Submerging floating oyster bags: an effective means for deterring coastal birds from roosting in aquaculture farms

P. St-Onge, L. A. Comeau, F. Pernet

Fisheries and Oceans
Gulf Fisheries Centre
Oceans and Science Branch
Mollusk Productivity Section
P.O. Box 5030, Moncton, NB, E1C 9B6

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by

P. St-Onge[1,2], L. A. Comeau[1*], F. Pernet[2]

Department of Fisheries and Oceans
Gulf Fisheries Centre
Oceans and Science Branch
Mollusk Productivity Section
P.O. Box 5030, Moncton, NB, E1C 9B6

[1]Department of Fisheries and Oceans Canada, Moncton, NB, E1C 9B6
[2]Institut de Recherche sur les Zones Côtières, Shippagan, NB, E8S 1J2

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Abstract

P. St-Onge, L.A. Comeau, F. Pernet. 2007. Submerging floating oyster bags: an effective means for deterring coastal birds from roosting in aquaculture farms. Can. Tech. Rep. Fish. Aquat. Sci. 2741.

In New Brunswick, floating bags are commonly used to cultivate American oysters (*Crassostrea virginica*). They are also incidentally used by several coastal bird species that take advantage of their presence to roost on them. The goal of this experiment was to compare bird diversity and abundance in relation to three deployment strategies: (1) a standard deployment (S) with the top portion of bags floating above surface; (2) a modified deployment (M1) with bags completely submerged approximately 3 cm under the surface; and (3) another modified deployment (M2) with bags submerged about 6 cm under the surface. The study was carried out in 2006 at three sites along the eastern coast of New Brunswick: Caribou Bay (CA), Neguac Bay (NE) and Richibucto Bay (RI). Results showed that bird diversity for all types of gear deployment was skewed towards a single species, the double-crested cormorant (*Phalacrocorax auritus*), which accounted for 84% of all observations. Gear type had a significant effect on bird diversity, total abundance of birds and abundance of *P. auritus*. Standard bags consistently attracted a significantly greater number of individuals and species compared to modified bags (Tukey's HSD). Mean species richness for standard bags was approximately twice the value observed for M1 bags and eight times the value of M2 bags. M2 bags reduced the abundance of roosting birds by approximately 38% when compared to standard bags. No significant interactions were detected between gear type and time of sampling, thus suggesting that the gear type effect is robust in time. Overall results indicate that submerging oyster bags a few centimetres below the surface significantly reduces the abundance and diversity of birds within oyster farms.

Résumé

P. St-Onge, L.A. Comeau, F. Pernet. 2007. Submerging floating oyster bags: an effective means for deterring coastal birds from roosting in aquaculture farms. Can. Tech. Rep. Fish. Aquat. Sci. 2741.

Au Nouveau-Brunswick, les poches flottantes sont communément utilisées pour cultiver les huîtres américaines (*Crassostrea virginica*). Ces structures aquacoles peuvent également être utilisées par plusieurs espèces d'oiseaux marins qui profitent de leur présence en s'y perchant. Le but de cette expérience était de comparer la diversité d'oiseaux et leur abondance en relation avec trois stratégies de déploiement: (1) un déploiement standard (S), avec la partie supérieure des poches qui flotte au-dessus de la surface de l'eau ; (2) un déploiement modifié (M1) avec les poches complètement submergées approximativement 3 cm sous la surface de l'eau ; et (3) un autre déploiement modifié (M2) avec les poches complètement submergées environ 6 cm sous la surface de l'eau. Cette étude a été réalisée en 2006 au niveau de trois sites localisés sur le long de la côte orientale du Nouveau-Brunswick : Baie de Caribou (CA), Baie de Néguac (NE) et Baie de Richibucto (RI). Les résultats ont montré que la diversité des oiseaux pour tous les types de déploiements était inclinée vers une seule espèce, le cormoran à aigrettes (*Phalacrocorax auritus*), qui représentait 84% de toutes les observations. Le type de poche a eu un effet significatif sur la diversité d'oiseaux, l'abondance totale d'oiseaux ainsi que l'abondance de *P. auritus*. De plus, les poches standard attiraient toujours une quantité supérieure d'oiseaux et d'espèces que les poches M2 (Tukey's HSD). La richesse moyenne observée au niveau des poches standard avait une valeur qui était approximativement le double des poches M1 et huit fois la valeur des poches M2. Un pourcentage de réduction moyen de 38% a été observé au niveau des poches M2 en comparaison avec les poches standard. Aucune interaction significative entre le type de poche et le temps d'échantillonnage n'a été détectée, suggérant ainsi un effet robuste du type de poche dans le temps. Les résultats de cette étude suggèrent que les poches flottantes submergées sont un moyen efficace pour empêcher les oiseaux de se percher sur les poches d'huîtres.

Introduction

Aquaculture of American oysters (*Crassostrea virginica*) in New Brunswick (NB) is mostly carried out using floating UV resistant PVC bags (also known as Vexar or Durethene bags) (GTA Consultants en Pêches, 2003). This technique optimizes the growth and production of oysters by maintaining the filter-feeding animals close to the water surface where temperatures are relatively warm and phytoplankton is abundant (Figure 1). The industry has been developing and improving the floating gear technique for the past two decades.

In spite of obvious advantages associated with this technique, floating bags also provide an important amount of roosting platforms for coastal bird species (Comeau et al., 2006). Communal roosting on oyster gear is a cause for concern in the aquaculture industry since bird fecal matter deposited on floating bags could contaminate market-sized oysters. Following routine sampling in September 2004, the Canadian Food Inspection Agency (CFIA) and Environment Canada (EC) obtained oyster and water samples that exceeded the standard for fecal coliforms. The situation was considered risky for human health and both agencies recommended that culture sites situated in the waters of eastern NB immediately be closed to harvesting. The Department of Fisheries and Oceans (DFO) thus proceeded with a closure order. As a result, production and marketing activities had to be temporarily stopped at more than 150 aquaculture sites.

Use of suspended gear is presently authorized for growing oysters until they reach market size (> 65 mm). A new policy was adopted to ensure the decontamination of market-sized oysters prior to harvesting. It involves converting suspended gear into non-floating gear, thus allowing a complete immersion of the bags at the depuration site. From the industry's perspective, this procedure is not a feasible option because it results in higher losses in capital investments, increases the amount of labour and lengthens the production cycle. Therefore, the industry acknowledges that any potential means to reduce fecal contamination needs to be seriously considered.

Communal roosting is a common behaviour in several species of social animals including coastal birds (McGowan et al., 2006). This behaviour is known to have evolved independently numerous times (Beauchamp, 1999; McGowan et al., 2006) and is thought to enhance sharing of information (Ward and Zahavi, 1973; Ydenberg and Prins, 1984; Dall, 2002) and population recruitment (Richner and Heeb, 1996; Dall, 2002). Increases in foraging efficiency and decreases in predation risk and thermoregulatory cost are also considered as major benefits of the behaviour (Ydenberg and Prins, 1984; Beauchamp, 1999; McGowan et al., 2006). In an ecological context, the phenomenon has already been studied extensively, which allowed the scientific community to gain knowledge on roost choice (e.g. Luís et al., 2001; Rogers, 2003; Rogers et al., 2006) and species distribution (e.g. King, 1996; Bugoni and Vooren, 2005; Dittman et al., 2005). However, knowledge on roosting behaviour associated with shellfish farming is limited and needs to be studied more extensively.

