeoch et al. 2016).

The U.S. Tropical Pacific (USTP) is a globally important area for seabirds, with tens of millions of individuals of at least 32 species breeding in five geographic regions: (1) the Main Hawaiian Islands (MHI), encompassing the larger islands from Hawai'i west to Ni'ihau, and including the offshore islets that are geologically associated with each larger island; (2) the Northwestern Hawaiian Islands (NWHI) from Nihoa west to Kure Atoll; (3) the Mariana Islands (MI), including Guam and the Commonwealth of the Northern Mariana Islands (CNMI); (4) American Samoa (AS), including Rose Atoll and Swains Island; and (5) the Pacific Remote Islands Marine National Monument (Remotes), which includes Palmyra Atoll, Kingman Reef, Wake, Johnston, Jarvis, Howland, and Baker (Figure 1). Collectively, the islands in the USTP support the largest tropical seabird colonies in the world (Naughton et al. 2005). Seabird breeding habitat within this region is highly variable, ranging from low-lying atolls that are vulnerable to sea level rise, to high elevation montane areas on larger islands. The 32 seabird species in the USTP vary in their distribution, with some species being widespread and occurring on most islands in all regions (e.g., Wedge-tailed Shearwater (*Ardenna pacifica*), Red-tailed Tropicbird (*Phaethon rubricauda*), Black Noddy (*Anous minutus*)), and other species being restricted to just one or a few islands in one region (e.g., Short-tailed Albatross (*Phoebastria albatrus*), Tahiti Petrel (*Pseudobulweria rostrata*), Tropical Shearwater (*Puffinus bailloni*), Polynesian Storm-petrel (*Nesofregetta fuliginosa*)).

Climate change is affecting marine and terrestrial systems worldwide, with perturbations in most island groups expected to intensify in the coming decades (Hoegh-Guldberg and Bruno 2010, Bruno et al. 2018, Gagne et al. 2018). The expected impacts of climate change on the USTP ecosystems and

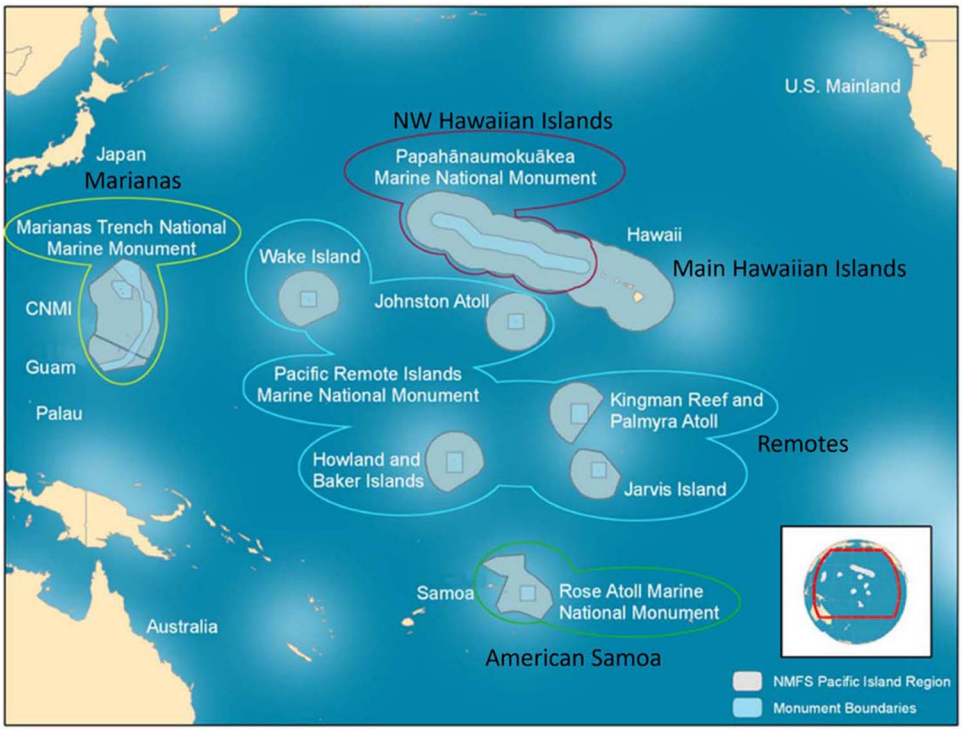


FIGURE 1. Map of regions within the U.S. Tropical Pacific.

seabirds depend, in large part, on oceanographic responses to changing atmospheric conditions (Grémillet and Boulinier 2009, Sydeman et al. 2012, 2021). Robust results from nearly all global climate models used by the Intergovernmental Panel for Climate Change in its 6th Assessment Report (IPCC 2019, Zhai et al. 2021) include: (1) warming of the atmosphere and the oceans leading to increased oceanic stratification, (2) pole-ward shifts of the westerly winds at mid latitudes, (3) sea level rise and (4) a reduction in ocean pH. The predicted decline in ocean pH will cause acidification that is expected to affect coral reefs in tropical ecosystems by accelerating the erosion of coral structures, and other factors mentioned will alter currents, increase marine heat waves, and result in prey shortages for some species. The most severe anticipated effects of climate change on seabirds in the USTP are inundation of breeding colonies from sea level rise and increased storm surge (see Figure 2). Therefore, it is important to determine which species and islands are at highest risk from inundation and to prioritize their restoration and establishment in new, higher locations.

Invasive, non-native predators are a serious threat to seabirds worldwide, affecting almost two-thirds of all seabird species (Jones et al. 2016, Dias et al. 2019). The impacts of predators are particularly severe on islands, which often host endemic seabird species that evolved in the absence of mammalian ground-predators and have limited natural defenses (Salo et al. 2009, Sih et al. 2010). Non-native predators are present on most islands in the USTP, including all larger, high islands and even many remote atolls. Feral cats can be the most serious predator because they are able to take adults of even larger seabirds, which results in more serious demographic consequences (Young et al. 2013, Raine et al. 2020, Vanderwerf 2021) but rats (*Rattus* spp.) prey on eggs, chicks, and sometimes adults of smaller species. Even house mice (*Mus musculus*) are known to be a threat to albatrosses, the largest of seabirds (Angel et al. 2009, Beal et al. 2021). Assessment of the threat from non-native predators to seabirds in the USTP is also essential to prioritizing and planning seabird conservation actions.

