AUTUMN AT-SEA DISTRIBUTION AND ABUNDANCE OF PHALAROPES *PHALAROPUS* AND OTHER SEABIRDS IN THE LOWER BAY OF FUNDY, CANADA

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ABSTRACT

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During late summer and early autumn, the Bay of Fundy, Canada, is an important foraging area for many species of post-breeding and migratory seabirds, yet there has been limited effort to quantify the number of birds using these waters. Furthermore, the numbers of phalaropes *Phalaropus* spp. using this region as a stopover during autumn migration is much lower than in previous decades, but an explanation of their disappearance remains elusive. We examined the species composition, abundance and distribution of seabirds using the lower Bay of Fundy during September, 2015. Aerial surveys were conducted in three regions known to encompass good habitat for seabirds: Brier Island Ledges (hereafter Brier: 622 km^2), shoals southeast of Grand Manan Island (hereafter Grand Manan: 531 km^2), and Lurcher Shoals/German Bank (hereafter Lurcher: 7 433 km^2). Using distance sampling, detection probabilities, densities and abundance estimates were calculated for phalaropes, shearwaters (Procellariidae), Northern Gannets *Morus bassanus*, gulls (Laridae), storm-petrels (Hydrobatidae), and alcids (Alcidae). All species were found in higher densities in Brier and Grand Manan than in the larger area of Lurcher, with phalaropes, shearwaters, and Northern Gannets being the most numerous. Among the three regions, we estimated >100 000 phalaropes during each of two survey periods, and upwards of 30 000 shearwaters, 3 500 Northern Gannets, 2 800 gulls, 2 000 alcids, and 2 000 storm-petrels during one of the two periods. Our abundance estimates for phalaropes were similar to recent surveys, and the low numbers seen in Lurcher suggests this area is not an alternative stopover. Areas of tidal upwelling around Brier and Grand Manan islands provide important foraging habitat for a diverse community of resident and migratory seabirds, but these areas do not account for the disappearance of very large numbers of Red-necked Phalaropes *P. lobatus* from the nearby Passamaquoddy Bay since the 1980s.

Key words: autumn abundance, Bay of Fundy, migration, phalaropes, seabirds, stopover

INTRODUCTION

The Bay of Fundy, Canada, provides rich foraging habitat in the summer for a number of breeding seabird species, including large gulls (Laridae), terns (Sternidae), Common Eiders *Somateria mollissima*, Atlantic Puffins *Fratercula arctica*, Razorbills *Alca torda,* and Common Murres *Uria aalge* (Diamond & Devlin 2003, Ronconi & Wong 2003, East Coast Aquatics 2011, Nisbet *et al.* 2013), and it is an important wintering ground for a significant proportion of the North American population of Razorbills (Huettman *et al*. 2005, Clarke *et al*. 2010). In the autumn, Red Phalaropes *Phalaropus fulicarius* and Red-necked Phalaropes *P. lobatus* are known to stop over in the lower Bay of Fundy during migration (Brown & Gaskin 1988, Hunnewell *et al*. 2016), and there is evidence that the region also provides significant foraging habitat to shearwaters (Great *Ardenna gravis* and Sooty *A. grisea*), Wilson's Storm-petrels *Oceanites oceanicus,* and Northern Gannets *Morus bassanus* (Brown *et al.* 1981, Braune & Gaskin 1982, Hicklin & Smith 1984, Ronconi *et al*. 2010, Huettmann & Diamond 2011, Nisbet *et al.* 2013, Powers *et al.* 2017).

Seabirds are widely valued as indicators of ecosystem health and functioning (Cairns 1987, Einoder 2009). Thus, understanding the distribution and abundance of various foraging guilds can be useful to identify important marine areas for conservation and management (e.g., Ronconi *et al.* 2012). Data on seabirds have been used as a key source of information in identifying and delineating ecologically and biologically significant areas (EBSAs) in marine waters of Atlantic Canada (DFO 2004, Buzeta 2014, Hastings *et al.* 2014). The Bay of Fundy experiences a high degree of human activity from shipping traffic (Simard *et al.* 2014) and fisheries activity (DFO 2015). Therefore, current information on the distribution and abundance of several seabird foraging guilds will be important not only for the conservation of seabirds, but also for a broader understanding of underlying ecosystem processes that make these areas ecologically and biologically significant.

Several regions in the lower Bay of Fundy, such as the Brier Island Ledges and the shoals southeast of Grand Manan Island (Fig. 1), have been identified as EBSAs, supporting large numbers of seabirds and marine mammals as a result of dynamic oceanographic processes that concentrate prey (Buzeta 2014). For example, strong tidal currents over the Brier Island Ledges create upwellings that make concentrations of copepods *Calanus finmarchicus* available to surface-feeding phalaropes during migratory stopovers (Brown & Gaskin 1988, Thorne & Read 2013, Buzeta 2014). Likewise, the Grand Manan Shoals attract large aggregations of seabirds and marine mammals as a result of upwelling and rip tides in the summer (Johnston & Read 2007, Buzeta 2014) and large concentrations of Razorbills in the winter (Huettman *et al*. 2005). The regions around Brier Island Ledges and the Grand Manan Shoals have been classified as Canadian Important Bird Areas (IBA Canada 2017; see sites NS021 and NB011 at www.ibacanada.org) due, in part, to their important aggregations of multiple seabird species. Yet, although they are recognized as ecologically and biologically important, little attempt has been made to quantify the numbers of seabirds using these regions in various seasons, apart from phalaropes (Hunnewell *et al*. 2016).

Just south of the Brier Island Ledges, a large area off the southwest coast of Nova Scotia has also been identified as an EBSA (Hastings *et al.* 2014), in part because it is known to support significant at-sea aggregations of several seabird functional guilds (Allard *et al.* 2014). Extending offshore to approximately the 100 m isobath, this EBSA includes areas of the Lurcher Shoals and German Bank, which are important fishing areas and herring *Clupea harengus* spawning grounds (DFO 2015, Hastings *et al.* 2014). This region is also known to provide important non-breeding and migratory habitat (from October to April) for some seabird species, such as Northern Gannets (Pittman & Huettmann 2006).

