

HIGH APPARENT SURVIVAL OF ADULT LEACH'S STORM PETRELS *OCEANODROMA LEUCORHOA* IN BRITISH COLUMBIA

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ABSTRACT

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Leach's Storm Petrels *Oceanodroma leucorhoa* were listed as Vulnerable by the IUCN in 2018. Population declines in the western North Atlantic are associated with low annual adult survival rates, but trends and vital rates of populations in the eastern North Pacific are poorly known. To address this knowledge gap, we estimated the annual apparent survival of breeding adults at two colonies off the coast of British Columbia (Rock Islets: 52°20'40"N, 131°14'10"W and Cleland Island: 49°10'17"N, 126°05'28"W), using capture-mark-recapture data collected between 2006 and 2010. Transient models received substantially more support than standard Cormack-Jolly-Seber models, suggesting that the initial capture and banding reduced burrow fidelity. The model-averaged annual apparent survival rates for both colonies were high (estimate for each colony = 0.975 ± 0.011), compared to rates reported for colonies in the western North Atlantic (< 0.80). Capture effects reduced annual apparent survival estimates for the first year after capture by *ca.* 6%. Higher apparent adult survival at colonies in the eastern North Pacific may be due to lower exposure to direct and indirect anthropogenic stressors while foraging (specifically, marine oil and gas infrastructure) and reduced avian predation by gulls at breeding colonies. The high survival rates we found suggests that eastern North Pacific populations of Leach's Storm Petrels are under less stress than those in the western North Atlantic.

Key words: apparent survival, capture-mark-recapture, Leach's Storm Petrel, *Oceanodroma leucorhoa*, British Columbia

INTRODUCTION

Large scale climate phenomena such as El Niño-Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) can create bottom-up effects in marine food webs that alter prey availability for top predators (Grosbois & Thompson 2005, Sydeman *et al.* 2006). Species like seabirds, which forage over hundreds to thousands of square kilometres, are frequently influenced by these indirect effects of climate, with numerous studies connecting ENSO and NAO to breeding success and to juvenile and adult survival (Borstad *et al.* 2011, Oro 2014, Bertram *et al.* 2017, Champagnon *et al.* 2018). However, seabirds can also adjust their behaviours in ways that make them more resilient to variation in oceanic climate. Species such as the Little Auk *Alle alle* adjust their foraging behaviour in response to climate-driven variation in foraging conditions (Grémillet *et al.* 2012). Many species defer breeding in poor years, allowing adults to maintain high survival rates (e.g., Rhinoceros Auklet *Cerorhinca monocerata* (Morrison *et al.* 2011) and Red-footed Booby *Sula sula* (Cubaynes *et al.* 2010)). Some species also have populations that include many non-breeding individuals that can buffer populations in years with low survival (e.g., Great Skua *Stercorarius skua* (Klomp & Furness 1992) and Black-browed Albatross *Thalassarche melanophris* (Nevoux *et al.* 2010)).

Despite their resilience to natural climatic variation, seabirds face increasing anthropogenic pressures that may explain long-term population declines (Croxall *et al.* 2012, Paleczny *et al.* 2015,

Rodríguez *et al.* 2019). Human activities have both direct and indirect effects on seabird survival and productivity. Fisheries bycatch is considered a significant threat for many albatross and petrel species (Barbraud *et al.* 2012, Croxall *et al.* 2012). Oil and gas operations attract foraging seabirds and increase mortality due to incineration or collision with infrastructure (Wiese *et al.* 2001, Ronconi *et al.* 2015). Marine contaminants such as oil, mercury, and plastics are ingested by seabirds and can increase mortality or reduce reproductive success (Wilcox *et al.* 2015, Stenhouse *et al.* 2018). Introduced predators can reduce adult survival and productivity, and they can extirpate breeding colonies (e.g., Martin *et al.* 2000, Jones *et al.* 2008). Anthropogenic stressors also indirectly impact seabird populations; for example, commercial fishing alters ocean food webs. Similarly, changes to the climate impact both ocean food webs and the frequency of extreme weather events, which in turn influence survival and productivity (Croxall *et al.* 2012).

