The Canadian Field-Naturalist

Volume 131, Number 3 July–September 2017

Annual and Seasonal Variation in Shorebird Abundance in the St. Lawrence River Estuary during Fall Migration

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Turcotte, Yves, Jean-François Lamarre, and Joël Bêty. 2017. Annual and seasonal variation in shorebird abundance in the St. Lawrence River estuary during fall migration. Canadian Field-Naturalist 131(3): 203–214. https://doi.org/10.22621/cfn.v131i3.1870

Many North American shorebird populations are declining. It is therefore urgent to identify major sites used during their annual cycle to achieve effective conservation measures. Our objective was to expand some aspects of the knowledge base needed to assess the ecological value of the St. Lawrence River Estuary for shorebird conservation. Here, we present the results of the most intensive shorebird survey ever conducted in the St. Lawrence River Estuary during fall migration. Surveys were conducted between St-Jean-Port-Joli and St-Simon-sur-Mer, Quebec, Canada, in 2011 and 2012, from late June/early July through late November, corresponding to the migration period of all species potentially present in the study area. The Semipalmated Sandpiper (*Calidris pusilla*) was one of the two most abundant species during both years of our study (most abundant species, followed by Dunlin [*Calidris alpina*] and Black-bellied Plover [*Pluvialis squatarola*] in 2011; second to Black-bellied Plover in 2012). Considering the entire shorebird community, abundance of individuals peaked in early September. Peak abundance occurred earlier for adults than for juveniles. For most species, juveniles largely outnumbered adults. Juveniles were relatively less abundant in 2012 than in 2011. This reflected a general trend observed in northeastern North America between those years, suggesting a lower breeding success in 2012. Given its importance as a staging site for juvenile birds (study area used annually by up to a few hundred thousand shorebirds) and therein, its conservation value, we recommend that the St. Lawrence River Estuary should be included within the Western Hemisphere Shorebird Reserve Network.

Key Words: *Calidris pusilla*; conservation; ecology; fall migration; migration timing; Semipalmated Sandpiper; shorebirds; St. Lawrence River Estuary; staging site; survey

Plusieurs espèces d'oiseaux de rivage étant en déclin, il importe d'identifier les sites d'importance fréquentés annuellement afin de concevoir des plans de conservation. Nous avons voulu documenter certains aspects nécessaires à l'évaluation de la valeur écologique de l'estuaire du Saint-Laurent pour ces espèces. Nous présentons les résultats de l'inventaire le plus intensif à ce jour pour l'estuaire du St-Laurent au cours de la migration automnale. Les inventaires ont été réalisés de St-Jean-Port-Joli à St-Simon-sur-Mer, Quebec, Canada, en 2011 et en 2012, de la fin juin/début juillet jusqu'à la fin novembre, soit pendant la période migratoire des espèces présentes dans l'aire d'étude. Le bécasseau semipalmé (*Calidris pusilla*) était l'espèce la plus abondante en 2011, suivie par le bécasseau variable (*Calidris alpina*) et le pluvier argenté (*Pluvialis squatarola*). En 2012, le pluvier argenté était l'espèce la plus abondante, suivie par le bécasseau semipalmé. Considérant l'ensemble des espèces, l'abondance des individus culminait en début septembre. L'abondance maximale des adultes précédait celle des juvéniles. Chez la plupart des espèces, les juvéniles était plus abondants que les adultes. Les juvéniles étaient relativement moins abondants en 2012 qu'en 2011. Cette tendance était générale dans le nord-est de l'Amérique du Nord. Cela pourrait signifier que le succès reproducteur était inférieur en 2012. Considérant son importance pour les juvéniles (l'aire d'étude pouvant être fréquentée annuellement par quelques centaines de milliers d'individus) et donc, sa valeur pour la conservation, nous proposons que l'estuaire du St-Laurent soit intégré au Réseau de réserves pour les oiseaux de rivage de l'hémisphère occidental.

Mots-Clés: Bécasseau semipalmé; *Calidris pusilla*; chronologie de la migration; conservation; écologie; estuaire du fleuve St-Laurent; halte migratoire; inventaire; migration automnale; oiseaux de rivage

Introduction

The ecological value of the St. Lawrence River Estuary for aquatic birds has long been recognized. Several thousand breeding colonial waterbirds belonging to 12 species (e.g., Double-crested Cormorant [*Phalacrocorax auritus*], Razorbill [*Alca torda*], and Black-legged Kittiwake [*Rissa tridactyla*]) are found on its numerous islands (Environment Canada 2016). Migrating (e.g., Snow Goose [*Anser caerulescens*]), breeding (e.g., American Black Duck [*Anas rubripes*]), and wintering (e.g., goldeneyes [*Bucephala* spp.]) waterfowl are also abundant (Bélanger *et al*. 1998; Gauthier *et al*. 2005; Ouellet *et al*. 2010). However, shorebird use of the St. Lawrence River Estuary has not received much attention so far and, as a result, there are few published studies documenting the biology of this taxonomic group in this ecosystem.

Indeed, we are aware of only four peer-reviewed publications dealing with shorebird use of the St. Lawrence River Estuary. Michaud and Ferron (1986, 1990) documented foraging techniques and food selection in four species of shorebirds during fall migration. Maisonneuve *et al*. (1990) conducted extensive ground surveys along the St. Lawrence system (river, estuary, and gulf) during the early part of the fall migration (late July to late August). They reported the presence of about 110 000 shorebirds belonging to 22 species in the estuarine section of their study area. As this number was the result of single counts conducted only in selected locations and moreover, before the juvenile peak of abundance for most species, it is very likely that the total number of shorebirds using the St. Lawrence River Estuary during fall migration was underestimated. More recently, Turcotte *et al*. (2013) studied seasonal change in body mass of Semipalmated Plover (*Charadrius semipalmatus*) and Semipalmated Sandpiper (*Calidris pusilla*) juveniles during fall migration. They found that mean body mass of birds captured on the southeast shore of the St. Lawrence River Estuary were similar to or higher than those of juveniles of both species captured along the North Atlantic coast.

