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Seasonal occurrence of waterbirds in Minas Passage, Bay of Fundy, Nova Scotia, Canada, 2010 to 2012

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Abstract

We determined patterns of seasonal abundance and diversity of seabirds and coastal waterfowl in Minas Passage, Bay of Fundy, Nova Scotia, Canada using quantitative, shore-based point surveys from mid-March to late August and mid-October to December 2010 to 2012. This area experiences the world's highest tides and greatest tidal currents. We showed that species and seasonal cycles of waterbirds in Minas Passage reflect patterns typical of the inner Bay of Fundy and the northeast Atlantic coast of North America. The study highlights the importance of Minas Passage as an important local migration pathway for waterbirds including Black Scoter (*Melanitta americana*) and Red-throated Loon (*Gavia stellata*) passing through the Bay of Fundy. Large numbers of sea ducks (Black Scoter, Surf Scoter [*Melanitta perspicillata*], White-winged Scoter (*Melanitta fusca*), and Long-tailed Duck [*Clangula hyemalis*]), and Red-throated Loon were observed at the site in spring and fall, corresponding to known peak movements elsewhere in the Bay of Fundy. Fewest species and smallest abundances of waterbirds overall occurred in summer and early winter, while most species and largest abundances occurred in April-May and early November. Of the 46 species observed, resident breeders such as Herring Gull (*Larus argentatus*), Great Black-backed Gull (*Larus marinus*), Common Eider (*Somateria mollissima*), Black Guillemot (*Cepphus grylle*), and Double-crested Cormorant (*Phalacrocorax auritus*), were most abundant in spring to early summer during breeding and migrants including Red-throated Loon, Black Scoter, Ring-billed Gull (*Larus delawarensis*), Surf Scoter, and Northern Gannet (*Morus bassanus*) occurred in moderate numbers during migration periods.

Key words: Waterbirds; shorebirds; seabirds; abundance; seasonal cycles; Bay of Fundy; Minas Passage; Nova Scotia

Introduction

Waterbirds—seabirds, waterfowl, waders, and shorebirds—are important higher-trophic-level organisms in the Bay of Fundy, Nova Scotia, Canada, the site of the world's highest tides (Hicklin and Smith 1984a; EPRI 2005; Karsten *et al.* 2008; Mills and Laviolette 2011). Longstanding interest in tidal energy development in the Bay of Fundy focussed attention on potential effects on the environment, in particular in the southeastern arm of the inner Bay of Fundy where Minas Passage, a narrow strait, connects Minas Channel and Minas Basin, a semi-enclosed tidal bay (Figure 1). Minas Passage is occupied throughout the year by various seabird, waterfowl, wader, and shorebird species.

Recently, the ecological significance of Minas Passage and Minas Basin has been recognized by their inclusion in the proposed new Ecologically and Biologically Significant Area (EBSA)—the Evangeline-Blomidon-Minas Basin EBSA—under the Canadian *Oceans Act* (Buzeta 2014; DFO 2018). This designation recognizes, in part, the importance of the area for shorebirds and coastal raptors such as Peregrine Falcon (*Falco peregrinus anatum*). Avifauna in Minas Basin and adjacent areas of the inner Bay of Fundy was comparatively poorly studied until the 1970s when the inner Bay of Fundy mudflats were recognized as important stopovers for transoceanic shorebird migrations (McNeil and Burton 1977), and interest in tidal power development led to increased scientific attention (Daborn 1977; Hughson 1977; Morrison 1977; Hicklin and Smith 1984a,b; Hicklin 1987). More recently, studies have increased the overall knowledge of waterbirds in both the inner bay and in the Bay of Fundy as a whole (e.g., Lock *et al.* 1994; Dietz and Chiasson 2000; Bond *et al.* 2007; Mills and Laviolette 2011; Cotter *et al.* 2012; Allard *et al.* 2014; Cameron 2014; MacKinnon and Kennedy 2014; Wong *et al.* 2018). Many of these studies focussed on particular species (e.g., shorebirds; Hicklin 1987) or

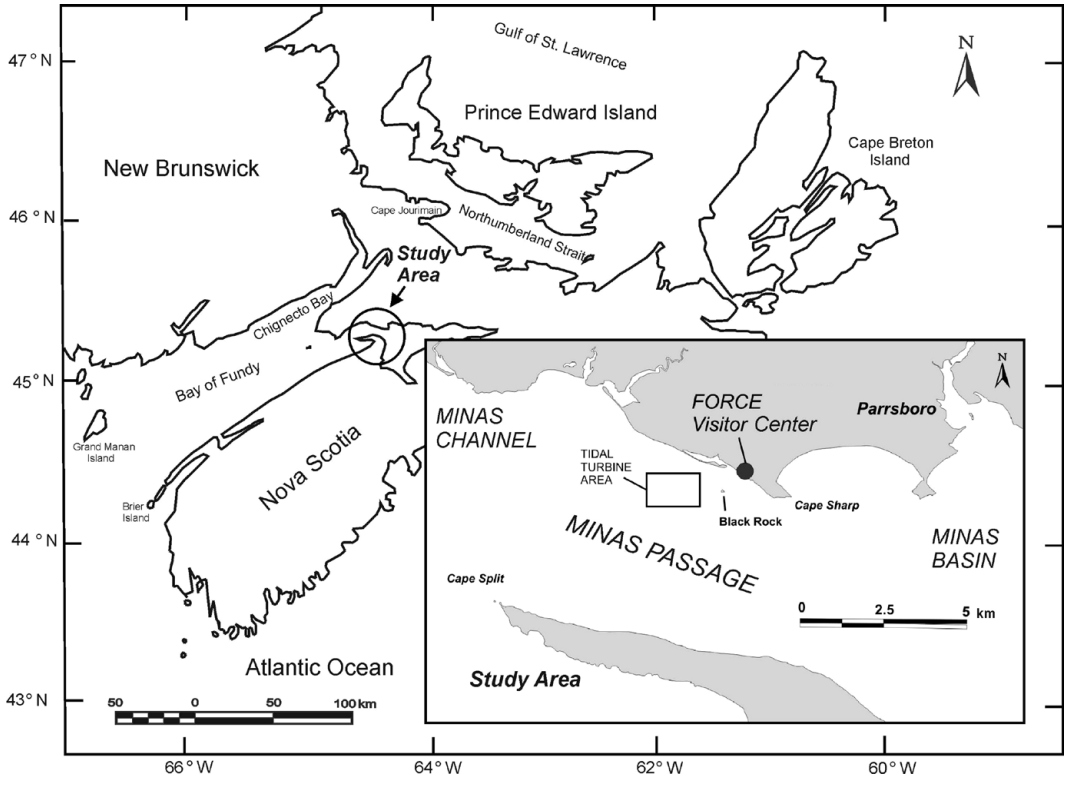

FIGURE 1. Study area for shore-based surveys for waterbirds in Minas Passage, 2010 to 2012.

seasonal migrations (e.g., Cameron 2014).

We report on baseline studies required for regulatory approvals of tidal energy development at Nova Scotia's first tidal energy demonstration site (Fundy Ocean Research Center for Energy, FORCE). These included quantitative observations of abundance, diversity, and behaviour of waterbirds in spring, summer, and fall to early winter, i.e., throughout most of the year, a perspective which is not typically available. These observations could then be used for assessing and managing risks of tidal energy development. The FORCE site is located at Black Rock near Cape Sharp in Minas Passage near Parrsboro, Nova Scotia (Figure 1), where the strongest tidal currents occur (EPRI 2005; Karsten *et al.* 2008). Such studies are also useful for establishing long-term trends in abundance, distribution, and migratory patterns of waterbirds, and for determining impacts of environmental changes such as global warming and impacts of other human activities and natural events (Votier *et al.* 2005; Sydeman *et al.* 2012; Paleczny *et al.* 2015).

