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Source: Wildlife Biology, 17(2) : 124-134

Published By: Nordic Board for Wildlife Research

URL: https://doi.org/10.2981/10-064

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Wildl. Biol. 17: 124-134 (2011)
DOI: 10.2981/10-064
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Original Article

Distribution of common eiders *Somateria mollissima* during the brood-rearing and moulting periods in the St. Lawrence Estuary, Canada

Hélène Diéval, Jean-François Giroux & Jean-Pierre L. Savard

Common eiders *Somateria mollissima* nest in colonies on islands of the St. Lawrence Estuary in Quebec, Canada. After hatching, attending females must reach suitable brood-rearing habitats while non-attending females and adult males must find appropriate moulting sites. The aim of our study was to determine the biotic and abiotic factors that influence the distribution of common eiders during the brood-rearing and moulting periods. We conducted biweekly surveys and recorded the number of ducks by age and sex in 2003 and 2004 at 68 sites along a 200-km stretch of the south shore of the St. Lawrence River. We further classified adult females according to the presence or absence of young. We evaluated human disturbance during the surveys and developed a sinuosity index describing shoreline protection. We determined the nature of the substrate and an estimate of food abundance for a subsample of sites (N = 38). At the scale of the estuary, common eiders did not distribute randomly but used the same sites in both years. Broods preferred mainland sites near nesting islands. Non-maternal females and males were located further east along the estuary, but their numbers were lower than expected based on the size of the breeding population, indicating that some birds undertake a moult migration outside of the area. In the eastern portion of our study area, densities of non-maternal females increased significantly as summer progressed. The distribution of common eiders was influenced by food abundance and type but was not related to our indices of human disturbance and shoreline protection. Males were associated with mussels, non-maternal females with both mussels and gammarids, while maternal females with ducklings were associated with periwinkles. Few of the sites used by common eiders along the south shore of the St. Lawrence Estuary are currently protected and measures should thus be taken to insure their conservation.

Key words: brood-rearing, common eider, disturbance, environmental factors, habitat selection, moult, Somateria mollissima

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Received 16 June 2010, accepted 28 January 2011

Associate Editor: Gregory W. Thiemann

In Anatidae, nesting and brood-rearing are crucial periods because they directly affect reproductive output and recruitment. Common eiders *Somateria mollissima* typically have high nest success in the absence of disturbance (Bolduc & Guillemette 2003) but low duckling survival (10-25%), mainly because of gull predation in the first weeks after hatching (Åhlund & Götmark 1989, Mawhinney & Diamond 1999, Donehower & Bird 2008). During brood-rearing, female common eiders must recover from their 26-day fast during incubation (Korschgen 1977) and prepare for the nutrient-demanding wing

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moult (Guillemette et al. 2007). Selection of optimal brood-rearing and moulting habitats is, therefore, essential for this sea duck. Accordingly, the spatial distribution of feeding areas should define primary and secondary brood movements (Bédard et al. 1986, Blinn et al. 2008) and habitat use among moulting birds (Gauthier & Bédard 1976).

Human disturbance may indirectly impact common eider duckling survival through increased gull predation (Åhlund & Götmark 1989, Keller 1991). Young eiders are also susceptible to adverse weather (Mendenhall & Milne 1985, but see Bédard et al. 1986 and Blinn et al. 2008), so broods benefit by selecting sheltered sites throughout the rearing period (Minot 1980). Little is known of the impacts of disturbance to flocks of moulting birds, although the sound of a nearby engine or airplane may lead to relatively high-energy activities (e.g. diving) at the expense of growing new feathers (Frimer 1994).

In our study, we focused on brood-rearing and moulting common eiders in the St. Lawrence River Estuary in southern Quebec. Bédard et al. (1986) described the distribution of eiders in the 1970s, but the current distribution is unknown. Since the 1970s, recreational activities such as kayak excursions, watercraft activities and cottage construction have increased along the shores of the St. Lawrence River while few areas have been protected (e.g. Parc national du Bic). Our main objective was to determine the spatial and temporal distribution of common eiders along the south shore of the St. Lawrence River Estuary and to identify habitats used during the brood-rearing and moulting periods. We also examined the influence of food, human disturbance and shoreline protection on habitat use and distribution.