In New Brunswick, the double-crested cormorant (*Phalacrocorax auritus*) was the most abundant species (48% of total bird count) that roosted in oyster farms in 2005, followed by the herring gull (*Larus argentatus*) (17%) and the common tern (*Sterna*

hirundo) (13%) (Comeau et al., 2006). These species are not considered oyster predators and were mostly seen preening and drying their wings (Comeau et al., 2006). Interactions between gregarious shorebirds and aquaculture activities have also been noticed elsewhere (e.g. Dorr et al., 2004; King, 2005; Roycroft et al., 2007). Conservationists are worried that shorebird populations might experience disturbance by aquaculture facilities (Cornelius et al., 2001; Bechard and Marquez-Reyes, 2003). Aquaculture operators consider them as nuisances as they are known to increase predation (e.g. Jenkins and Smith, 1998; Dorr et al., 2004; King, 2005), fecal contamination (e.g. Kirschner et al., 2004; Kuntz et al., 2004; Bucio et al., 2006), propagation of pathogen agents (e.g. Flowers et al., 2004; Overstreet and Curran, 2004; Mitchell et al., 2005) and eutrophication by seagrass enrichment (e.g. Powell et al., 1991).

Considerable advancements has been made to discourage birds from roosting in areas where they cause disturbance, although some methods remain unsuccessful or logistically impossible to use in or around aquaculture facilities (see review by Mott and Boyd, 1995). These methods include scaring effigies (e.g. Stickley et al., 1995; Seamans, 2004), repelling chemicals (e.g. Cotterill et al., 2004; McWilliam and Cheke, 2004; Harpaz and Clark, 2006), fencing and netting (e.g. Mott and Flynt, 1995; Nemtzov and Olsvig-Whittaker, 2003), harassment devices (e.g. Mott et al., 1998; Tobin et al., 2002) and more drastic methods like hunting (e.g. Bechard and Marquez-Reyes, 2003; McWilliam and Cheke, 2004). In New Brunswick, the oyster industry has begun giving serious consideration to low-cost gear modifications which could effectively deter birds from using the gear without having to resort to bird scaring devices.

Coastal birds often change their roost location upon the rising of tides (e.g. Luís et al., 2001; Rogers, 2003; Rosa et al., 2006), partly to remain dry. Completely submerging floating bags under the surface at water depths greater than bird tarsus lengths could thus be considered a low-cost modification that may discourage birds from roosting on floating bags. In 2005, a few oyster farms deployed a small number of submerged bags as a preliminary test of this hypothesis. The gear modification consisted of positioning the two side floaters onto the top of the oyster bag, allowing the bag to remain in the optimal growth zone by sinking approximately 3 cm below the water surface. While the two floaters remained a potential perching platform, they represented less than 20% of the total area normally offered to birds with standard bags. Comeau et al. (2006) reported low bird counts for the submerged gear and concluded that the design warranted experimental testing.

This document reports on the results of an experiment that was carried out in the summer and fall of 2006 to test the effects of submerged floating bags on the behaviour of roosting birds according to (1) species richness (number of species), (2) abundance of birds (all species included), (3) abundance of *Phalacrocorax auritus*, the most common species seen roosting on floating oyster bags in 2005 (Comeau et al., 2006) and (4) abundance of *Larus* spp, the second most common species seen roosting on floating oyster bags in 2005 (Comeau et al., 2006). All four variables were predicted to significantly decrease depending on treatment, from S to M1 to M2 bags, respectively.

Methods

Study sites

This study was carried out in three bays situated along the eastern coastline of New Brunswick: (1) Caribou Bay near Shippagan, NB (hereafter CA); (2) Neguac Bay in Neguac, NB (hereafter NE); and (3) Richibucto Bay, near Indian Island, Richibucto, NB (hereafter RI) (Figure 2). These sites were located at a substantial distance (approximately 0.5 km) from any other aquaculture activity.

Gear types

Birds were offered three different types of floating Vexar® bags. (1) The s*tandard* floating bag (hereafter S) (Figure 3a, dimensions: 80 cm × 40 cm × 10 cm) is currently used by all farmers working with this technique and was included in this study as a control treatment. These bags were suspended by two lateral cylindrical buoys, one attached at each side of the bag, which allowed them to be partially immersed in water. (2) A *first modification* to this standard bag (hereafter M1), initially reported in Comeau et al. (2006), consisted of placing two cylindrical buoys on top of the bag instead of laterally (Figure 3b, dimensions: 80 cm × 40 cm × 10 cm). This modification allowed the bag to sink approximately 3 cm below the surface. (3) Finally, a *second modification* to the standard bag (hereafter M2) was also tested as part of the present study. Similarly to M1, M2 had two cylindrical buoys on top of the bag (Figure 3c, dimensions: 80 cm × 40 cm × 10 cm) and were more deeply submerged than M1 (i.e. approximately 6 cm below the surface).

Experimental design

This design allowed coastal birds to choose between different gear types and thus constitutes a preference study. Three oyster culture lines were deployed equidistantly (6.1 m) and in a parallel fashion at each of the three selected sites (Figure 4). Each culture line held 33 floating bags (11 of each type) for a grand total of 99 floating bags per site (33 of each type). Floating bags of the same type were placed in groups of three consecutive bags (Figure 4a). Nine such groups of bags (three for each bag type) were randomly and sequentially filed along every deployed line (Figure 4b). These were immediately followed by three randomly placed groups of two consecutive bags of the same gear type (one group for each type), thus ending each culture line with three groups of two bags instead of three (Figure 4c). This latter procedure accounted for a shortage of experimental bags upon initiation of the study.

Sampling procedure

Sampling was carried out between August 28th and November 7th 2006. Within this ten-week period, each of the three selected sites was visited several times according to weather, logistics and technician availability. During each visit, bird observations were carried out either from land or from a kayak using binoculars and a spotting scope at a considerable distance from the bags to avoid any possible interactions with the behaviour of the birds. Only birds perching on oyster gear and any associated buoys were identified and counted. Bird abundance was noted according to gear type

(i.e. one count for all 33 bags of the same type). Count period consisted of four consecutive 15-minute intervals. Data pertaining to the interval with the maximum number of individuals of the same species was kept for analysis. To standardize observations, these counts were divided by the number of bags present within the count area (i.e. 33). Afterwards, the outcome was multiplied by 100 to provide an estimate of the bird abundance per species per 100 bags (amount of bags normally observed in one standard line of culture), hereafter known as standardized abundance.

Statistical analyses

The above design and sampling allowed the testing of four main statistical null hypotheses: i) gear type has no effect on the roosting bird richness (i.e. number of bird species) in oyster farms, (ii) gear type has no effect on the abundance of birds (all species) in oyster farms, (iii) gear type has no effect on the standardized abundance of the double-crested cormorant (*Phalacrocorax auritus*), and finally (iv) gear type has no effect on the abundance of all species within the genus *Larus*.

In order to test the abovementioned hypotheses, data were partitioned into five intervals of two-weeks. Factors for each variable were analyzed using a complete randomized block with repeated measures according to gear types (fixed between-subjects factor with three levels; M1, M2 and S), sites (fixed between-subjects factor with three levels; CA, NE and RI), sampling time (random factor with five levels of repeated measurements) and all their mutual interactions. Mauchly's test was used ($\alpha = 0.05$) to assess whether these datasets conformed to the sphericity assumption required for a repeated measure analysis. If not, the degrees of freedom were adjusted with the Huynh-Feldt correction. Significant differences between all possible combinations of sample means for gear type were also assessed using Tukey's HSD test ($\alpha = 0.05$). All analyses were performed with SPSS 10.0 for Windows© (SPSS inc., Chicago, IL, USA). Diversity of species was also transformed into a diversity index H^I (Shannon-Wiener) for each site and for all sites pooled together. Finally, descriptive statistics were carried out on pooled data from every visit to determine total bird abundance and diversity according to each selected site and according to all sites pooled together.