Storm petrels of the family Hydrobatidae are small, relatively long-lived seabirds that breed in the Northern Hemisphere. Storm petrels are particularly vulnerable to introduced predators, human disturbance, offshore platforms, and light pollution (Wiese *et al.* 2001, Miles *et al.* 2010, Watson *et al.* 2014). Some populations of storm petrels have declined dramatically. In California, Ashy Storm Petrel *Oceanodroma homochroa* populations were estimated to have declined by 44% over two decades (Sydeman *et al.* 1998), although this decline may have been overestimated, given that

oceanographic conditions differed between 1971–1972 and 1992 (Ainley & Hyrenbach 2010). In Scotland and the province of Newfoundland in Canada, Leach's Storm Petrels *Oceanodroma leucorhoa* are estimated to have declined by more than 50% since the late 1990s (Newson *et al.* 2008, Wilhelm *et al.* 2015, Wilhelm *et al.* 2019).

Population declines of Leach's Storm Petrel in the western North Atlantic are thought to be primarily driven by factors reducing adult survival, since the estimated annual apparent survival of adults at breeding colonies in Atlantic Canada are lower than those for other procellariiforms (Fife *et al.* 2015). However, population trends and vital rates of Leach's Storm Petrels breeding at colonies in the eastern North Pacific are unknown. To address this knowledge gap, we estimated the annual apparent survival of Leach's Storm Petrels using capture-mark-recapture data from two breeding colonies in British Columbia (BC), Canada: Rock Islets and Cleland Island. We compared our survival estimates with those of other studies on storm petrels and discuss the implications of our study for the management of Leach's Storm Petrels on the Pacific coast of North America.

METHODS

Our research was conducted during 2006–2010 under the following permits issued to Anne Harfenist: Banding Permit No. 10780, BC Park Use Permit #V10610242, and Parks Canada Research and Collection Permit #GWA-2006-570. Capture and handling procedures were reviewed and approved by Parks Canada's Animal Care Committee.

Study species

Leach's Storm Petrels are small (~45 g) procellariids that breed around the periphery of the North Atlantic and North Pacific oceans (Pollet *et al.* 2019a). Leach's Storm Petrels are listed as Vulnerable by the International Union for the Conservation of Nature (IUCN) because 75%–80% of the global population has decreased by more than 30% over three generations (BirdLife International 2018). In North America, breeding colonies along the Pacific coast are found from the Aleutian Islands to the coastal islands of Baja California, Mexico. Breeding colonies on the Atlantic coast are found from Newfoundland to Massachusetts (Pollet *et al.* 2019a). Tracking studies have been conducted in both the eastern North Pacific and western North Atlantic oceans. For birds in the eastern North Pacific, Halpin *et al.* (2018) found that breeding adults on Gillam Island, BC, made foraging trips that could take them up to 1600 km from the colony. Following breeding, these birds migrated south in October, wintering to the west of central Mexico, Ecuador, and northern Peru. For birds in the western North Atlantic, Pollet *et al.* (2014a) and Hedd *et al.* (2018) found that adults breeding on islands travelled an average of 400–1000 km from their colonies during foraging trips that lasted four to six days. Following breeding, these birds followed a clockwise migration route across the North Atlantic to west Africa between October and December, then southwest to tropical waters off the coast of South America for January through March, before returning north in April (Pollet *et al.* 2014b).

Study site

We studied Leach's Storm Petrels at colonies on Rock Islets (52°20'40"N, 131°14'10"W) and Cleland Island (49°10'17"N, 126°05'28"W), BC, during 2006–2010 (Fig. 1). Rock Islets are a

group of small treed islands located off the east coast of Moresby Island, within the Gwaii Haanas National Park Reserve/Haida Heritage Site in the coastal downwelling domain. Both Leach's Storm Petrels and Fork-tailed Storm Petrels *Oceanodroma furcata* breed on these islets; the most recent population estimates are 12000 pairs of Leach's Storm Petrels and 4700 pairs of Fork-tailed Storm Petrels (Rodway *et al.* 1988). Cleland Island is a treeless ecological reserve located off western Vancouver Island in the coastal upwelling domain; the island supports about 500 pairs of Leach's Storm Petrels and 700 pairs of Fork-tailed Storm Petrels, according to the most recent estimates (Rodway & Lemon 1990).