Material and methods

Study area

Our study took place along a 200-km stretch of shoreline between Notre-Dame-du-Portage (47°4'N, 69°3'W) and Matane (48°5'N, 67°3'W) on the south shore of the St. Lawrence River in Quebec, Canada (Fig. 1). We divided the area into 68 zones according to landscape features (e.g. bay, islet and boulder) and shore accessibility for observers. In total, 157 km, or 78%, of our study area was surveyed. We combined the zones into four geographical areas depending on their proximity to important breeding colonies: Île Blanche (3,000 nests), Île aux Pommes (3,500 nests), Île Bicquette (10,000 nests) and Matane, where no major colony exists (The Joint Working Group on the Management of the Common Eider 2004). Hatching peak occurs during the first week of June (J-F. Giroux, unpubl. data). The St. Lawrence River Estuary is characterized by semi-diurnal tides of 5-6 m amplitude. Substrates along the shorelines of the western portion of our study area consist primarily of mud, whereas those of the eastern section are

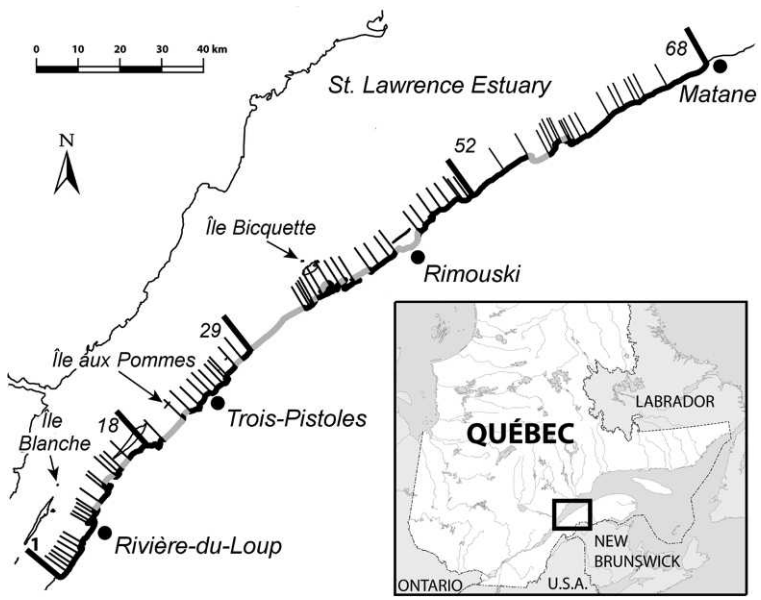


Figure 1. Location of our study area along the south shore of the St. Lawrence River, Quebec. The black lines perpendicular to shore correspond to the limits of the 68 observation zones with identification numbers for the first and last zone of each geographical area, delineated by bold lines. The three main breeding islands correspond to the first three areas (Blanche, Pommes and Bicquette) whereas no colony is located near the fourth area referred as Matane. Shoreline sections not sampled during the surveys are indicated in grey.

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dominated by rocks. Bladderwrack (*Fucus vesiculosus* and *Ascophyllum nodosum*) are the dominant algal species covering the intertidal and shallow subtidal areas (Centre Saint-Laurent 1996). Common eiders feed primarily on periwinkles *Littorina littorea* that are distributed throughout our study area as well as on blue mussels *Mytulis edulis* and amphipods *Gammarus oceanicus*, the latter two being most abundant in the eastern portion of our study area (Cantin et al. 1974, Ardisson & Bourget 1992).

Bird surveys

We conducted ground observations twice a week in 2003 (N = 15) and 2004 (N = 17) from early June to the end of August. We identified and counted birds with a spotting scope (20-60 x). We sexed adult birds and distinguished between maternal and non-maternal females, which consisted of failed breeders, females that abandoned their young or subadult females. Only females with the 'leading' behaviour (status 'B' in Bédard & Munro 1977) were considered maternal. Moulting birds could not always be identified with confidence from a distance. Therefore, we considered that adult eiders observed in August represented birds that were either preparing for their moult, moulting or having just completed their moult. We visited the zones at different times of the day, between 06:30 and 20:00, throughout the summer, but usually with the same tide condition because some zones were more easily surveyed at high tide while others were more accessible at low tide. H. Diéval conducted all surveys in 2003 and was aided by an assistant in 2004. Training sessions were conducted at the beginning of 2004 and on several occasions throughout the summer to insure consistency in counting and aging birds between the two observers. To standardize observations, we computed densities of birds per km of shoreline. For each zone, we calculated the mean number of individuals per survey for each category of birds (maternal females, ducklings, non-maternal females and males). We then compared the four areas and the three periods (June, July and August) using each zone as a sampling unit.

Human disturbance

Disturbance was defined as human activity that could induce a visible reaction from the birds (swimming, diving or taking off). Presence or absence of humans along the shoreline or on the water was noted by an instantaneous scan of the zone at the beginning of each survey. In 2004, we also characterized the intensity of disturbance for each person observed along the shore: low (immobile), moderate (moderately active such as walking) and extreme (running, shouting or approaching eiders). When the disturbance was on the water, similar criteria were used: low (immobile and anchored boat), moderate (slow-moving canoes and kayaks) and extreme (fast-moving kayaks and speedboats). We developed an overall human disturbance index using the first component of a principal component analysis that considered five variables: 1) the frequency of human disturbance, 2) the total number of persons/km and the number of persons in 3) passive, 4) moderate and 5) extreme activity/km. This first component explained 74% of the variation. In 2003, we simply calculated the proportion of surveys with human presence for each zone.