One issue of conservation and management concern in the lower Bay of Fundy has been the observed decline of phalaropes from the area. An extremely high abundance of phalaropes have, historically, used this region as a staging area during fall migration from the Arctic. It is estimated that, before the 1980s, 1 to 2 million Red-necked Phalaropes used waters of the lower Bay of Fundy, in the Passamaquoddy Bay region northwest of Grand Manan Island, during their post-breeding migration (Vickery 1978, Mercier & Gaskin 1985). However, by the mid-1980s to early 1990s, their numbers dropped significantly, raising conservation concerns (Duncan 1996, Nisbet *et al.* 2013, Nisbet & Veit 2015). Duncan (1996) suggested Red-necked Phalaropes might have shifted to the eastern and southern sides of Grand Manan Island and the Brier Island Ledges, both of which have historically provided foraging habitat for Red Phalaropes and, to a lesser extent, Red-necked phalaropes. Recent aerial surveys of the Brier Island Ledges and Grand Manan Shoals estimated the stopover population of phalaropes (both Red and Red-necked combined) to be 103 496 in 2009 and 287 558 in 2010 (Hunnewell *et al*. 2016), confirming that the population is just a fraction of the abundance in previous decades. The decline may be attributed to the effects of El Nino–Southern Oscillation (ENSO) events (Nisbet& Veit 2015), although ship-based survey data from the Eastern Canada Seabirds at Sea (ECSAS) monitoring program (Gjerdrum *et al*. 2012) suggests that additional concentrations of phalaropes may be found just south of the Brier Island Ledges, along the Lurcher Shoals and German Bank (CWS, unpubl. data). Targeted surveys of this region may help determine whether phalaropes are using different areas during their fall stopover than they were in previous decades.

In this study, our objectives were to describe the species composition of seabirds using Brier Island Ledges, Grand Manan Shoals, and Lurcher Shoals/German Bank in the autumn, and estimate their abundance across these regions and between survey periods. For phalaropes, specifically, we used this information to determine whether there is evidence of additional concentrations along the southwest coast of Nova Scotia that could account for the observed population decline within the lower Bay of Fundy.

METHODS

Study area and data collection

Aerial seabird surveys were conducted in the lower Bay of Fundy, Canada (44°38′31″N, 66°27′21″W) and off the southwest coast of Nova Scotia (43°36′18″N, 66°33′07″W) in September 2015. Surveys were conducted twice during this month (1–2 and 15–16 September) in three regions: Brier Island Ledges (hereafter Brier), Grand Manan Shoals (hereafter Grand Manan) in the lower Bay of Fundy, and Lurcher Shoals and German Bank (hereafter Lurcher), south of Brier Island Ledges and off the southwest coast of Nova Scotia (Fig. 1).

Transects flown within the Brier and Grand Manan regions duplicated the transects conducted for phalaropes by Hunnewell *et al*. (2016) in 2009 and 2010. As per Hunnewell *et al*. (2016), 16 transect lines totalling 251 km (average length 15.7 km, standard deviation [SD] 4.9, range 7.9–23.2 km) were surveyed in the Brier region. A total of 12 transect lines totalling 203 km (average length 16.9 km, SD 3.7, range 8.8–9.9 km) were surveyed in the Grand Manan region. The Brier and Grand Manan regions encompassed a study area of 622 km^2 and 531 km^2, respectively. The Lurcher study area was defined by creating a polygon (7 433 km^2) that spanned

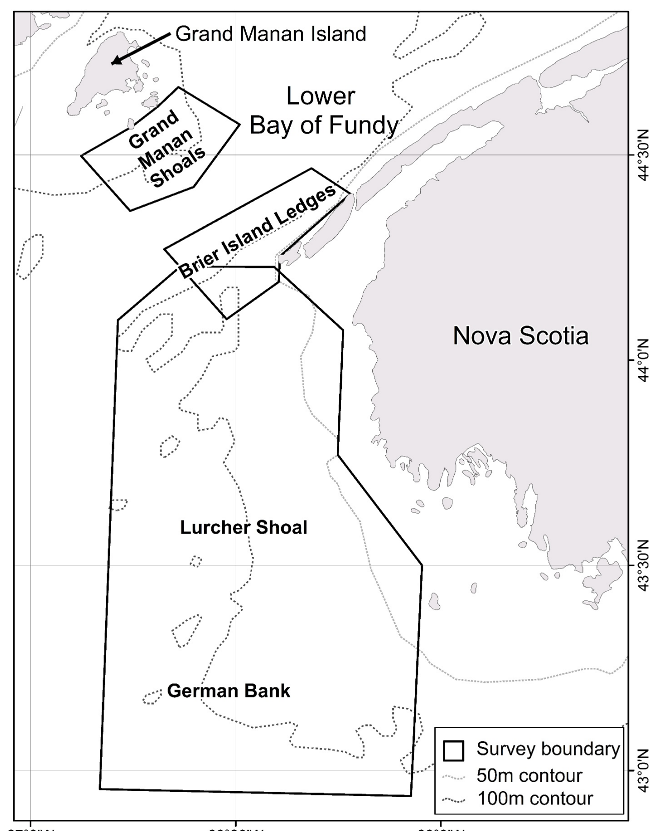

Fig. 1. Study area in the Bay of Fundy where aerial surveys for seabirds were conducted in September 2015. The map shows the boundaries of the three survey regions, which were defined to encompass bathymetric features of significance (e.g., shoals, banks, and ledges). Survey regions included 1) Grand Manan, which encompasses Grand Manan Shoals; 2) Brier, which encompasses Brier Island Ledges; and 3) Lurcher, which encompasses Lurcher Shoal and German Bank. See Figs. 2–7 for survey transect lines.