Field methodology

We visited the Rock Islets in mid to late July 2006–2010 and Cleland Island in early July 2007–2010. Colony visits were timed to coincide with late incubation for most of the population, when careful annual excavation of Leach's Storm Petrel burrows does not cause significant desertion (Butler *et al.* 1988, Blackmer *et al.* 2004). Study plots were selected based on the British Columbia Seabird Colony Inventory (Rodway *et al.* 1988, Rodway & Lemon 1990); for this study, plots were located on the north section of the main islet (Islet #1) in the Rock Islets and on the western side of Cleland Island.

In the first year of study, we captured 305 and 400 adults at Rock Islets and Cleland Island, respectively, and banded them with USFWS stainless steel bands. Only one adult per burrow was captured and banded. Adults were extracted from their burrows using standard research protocols. These protocols included making access holes into burrows when the nest chamber could not be reached from the burrow entrance. We sealed each access hole with a piece of cedar shingle, then covered it with a thick layer of soil and branches or a rock. On Cleland Island, burrows were short, and the birds were easily reached without use of access holes. In contrast, burrows on Rock Islet were long and convoluted and usually required multiple access holes to reach the nest chamber.

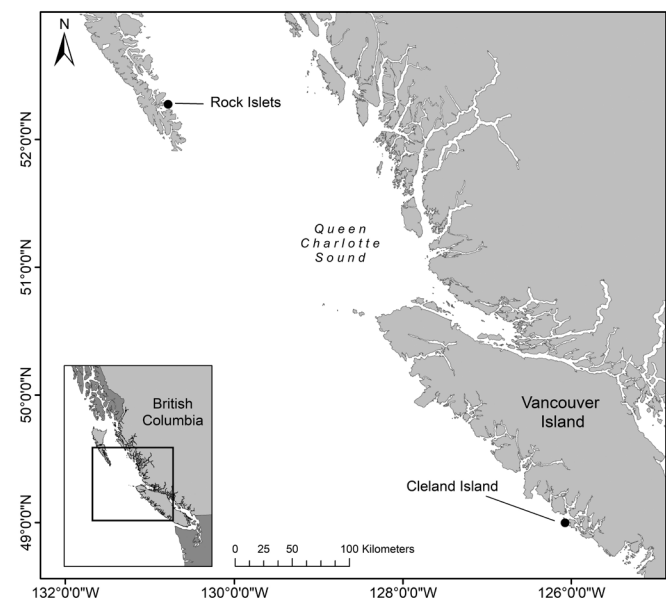


Fig. 1. Location of the study sites on Rock Islets and Cleland Island off the west coast of British Columbia, Canada.

We revisited burrows in subsequent years to recapture marked birds and band previously unmarked adults. Burrows were checked daily or every second day, as weather permitted, until the original banded bird was recaptured or both members of the breeding pair were caught. The burrow checks occurred over a nine-day period on Rock Islets and over a three-day period on Cleland Island. We also checked any new burrows and burrows that had previously been empty in the study area, and we banded adults found. Only data from the first bird encountered of any breeding pair were used in the survival analyses to ensure the independence of data from each burrow. The total number of study birds includes birds banded in the first year, as well as the first birds encountered in new and previously empty burrows in the second and third years of the study.

On Rock Islets, 23 burrows disappeared during storms during the winter of 2006/07. We therefore expanded our Rock Islet study area in 2007 and excavated 85 new burrows to replace those that had been lost and in anticipation of future losses; data from the destroyed burrows were not used in the analyses.

TABLE 1
Reduced m-array showing when and how many Leach's Storm Petrels were recaptured for the first time after release on Cleland Island and Rock Islets, British Columbia, 2006–2010

Year released	# released	# recaptured for first time after release				
		2007	2008	2009	2010	Total
Cleland Island ($n = 436$)						
2006	0	0	0	0	0	0
2007	400		301	59	4	364
2008	337			265	50	315
2009	324				257	257
Rock Islets ($n = 546$)						
2006	282 ^a	213	35	6	0	254
2007	370		289	49	7	345
2008	324			262	44	306
2009	317				260	260

^a 305 birds were banded in this year, but 23 were excluded from the analyses because their burrows were washed away in storms during the first winter post-banding (see Methods for full explanation).