Bio-physical characteristics

We established transects perpendicular to the shore to characterize the entire intertidal area of 38 zones that were chosen randomly. Number of plots per zone varied between 100 (zone with < 40 ha of intertidal area) and 200 (zone with > 40 ha of intertidal area) for a total of 5,644 plots along 409 transects. All transects were equidistant in each zone, as well as the plots along each transect, making it a systematic sampling throughout the area where the bird surveys took place. Plots had a radius of 30 cm (0.28 m^2) and sampling took place at low tide. We classified substrate at the centre of each plot as mud, sand, gravel, stone, rock or boulder using Wentworth size class (Folk 1980) and expressed each substrate as a percentage for the entire zone. Percentages were included into a principal component analysis and the first component, which explained 42% of the total variation, was used to characterize the substrate of the zone. Algal and mussel cover were recorded separately in each plot as: 0 = absence, 1 = 1-25%, 2 = 26-50%, 3 = 51-75% and 4 = 76-100%. We recorded periwinkles and amphipods as either present or absent in each plot and then expressed them as a percentage of the zone. Mussel cover and the presence of periwinkles and amphipods were used as an index of food availability.

A shoreline sinuosity index was calculated from digitized maps (1:50,000) using ArcView to characterize shoreline protection from wind and currents. We divided the length of the straight distance between the two limits of each observation zone by the total length of the shoreline within the zone.

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A sinuosity index of 1 referred to a straight shoreline, whereas a bay or a sinuous shoreline resulted in an index of < 1.

Statistical analyses

We first used data from Bédard et al. (1986, Fig. 1.1) for a historical comparison of eider distribution in our study area between 1972 and 2003-2004. Bédard et al. (1986) did not distinguish between maternal and non-maternal females, so we combined the two categories for 2003-2004. For 1972, the mean number of birds in all zones of our study area was calculated ($N = 26$) and compared with the mean for the 68 zones surveyed in 2003 and 2004 using ANOVA with post-hoc Tukey-Kramer tests. We used the same tests to explore temporal changes within each of the four geographic areas.

We also used ANOVA with post-hoc Tukey tests to compare the shore bio-physical characteristics among the four geographical areas, as well as the eider distribution among the four areas and four bird categories. Because of lack of normality, Spearman's rho correlation coefficients were calculated on densities among the different categories of eiders using the 68 zones for each year as well as between years for each category.

Finally, we used stepwise multiple regressions to identify environmental variables explaining distribution of each eider category at the 38 sampled zones. We included five variables: shoreline sinuosity, human disturbance index, blue mussel cover and presence of periwinkles and amphipods. Substrate type and algal cover were excluded from this analysis because they were related to the presence of periwinkle, causing multicollinearity. Angular transformations were applied to proportions for the analyses, but the untransformed means are presented throughout (Zar 1996). Analyses were made with JMP IN software (Sall et al. 2001).

Results

Historical comparison

For the entire area, there were about half as many adult females in 2003 and 2004 than in 1972 ($F_{2,159} = 7.77$, $P < 0.001$; Table 1). Likewise, duckling density in 2004 was three times less than in 1972 ($F_{2,159} = 11.5$, $P < 0.001$). Male density, however, did not change over the years ($P > 0.05$). In the Bicquette area, the abundance of birds was lower in 2003 and 2004 than in 1972 for females ($F_{2,52} = 5.90$, $P = 0.005$), ducklings ($F_{2,52} = 12.88$, $P < 0.001$) and males ($F_{2,52} = 7.17$, $P = 0.002$). The number of females was also much reduced in recent years compared to 1972 in the Matane area ($F_{2,37} = 3.655$, $P = 0.04$). Finally, there was no difference among years in the Blanche and Pommes areas (see Table 1).

Table 1. Historical comparison of the density (number of birds/km of shore) of common eiders in the St. Lawrence Estuary, Quebec. Females include both maternal and non-maternal females. Data for 1972 are from Bédard et al. (1986). Means followed by the same letters are not significantly different across years (Tukey-Kramer tests, $P > 0.05$).