Methods

From 2010 to 2012, FORCE undertook a series of 19, 6 h/day shore-based, spring-to-late summer, and late-fall to early-winter surveys at the Minas Passage site. Six to seven surveys were conducted each year, focussed on particular periods (late spring to early summer and late fall in 2010, early spring and early winter in 2011, and summer in 2012) deliberately omitting winter and late summer to reduce effort when abundance and diversity was expected to be low. Observations were conducted from approximately noon to 1800 on days with a high tide around noon and coinciding with the transition from high to low ebb tide. This schedule resulted in 12, 30 min observation periods each day except for 1 May and 22 November 2010 that had 11 periods. Fixing the survey timing in relation to tidal and daylight cycles (i.e., beginning at high tide near noon) ensured consistent conditions of tide and time of day to reduce some of the variability due to environmental factors.

Observations were made either from the beach berm (4 m above mean high water, used in 2010 only), or the FORCE Visitor Center (45.3702°N, 64.4037°W, 22 m above mean high water) which gives an unobstructed view for about 5 km across Minas Passage (Figure 1) and a panoramic view including Cape Split (Figures 1 and 2). Black Rock, a basalt island ~85×25 m at high tide, is a prominent physical feature ~650

Figure 2. View of study area in Minas Passage from observation location (FORCE Visitor Center), showing Black Rock and Cape Split. Photo: Patrick Stewart.

m from shore and is a nesting, resting, and aggregation site for some species. A broad, steeply-sloping gravel beach flat occupies the intertidal zone extending seaward for ~100 m from an alongshore barrier beach berm.

Surveys were coordinated by P.L.S. with principal observer F.L.L. and field assistants P.L.S. in 2010 or Matthew MacLean in 2011 and 2012. The observer used a tripod-mounted, 22× spotting scope and 10×42 binoculars, and had previous experience with, and could confidently identify, all the birds encountered. For the first five minutes of each 30 min period, the observer scanned the entire study area. For the rest of the period, birds entering or moving through the area were noted, providing an estimate of the number observed in each 30 min period. All birds in the designated survey area, flying or on the water, including those on Black Rock were included.

The average count of each species per 30 min period based on 11 to 12 periods on a given day was used to summarize bird occurrence during each survey. Average counts do not distinguish among species normally seen as individuals, versus those typically occurring in groups, or the frequency of occurrence during the day; many of the birds were seen in only a single 30 min period during the day. Survey timing was arranged to ensure suitable viewing weather conditions (wind, rain, fog, glare, etc.) as recommended in standard survey protocols (e.g., Gjerdrum *et al.* 2012).

Reports on the seabird monitoring studies in Minas Passage are presented on the FORCE website (https://fundyforce.ca/). Kruskal-Wallace non-parametric analysis of variance (Systat 5.0; Systat Software Inc. 1990) was used to compare the number of species occurring among seasons.

Results

Dominant species and seasonality

Forty-six species of seabirds, waterfowl, and shorebirds occurred at the study site (Table 1). Herring Gull (*Larus argentatus*), Great Black-backed Gull (*Larus marinus*), and Common Eider (*Somateria mollissima*) were observed in all surveys, while Black Guillemot (*Cepphus grylle*), Common Loon (*Gavia immer*), and Red-throated Loon (*Gavia stellata*) were each seen in 16 surveys (84.2%) and Double-crested Cormorant (*Phalacrocorax auritus*) and Great Cormorant (*Phalacrocorax carbo*) in 14 surveys (Table 1).

TABLE 1. Counts of waterbirds (average per 30 min) and (SD), May 2010 to August 2012, Minas Passage, Nova Scotia, Canada. Blank cells represent zero counts. Species are arranged alphabetically by common name in taxonomic order from Clements *et al.* (2019).

Species	Survey date																		
	1-May-2010	13-May-2010	27-May-2010	12-Jun-2010	23-Oct-2010	13-Nov-2010	22-Nov-2010	16-Mar-2011	31-Mar-2011	15-Apr-2011	30-Apr-2011	2-Dec-2011	13-Dec-2011	21-Jun-2012	4-Jul-2012	18-Jul-2012	2-Aug-2012	15-Aug-2012	29-Aug-2012
Ducks, geese, swans, and mergansers (Anseriformes)																			
Diving ducks and bay ducks (Anatidae, Athyinae)																			
Black Scoter (*Melanitta americana*)					0.92 (2.87)	0.08 (0.29)		0.58 (1.38)	1.17 (2.12)	12.75 (20.37)	6.75 (9.44)		0.25 (0.45)						
Common Eider (*Somateria mollissima*)	3.45 (4.78)	1.83 (1.47)	2.50 (2.61)	12.75 (4.49)	2.83 (4.20)	5.58 (7.06)	0.27 (0.90)	1.42 (2.64)	0.75 (1.54)	4.75 (4.31)	2.83 (4.04)	0.33 (0.78)	0.67 (0.49)	13.42 (7.14)	8.08 (5.18)	0.58 (1.00)	2.08 (3.29)	0.58 (0.90)	0.17 (0.58)
Common Goldeneye (*Bucephala clangula*)								0.25 (0.86)											
Harlequin Duck (*Histrionicus histrionicus*)				0.17 (0.39)	0.58 (1.73)														
King Eider (*Somateria spectabilis*)											0.08 (0.29)								
Long-tailed Duck (*Clangula hyemalis*)					0.42 (0.79)	0.17 (0.58)	0.09 (0.30)			7.75 (12.45)	0.08 (0.29)	0.25 (0.87)	0.25 (0.87)						
Scoter unidentified									0.17 (0.58)		0.08 (0.29)								
Surf Scoter (*Melanitta perspicillata*)	0.27 (0.90)				0.42 (1.44)	0.33 (1.15)		0.25 (0.87)	0.25 (0.87)	4.76 (10.48)	7.58 (14.41)		0.75 (1.54)						
White-winged Scoter (*Melanitta fusca*)		0.33 (1.15)			0.25 (0.62)	0.25 (0.62)	0.45 (1.51)	0.67 (0.49)	0.67 (0.65)	0.33 (1.15)	0.42 (1.44)	0.83 (0.39)	0.58 (0.67)						
Dabbling ducks (Anatidae, Anatinae)																			
American Black Duck (*Anas rubripes*)		0.17 (0.58)			1.50 (4.34)	0.58 (1.38)	0.09 (0.30)	1.08 (2.19)	2.92 (3.82)	0.50 (1.17)	0.08 (0.29)	0.17 (0.58)	0.25 (0.87)						
Mallard (*Anas platyrhynchos*)					0.17 (0.58)														
Northern Shoveler (*Anas clypeata*)										0.08 (0.29)									
Geese (Anatidae, Anserinae)																			
Canada Goose (*Branta canadensis*)					0.08 (0.29)			6.25 (11.89)	1.25 (4.33)										

TABLE 1. *Continued.*

Species	Survey date																		
	1-May-2010	13-May-2010	27-May-2010	12-Jun-2010	23-Oct-2010	13-Nov-2010	22-Nov-2010	16-Mar-2011	31-Mar-2011	15-Apr-2011	30-Apr-2011	2-Dec-2011	13-Dec-2011	21-Jun-2012	4-Jul-2012	18-Jul-2012	2-Aug-2012	15-Aug-2012	29-Aug-2012
Mergansers (Anatidae, Merginae)																			
Common Merganser (*Mergus merganser*)					0.33 (1.15)	0.42 (1.00)							0.67 (1.56)						
Red-breasted Merganser (*Mergus serrator*)	0.09 (0.30)				0.08 (0.29)	1.17 (1.59)	0.09 (0.30)	0.25 (0.45)	0.17 (0.39)	0.25 (0.87)	0.50 (1.17)	0.08 (0.29)	0.33 (0.78)						0.17 (0.58)
Grebes (Podicipediformes)																			
Horned Grebe (*Podiceps auratus*)						0.25 (0.62)	0.09 (0.30)					0.08 (0.29)							
Red-necked Grebe (*Podiceps grisegena*)					0.25 (0.87)	0.08 (0.29)													
Sandpipers, plovers, gulls, auks, and allies (Charadriiformes)																			
Sandpipers and allies (Scolopacidae)																			
Greater Yellowlegs (*Tringa melanoleuca*)																			0.08 (0.29)
Red Phalarope (*Phalaropus fulicarius*)																			0.08 (0.29)
Red-necked Phalarope (*Phalaropus lobatus*)																			2.08 (7.22)
Ruddy Turnstone (*Arenaria interpres*)																	0.08 (0.29)		
Sanderling (*Calidris alba*)																	1.25 (3.19)		
Semipalmated Sandpiper (*Calidris pusilla*)																0.08 (0.29)	0.08 (0.29)		
Spotted Sandpiper (*Actitis macularius*)																	0.17 (0.58)		
Auks, murres, and puffins (Alcidae)																			
Alcid unidentified										0.08 (0.29)									
Atlantic Puffin (*Fratercula arctica*)						0.92 (1.37)	0.09 (0.30)												

