

LEVELS OF PREDATION AT TWO LEACH'S STORM PETREL *HYDROBATES LEUCORHOUS* BREEDING COLONIES

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ABSTRACT

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Seabirds are declining worldwide, and predation by introduced and endemic species is one threat that affects many of them. Leach's Storm Petrel *Hydrobates leucorhous* (hereafter LHSP) populations are declining in a number of locations for reasons that are likely multicausal, and perhaps local or regional, but relative contributions of individual causes are poorly understood. To help understand causes, we quantified predation at two Nova Scotian LHSP breeding colonies that differ in predator management: no management occurs on Bon Portage (BP) Island, whereas management is used on Country Island (CI). Transects were monitored for evidence of predation approximately biweekly on BP and CI in 2018 and 2019, during May–October on BP and May–July on CI. We did not have data on predator densities, but in both colonies, predatory density would have been very location-specific. Evidence such as LHSP carcasses, feather piles, dug up nest burrows, and gull and owl pellets was removed or destroyed during each visit. Predation of eggs and nestlings was scarcely detected. Similarly, adult predation on CI was seldom detected. We estimated that 4000 individuals were depredated on BP in each year of this study. Approximately 42% of predation events were ascribed to gulls and 10% to owls; 48% of remains could not confidently be ascribed to a particular predator. We do not know how general these rates will be because of differences among colonies in predator communities. In any case, LHSP are listed as “Vulnerable” globally, and although up to a 5% annual loss of adults may be sustainable for a healthy population, such losses may exacerbate population declines if other factors are additive.

Key words: breeding colony, *Hydrobates leucorhous*, Leach's Storm Petrel, predation, predator management, seabird

INTRODUCTION

Seabirds are in decline worldwide, with the top three threats being invasive species predation, fisheries bycatch, and climate change; pollution, overfishing, and problematic native species are also of concern (Palczyński *et al.* 2015, Dias *et al.* 2019). Whether it comes from introduced or native species, predation is often the strongest selective force that individuals face (Lima & Dill 1990). As a result, prey use a variety of behavioral and/or physical strategies to avoid or protect themselves from predators (Hamilton 1971, Lima & Dill 1990, Caro 2005, Clemente & Wilson 2016). Species that have evolved without predators are unlikely to have developed these adaptations, so when faced with predators, the prey population decreases and extirpation or extinction can occur, making it important to quantify predation for conservation purposes (Hartman *et al.* 1997).

Seabirds at breeding colonies may have to contend with avian and terrestrial predators. To limit terrestrial predation, seabirds almost always breed at high densities in areas, such as islands, that provide limited access to these predators. Leach's Storm Petrels *Hydrobates leucorhous* (hereafter LHSP) are seabirds that have suffered a 30% population decline in the past 30 years (Birdlife International 2016), but reasons for this decline remain unclear. To determine impacts of one cause of mortality, we quantified levels of predation on LHSP on Bon Portage Island (BP) and Country Island (CI), Nova Scotia, Canada (Fig. 1). To protect endangered Roseate Terns *Sterna dougallii*, predator control measures take place on CI from May to July annually (Canadian Wildlife Service 2019). No predator control occurs on BP. We evaluated predation

on LHSP eggs, nestlings, and adults, and, where possible, compared predation rates between islands.

METHODS

Study areas

This study was conducted on BP (sometimes referred to as Outer Island; 43°28'N, 65°44'W), and CI (45°06'N, 61°32'W), Nova Scotia, Canada in 2018 and 2019 (Fig. 1). LHSP are present on BP and CI during May–October, and the timing of LHSP breeding is the same at each colony. On BP, data were collected for most of the duration of LHSP presence, whereas data were only collected May–July from CI, when staff were present. Hereafter, the term “adult” when referring to storm petrels, unless otherwise specified, is assigned to an individual that is not an egg or burrow-dwelling chick, and thus can include breeding adults, non-breeding adults, and subadults/pre-breeders. Although these distinctions are important when considering predation in population modelling, morphological traits that would allow for differentiation between breeders and subadults/non-breeders (presence of a brood patch), or adults from fledglings (degree of feather wear), were often destroyed in depredated individuals.

