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POPULATION SURVEY OF LEACH'S STORM-PETRELS BREEDING AT GRAND COLOMBIER ISLAND, SAINT-PIERRE AND MIQUELON ARCHIPELAGO

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ABSTRACT.—The St Pierre and Miquelon Archipelago hosts the only French Leach's Storm-Petrel (*Oceanodroma leucorhoa*) colony. We conducted a survey during the 2008 breeding season to estimate the breeding population size on Grand Colombier Island. This survey included an estimation of burrow detection probability using a double-observer approach. We estimated that 3% of Leach's Storm-Petrels nests had failed before we started the survey. Nest occupancy probability was neither affected by slope nor vegetation type and was 0.546 ± 0.029 . Burrow density was positively affected by slope and, consequently, was much lower on the plateau than on island slopes. Burrow detection probability was neither affected by observer nor by habitat and was 0.89 ± 0.01 . We estimated the population to be 363,787 [95% CI = 295,502–432,072] breeding pairs, which is among the largest Leach's Storm-Petrel colonies in the northwestern Atlantic Ocean. Received 10 May 2011. Accepted 19 November 2011.

Questions associated with the population dynamics of colonial seabirds are of intrinsic interest to biologists and managers of protected areas. Answers to basic questions about population estimates and trends are often needed, as seabirds are recognized as monitors of marine ecosystems and act as indicators of marine environmental changes (Cairns 1984; Montevecchi 1993; Montevecchi and Myers 1995a, b; Piatt et al. 2007; Einoder 2009). Breeding surveys are particularly relevant for burrow-dwelling species such as storm-petrels as a decline could go unnoticed in these inconspicuous species, even for decades. These species may also be highly vulnerable to introduced predators or soil erosion in breeding colonies (Brooke 2004). Population estimates and trends must rely upon rigorous standardized protocols that should be developed throughout the range of species or population of concern (Walsh et al. 1995).

Monitoring programs have two important sources of variation that must be considered in monitoring design: spatial variation and detection rate (Thompson 1992, Lancia et al. 1994, Nichols et al. 2000, Pollock et al. 2002). Spatial variation arises when the observer cannot monitor the entire

area of interest. Monitoring effort thus has to concentrate on sample areas from which the results are used to draw inference about the entire area of interest (Pollock et al. 2002). Detection probability is important as survey methods do not detect all individuals present in the sampled area. Monitoring has to incorporate methods for estimating effects of detection rate so any estimated temporal or spatial changes in the number of individuals counted reflect true changes and not differences in detection. Observer identity and experience are recognized as covariates likely to be relevant to variation in detection probability (Sauer et al. 1994, Kendall et al. 1996); thus, estimation of detection probability is particularly required in long-term monitoring where inevitable changes in observers over time or between sample areas are likely to impact survey accuracy.

Our objective was to estimate the population size of a Leach's Storm-Petrel (*Oceanodroma leucorhoa*) breeding colony in the French Saint-Pierre and Miquelon Archipelago in the northwestern Atlantic Ocean, relying on a land-based survey conducted in 2008. We applied similar survey methods, keeping with recent efforts to obtain up to date estimates for major Leach's Storm-Petrel colonies in eastern North America (Robertson et al. 2006). We explicitly considered estimation of detection probability in the survey. These surveys are expected to be regularly repeated in future years, and we emphasized the double-observer method (Nichols et al. 2000), which appears less logistically expensive compared to other methods for estimating detection rates (i.e., capture-recapture methods).

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METHODS

Study Site.—Field work was conducted on Grand Colombier Island (46° 49' N, 56° 10' W), Saint-Pierre and Miquelon Archipelago, in the northwestern Atlantic Ocean from 18 June to 18 July 2008 (Fig. 1). Grand Colombier Island has an estimated surface area of 480,000 m² and hosts large breeding populations of seabirds (Table 1), particularly Atlantic Puffin (*Fratercula arctica*) and Leach's Storm-Petrel (Desbrosses and Etchberry 1989). The island is free of all mammal species but one, the meadow vole (*Microtus pennsylvanicus*). The main topographical features of the island are a central plateau surrounded by vegetated or rocky slopes and cliffs. Grand Colombier has dry soils and is densely vegetated (mainly ferns, *Dryopteris spinulosa*, and graminoids, *Deschampsia flexuosa*), providing diverse and highly suitable breeding sites for burrow-dwelling petrels and Atlantic Puffins.