It follows that the ecological value of the St. Lawrence River Estuary for this group has not yet been sufficiently assessed. As many North American shorebird populations are declining (Morrison *et al*. 2001; Bart *et al*. 2007; Jehl 2007; Hicklin and Chardine 2012; North American Bird Conservation Initiative Canada 2012), it is important to readily identify critical habitats and sites used during their annual cycle to achieve effective conservation objectives (Donaldson *et al*. 2000; Warnock 2010). Including the St. Lawrence River Estuary within the Western Hemisphere Shorebird Reserve Network (Western Hemisphere Shorebird Reserve Network 2009) would likely help attain these objectives. The Western Hemisphere Shorebird Reserve Network is an international conservation strategy established in 1986 to protect key shorebird habitats. In eastern North America, along the West Atlantic flyway (also known as the Atlantic Americas flyway or Atlantic flyway), it includes Delaware Bay and two sections of the Upper Bay of Fundy. These sites are considered among the most important for shorebird conservation in the Americas. Expansion of the Western Hemisphere Shorebird Reserve Network is considered as the importance of other major candidate sites would be properly assessed and recognized (Western Hemisphere Shorebird Reserve Network 2009). Thus, our objective was to document timing of migration and abundance of southbound shorebirds using the St. Lawrence River Estuary to expand the knowledge base needed to assess the ecological value of the St. Lawrence River Estuary for their conservation. Here, we present the results of the most intensive shorebird survey ever conducted in the St. Lawrence River Estuary during fall migration.

Study Area

This study was conducted on the southeast shore of the St. Lawrence River Estuary, approximately 100 km northeast of Québec City, along a 150 km stretch of shoreline between St-Jean-Port-Joli (47.189°N, 70.296°W) and St-Simon-sur-Mer (48.205°N, 69.082°W), Quebec, Canada (Figure 1). The St. Lawrence River Estuary exhibits a strong salinity gradient west to east (Fradette and Bourget 1980; Saucier *et al*. 2009). This gradient is reflected by major changes in riparian and intertidal vegetation (Gauthier 2000) as well as in benthic invertebrate communities (Bourget 1997). Within the study area, water circulation is dominated by semidiurnal tides that can reach over 5 m in height (Fisheries and Oceans Canada 2016). The intertidal zone may reach more than 3 km at its widest points (e.g., Ste-Anne Bay and Kamouraska Islands) according to marine charts (Natural Resources Canada 2016). Intertidal substrates are highly variable, ranging from mud-

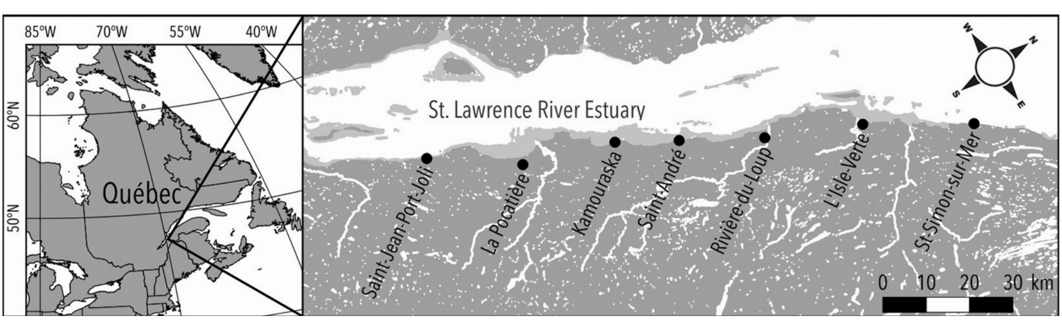

FIGURE 1. The study area on the southeast shore of the St. Lawrence River Estuary, Quebec, Canada, 2011 and 2012. Light grey areas represent the intertidal zone.

flats adjacent to American Bulrush (*Schoenoplectus americanus* (Persoon) Volk ex Schinz & R. Keller) or cordgrass (*Sporobolus* spp.) marshes in protected bays, to boulders and bare rock at exposed sites. Peregrine Falcons (*Falco peregrinus*) and Merlins (*Falco columbarius*), two important shorebird predators (Dekker *et al*. 2011), nest in and migrate through the study area. Attacks on migrating shorebirds by these predators were witnessed regularly during this study (see also Turcotte *et al*. 2013).

Methods

Shorebird Surveys

We established 30 survey sites 5 km apart along the shoreline. Each survey site corresponded to a 600 m stretch of shoreline measured with a handheld GPS at the higher high water mean tide level (the average of all higher high waters; Fisheries and Oceans Canada 2016). The higher high water mean tide level coincides with the upper limit on the shore of, depending on water salinity, American Bulrush or Smooth Cordgrass (*Sporobolus alterniflorus* (Loiseleur-Deslongchamps) P. M. Peterson & Saarela; Gauthier 2000). Thus, a total of 18 km of shoreline were covered per survey. Survey sites included all adjacent shorebird habitats above and below the shoreline (marshes, beaches, rocky shores, and tidal flats). The location of a first survey site was randomly selected to the nearest meter along a longitudinal axis within the study area. The other sites were thereafter positioned progressively every 5 km along the shoreline (systematic random sampling). In some cases, survey sites were relocated in similar habitat type, as close as possible from the selected site when, chiefly due to duck hunting activity, observer safety could have been compromised.