Results

Over the ten-week period of the experiment, nine species of birds were identified and a total of 526 individuals were counted (Table 1). The Shannon-Wiener diversity index (H^I) for all sites pooled together reached $H^I_T = 0.696$. According to the same index, the most diverse site was NE ($H^I_{NE} = 1.289$), immediately followed by RI ($H^I_{RI} = 1.067$) and CA ($H^I_{CA} = 0.042$) (Figure 6). The most abundant species was the double-crested cormorant (*Phalacrocorax auritus*), representing 84% of all counts (Table 1). This species was most commonly observed roosting on oyster gear in CA (Figure 5). Remarkably, all *P. auritus* identified roosting at the CA site accounted for 73% of the total cormorant count (442) observed over the course of the experiment. Furthermore, *P. auritus* accounted for 99% of the total bird count (325) obtained at the CA site, with only two individuals (1%) in the total count representing other species (i.e. one red-breasted merganser, *Mergus serrator*, and one common scoter, *Melanitta nigra*). Although cormorants represented the most abundant species in both NE and RI sites (i.e. 59% and 60% respectively), other species of birds accounted for

over 40% of total site abundance. With all sites accounted for, the second and third most abundant species were respectively the herring gull (*Larus argentatus*) (nearly 7%) and the greater black-backed gull (*Larus marinus*) (over 3%) (Table 1). Both species were absent in CA while they remained constant in both NE and RI (Figure 5). As for common terns (*Sterna hirundo*), they only represented 2% of all counts and were exclusive to NE (Table 1; Figure 5). Other species were scattered amongst sites, especially in NE where eight black-bellied plovers (*Pluvialis squatarola*) and six great blue herons (*Ardea herodias*) were observed.

Bird richness showed insignificant interactions between time of sampling and both fixed between-subjects factors, i.e. gear type and sampling site (Table 2). As a result, all three factors were analyzed independently. Type of gear was the only factor that yielded a significant effect on roosting bird richness (Table 2; Figure 6). Mean richness observed for standard bags was approximately twice the value as the one observed for M1 bags and eight times the one for M2 bags (Figure 6). Results obtained from Tukey's HSD showed that only standard and M2 bags attracted a significantly different number of species (Figure 6). As for time of sampling and sampling site, both factors were shown to insignificantly affect the mean roosting bird richness (Table 2; Figures 7 and 8).

Standardized abundance, also known as the amount of birds per 100 floating bags, was the basic measure for three variables: total abundance (all species included); the abundance of *P. auritus*, and the abundance of *Larus* spp. None of these variables fluctuated significantly according to any interaction between time of sampling and gear type (Table 2). Main effect of gear type for all three factors was thus analyzed for each variable. Gear type was shown to have a significant effect on total and *P. auritus* abundance while it was shown to be insignificant for *Larus* spp. (Table 2, Figure 10). Mean standardized abundance for all three abundance variables was always highest for standard bags, immediately and respectively followed by M1 and M2 bags. Tukey's HSD detected a significantly higher number of birds roosting on standard bags compared with M2 bags for both total and *P. auritus* abundances, but not for the *Larus* spp. abundance (Figure 10). All other multiple comparisons between levels of gear type were insignificant (Figure 10). A significant interaction between time of sampling and sampling site was detected for two variables, i.e. total and *P. auritus* abundances (Table 2; Figure 9).

Discussion

Comeau et al. (2006) reported that the three most abundant species roosting on oyster gear in 2005 were respectively the double-crested cormorant (*Phalacrocorax auritus*), herring gulls (*Larus argentatus*) and common terns (*Sterna hirundo*). Although true for the first two species, *S. hirundo* represented but a mere 2.28% of the total bird count in this present study. The third most abundant species on oyster gear in 2006 was rather the greater black-backed gull (*Larus marinus*), which represented 3.42% of the total count. The two studies yielded remarkably similar results despite different sampling schemes. Comeau et al. (2006) examined bird abundance within commercial oyster farms where several thousand bags were deployed, whereas the current study recorded abundance at remote sites where only a small amount of bags were deployed. Despite these notable differences, the two most abundant species roosting on oyster gear in both studies were *P. auritus* and *L. argentatus*.

Gear type was shown to have a significant effect on the mean richness of species roosting on oyster gear. Standard bags attracted the most species, respectively followed by M1 and M2. The first null statistical hypothesis stated in the methods section is thus rejected. Standard bags offered more surface area with approximately half of its total volume outside of the water, potentially attracting more species. For example, bags covered with common eelgrass (*Zostera marina*) can be especially appealing to *S. hirundo*. Individuals from this species were often observed feeding on small invertebrates entangled within *Z. marina* (Comeau et al., 2006). Remarkably, of the 12 *S. hirundo* identified in this study (all in NE), only one was observed roosting on a M1 bag while the other 11 remained exclusively on standard bags. Bags that underwent the second modification (M2) yielded the lowest mean richness attracting only 0.267 species per 33 floating bags. This was significantly different from the mean richness observed for standard bags (Tukey's HSD). Most of the individuals roosting on M2 bags (exclusively *P. auritus* and *L. argentatus*) did so for a very short period of time (i.e. matter of seconds) after which they flew away. Some tried to perch on M2 buoys. Unless covered with *Z. marina*, they were rendered quite unstable from their modification, thus resulting in perching platforms of seemingly poorer quality. Other birds perching on M2 bags changed their roost location immediately after trying them.

Results for the total and *P. auritus* abundance variables were expected to be similar, since *P. auritus* represented most of the individuals included in each variable. This is especially true since a significant effect of gear type was observed for both variables. The statistical null hypotheses pertaining to the effect of gear type on total and *P. auritus* abundances were therefore rejected. However, no effect of gear type was detected for the *Larus* spp. abundance, which represented the second most frequent species encountered in the observations. This insignificant result suggests that the gear type modifications investigated in this study cannot effectively deter *Larus* spp. individuals from roosting on floating oyster bags. The statistical null hypothesis pertaining to the effect of gear type on *Larus* spp. individuals is thus accepted. Submergence of floating oyster bags below the water surface can thus be considered as a potential mean for attracting a lesser amount of birds, especially double-crested cormorants but not *Larus* spp.. Results from a multiple comparison analysis (i.e. Tukey's HSD) support the last affirmation. The analysis denoted significant differences between sample means of S and M2 bags for both total and *P. auritus* abundance variables, thus suggesting that the submergence model used for the construction of hypotheses might explain most of the observed variance.

Mean standardized abundances for standard and M1 bags were considerably higher in this study (e.g. total abundance was equal to 44.4 and 18.8 birds per 100 floating bags, respectively) compared to those observed in Comeau et al. (2006) (respectively 15.3 and 1.7 birds per 100 floating bags). There is one major methodological difference between the two studies which might explain this outcome. In the latter study, observations were carried out within aquaculture farms having considerable different types of culture techniques. Some of these sites included OysterGro® cages. Floating cages, also used for cultivating oysters, are more voluminous than floating bags. When offered a choice between both types of floating structures, birds seem to be more attracted to these larger platforms (Comeau et al., 2006), thus partly explaining the lower values of standardized abundance observed for floating bags. In this present

study, proximate floating cages were also present, but in lesser quantities than those observed by Comeau et al. (2006). Furthermore, in 2005, counts were achieved within farms where numerous bags were present, consequently increasing the dispersal of birds. This interpretation is well supported by Figure 9 in Comeau et al. (2006). Even though the figure relates to cages, one may reasonably assume that the same relationship does exist for bags.