TABLE 1. *Continued.*

Species	Survey date																		
	1-May-2010	13-May-2010	27-May-2010	12-Jun-2010	23-Oct-2010	13-Nov-2010	22-Nov-2010	16-Mar-2011	31-Mar-2011	15-Apr-2011	30-Apr-2011	2-Dec-2011	13-Dec-2011	21-Jun-2012	4-Jul-2012	18-Jul-2012	2-Aug-2012	15-Aug-2012	29-Aug-2012
Black Guillemot (*Cepphus grylle*)	3.18 (2.71)	1.08 (2.02)	3.75 (2.18)	2.83 (2.25)	0.08 (0.29)	0.83 (1.27)	0.27 (0.47)	0.25 (0.45)	0.50 (1.24)	2.33 (1.87)	1.83 (1.80)	0.25 (0.62)	0.08 (0.29)	3.42 (3.34)	6.58 (3.00)	2.50 (3.40)	1.92 (3.06)	0.58 (0.79)	
Common Murre (*Uria aalge*)						0.17 (0.58)	0.18 (0.60)				0.58 (1.50)								
Razorbill (*Alca torda*)	0.55 (1.81)					1.92 (3.75)	3.55 (7.05)				0.75 (1.76)	0.08 (0.29)							
Thick-billed Murre (*Uria lomvia*)							0.09 (0.30)				0.08 (0.29)								
Gulls, terns, and skimmers (Laridae)																			
Black-legged Kittiwake (*Rissa tridactyla*)					0.08 (0.29)	3.67 (10.20)	1.00 (2.32)	0.17 (0.39)				0.25 (0.62)	0.17 (0.39)						
Black Tern (*Chlidonias niger*)															0.08 (0.29)				
European Common Gull (*Larus canus*)						0.08 (0.29)													
Great Black-backed Gull (*Larus marinus*)	24.27 (3.17)	22.5 (4.56)	23.42 (5.55)	22.25 (4.90)	3.50 (8.02)	0.17 (0.39)	0.18 (0.40)	17.58 (5.87)	19.83 (8.32)	16.67 (6.85)	20.50 (6.33)	0.83 (2.04)	0.08 (0.29)	18.33 (6.46)	8.42 (3.20)	3.92 (2.31)	0.50 (0.90)	0.33 (0.89)	0.08 (0.29)
Herring Gull (*Larus argentatus*)	10.0 (4.17)	11.17 (6.75)	19.58 (7.01)	22.67 (8.52)	2.00 (1.21)	5.17 (6.56)	6.00 (6.00)	2.00 (1.76)	3.75 (4.02)	2.17 (1.27)	6.25 (2.77)	2.33 (3.05)	0.67 (1.07)	32.17 (13.13)	7.50 (2.15)	7.25 (3.28)	4.42 (3.40)	5.00 (4.49)	5.17 (5.44)
Iceland Gull (*Larus glaucoides*)		0.08 (0.29)	0.08 (0.29)										0.08 (0.29)						
Laughing Gull (*Leucophaeus atricilla*)				0.08 (0.29)															
Lesser Black-backed Gull (*Larus fuscus*)		0.08 (0.29)	0.08 (0.29)		0.08 (0.29)				0.08 (0.29)										
Ring-billed Gull (*Larus delawarensis*)					1.58 (1.50)	2.08 (3.15)	1.09 (1.70)		0.92 (2.02)	0.08 (0.29)		0.42 (0.67)	0.33 (0.89)	0.58 (1.73)			0.75 (1.05)	7.67 (10.97)	1.17 (1.75)
Loons (Gaviiformes)																			
Common Loon (*Gavia immer*)	0.45 (0.68)		1.08 (1.68)	0.25 (0.62)	0.42 (0.67)	0.58 (0.90)	0.09 (0.30)		0.17 (0.39)		0.42 (0.67)	0.25 (0.45)	0.42 (0.51)	0.25 (0.62)	0.25 (0.62)	0.25 (0.45)	1.58 (2.81)	0.58 (0.90)	0.08 (0.28)
Pacific Loon (*Gavia pacifica*)	0.27 (0.47)		0.08 (0.29)	0.08 (0.29)		0.17 (0.58)			0.08 (0.29)				0.08 (0.29)		0.17 (0.58)		0.58 (1.00)		

TABLE 1. *Continued.*

Species	Survey date																		
	1-May-2010	13-May-2010	27-May-2010	12-Jun-2010	23-Oct-2010	13-Nov-2010	22-Nov-2010	16-Mar-2011	31-Mar-2011	15-Apr-2011	30-Apr-2011	2-Dec-2011	13-Dec-2011	21-Jun-2012	4-Jul-2012	18-Jul-2012	2-Aug-2012	15-Aug-2012	29-Aug-2012
Red-throated Loon (*Gavia stellata*)	2.27 (3.66)	0.25 (0.87)	2.83 (1.64)	0.17 (0.39)	0.58 (1.16)	31.67 (39.66)	6.82 (6.53)		0.42 (0.67)	3.42 (6.39)	7.42 (6.61)	2.33 (2.31)	0.83 (2.59)	0.33 (0.65)	3.33 (6.20)		0.17 (0.39)		0.08 (0.29)
Petrels, shearwaters, albatrosses, and diving petrels (Procellariformes)																			
Shearwaters and petrels (Procellariidae)																			
Cory's Shearwater (*Calonectris diomedea*)																			0.08 (0.28)
Great Shearwater (*Ardenna gravis*)														0.25 (0.87)			0.08 (0.29)		0.75 (1.54)
Sooty Shearwater (*Ardenna grisea*)																			0.83 (2.89)
Frigatebirds, boobies, and cormorants (Suliformes)																			
Boobies and Gannets (Sulidae)																			
Northern Gannet (*Morus bassanus*)		2.17 (3.64)	0.83 (1.80)	3.08 (3.75)		0.17 (0.38)				0.50 (0.90)	1.75 (2.67)			0.08 (0.29)	0.08 (0.29)	2.42 (8.06)	0.42 (0.90)	0.17 (0.39)	
Cormorants and shags (Phalacrocoracidae)																			
Double-crested Cormorant (*Phalacrocorax auratus*)	1.45 (1.92)	0.33 (0.49)	1.92 (2.27)	4.50 (2.15)	0.33 (0.49)	0.58 (0.90)				0.42 (1.44)	24.17 (3.38)			0.83 (1.27)	1.92 (1.38)	0.58 (0.51)	1.58 (2.91)	1.00 (0.74)	0.33 (1.15)
Great Cormorant (*Phalacrocorax carbo*)	1.00 (0.63)	0.08 (0.29)	0.58 (0.51)	1.08 (0.67)	0.08 (0.29)	0.17 (0.39)			0.17 (0.58)	1.17 (2.33)	0.75 (1.21)	0.08 (0.29)		0.08 (0.29)	0.08 (0.29)	0.42 (0.51)			0.67 (1.15)
Number of periods	11	12	12	12	12	12	11	12	12	12	12	12	12	12	12	12	12	12	12
Combined counts / 30 min	47.3 (9.7)	40.1 (11.3)	56.8 (11.8)	69.8 (16.0)	16.6 (12.3)	57.3 (43.6)	20.5 (10.8)	30.8 (13.8)	33.3 (15.5)	57.8 (34.9)	82.9 (23.0)	8.6 (4.0)	6.5 (4.4)	69.8 (16.0)	37.3 (9.4)	18.0 (12.1)	15.7 (10.3)	16.2 (13.2)	11.8 (12.2)
Number of species	12	12	12	9	23	25	17	12	16	16	19	15	17	9	11	8	14	8	14