Based on radiotelemetry studies conducted during the non-breeding season, we assumed that this spacing would on the one hand, reduce, though certainly not eliminate, the likelihood that shorebirds would be counted in more than one survey site on a given day (see Conklin and Colwell 2007; Sprague *et al*. 2008; Obernuefemann *et al.* 2013; Turcotte *et al*. 2013), while providing, on the other hand, as much as possible a representative coverage of the study area in order to properly describe the structure of the shorebird community. Thus, abundance values presented here should be interpreted cautiously because some "double counting" (i.e., birds counted in more than one nearby [5–15 km] survey sites not visited simultaneously) likely occurred. Conversely, "double missing" (i.e., birds missed in all nearby survey sites not visited simultaneously) would have occurred as well, counterbalancing, in an unknown proportion, double counting bias. Costly aerial surveys would have eliminated this problem. However, for most species, they would not have provided, unless supported by ground surveys, information on age class.

Surveys were conducted in 2011 and 2012 from late June/early July through late November, corresponding to the migration period of all species potentially present in the study area. Surveys were conducted every week in 2011 (21 survey weeks). In 2012, surveys were conducted every other week (11 survey weeks). During 30 min, one or two observers (same observers in both years) walked the entire 600-m survey site to ensure complete visual coverage. Shorebirds were identified with ×60 spotting scopes. Age class (juveniles or adults) of shorebirds on ground was determined according to Hayman *et al*. (1986) and Paulson (2005), whenever conditions permitted (distance, light conditions, flock density, and behaviour). We surveyed sites in different tidal conditions (tidal flat covered and most birds roosting or tidal flat partly uncovered and most birds foraging) during consecutive weekly or bi-weekly surveys. Thus, it took four or five days per survey week to visit all 30 sites in requested tidal conditions. As a result, double counting and double missing were likely unavoidable.

Statistical Analyses

Statistical analyses were carried out using R version 3.3.1 (R Development Core Team 2016). Values reported are abundance (number of individuals detected) and relative abundance (%) per age class (calculated from the total number of known-age individuals detected per year). Abundance values were tested for normality (Shapiro-Wilk test; the statistical test of the null hypothesis of normality with the highest power; Ruxton *et al*. 2015) and homoscedasticity (*F* test). Square-root-transformation (0.5 added to data before transformation due to the presence of a value equal to 0), a transformation frequently applied to count data (Sokal and Rohlf 1995; Gotelli and Ellison 2004), was used to meet *t*-test assumptions. A Pearson's Chi-square test was utilized to assess the association between categorical variables.

Results

Timing of Migration

Considering the entire shorebird community, abundance of individuals peaked in early September (Tables 1 and 2, Figure 2). Shorebird juveniles initiate migration later than adults (Warnock *et al*. 2002; van de Kam *et al*. 2004). Therefore, raw values such as those appearing in Tables 1 and 2 may limit our understanding of shorebird migration dynamics. Thus, for species in which the less abundant age class included at least 2% of known age individuals (Table 3), Figure 3 (2011: weekly survey) and Figure 4 (2012: bi-weekly survey) illustrate relative abundance and timing of migration per age class. We only present species for which we were able to determine age class for at least one fourth of all individuals detected, represented by a conservative sample size (250 or more known age individuals). We thus reduced the risk of potential bias hampering

TABLE 1. Shorebird abundance per weekly survey during fall migration on the southeast shore of the St. Lawrence River Estuary, Quebec, Canada, 2011. Numbers in brackets are survey week order given a 21 consecutive week schedule.

Species	Survey week																					Total
	1 July (1)	8 July (2)	15 July (3)	22 July (4)	29 July (5)	5 Aug. (6)	12 Aug. (7)	19 Aug. (8)	26 Aug. (9)	2 Sep. (10)	9 Sep. (11)	16 Sep. (12)	23 Sep. (13)	30 Sep. (14)	7 Oct. (15)	14 Oct. (16)	21 Oct. (17)	28 Oct. (18)	4 Nov. (19)	11 Nov. (20)	18 Nov. (21)	
Nesting in the study area																						
Killdeer (*Charadrius vociferus*)	3	9	1	5	8	5	5	3	0	1	1	0	0	0	0	0	0	0	0	0	0	41
Spotted Sandpiper (*Actitis macularius*)	0	0	9	6	20	17	10	14	11	12	4	4	5	4	4	1	2	1	0	0	0	124
Wilson's Snipe (*Gallinago delicata*)	0	0	0	1	0	0	1	2	0	0	0	0	2	1	1	1	2	1	3	0	0	15
Migrating through the study area																						
Black-bellied Plover (*Pluvialis squatarola*)	0	1	0	0	5	99	718	1269	1256	626	220	60	651	533	414	92	177	136	51	2	1	6311
American Golden-Plover (*Pluvialis dominica*)	0	0	0	0	0	0	0	0	0	0	4	12	4	3	3	0	0	0	0	0	0	26
Semipalmated Plover (*Charadrius semipalmatus*)	0	0	0	36	191	206	163	349	375	643	680	211	231	104	84	114	109	2	1	0	0	3499
Solitary Sandpiper (*Tringa solitaria*)	0	0	0	0	1	1	0	0	0	0	5	2	0	0	0	0	0	0	0	0	0	9
Greater Yellowlegs (*Tringa melanoleuca*)	0	0	0	0	0	13	39	9	9	12	21	5	25	15	8	6	18	7	3	0	0	190
Lesser Yellowlegs (*Tringa flavipes*)	0	0	1	1	3	42	67	14	47	11	6	0	1	0	0	0	3	1	0	0	0	197
Whimbrel (*Numenius phaeopus*)	0	0	0	6	6	60	20	1	4	18	39	0	2	2	1	0	0	0	0	0	0	159
Hudsonian Godwit (*Limosa haemastica*)	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	1	0	0	0	0	0	7
Ruddy Turnstone (*Arenaria interpres*)	0	0	0	0	0	1	3	49	11	64	57	48	22	30	7	0	1	10	0	0	0	303
Red Knot (*Calidris canutus*)	0	0	0	0	0	0	2	17	32	54	7	0	85	48	84	0	5	0	0	0	0	334
Stilt Sandpiper (*Calidris himantopus*)	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Sanderling (*Calidris alba*)	0	0	0	0	0	2	1	21	45	78	153	186	81	31	59	71	144	117	40	30	1	1060
Dunlin (*Calidris alpina*)	0	0	0	0	0	0	0	0	0	9	11	126	4155	3589	463	82	212	167	35	0	0	8849
Baird's Sandpiper (*Calidris bairdii*)	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0	0	0	6
Least Sandpiper (*Calidris minutilla*)	1	18	20	28	49	53	229	184	169	174	41	16	3	0	1	0	0	0	0	0	0	986
White-rumped Sandpiper (*Calidris fuscicollis*)	0	0	0	0	0	53	86	12	5	4	16	44	5	529	1768	635	504	351	47	67	0	4126
Pectoral Sandpiper (*Calidris melanotos*)	0	0	0	0	0	0	0	0	0	5	11	1	3	18	4	13	13	0	0	0	0	68
Semipalmated Sandpiper (*Calidris pusilla*)	0	0	0	24	72	86	78	180	3337	8059	7085	3007	391	68	12	29	10	0	0	0	0	22 438
Short-billed Dowitcher (*Limnodromus griseus*)	0	0	1	0	0	0	1	3	4	5	0	0	0	0	0	0	0	0	0	0	0	14
Yellowlegs (*Tringa* spp.)	0	0	0	0	0	30	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	36
Unidentified shorebirds	0	0	0	0	54	140	40	623	801	439	169	30	32	122	6	15	0	0	0	0	0	2471
All species	4	28	32	107	409	808	1463	2752	6106	10 222	8534	3752	5698	5103	2919	1060	1200	793	180	99	2	51 271