		1972			2003			2004		
Category	Area	Mean	SE	N	Mean	SE	N	Mean	SE	N
Females	Blanche	8.5^{A}	3.4	6	7.5^{A}	1.8	18	8.0^{A}	2.1	18
	Pommes	17.3^{A}	0.7	3	9.2^{A}	1.8	11	11.4^{A}	2.1	11
	Bicquette	32.2^{A}	4.1	11	17.1^{B}	2.9	22	16.1^{B}	2.9	22
	Matane	54.3^{A}	24.0	6	17.6^{B}	3.5	17	27.7^{AB}	6.0	17
	Total	30.1^{A}	6.6	26	13.4^{B}	1.5	68	16.1^{B}	1.9	68
Males	Blanche	0.8^{A}	0.8	6	0.5^{A}	0.2	18	1.8^{A}	0.6	18
	Pommes	1.7^{A}	1.7	3	0.6^{A}	0.2	11	2.4^{A}	0.7	11
	Bicquette	13.6^{A}	11.9	11	3.6^{B}	4.8	22	6.6^{B}	1.3	22
	Matane	38.3^{A}	22.9	6	30.6^{A}	13.0	17	52.1^{A}	11.7	17
	Total	15.0^{A}	5.9	38	9.0^{A}	3.5	68	16.0^{A}	3.9	68
Ducklings	Blanche	7.7^{A}	4.5	6	14.5^{A}	3.4	18	6.3^{A}	1.6	18
	Pommes	8.3^{A}	1.5	3	11.5^{A}	3.1	11	4.8^{A}	1.2	11
	Bicquette	18.0^{A}	11.1	11	10.5^{B}	8.1	22	4.2^{C}	3.7	22
	Matane	8.2^{A}	4.0	6	6.4^{A}	2.3	17	2.5^{A}	0.8	17
	Total	12.2^{A}	2.1	26	10.7^{A}	1.3	68	4.4^{B}	0.6	68

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Table 2. Spearman correlation coefficients of the density (number of birds/km of shore) of common eiders between pairs of age and sex categories along the St. Lawrence Estuary, Quebec, during 2003-2004. * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$; df = 66.

Comparison	2003	2004
Maternal females vs ducklings	0.94 ***	0.94 ***
Maternal females vs non-maternal females	0.20	0.37 **
Maternal females vs males	0.22	0.06
Non-maternal females vs ducklings	0.28 *	0.34 **
Non-maternal females vs males	0.65 ***	0.72 ***
Males vs ducklings	0.02	0.01

Spatial and temporal variation in eider distribution

The density of maternal females was highly correlated with duckling density but not with adult males (Table 2). The distribution of non-maternal females was moderately correlated with the distribution of males and slightly with ducklings (see Table 2). There was a seasonal reduction in the strength of the correlations in the distribution of maternal and non-maternal females (2003: $r_{June} = 0.48$, $P < 0.001$; $r_{July} = 0.28$, $P < 0.01$ and $r_{August} = 0.31$, $P < 0.001$; 2004: $r_{June} = 0.53$, $P < 0.001$; $r_{July} = 0.44$, $P < 0.001$ and $r_{August} = 0.33$, $P < 0.001$).

Broods generally used the same sites in 2003 and 2004 within each geographical area except for ducklings in the Bicquette area (Table 3). Values of the correlation coefficients declined for non-maternal females from Blanche to Matane. This indicates that a greater proportion of the population consistently used the western portion of our study area across years. Male densities were correlated between years only for Bicquette and Matane (see Table 3), possibly reflecting the low numbers of males in the western areas and the concentration of moulting birds in August in the eastern area.

There was considerable variation in bird density between and within years as well as among areas and eider categories (Fig. 2). Non-maternal females were more abundant than maternal females in both 2003 and 2004. They were principally found in the eastern part of our study area with maximum numbers occurring in August. Male densities were highest in Matane for all months and years (June 2003: $F_{3,67} = 4.9$, $P < 0.01$; July 2003: $F_{3,67} = 4.9$, $P < 0.01$; August 2003: $F_{3,67} = 3.6$, $P < 0.02$; June 2004: $F_{3,67} = 24.0$, $P < 0.001$; July 2004: $F_{3,67} = 10.0$, $P < 0.001$ and August 2004: $F_{3,67} = 6.2$, $P < 0.001$). There were more non-maternal females in Matane in August 2003 and 2004 than in the other areas (2003: $F_{3,67} = 3.8$, $P < 0.02$; 2004: $F_{3,67} = 6.7$, $P < 0.001$). Non-maternal females showed little annual variation whereas the total number of maternal females and ducklings were lower in 2004 than 2003 ($F_{1,135} = 17.7$, $P < 0.001$) indicating decreased production during the second year of our study. The Blanche and Bicquette areas had high numbers of broods during June and July, but these numbers declined as they moved eastward in August ($F_{3,67} = 4.2$, $P < 0.01$). Generally, brood numbers were higher around the main breeding areas compared to Matane.