Efforts have accelerated recently to restore seabird populations to islands, and, in addition to habitat management and predator removal, frequently have involved social attraction and translocations (Jones and Kress 2012, Zhou et al. 2017, VanderWerf et al. 2022*b*). These efforts have helped seabirds reclaim some historical nesting areas and find safer nesting places in the face of increasing anthropogenic threats. The effectiveness of social attraction and translocation for restoring or creating seabird breeding colonies depends on multiple factors, including the natural history of the species involved, the biotic and abiotic characteristics of the restoration site, and proximity to the nearest existing colony (Jones and Kress 2012, Buxton et al. 2014, VanderWerf et al. 2019). Social attraction involves attracting seabirds to a site with visual, auditory, and occasionally olfactory lures and is more effective in colonial species with weak natal philopatry, post-fledging parental

FIGURE 2. Comparison of erosion over three years from 2019 (left) to 2022 (right) on Midway Atoll in the NWHI.

care, and where existing colonies of the target species are nearby (Buxton et al. 2014). Translocation involves physically moving birds from one location to another, usually when they are chicks, and caring for them until they fledge, and is necessary more often in species with strong natal philopatry, limited or no post-fledging care, and where there are no nearby colonies (Jones and Kress 2012, VanderWerf et al. 2022*b*). Seabird restoration is a long-term process; it often takes years to begin achieving desired results and thus it is crucial to start the process as soon as a threat or need is identified.

The purposes of this project were to (1) evaluate the conservation status of all seabird species breeding in the USTP; (2) assess the threats of climate change and invasive predators to each seabird species; and (3) use this information to prioritize restoration actions for seabirds nesting in the USTP. We also assessed whether social attraction or translocation is likely to be more effective in creating additional breeding populations of each species, and, for the highest priority species, we suggested source and restoration locations that would be most appropriate and effective.

## MATERIALS AND METHODS

We included all seabird species known to nest in the USTP in this study (Table 1). We scored each species on nine criteria that reflected their extinction risk and vulnerability to climate change and non-native predators, and then summed the scores of all criteria to obtain an overall score. Scores for each criterion were structured so that higher scores indicated greater extinction risk. We then used the overall score to rank species in terms of overall conservation need. Below we describe each criterion, including justification for its inclusion, the scale, the data source(s), and any other information important for understanding that criterion and how it was used.

### *Range, Abundance, and Population Trend*

The range, abundance, and population trend of a species are fundamental indicators of status and extinction risk. For global population size and trend of each species, we used estimates provided in the International Union for the Conservation of Nature (IUCN) species accounts (https://www.iucnredlist.org, accessed 18 October 2021), with exceptions described below in cases where more current or complete information existed. Because this project was focused on conservation status and actions needed within the USTP, we also used distribution and population size of seabirds within the USTP as an indicator of conservation status, and we obtained this information from a variety of sources.

For species occurring in the Hawaiian Islands, we obtained population size estimates primarily from Pyle and Pyle (2017), which contains an appendix of seabird populations by island that were provided by researchers and managers familiar with each island. For some species we supplemented data in Pyle and Pyle (2017) with more recent data for certain locations from personal observations and other sources, including Bonin Petrels on O‘ahu (PRC unpubl. data), Wedge-tailed Shearwaters on Kaua‘i and O‘ahu (Felis et al. 2019, PRC unpubl. data), Red-footed Boobies on Kaua‘i (Felis et al. 2019), Red-tailed Tropicbirds on Lehua Islet, Kaua‘i, and O‘ahu (Felis et al. 2019, Raine et al. 2021, Vanderwerf 2021), White Terns on O‘ahu (VanderWerf and Downs 2018), and Least Terns on O‘ahu (Harmon et al. 2021). Hawaiian Petrels and Newell’s Shearwaters have been detected regularly on O‘ahu recently (Young et al. 2019), but because no nests have been found yet they were not counted as breeding on O‘ahu for the purposes of this study.

For islands in the Pacific Remote Islands Marine National Monument, we obtained information from these sources: Palmyra (Wegmann and Kropidlowski unpubl. data), Baker, Howland, and Jarvis (Rauzon et al. 2011), and Johnston (Schreiber 2003), with more recent data from USFWS (2021) for boobies, frigatebirds, and tropicbirds.

In the Marianas, we obtained data for some islands from Reichel (1991), but we used more recent data from the following islands and sources: Guam; Rota, Commonwealth of the

TABLE 1

Species Included in the Analysis (Ordered Taxonomically) With Conservation Status, Population Size and Trend Data

