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Distribution, Abundance and Trends of Gulls and Terns Breeding on Sable Island, Nova Scotia, Canada

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Abstract.—Sable Island is the most isolated seabird colony site in eastern Canada and the United States, offering a unique opportunity to study the population dynamics of terns and gulls in an area removed from human activities. Sable Island likely supported tens of thousands of terns prior to 1900, but the population declined during the first half of the 20th century, coinciding with colonization by breeding gulls. An island-wide census of terns and gulls was conducted in 2012 and 2013, and those results were compared with surveys conducted over the previous 45 years to assess changes in population abundance and distribution. The current island-wide population of Common (*Sterna hirundo*) and Arctic (*S. paradisaea*) terns was approximately 6,500 and 4,200 combined breeding pairs in 2012 and 2013, respectively, down from about 9,000 pairs estimated in 2008/2009, but higher than all estimates between 1970 and 2006. Population growth of these tern species has been concentrated at two large colonies, each with over 2,000 breeding pairs, whereas the number of small colonies on the island has been in decline since 1998. Fewer than six pairs of Roseate Terns (*S. dougallii*) have nested on Sable Island since 1993, down from counts of more than 100 individuals in the 1970s. Estimates of breeding pairs ranged from 744 to 951 Herring Gulls (*Larus argentatus*) and 398 to 472 Great Black-backed Gulls (*L. marinus*) during 2012 and 2013. A survey of gulls documented 33 to 50% fewer Herring Gulls and 23% fewer Great Black-backed Gulls than in 1970. Sable Island's tern and gull populations have fluctuated asynchronously over the past 100 years, and may be returning to a previous ecosystem state when gulls were absent and terns were abundant, but mechanisms underlying these trends are unknown.
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Key words.—Arctic Tern, colony abandonment, Common Tern, Great Black-backed Gull, Herring Gull, population recovery, Roseate Tern, Sable Island, status, trends.

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Situated about 160 km east of mainland Nova Scotia, Sable Island is the most isolated seabird colony site in eastern Canada. Breeding seabirds on Sable Island include small dispersed colonies of Herring Gulls (*Larus argentatus*), solitary nests of Great Black-backed Gulls (*L. marinus*), and mixed colonies of Common (*Sterna hirundo*), Arctic (*S. paradisaea*), and Roseate (*S. dougallii*) terns (McLaren 1981). Though historical mammalian introductions have likely had an impact on the seabird populations at this site (St. John 1921; Wright 1989), this island has been free of mammalian predators for more than 50 years (Wright 1989), and it is too distant for breeding birds to be influenced by most human activities that have been implicated in the population trends of gulls on the mainland (e.g., landfills and fish processing plants; Lock 1973; Cotter *et al.* 2012; Wilhelm *et al.* 2016).

Accurate survey data are limited to recent decades, but occasional records and anecdotal evidence suggest that the population sizes of breeding seabird species on Sable Island have fluctuated considerably over the past century. Based on “rough computations per acre,” it was estimated that in 1901 as many as one million adult terns may have inhabited the island (St. John 1921; McLaren 1981), but more plausibly between 30,000 and 100,000 breeding pairs of terns were nesting there in the late 1800s (Saunders 1902; Lock 1989; Horn 1998). In 1921, terns were reported to be nesting “everywhere” (Kress *et al.* 1983), and in the late 1940s “thousands, perhaps a hundred thousand” terns were reported to be on the island (Kress *et al.* 1983). An island-wide survey of terns in 1969 counted approximately 2,600 individuals, including some non-breeders (Lock 1989); thus, this popula-

tion experienced an exceptionally large decline sometime between the 1940s and 1969. Since 1969, numbers of Arctic and Common terns appear to have been stable through the 1990s (Horn 1998; Taylor *et al.* 2001) or increasing since 2006 (Toms *et al.* 2006), yet populations of Roseate Terns continued to decline from more than 100 individuals and at multiple colonies in 1969 (Lock 1989 cited in Horn 1988) to fewer than six pairs at a single colony in the 1990s and 2000s (Horn 1998; Sable Island Preservation Trust 2009).