Influence of environmental factors on eider density

There was a greater proportion of muddy shores in the western parts of our study area ($F_{3,37} = 9.3$, $P < 0.001$; Table 4) and more rocky shores in the east ($F_{3,37} = 3.0$, $P < 0.05$). Shoreline sinuosity was similar in the four areas whereas human disturbance in Matane and Bicquette was greater than at Blanche ($F_{3,37} = 6.0$, $P < 0.002$). The presence of blue mussels and amphipods was greater in the east than in the west ($F_{3,37} = 13.6$, $P < 0.001$; $F_{3,37} = 8.2$, $P < 0.001$, respectively).

At the scale of the estuary, the distribution of maternal females was associated positively with the presence of periwinkles and negatively with mussel cover in 2003 and 2004 (Table 5). Duckling numbers were mainly correlated to periwinkle abundance while non-maternal females were distributed according to mussels in 2003 and gammarids in 2004. Moreover, non-maternal females showed seasonal differences. In 2003, for instance, they were distrib-

Table 3. Spearman correlation coefficients of the density (number of birds/km of shore) of four categories of common eiders in four regions of the St. Lawrence Estuary between 2003 and 2004. * $P < 0.05$, ** $P < 0.01$ and *** $P < 0.001$.

Geographical area (N)	Maternal females	Ducklings	Non-maternal females	Males
Blanche (18)	0.94 ***	0.86 ***	0.84 ***	0.29 n.s.
Pommes (11)	0.64 *	0.62 *	0.62 *	0.48 n.s.
Bicquette (22)	0.66 ***	0.38 n.s.	0.41 *	0.41 *
Matane (17)	0.74 ***	0.67 **	0.35 n.s.	0.45 *

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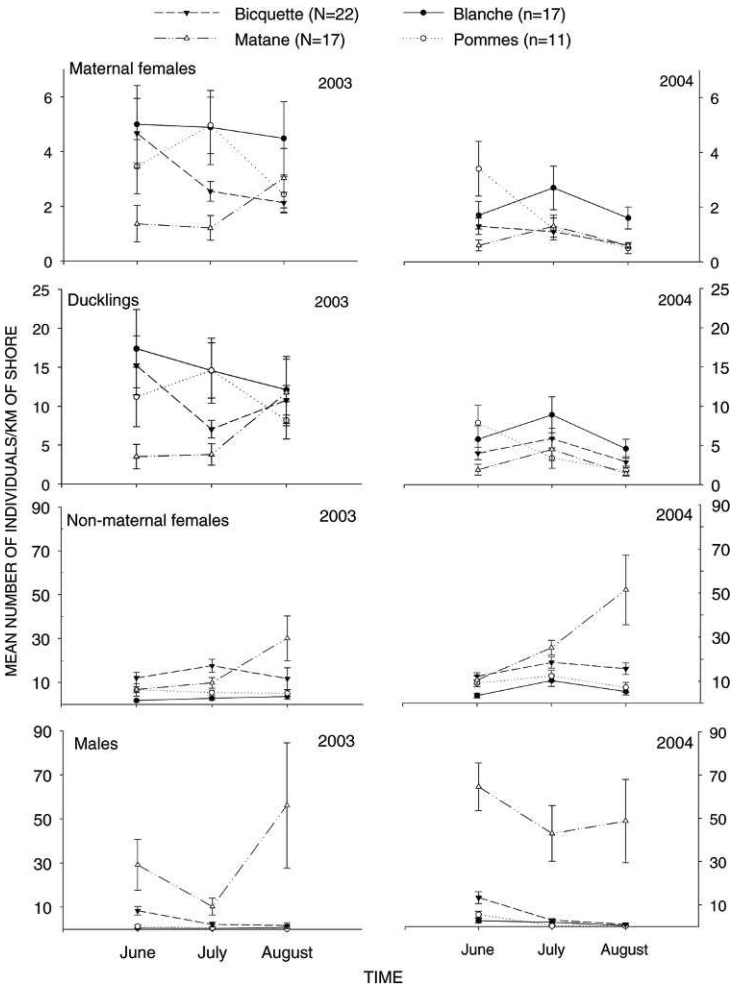


Figure 2. Density of common eiders during the summer in the St. Lawrence Estuary, Quebec, in 2003 and 2004. Data are means ± SE. Note that the y axes vary among bird categories.

uted according to gammarid abundance in June ($R^2 = 0.35$, $F_{2,37} = 9.5$, $P < 0.001$) and mussel cover in July ($R^2 = 0.37$, $F_{2,37} = 10.3$, $P < 0.001$) and August ($R^2 = 0.28$, $F_{1,37} = 14.2$, $P < 0.001$). No seasonal variation was observed for maternal females and their ducklings. In both years, male distribution was only influenced by blue mussel abundance and this was consistent throughout the summer months. Our indices of shoreline protection and human disturbance were not correlated with the distribution of eiders.