TABLE 2. Shorebird abundance per bi-weekly survey during fall migration on the southeast shore of the St. Lawrence River Estuary, Quebec, Canada, 2012. Numbers in brackets are survey week order given a 21 consecutive week schedule.

	Survey week											
Species	29 June (1)	13 July (3)	27 July (5)	10 Aug. (7)	24 Aug. (9)	7 Sep. (11)	21 Sep. (13)	5 Oct. (15)	19 Oct. (17)	2 Nov. (19)	16 Nov. (21)	Total
Nesting in the study area												
Killdeer (*Charadrius vociferus*)	1	5	3	3	13	0	0	0	0	1	0	26
Spotted Sandpiper (*Actitis macularius*)	2	2	7	10	16	11	0	0	0	0	0	48
Wilson's Snipe (*Gallinago delicata*)	0	0	0	1	1	0	0	1	0	1	0	4
Migrating through the study area												
Black-bellied Plover (*Pluvialis squatarola*)	0	1	11	835	34	2060	627	65	30	72	0	3735
American Golden-Plover (*Pluvialis dominica*)	0	0	0	1	0	0	2	1	0	0	0	4
Semipalmated Plover (*Charadrius semipalmatus*)	0	0	71	185	238	605	251	97	125	3	0	1575
Solitary Sandpiper (*Tringa solitaria*)	0	0	0	5	2	0	0	0	0	0	0	7
Greater Yellowlegs (*Tringa melanoleuca*)	0	0	0	3	1	18	4	6	7	17	0	56
Lesser Yellowlegs (*Tringa flavipes*)	0	1	0	18	3	19	3	0	0	0	0	44
Whimbrel (*Numenius phaeopus*)	0	5	27	28	8	10	9	0	0	0	0	87
Ruddy Turnstone (*Arenaria interpres*)	0	0	1	24	6	15	24	5	2	4	0	81
Red Knot (*Calidris canutus*)	0	0	0	24	2	220	68	0	1	0	0	315
Sanderling (*Calidris alba*)	0	1	0	0	6	58	45	2	1	2	0	115
Dunlin (*Calidris alpina*)	0	0	0	0	0	47	50	24	31	216	0	368
Baird's Sandpiper (*Calidris bairdii*)	0	0	0	1	0	0	0	0	0	0	0	1
Least Sandpiper (*Calidris minutilla*)	20	66	41	281	104	28	3	0	0	0	0	543
White-rumped Sandpiper (*Calidris fuscicollis*)	0	0	6	2	1	1	0	2	51	70	0	133
Pectoral Sandpiper (*Calidris melanotos*)	0	0	0	0	6	26	59	10	11	0	0	112
Semipalmated Sandpiper (*Calidris pusilla*)	0	0	24	259	398	1188	142	30	26	0	0	2067
Short-billed Dowitcher (*Limnodromus griseus*)	0	0	0	1	0	4	0	0	0	0	0	5
Unidentified shorebirds	0	0	9	130	82	182	42	0	25	15	0	485
All species	23	81	200	1811	921	4492	1329	243	310	401	0	9811