Gulls were first observed on the island in the late 1890s, though Herring and Great Black-backed gulls were not breeding at this time (Dwight 1895; Saunders 1902). None were noted to be breeding during bird surveys conducted in 1913, and it appears as though they were intermittent visitors (St. John 1921). By 1922, Herring Gulls were “present in significant numbers” (Lock 1973), and both species were noted as breeding in 1952 (Erskine 1954). In 1970, a systematic census of gulls estimated about 2,000 and 600 breeding pairs of Herring and Great Black-backed gulls, respectively (Lock 1973).

Here, we report on an island-wide survey of breeding Common, Arctic, and Roseate terns (terns) and Herring and Great Black-backed gulls (gulls) conducted in 2012 and 2013. We used survey techniques that were employed on the island for terns since 1998 (Horn 1998;

Taylor *et al.* 2001; Toms *et al.* 2006; Sable Island Preservation Trust 2009) and for gulls since the early 1970s (Lock 1973). Our objectives were to: 1) determine the current population sizes of breeding seabirds on Sable Island; and 2) quantify changes in their distribution and abundance during the past five decades.

METHODS

Study Area

Sable Island (43° 57' N, 60° W; Fig. 1) is situated on the Scotian Shelf approximately 160 km from mainland Nova Scotia, Canada. It is a crescent-shaped sandbar approximately 40 km in length and 1.5 km at its widest point. Terns nest in colonies ranging in size from 10s to 1,000s of breeding pairs distributed throughout the island (Fig. 1). Gulls nest in small colonies (typically < 50 breeding pairs) or solitarily throughout the vegetated part of the island (Lock 1973). The island is surrounded by shallow and shifting sandbars, most water is less than 100 m deep within 50 km of the island, and the continental shelf edge is approximately 40 km to the southeast. On land, freshwater ponds are found on parts of its western half, and approximately 50% of the island's surface area is vegetated (Catling *et al.* 1984). The island supports a population of feral horses, currently at an all-time high of more than 500 individuals (van Beest *et al.* 2014), which have an impact the vegetation cover (Freedman *et al.* 2011).

Arctic, Common and Roseate Terns

Terns were surveyed following standard techniques for seabirds (Walsh *et al.* 1995) used on Sable Island since 1998 (Horn and Shepherd 1998; Toms *et al.* 2006;

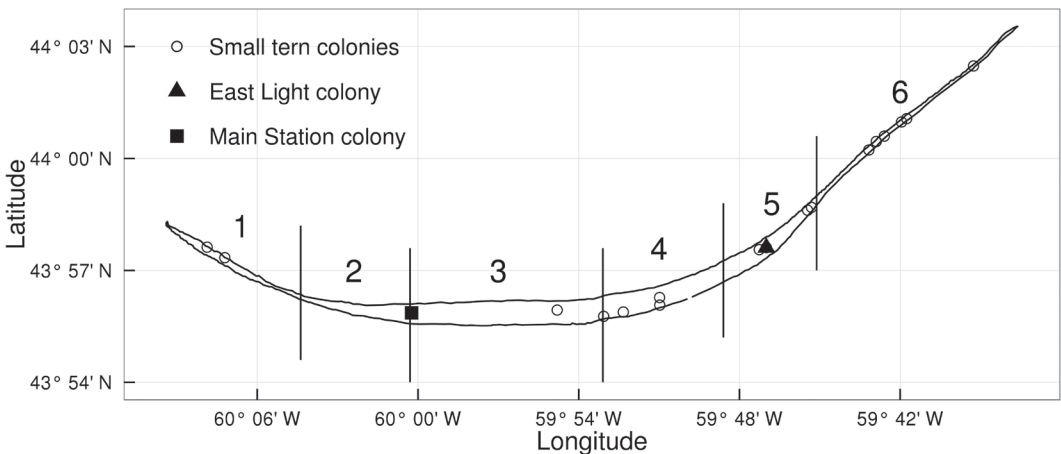


Figure 1. Shoreline of Sable Island, Nova Scotia, Canada. Locations of known colonies of Common and Arctic terns since 2006 (points). Numbers and vertical lines correspond with survey sectors for Herring and Great Black-backed gulls.