TABLE 1
Summary of seabirds recorded during aerial surveys conducted in three regions of the lower Bay of Fundy and southwest coast of Nova Scotia in September 2015, by region and date

Family	Species		Location and date, count[a] (%)						Total count (%)
	Common name	Scientific name	Brier 2 September	Brier 15 September	Grand Manan 2 September	Grand Manan 15 September	Lurcher 1 September	Lurcher 16 September	
Scolopacidae	Unidentified Phalarope	*Phalaropus* spp.	3 347 (80.5)	2 719 (73.7)	2 031 (56.3)	2 373 (87.1)	398 (34.6)	169 (25.4)	11 037 (69.0)
Procellariidae	Cory's Shearwater	*Calonectris borealis*	0	0	0	0	1 (0.5)	3 (0.1)	4 (<0.1)
	Great Shearwater	*Ardenna gravis*	236 (5.7)	316 (8.6)	967 (27.8)	34 (1.3)	542 (47.1)	136 (20.4)	2 231 (14.0)
	Manx Shearwater	*Puffinus puffinus*	0	0	0	0	1 (0.1)	2 (0.3)	3 (<0.1)
	Sooty Shearwater	*Ardenna grisea*	0	2 (0.1)	0	2 (0.1)	6 (0.5)	1 (0.2)	11 (0.1)
	Northern Fulmar	*Fulmarus glacialis*	3 (0.1)	3 (0.1)	1 (<0.1)	0	12 (1.0)	1 (0.2)	20 (0.1)
	Unidentified Shearwater		101 (2.4)	378 (10.3)	319 (8.8)	148 (5.4)	31 (2.7)	10 (1.5)	987 (6.2)
Alcidae	Black Guillemot	*Cepphus grylle*	0	0	1 (0.03)	0	0	0	1 (<0.1)
	Unidentified Alcid		320 (7.7)	151 (4.1)	95 (2.6)	25 (0.9)	47 (4.1)	2 (0.3)	640 (4.0)
Sulidae	Northern Gannet	*Morus bassanus*	30 (0.7)	76 (2.1)	10 (0.3)	48 (1.8)	49 (4.3)	196 (29.4)	409 (2.6)
Laridae	Black-legged Kittiwake	*Rissa tridactyla*	1 (<0.1)	0	0	5 (0.2)	10 (0.9)	2 (0.3)	18 (0.1)
	Great Black-backed Gull	*Larus marinus*	8 (0.2)	6 (0.2)	10 (0.3)	25 (0.9)	14 (1.2)	69 (10.4)	132 (0.8)
	Herring Gull	*Larus argentatus*	8 (0.2)	3 (0.1)	14 (0.4)	7 (0.3)	3 (0.3)	9 (1.4)	44 (0.3)
	Unidentified Gull		27 (0.7)	11 (0.3)	32 (0.9)	32 (1.2)	19 (1.7)	34 (5.1)	155 (1.0)
	Unidentified Tern	*Sterna spp.*	0	0	0	1 (<0.1)	1 (0.1)	14 (2.1)	16 (0.1)
Anatidae	Common Eider	*Somateria mollissima*	0	0	105 (2.9)	0	0	0	105 (0.7)
Hydrobatidae	Unidentified Storm-petrel		72 (1.7)	20 (0.5)	22 (0.6)	25 (0.9)	14 (1.2)	4 (0.6)	157 (1.0)
Stercorariidae	Great Skua	*Stercorarius skua*	0	0	0	0	1 (0.1)	0	1 (<0.1)
	Unidentified Jaeger	*Stercorarius spp.*	0	1 (<0.1)	0	0	0	0	1 (<0.1)
	Unidentified Skua	*Stercorarius spp.*	0	0	0	0	3 (0.3)	11 (1.7)	14 (0.1)
Phalacrocoracidae	Double-crested Cormorant	*Phalacrocorax auritus*	4 (0.1)	0	0	1 (<0.1)	0	0	5 (0.3)
	Unidentified Cormorant	*Phalacrocorax spp.*	0	2 (0.1)	0	0	0	3 (0.1)	5 (0.3)
Gaviidae	Common Loon	*Gavia immer*	0	0	1 (<0.1)	0	0	0	1 (<0.1)
All species			**4 157**	**3 688**	**3 608**	**2 726**	**1 152**	**666**	

[a] Counts are uncorrected estimates of individuals and % of individuals observed within each survey region on each survey date.

from the southern portion of the Brier Island Ledges in the north to the German Bank in the south, and straddled the 100 m bathymetric contour (Fig. 1). The survey design was created using program DISTANCE 7.0 (Thomas *et al*. 2010) using an "equal-spaced zigzag" placement of transects along a north–south gradient. A total of 990 km of transects were placed, resulting in 19 survey lines (average length 52.6 km, SD 11.0, range 23.8–62.3 km).

All surveys were conducted by the same two observers. The observers sat on opposite sides of the aircraft, and switched seats between some of the surveys. Two different twin-engine planes (Partenavia and Islander) were used for the surveys, depending on availability. The nose of the Partenavia has a window where one observer is positioned (port side), and a bubble window for the second observer (starboard side). The Islander lacks either of these features (flat windows on both sides). Surveys were flown at a speed of 100 knots (185 km/h) at an altitude of 60 m. At the beginning of each transect, the date, time, sea state (on the Beaufort scale), and glare conditions (0 = none, 1 = slight/grey, 2 = bright on observer side, 3 = bright forward) were recorded. When a flock was observed, species (or genus/family), flock size, behaviour (flying or on water), and the perpendicular distance bin to the centre of the flock (0–50, 50–100, 100–200, 200–300, and 300–500 m) were recorded. To facilitate quick and accurate assignment of the distance bin for each sighting, the angle of sight for each observer for each distance bin was calculated before conducting the surveys, and tape was applied to the observation windows delineating the upper limits of each bin. We used program dLOG3 (version 1.1, Ford Ecological Consultants) to display and navigate transect lines, as well as to record the flight track line at 1 s intervals. Observations were recorded to digital voice recorders that were synchronized to global positioning system (GPS) time. After the survey, observations were transcribed in a spreadsheet, and R version 3.3.3 (R Core Team, 2015) was used to link observations with latitude and longitude coordinates of flight track lines to the nearest one second.

Analysis

To investigate species composition, the total count of all seabird species (or genus/family) were summed by survey date and region. To estimate abundance for each species group by survey date and region, detection functions for each species (or species group) were fitted by modelling detectability as a function of distance from the observer and a number of covariates, including flock size, plane side (four levels: two planes with two sides), sea state (three levels: 1–3), glare (three levels 0–2: glare values of 2 and 3 were pooled due to the limited number of observations within each), observer (two levels), behaviour (two levels: fly, water), and region (three levels: Grand Manan, Brier, Lurcher). Only species groups with a sufficient numbers of sightings (>100 flocks) were included: phalaropes (Red-necked and Red Phalaropes), shearwaters (Great, Sooty, and Manx Shearwaters *Puffinus puffinus*), storm-petrels (Wilson's and Leach's Storm-Petrels *Oceanodroma leucorhoa*), Northern Gannets, alcids (Common Murres, Atlantic Puffins, Razorbills), and gulls and terns (Herring Gulls *Larus aregentatus*, Great Black-backed Gulls *L. marinus*, Black-legged Kittiwakes