Although time of sampling was not included in the initial hypotheses, the repeated measures analysis was able to determine whether it significantly affected the observed variability. Time of sampling did not have a significant effect on any of the investigated abundance variables. However, a significant interaction between time of sampling and sampling site was detected for both total and *P. auritus* abundances. For CA, there is a steady decline in both total and *P. auritus* abundances from T2 to T5, which is suggestive of a migration from the northern part of the province. The peak in *P. auritus* at T3 for more southerly sites (NE, RI, figure 9B) lends further support to this interpretation. Autumnal migratory movements were likely responsible for the lack of sphericity in the repeated measures datasets. The lack of sphericity was compensated for using the Huynh-Feldt correction since it yielded the highest power out of all available corrections (i.e. Greenhouse-Geisser and lower-bound). As a result, the degrees of freedom and the theoretical F statistic used to assess P values were adjusted accordingly. The implication for the industry is that sites such as NE and RI have a short-term (couple of weeks) issue with *P. auritus*, whereas CA is faced with a longer-term residency up until T5.

In terms of farm-scale applicability, results acquired from the present study are promising and of pertinence to the oyster aquaculture industry. A complete immersion of floating bags has potential in limiting bird diversity and abundance. Submergence depth greater than most birds' tarsus lengths is recommended. However, these modifications don't seem to be realistic with current culture procedures, especially when bags need to be rotated in order to control biofouling. Consequently, additional modifications allowing such rotations need to be developed and tested to satisfy the industry's needs. Once discovered, the prototype could thereafter be subjected to a rigorous experimental design testing whether birds are able to adapt to the modification, especially when all culture gear within a same isolated site have been exclusively modified.

In conclusion, low-cost gear modifications can be effective in deterring birds from using oyster gear as roosting platforms. Submerging floating bags under the water surface represent a humane and relatively inexpensive way of addressing the issue. In terms of future work, there is a need to investigate the implications of such deployment schemes on oyster growth performance and biofouling control. There is also a requirement for providing advice to the industry on effective gear-modifications. By deterring birds away from oyster gear, bird feces are eliminated, thus satisfying DFO's requirements to ensure safe and productive waters under the Canadian Shellfish Sanitation Program.

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Table 1. Bird species identified roosting on floating oyster bags in all three sites (CA, NE and RI) with their respective total and relative abundances.

Common name	Latin name	Abundance (total number recorded during survey)	Percentage (%) of total count
Double-crested cormorant	*Phalacrocorax auritus*	442	84.03
Herring gull	*Larus argentatus*	35	6.65
Greater black-backed gull	*Larus marinus*	18	3.42
Common tern	*Sterna hirundo*	12	2.28
Black-bellied plover	*Pluvialis squatarola*	8	1.52
Great blue heron	*Ardea herodias*	6	1.14
Ringed-bill gull	*Larus delawarensis*	3	0.57
Red-breasted merganser	*Mergus serrator*	1	0.19
Common scoter	*Melanitta nigra*	1	0.19
Total		526	100

Table 2. Summary of a complete randomized block with repeated measures carried out on four variables: a) species richness (i.e. per 33 floating bags); b) total standardized bird abundance (i.e. per 100 floating bags) for all species included; c) standardized bird abundance for *P. auritus*; and d) standardized abundance for *Larus* spp.

Source of Variation	df	SS	Adjusted df[1]	MS[2]	*F*	P[3]
a) roosting bird richness (per 33 floating bags)						
Site (S)	2	5.91	---	2.96	2.08	0.241
Gear type (G)	2	26.31	---	13.16	9.25	**0.032**
Between-subjects error	4	5.69	---	1.42	---	---
Time of sampling (T)	4	1.47	---	0.37	0.82	0.534
T X G	8	0.80	---	0.10	0.22	0.981
T X S	8	6.53	---	0.82	1.82	0.148
Within-subjects error	16	7.20	---	0.45	---	---
Total	44	53.91	---	---	---	---
b) total standardized abundance for all species included						
Site (S)	2	6019.38		3009.69	4.38	0.098
Gear type (G)	2	14181.00	---	7090.50	10.32	**0.026**
Between-subjects error	4	2745.84	---	686.46	---	---
Time of sampling (T)	4	4018.77	---	1004.69	5.33	0.006
T X G	8	2549.94	---	318.74	1.69	0.176
T X S	8	4730.53		591.31	3.13	**0.025**
Within-subjects error	16	3014.79	---	188.42	---	---
Total	44	37260.25	---	---	---	---
c) standardized abundance of *P. auritus*						
Site (S)	2	4150.17	---	2075.08	4.00	0.111
Gear type (G)	2	10280.67	---	5140.33	9.91	**0.028**
Between-subjects error	4	2074.46	---	518.61	---	---
Time of sampling (T)	4	4878.04	3.24	1503.75	3.35	0.050
T X G	8	4317.36	6.49	665.46	1.48	0.257
T X S	8	8493.23	6.49	1309.10	2.92	**0.048**
Within-subjects error	16	5817.84	12.98	448.37	---	---
Total	44	40011.77	---	---	---	---
d) standardized abundance of *Larus* spp.						
Site (S)	2	880.13	---	440.07	1.39	0.348
Gear type (G)	2	1846.76	---	923.38	2.92	0.165
Between-subjects error	4	1264.04	---	316.01	---	---
Time of sampling (T)	4	71.36	3.37	21.17	0.58	0.654
T X G	8	76.06	6.74	11.28	0.31	0.933
T X S	8	255.65	6.74	37.92	1.05	0.444
Within-subjects error	16	489.10	13.48	36.28	---	---
Total	44	4883.10	---	---	---	---

[1]Adjusted degrees of freedom (Huynh-Feldt correction) where sphericity assumption is not met, $\alpha = 0.05$.
[2] Computed with adjusted degrees of freedom where available.
[3] Bold font used to state significance, $\alpha = 0.05$.

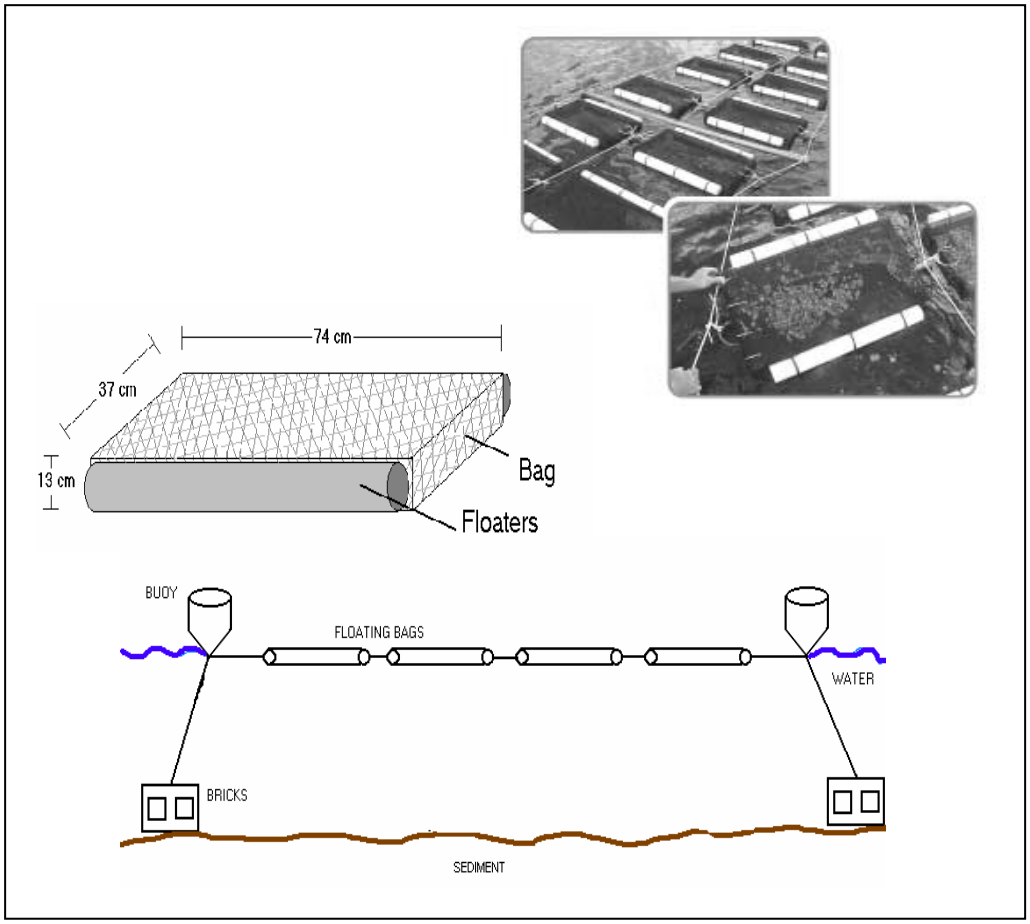

Figure 1. Floating bag technique, most commonly used in the American oyster (*Crassostrea virginica*) culture industry in N.B. Drawing adapted from Sonier (2006) photos from www.maisonbeausoleil.ca