Survival analysis

We estimated annual apparent survival of Leach's Storm Petrels between 2006 and 2010 using the Cormack-Jolly-Seber (CJS) model. We calculated annual apparent survival (ϕ) after accounting for the resighting probability (p), i.e., the probability of encountering an individual if it was alive, using the program MARK (White & Burnham 1999). We fitted a global transient CJS model (Pradel *et al.* 1997, Sanz-Aguilar *et al.* 2010) that allowed (1) survival in the first year to be lower than in subsequent years (to control for disturbance and capture effects), (2) survival at the two islands to differ, and (3) survival to vary across years. We allowed the resighting probability to vary with island and year, and we assessed the fit of the global model using the median c -hat procedure implemented in MARK.

Next, we used the global transient CJS model and a two-step approach to determine the best model structure for the resighting probability and to model annual apparent survival. The candidate model set examining variation in resighting probability included a model that allowed resighting probability to be lower in 2007 (following the storms that led to the loss of some burrows) than in other years, as well as models where resighting probability varied with island and year ($n = 6$ models). The candidate model set examining variation in survival included 11 models. Since we found some evidence of overdispersion in the data (see Results), we used Quasi-Akaike's Information Criterion (QAICc) to rank competing models in the two candidate sets (Burnham & Anderson 2002).

RESULTS

Our capture-mark-recapture data set included a total of 982 birds (546 from Rock Islets and 436 from Cleland Island) and 2271 recapture events. We recaptured birds, on average, two times over the five years (range 0–4, Table 1). The global transient CJS model was an adequate fit to the data (median c -hat = 2.71). We nevertheless controlled for the slight overdispersion in our data in the two candidate model sets (Anderson *et al.* 1994).

Resighting probability was best modelled as a constant (0.81 ± 0.01 , 0.78–0.84). This model received 2.4 times the support of models in which the resighting probability was lower in 2007 than in other years, or lower on Rock Islet than Cleland Island (Table 2).

There was some model uncertainty in the candidate model set examining variation in annual apparent survival, as three models received strong support (Table 3). The top model indicated that

TABLE 2
Model results for the candidate set examining variation in the resighting probability of Leach's Storm Petrels on Rock Islet and Cleland Island between 2007–2010. Apparent survival (ϕ) in all models varies with island in the first year after capture and with island and year thereafter (i/i^*t). Resighting probability (p) may vary with island (i), year (t), or differ in 2007.

Model	QAICc	Δ QAICc	AICc Weights	Model Likelihood	Num. Par	QDeviance
$\phi (i/i^*t) p (.)$	1289.74	0.00	0.437	1.000	8	31.74
$\phi (i/i^*t) p (2007)$	1291.51	1.77	0.180	0.413	9	31.49
$\phi (i/i^*t) p (i)$	1291.58	1.84	0.174	0.398	9	31.57
$\phi (i/i^*t) p (t)$	1292.28	2.54	0.123	0.282	10	30.25
$\phi (i/i^*t) p (t+i)$	1294.28	4.54	0.045	0.103	11	30.23
$\phi (i/i^*t) p (t^*i)$	1294.47	4.73	0.041	0.094	12	28.40

survival was lower in the first year after capture than in subsequent years. This model received 2.6 times the support of the model that allowed survival in the first year after capture to vary by island, and 2.5 times the support of the model that allowed survival in subsequent years to vary by island. The transient model that accounted for disturbance and capture effects had 33.5 times the support of the standard CJS model, in which we did not control for these effects (Table 3).

Model averaging across the strongly supported models indicated that rates of annual apparent survival on both islands were high and similar to each other (Table 4). The estimated annual apparent survival rates for the first year after capture and for subsequent years were all over 0.90. Disturbance and capture effects reduced estimated apparent annual survival by 5.9% and 6.3% on Rock Islets and Cleland Island, respectively.

DISCUSSION

Increasing concern with the status of Leach's Storm Petrel populations led to the species being up-listed to Vulnerable by the IUCN in August 2018. This assessment was based on data indicating that the global population had declined by more than 30% over three generations, or 39 years (Pollet *et al.* 2019a, BirdLife International 2018). Declines in storm petrel populations are attributed to anthropogenic threats that reduce adult survival at sea and increase predation by native and introduced predators at breeding colonies. In the western North Atlantic, population declines are primarily driven

by the low annual adult survival rates (Fife *et al.* 2015). Recent population assessments for Leach's Storm Petrels along the eastern North Pacific, particularly in Alaska, indicate that populations are stable or increasing (Dragoo *et al.* 2019, Pollet *et al.* 2019a), and our results from British Columbia support this assessment. We found that, after controlling for capture effects, apparent survival rates of Leach's Storm Petrels in the eastern North Pacific exceeded 0.97. Relatively few studies have estimated the annual apparent survival of storm petrels. However, in the seven published studies, survival estimates ranged from 0.750–0.975 (Table 5), with our estimates being the highest documented. The high apparent survival rates of Leach's Storm Petrels from the Rock Islets and Cleland Island colonies, which are located 500 km apart and in different oceanic domains, contrasts sharply with low annual apparent adult survival at three breeding colonies in the western North Atlantic (Table 5). This suggests that differences in adult survival are driven by factors that are specific to the ocean rather than the colony.