CI hosts a variety of nesting seabirds, including approximately one third of Canada's nesting Roseate Tern population (Canadian Wildlife Service 2019). American Herring Gulls *Larus smithsonianus* and Great Black-backed Gulls *L. marinus* are present on CI, but none have nested there in recent years

because of May–July predator control measures, including the use of pyrotechnics, chasing, trapping, or lethal control (Canadian Wildlife Service 2019). BP has nesting American Herring and Great Black-backed gulls, and Great Horned Owls *Bubo virginianus*. At least one pair of Great Horned Owls consumes an estimated 0.33% of BP's adult LHSP annually; however, this could be an underestimate because there may be a second pair nesting on BP (Pollet & Shutler 2019). On BP and on islands adjacent to CI, both species of gulls breed April–August and are mostly found along the shoreline or at sea rather than within the breeding colony area after this time (Good 2020, Weseloh *et al.* 2020). Great Horned Owls breed February–April, but breeding pairs typically remain in their territory year-round (Artuso *et al.* 2020). American Herring Gulls, Great Black-backed Gulls, and Great Horned Owls regurgitate indigestible material in the form of pellets. Gull pellets each typically consist of one petrel or a set of wings, whereas owl pellets are typically more compact and may contain multiple petrels, as well as other prey (Pollet & Shutler 2019). American Crows *Corvus brachyrhynchos* and Northern Ravens *C. corax* also nest and forage on BP and may dig up LHSP burrows to eat nestlings. Additionally, mammalian predators, such as North American river otters *Lontra canadensis* and American mink *Neovison vison* have appeared on each island in the past and

have killed LHSP before disappearing or being trapped or killed (Canadian Wildlife Service 2019, DS unpubl. data).

Data collection

One way to quantify predation rates is to use transects to search for prey remains (Hartman *et al.* 1997). In some cases, remains from predation can be used to identify predator type (Hartman *et al.* 1997, Cuthbert 2003, Hilton & Cuthbert 2010). For example, some mammals, such as raccoons *Procyon lotor*, typically decapitate prey, whereas avian scavengers, such as corvids and gulls, may leave everted carcasses or feather piles (Cuthbert 2003) and may also produce pellets that are left mainly where they roost.

Predation rates were quantified by one to three observers scanning the same 2-m wide transects approximately biweekly during the breeding season (Table 1). Transect locations were chosen opportunistically on BP based on survey transects from Pollet & Shutler (2018), and on CI based on proximity to the research station and where no other monitoring was taking place. All pellets, carcasses, and other remains such as wings, pellets, or feather piles were removed from transects on the first visit of the year, occurring in June 2018 and May 2019 on BP, and in May 2018