Sable Island Preservation Trust 2009): flush counts were conducted at small colonies (< 150 pairs), and quadrat samplings were conducted at large colonies. All surveys were done during the second week of June, which is approximately the middle of incubation for all tern species.

To locate small colonies, we scanned with binoculars from dune tops and ridges while traveling along the north and south shores of the island during gull surveys, described below. We also investigated inland areas adjacent to locations where terns were roosting on the beach. Finally, we visited all colony locations reported during the 2006 and 2009 surveys. At the small colonies, flush counts were conducted by one observer who counted from a distance while another person flushed birds in the colony (Bibby *et al.* 1992; Horn and Shepherd 1998). The total number of flushed adults was converted to the number of nests by using a ratio of 1.5 flushed adults per nest (Walsh *et al.* 1995), which was validated by Toms *et al.* (2006) on Sable Island. Species ratios of Common Terns to Arctic Terns were made by complete counts of incubating and standing birds that were visible with a spotting scope both before and after flush counts; multiple ratios were averaged.

At the two largest colonies, Main Station (43° 55' 51" N, 60° 00' 14" W) and East Light (43° 57' 36" N, 59° 46' 59" W; Fig. 1), nest densities were determined from randomly placed quadrats within the colony perimeters (Toms *et al.* 2006; Sable Island Preservation Trust 2009). Due to the large size of these colonies and patchy distribution of Arctic Terns within them, species ratio counts were an unreliable index of species composition. In 2012, 5 x 5-m quadrats were used at the Main Station ($n = 20$ quadrats) and East Light ($n = 10$) colonies. In 2013, at Main Station, 20 quadrat locations sampled in 2012 were resampled as larger quadrats (10 x 10 m) along with one additional quadrat. At East Light in 2013, a direct nest count was conducted in the western half of the colony (0.7 ha). We did not sample the eastern half of the colony to avoid trampling Roseate Tern nests. Aided by the placement of temporary flags on each pass, four individuals walked side-by-side in adjacent swaths perpendicular to the east-west axis of the colony. All nests were counted and marked with a small dot of spray paint on the sand or grass adjacent to the nest. After the count, we obtained a ratio of marked to unmarked nests used to correct for nests missed during the count. This ratio was obtained by two observers walking across the colony in a direction that was perpendicular to the walking path of the count. Only active nests containing eggs were included in density estimates in both years, as was done with previous surveys.

The area of the Main Station colony was determined by walking around its perimeter with a hand-held GPS (Toms *et al.* 2006). In 2012, the colony edge was loosely defined by areas of continuous nests spaced no more than 10-15 m apart, thus omitting some scattered nests from the mapped areas or small satellite colonies. In 2013, perimeter mapping was not completed; therefore, we assumed the same colony area as in 2012. For other years, the colony area was obtained from reports (Toms

et al. 2006; Dillon 2008; Sable Island Preservation Trust 2009). At the East Light colony, the colony boundaries are clearly defined by a fence, though a small number of nests (less than 20) were found outside of the fence in each year. The colony area of 1.34 ha was used for calculations in all years; this included the fenced area minus the areas of the buildings (Applied Geomatics Research Group 2011).

We searched for Roseate Tern nest sites by scanning with a spotting scope and binoculars at the East Light colony where they have been previously recorded. Observers scanned from inside or adjacent to buildings within the fenced area. We recorded locations of Roseate Terns landing in the colony with the aid of sketches and photographs.

Herring and Great Black-backed Gulls

We adopted the island-wide survey approach used by Lock (1973) for a complete count of individual gulls across six sectors of the island (Fig. 1). During the first week of June of each year (mid-incubation for Herring Gulls and post-hatch for Great Black-backed Gulls), a complete count of all sectors was conducted during two consecutive days by a single observer. The observer traveled by all-terrain vehicle along the north and south shores of the island, stopping every 100 to 300 m and walking to the tops and ridges of dunes adjacent to the beach. At each stop, the inland portion of the dunes was scanned with binoculars, and we counted all gulls, standing or in flight, over the vegetated part of the island and identified individuals to species and age group (immature gulls, aged by plumage, included second and third years, but not chicks). Where the island was too wide to count across the entire vegetated area, birds were counted separately from the north and south dune margins, up to the center of the vegetated area. While traveling between stops, the observer also counted gulls along the shoreline and sand flats. In these latter cases, we distinguished between birds counted along the vegetated dunes, where gulls are known to nest, from birds counted at loafing areas outside of the vegetated parts of the island, including the east and west spits and large sand flats (loafing birds in these three areas were omitted from breeding population estimates).