The large differences in apparent adult survival of Leach's Storm Petrels in the eastern North Pacific and western North Atlantic may be due to the differences in their exposure to a variety of anthropogenic stressors. Storm petrels are particularly vulnerable to offshore oil and gas operations, since the lights and flares attract birds and lead to collisions with infrastructure, overexposure to heat, incineration in flares, and exposure to oil on the ocean surface (Ronconi *et al.* 2015). A study using geologgers to track storm petrel movements in the western North Atlantic found that birds foraged in areas that overlapped extensively with oil and gas operations

TABLE 3
Summary of models in the candidate set examining variation in the annual survival of Leach's Storm Petrels on Rock Islet and Cleland Island, 2007–2010. Apparent survival (ϕ) may vary with island (i) in the first year after capture and with island (i) and/or year (t) thereafter. Resighting probability (p) is held constant(.).

Model	QAICc	Δ QAICc	AICc Weights	Model Likelihood	Num. Par	QDeviance
$\phi (.) p (.)$	1280.09	0.00	0.43832	1.000	3	32.14
$\phi (.i) p (.)$	1281.96	1.86	0.17267	0.394	4	32.00
$\phi (.i.) p (.)$	1282.01	1.92	0.16807	0.383	4	32.05
$\phi (.t) p (.)$	1283.80	3.70	0.06882	0.157	5	31.83
$\phi (.i/i) p (.)$	1283.95	3.85	0.06389	0.146	5	31.98
$\phi (.i/t) p (.)$	1285.72	5.63	0.02627	0.060	6	31.75
$\phi (.i/t) p (.)$	1285.74	5.64	0.02608	0.060	6	31.76
$\phi (.) p (.)$	1287.12	7.02	0.01309	0.030	2	41.17
$\phi (.i*t) p (.)$	1287.73	7.63	0.00964	0.022	7	31.74
$\phi (.i/i+t) p (.)$	1287.73	7.64	0.00962	0.022	7	31.75
$\phi (.i/i*t) p (.)$	1289.74	9.65	0.00353	0.008	8	31.74

TABLE 4
Model-averaged annual survival estimates for Leach's Storm Petrels in the first year after capture and in subsequent years on Rock Islets and Cleland Island, British Columbia, Canada

Parameter	Colony	Estimate	SE	Lower CI	Upper CI
Survival for first year after capture	Rock Islets	0.9120	0.0185	0.8684	0.9421
	Cleland Island	0.9163	0.0193	0.8700	0.9471
Survival for subsequent year(s)	Rock Islets	0.9745	0.0111	0.9408	0.9892
	Cleland Island	0.9752	0.0112	0.9407	0.9898

TABLE 5
Summary of survival estimates obtained for Leach's Storm Petrels (family Hydrobatidae) and related species

Latin Name	Common Name	Location	Methods	Year Range	Mean Survival Estimate	95% CI ^a	Reference
<i>Oceanodroma leucorhoa</i>	Leach's Storm Petrel	Rock Islets, British Columbia	Transient CJS	2006–2010	0.975 ± 0.011	0.941–0.989	This study
		Cleland Island, British Columbia	Transient CJS	2007–2010	0.975 ± 0.011	0.940–0.990	This study
		Baccalieu Island, Newfoundland	Transient CJS	2013–2015	0.79 ± 0.034	NA	Pollet <i>et al.</i> 2019a
		Gull Island, Newfoundland	Transient CJS	2003–2015	0.79 ± 0.015	NA	Pollet <i>et al.</i> 2019a
		Bon Portage Island, Nova Scotia	Transient CJS	2009–2014	0.78 ± 0.04	NA	Fife <i>et al.</i> 2015
		Matinicus Rock, Maine	Age distribution	1955–1975	0.789	NA	Morse & Buchheister 1977
		Matinicus Rock, Maine	Age distribution (corrected)	1955–1975	0.937	NA	Pollet <i>et al.</i> 2019a
<i>Oceanodroma homochroa</i>	Ashy Storm Petrel	Southeast Farallon Island, California	CJS	2001–2014	0.75 ^b	NA	Nur <i>et al.</i> 2019
<i>Hydrobates pelagicus</i>	European Storm Petrel	Eilean Hoan, Scotland	CJS		0.871 ± 0.262	0.357–1.385 ^c	Insley <i>et al.</i> 2002
		Aketx Islet, Spain	Transient CJS	1990–2001	0.89	0.81–0.93	Zabala <i>et al.</i> 2011