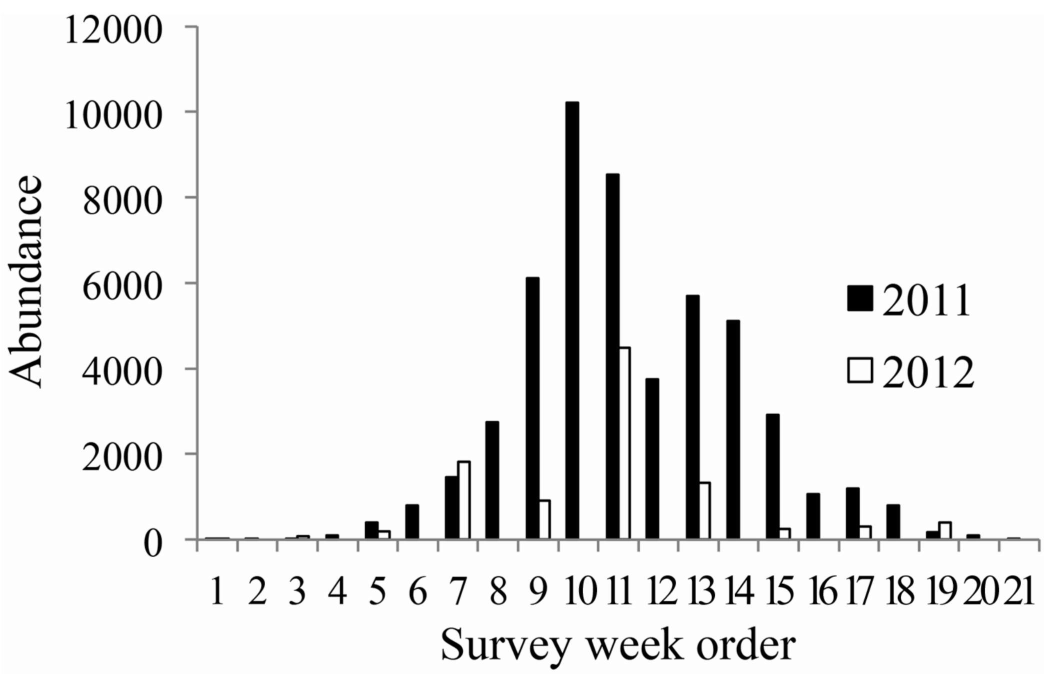

FIGURE 2. Shorebird abundance during fall migration on the southeast shore of the St. Lawrence River Estuary, Quebec, Canada, 2011(weekly survey) and 2012 (bi-weekly survey). Survey week order as in Tables 1 and 2.

TABLE 3. Relative abundance per age class of known-age shorebirds during fall migration on the southeast shore of the St. Lawrence River Estuary, Quebec, Canada, 2011 and 2012.

	2011			2012		
	n	Adults (%)	Juveniles (%)	*n*	Adults (%)	Juveniles (%)
Nesting in the study area						
Killdeer (*Charadrius vociferus*)	1	100.0	0.0	6	66.7	33.3
Spotted Sandpiper (*Actitis macularius*)	24	16.7	83.3	19	0.0	100.0
Wilson's Snipe (*Gallinago delicata*)	–	–	–	1	100.0	0.0
Migrating through the study area						
Black-bellied Plover (*Pluvialis squatarola*)	5188	65.7	34.3	2959	92.8	7.2
American Golden-Plover (*Pluvialis dominica*)	15	6.7	93.3	4	25.0	75.0
Semipalmated Plover (*Charadrius semipalmatus*)	2666	19.1	80.9	1408	19.1	80.9
Solitary Sandpiper (*Tringa solitaria*)	2	0.0	100.0	–	–	–
Greater Yellowlegs (*Tringa melanoleuca*)	69	18.8	81.2	27	14.8	85.2
Lesser Yellowlegs (*Tringa flavipes*)	35	34.3	65.7	6	0.0	100.0
Whimbrel (*Numenius phaeopus*)	86	65.1	34.9	69	82.6	17.4
Hudsonian Godwit (*Limosa haemastica*)	1	0.0	100.0	–	–	–
Ruddy Turnstone (*Arenaria interpres*)	285	17.9	82.1	79	32.9	67.1
Red Knot (*Calidris canutus*)	321	1.6	98.4	302	1.0	99.0
Stilt Sandpiper (*Calidris himantopus*)	–	–	–	–	–	–
Sanderling (*Calidris alba*)	906	0.2	99.8	43	2.3	97.7
Dunlin (*Calidris alpina*)	62	6.5	93.5	13	15.4	84.6
Baird's Sandpiper (*Calidris bairdii*)	2	0.0	100.0	1	0.0	100.0
Least Sandpiper (*Calidris minutilla*)	333	15.6	84.4	192	17.2	82.8
White-rumped Sandpiper (*Calidris fuscicollis*)	1202	2.2	97.8	49	22.4	77.6
Pectoral Sandpiper (*Calidris melanotos*)	17	0.0	100.0	11	0.0	100.0
Semipalmated Sandpiper (*Calidris pusilla*)	8758	2.0	98.0	964	2.5	97.5
Short-billed Dowitcher (*Limnodromus griseus*)	2	0.0	100.0	–	–	–
All species	19 975	21.6	78.4	6153	51.7	48.3

interpretation. Six species and three species met these criteria in 2011 and 2012, respectively.

Abundance

In 2011, a total of 51 271 shorebirds belonging to 22 species were detected in the 30 survey sites during the 21 weekly surveys (Table 1). In 2012, a total of 9811 shorebirds belonging to 20 species were detected in these survey sites during the 11 bi-weekly surveys (Table 2).

Semipalmated Sandpiper, one of the most abundant shorebird species in eastern North America during migration (Hicklin and Gratto-Trevor 2010), was one of the two most abundant species during both years of our study (most abundant species followed by Dunlin [*Calidris alpina*] and Black-bellied Plover [*Pluvialis squatarola*] in 2011; second to Black-bellied Plover in 2012; Tables 1 and 2).

Abundance per Age Class

Age class of 39% and 66% of shorebirds could be determined in 2011 and 2012, respectively. With the exception of Whimbrel (*Numenius phaeopus*) and Black-bellied Plover, juveniles outnumbered adults in species migrating through the study area (Table 3). Considering all species, juveniles were relatively less abundant in 2012 (48% of known-age birds) than in 2011 (78% of known-age birds; Table 3; $\chi^2_1 = 2080.1$, $P < 0.0001$).

Between-year Differences in Abundance

We observed a 64% decrease in mean shorebird abundance per survey week between 2011 (n = 21 weeks, 2442 birds) and 2012 (n = 11 weeks, 892 birds). Considering the entire migration period, when 2011 and 2012 shorebird abundances are compared on a weekly basis, this decrease was significant at the 0.05 level (paired *t*-test, one-tailed, $t_{10} = 2.35$, $P = 0.02$). Moreover, Figure 2 suggests that shorebird abundance from late August through October differed greatly between years, corresponding with a less abundant arrival of juveniles in 2012 than in 2011 (Table 3) and the departure of adults from our study area.