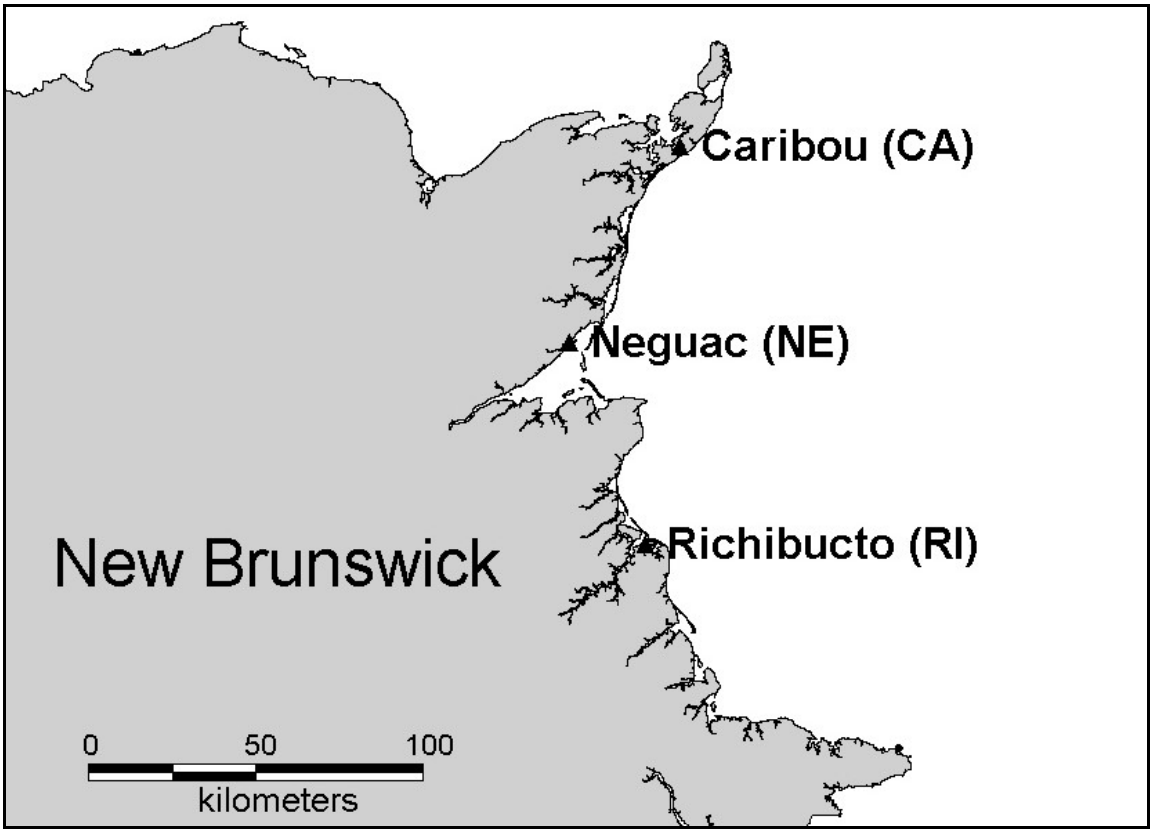

Figure 2. Map of north-eastern New Brunswick showing locations (i.e. grey circles) of all three sampling sites: CA = Caribou Bay, near Shippagan, NB; NE = Neguac Bay, in Neguac, NB; and RI = Richibucto Bay, at Indian Island near Richibucto, NB.

a) standard (S)

b) 1st modification (M1)

c) 2nd modification (M2)

Figure 3. Photographs of three levels of oyster gear type that were tested to evaluate their bird-deterring efficiency: a) standard (S) floating bags; b) floating bags with first modification (M1), i.e. submerged 3 cm below water surface; and c) floating bags with second modification (M2), i.e. submerged 6 cm below water surface.

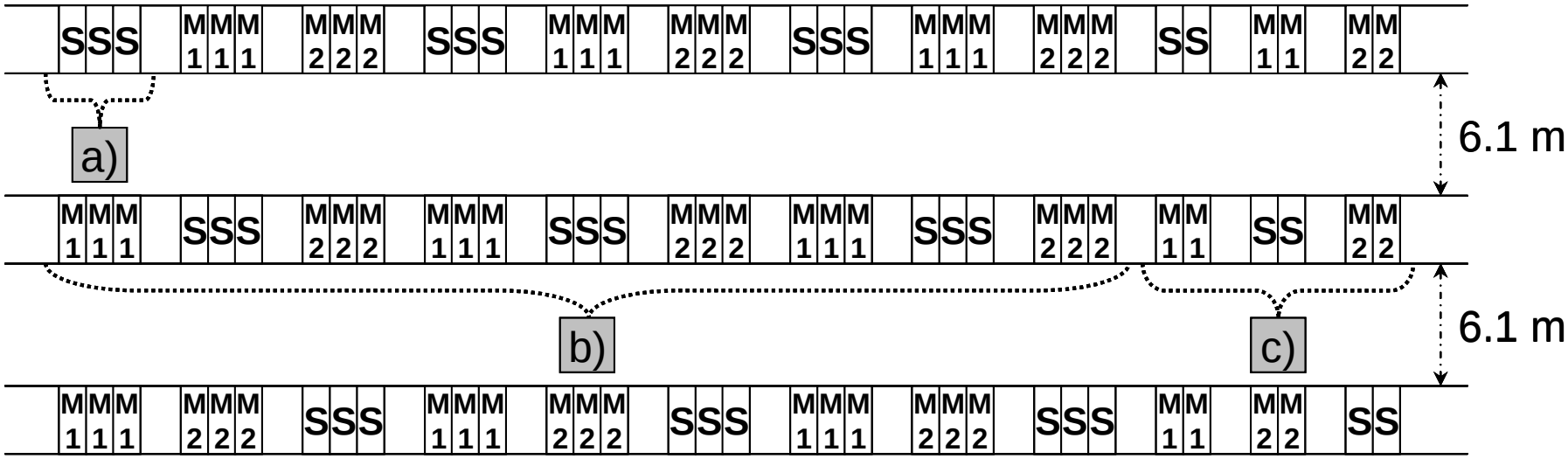

Figure 4. Layout example of three experimental culture lines holding three types of floating oyster bags: standard (S), first modification (M1) and second modification (M2). a) Group of three bags of the same gear type. b) Beginning of culture line with nine groups of three bags laid out in a random order. c) End of experimental culture line with three groups of two bags (same gear type) laid out in the same random order as the first nine groups of respective line.