Highest combined counts (average per 30 min) of all birds at the site occurred in April to mid-June and mid-November 2010 reflecting regional migration patterns, while the lowest numbers were seen in early winter (December 2011) and late summer (mid-July to late August 2012; Table 1, Figure 3). As a group, resident species (those that breed in and around the Bay of Fundy) accounted for most sightings year-round (Figure 3). However, during spring and fall, migrants (that occur seasonally but do not typically breed), particularly sea ducks (scoters and Long-tailed Duck [*Clangula hyemalis*]) and Red-throated Loon passed through (Table 1, Figures 4 and 5). As well, in late summer to fall, Ring-billed Gull (*Larus delawarensis*) moved into the area in moderate numbers (Table 1, Figure 6). Peak numbers of Black Scoter (*Melanitta americana*) and Surf Scoter (*Melanitta perspicillata*) and smaller numbers of White-winged Scoter (*Melanitta fusca*) were recorded in two mid-to-late April 2011 surveys, and a smaller late-fall, early-winter peak was also observed (Table 1, Figure 4). Great Black-backed Gull and Herring Gull were usually most numerous, but Double-crested Cormorant, Red-throated Loon, and Black Scoter were as or more abundant during migration. Peak counts of Herring Gull and Great Black-backed Gull were observed from early May to mid-to-late June 2010 (Table 1, Figure 6), with Great Black-backed Gull dominating in early spring and Herring Gull at other times of year (Table 1, Figure 6).

Common Eider and American Black Duck (*Anas rubripes*), which both breed in the Bay of Fundy, were seen in late winter to early spring (mid-December and mid-to-late March 2011), occasionally with migrating White-winged Scoter, Surf Scoter, Black Scoter, and Red-breasted Merganser (*Mergus serrator*; Table 1, Figures 4 and 7). Counts of both cormorant species peaked in April to mid-June 2010 and were low in late summer and early fall (Table 1, Figure 8). Migrant sea ducks predominated in mid-to-late April 2011, mainly Black Scoter, Surf Scoter, and Long-tailed Duck, but including Common Eider, White-winged Scoter, and Red-throated Loon (Table 1, Figures 4 and 5), and Double-crested Cormorant made up a third of counts (29%) in late April 2011 (Table 1, Figure 8). Combined counts (average per 30 min) remained relatively high in late spring to mid-June, mostly due to Herring Gull and Great Black-backed Gull (Table 1, Figure 6), with other resident species including Common Eider, Black Guillemot, Double-crested Cormorant, and Great Cormorant contributing (Table 1, Figures 4, 8, and 9). Black Guillemot was common and seasonally abundant, occurring in 18 surveys (94.7%) from mid-March to December, with largest counts from May to late July, reflecting nesting observed on Black Rock and post-breeding aggregation (Table 1, Figure 9). Common Eider occurred in most surveys (18 surveys, 94.7%; Table 1), with peak abundance in early summer coincident with breeding and post-breeding occupation and a smaller peak in fall presumed to include both resident and migrant birds (Table 1, Figure 4). Red-throated Loon was an occasionally abundant and frequent visitor (16 of 19 surveys, 84.2%; Table 1). High numbers passed through the site during spring migration (mid-April to early May) and in late fall (mid-to-late November; Table 1, Figure 5).

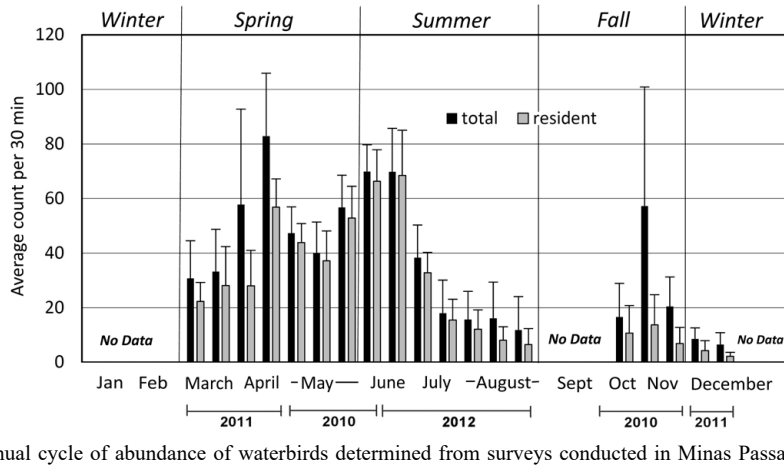

FIGURE 3. Annual cycle of abundance of waterbirds determined from surveys conducted in Minas Passage, Nova Scotia, presented as average counts (+ SD) per 30 min. Year in which each survey was conducted is presented at the bottom of the figure. Supporting abundance data are presented in Table 1. Resident species = Great Black-backed Gull (*Larus marinus)*, Herring Gull (*Larus argentatus*), Double-crested Cormorant (*Phalacrocorax auritus*), Great Cormorant (*Phalacrocorax carbo*), Black Guillemot (*Cepphus grylle*), Common Eider (*Somateria mollissima*), Common Loon (*Gavia immer*), and American Black Duck (*Anas rubripes*).

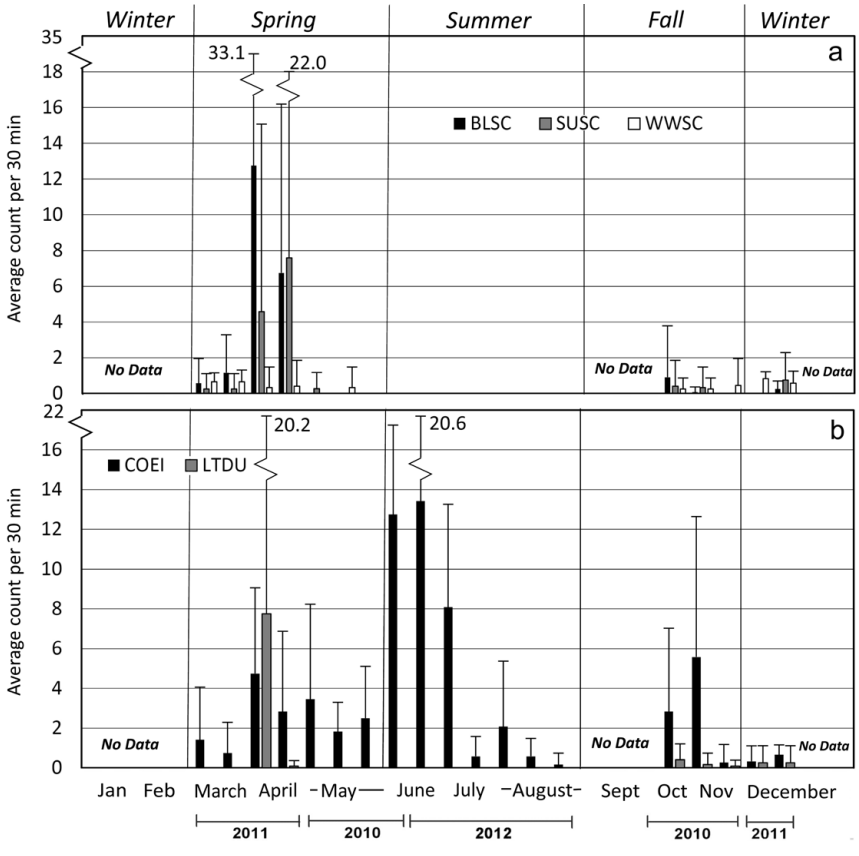

FIGURE 4. Annual cycle of abundance of predominant sea ducks determined from surveys conducted in Minas Passage, Nova Scotia, presented as average counts (+ SD) per 30 min. Year in which each survey was conducted is presented at the bottom of the figure. Supporting abundance data are presented in Table 1. Illustrated are: a. Black Scoter (*Melanitta americana*, BLSC), Surf Scoter (*Melanitta perspicillata*, SUSC), and White-winged Scoter (*Melanitta fusca*, WWSC); and b. Common Eider (*Somateria mollissima*, COEI) and Long-tailed Duck (*Clangula hyemalis*, LTDU).