| Scientific Name | Species | IUCN Status | ESA Status | Global Population Size | Population Trend | # Oceans | # Islands Present | USTP Pop. Size | % Pop. in USTP Area | % Pop. < 5 m ASL | % Pop. in Predator Free Locations |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Phoebastria nigripes* | Black-footed Albatross | NT | SOC | 139,800 | Stable | 1 | 12 | 135,800 | 0.97 | 1 | 0.59 |
| *Phoebastria immutabilis* | Laysan Albatross | NT | SOC | 1,600,000 | Stable | 1 | 14 | 1,605,434 | 1 | 1 | 0.25 |
| *Phoebastria albatrus* | Short-tailed Albatross | VU | EN | 3,000 | Increasing | 1 | 2 | 4 | 0 | 1 | 0.5 |
| *Pterodroma sandwichensis* | Hawaiian Petrel | EN | EN | 11,910 | Decreasing | 1 | 4 | 11,910 | 1 | 0 | 0 |
| *Pterodroma hypoleuca* | Bonin Petrel | LC | NL | 1,000,000 | Decreasing | 1 | 6 | 842,246 | 0.84 | 1 | 0.64 |
| *Bulweria bulwerii* | Bulwer's Petrel | LC | NL | 211,660 | Stable | 3 | 19 | 186,560 | 0.88 | 0.02 | 0.99 |
| *Pterodroma alba* | Phoenix Petrel | EN | NL | 20,000 | Decreasing | 1 | 0 | 0 | 0 | 1 | 0.75 |
| *Pterodroma heraldica* | Herald Petrel | LC | NL | 150,000 | Decreasing | 1 | 1 | 20 | 0 | 0 | 0 |
| *Pseudobulweria rostrata* | Tahiti Petrel | NT | NL | 15,000 | Decreasing | 1 | 1 | 1,100 | 0.07 | 0 | 0 |
| *Ardenna pacifica* | Wedge-tailed Shearwater | LC | NL | 5,200,000 | Decreasing | 2 | 25 | 696,062 | 0.13 | 0.56 | 0.9 |
| *Puffinus nativitatis* | Christmas Shearwater | LC | NL | 150,000 | Stable | 1 | 12 | 6,422 | 0.04 | 0.88 | 0.93 |
| *Puffinus bailloni* | Tropical Shearwater | LC | NL | 350,000 | Stable | 2 | 2 | 640 | 0.01 | 0.06 | 0 |
| *Puffinus newelli* | Newell's Shearwater | CR | TH | 10,600 | Decreasing | 1 | 3 | 10,600 | 1 | 0 | 0 |
| *Oceanodroma castro* | Band-rumped Storm-petrel | LC | EN | 150,000 | Decreasing | 3 | 3 | 660 | 0 | 0 | 0 |
| *Nesofregetta fuliginosa* | Polynesian Storm-petrel | EN | NL | 1,000 | Decreasing | 1 | 1 | 13 | 0.01 | 0.23 | 0 |
| *Oceanodroma tristrami* | Tristram's Storm-petrel | LC | NL | 20,000 | Stable | 1 | 6 | 11,680 | 0.58 | 0.49 | 0.99 |
| *Phaethon lepturus* | White-tailed Tropicbird | LC | NL | 400,000 | Decreasing | 3 | 15 | 3,951 | 0.01 | 0.07 | 0.06 |
| *Phaethon rubricauda* | Red-tailed Tropicbird | LC | NL | 70,000 | Decreasing | 2 | 28 | 64,092 | 0.92 | 0.9 | 0.64 |
| *Sula dactylatra* | Masked Booby | LC | NL | 100,000 | Decreasing | 3 | 19 | 21,032 | 0.21 | 0.84 | 0.59 |
| *Sula leucogaster* | Brown Booby | LC | NL | 500,000 | Decreasing | 3 | 23 | 7,825 | 0.02 | 0.51 | 0.49 |
| *Sula sula* | Red-footed Booby | LC | NL | 1,400,000 | Decreasing | 3 | 24 | 77,287 | 0.06 | 0.66 | 0.73 |
| *Fregata minor* | Great Frigatebird | LC | NL | 120,000 | Decreasing | 2 | 26 | 27,930 | 0.23 | 0.65 | 0.9 |
| *Fregata ariel* | Lesser Frigatebird | LC | NL | 300,000 | Decreasing | 2 | 7 | 24,159 | 0.08 | 1 | 0.83 |
| *Anous stolidus* | Brown Noddy | LC | NL | 1,100,000 | Stable | 3 | 26 | 290,345 | 0.26 | 0.44 | 0.88 |
| *Anous minutus* | Black Noddy | LC | NL | 1,300,000 | Decreasing | 3 | 30 | 59,596 | 0.05 | 0.62 | 0.52 |
| *Procelsterna cerulea* | Blue Noddy | LC | NL | 73,500 | Stable | 1 | 7 | 8,360 | 0.11 | 0.09 | 0.91 |
| *Gygis alba* | White Tern | LC | NL | 125,000 | Stable | 3 | 25 | 94,473 | 0.76 | 0.52 | 0.13 |
| *Onychoprion fuscatus* | Sooty Tern | LC | NL | 23,000,000 | Unknown | 3 | 20 | 6,327,780 | 0.28 | 0.98 | 0.92 |
| *Onychoprion lunatus* | Gray-backed Tern | LC | NL | 550,000 | Decreasing | 1 | 17 | 95,152 | 0.17 | 0.65 | 0.96 |
| *Sternula antillarum* | Least Tern | LC | NL | 120,000 | Decreasing | 1 | 3 | 20 | 0 | 0.5 | 0 |
| *Sternula albifrons* | Little Tern | LC | NL | 300,000 | Decreasing | 2 | 2 | 8 | 0 | 0.5 | 0 |
| *Onychoprion anaethetus* | Bridled Tern | LC | NL | 700,000 | Unknown | 3 | 1 | 20 | 0 | 0 | 0 |

CR, critically endangered; EN, endangered; TH, threatened; NT, near threatened; SOC, species of concern; LC, least concern; NL, not listed.

Northern Marianas (Commonwealth of the Northern Marianas 2020); Farallon de Medinilla (FDM; Liske-Clark et al. 2016); Tinian, Aguiguan, and Naftan Rock (Amidon et al. 2014); Guguan (Liske-Clark et al. 2016). We also filled in data gaps for a few species with estimates from Stinson (1995) and for Maug from Eldredge et al. (1977). Camp et al. (2014) analyzed long-term helicopter survey data of the three booby species from FDM but did not provide population estimates. If population estimates for a species differed among sources, we used the more recent estimate unless there was evidence that the variation was related to breeding seasonality, in which case we used the estimate during the breeding season.

In American Samoa, we obtained data from the following sources: Swains Atoll (Titmus et al. 2016), Tutuila and Taʻu (O'Connor and Rauzon 2004, Titmus 2017, PRC unpubl. data).

### *Species Prioritization Criteria*

We used nine criteria to evaluate the extinction risk and conservation need of each species. Some criteria were related to the distribution and abundance of the species (globally and within the USTP), some were based on existing international and national conservation assessments, and others were based on severity of threats. We assigned a numerical score ranging from 1 to 3, 4, or 5 to each species for each criterion, with higher scores indicating greater extinction risk and higher priority for restoration.