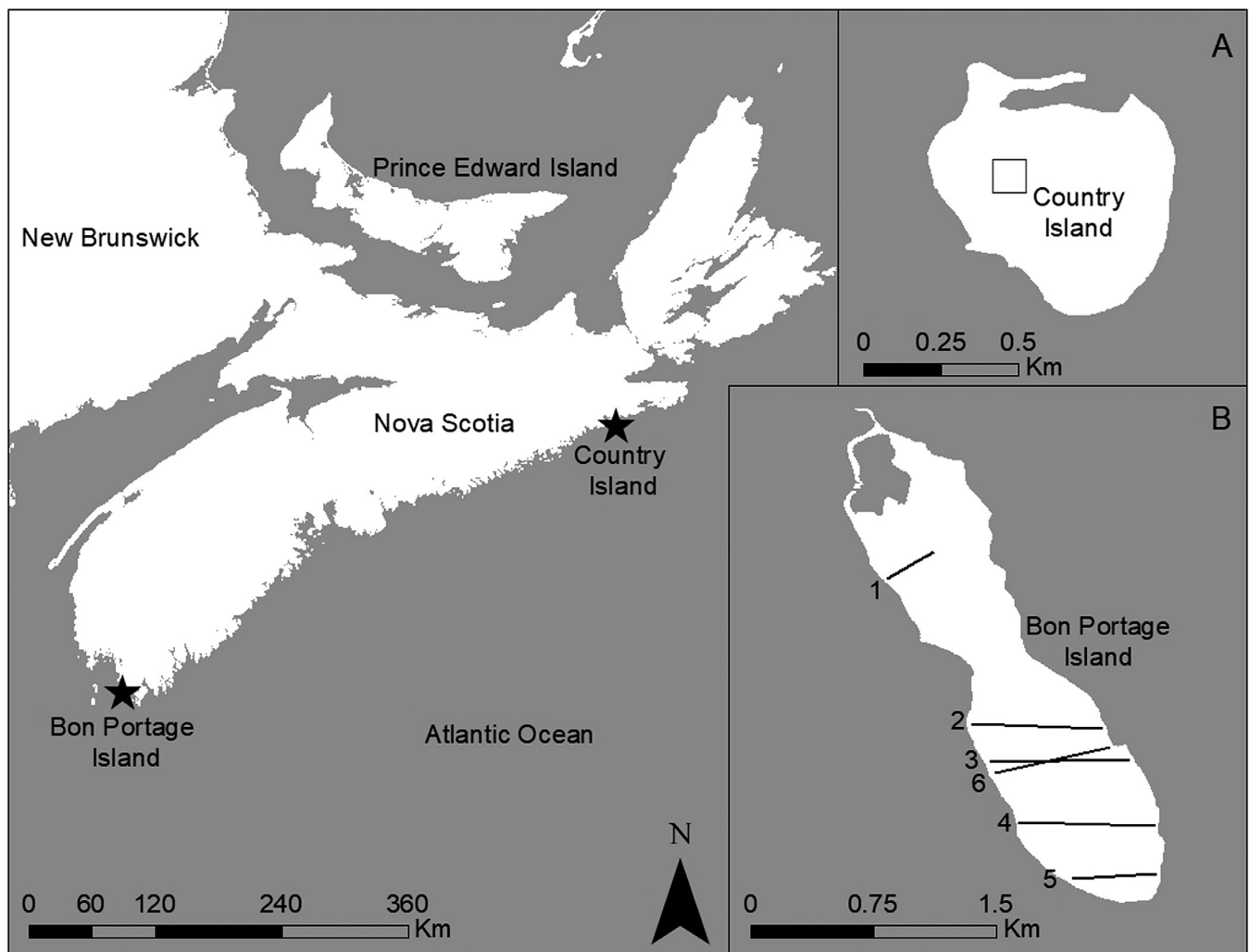


Fig. 1. Map of Nova Scotia, Canada showing locations of Bon Portage and Country islands. (A) Country Island with approximate location of transects indicated by open square; transect coordinate data for Country Island are unavailable. (B) Bon Portage Island predator transects 1–6.

and 2019 on CI. Evidence previously listed, as well as dug up burrows with accompanying carcasses, feathers, or eggshells, were recorded on subsequent checks until September 2018 and October 2019 on BP, and until mid-July in 2018 and 2019 on CI. Sections of some transects had dense vegetation or deadfalls, and evidence of predation events may have been obscured or overlooked. To avoid this, two observers walked transects in an assigned order, and observers' order numbers were recorded when evidence of predation was found; however, in some cases in 2019, only one observer was available. Eggs that have hatched naturally typically have a thick inner membrane that develops just prior to hatching and detaches from the shell, whereas inner membranes are thinner and more brittle in depredated eggs and tend to stick to the shell (Klett *et al.* 1986, Hartman *et al.* 1997). Carcasses and other remains were assessed for evidence of predator type following Cuthbert (2003). Although feather pile appearance is ambiguous with regards to predator type, it was easy to determine whether feather piles were from LHSP or other prey due the former's strong, distinct odor (Pollet *et al.* 2019), not shared by other bird species on either island.