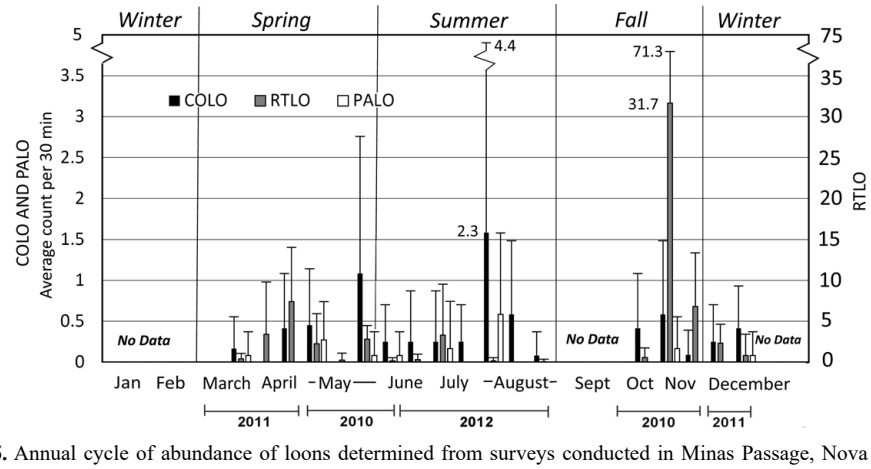

FIGURE 5. Annual cycle of abundance of loons determined from surveys conducted in Minas Passage, Nova Scotia, presented as average counts (+ SD) per 30 min. Year in which each survey was conducted is presented at the bottom of the figure. Supporting abundance data are presented in Table 1. Illustrated are Common Loon (*Gavia immer*, COLO), Red-throated Loon (*Gavia stellata*, RTLO), and Pacific Loon (*Gavia pacifica*, PALO).

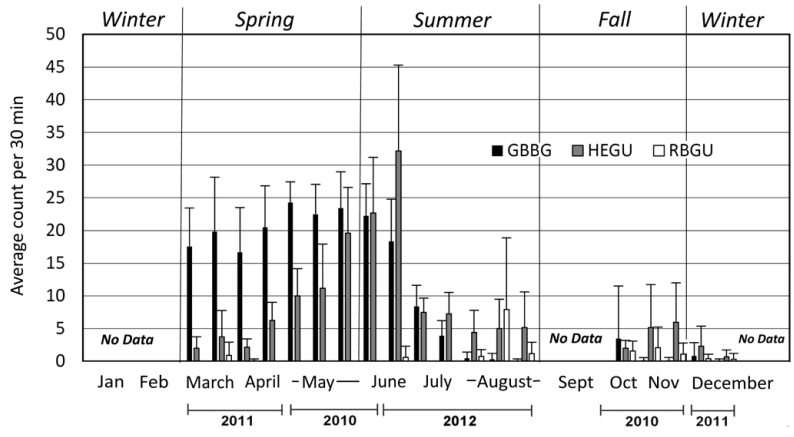

FIGURE 6. Annual cycle of abundance of predominant gulls determined from surveys conducted in Minas Passage, Nova Scotia, presented as average counts (+ SD) per 30 min. Year in which each survey was conducted is presented at the bottom of the figure. Supporting abundance data are presented in Table 1. Illustrated are Great Black-backed Gull (*Larus marinus*, GBBG), Herring Gull (*Larus argentatus*, HEGU), and Ring-billed Gull (*Larus delawarensis*, RBGU).

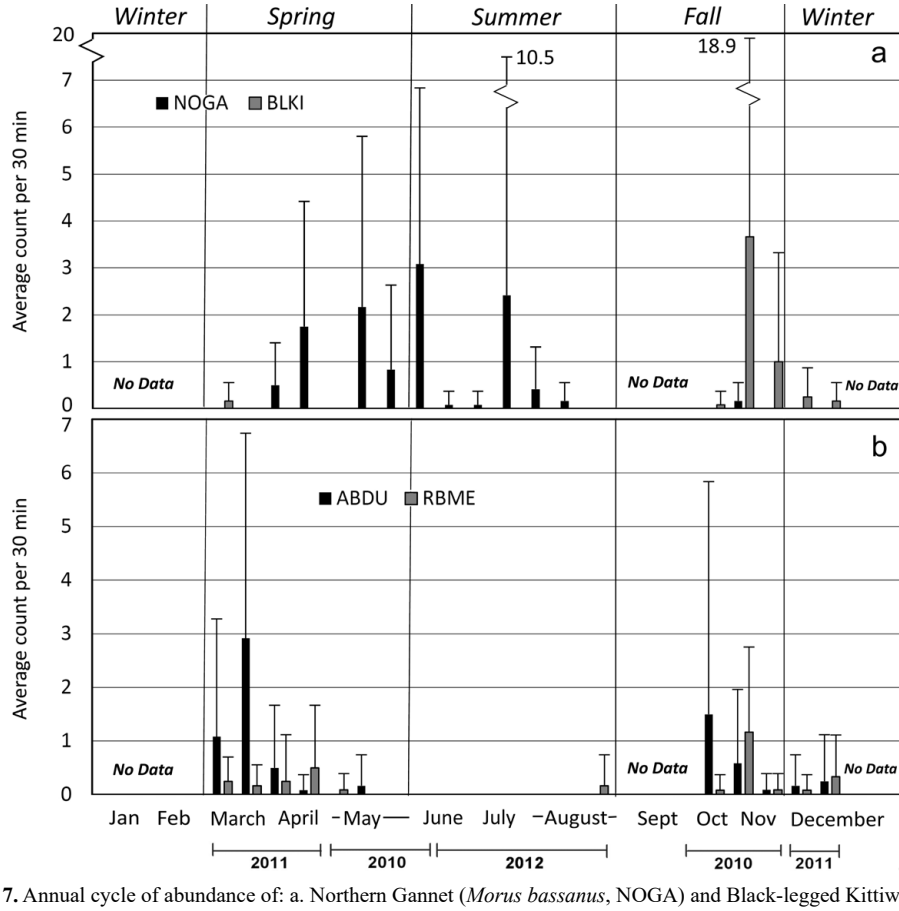

FIGURE 7. Annual cycle of abundance of: a. Northern Gannet (*Morus bassanus*, NOGA) and Black-legged Kittiwake (*Rissa tridactyla*, BLKI); and b. American Black Duck (*Anas rubripes*, ABDU) and Red-breasted Merganser (*Mergus serrator*, RBME) in Minas Passage, Nova Scotia, presented as average counts (+ SD) per 30 min. Year in which each survey was conducted is presented at the bottom of the figure. Supporting abundance data are presented in Table 1.