Discussion

We have shown that common eiders are not distributed randomly along the St. Lawrence Estuary during the brood-rearing and moulting periods and that food resources appear to be the main factor influencing their distribution. Broods first concentrate along the mainland shores in the vicinity of the nesting islands before moving further downstream. Adult males quickly reach the moulting sites located downstream while non-maternal females exhibit a combination of these two strategies.

Considering the annual variation in bird density between 2003 and 2004, however, caution is required when discussing long term differences based on a limited number of years. Adult common eiders generally have high survival rate (ca 85%; Krementz et al. 1996) and long life expectancy (ca 21 years; Coulson 1984). The decrease in the number of adult females may be due to avian cholera outbreaks that occurred in the mid-80s and again in 2002 on most of the breeding islands of the St. Lawrence Estuary (The Joint Working Group on the Management of the Common Eider 2004). We estimated that 20% of nesting females were killed in 2002 (J-F. Giroux, J. Bédard & J-P. Savard, unpubl. data). The decline was more pronounced in the Bicquette area

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Table 4. Bio-physical characteristics of the shores used by common eiders during brood-rearing and moulting along the St. Lawrence Estuary, Quebec. For each parameter, means followed by the same letters are not significantly different (Tukey-Kramer tests, $P > 0.05$).

	Geographical areas														
	Blanche			Pommes			Bicquette			Matane			Study area		
Parameters	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N
Shore length (km)	1.7	0.2	18	2.1	0.2	11	2.3	0.3	22	3.1	0.7	17	2.3	0.2	68
Shoreline sinuosity	0.8 ^{A}	0.1	10	0.9 ^{A}	0.1	5	0.7 ^{A}	0.1	13	0.8 ^{A}	0.1	10	0.8	0.1	38
Frequency of human-disturbance (%)	14.7 ^{A}	6.6	10	40.0 ^{AB}	9.3	5	51.1 ^{B}	5.8	13	41.1 ^{B}	6.6	10	37.4	4.0	38
Total number of humans/km	5.5 ^{A}	39.5	10	25.4 ^{A}	55.8	5	90.5 ^{A}	34.6	13	11.5 ^{A}	39.5	10	38.7	20.4	38
Number of passive persons/km	0.6 ^{A}	22.9	10	2.8 ^{A}	32.4	5	42.1 ^{A}	20.1	13	2.2 ^{A}	22.9	10	15.5	11.7	38
Number of moderate persons/km	2.5 ^{A}	12.7	10	18.3 ^{A}	17.9	5	37.4 ^{A}	11.1	13	7.1 ^{A}	12.6	10	17.7	6.6	38
Number of high activity persons/km	2.3 ^{A}	4.7	10	4.2 ^{A}	6.4	5	10.9 ^{A}	4.0	13	2.3 ^{A}	4.7	10	5.5	2.3	38
Nature of substrate (%): mud	44.0 ^{A}	6.2	10	7.7 ^{B}	8.7	5	8.5 ^{B}	5.4	13	2.9 ^{B}	6.2	10	16.3	4.1	38
Sand	15.9 ^{A}	5.5	10	27.9 ^{A}	7.8	5	28.2 ^{A}	4.8	13	14.4 ^{A}	5.5	10	21.3	2.9	38
Gravel	16.2 ^{A}	3.3	10	23.7 ^{A}	4.7	5	24.2 ^{A}	2.9	13	29.4 ^{A}	3.4	10	23.4	1.8	38
Stone	13.0 ^{A}	2.8	10	25.1 ^{A}	4.0	5	17.0 ^{A}	2.5	13	19.7 ^{A}	2.8	10	17.7	1.5	38
Rock	7.1 ^{A}	4.8	10	10.5 ^{AB}	6.8	5	17.1 ^{AB}	4.2	13	26.7 ^{B}	4.8	10	16.1	2.6	38
Boulder	3.8 ^{A}	1.8	10	4.9 ^{A}	2.5	5	3.1 ^{A}	1.6	13	6.8 ^{A}	1.8	10	4.5	0.9	38
Algal cover (%)	14.4 ^{A}	2.8	10	23.2 ^{A}	4.0	5	15.5 ^{A}	2.5	13	18.1 ^{A}	2.8	10	16.9	1.5	38
Blue mussel cover (%)	0.6 ^{A}	1.7	10	9.8 ^{B}	2.4	5	10.9 ^{B}	1.5	13	15.9 ^{B}	1.7	10	9.4	1.3	38
Percentage of plots with periwinkles	49.5 ^{A}	7.6	10	74.8 ^{A}	5.2	5	60.3 ^{A}	7.7	13	70.0 ^{A}	2.2	10	61.9	3.6	38
Percentage of plots with amphipods	24.6 ^{A}	3.7	10	51.8 ^{B}	5.3	5	38.8 ^{B}	3.3	13	46.5 ^{B}	3.7	10	38.8	2.4	38

where the largest breeding colony (ca 10,000 pairs) is located and in the Matane area used by non- or failed breeders.