Leach's Storm-Petrels breed almost exclusively on Grand Colombier Island within the Saint-Pierre and Miquelon Archipelago where they nest in more or less aggregated burrows, forming relatively dense colonies (Desbrosses and Etchberry 1989). Petrels return to colonies in May, lay their single egg in June, and start visiting colonies at dusk and during the first part of the night. Young hatch in July and fledge in September. Males and females alternate foraging trips at sea during breeding and feed on fish, krill, and squid (Montevecchi et al. 1992).

Sampling Design.—We used a systematic sampling approach to estimate Leach's Storm-Petrel density (Harris and Murray 1981) following Catry et al. (2003). We conducted line transects ($n = 19$) from 8 to 18 July 2008, crossing the entire island from north to south, during the second half of the incubation and early brooding periods. The first transect location was chosen randomly and the following transects paralleled the first one. The distance between successive transects was ~50 m. Each transect starting point was located with a Global Positioning System (GPS) and plotted on a map (Fig. 2).

We stopped at counting points every 30 m along each transect (measured using a 10-m rope). The application of these procedures resulted in all plots ($n = 162$) being pseudo-randomly located in relation to habitat features and burrow density. One fieldworker stood at the center of the plot at each location, holding the tip of a 3-m rope, while

a second observer holding the other tip walked in circle (total surface of the plot = 28.27 m²) and counted all burrow entrances that were within the plot. The slope angle of each plot was estimated using a clinometer. Petrel burrows were identified by entrance diameter (4–5 cm). Burrows consist of a tunnel of 23 cm (range = 12–39 cm) depth on average which may be straight or with several turns (Huntington et al. 1996). The nest chamber is at the end of the tunnel. We only counted burrows used by Leach's Storm-Petrels (Huntington et al. 1996) excluding double-entrance burrows and vole tunnel entrances. Leach's Storm-Petrel and meadow voles, respectively, use burrows and tunnels with similar size entrances, but which generally have different tunnel shape (vole tunnels stay just below the surface) and habitat requirements in terms of vegetation cover and soil substrate (Cramp and Simons 1977, Huntington et al. 1996). We counted burrows with a clear entrance. Burrow entrances overgrown by vegetation were considered inactive and were not counted. Non-surveyed areas (lakes, steep cliffs) represented 2.2% of Grand Colombier Island.

Burrow density may be affected by habitat characteristics including slope angle and/or vegetation type. Fern patches on Grand Colombier Island were highly associated with steep slopes of the island while herbaceous vegetation was nearly exclusively on the plateau and low slopes. We investigated the relationship between burrow density and slope angle using a generalized linear model (log link, negative binomial distribution).

Estimating Burrow Occupancy Probability.—We estimated burrow occupancy probability by acoustic playback, to minimize disturbance of breeding birds, on a sample of 301 burrows at 19 stations spread over the island. Sample plots were selected to be representative of the habitat diversity and slope range; 11 and eight plots were sampled, respectively, in fern and graminaceous habitats, covering a large range in slope (from 5 to 38.1%). Leach's Storm-Petrel calls are sex-specific (Huntington et al. 1996); calls of both males and females were played into each burrow with a digital voice recorder during 1 min and we recorded whether or not a bird responded (Ratcliffe et al. 1998, Ambagis 2004). It is known that a proportion of Leach's Storm-Petrels present in burrows may not respond to playback (Ambagis 2004), and we systematically inspected burrows with no response to playback using a burrow-scope. We checked nest