In 2013, we counted individual Herring Gull colonies, recording the total number of standing and/or flushed birds (hereafter standing adults) and, for a subset of colonies selected haphazardly, a count of active and empty nests. The number of breeding pairs was estimated as follows. First, from the island-wide survey, we summed the total number of adult Herring Gulls counted on the "consolidated part of the island" (i.e., omitting birds from loafing/roosting areas and the spits; Lock 1973). Then, we calculated the ratio of standing adults to nests and applied this to the total adult gull count to get an estimate of nests. We used this ratio for both active nests and total nests (active + empty), allowing the calculation of a potential range of breeding pairs including failed breeders. Colony studies allowed a ratio of adults to nests to be calculated for Great Black-backed Gulls in 1970 (Lock 1973).

Population Trends

To assess population trends for both gulls and terns, we collected data from published and unpublished reports. To present the most complete information available, we developed no *a priori* rules for inclusion of data. However, because most of these data have not been peer-reviewed, we carefully scrutinized the methods and, where possible, calculations were made from raw data (e.g., nest density estimates: Toms *et al.* 2006; Dillon 2007, 2008; Sable Island Preservation Trust 2009). To make population estimates directly comparable among years, colony sizes were reestimated with the following considerations. At Main Station, we reestimated the 2006 colony size (Toms *et al.* 2006) by omitting a 10-m buffer on the colony perimeter, and recalculated 2008 and 2009 colony size estimates by eliminating a 1.5 “correction factor” (Dillon 2008; Sable Island Preservation Trust 2009), because correction is not needed for nest counts. We also used a standard area estimate for the fenced colony at East Light. We calculated 95% confidence intervals for all estimates, where possible. Colonies with possible underestimation of population size are identified (Tables 1 and 2). Population trends were assessed with linear and exponential models using statistical program R (R Development Core Team 2014).

RESULTS

Arctic, Common and Roseate Terns

Small colonies. Sixteen small colonies (< 150 nests) of terns were identified between 2006 and 2013 (Toms *et al.* 2006; Sable Island Preservation Trust 2009; this study). Three small colonies were found on 6 June 2012, all on the east spit, where flush counts estimated 16, 23, and 73 breeding pairs. The smallest colony was abandoned by mid-June. Species composition at these colonies was about 95% Common Terns. No birds were found at the locations of other small colonies identified prior to 2012. In 2013, all previously known small colonies (Toms *et al.* 2006; Sable Island Preservation Trust 2009) were revisited; none were active. One new colony, identified on 13 June 2013 at the base of the old east lighthouse (43° 57' 34" N, 59° 47' 16" W), contained 13 active nests, > 15 scrapes, and 40 flushed individuals; only Common Terns were observed.

Large colonies. At Main Station, population estimates were 4,100 and 2,309 nests in 2012 and 2013, respectively (see Table 1 for nest densities and 95% confidence intervals). At

East Light, nest densities were approximately four times higher than at Main Station in both 2012 and 2013, though the total population estimates were similar among sites (Table 1). In 2013, a direct count of 0.7 ha yielded 985 active nests. The proportion of nests missed was estimated to be 0.066 (from a ratio of 5:71 unmarked:marked nests), providing an adjusted estimate of 1,054 nests in 52.2% of the colony, or a total population estimate of 2,018 pairs.