Data analysis

We calculated predations/d/km² since a transect was last checked and cleared, controlling for LHSP nesting density on each island (Table 1). When calculating total predation at each colony per breeding season, we used peak times for each age group over which Pollet *et al.* (2019) indicated that eggs, nestlings, and adults were present. Thus, eggs were assumed to be present between 01 June and 15 August (76 d), nestlings between 15 July and 31 October (107 d), and adults between 15 May and 31 October (169 d). Outside these peak times, predation rates on particular age groups are expected to be trivial.

Suitable breeding habitat on BP was estimated from a recent survey (Pollet & Shutler 2018; Table 1). Total suitable breeding habitat on CI has not been formally assessed, but petrel burrows are found on approximately two thirds of the island, excluding the tern colony that occupies about one third of the island (RH pers. obs.). For this reason, we used two-thirds of the total area as the minimum area of suitable habitat on CI (Table 1). Predation rates for eggs, nestlings, and adults were calculated during their respective peak colony presences and were normalized to estimated suitable breeding habitat. Shapiro-Wilk tests indicated that data were not normally distributed, so we

used Wilcoxon signed-rank tests to compare predation rates between islands. Spearman's rank correlation was used to examine predation rates over time. All statistical analyses were conducted in R using R Studio (R Core Team 2019, R Studio Team 2020).

RESULTS

Detection of remains

Approximately 75% of detected predation was found by the first observer and 25% by the second. Assuming a constant decay rate of detection, additional observers would only detect 8.3%, 2.8%, 0.9%, 0.3%, and 0.1% of what the previous observers detected, respectively. Thus, we estimated that 88.9% of predation evidence was detected when two observers were used.

Comparison of predation between BP and CI

June and July were the only overlapping time frames in which field work was conducted on both islands, and so these were the intervals used in comparisons of predation rates. Predation rates were corrected for LHSP nesting density within suitable habitat on each island (densities in Table 1). On BP, one depredated egg was found in each year. On CI, there were one and two depredated eggs found in 2018 and 2019, respectively. No nestling remains were detected on either island in June or July of either year; however, surveys took place for the first ~15 out of a potential 107 d where nestlings are normally present at colonies. Thus, there were insufficient data to test for differences in egg and nestling predation between islands. Remains of two adults were found on CI in 2018, and no evidence of adult predation was found in 2019. Finally, on BP, 46 and 47 adult remains were found in 2018 and 2019, respectively, when both islands were being monitored.

Predation rates of adults in June and July did not differ between years on CI (Wilcoxon signed-rank test, $W = 30$, $P = 0.24$) or on BP ($W = 51$, $P = 0.67$), so years were pooled for analysis. Adult predation rate data were normally distributed on BP (Shapiro-Wilk test, $W = 0.93$, $P = 0.11$), but not on CI (Shapiro-Wilk test, $W = 0.46$, $P < 0.0001$). Adult predation in June and July was significantly higher on BP than CI when controlling for LHSP nest density based on suitable habitat area (Wilcoxon signed-rank test, $W = 232$, $P < 0.0001$).