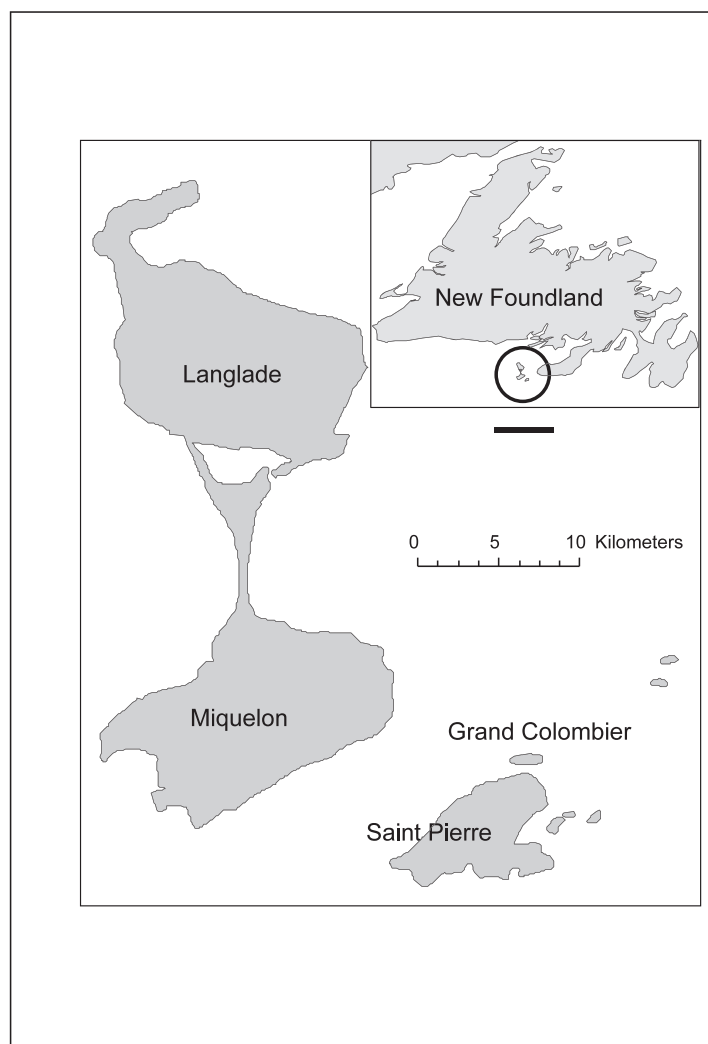


FIG. 1. Location of Saint Pierre et Miquelon Archipelago and Grand Colombier Island.

TABLE 1. Estimates of breeding pairs of seabirds on Grand Colombier Island in 2008 (Lormée et al. 2008).

Species	Scientific name	Year		
		1980s	2004	2008
Atlantic Puffin	<i>Fratercula arctica</i>	400 (1974)	>1,000	9,543 (7,160–11,926)
Black Guillemot	<i>Cepphus grylle</i>			>46
Common Murre	<i>Uria aalge</i>	0		>3
Razorbill	<i>Alca torda</i>			>50
Great Cormorant	<i>Phalacrocorax carbo</i>	30 (1983)		63 (60–66)
Great Black-backed Gull	<i>Larus marinus</i>			10–20
Herring Gull	<i>L. argentatus</i>			60–100
	<i>smithsonianus</i>			
Black-legged Kittiwake	<i>Rissa tridactyla</i>	200 (1989)	291	196 (186–204)

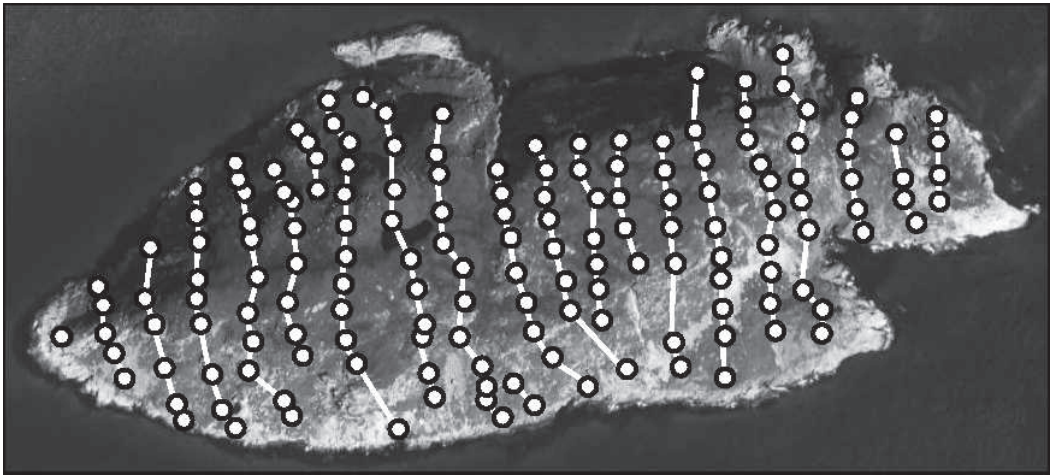


FIG. 2. Location of transects and plots (white dots) on Grand Colombier Island.