Maternal females with ducklings used the same rearing sites year after year, as previously reported by Munro & Bédard (1977). When leaving the islands, broods move along the mainland shores closest to their original breeding islands (Gauthier & Bédard 1976). Great black-backed gulls *Larus marinus* and herring gulls *Larus argentatus* often nest on islands with eiders and prey heavily upon ducklings near the colonies (Swennen 1989, Bolduc & Guillemette 2003, Donehower & Bird 2008). Along the mainland shores, however, gull predation is rare because it is probably unprofitable for them to reach the mainland. During two years, we witnessed only one instance of predation by two great black-backed gulls on a 20-day old duckling. Annual difference in duckling distribution was probably related to the reduced number of broods in the second year when many zones that were used in 2003 were not used in 2004. Adverse weather conditions during the hatching peak may have been responsible for the reduced production (Mendenhall & Milne 1985). During the first 15 days of June, precipitation totaled 220 mm in 2004 but only 27 mm in 2003, while wind gust > 30 km/hour occurred during 12 days in 2004 and only six in 2003 (Environment Canada, Station Rivière-du-Loup).

Table 5. Environmental variables that explained the density (number of birds/km of shore) of different categories of common eiders in 2003 and 2004, along the St. Lawrence Estuary, Quebec (N = 38 zones). Regression coefficients (± SE) are presented for each significant variable entered into the model. * $P < 0.05$ and ** $P < 0.001$.

	2003				2004			
Category	Statistical model	R^2	F	P	Statistical model	R^2	F	P
Maternal females	- 1.9 mussels (± 0.79)* + 2.0 periwinkles (± 0.53)**	0.28	7.1	< 0.002	- 1.22 mussels (± 0.55)* + 1.51 periwinkles (± 0.37)**	0.31	8.1	< 0.001
Ducklings	1.69 periwinkles (± 0.6)*	0.16	7.1	< 0.01	- 1.84 mussels (± 0.87)* + 2.50 periwinkles (± 0.58)**	0.34	9.23	< 0.001
Non-maternal females	3.70 mussels (± 0.77)**	0.38	22.9	< 0.0001	3.91 gammarids (± 0.75)**	0.42	26.8	< 0.001
Males	4.37 mussels (± 0.9)**	0.39	23.3	< 0.0001	3.84 mussels (± 1.04)**	0.27	13.59	< 0.001

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Maternal females used zones with more periwinkles but with fewer mussels, thus selecting optimal habitats for their ducklings, but less productive for themselves (Cantin et al. 1974, Öst & Kilpi 1999). Nyström et al. (1991) and Öst & Kilpi (2000) found that broods tended to distribute according to the preferred prey of young in the Baltic Sea but in New Brunswick, Blinn et al. (2008) failed to find a relationship between duckling abundance and rockweed *Ascophyllum nodosum* beds known to support periwinkles and gammarids. Nevertheless, they found that sites with a gradual slope and with shallower depth that offered larger feeding areas were used to a greater extent by broods than sites with a steep slope.

Gauthier & Bédard (1976) and Bédard et al. (1986) observed that moulting sites for females were mainly located in the Matane area. Non-maternal females were more likely to be located in this area in August, but we failed to find consistent use of local sites in successive years. Non-maternal females were probably failed-breeders or birds that had lost their ducklings after hatching through predation or brood amalgamation and their numbers vary annually, depending on hatching and brood-rearing success (Milne & Reed 1974, Mawhinney & Diamond 1999, Mawhinney et al. 1999). In 2004, the reduced production of young implied a greater number of non-maternal females than in 2003. Kilpi et al. (2001) found that individual females can switch from maternal to non-maternal behaviour according to their body condition. Thus, non-maternal females are less likely to be the same individuals each year, which would explain the weak correlation between 2003 and 2004 in the density of non-maternal females in the Matane area.

Non-maternal females need to recover some energy before undertaking their moult. The persistence of maternal behaviours (Schmutz et al. 1982) and poor body condition (Korschgen 1977, Kilpi & Lindström 1997) just after hatching may explain why some of these females tended to follow broods in June. They gradually moved eastward during the summer, as shown by the increasing numbers in Matane in August, where richer prey like blue mussels are available. Cantin et al. (1974) observed that non-maternal females moved further from shore (seawards) than maternal females, possibly to feed on mussels, whereas maternal females fed in the intertidal zone on periwinkles with their ducklings. We would expect a greater range in the body condition of non-maternal than maternal females as some would have lost their clutch early on, whereas others would have lost their ducklings or may not even have bred (Coulson 1984).