TABLE 1
Summary of relevant information for Bon Portage Island and Country Island
Leach's Storm Petrel *Hydrobates leucorhous* (LHSP) breeding colonies in Nova Scotia, Canada

Metric	Bon Portage Island	Country Island
Total island area (km ²)	1.20	0.19
Suitable breeding habitat (km ²)	0.38	0.13
LHSP population estimate (pairs ± 95% confidence interval)	38916 ± 8749 from Pollet & Shutler (2018)	11990 ± 1799 from Canadian Wildlife Service (2017)
Population density in suitable habitat area (LHSP/km ²)	204821	184461
Predator control	No	Yes
Area of transects (m ²)	5542	330
Months when surveys occurred	May–October	May–July
Total transect surveys	62	14

Predation on BP for the entire breeding season

Egg predation was only detected on BP in June and July, so egg data for BP did not change if the entire breeding season was included (see above). Nine and 18 nestling remains were found in 2018 and 2019, respectively. Because egg and nestling predation were infrequently detected, we did not subject these data to analysis. Sixty-six and 101 adult remains were detected during the 2018 and 2019 breeding seasons, respectively.

Adult losses from May–October did not differ by year (Wilcoxon signed-rank test, $W = 584.5$, $P = 0.14$), so they were pooled. In contrast to results from June and July, rates of adult predation on BP from May–October were not normally distributed (Shapiro-Wilk test, $W = 0.78$, $P < 0.0001$). Based on a median predation rate of 61.5 adults/d/km², 3949 adult LHSP were depredated per year. Predation rates declined significantly over the course of each season (Spearman rank correlations, 2018: $S = 8044.9$, $\rho = -0.47$, $P = 0.006$; 2019: $S = 7148.6$, $\rho = -0.59$, $P = 0.0006$; Fig. 2).

Predator type

A total of five depredated eggs were detected on BP and CI in 2018 and 2019, and they were ascribed to unknown predator species. All 32 nestling predation events were observed on BP. They consisted of dug up burrows with feather piles and were ascribed to corvids. Out of 178 adults deemed to be depredated (two on CI), we ascribed 74 (42%) to gulls, 19 (10%) to owls, and the remaining 85 (48%) to unknown predators.

DISCUSSION

Predation at breeding colonies is one of many threats facing LHSP that may be contributing to their decline (Birdlife International 2016, Pollet *et al.* 2019, Pollet & Shutler 2019). The number of adults depredated corresponds to ~5% of the breeding population on BP in each year; however, it is unknown whether these birds were breeding adults, pre-breeding prospectors, or fledged nestlings.

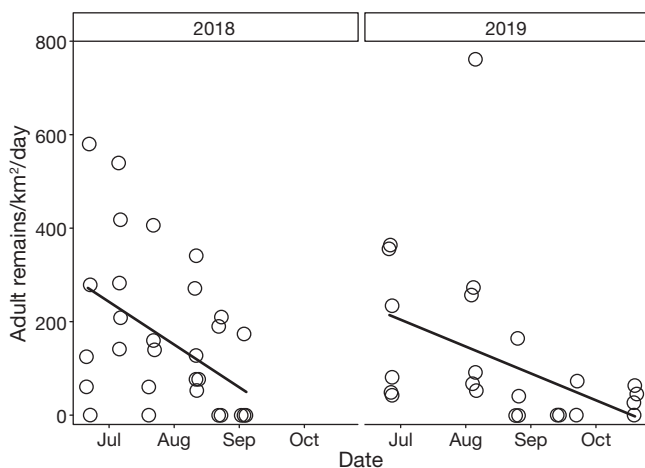


Fig. 2. Rates of predation on adult Leach's Storm Petrel *Hydrobates leucorhous* (LHSP) on Bon Portage Island, Nova Scotia, Canada in 2018 and 2019 from June to October of each breeding season. Each point represents an individual transect survey. Points are offset laterally (jittered) to improve visibility. The parametric trendlines are based on unjittered data.

Breeding adults, and therefore adult survival, is more important for affecting population change than the survival of juveniles or prebreeders (Warham 1996, Erikstad *et al.* 1998, Hamer *et al.* 2001), so future studies should invest extra effort in distinguishing between fledglings, subadults, and adults by examining differences in feather color and feather wear in the remains left by predators. Indeed, feather wear can be used to age storm petrels (Bolton & Thomas 2001); however, most (80%) of our evidence of predation involved partially digested feathers, or feather type was unknown so aging may not have been possible in those cases.