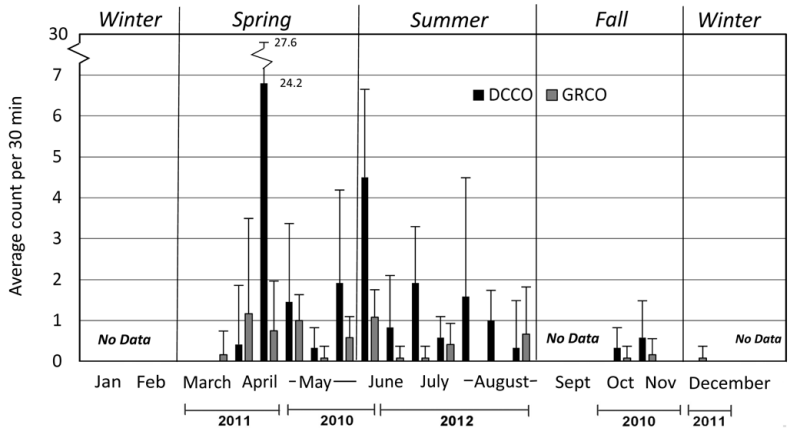

FIGURE 8. Annual cycle of abundance of cormorants determined from surveys in Minas Passage, Nova Scotia, presented as average counts (+ SD) per 30 min. Year in which each survey was conducted is presented at the bottom of the figure. Supporting abundance data are presented in Table 1. Illustrated are Double-crested Cormorant (*Phalacrocorax auritus*, DCCO) and Great Cormorant (*Phalacrocorax carbo*, GRCO).

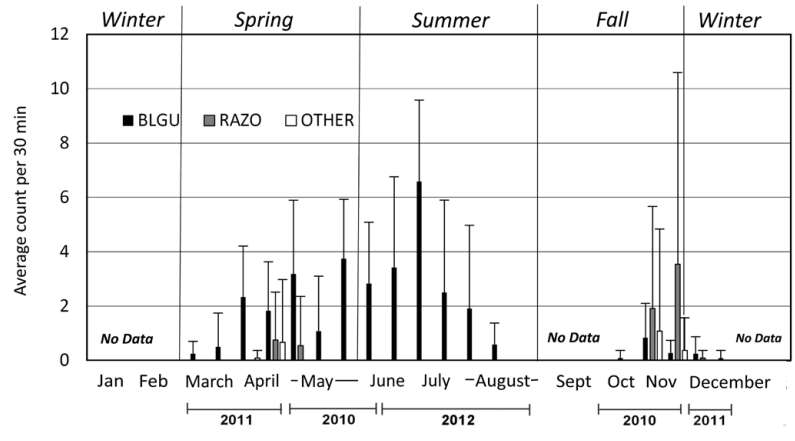

FIGURE 9. Annual cycle of abundance of alcids determined from surveys in Minas Passage, Nova Scotia, presented as average counts (+ SD) per 30 min. Year in which each survey was conducted is presented at the bottom of the figure. Supporting abundance data are presented in Table 1. Illustrated are Black Guillemot (*Cepphus grylle*, BLGU), Razorbill (*Alca torda*, RAZO), and OTHER (Common Murre [*Uria aalge*], Thick-billed Murre [*Uria lomvia*], and Atlantic Puffin [*Fratercula arctica*]).

Common Loon occurred in low numbers on most surveys (16 of 19, 84.2%), and Pacific Loon (*Gavia pacifica*) was seen in eight surveys (42%; Table 1, Figure 5). Northern Gannet (*Morus bassanus*) occurred occasionally (11 surveys, 57.9%), chiefly from late April to mid-July (Table 1, Figure 7).

Combined counts (average per 30 min) were low from mid-June to late August (Figure 3), mainly due to the same resident species as in early summer, but both Black Guillemot and Great Black-backed Gull showed reduced numbers in mid-to-late August 2012 (Table 1, Figures 6 and 9), and Ring-billed Gull moved into the area in mid-August (Figure 6). Several species of shorebirds in August 2012 also contributed to combined counts at that time (Table 1). North-south migrants appeared in late-fall to early-winter surveys in 2010 with a peak in late November, mainly Red-throated Loon but including Red-breasted Merganser, Common Merganser (*Mergus merganser*), and Common Eider (Table 1, Figures 4, 5, and 7). Red-breasted Merganser occurred commonly in low numbers (11 surveys, 57.9% of surveys), and was most abundant in early-spring and late-fall to early-winter surveys in 2011 and 2010, respectively (Table 1, Figure 7). Common Merganser occurred only occasionally in late fall to early winter (five surveys; Table 1). Low,

early-December numbers included Common Eider and Red-throated Loon (Table 1, Figures 4 and 5).

Miscellaneous seabirds, shorebirds and waterfowl

Various other species occurred in smaller numbers or were infrequently recorded at the site. Alcids are an important group occurring in the Bay of Fundy, and apart from Common Guillemot, which was the predominant alcid species at the site, Common Murre (*Uria aalge*), Razorbill (*Alca torda*), Thick-billed Murre (*Uria lomvia*), and Atlantic Puffin (*Fratercula arctica*) occurred occasionally, mainly in spring (late April and early May) and late fall to early winter (Table 1). Razorbill occurred both in spring 2010–2011 and mid-to-late November 2010 (Table 1, Figure 9), while Atlantic Puffin were seen only in mid-to-late November 2010 (Table 1).

Among less common and abundant gulls, Black-legged Kittiwake (*Rissa tridactyla*) was seen at the site from late October to early March (Table 1), mostly as singles but two flocks of nine and 35 individuals were observed on 13 November 2010. Iceland Gull (*Larus glaucoides*), Lesser Black-backed Gull (*Larus fuscus*; seen on four surveys at different times of year), Laughing Gull (*Leucophaeus atricilla*), and European Common Gull or Mew Gull (*Larus canus*; Table 1) also visited the site. A single Black Tern (*Chlidonias niger*) was seen on 4 July 2012 (Table 1).

Three oceanic shearwaters (Cory's Shearwater [*Calonectris diomedea*], Great Shearwater [*Ardenna gravis*], and Sooty Shearwater [*Ardenna grisea*]) were seen at the site in August 2012. These included a single Great Shearwater on 2 August 2012, and all three species on 29 August 2012, which included a single Cory's Shearwater, several singles and a group of four Great Shearwater, and a group of 10 Sooty Shearwater, all seen in one 30 min mid-afternoon observation period (Table 1).

Shorebirds were seen at the site only during surveys in August 2012, including a flock of Ruddy Turnstone (*Arenaria interpres*; 2 August) and a flock of Red-necked Phalarope (*Phalaropus lobatus*; August 29), and individual sightings of Red Phalarope (*Phalaropus fulicarius*), Sanderling (*Calidris alba*), Semipalmated Sandpiper (*Calidris pusilla*), Spotted Sandpiper (*Actitis macularius*), and Greater Yellowlegs (*Tringa melanoleuca*; Table 1).

Waterfowl species occurring occasionally included Northern Shoveler (*Anas clypeata*) and Canada Goose (*Branta canadensis*) in early spring, Common Goldeneye (*Bucephala clangula*; early spring), Mallard (*Anas platyrhynchos*; fall), Horned Grebe (*Podiceps auritus*), and Red-necked Grebe (*Podiceps grisegena*) in late fall to early winter (Table 1). Individual Harlequin Duck (*Histrionicus histrionicus*) were recorded in mid-June and late October 2010 (Table 1). A single King Eider (*Somateria spectabilis*), a rare species in the Bay of Fundy, was seen on 30 April 2011.