^a NA indicates that 95% confidence interval were not reported in this study.

^b Mean of estimated annual survival from the fully time-dependent Cormack-Jolly-Seber (CJS) model.

^c Upper level of reported confidence interval exceeds 1.

at five of the seven breeding colonies studied (Hedd *et al.* 2018). These birds may also be exposed to offshore oil and gas operations in the equatorial zone between Macaronesia and northeastern Brazil during migration and during the winter (Pollet *et al.* 2019b). Additional data on the migration routes and wintering locations of individuals from a range of colonies in the western North Atlantic would help assess this potential risk. In contrast, storm petrels breeding in the eastern North Pacific are not exposed to offshore oil and gas platforms while foraging during the breeding season. Birds from the eastern North Pacific may encounter offshore oil and gas operations as they migrate along the coast of California or when overwintering off the coast of Peru (McCrary *et al.* 2003, Halpin *et al.* 2018), but total year-round exposure is probably lower for birds breeding in the eastern North Pacific relative to birds breeding in the western North Atlantic.

Storm petrels are vulnerable to mortality from both native and introduced predators. In the western North Atlantic, large gulls (mainly European Herring Gulls *Larus argentatus* and Great Black-backed Gulls *Larus marinus*) and Great Horned Owls *Bubo virginianus* have been observed to prey on Leach's Storm Petrels (Stenhouse *et al.* 2000, Pollet & Shutler 2019, A. Hedd pers. comm.). Gulls have been documented killing tens of thousands of adult storm petrels during a single breeding season (49000 on Great Island, Newfoundland; Stenhouse *et al.* 2000). Gull predation on storm petrels is highest when capelin numbers are low or the fish are unavailable to gulls (Stenhouse & Montevecchi 1999, Stenhouse *et al.* 2000). Herring Gulls nesting in census plots on Bon Portage, Nova Scotia, Canada were associated

with a 7% reduction in the estimated annual apparent survival of adult storm petrels (Fife *et al.* 2015). Direct mortality by gulls has consequently been identified as a potential driver of declines in the western North Atlantic (A. Hedd pers. comm.). In the eastern North Pacific, however, there is no evidence that avian predators kill large numbers of Leach's Storm Petrels, despite the presence of Glaucous-winged Gull *Larus glaucescens* and Bald Eagle *Haliaeetus leucocephalus* nests on Rock Islets and a Glaucous-winged Gull colony on Cleland Island (Rodway *et al.* 1988, Rodway & Lemon 1990, A. Harfenist pers. obs.). Similarly, although American Mink *Neovison vison* have occasionally been sighted on Cleland Island, there are no reports of predation on Leach's Storm Petrels by this species (Rodway & Lemon 1990). Differences in the predator community and lower depredation rates could, therefore, explain the higher adult apparent survival at the eastern North Pacific colonies.

Introduced mammalian predators are considered a major threat to many species of colonially nesting seabirds (e.g., Jones *et al.* 2008). For example, introduced cats extirpated Leach's Storm Petrels breeding on small islands off the coast of California in the early 1900s (McChesney & Tershy 1998). However, introduced predators were not present on any of the Canadian Leach's Storm Petrel nesting islands studied to date (A. Hedd pers. comm., A. Harfenist pers. obs.).