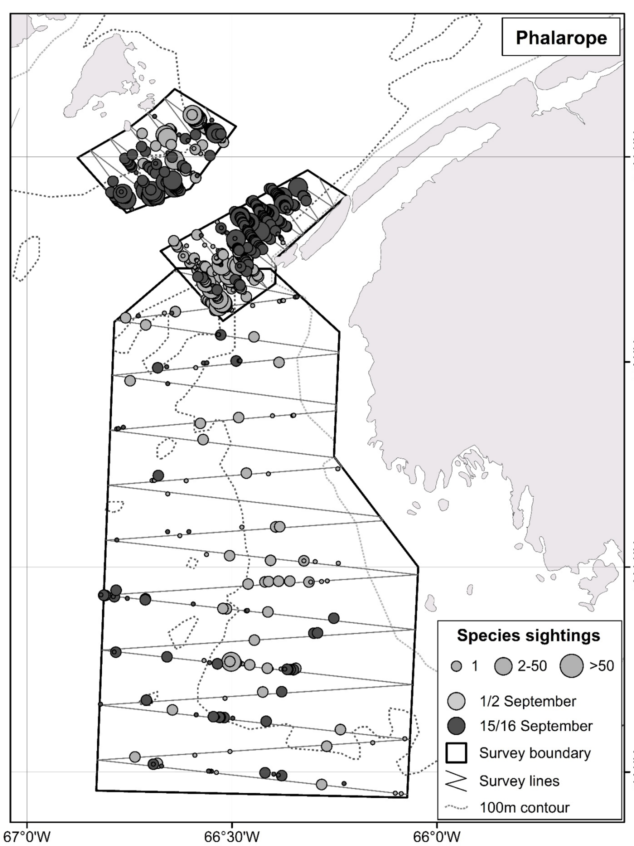

Fig. 2. Raw counts of phalaropes along aerial transect lines during two survey periods (1–2 September, 15–16 September). The three regions are Grand Manan, Brier, and Lurcher (see Fig. 1 for details).

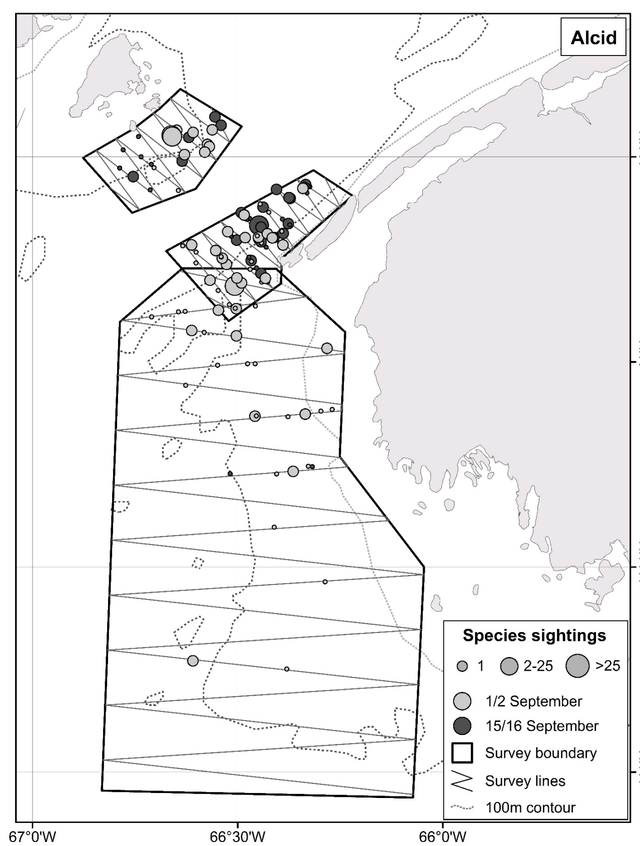

Fig. 3. Raw counts of alcids along aerial transect lines during two survey periods (1–2 September, 15–16 September). The three regions are Grand Manan, Brier, and Lurcher (see Fig. 1 for details).

Rissa tridactyla, Arctic Terns *Sterna paradisaea,* and Common Terns *S. hirundo*), hereafter referred to as gulls.

Because of the configuration of the windows in the planes, birds could not be seen in the first 0–30 m on both sides of each of the planes. Left truncation at x = 30 m (Alldredge & Gates 1985) was initially used; however, this resulted in poor model fit. Instead, distance bins were rescaled with no truncation (Laake *et al*. 2008, Hunnewell *et al*. 2016), such that the truncation distance (30 m) was subtracted from all the distance bins, effectively moving the centreline by 30 m on either side. Thus, the distance bins used in the analyses were: 0–20, 20–70, 70–170, 170–270, and 270–470 m.

Models were run using two key functions (hazard-rate and half-normal), without any adjustments. Although the search image strip width was up to 500 m, some species (phalaropes, storm-petrels, alcids) were rarely or never seen within the 300–500 m distance bin. Therefore, the detection function analysis used the 170–270 m distance bin as the farthest bin for these species. Model selection was based on Akaike information criterion (AIC) (Burnham & Anderson 2002), but model fit was also evaluated by looking at the resulting model plots and goodness-of-fit tests. Using the best model for each group of species, density and abundance estimates were calculated for each region (using the total area within the boundary delineating each region) for each survey date. All analyses were conducted in R 3.3.2 using package Distance (Miller 2016).

RESULTS

Surveys

A total of 2826.7 km were surveyed over the four survey days in September 2015 (Brier on 2 September = 250.6 km, Brier on 15 September = 250.3 km, Grand Manan on 2 September = 135.3 km, Grand Manan on 15 September = 202.9 km, Lurcher on 1 September = 990.8 km, and Lurcher on 16 September = 990.8 km). Grand Manan surveys conducted on 2 September were cut short due to fog, which precluded the completion of 3 transect lines.

During the surveys, a total of 15 997 individuals were recorded, with phalaropes being the most commonly sighted group of species overall (69% of total), especially in the Brier and Grand Manan regions (77% and 70% of individuals, respectively; Table 1). Shearwaters (Great and unidentified) were also commonly encountered (14% and 6% of total, respectively) and were within the top three most frequently sighted species for all three regions and for both surveys dates. Northern Gannets were commonly encountered in the Lurcher region (particularly during the 16 September survey; 29%). Alcids were numerous in the first Brier survey (2 September; 8%).