content by hand when burrow-scoping inspection was not possible. Occupancy was defined as a binomial variable (1 = presence of adult, egg or chick; 0 = empty), and occupancy probability was estimated as the proportion of occupied burrows over the number of checked burrows. We tested for an effect of slope and vegetation type on occupancy probability using a logistic regression (logit link, binomial distribution). Candidate models were selected using an information theoretic approach (Burnham and Anderson 2002). Non-breeding birds or failed breeders within burrow-dwelling petrel species are known to visit or temporarily occupy unoccupied burrows, potentially resulting in overestimates of abundance (Heaney et al. 2002). However, non-breeding birds visit the colony mainly at night and rarely stay in the burrow during the day (Warham 1990, Huntington et al. 1996). Ratcliffe et al. (1998) estimated the probability of a nest being occupied diurnally by a non breeder on a given day at 0.024 in the closely related European Storm Petrel (*Hydrobates pelagicus*). Thus, we do not exclude the possibility that non-breeding birds may have occupied some burrows during our survey, but they were unlikely to constitute a serious bias in estimation of the breeding population.

Estimating Incubation Failure Preceding the Survey.—We estimated incubation failure probability between laying, occurring in June, and the start of the survey in early July, to correct the burrow occupancy probability estimated during the survey and to estimate the density of occupied burrows at the beginning of the breeding

season. Quadrats with active burrows covering all habitat types on the island were randomly selected ($n = 13$; number of burrows per quadrat = 8 ± 0.3) by 18–19 June. Burrows were individually identified within each quadrat, using numbered 30-cm long wood sticks with red colored tips. Contents of active burrows occupied by an incubating adult ($n = 105$) were inspected at ~10-day intervals (18–19 Jun, 2 Jul, 10 Jul), until the start of the survey, allowing us to observe if burrows were failed or successful. A nest was considered failed if no egg was detected during one of the inspections. Failure was considered as a binomial variable and failure probability was estimated as the proportion of nests that failed over the number of active burrows.

Burrow Detection Probability.—We used a double-observer approach to estimate the burrow detection probability of each observer (Nichols et al. 2000). A sample of plots ($n = 13$) was surveyed by pairs of observers counting burrow entrances independently. Plots were selected in both fern ($n = 8$) and herbaceous habitats ($n = 5$). The first observer marked all the detected burrows. Marks were placed within the burrows so they were invisible for the second observer. The second observer systematically recorded previously-marked burrows and those missed by the first observer. The rank of each observer alternated randomly. We ran a set of models incorporating different sources of variation in detection probability, i.e., observer identity and habitat type, and selected among candidate models using an information theoretic approach (Burnham and Anderson 2002).

TABLE 2. Detection probability of Leach's Storm-Petrel burrows on Grand Colombier Island, Saint Pierre and Miquelon Archipelago. Dev = deviance, Np = number of parameters, Gof = goodness of fit *P*-value. The selected model is in bold.

Model	AICc	ΔAICc	Dev	Np	Gof
Observer	23.85	-	19.84	2	0.99
Constant	24.37	0.52	22.36	1	0.77
Habitat	26.35	2.5	22.36	2	0.64
Observer × Habitat	27.80	3.95	19.80	4	1

Calculation of Leach's Storm-Petrel Breeding Population Size.—The mean Leach's Storm-Petrel breeding population size (*N*) was calculated as:

$$N = \frac{O \times D \times A}{p \times (1 - B)}$$

where *O* is the mean burrow occupancy probability, *D* is the mean burrow density estimated from plots, *A* is the surface area of the island, *p* is the burrow detection probability, and *B* is the breeding failure probability. The variance of *N* was calculated using the delta method following Seber (1982). All values are means ± SE, unless otherwise stated.

RESULTS

Burrow Occupancy Probability.—Occupancy probability was neither affected by slope angle nor by vegetation type (slope: $F_1 = 2.13$, $P = 0.14$; habitat: $F_1 = 0.50$, $P = 0.47$) and was considered similar for every sector (0.546 ± 0.029).

Failure Probability.—Breeding failure was estimated from 73 burrows (32 of the 105 active burrows initially chosen could not be found during the second visit because of fern growth). Failure probability was 0.068 ± 0.029 on 10 July, just before we started the survey. Only 3% of the active nests contained a recently hatched chick by this date.