We used two criteria that reflected existing conservation status assessments: the IUCN status and status under the U.S. Endangered Species Act (ESA). We used two criteria because the status of some species differed between them, reflecting variation in global vs. national importance or differences in taxonomy, and because the methods for determining the status of a species differs between the two metrics. In most cases the IUCN and ESA status were similar, but in a few cases they were different, such as for the Band-rumped Storm-petrel (*Oceanodroma castro*), which is globally fairly common and widespread but has a distinct population segment in the Hawaiian Islands that is rare and was recently listed as endangered in the U.S. (USFWS 2015). Harris et al. (2012) found that 40.3% of U.S. birds considered imperiled by the IUCN are not listed under the ESA, and usually only species with higher IUCN threat levels are recognized by the ESA.

1. IUCN global population status. We used global population status information directly from the latest version of the IUCN redlist (https://www.iucnredlist.org, accessed 18 October 2021), and we scored each species on a scale from 1 to 5 according to its IUCN category: Least Concern (1), Near Threatened (2); Vulnerable (3); Endangered (4); and Critically Endangered (5).
2. Status under the U.S. Endangered Species Act. We scored each species on a scale of 1 to 4 according to its ESA status: Not listed (1); Species of concern (2); Threatened (3); and Endangered (4). A list of species of concern is maintained by the U.S. Fish and Wildlife Service (USFWS 2021). Although these species are not actually listed and are not afforded any legal protection because of this designation, their inclusion in this category indicates there is reason for concern about their status. They are sometimes regarded as species that might warrant listing in the future (USFWS 2021).
3. Global population size. For global population size, we used data provided in the latest version of the IUCN redlist (https://www.iucnredlist.org, accessed 18 October 2021), with a few exceptions that warrant explanation. For some species the population size estimate was a range; in such cases we used the average of the high and low values. For a few species, the population size was given as unknown by IUCN; for these species we obtained information from the following sources: Southey and Frost (2013 for Bulwer's Petrel); Brooke (2004) for Herald Petrel and Christmas Shearwater; and Partners in Flight (2021) for Masked Booby, Brown Booby, Red-footed Booby, and Least Tern. We scored population size on a scale of 1 to 5 based on the number of individuals: (1): >100,000; (2): 50,000–

100,000; (3): 10,000–50,000; (4): 1,000–10,000; (5): <1,000.

4. Global population trend. Similar to population size, for global population trend we used data provided in the latest version of the IUCN redlist (https://www.iucnredlist.org, accessed 18 October 2021), with a few exceptions. We considered the population trend of Black-footed Albatross to be stable (rather than increasing as in IUCN), because most recent information indicates the species is stable or possibly increasing (Arata et al. 2009, USFWS unpub data). We scored population trend on a scale of 1 to 3 as follows: (1): increasing; (2): stable; (3): decreasing. Species with an unknown population trend were assigned a value of 2.
5. Number of oceans occupied. The purpose of this criterion was to reflect the geographic vulnerability in the at-sea range. As with number of islands occupied (see below), species that inhabit fewer ocean basins are inherently more vulnerable to local threats and climatic changes. We scored each species based on the number of ocean basins with tropical and subtropical habitats (Pacific, Atlantic, Indian) where it occurs: 1: 3 oceans, 2: 2 oceans, 3: 1 ocean only.
6. Number of islands currently occupied in the USTP. The purpose of this criterion was to measure the geographic range within the USTP. We copied information about the number of islands currently occupied by each species in the USTP from the seabird monitoring gap analysis conducted by VanderWerf and Young (2017). In a few cases the number of islands occupied has changed since 2017, or more complete information has become available, including establishment of Bonin Petrels on O'ahu. This does not include islands where the species has been extirpated or islands where the species is suspected to breed but has not been confirmed. All islets within an atoll were considered part of the same island. Offshore islets were included with the larger island they are close to, with a few exceptions that we counted separately because they are larger and/or support exceptionally large seabird populations (Lehua and Ka'ula near Ni'ihau, Moku Manu, and Manana near O'ahu, and Naftan near Aguiguan). We scored the number of islands occupied on a scale of 1 to 5 as follows: (1): >20; (2): 11–19; (3): 6–10; (4): 3–5; (5): 1–2.
7. Proportion of global population breeding in the U.S. Tropical Pacific. This criterion was intended to capture the importance of breeding colonies in the U.S. Tropical Pacific relative to the species as a whole. We scored proportion of the population within the USTP on a scale of 1 to 5 based as follows: (1): <10%; (2): 10–30%; (3): 30–70%; (4): 71–90%; (5): >90%.
8. Proportion of population in the USTP breeding < 5 m ASL. Species with a larger proportion of their population breeding on low islands are at greater risk from sea level rise and in greater need of actions that restore or create colonies in safer locations. We used information about island elevation from Nunn et al. (2016). We regarded entire atolls as being in this category even if small portions of an atoll were >5m above sea level, because those smalls areas would become increasing isolated and unstable and of negligible value to seabirds for breeding. We scored each species on a scale from 1 to 5 based on the proportion of the population in the USTP < 5 m above sea level: 1: <10%, 2: 10–30%, 3: 30–70%, 4: 70–90%, 5: >90%.
9. Proportion of population in the USTP in predator free locations. Species with a higher proportion of their breeding population in locations with non-native predators are at greater risk. Locations we considered secure from predators included islands with no predators or from which predators have been eradicated, and locations from which predators have been excluded with fencing or have been effectively managed to remove the predation threat. In cases where only part of a species population on an island was secured from predators, we treated the island as predator free if the majority of the population was protected, such as for Laysan Albatross (*Phoebastria immutabilis*)

and Wedge-tailed Shearwater on O'ahu. We scored each species on a scale from 1 to 5 based on the proportion of the population breeding in areas that are predator free or protected from predators: 1: >90%, 2: 70–90%, 3: 30–70%, 4: 10–30%, 5: <10%.