Gauthier & Bédard (1976) found that 93% of females tagged on the breeding islands were observed on the south shore of the St. Lawrence River. However, the number of maternal and non-maternal females observed along the south shore compared to the breeding population (ca 30,000 breeding pairs; The Joint Working Group on the Management of the Common Eider 2004) suggests that a portion of adult females migrate just after the nesting period to moult outside of our study area. It is still unknown whether maternal females undertake their moult while attending their broods.

Male eiders stay close to breeding islands until one week after nest initiation (McKinney 1961). Most have left the surroundings of the breeding islands when young have hatched (Bédard et al. 1986). In fact, the majority of males observed during our study were already at moulting sites in the eastern part of our study area as early as June. The total number of males observed in our area was much lower than expected based on the breeding population, suggesting that a significant proportion of males also migrate to moulting sites outside of our study area. Rail & Savard (2003) has noted large concentrations of moulting males around Anticosti Island and a few small ones along the north shore of the estuary. Similarly, Mosbech et al. (2006) found that all their male common eiders implanted with satellite transmitters moved $>$ 100 km from breeding colonies to moult.

In the Matane area, the same moulting sites were consistently used by males across years, but we could not establish whether common eiders were faithful to their moulting sites as shown for Steller's *Polysticta stelleri* and king eiders *Somateria spectabilis* in Alaska (Flint et al. 2000, Phillips & Powell 2006). During both years, male common eiders were distributed according to the abundance of blue mussels in the eastern part of the estuary. Contrary to some non-maternal females that suffer from energy depletion during the breeding season, males are not as energetically stressed after breeding and are likely less constrained to move to optimal sites with mussel beds.

Substrate and food availability were only measured in 2004, but we are confident that the same values could be used to explain the 2003 distribution of eiders. At the scale of the estuary, the substrate is unlikely to have changed between years. Bayne

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(1964) and Armonies (1996) found that spats of young blue mussels settle on existing adult mussel beds year after year. Similarly, Saier (2000) and Dethier & Schoch (2005) found a similar spatial distribution of periwinkles in consecutive years. Furthermore, the frequency of the presence of humans along the shoreline was similar in both years ($P > 0.05$).

Human disturbance and shoreline protection did not influence the distribution and density of common eiders in the St. Lawrence Estuary. Human related disturbances affect duckling survival mainly by enhancing gull predation (Åhlund & Götmark 1989, Keller 1991, Hamilton 2001). This was not a problem along the south shores of the St. Lawrence River because gulls spent more time foraging near the nesting islands. It is also possible that disturbance levels recorded along the shores of the St. Lawrence River were not sufficient to adversely affect eider distribution, although they influenced their activity (Diéval 2006). Near Grand Manan Island, Blinn et al. (2008) found a negative correlation between duckling abundance and the number of passing boats. However, boat traffic appears much more important in New Brunswick than in Quebec.

We suspect that shoreline protection has little influence on eider distribution at the landscape level (ca 2 km long), but may be important locally (~100 m). Significant scale effects have been observed with respect to eider distribution by Chaulk et al. (2007). Minot (1980) found that sheltered shore sections were preferred by broods during some weather and tide conditions. Bédard et al. (1986) as well as Blinn et al. (2008) failed to find such influence in the St. Lawrence Estuary and the Bay of Fundy, respectively. Our results suggest that eider density during the brood-rearing and moulting periods was probably influenced more by the spatial distribution of food resources than by any other environmental variables.

In conclusion, we identified the main brood-rearing and moulting sites of common eiders along the south shore of the St. Lawrence River. Food abundance was the most important characteristic predicting the presence of eiders. There is growing pressure to exploit these intertidal habitats for mussel farming or algae harvesting that may lead to changes in food distribution or abundance (Žydelis et al. 2009). Most nesting islands have been secured and protected, but conservation of the integrity of rearing and moulting habitats is required to ensure appropriate management. Our study provides useful information to identify areas in the St. Lawrence Estuary that should receive some form of protection.

Acknowledgements - we thank Environment Canada and the Sea Duck Joint Venture for their financial assistance. The Parc National du Bic, the Université du Québec à Rimouski, the Université du Québec à Montréal and Fisheries and Oceans Canada provided logistical and financial support. We are grateful to field assistants E. Lessard and F. Beaucher and to S. Craik and K. Chaulk for their critical review and improvement of the manuscript.

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