Overall, higher numbers of seabirds were recorded in the Brier and Grand Manan regions than in the Lurcher region (Table 1),

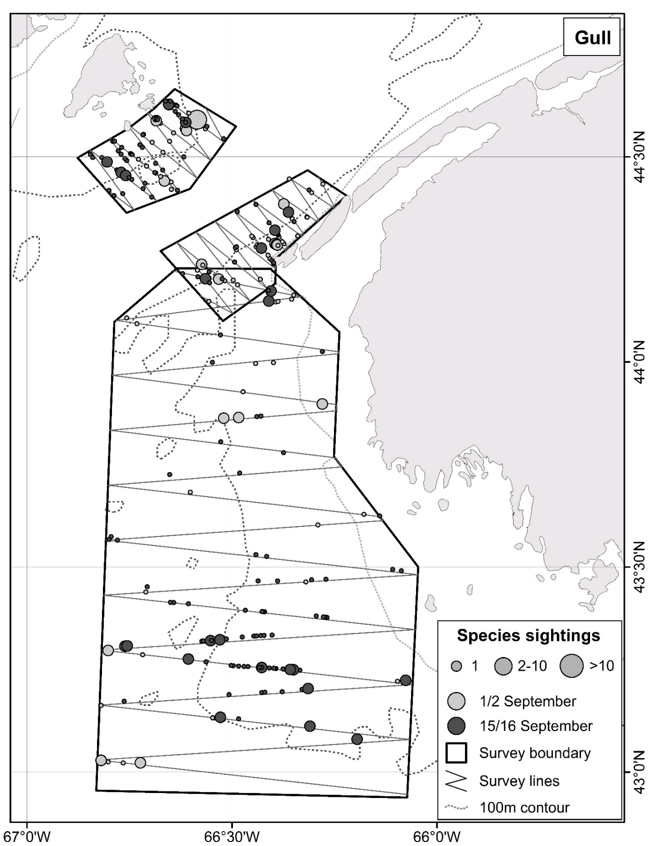

Fig. 4. Raw counts of gulls along aerial transect lines during two survey periods (1–2 September, 15–16 September). The three regions are Grand Manan, Brier, and Lurcher (see Fig. 1 for details).

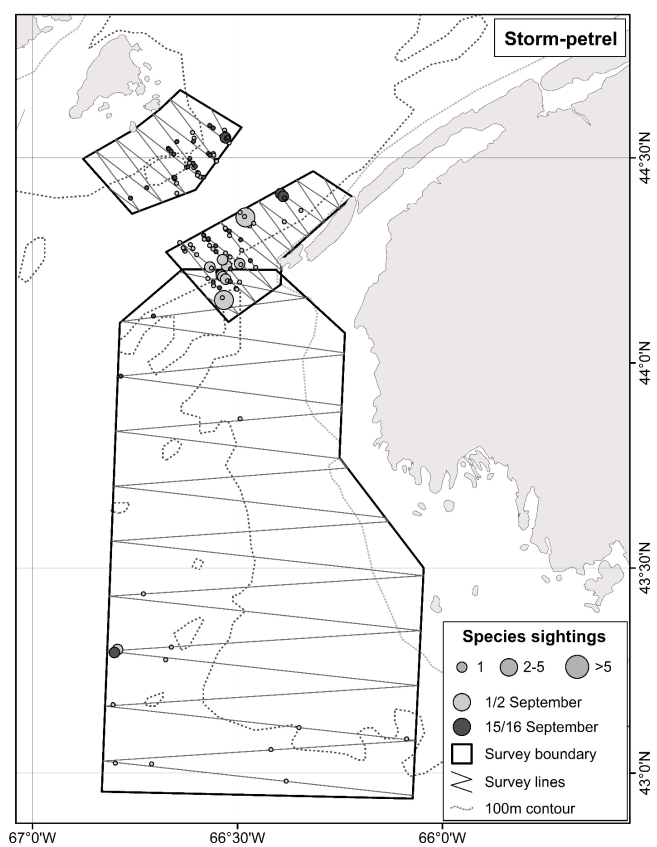

Fig. 5. Raw counts of storm-petrels along aerial transect lines during two survey periods (1–2 September, 15–16 September). The three regions are Grand Manan, Brier, and Lurcher (see Fig. 1 for details).

an observation that is notable given the survey effort (linear kilometres) was more than four times greater in the Lurcher study area than in either Brier and Grand Manan. Very few storm-petrels or alcids were recorded in the Lurcher region (Table 1). Between the two survey periods, phalaropes appeared to shift their distribution within Brier (to northeast in the later survey) and Grand Manan regions (southwest in the later survey) (Fig. 2); alcids appeared to shift their distribution within Brier (northwest in the later survey) (Fig.3); and gulls appeared on the German Bank (part of Lurcher) during the later survey (Fig. 4). No clear temporal shift in distribution was evident for storm-petrels (Fig. 5), Northern Gannets (Fig. 6), or shearwaters (Fig. 7). Some species favoured certain habitats within study regions, such as storm-petrels, which were found in the deeper waters of the Grand Manan and Brier regions (Fig. 5), Northern Gannets (Fig. 6), and gulls (Fig. 4), which were found in more shallow waters within the 100 m bathymetric contour line.

Density and abundance estimates

Detection probability ranged from 0.26 (standard error [SE] <0.001) for shearwaters and 0.45 (SE = 0.021) for Northern Gannets. Covariates that were consistently included in the best selected models were plane side (five of the six final models) and region (four of the six final models), while observer was included in half of the best selected models (Table 2). Based on examination of plots