### *Evaluation of Potential Source and Restoration Sites*

We attempted to identify suitable locations that could serve as sources or restoration sites for high priority seabird conservation actions in the USTP. We assessed 86 locations in the USTP, including 77 sites with known seabird colonies in all five regions in the USTP previously identified by VanderWerf and Young (2018) and 9 additional islands in the CNMI that were not included in that analysis. Factors we considered in assessing suitability as a source or restoration site included: elevation, presence of predators, ability to exclude or eradicate predators, and other anthropogenic risk factors. We considered a colony to be a suitable source if it was: (1) at risk of inundation from sea level rise and storm surge such that the long-term persistence of the colony is in jeopardy; (2) subject to predation by invasive species that has not been effectively managed and would be difficult to manage; and (3) large enough to sustain removal of the desired number of individuals for several years. If a suitable source location was not available for a species within the USTP, we attempted to identify the closest and most suitable location outside of the USTP. We considered a site to be suitable for restoration if: (1) it was not at risk of inundation; (2) predators and other anthropogenic threats were absent, had been eliminated or effectively managed, or could be effectively managed on a long term scale; (3) there were no serious logistical constraints that could limit the ability to safely move birds to them in a timely manner, and sufficient facilities to carry out the action or the facilities could be constructed without damaging the integrity of the site. For the albatross species, we also considered sites in the Eastern Pacific (Channel Islands of California and Islands off Mexico) as restoration locations because of the existence of incipient colonies in these areas and because there are planning documents already drafted related to implementing those activities (VanderWerf et al. 2022*a*).

Islands and atolls where the majority of the island was < 5 m ASL we generally did not consider to be suitable restoration sites (Nunn et al. 2016), but in certain cases we did consider low islands for restoration if an action was urgently needed to mitigate another threat and no other suitable sites were available in the near-term, with the realization that the island would serve primarily as a temporary stepping-stone that would facilitate eventual restoration at another location. For example, Palmyra Atoll is vulnerable to inundation in the long-term, but rats were eradicated from the atoll recently (Wegmann et al. 2012), and it could serve as a valuable location in which to establish colonies of some of the highest priority species, and could serve as a source for future efforts on other islands. Some sites, such as Upper Limahuli Preserve on Kaua'i, we considered as both a source and restoration site due to the presence of target focal species and planned management to exclude predators in the future (see Young et al. 2018, 2021).

### *Determination of Restoration Techniques to be Recommended*

To determine which restoration technique (social attraction or translocation coupled with social attraction) was likely to be more effective, we considered whether each species exhibited natal philopatry and post-fledging care and the relative location of potential source and restoration sites. If a species does not exhibit high natal philopatry, then the chances of a translocation succeeding are low. Only species with high natal philopatry and no post-fledging parental care were considered suitable candidates for translocation.

## RESULTS

The prioritization showed that the five most at-risk seabird species in the USTP were, in order, Hawaiian Petrel, Newell's Shearwater,

Polynesian Storm-Petrel , Phoenix Petrel ,and Black-footed Albatross. The prioritization exercise also revealed several noteworthy patterns. Only five of 32 seabird species that nest in the USTP are considered imperiled by the IUCN (Short-tailed Albatross, Hawaiian Petrel, Phoenix Petrel, Newell's Shearwater, Polynesian Storm-petrel), and only four are listed under the U.S. ESA (Short-tailed Albatross, Hawaiian Petrel, Newell's Shearwater, and Band-rumped Storm-petrel), with two more considered species of concern (Laysan and Black-footed Albatross), but the majority, 20 species, were decreasing in abundance and only one species was increasing in abundance (Short-tailed Albatross). Taxonomically, Procellariformes (albatrosses, petrels, shearwaters, and storm-petrels) had generally higher scores, indicating greater extinction risk, with 11 of the top 12 most at-risk species in this order (Table 2). Five species occurred primarily within the USTP, with >90% of their global populations in this region, with another three species having >70% of their populations in the USTP, while 16 species occurred primarily (>90%) outside the USTP. About one-third of the species (10) nest primarily (>70%) in locations < 5 m ASL, indicating their vulnerability to climate change. Seven species nested primarily (>70%) in locations with non-native predators.

Of the top 12 species (Table 3), 11 exhibit strong natal philopatry and thus would be suitable for translocation (Table 2). For 6 of these 11 species, there were potential source colonies close enough to suitable restoration sites such that social attraction might be effective. For five species, social attraction is unlikely to work because there are no colonies close enough to suitable restoration sites, indicating translocation would be necessary to create colonies. For the Band-rumped Storm-petrel, there are no known breeding colonies from which to collect chicks for translocation, so social attraction currently is the only option. One of the top 12 species, Red-tailed Tropicbird, exhibits lower natal philopatry and thus should only be considered for social attraction. Specific locations are described in the species accounts below.

### *Source and Restoration Locations*

Of the 86 seabird colonies we evaluated in the USTP, 12 were suitable sources for the top 12 priority species. Twelve sites were suitable for restoration and five more sites will become suitable for restoration pending completion of planned predator exclusion fences or predator removal (Table 4, also see **Appendix 1**). For three of the priority species, Short-tailed Albatrosses, Phoenix Petrel, and Polynesian Storm-petrel, no suitable sources exist within the USTP. For all three albatross species, alternative sites in the Eastern Pacific (Channel Islands off California and islands off Mexico) were considered suitable restoration sites because of either existing nesting colonies in those areas or planning documents that already include those locations.

## DISCUSSION

### *Priority Species*

While five seabird species in the USTP are considered imperiled by the IUCN and only four are listed under the U.S. ESA, the results of this prioritization exercise indicated that several of the 32 species face serious threats that can be expected to decrease their populations in the foreseeable future. Most of the species are already in decline, and the threats from climate change and non-native predators will not decrease, and likely will worsen, without human intervention. Conservation actions are needed to ensure their continued survival, and undertaking such actions now is highly recommended to avoid emergency situations.