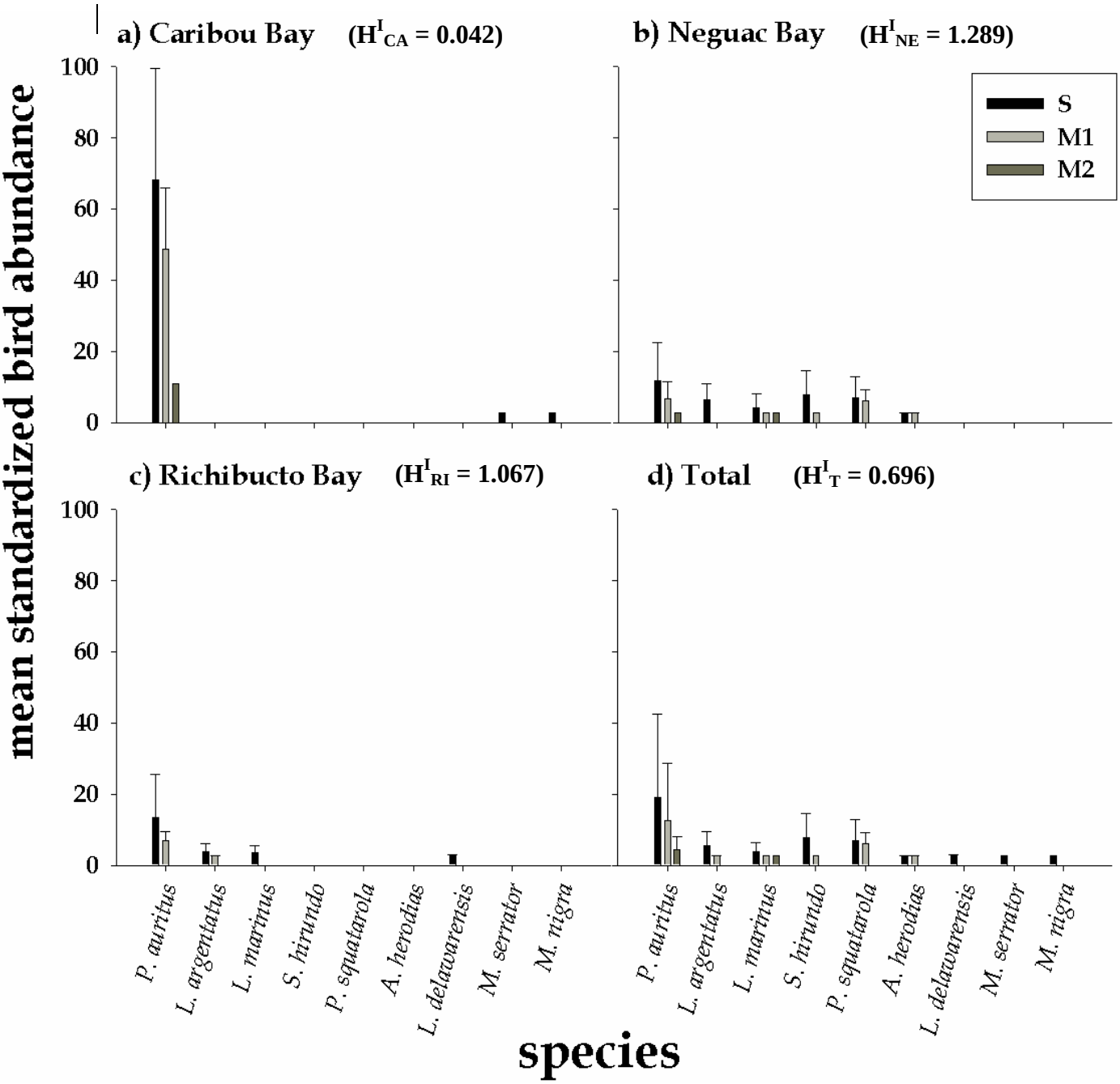

Figure 5. Mean (± SD; all n = 5 for a, b and c; n = 15 for d) standardized abundance (i.e. number per 100 floating bags) for each bird species identified roosting on standard (S) and modified (M1 and M2) bags for a) Caribou Bay, b) Neguac Bay, c) Richibucto Bay and d) all sites pooled together. Shannon-Wiener diversity index (H^I) for each site is also presented.

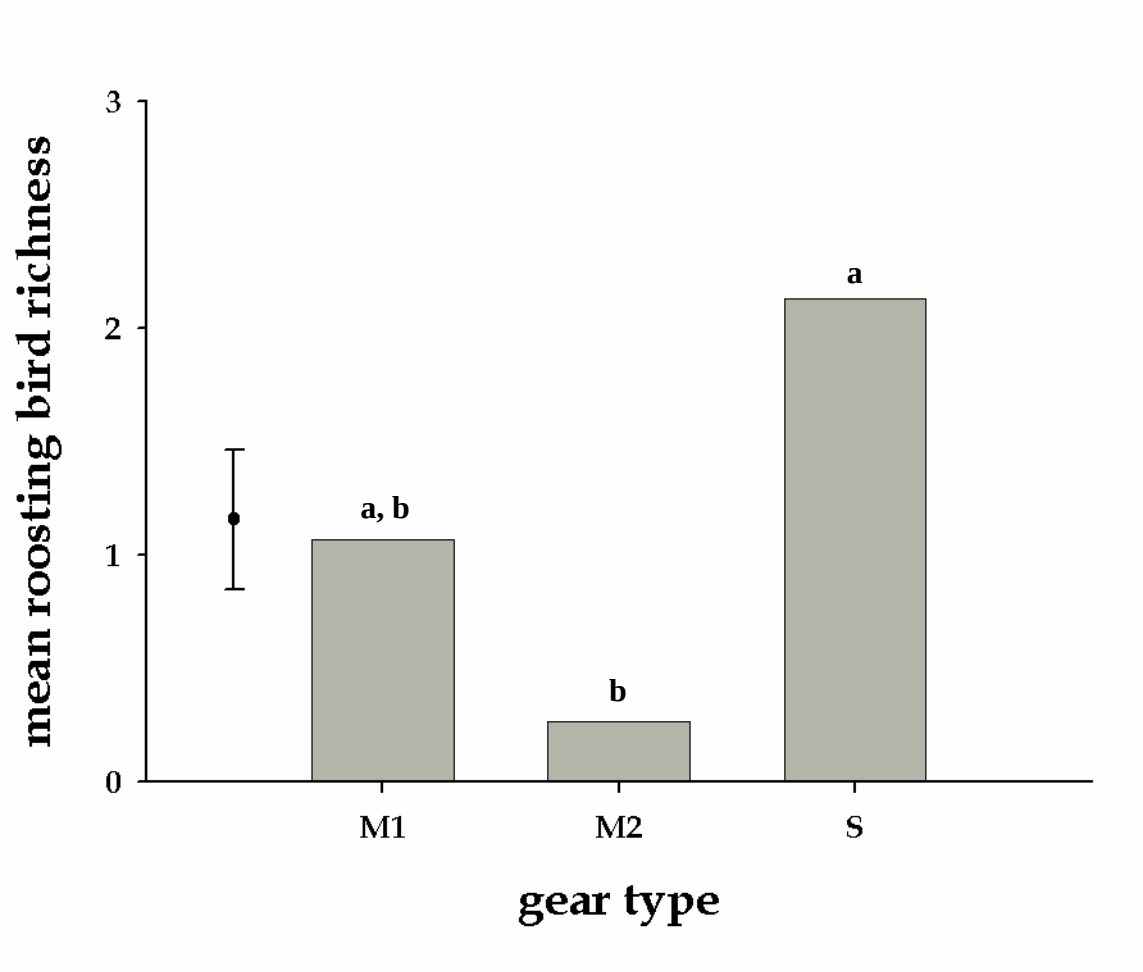

Figure 6. Mean richness of roosting bird species (n = 15) per 33 floating bags of type S (standard), M1 (first modification) and M2 (second modification). Means are presented with a single error bar provided by the standard model error (SME). Bars having dissimilar letters above them differ significantly from each other (Tukey's HSD).