Discussion

Timing of Migration and Abundance

As expected, peak abundance occurred earlier for adults than for juveniles. The relative abundance of Semipalmated Sandpipers in the total shorebird community (46% and 22% in 2011 and 2012, respectively) was much lower than what had been reported for the Bay of Fundy (95% of all shorebirds; Hicklin 1987), a major shorebird fall staging site in eastern North America along the West Atlantic flyway. The abundance of Black-bellied Plover adults and juveniles during several weeks is also worth mentioning. The presence of numerous Black-bellied Plovers has been previously

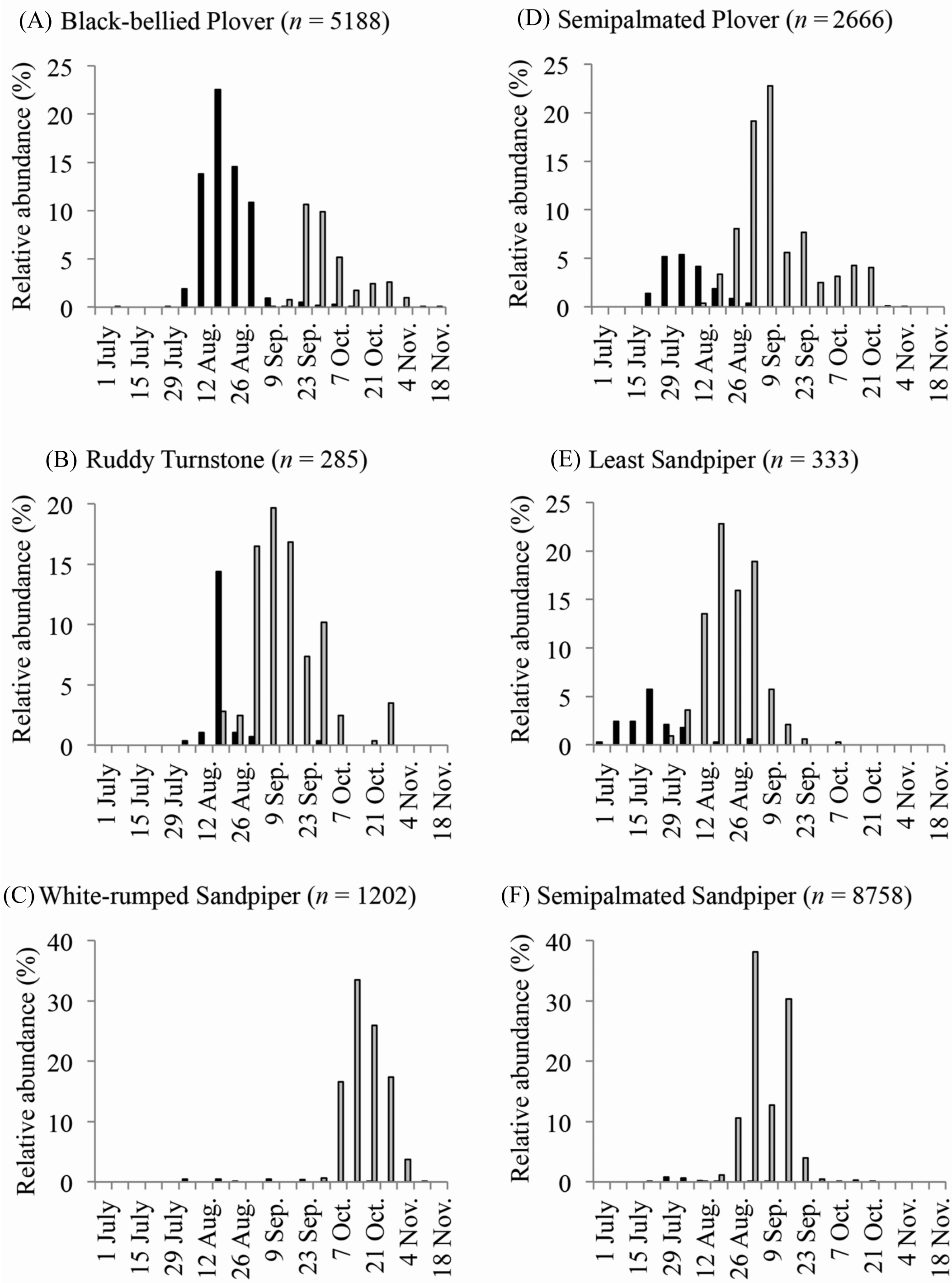

FIGURE 3. Relative abundance of some shorebird species per age class (calculated from the total number of known-age individuals detected per year; sum of all bars = 100%) during fall migration on the southeast shore of the St. Lawrence River Estuary, Quebec, Canada, 2011 (weekly survey). Solid and light grey bars represent adults and juveniles, respectively.