Phoenix Petrel and Polynesian Storm-petrel were the most highly endangered species based on biological criteria, but Hawaiian Petrel and Newell's Shearwater ranked higher in this exercise because their entire global populations occur within the USTP. Persistence of these two species endemic to the USTP will rely entirely on actions carried out in this region. Conversely, conservation of the 16 species that occur primarily outside the USTP, including Phoenix Petrel and Polynesian Storm-petrel, will rely primarily on actions conducted else-

TABLE 2

Seabird Species in the USTP Ranked by Conservation Need, with Preferred Restoration Technique Based on Species Natural History

| Rank | Species | Total Score | Natal Philopatry | Post-Fledging Care | Translocation, SA, or Both |
|---|---|---|---|---|---|
| 1 | Hawaiian Petrel | 32 | Yes | No | Both |
| 1 | Newell's Shearwater | 32 | Yes | No | Both |
| 3 | Polynesian Storm-petrel | 30 | Yes | No | Translocation |
| 4 | Phoenix Petrel | 29 | Yes | No | Translocation |
| 5 | Black-footed Albatross | 25 | Yes | No | Both |
| 6 | Laysan Albatross | 24 | Yes | No | Both |
| 6 | Bonin Petrel | 24 | Yes | No | Translocation |
| 8 | Short-tailed Albatross | 23 | Yes | No | Translocation |
| 8 | Red-tailed Tropicbird | 23 | No | No | SA |
| 10 | Tahiti Petrel | 21 | Yes | No | Both |
| 10 | Band-rumped Storm-petrel | 21 | Yes | No | SA |
| 12 | Tristram's Storm-petrel | 20 | Yes | No | Translocation |
| 13 | Masked Booby | 19 | No | Yes | SA |
| 13 | Lesser Frigatebird | 19 | No | Yes | SA |
| 15 | Herald Petrel | 18 | Yes | No | Translocation |
| 15 | White Tern | 18 | No | Yes | SA |
| 17 | Gray-backed Tern | 17 | No | Yes | SA |
| 17 | Least Tern | 17 | No | Yes | SA |
| 19 | Little Tern | 17 | No | Yes | SA |
| 20 | Christmas Shearwater | 16 | Yes | No | Both |
| 20 | Tropical Shearwater | 16 | Yes | No | Both |
| 20 | White-tailed Tropicbird | 16 | No | No | SA |
| 20 | Blue Noddy | 16 | No | Likely | SA |
| 20 | Sooty Tern | 16 | No | Yes | SA |
| 20 | Wedge-tailed Shearwater | 15 | Yes | No | Both |
| 26 | Brown Booby | 15 | No | Yes | SA |
| 26 | Great Frigatebird | 15 | No | Yes | SA |
| 26 | Black Noddy | 15 | No | Yes | SA |
| 26 | Bridled Tern | 15 | No | Yes | SA |
| 26 | Bulwer's Petrel | 14 | Yes | No | Both |
| 26 | Red-footed Booby | 14 | No | Yes | SA |
| 32 | Brown Noddy | 14 | No | Yes | SA |

where. Nevertheless, islands in the USTP can play important supporting roles in their conservation.

Procellariiformes are known to be among the most threatened groups of seabirds, and all birds (Spatz et al. 2014, Dias et al. 2019), and most of the highest ranked species in this exercise were in this order. One reason that Procellariiformes are especially endangered is their strong natal philopatry, which can limit gene flow among populations and result in evolution of species with limited ranges and local endemism (Greenwood 1980, Friesen 2015, Antaky et al. 2021). In contrast, boobies, tropicbirds, and frigatebirds have lower rates of natal philopatry, with greater movement of individuals among colonies, and species in those groups are more widespread (Steeves et al. 2003, Varela et al. 2020).

In Appendix 1, we present accounts for the top 12 priority species, ordered taxonomically, which include a brief review of the threats and

TABLE 3

Top 12 Priority Species List With Potential Source and Restoration Sites

| Rank | Species | Abbreviation | Suitable Sources | Suitable Restoration Sites |
|---|---|---|---|---|
| 1 | Hawaiian Petrel | HAPE | Lana'i, Kaua'i | Predator fences and offshore islets in MHI |
| 1 | Newell's Shearwater | NESH | Kaua'i | Predator fences and offshore islets in MHI |
| 3 | Polynesian Storm-petrel | POSP | Kiribati | Palmyra, coastal predator fences and offshore islets in MHI |
| 4 | Phoenix Petrel | PHPE | Kiribati | Palmyra, coastal predator fences and offshore islets in MHI |
| 5 | Black-footed Albatross | BFAL | Midway, Tern | Mexico, California Channel Islands, coastal predator fences in MHI, CNMI |
| 6 | Laysan Albatross | LAAL | Kauai, Midway, Tern | California Channel Islands, coastal predator fences in MHI, CNMI |
| 6 | Bonin Petrel | BOPE | Midway | Coastal predator fences and offshore islets in MHI |
| 8 | Short-tailed Albatross | STAL | Torishima, Japan | California Channel Islands, coastal predator fences in MHI, Guadalupe Island, Mexico |
| 8 | Red-tailed Tropicbird | RTTR | N/A | Coastal predator fences and offshore islets in MHI |
| 10 | Tahiti Petrel | TAPE | Ta'u | Predator fences on Ta'u and Tutuila that would need to be constructed |
| 10 | Band-rumped Storm-petrel | BRSP | None currently | Lehua Islet, predator fences and offshore Islets in MHI |
| 12 | Tristram's Storm-petrel | TRSP | Tern | Lehua Islet, predator fences and offshore Islets in MHI |

MHI, Main Hawaiian Islands.

conservation needs, recommended actions, potential source locations, suitable restoration locations, and existing conservation efforts. In some cases, we grouped species that are closely related and/or sympatric because the actions and locations were similar.

### *Priority Locations*

The locations we identified as potential sources and suitable restoration sites are those sites in the USTP where social attraction and translocation would be appropriate for the top 12 priority species identified in this exercise. There are many other locations in the USTP that support important seabird populations and where other beneficial management actions, such as habitat improvement and predator control, are being conducted or planned, and still more where they are needed (VanderWerf and Young 2017, 2018).