Adult predation rates declined over the course of the breeding season on BP. This was in accord with fewer breeders being present as nests failed or nestlings fledged, and as subadults decreased visits to colonies (Ainley *et al.* 1974, Warham 1996). In addition, feeding rates decrease as nestlings age (Pollet *et al.* 2019), so breeding adult movements to and from the colony are expected to decrease as nestlings near the age of fledging (Ainley *et al.* 1974). Hatching and fledging times are asynchronous among nests, so peak breeder activity at the colony lasts multiple month, and dwindles as more fledglings leave the colony. Besides fluctuations in density of adult petrels, the timing of gull breeding (often within the petrel colony) is earlier than that of petrels, and as the gull breeding season ends and gulls leave the island or move to the shore, it is likely that fewer adult petrels are depredated. At the shore, gulls may also switch to different food sources depending on food availability or because of anthropogenic activities such as fishing (Stenhouse & Montevecchi 1999).

Adult LHSP predation was significantly higher on BP than CI, likely because of predator control on CI. Predator control is focused on protecting Roseate Terns, so not all areas with petrel nests were regularly monitored and protected. Further, transect monitoring and predator control only occurred while staff were present on the island during May–July, leaving three months in which predation levels were unknown and predators were not controlled. After July, active predator control and human presence cease on CI and predators have the freedom to visit the island, with unknown effect on levels of predation.

Another possible reason for differences in predation between islands is that CI's transects were grouped in a small, forested area, and they covered less area overall than BP transects. Transects on BP represented most habitat types on the island. In future studies, transects on CI should be converted into one or two that span the width of the island, or they should be placed in a wider variety of habitats, because petrels are present in most areas of the island outside the tern colony. Future studies should also consider habitat type. For example, some areas, such as open spaces, may provide more opportunity for predators to attack prey. On the other hand, enclosed habitats, or those where the ground is obstructed from view, may hinder carcass detection.

We had insufficient evidence to reliably estimate total egg and nestling predation on either island. Depending on the predator type, transects may not be the best way to detect eggs and nestlings depredated below the surface. Meadow voles *Microtus pennsylvanicus* are present on each island, and possibly at much greater densities on CI (RH pers. obs.), and stable isotope data indicate that they may depredate seabird nests (RH unpubl. data). Common garter snakes *Thamnophis sirtalis*, redbelly snakes *Storeria occipitomaculata*, and masked shrews *Sorex cinereus* are also present on BP, although there is no evidence they depredate nests. If predators consume entire eggs,

they would not be detectable during transect surveys. Due to the underground, concealed nature of LHSP nests, frequent monitoring of nests, and/or the use of trail cameras might be better for detecting both egg and nestling predation, but one needs to weigh the effort involved in trail camera monitoring.

Scavenging was a consideration in this study, but due to logistical constraints, we did not gather enough data to estimate scavenging rates. Most predation involving adults likely results in wings, pellets, or feather piles, which may be less desirable to scavengers than a fresh carcass. Scavenging rates determined from one study are likely to be unreliable in predicting optimal monitoring rates for another because they may vary with year, season, environment, weather, and the size, species, and density of predators, scavengers, and prey (Prosser *et al.* 2008, Santos *et al.* 2011). Prosser *et al.* (2008) suggested that the results of scavenging studies are often unreliable and variable; therefore, performing a scavenging study to determine appropriate survey frequency may be hit-or-miss, so we did not reattempt a scavenging estimation.

Based on our data, we suggest that most predation events were detected by a first observer walking a transect; however, individual experience possibly plays a role in detection. RH was present for almost all transect checks on BP, and in the latter half of the 2019 breeding season, she performed most transect checks by herself. It is likely that she was better able to detect remains than someone who had not seen them before, but it is also possible that she missed some evidence when alone.