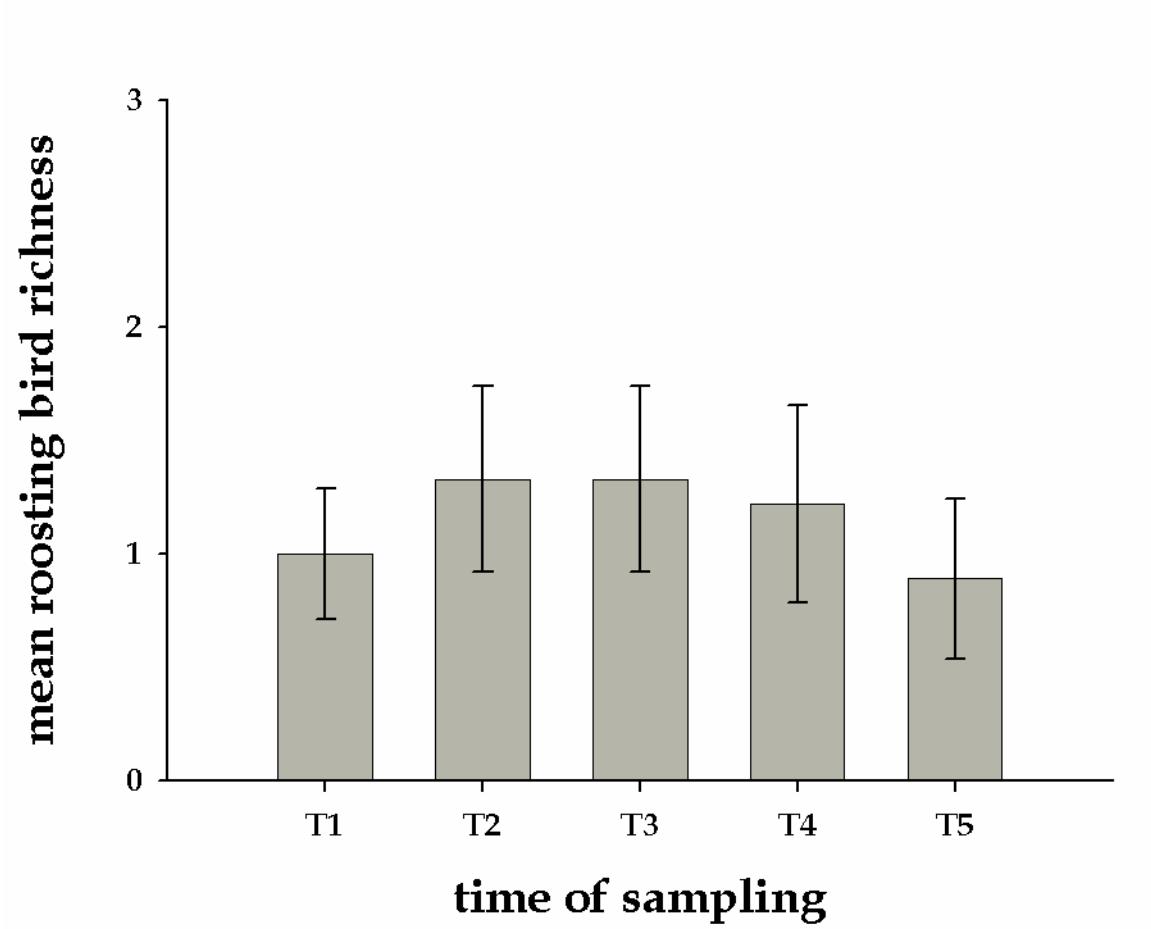

Figure 7. Mean richness ± SE (all n = 3) of roosting bird species according to five times of sampling (T1 = August 28th to September 10th 2006; T2 = September 11th to September 25th 2006; T3 = September 26th to October 9th 2006; T4 = October 10th to October 24th 2006; and T5 = October 25th to November 7th 2006).

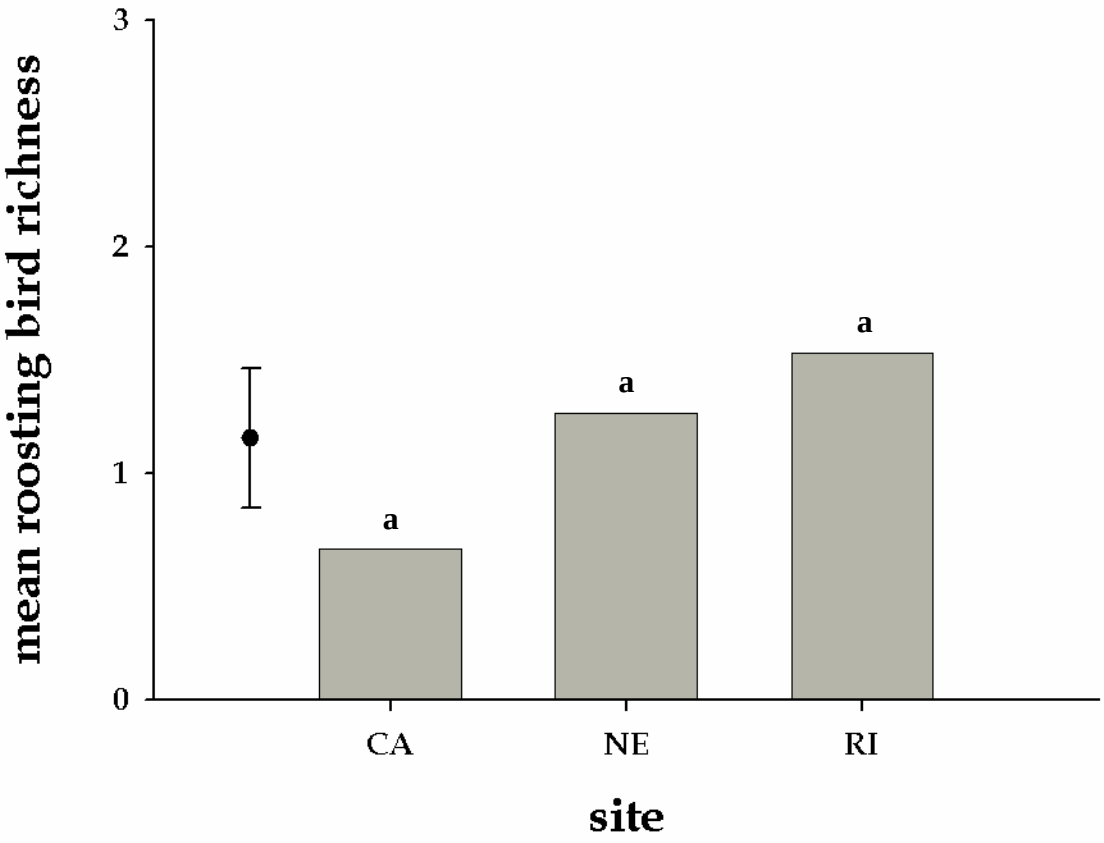

Figure 8. Mean richness (all n = 3) of roosting bird species according to sampling site (CA: Caribou Bay; NE: Neguac Bay; and RI: Richibucto Bay). Means are presented with a single error bar provided by the standard model error (SME). Bars having similar letters above them differ insignificantly from each other (Tukey's HSD).