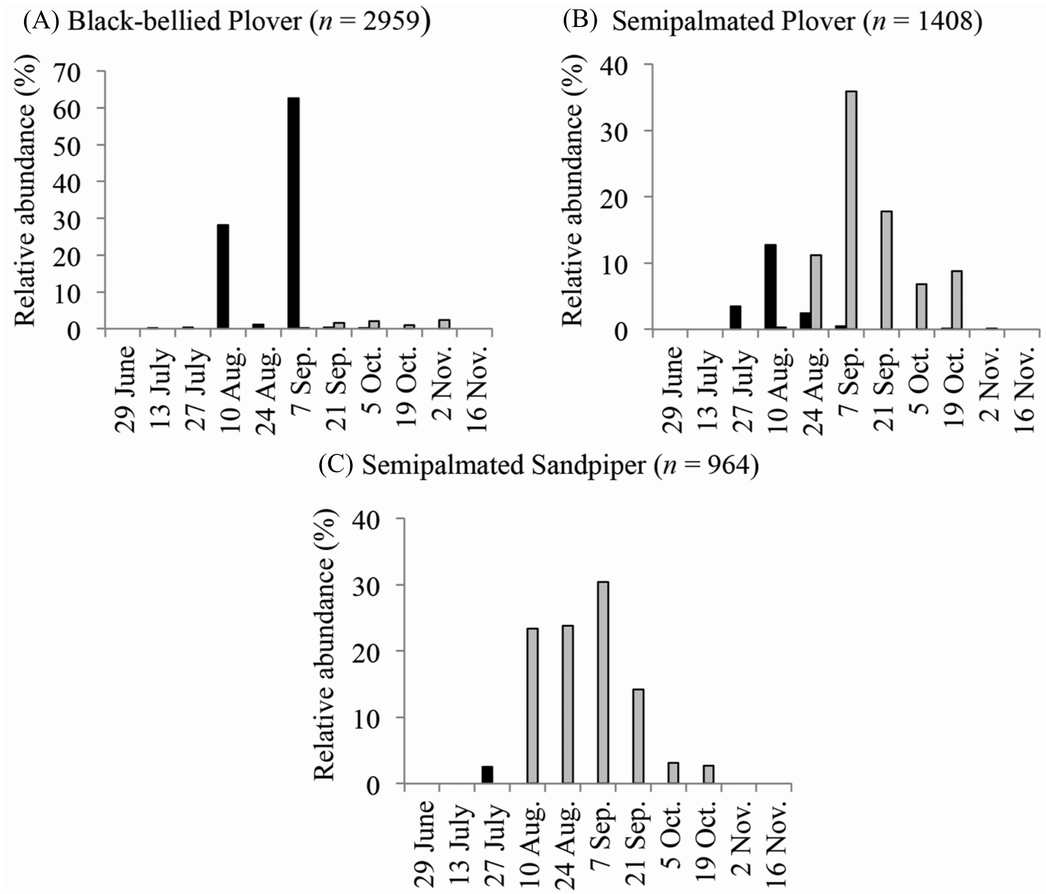

FIGURE 4. Relative abundance of some shorebird species per age class (calculated from the total number of known-age individuals detected per year; sum of all bars = 100%) during fall migration on the southeast shore of the St. Lawrence River Estuary, Quebec, Canada, 2012 (bi-weekly survey). Solid and light grey bars represent adults and juveniles, respectively.

noted near our study area during fall migration (Maisonneuve *et al*. 1990).

We do not know length of stay for most species in the St. Lawrence River Estuary. Because we consider that double counting some individuals in the survey sites between consecutive weekly or bi-weekly surveys was inevitable, it would be hazardous to extrapolate abundance values presented here to the 150 km long shoreline of our study area. Indeed, to estimate population size, survey site raw abundance values such as ours need to be corrected to take into account turnover of migrant birds between surveys (Clark *et al*. 1993; Cohen *et al*. 2009), before being extrapolated to an entire study area. Nevertheless, as shoreline covered during each survey (18 km) represented approximately 12% of total shoreline within our study area (150 km), we consider it likely that, during years of high nesting success such as 2011, a few hundred thousand shorebirds would use the study area.

Semipalmated Plover is however the only species for which published results for this study area during fall migration are available. In this species, minimal length of stay of juveniles is, on average, 12.5 days (n = 8; Turcotte *et al*. 2013). Based on this value and abundance of Semipalmated Plover juveniles (estimated from values in Tables 1, 2, and 3), we consider that, because survey sites were randomly selected, approximately 11 800 and 10 600 Semipalmated Plover juveniles used our study area during fall migration in 2011 and 2012, respectively. These rough estimates would represent about 5% of the estimated world population (200 000; Andres *et al*. 2012).

Abundance per Age Class

When compared to 2011, the lower relative abundance of juveniles in 2012 suggests lower breeding success on the breeding grounds for that year. Breeding output of tundra nesting birds is affected by weather conditions. Low temperatures and precipitation can affect breeding density, timing of breeding, and survival of juveniles (Meltofte *et al*. 2007; Robinson *et al*. 2014). Furthermore, pulsed resources such as rodent cycles can strongly affect nesting success (proportion of nests fledging at least one young). During low rodent abundance years, predators such as Arctic Fox (*Vulpes lagopus*), Glaucous Gull (*Larus hyperboreus*), and jaegers (*Stercorarius* spp.) rely more on alternative prey such as terrestrial bird nests and flightless juveniles (McKinnon *et al*. 2014). Most birds migrating through the St. Lawrence system likely nest at higher latitudes along the West Atlantic flyway (van de Kam *et al*. 2004; Winn *et al*. 2013; Brown *et al*. 2017). Information on nesting success at source locations within this flyway could help understand what we observed in our study area. Such data are available for 2011 and 2012 for a few study sites in the eastern Arctic, all located in Canada: Bylot Island (73.2°N, 80.0°W) and East Bay (64.0°N, 81.7°W), Nunavut, and Churchill (58.7°N, 93.8°W), Manitoba (Arctic Shorebird Demographics Network 2015). Though anecdotal, it is noteworthy that nesting success at these three sites was lower in 2012 (35%, $n = 220$) than in 2011 (52%, $n = 175$; $\chi^2_1 = 10.9$, $P = 0.001$). Moreover, particularly detailed information is available for the Bylot Island study site for both years on arctic weather conditions, rodent abundance, and terrestrial bird nesting success (Gauthier *et al*. 2013). On Bylot Island, after two years of high density, Brown Lemming (*Lemmus trimucronatus*) populations crashed in 2012 (Gauthier *et al*. 2013; Fauteux *et al*. 2016). Furthermore, 2012 was the wettest summer since 1995, contrasting with warm and sunny conditions encountered in 2011 (Gauthier *et al*. 2013). These factors likely contributed to the particularly low nesting success of shorebirds on Bylot Island in 2012 (13%) as compared to 2011 (75%; Lamarre *et al*. 2012).