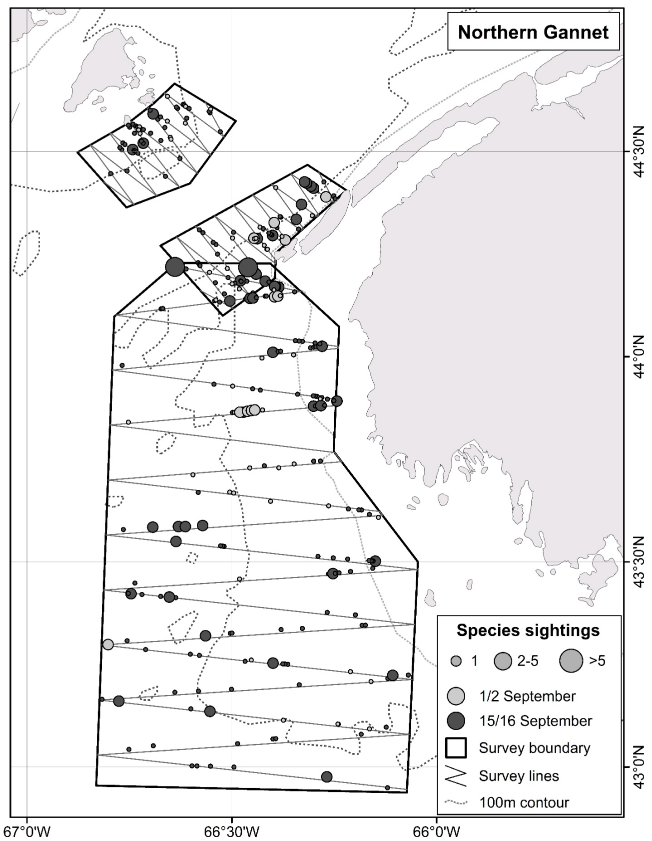

Fig. 6. Raw counts of Northern Gannets along aerial transect lines during two survey periods (1–2 September, 15–16 September). The three regions are Grand Manan, Brier, and Lurcher (see Fig. 1 for details).

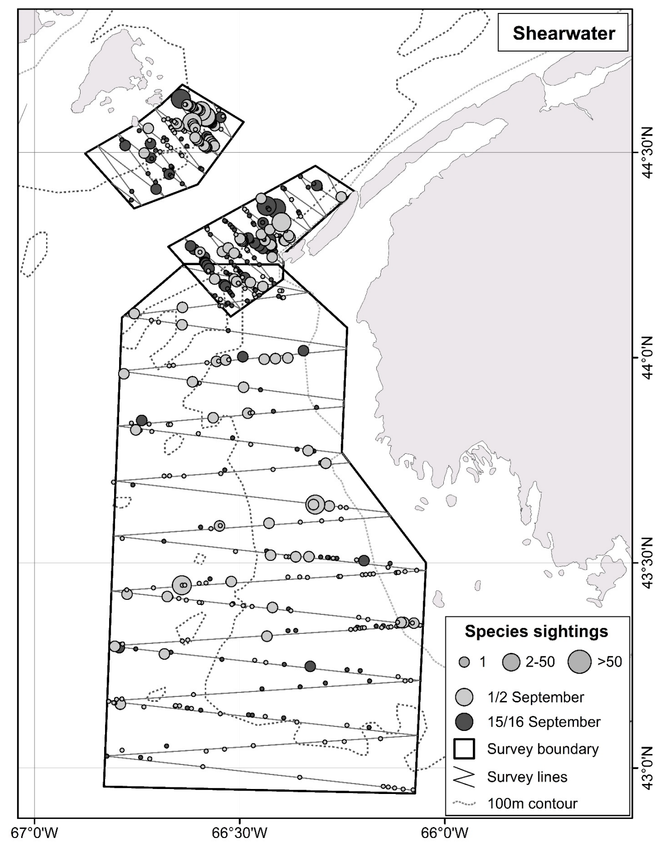

Fig. 7. Raw counts of shearwaters along aerial transect lines during two survey periods (1–2 September, 15–16 September). The three regions are Grand Manan, Brier, and Lurcher (see Fig. 1 for details).

TABLE 2
Summary of best selected detection function models for phalaropes, shearwaters, Northern Gannets, gulls, storm-petrels, and alcids surveyed by airplane in three regions of the Bay of Fundy

Species	n	Key function	Model covariates	Strip-width (m)	Average *p*	SE	% CV
Phalaropes	778	hazard-rate	seastate, behaviour, plane side, region	270	0.29	0.014	4.73
Shearwaters	559	hazard-rate	flock size, observer, plane side, region	470	0.26	<0.001	5.07
Northern Gannet	315	half-normal	observer, plane side, region	470	0.45	0.021	4.73
Gulls	265	half-normal	glare, observer, region	470	0.38	0.019	5.06
Storm-petrels	127	hazard-rate	glare, plane side	270	0.29	0.031	10.49
Alcids	124	hazard-rate	plane side	270	0.36	0.042	11.67

n = number of observations (flocks) used, *p* = detection probability, SE = standard error, % CV = % coefficient of variation.

and goodness-of-fit tests, best fit key functions (i.e., hazard-rate vs. half-normal) of the final selected models were species-specific (Table 2). The percentage coefficient of variation associated with the detection probability (p) was highest for storm-petrels (10.5) and alcids (11.7), which also had the lowest number of observations (Table 2). To improve model fit for the alcid models, we excluded a large flock of 200 individuals (recorded during the first Brier survey) from the detection function models, but added this flock to the estimated total abundance. Inclusion of the large flock resulted in very large confidence intervals and an abundance estimate five times greater than the estimate that excluded the flock, which we deemed unrealistic for this region at this time of year given the relative small breeding population in the area.

Densities of species groups were higher in the Brier and Grand Manan regions than in Lurcher for both survey periods, with the exception of gulls during the later September survey (Table 3). The difference in densities between regions in the lower Bay of Fundy and the southwest coast of Nova Scotia were particularly striking for phalaropes, which had much higher densities in the Brier region (72.6/km^2 and 73.9/km^2 for 2 and 15 September, respectively) and Grand Manan region (87.6/km^2 and 89.1/km^2) than in Lurcher (1.7/km^2 and 1.0/km^2) (Table 3). Density estimates for some species groups changed between survey dates in some regions. For example, densities of shearwaters were highest in the Grand Manan region earlier in September (25.3/km^2), but highest in the Brier region mid-September (12.4/km^2); densities of Northern Gannets increased three-fold between the two survey dates, while densities of alcids declined by nearly half for some regions (Table 3).

Total estimated abundance varied across regions within species groups (Table 4). Phalaropes were most abundant in the Brier and Grand Manan Regions, while Northern Gannets and gulls were most abundant in the Lurcher region for both survey dates (Table 4). However, for some species, regional variation in abundance depended on survey date. For example, higher total abundance of shearwaters was found in Lurcher and Grand Manan in early September, while higher numbers were found in Brier in mid-September (Table 4). Estimated abundance of storm-petrels was highest in Brier in early September, but more evenly distributed across all three regions by mid-September (Table 4). Alcids were most abundant in the Lurcher region during the first survey but, by mid-September, were nearly absent from Lurcher (Table 4).