Detection Probability.—The total number of burrows used to estimate detection probability of all observers ($n = 5$) was 513 (219 in fern and 294 in herbaceous habitats). Burrow densities within the plots used to estimate detection probability were comparable to those in the entire set of plots (plots sampled on plateau: t -test = 1.679, $df = 57$, $P = 0.098$; plots sampled on island slope: t -test = 1.745, $df = 114$, $P = 0.084$). Forty-three burrows were detected by primary observers only, 59 by secondary observers only, and 411 by both observers. The detection probability of each

observer was estimated for 185 ± 3.3 burrows. All tested models had a good fit to the data. Both constant and observer effect models received relatively similar support ($\Delta AICc < 2$; Table 2). Detection probabilities based on the observer effect model, ranged from 0.787 ± 0.040 to 0.913 ± 0.018 . We chose the most parsimonious model to estimate detection probabilities, i.e., the constant model (detection probability of a burrow of Leach Storm-Petrel was neither affected by observer nor by habitat type). Detection probability for a single observer was obtained from the constant model and estimated at 0.89 ± 0.01 .

Relationships Among Burrow Density, Slope, and Habitat Type.—Burrow density was positively affected by slope ($Z = 7.016$, $P < 0.0001$). We separated the island into four sectors depending upon the importance of slope angle: plateau, southern and northern sides, and steep area. Burrow density was estimated specifically for each sector (Table 2). This stratification was used to estimate the number of breeding pairs.

Leach's Storm-Petrel Breeding Population.—We estimated the Leach's Storm-Petrel breeding population size at $363,787 \pm 19,991$ (95% CI = 295,502–432,072; Table 3) pairs on Grand Colombier Island in 2008 considering burrow occupancy, nest failure, detection probability, and specific burrow density for each sector.

DISCUSSION

Survey Method.—The estimates of detection probability suggested an individual observer may miss up to 11% of burrows. We strongly encourage systematic estimation of detection probability during surveys to increase their accuracy and the power to detect subtle temporal changes in population size. Detection probability estimation would be particularly relevant if observers are expected to change throughout successive surveys.

Failure at the egg stage appears to be the main factor affecting breeding success for Leach's Storm-Petrel (Bicknell et al. 2009). Breeding failure preceding the survey was low at our study site ($\sim 7\%$) in comparison with reported values in the literature (hatching success = $77.9 \pm 5.1\%$, min = 66%, max = 86%) (Huntington et al. 1996). We may have slightly underestimated incubation failure rate since the laying period starts in early June and some breeding pairs may have failed in the 2 weeks preceding monitoring of burrows. Additional failures also occur near

TABLE 3. Estimated Leach's Storm-Petrel breeding population on Grand Colombier Island in 2008. Parameters are presented as mean \pm SE. The 95% confidence interval is in brackets.

Parameters	Sector			
	Plateau	Southern side	Northern side	Steep area
Number of plots	54	67	36	5
Sector area (m ²)	105,542	187,785	160,794	32,662
Sector slope (°)	16.3 \pm 1.2	31.6 \pm 0.9	36.0 \pm 1.1	40.0 \pm 2.2
Adjusted sector area (m ²)	109,962 \pm 31	220,476 \pm 51	198,752 \pm 67	42,637 \pm 71
Burrow density	0.32 \pm 0.06	1.15 \pm 0.09	1.22 \pm 0.11	0.45 \pm 0.13
Detection probability	0.89 \pm 0.01			
Occupancy rate	0.55 \pm 0.03			
Breeding success (10 Jul)	0.93 \pm 0.03			
Number of breeding pairs	23,426 \pm 4,063	167,557 \pm 12,722	160,267 \pm 14,427	12,536 \pm 3,626
Total number of breeding pairs	363,787 \pm 19,991	[295,502–432,072]		

hatching (mostly due to infertile eggs). Leach's Storm-Petrel surveys should be conducted no later than the first half of the incubation period to minimize underestimation and if breeding failure cannot be estimated precisely to correct survey estimates.