Between-year Differences in Abundance

To determine whether the between-year differences we observed were a local phenomenon or a general trend in northeastern North America between 2011 and 2012, we compared our results with data corresponding to our survey weeks available from eBird (Table 4), an online citizen-science project repository for bird observation (Sullivan *et al*. 2009). We used eBird weekly average counts (average number of birds detected when encountered; eBird 2016) for coastal eastern Canada (Quebec [excluding our data], Newfoundland and Labrador, Prince Edward Island, New Brunswick, and Nova Scotia) and coastal New England (Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut). For this comparison, we only considered species for which at least 1000 individuals were detected in our study area in 2011, our high abundance reference year. Six species met this criterion, representing 90% of all individuals detected in 2011.

Data in the eBird repository are not collected following a constant effort protocol as ours nor do they present age class information. They should therefore be interpreted cautiously. Nevertheless, for most species, the decline we observed along the St. Lawrence River Estuary between 2011 and 2012 appears to have been general across both coastal eastern Canada and coastal New England (Table 4).

Ecological Value of the St. Lawrence River Estuary for Shorebird Conservation

We found that, for most species, juveniles largely outnumbered adults in the St. Lawrence River Estuary during fall migration (Table 3). For Semipalmated Sandpiper, the most abundant species in northeastern North America during fall migration, the situation reported here (~ 98% juvenile and ~ 2% adult birds) appears to differ from what is observed at two major staging sites, James Bay (Morrison 1984) and the Bay of Fundy (Hicklin 1987). James Bay and the Bay of Fundy are located approximately 1000 km northwest and 400 km southeast of the St. Lawrence River Estuary, respectively. In James Bay, Semipalmated Sandpiper juveniles are also more abundant overall than adults (juvenile peak population size in August 1982, 10 055 individuals [Morrison 1984]; adult peak population size

TABLE 4. Mean abundance in some shorebird species per survey week on the southeast shore of the St. Lawrence River Estuary, Quebec, Canada (this study), coastal eastern Canada, and coastal New England (eBird 2016), 2011 and 2012.

	St. Lawrence River Estuary			Coastal eastern Canada			Coastal New England		
Species	2011	2012	Change (%)	2011	2012	Change (%)	2011	2012	Change (%)
Black-bellied Plover (*Pluvialis squatarola*)	300.5	339.5	13	15.9	12.4	−22	31.7	31.1	−2
Semipalmated Plover (*Charadrius semipalmatus*)	166.6	143.2	−14	21.8	24.7	13	32.7	27.7	−15
Sanderling (*Calidris alba*)	50.5	10.5	−79	33.0	25.9	−22	74.9	67.1	−10
Dunlin (*Calidris alpina*)	421.4	33.5	−92	23.7	11.2	−53	33.6	22.0	−34
White-rumped Sandpiper (*Calidris fuscicollis*)	196.5	12.1	−94	19.5	12.5	−36	7.1	4.1	−42
Semipalmated Sandpiper (*Calidris pusilla*)	1068.5	187.9	−82	506.1	182.6	−64	85.1	71.5	−16

in July 1982, ~3570 individuals, estimated from Figure 13 in Morrison [1984]). By contrast, in the Bay of Fundy, the vast majority of staging birds, including Semipalmated Sandpipers, are adults (Hicklin 1987; Morrison *et al*. 1994). This suggests different migration strategies between southbound adult and juvenile birds.

The St. Lawrence River Estuary may be skipped by many adult Semipalmated Sandpipers and adults from most species, thus reducing the risk of predation when moving to an additional stopover (Ydenberg *et al*. 2002), because their body condition can take them further. In contrast, the St. Lawrence River Estuary may represent a mandatory staging site for lean juveniles trying to avoid fatal body reserve depletion before reaching the Atlantic coast. Indeed, early in their migration period, many Semipalmated Sandpiper and Semipalmated Plover juveniles weigh less than estimated mean fat-free mass at their arrival in the St. Lawrence River Estuary (Turcotte *et al*. 2013). That could be especially true for birds confronted *en route* with unpredictable winds (Shamoun-Baranes *et al*. 2010). Moreover, the St. Lawrence River Estuary may represent the last staging site for many juveniles able to accumulate sufficient body reserves to fly directly to their winter range (Hicklin 1987; Turcotte *et al*. 2013).

Based on the evidence presented here (abundance of birds [Tables 1 and 2], relative abundance of juvenile birds [Table 3]) and elsewhere (Maisonneuve *et al*. 1990; Turcotte *et al*. 2013), we recommend that, given its importance as a staging site for juvenile birds and therein, its conservation value, the St. Lawrence River Estuary, or sections of it, should be included within the Western Hemisphere Shorebird Reserve Network.

Acknowledgements

We are grateful to J.-É. Joubert and C. Pomerleau for their help in the field. M.-J. Gibson, J. R. Foote, and two anonymous reviewers improved the quality of the manuscript by their comments. We acknowledge the cooperation of several landowners for graciously allowing us land access. Y.T. received support from Fonds de recherche du Québec – Nature et technologies (FRQNT), Environnement et Changement climatique Canada (contract K2C55-12-2053), Comité Z.I.P. du Sud-de-l'Estuaire and Cégep de La Pocatière. J.-F.L. and J.B. received support from Fonds de recherche du Québec – Nature et technologies, Conseil de recherches en sciences naturelles et en génie du Canada (CRSNG/NSERC), and Université du Québec à Rimouski.

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Received 26 October 2016
Accepted 29 August 2017