Finally, overall total abundances of some species groups within all three regions changed considerably between survey periods. By mid-September, shearwater abundance had declined by over 50% (from 31 550 on 1–2 September to 13 565 on 15–16 September), storm-petrel abundance had declined by 40% (2 034 to 1 208), and alcids had declined by over 75% (2 152 to 520) (Table 4). By contrast, estimated abundance of Northern Gannets and gulls increased later in September (Northern Gannets: 1 125 to 3 854, and gulls: 1 855 to 2 843). Total abundance of phalaropes was similar between the two survey dates (104 347 on 1–2 September and 100 696 on 15–16 September), and most of the birds occurred in the Brier and Grand Manan regions (88% in early September and 93% in mid-September).

DISCUSSION

Our results show striking differences in these species' use of the lower Bay of Fundy compared to the southwest coast of Nova Scotia. Densities of seabirds were higher in the Brier and Grand Manan regions than in the Lurcher region, and this finding was consistent across all species (Table 3). Although the study area of Lurcher is much larger than those of Brier and Grand Manan, total abundance estimates were frequently higher in Brier and Grand Manan regions for many species, particularly phalaropes (Table 4). The combination of strong tidal currents and steep bathymetric features in the lower Bay of Fundy leads to large surface aggregations of copepods (Thorne & Read 2013, Buzeta 2014) and other prey (Johnston & Read 2007), resulting in ideal foraging habitat for the large numbers of surface-feeding phalaropes and storm-petrels, and for the fish-eating shearwaters. Although German Bank and Lurcher Shoals encompass well-used herring fishing areas (DFO 2015), little is known about the mechanisms that concentrate prey for seabirds in this area or how prey availability changes seasonally. The majority of herring in the Bay of Fundy and southwest coast of Nova Scotia spawn in the fall (DFO 2015). The distribution and abundance of species known to interact with fishing vessels, such as gulls and shearwaters, may be affected by movements of herring and the seasonal distribution of vessels fishing for the various stocks.

TABLE 3
Density estimates for seabirds surveyed by plane in three regions of the Bay of Fundy, September 2015

Date	Survey region	Individuals/km^2 (SE)					
		Phalaropes	Shearwaters	Northern Gannet	Gulls	Storm-petrels	Alcids
1–2 September	Lurcher	1.71 (0.51)	1.93 (0.42)	0.11 (0.04)	0.12 (0.03)	0.08 (0.03)	0.15 (0.05)
	Brier	72.58 (25.74)	6.03 (2.36)	0.34 (0.14)	0.57 (0.14)	1.64 (0.55)	0.91 (0.28)
	Grand Manan	87.58 (59.46)	25.34 (14.33)	0.18 (0.05)	1.21 (0.51)	0.84 (0.24)	0.45 (0.15)
15–16 September	Lurcher	0.99 (0.31)	0.52 (0.20)	0.40 (0.07)	0.28 (0.08)	0.03 (0.02)	0.01 (0.01)
	Brier	73.91 (23.24)	12.39 (3.63)	0.91 (0.24)	0.26 (0.07)	0.79 (0.46)	0.55 (0.19)
	Grand Manan	89.13 (31.61)	3.80 (1.80)	0.61 (0.14)	1.09 (0.33)	0.95 (0.35)	0.23 (0.08)

Furthermore, our results showed differences in abundance and distribution of seabirds between the two survey periods. The direction of change from early to mid-September in densities and abundance for local breeders differed between alcids and gulls. Alcids nearly disappeared from the study area by mid-September (Table 4), likely as result of migration to offshore wintering areas in the case of Atlantic Puffins and Common Murres (see also Nisbet *et al*. 2013). Although Razorbills aggregate on the Grand Manan Ledges by the tens of thousands in January and February (Huettman *et al*. 2005, Clarke *et al*. 2010), our results indicate that local breeders may leave the Bay of Fundy region in the autumn. (Unfortunately, species identification of alcids was not possible during our aerial surveys.) By contrast, gull abundance increased in mid-September (Table 4), possibly due to an influx of non-breeders. Black-legged Kittiwakes use regions around Grand Manan post-breeding (Huettmann & Diamond 2011), as do Bonaparte's Gulls *Chroicocephalus philadelphia* (Braune & Gaskin 1982). Great Black-backed Gulls made up a higher proportion of the species composition in the Lurcher region by mid-September (Table 1), perhaps as local breeders moved out of the Bay of Fundy or populations arrived from elsewhere (Gjerdrum & Bolduc 2016).

Between the two survey periods, shearwater and storm-petrel abundance declined by over 55% and 40%, respectively (Table 4). Seabirds that breed in the southern hemisphere, such as shearwaters and Wilson's Storm-petrels, are known to forage in the Bay of Fundy during the austral summer (Brown 1986, Huettmann & Diamond 2011, Nisbet *et al.* 2013), when they occur in large aggregations at upwelling areas and regions of tidal mixing (Brown *et al*. 1981, Brown 1988, Ronconi *et al*. 2010, Powers *et al.* 2017). Telemetry studies suggest that most Sooty and Great shearwaters leave the Bay of Fundy during the first two weeks of September, with some individuals lingering into October and November (Ronconi, unpubl. data), a pattern that would explain the observed decline in abundance by mid-September. Abundance estimates of shearwaters is of particular interest to the identification of EBSAs in the Bay of Fundy. Neither species nests in the bioregion and, despite the fact they could be anywhere in waters off Eastern Canada or the North Atlantic, they aggregate in these regions of the Bay of Fundy. During aerial surveys, Wilson's Storm-petrels could not be distinguished from locally breeding Leach's Storm-petrels. Therefore, the decline in storm-petrel abundance by mid-September may reflect both the autumn departure of Wilson's Storm-petrels from the area (Nisbet *et al.* 2013) to their breeding grounds in the Southern Ocean, which they reach in late fall (Beck & Brown 1972), as well as the post-breeding departure of locally nesting Leach's Storm-petrels. Although we were unable to distinguish species from the aerial surveys, the relatively low density and abundance of storm-petrels across our study areas does, however, agree with recent telemetry studies suggesting that populations of locally breeding Leach's Storm-petrels forage in deeper, offshore waters rather than the shoals surrounding their colonies (Pollet *et al.* 2014).