In the USTP, two entire regions, the Northwestern Hawaiian Islands and the Pacific Remote Islands Marine National Monument, consist primarily of islands < 5 m ASL and thus were not considered suitable long-term restoration sites. However, they still can serve as important sites through other management actions. Predators have been removed from multiple islands within the USTP (e.g., Palmyra, Baker), but some seabirds, particularly ground-nesting species, are still missing from those islands. For example, invasive rodents were eradicated from Palmyra Atoll in 2011, and the natural recovery of many species has been spectacular (Wegmann et al. 2012, Wolf et al. 2018), but there still are no Procellariform seabirds nesting on Palmyra. Although Palmyra is low elevation and may not provide habitat safe from sea level rise in the long-term, it has the potential to serve as a valuable stepping-stone for colonization of other islands.

The majority of restoration sites we identified were in the Main Hawaiian Islands. This is a function of two factors: first,

TABLE 4

Site Characteristics of the 17 Potential Seabird Restoration Sites Identified in the US Tropical Pacific

| Island | Site | Target Species | # Species Present | Ownership | Habitat State | Access Method | Modifications Needed | Existing Target Species Nesting | Fenced? | Coastal? |
|---|---|---|---|---|---|---|---|---|---|---|
| Hawai'i | Pu'u O'umi | HAPE, NESH, BSTP | 2 | State | Native | Helicopter | Completion of fence | None | Yes | No |
| Kaua'i | Upper Limahuli | HAPE, NESH | 2 | Private | Native | Helicopter | Completion of fence | HAPE, NESH | Yes | No |
| | Hono o Na Pali | HAPE, NESH, BSTP | 2 | State | Native | Helicopter | Completion of fence | HAPE, NESH | Yes | No |
| | Upper Manoa | HAPE, NESH | 1 | Private | Mixed | Helicopter | Completion of fence | NESH | Yes | No |
| | Lehua Islet | HAPE, NESH, BSTP BOPE, TRSP, PHPE, POSP | 9 | State | Native | Small boat | None | LAAL, BFAL | Island | Yes |
| | Moku'ae'ae Islet | HAPE, NESH, BSTP BOPE, TRSP, PHPE, POSP | 3 | State | Native | Small boat | None | None | Island | Yes |
| | Kilauea Pt. NWR | HAPE, NESH, BRSP, BOPE, TRSP, PHPE, POSP, BFAL | 7 | Federal | Mixed | Car | None | LAAL, NESH, HAPE | Yes | Yes |
| O'ahu | Ka'ena Point NAR | HAPE, NESH, BOPE, TRSP, PHPE, POSP, BFAL | 4 | State | Native | Car | None | BFAL, LAAL | Yes | Yes |
| | Kuaokala GMA | HAPE, NESH, BFAL | 1 | State | Degraded | Car | None | LAAL | Yes | No |
| | James Campbell NWR | HAPE, NESH, BOPE, TRSP, PHPE, POSP, BFAL | 4 | Federal | Native | Car | None | LAAL, BOPE, TRSP | Yes | Yes |
| | Offshore Islets | HAPE, NESH, BRSP, BOPE, TRSP, PHPE, POSP | 12 | State | Native | Small boat | None | None | Island | Yes |
| Lana'i | Lanaihale | NESH | 2 | Private | Mixed | Car | None | HAPE | Yes | No |
| Maui | West Maui (Makamakaole) | HAPE, NESH | 6 | Mixed | Native | Helicopter | None | NESH | Yes | No |
| | Molokini | HAPE, NESH | 3 | State | Native | Small boat | None | None | Island | Yes |
| Moloka'i | Mokio | HAPE, NESH, BRSP, BOPE, TRSP, PHPE, POSP, BFAL, LAAL | 0 | Private | Native | Car | Completion of fence | None | Yes | Yes |
| Swains | Swains | PHPE, POSP | 6 | Private | Mixed | Ship | Completion of eradication | None | Island | Yes |
| Palmyra | Palmyra | PHPE, POSP | 11 | Federal | Mixed | Plane | None | None | Island | Yes |

numerous predator-free offshore islets exist in the MHI, especially on O‘ahu, and second, the majority of predator exclusion fences that have been built to create predator-free ‘mainland islands’ are in the MHI. Predator eradications and predator exclusion fencing on high islands in the Marianas and American Samoa would increase the potential to use those regions for restoration and should be considered a high priority management activity to increase the geographic scope of seabird restoration in the USTP.

Three important seabird nesting islands in the USTP, Midway in the Hawaiian Islands, and Baker and Jarvis in the Remotes, are free of all predators except house mice (*Mus musculus*). Although predation by mice on seabirds is rare, it has been documented on adult Laysan Albatrosses on Midway (Duhr et al. 2019, Work et al. 2021) and on Wandering Albatross chicks on Gough Island in the South Atlantic (Angel et al. 2009), and may occur on other species. In addition to being low elevation, the presence of mice reduced the value of these sites for seabird restoration.

For three species in the USTP (Short-tailed Albatross, Phoenix Petrel, and Polynesian Storm-petrel), there were no suitable source sites in the USTP because they either no longer breed in the USTP or breed in such low numbers that removing individuals for translocation is not practical. If translocation were attempted for these species, they would need to be collected outside the USTP. The countries suitable as potential sources outside the USTP are Japan (for Short-tailed Albatrosses) and Kiribati (for Phoenix Petrel and Polynesian Storm-petrel). It should be noted that international translocation of any of these species has not been proposed or discussed with the government of either of these countries and is only being considered as biologically feasible at this time, without taking into consideration permitting and political considerations.