Great Horned Owls, and both gull species mentioned in this study, are considered generalist predators (Artuso *et al.* 2020, Good 2020, Weseloh *et al.* 2020); however, individuals may specialize, especially when an abundant food source is present, such as at seabird breeding colonies (Hey *et al.* 2019, Nur *et al.* 2019, Pollet & Shutler 2019). Pollet & Shutler (2019) determined that approximately 0.33%–1.00% of BP's LHSP adults were being eaten annually by a pair of Great Horned Owls, with the diet of these owls consisting of up to 65.5% LHSP by mass. In our study, we similarly estimated that 0.30% of adult petrels were depredated by owls, but in each study, the morphological distinction amongst breeding adults, non-breeding adults, and subadults/prebreeders cannot be made from remains in pellets. Similar to Pollet & Shutler (2019), we did not locate owl nests and only found a few areas where multiple pellets had been egested. These areas were not likely to have been used repeatedly because no new pellets were found at these locations on subsequent visits. Approximately 48% of remains, such as feather piles and wings, could not be ascribed to a particular predator, but were likely attributable to gulls and owls.

In June 2018, river otters were detected by a trail camera on CI; they depredated an unknown number of adult petrels and potentially consumed eggs and nestlings. Otters were never detected on transects, possibly due to transect proximity to the camp where staff lived; the otters eventually left CI. Mink and otters occasionally swim to BP and CI, but their predation of storm petrels is uncommon and poorly documented. These predators can kill hundreds of individuals in a short period of time (Quinlan 1983, Craik 1997, Clode & Macdonald 2002), so these events should be documented and kills quantified whenever possible.

Adult survival, more so than that of nestlings or subadults, is crucial for maintaining and increasing populations in long-

lived seabirds, and knowledge of mortality from all sources is important for understanding population trends. Annual breeding adult survival rates for tubenoses are typically > 90% (Warham 1996, Hamer *et al.* 2001), but Fife *et al.* (2015) estimated LHSP survival at 78%–80% for three colonies in Atlantic Canada, and a similar rate of $77.9\% \pm 2.7\%$ was reported at a colony in Iceland (E. Hansen unpubl. data). In particular, BP had an average annual breeder survival rate of $78\% \pm 4\%$, and LHSP nesting in close proximity to gulls had a survival rate closer to 71% (Fife *et al.* 2015). Although breeding status and age class of depredated LHSP in the present study are unknown, the results of this study, along with survival estimates by Fife *et al.* (2015), suggest that predation at the breeding colony may be largely responsible for low breeder survival at BP. Rennie *et al.* (2020) suggest that LHSP in Atlantic Canada are exposed to more colony predation by gulls and other anthropogenic stressors for which estimates are not available, in part because they report a 97.5% breeder survival rate at colonies in British Columbia, where predation is minimal or non-existent.

Predators are a concern for many seabirds, so it is important to quantify predation rates at seabird colonies to explain results of seabird population modelling. Predator management and eradication can be costly and time-consuming, so proper assessments of predator impacts should be conducted if these measures are being considered. Such measures are used in the management of endangered Ashy Storm Petrels *Oceanodroma homochroa* in California (Ainley *et al.* 2020) and should be implemented in regular monitoring and recovery planning for LHSP. Significantly more LHSP are depredated on BP than on CI, likely due to predator management practices on the latter. Predator presence, composition, and density will play a major role in predation rates at other unmanaged petrel colonies. For example, the LHSP breeding colony on St. Kilda in Scotland has suffered a decline of 54% over 10 years, which is likely attributable to Great Skua *Stercorarius skua* predation (Newson *et al.* 2008). Globally, LHSP are listed as “Vulnerable” (Birdlife International 2016), and although up to a 5% loss of adults from predation may be manageable in a healthy population, this may not be the case if other contributors are additive.

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