Ocean-specific adult survival rates of Leach's Storm Petrels could also arise due to differences in how fisheries or changing ocean conditions influence the quantity or quality of their prey. Leach's

Storm Petrels eat a range of small fishes, crustaceans, jellyfish, and cephalopods (Pollet *et al.* 2019a), and their diet varies spatially and temporally. However, storm petrel diets are typically composed of 40%–60% of myctophids, small deep-water fishes that undertake a nocturnal migration toward the surface (Watanuki & Thiebot 2009). The population status of deep-water fishes is poorly known, but limited trawl data suggests that the abundance of many species in the North Atlantic is impacted by fisheries (Bailey *et al.* 2009). However, we have no additional evidence to suggest that fisheries or changing ocean conditions have resulted in regional differences in the quantity or quality of food available for storm petrels. The fledging success and productivity of Leach's Storm Petrels is not lower in the western North Atlantic than in the eastern North Pacific (Pollet *et al.* 2019a). Further assessments of whether broad-scale differences in food availability impact storm petrels would be important in identifying potential management actions. Interestingly, the National Oceanic and Atmospheric Association's Marine Fisheries Service recognized the ecological importance of forage fishes in 2016 by banning the commercial fishing of myctophids and other forage fishes in US North Pacific waters.

Plastic pollution in the oceans is an emerging environmental concern and it is pervasive (Eriksen *et al.* 2014); seabirds may be particularly vulnerable due to the frequency with which they ingest plastic (Wilcox *et al.* 2015). Seabirds that ingest plastic can have reduced gut volume (Ryan 1987) and lower body mass (Spear *et al.* 1995), and they can accumulate plastic-derived chemicals in tissues (Yamashita *et al.* 2011), although evidence that ingestion of plastic affects survival in the wild remains scant. Storm petrels are known to have relatively high ingestion rates of plastic for their body size (Wilcox *et al.* 2015). Exposure to plastics is likely higher in the eastern North Pacific than in the western North Atlantic (Wilcox *et al.* 2015), yet documented rates of ingestion by storm petrels in the two regions do not differ (Pollet *et al.* 2019a). Differences in the exposure to or ingestion of plastics therefore do not explain the higher survival rates of Leach's Storm Petrels in the eastern North Pacific.

Accurately estimating survival in storm petrels is challenging because of their high sensitivity to capture and handling during some stages of reproduction (Blackmer *et al.* 2004; Fife *et al.* 2015). For example, in a study on Kent Island, New Brunswick, Canada, handling Leach's Storm Petrels once a week for the duration of the incubation period reduced hatching success by 50% and reduced burrow fidelity in the following breeding season by 37% (Blackmer *et al.* 2004). Reduced burrow fidelity will bias detection probabilities and, potentially, alter survival estimates. In our study, we visited burrows during late incubation 1–2 times per season on Cleland Island and 1–4 times per season on Rock Islet, a level of disturbance that was slightly higher than that for the control pairs in the Blackmer *et al.* (2004) study. This level of disturbance was associated with a *ca.* 6% reduction in estimated annual apparent survival in the first year after capture, and we attribute this reduction to permanent dispersal from the study area. Higher rates of disturbance at breeding colonies could reduce estimates of apparent survival. However, disturbance at colonies in Nova Scotia (Bon Portage Island, 1–2 times during incubation, with occasional recapture of adults using burrow traps; Fife *et al.* 2015) and Newfoundland (Baccalieu Island, 1–2 times during incubation; Gull Island, plots visited 1–6 times during the breeding season; A. Hedd pers. comm.) was very similar to our study. Fife *et al.* (2015) also estimated that only 8% of birds switched burrows and almost all moves were to burrows located less than one metre away. Survival estimates in both regions were also generated using transient

CJS models that controlled for disturbance; therefore, differences in research disturbance across regions cannot explain the large differences in annual apparent survival documented in the eastern North Pacific and western North Atlantic.

Studies estimating the vital rates of populations are essential in understanding geographic variation in the population trends of seabirds. Here we show that apparently stable populations of Leach's Storm Petrels breeding at colonies in the eastern North Pacific have extremely high adult survival compared to those breeding at colonies in the western North Atlantic, where populations are declining. The higher apparent survival estimates for adults in the eastern North Pacific cannot be explained by differences in exposure to plastic pollution or research protocols. The higher survival could be associated with reduced exposure to oil and gas infrastructure and lower avian predation rates. Further research into how anthropogenic changes to ocean ecosystems, both direct (e.g., infrastructure) and indirect (e.g., the behaviour of predators), can influence storm petrel survival would shed additional light on the resilience of populations in the eastern North Pacific and support the identification of effective management actions.

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