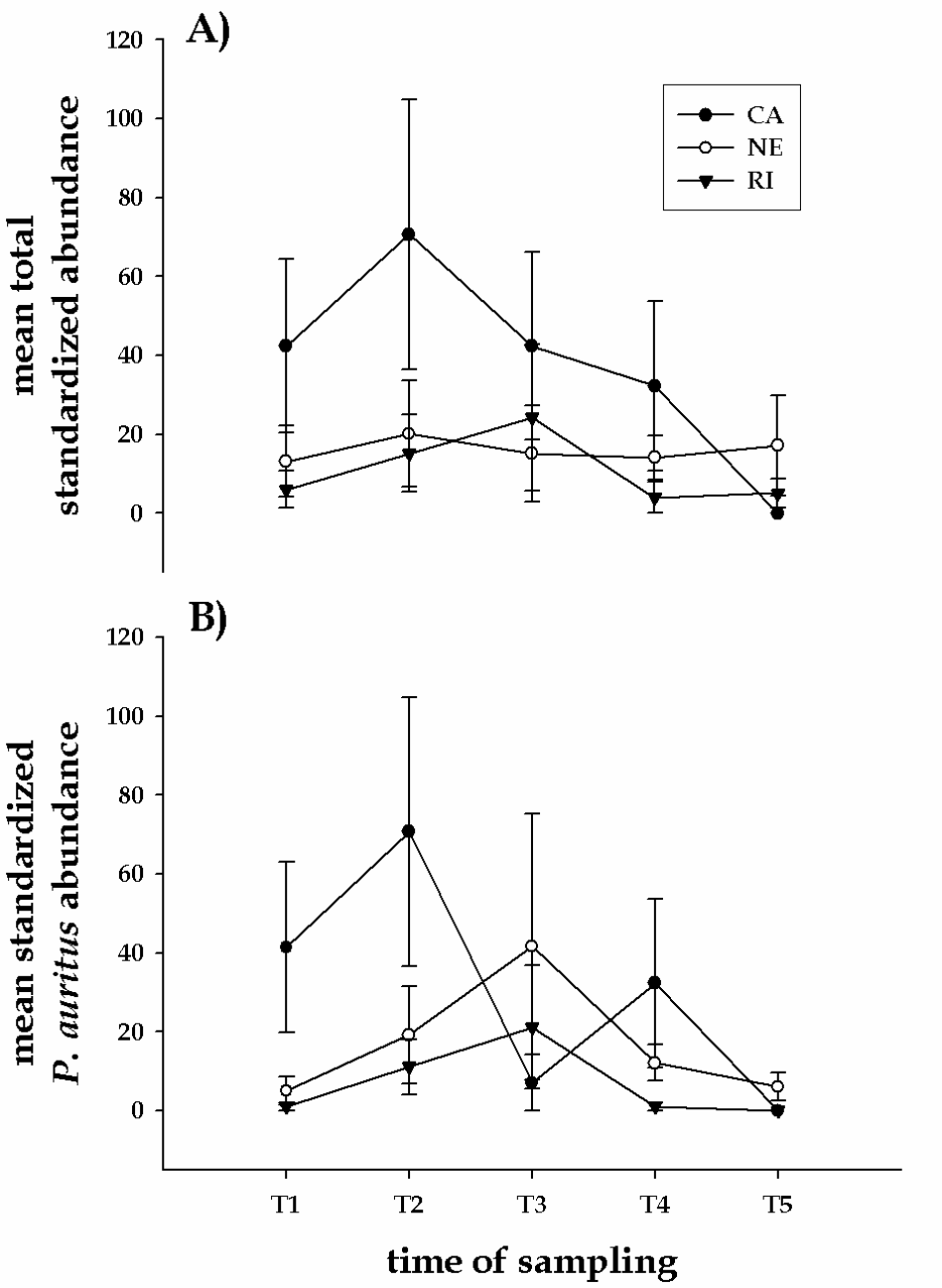

Figure 9. Mean standardized abundance (± SE; all n = 3) of A) all species and B) *P. auritus*, both according to an interaction between time of sampling (five two-week intervals: T1 = August 28th to September 10th 2006; T2 = September 11th to September 25th 2006; T3 = September 26th to October 9th 2006; T4 = October 10th to October 24th 2006; and T5 = October 25th to November 7th 2006) and sampling site (CA: Caribou Bay; NE: Neguac Bay; and RI: Richibucto Bay).

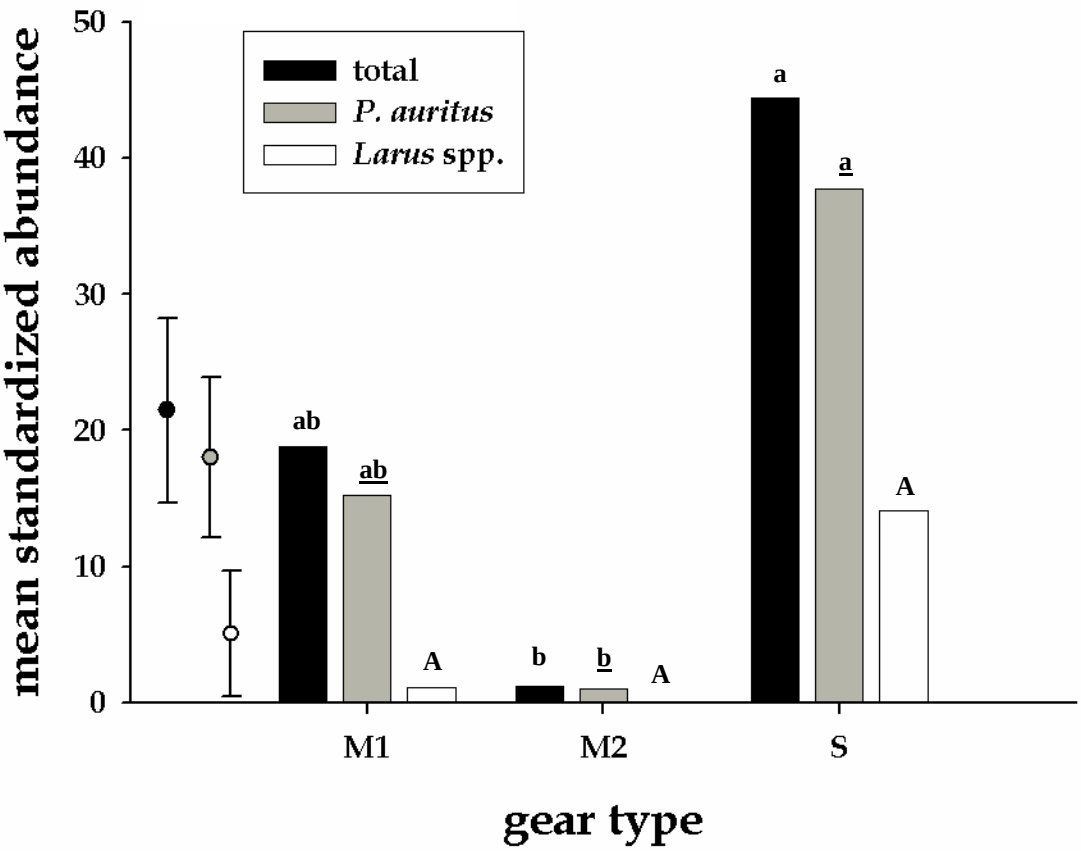

Figure 10. Mean standardized abundance (n = 3) of birds seen roosting on oyster gear of type S (standard), M1 (first modification) and M2 (second modification). Means are presented with their respective error bar (i.e. of same color) provided by the standard model errors (SME). Bars having dissimilar letters above them (lower case: all species; underlined case: *P. auritus*; and upper case: *Larus* spp.) differ significantly from each other (Tukey's HSD).