Population Estimate on Grand Colombier Island.—The world Leach's Storm-Petrels population is estimated to be >8 million breeding pairs (Huntington et al. 1996). The species' breeding range is centered in the northwestern Atlantic Ocean in eastern Newfoundland, Canada, where over half of the world's breeding population (up to 5 million pairs) occurs (Huntington et al. 1996). Most colonies are in the Newfoundland region with the world's largest colony reaching 3,360,000 breeding pairs at Bacallieu Island (Sklepkovych and Montevecchi 1989). Thus, the Grand Colombier colony contributes ~6% of the North Atlantic breeding population.

The Grand Colombier Leach's Storm-Petrel colony ranked second with ~363,000 breeding pairs among Leach's Storm-Petrel colonies in the northwestern Atlantic (i.e., Newfoundland, Labrador, Canada; and St Pierre and Miquelon, France). Previous surveys conducted during the late 1980s and in 2004 on Grand Colombier Island, respectively, estimated population size at ~178,000 (Desbrosses and Etcheberry 1989) and ~143,000 breeding pairs (Robertson et al. 2006). Our estimate is twice those in previous years. This difference is unlikely to entirely result from a Leach's Storm-Petrel population increase. A mean age at first breeding of 5 years (Huntington et al. 1996), and overall mean annual survival of 0.79 (Huntington et al. 1996) suggests the maximal annual growth rate (λ_{\max}), following Niel and

Lebreton (2005), is 1.1 (i.e., a maximal 10% annual increase). Large Leach's Storm-Petrel colonies appeared stable in the northwestern Atlantic from the 1970s to early 2000s, and only small colonies showed declines (Robertson et al. 2006). The difference between the 2004 and 2008 surveys probably partly results from a sampling artefact as sampling effort was highly variable between surveys. The sampled area consisted of 8 \times 25-m² plots in the late 1980s (200 m²), 90 \times 16-m² plots in 2004 (1,440 m²), and 162 \times 28.3-m² plots in 2008 (4,585 m²). Burrow density was 30% higher in 2008 than in 2004, whereas occupancy rate was only 11% lower in 2008. The 2008 survey was the first to include burrow detection probability, which indicated that burrow density could be underestimated by 11%. We showed that breeding failure from mid-June to the start of the survey could account for a 7% loss in breeding pairs.

Identification of potential threats to this population, because of the significant size of this colony, should be encouraged for effective conservation. We observed Leach's Storm-Petrel remains in regurgitation pellets at Herring Gull (*Larus argentatus*) nests. Predation of Leach's Storm-Petrels by Herring Gulls has been reported (Stenhouse et al. 2000) with up to 9% of a colony of 269,765 breeding pairs being killed by 2,144 gull pairs in one breeding season. Predation was mostly by specialized individuals or pairs (11.6% of the gull breeding population; Stenhouse et al. 2000). These authors considered that, despite large losses, the Leach's Storm-Petrel breeding population did not appear to substantially decline, probably because recruitment could maintain the population. We estimated that 60–100 gull pairs

were breeding on Grand Colombier Island during our survey (Lormée et al. 2008; Table 1). The temporal trend of the gull population on Grand Colombier Island is not well known but no major increase seems to have occurred recently. Thus, the impact of the gull population on Leach's Storm-Petrels is likely limited. We also found occasional eggs inside burrows and dead chicks at burrow entrances predated, presumably by meadow voles, during our survey.

Another potential threat to the Leach's Storm-Petrel breeding population on Grand Colombier Island could arise from increase of the breeding population of Atlantic Puffins. The number of puffin breeding pairs dramatically increased during the last several decades, from ~400 pairs in the late 1970s (Desbrosses and Etcheberry 1989) to >1,000 in 2004 (R. L. Bryant, unpubl. data) and reached $9,543 \pm 1,216$ in 2008 (Lormée et al. 2008). This increase was paralleled by colonization of new sectors on Grand Colombier Island, including slope habitats which are also favored by Leach's Storm-Petrels. Puffins dig large burrows and eject the excavated soil around the nest, resulting in fern disappearance and a marked reduction in vegetation cover, making habitats unfavorable for Leach's Storm-Petrels. SOWLS et al. (1980) reported similar destruction of nesting habitat of Leach's Storm-Petrels through competition with Cassin's Auklets (*Ptychoramphus aleuticus*) and Double-crested Cormorants (*Phalacrocorax auritus*). The spatial colonization and population trend of Atlantic Puffins breeding on Grand Colombier Island should be carefully monitored in future years to detect and quantify potential competition for breeding habitat with Leach's Storm-Petrels.

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