Diversity

Spring and fall migration each contributed a large fraction of the 46 species recorded at the site, with 16 to 19 species per 6 h survey in spring (late March to April) and 23 to 25 species (over half of the total) in late fall (late October to early November; Table 1, Figure 10). Fewer species occurred in summer (June to late August; eight to 14) and in early winter (15 to 17; Table 1, Figure 10). Differences among seasons overall were statistically significant (Kruskal Wallace [KW] one-way analysis of variance [ANOVA], P = 0.004), however the number of species in the spring (mid-March to late May, n = 7; which included the

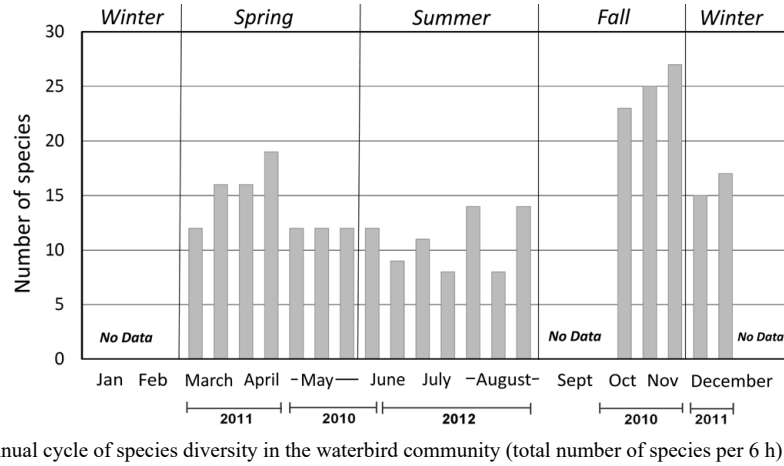

FIGURE 10. Annual cycle of species diversity in the waterbird community (total number of species per 6 h) determined from surveys conducted in Minas Passage, Nova Scotia. Year in which each survey was conducted is presented at the bottom of the figure. Supporting data are presented in Table 1.

spring migration) was not significantly different from the number of species in the summer (June to late August, $n = 7$; KW one-way ANOVA, $P = 0.057$). The number of species observed in late fall to winter (late October to mid-December, $n = 5$) was significantly greater than the numbers observed in both summer and spring (KW one-way ANOVA, $P = 0.004$ and $P = 0.025$, respectively).

Discussion

Role in migration

Minas Passage is an important although comparatively unstudied habitat and migratory route for waterbirds in the inner Bay of Fundy system, which includes Chignecto Bay and Minas Basin. Our study has shown that species and seasonal cycles of waterbirds in Minas Passage reflect patterns generally known for the inner Bay of Fundy and for the northeast Atlantic coast of North America as a whole (e.g., Tufts 1986; Hicklin and Smith 1984a; Mills and Laviolette 2011). Occurrences of large numbers of migratory species in Minas Passage in spring and relatively large numbers in fall demonstrate that the system comprised of Minas Passage, Minas Channel, and Minas Basin forms an important part of the migration pathway for seabirds and waterbirds along the East Coast of North America.

Prominent spring migrants in Minas Passage included sea ducks (Black Scoter, Surf Scoter, White-winged Scoter, and Long-tailed Duck), and Red-throated Loon. The latter was also relatively abundant in our study area in fall, in parallel with peak fall movements of the species in the outer Bay of Fundy (Dietz and Chiasson 2000). Occurrence of peaks in scoter abundance in spring at the study site shows that some scoters from the major March to May northward scoter migration through the Bay of Fundy (Bond *et al*. 2007) and seen in large numbers moving along the north side of the outer Bay of Fundy in spring (Dietz and Chiasson 2000; Bond *et al*. 2007, 2009; MacKinnon and Kennedy 2011; Cameron 2014), pass through Minas Channel and Minas Passage. Bond *et al.* (2007) inferred that some northward-migrating scoters may move along the south side of the Bay of Fundy (which includes our study area), and scoters are commonly seen in spring in outer Minas Channel areas such as Black Rock and Scot's Bay, Kings County, and spring and fall movements of scoters at the FORCE site have subsequently been observed in tidal monitoring surveys in 2017 to 2019 (P.L.S. pers. obs.).

Occurrences of all scoter species, although in lower numbers, at the site in fall suggest that some scoters pass through Minas Passage during the southward migration as well. Fall observation timing in our study coincides with scoter movement for Northumberland Strait (Hicklin and Bunker-Popma 2001) where peak movements in the vicinity of Cape Jourimain, New Brunswick, were observed from mid-October to mid-November.

Common Eider, another migrant through the Bay of Fundy, occurred in spring (i.e., April to May), a time when a strong spring movement typically occurs along the north side of the inner Bay of Fundy (Cameron 2014), and through nearby Chignecto Bay and Tantramar Marsh during April to May (Erskine and Smith 1986; MacKinnon and Kennedy 2011). A similar movement would be indistinguishable in our data from the arrival of locally-breeding birds. Common Eider observed in mid-March are probably local breeders. The species has previously been reported to arrive in Minas Basin in March (Erskine and Smith 1986) and nests in the area (Allard *et al.* 2014). Occurrence of Common Eider in small numbers at the site in two fall surveys (late October and mid-November 2010; Table 1, Figure 4) coincides with the early-October to mid-December southward migration of Common Eider through the northern Bay of Fundy (Erskine and Smith 1986; MacKinnon and Kennedy 2011; Goudie *et al*. 2020). Common Eider have been known to reach Minas Basin during their southerly fall migration (Erskine and Smith 1986), but it does not appear to be a main route, and the birds observed in Minas Passage are likely local breeders moving out of the area.

Occurrences of Long-tailed Duck in some early-spring and late-fall to early-winter surveys coincided with the species' March to early-April northerly East Coast migration (Robertson and Savard 2020). Timing of occurrences of Red-breasted Merganser and Common Merganser reflects typical migration patterns (e.g., Craik *et al*. 2020).

Migration brings a higher species diversity as migrants co-occur briefly with resident species. The highest species diversity in our study was observed during spring and fall migration when waterbirds of various kinds were moving to coastal areas or migrating through. These numbers (16 to 19 and 23 to 25 species in spring and fall surveys, respectively) are comparable to lists from shore-based point surveys conducted during migration periods in 1997 at Cape Jourimain, New Brunswick, on Northumberland Strait, Gulf of St. Lawrence, where 20 and 26 species of waterbirds were observed in spring and fall, respectively (Hicklin and Bunker-Popma 2001). Although both studies showed a similar cross-section of migrating species, they differed in levels of effort (49.8 and 156.0 h in spring and fall respectively, versus 17.5 h in our study) over roughly the same periods in both spring and fall.

Use of the study area by migrating waterbirds may reflect the geography of the Minas Channel-Minas Passage system, causing it to act as geographic trap for birds (see Figure 1). This is similar to the Bay of Fundy as a whole that is a funnel for northerly spring migratory movements of waterbirds and landbirds (Dietz and Chiasson 2000; Mills and Laviolette 2011; Cameron 2014). The tidal current regime in Minas Passage also represents a unique aspect of the site that could draw birds resting on the water into the area, as the tidal excursion, which can be upwards of 20 km, can potentially transport birds on the water significant distances both into and out of the area.

Waterbird community

Relationship to other areas—This study provides a representative list of species for almost the entire year; we did not survey in early fall (September and early October) and mid-to-late winter. Sampling in December and mid-March captured occurrences of many species typically seen in winter, such as most alcids (with the exception of Dovekie [*Alle alle*]) and some waterfowl including Harlequin Duck which overwinter in the Bay of Fundy (Dietz and Chiasson 2000). The 46 species recorded represent about a third of waterbirds likely to occur in the Bay of Fundy, based on 154 species of waterbirds in the list for Brier Island (Mills and Laviolette 2011). Moderate diversity compared with the outer Bay of Fundy is consistent with the opinion of Hicklin and Smith (1984a) who suggested that diversity and abundance in mid-portions of the Bay of Fundy are likely to be lower than Minas Basin mudflats and marshes, and the outer Bay of Fundy upwelling areas between Brier Island and Grand Manan.

Gulls—Presence of Herring Gull and Great Black-backed Gull year-round and timing of peak counts was coincident with the breeding period in the area (e.g., MacKinnon and Kennedy 2014). Both species sometimes nest on Black Rock, and lower numbers in late summer and fall suggest a movement by both species away from nesting sites post-breeding to other offshore and more southerly areas as is typical for the area (Wong *et al.* 2018; Good 2020; Weseloh *et al.* 2020). Ring-billed Gull sightings through August 2012 and in late-fall and early-winter surveys in 2010 to 2011 are consistent with southerly and easterly post-breeding movements from eastern Canadian and inland colonies (Lock 1988; Cotter *et al*. 2012; Pollet *et al*. 2020). Occurrences of Black-legged Kittiwake reflect the species' winter nearshore distribution in northeastern North America (Cotter *et al*. 2012; Hatch *et al*. 2020a), but the gap in our surveys in September and early October may have missed fall post-breeding occurrences of outer Bay of Fundy breeders observed in the Gulf of Maine (Wong *et al.* 2018). Of the occasional uncommon gulls observed (Table 1), Iceland Gull is an Arctic breeder and sightings on the Atlantic coast reflect southerly movements in winter (Snell *et al.* 2020), Laughing Gull breeds on the east coast from the Gulf of Maine southward and wanders post-breeding before moving south in winter (Burger 2020), and European Common Gull has a widespread distribution in the North Atlantic, occurring as a casual winter visitor along the Atlantic seaboard (Moskoff and Bevier 2020). Occurrences of Lesser Black-backed Gull (seen on four surveys at different times of year) reflect the widespread distribution of this European species along the east coast of North America.