Seabirds that breed in the northern hemisphere, but not locally, such as Northern Gannets, increased in abundance in mid-September (Table 4). Northern Gannets occur in the Bay of Fundy in the summer (Huettmann & Diamond 2011), and, in recent years, more immatures have been observed in the lower Bay of Fundy (Murison, pers. comm.). However, since Northern Gannets do not typically leave their colonies in Quebec and Newfoundland until October (Fifield *et al*. 2014), the birds observed during September surveys were likely failed breeders or immatures. Of the Northern Gannets observed during our surveys, age class was recorded for 246 individuals, 34% of which were immatures.

Other species observed during the fall surveys that do not breed in the Bay of Fundy region included small numbers of skuas and jaegers (Stercorariidae), which migrate along the Atlantic coast during the autumn (Nisbet *et al.* 2013), and other species

TABLE 4
Summary of abundance estimates for seabirds most commonly recorded in three regions of the Bay of Fundy in September 2015 during aerial surveys

Date	Survey region	Abundance (95% CI) and % CV											
		Phalaropes		**Shearwaters**		**Northern Gannet**		**Gulls**		**Storm-petrels**		**Alcids**	
1–2 September	Lurcher	12 675 (6 903–23 275)	29.8	14 342 (9 170–22 431)	22.0	819 (419–1 600)	33.1	861 (508–1 459)	25.8	570 (273–1 190)	37.0	1 151 (584–2 266)	33.9
	Brier	45 157 (21 777–93 638)	35.5	3 752 (1 695–8 304)	39.1	212 (94–478)	40.1	352 (212–583)	24.7	1 020 (520–2 002)	33.3	765[a] (502-1 255)	31.2
	Grand Manan	46 515 (10 958–197 445)	67.9	13 456 (4 033–44 901)	56.6	95 (54–165)	26.5	642 (249–1 653)	42.3	444 (237–833)	29.1	236 (114–491)	44.5
	Total	104 347 (39 638–314 358)		31 550 (14 898–75 636)		1 125 (567–2 243)		1 855 (969–5 254)		2 034 (1 030–4 025)		2 152 (1 200–4 012)	
15–16 September	Lurcher	7 373 (3 945–13 782)	30.9	3 837 (1 787–8 240)	38.0	2 968 (2 070–4 257)	17.7	2 106 (1 168–3 795)	28.9	210 (64–688)	62.6	53 (9–318)	
	Brier	45 984 (24 030–87 995)	31.4	7 710 (4 274–13 907)	29.2	564 (331–961)	26.1	160 (88–290)	29.1	491 (160–1 507)	57.7	122 (171–696)	35.1
	Grand Manan	47 339 (22 412–99 994)	35.5	2 018 (764–5 332)	47.4	322 (196–529)	23.9	577 (304–1 095)	30.4	507 (239–1 078)	37.0	345 (59–253)	35.9
	Total	100 696 (50 387–201 771)		13 565 (6 825–27 479)		3 854 (2 597–5 747)		2 843 (1 560–5 180)		1 208 (463–3 273)		520 (239–1 267)	

[a] A flock of 200 individuals that was excluded from the analysis, due to poor model fit, was added to this total.

of shearwaters (Manx and Cory's *Calonectris borealis*) (Table 1), which are regularly encountered in low numbers in the Gulf of Maine during the summer (Nisbet *et al.* 2013). Very low encounter rates of cormorants, loons, eiders, and Black Guillemots *Cepphus grylle* were not surprising, since these species are very coastal in their habitat preferences, whereas surveys were designed to detect species that are more pelagic (Table 1).

Density estimates for phalaropes obtained in our study fall well within the range of those reported by Hunnewell *et al.* (2016) based on surveys of the same transects in 2009 and 2010. However, abundance estimates by Hunnewell *et al*. (2016) were made only within the sampled transect area (175 km^2 for Brier, 145 km^2 for Grand Manan), whereas we made estimates over the entire survey area. From late August to mid-September, combined estimates for Brier and Grand Manan on any single survey day ranged from 7 302 to 48 396 individuals in 2009 and from 32 473 to 127 891 individuals in 2010 (Hunnewell *et al.* 2016). If our 2015 density estimates were applied only to the sampled transect areas used by Hunnewell *et al*. (2016), abundance estimates for both Brier and Grand Manan would be in the range of approximately 25 500 for each survey period (1–2 September: 25 404 [9 117–80 244], 15–16 September: 25 859 [12 878–52 051]), values that fall within the 2009 estimates but lower than the 2010 estimates. To capture the inter-annual and intra-seasonal variability in population size that was observed by Hunnewell *et al.* (2016), more surveys within and among years would be required. Searching over a broader area of Lurcher Shoals and German Bank found additional numbers of dispersed phalaropes, but only accounted for 7%–12% of the total estimated population in the three regions during our study. Thus, these low numbers do not account for the reported disappearance of phalaropes from the lower Bay of Fundy (Nisbet & Veit 2015).

CONCLUSION

This study provides the first comprehensive estimates of distribution and abundance of seabirds commonly found in the lower Bay of Fundy and off the southwest coast of Nova Scotia in the autumn, including phalaropes, shearwaters, Northern Gannets, gulls, storm-petrels, and alcids. The abundances for storm-petrels and alcids are likely overestimated, due to the high coefficient of variation in the best models for these species groups, and model plots showing that, for some distance bins, the detection probability was lower than the data would imply (e.g., 20–70 m). However, these abundances represent the best (and only) estimates to date. Overall, Brier Island Ledges and Grand Manan Shoals supported a high abundance of seabirds, most of which are likely associated with tidal upwelling features that concentrate prey at the surface (Brown *et al*. 1981, Johnston & Read 2007, Thorne & Read 2013). Lurcher Shoals and German Bank provided important habitat for some species, such as Northern Gannets, shearwaters, and gulls, at this time of year. The estimated stopover population of phalaropes in the lower Bay of Fundy remains low compared to previous decades, and there is no evidence that they have shifted their distribution to the southwest coast of Nova Scotia (Lurcher Shoals and German Bank). With the recent recognition of Brier Island Ledges and Grand Manan Shoals as ecologically and/or biologically significant (Buzeta 2014), and their classification as Important Bird Areas in Canada (IBA Canada 2017), our abundance estimates and description of seabird composition using these areas in the autumn help to quantify the extent of their importance to breeding and migratory seabird species, locally, regionally, and perhaps internationally, since phalaropes from Europe also stop over in this region (Smith *et al*. 2014).

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