### *Main Hawaiian Islands*

Most of the suitable restoration sites identified in this exercise were in the MHI, and these can be divided into two groups: (1) predator free offshore islets, and (2) predator exclusion fences on the larger islands. Lehua Islet, located near Ni‘ihau, is the largest of the offshore islets, and Polynesian rats were eradicated from the islet in 2020 (Raine et al. 2021), making it an ideal location for restoration of several species. Ka‘ula Islet, southwest of Ni‘ihau, is predator-free and has the most diverse seabird fauna of any site in the MHI with 15 nesting species (Normandeau Associates 2016), but it is unavailable because it is still used as a target for training by the U.S. Navy. On Kaua‘i, multiple predator exclusion fences exist where it would be appropriate to attract and/or translocate several high priority species, including fenced areas at Kīlauea Point NWR, Honopū Forest Reserve, Hono O Nā Pali Natural Area Reserve, and Kōke‘e State Park (PRC unpub. data), and additional fences that are planned in Upper Limahuli and Upper Manoa Valley (PRC unpub. data). Moku’ae’ae Islet, located just off Kīlauea Point NWR, is predator free but is very small. On O‘ahu, several predator-free islets would be excellent release sites for several species of Procellariforms, particularly Moku Manu, which has the second-most diverse seabird fauna of any location in the MHI. A predator exclusion fence at James Campbell NWR on O‘ahu has already been used for social attraction and translocation of several species (VanderWerf et al. 2019) and could accommodate other species. Other predator fences that would be suitable restoration sites exist at Ka‘ena Point Natural Area Reserve on O‘ahu (Young et al. 2013), Lana‘i Hale, and in Hawai‘i Volcanoes National Park, with another predator fence planned at Pu’u O’umi Natural Area Reserve, Hawai‘i. On Maui, Haleakalā National Park does not have a predator exclusion fence, but an extensive cat trapping program has been effective at protecting a large population of Hawaiian Petrels (Hawai‘i Department of Land and Natural Resources unpub. data) and this area would be suitable for Newell’s Shearwater and Band-rumped Storm-petrel. Perhaps the most serious limitation to restoration of seabirds in the MHI is predation by non-native Barn Owls, which are widespread and

can reach some offshore islets (Raine et al. 2020, 2021).

*Northwestern Hawaiian Islands*

In the NWHI, Midway is a suitable source for several species because it is easily accessible by airplane and it supports very large populations of many species that easily could withstand removal of a small number of individuals for translocation (VanderWerf et al. 2019). French Frigate Shoals, Mokumanamana, and Nihoa were considered potential sources for some species because they are relatively close to the MHI and can be reached by ship in a reasonable length of time (2–3 days). The other NWHI, including Laysan, Lisianski, and Kure, do not have a functional airstrip and cannot be reached by plane and are too distant from the MHI for transporting chicks by ship in a reasonable length of time. Kure could be reached in a few hours by boat from Midway, but all species on Kure can be obtained more easily on Midway. Midway Atoll also has extensive infrastructure to support the capture, holding, and transport of birds for translocation, which make it the best source for several species. Tern Island has been used as a source in previous translocations of Black-footed Albatross and Tristram's Storm-petrel because of the ongoing damage and imminent threat the island faces from sea level rise (VanderWerf et al. 2019).

*Mariana Islands*

In the Mariana Islands, most of the northern islands support large and regionally important breeding colonies of several seabird species, but all the islands have rats and thus were not considered suitable for restoration at this time. The southern islands in the CNMI have several species of predators, and Guam also has the brown treesnake (*Boiga irregularis*), which collectively have wiped out most seabirds on those islands (Wiles et al. 2003). Construction of predator exclusion fences (on Guam and the southern CNMI) or eradication of rats (from the northern CNMI) would make the islands suitable as restoration sites. As potential source colonies, all the species on these islands could be obtained more easily elsewhere in the USTP. Some islands in the northern CNMI are volcanically active and have erupted recently, particularly Anatahan and Pagan, posing long-term risks to seabird colonies.

*Pacific Remote Islands Marine National Monument*

All six islands in this region support very large populations of many seabird species and could in principle serve as sources of individuals for translocation, but logistical considerations render them less useful as sources. Baker, Howland, and Jarvis are very remote, not accessible by airplane, and would require several days to reach by ship. Wake, Palmyra, and Johnston are accessible by airplane, but all seabird species present on those islands could be obtained for translocation more easily from Midway. These islands still warrant protection because of the large seabird colonies they support, and they could serve as sources of emigrants for social attraction on other islands. All islands in this region are $<5$ m ASL and thus were not considered to be suitable restoration sites in general. However, we considered Palmyra to be a partial exception to this rule because it is geographically close to the largest world populations of Phoenix Petrel and Polynesian Storm-petrel on Christmas Island in the Republic of Kiribati (Pierce and VanderWerf 2020). Black rats and Polynesian rats both are present on Kiritimati Island, and although rats are not known to have caused declines in those two seabirds, this raises concerns about the security of those populations. Baker and Jarvis both have populations of non-native house mice, which reduces their value as restoration sites. Wake Atoll, home to several large tropical seabird colonies, has Pacific Rats; eradication of rats from Wake would protect existing colonies, possibly allow other species to colonize the island, and increase the value as a restoration site but its current use as a military airfield may constrain those opportunities.

*American Samoa*

American Samoa is an important region because it contains the only breeding

populations of two species, Herald Petrel and Tahiti Petrel, in the region, and the largest populations of Polynesian Storm-Petrel and Tropical Shearwater in the USTP (O'Connor and Rauzon 2004, Titmus 2017), all of which occur primarily outside the USTP. Ta'u supports the bulk of the populations of those species and is especially important. Tutuila, Ta'u, and Ofu-Olosega are high islands and are not threatened by sea level rise, but all of them have rats and people. Construction of predator exclusion fences on these islands would create suitable "mainland-island" restoration sites. Swains Island is a low atoll and has Pacific rats, and all ground-nesting seabirds have been extirpated and only tree-nesting species remain (Titmus et al. 2016). Rose Atoll is predator-free but is <5 m ASL and thus was not considered as a restoration site. Eradication of rats from Swains would benefit many species and make social attraction of ground-nesting species an option, including the Polynesian Storm-petrel.

## CONCLUSIONS

The two greatest threats to breeding seabirds in the USTP are inundation of colonies caused by global climate change and invasive non-native predators. Significant actions have already been taken to eliminate invasive species in some areas and reduce the threat of sea level rise through translocations aimed at climate resilience. Using continued refinement of social attraction and translocation as management techniques to restore seabird species, we identified new opportunities, both in terms of species and restoration sites, to help maintain and restore the seabird fauna of the USTP. Without implementing these actions, continued declines in ranges and population sizes are likely for the species nesting in this region, and actions should be undertaken with a sense of urgency moving forward.

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