Cormorants—Occurrences of Double-crested Cormorant and Great Cormorant reflected pre-breeding aggregation and occurrence during the normal breeding periods of both species in the area (Lock and Ross 1973; Dorr *et al.* 2020; Hatch *et al*. 2020b). Low counts in late summer and early fall show movement out of the area and typically southward post-breeding, with numbers in March representing early arrivals as is typical (Dorr *et al*. 2020; Hatch *et al*. 2020b). Nearest colonies in Minas Passage are at Cape Split and Spencer's Island and in Minas Basin in the Five Islands area (Milton and Austen-Smith 1983; Allard *et al*. 2014).

Loons—Sightings of Common Loon were consistent with typical patterns of occurrence in the Bay of Fundy and other coastal waters of Atlantic Canada throughout the year both for overwintering and summer occupation by non-breeders (Clay and Clay 1997; Paruk *et al.* 2021). Pacific Loon, considered rare (Russell 2020), had only occasionally been reported in the Bay of Fundy previously (e.g., Mills and Laviolette 2011). Our sightings and recent (2019) sightings off southwest Nova Scotia (eBird 2019) show potential for movement through the area and perhaps indicate an increasing use of the area by this species. F.L.L. had previous experience with the species on its breeding range and mis-identification is unlikely. The spring migration peak of Red-throated Loon observed corresponds to the timing of the early-May peak movement for the species observed along the New Brunswick coast in the outer Bay of Fundy (Clay and Clay 1997; Maybank 1997; Dietz and Chiasson 2000; Rizzolo *et al*. 2020), where Red-throated Loon is the most abundant loon in the vicinity of Saint John, New Brunswick, from March to May (Dietz and Chiasson 2000). The fall peak aligns with the early-November fall migration peak observed along the northeast coast of the USA (Barr *et al*. 2000).

Alcids—Presence throughout the year and seasonal abundance of Black Guillemot was consistent with the known local nesting period in the area (e.g.,

May to late June in the outer Bay of Fundy to Maine; Butler *et al.* 2020) and nesting activity observed on Black Rock during the study. Occurrences of Common Murre, Razorbill, Thick-billed Murre, and Atlantic Puffin are consistent with use of waters in the area by overwintering birds from east coast colonies and winter coastal aggregations in the Outer Bay of Fundy (e.g., Huettmann *et al*. 2005; Wong *et al.* 2018), and east coast winter distributions from October to April (Ainley *et al.* 2020; Gaston and Hipfner 2020; Lowther *et al*. 2020). Occasional sightings of Common and Thick-billed Murre (Table 1) reflect winter dispersal from northern colonies (Wong *et al.* 2018; Ainley *et al.* 2020; Gaston and Hipfner 2020). Lack of surveys in late winter (late December to early March) in our study, a period when many alcids overwintering in the Bay of Fundy may be present, is a data-gap in estimating the potential occurrence of those species in the area.

Miscellaneous seabirds—Occurrence of Northern Gannet at the site is consistent with the species' use of the Bay of Fundy in summer (Huettmann and Diamond 2011; Mills and Laviolette 2011; Mowbray 2020) and seasonal movements through the area to and from colonies in the Gulf of St. Lawrence and Newfoundland. However, occurrence of fall southerly movements in the lower Bay of Fundy as noted by Wong *et al.* (2018) could not be determined due to the September to early October gap in coverage in our survey. Great Shearwater and Sooty Shearwater, seen in August 2012, are often seen in the outer Bay of Fundy and Gulf of Maine during their summer feeding movements in the northwest Atlantic from breeding sites in the southern hemisphere. They leave the Bay of Fundy and Gulf of Maine from early September to October–November (Huettmann 2000; Pittman and Huettmann 2006; Wong *et al.* 2018), and all three species have been recorded at Brier Island (Mills and Laviolette 2011). The occurrence of Northern Gannet, Cory's Shearwater, Great Shearwater, and Sooty Shearwater in our area reflects the close connection of the study site with the outer Bay of Fundy and Gulf of Maine, where these species occur in summer (Pittman and Huettmann 2006). The single Black Tern sighting in early July is consistent with the species' typical occurrence as a rare migrant to Atlantic Canada (Mills and Laviolette 2011; Heath *et al.* 2020).

Shorebirds and miscellaneous waterfowl—All species of shorebirds that occurred, including Ruddy Turnstone, Red-necked Phalarope, Red Phalarope, Sanderling, Semipalmated Sandpiper, Spotted Sandpiper, and Greater Yellowlegs, were expected based on known late summer southerly migration through the Bay of Fundy at this time of year (Hicklin and Smith 1984a; Hicklin 1987). American Black Duck is a regular winter coastal resident in the Bay of Fundy (Hicklin and Smith 1984a; Allard *et al*. 2014). Other species of waterfowl occurring occasionally including Northern Shoveler, Canada Goose, Common Goldeneye, and Mallard. Horned Grebe and Red-necked Grebe are expected based on their previous occurrence in the area (e.g., Mills and Laviolette 2011). Individual sightings of Harlequin Duck are consistent with the species' overwintering distribution along the east coast including in the Bay of Fundy (Dietz and Chiasson 2000; Robertson and Goudie 2020).

Study limitations

The 19 surveys in our study are insufficient to capture all the nuances of seabird seasonal and migratory cycles, which are highly variable in space and time. However, they represent a substantial source of information to profile the waterbird community (species composition and relative abundance) over the three years of our study. In particular, with reference to tidal energy development, the information has been used to assess potential impacts and to develop monitoring strategies for seabirds as well as other organisms (e.g., marine mammals and fish) in relation to tidal device installations. The study was completed over three years, with potential year-to-year variability superimposed on seasonal patterns. The sampling frequency (minimum of two to three weeks separation between surveys) could allow major brief movements of birds to be missed. For example, the expected late-summer, early-fall migration of shorebirds through Chignecto Bay and Minas Basin (Hicklin 1987) was only slightly mirrored in our observations.

This survey interval was effective for other species (e.g., scoters, Red-throated Loon), which were detected in consecutive surveys. Counts obtained in this study give a measure of relative abundance that is comparable between surveys, but which likely underestimates total numbers of birds, particularly when many birds are present, or when they occur too far in the distance. Bird behaviour, such as resting on Black Rock for long periods during the day seen in gulls, cormorants, and Common Eider, can inflate average counts relative to those of more mobile species such as migrating scoters that typically move quickly through the site.

Time of day selected for the surveys, which was mainly from mid-day to late afternoon, may also affect abundances observed. Some birds migrate mainly at other times of day (e.g., Black Scoters typically move in the early morning; Cameron 2014), and some species move at night. Birds on Black Rock were incompletely censused, as the far side of the island was not visible from shore but likely supported some birds. All observations were made on the ebbing tide; while the tide affects flying birds only to a limited degree,

birds remaining on the water on an outgoing tide also move past the site. Future studies at the site should address these issues if possible.

Author Contributions

Project Administration: P.L.S.; Investigation & Field Observations: F.L.L. and P.L.S.; Data Compilation & Analysis: H.A.L. and P.L.S.; Formal Analysis: P.L.S.; Writing – Original Draft: P.L.S.; Writing – Review & Editing: P.L.S., F.L.L., and H.A.L.

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