Trends in abundance. Total population estimates and number of breeding colonies since 1969 are summarized (Table 2; Fig. 2). The total number of colonies on Sable Island fluctuated between 10 and 20 during the 1980s and early 1990s; however, since 1998 there has been a significant decline in the total number of colonies ($n = 10$ survey years, $P < 0.001$, $R^2 = 0.902$) from 21 in 1998 to 3 in 2013. There has also been a significant decline in the number of pairs nesting in small colonies between 1998 and 2013 ($n = 10$, $P < 0.001$, $R^2 = 0.811$) from 713 pairs in 1998 to 13 pairs in 2013. During this same period, there has been a rapid growth of the colonies at Main Station and East Light (Table 1); however, both of these colonies appear to have peaked in size in 2008/2009 and numbers have since decreased by nearly half in 2012/2013.

Population trends for total breeding pairs may be considered in two phases (Fig. 2). There was no significant trend from the years 1969 to 1995 (linear model, $n = 8$, $P = 0.414$, $R^2 = 0.114$), but a rapid increase after 1998 (exponential model, $P = 0.010$, $R^2 = 0.589$). From 1969 to 2013 inclusive, an exponential model ($P = 0.004$, $R^2 = 0.418$) indicates an increasing population trend over the past 45 years.

Information regarding species-specific population trends for Arctic and Common terns is less certain, but may be inferred from available literature. Arctic Terns comprised about two-thirds of the total tern population in the late 1800s (Dwight 1895), 1971 (McLaren 1981) and 1982 (Kress *et al.* 1983), but during breeding surveys in 1983 a shift had occurred with Common Terns outnumbering Arctic Terns “by 10 to 1” (A.

Table 1. Summary of surveys conducted at the two largest mixed colonies of Common and Arctic terns on Sable Island. Data from 1998 to 2009 were obtained from unpublished reports and, where necessary, new population estimates were recalculated to include 95% confidence intervals. n/a = not applicable.

| Colony | Year | Date | Method | n (plots) | Nests/ha | | Colony Area (ha) | Breeding Pairs (95% CI) | Source |
|----------------------------|-------------------|-----------|-----------------------------------|--------------|----------|-------|---------------------|----------------------------|--------------------------------------|
| | | | | | Mean | SD | | | |
| Main Station Colony | | | | | | | | | |
| | 1998 | 23-24 Jun | flush count | n/a | n/a | n/a | n/a | 213 | Horn and Shepherd 1998 |
| | 2000 | late June | flush count | n/a | n/a | n/a | n/a | 150 | Taylor <i>et al.</i> 2001 |
| | 2001 | 17-29 Jun | flush count | n/a | n/a | n/a | n/a | 207 | Taylor <i>et al.</i> 2001 |
| | 2002 | 20-21 Jun | flush count | n/a | n/a | n/a | n/a | 135 | Horn <i>et al.</i> 2003 |
| | 2006 | 17-21 Jun | quadrats (20 x 20 m) ¹ | 5 | 214 | 177 | 13.42 | 2,872 (790-4,954) | Toms <i>et al.</i> 2006 |
| | 2007 ² | 25 Jun | photography/flush count | n/a | n/a | n/a | n/a | 875 | Dillon 2007 |
| | 2008 | 16 Jun | quadrats (10 x 10 m) | 10 | 490 | 240 | 11.81 | 5,787 (4,030-7,544) | Dillon 2008 |
| | 2009 | unknown | quadrats (10 x 10 m) | 15 | 490 | 150 | 11.92 | 5,841 (4,936-6,746) | Sable Island Preservation Trust 2009 |
| | 2012 | 13 Jun | quadrats (5 x 5 m) | 20 | 380 | 588 | 10.79 | 4,100 (1,320-6,881) | this study |
| | 2013 | 13/14 Jun | quadrats (10 x 10 m) | 21 | 214 | 231 | 10.79 | 2,309 (1,243-3,375) | this study |
| East Light Colony | | | | | | | | | |
| | 1998 | 23-24 Jun | photography/flush count | n/a | n/a | n/a | n/a | 833 | Horn and Shepherd 1998 |
| | 2000 | late June | photography/flush count | n/a | n/a | n/a | n/a | 759 | Taylor <i>et al.</i> 2001 |
| | 2001 | 17-29 Jun | photography/flush count | n/a | n/a | n/a | n/a | 685 | Taylor <i>et al.</i> 2001 |
| | 2002 | 20-21 Jun | photography/flush count | n/a | n/a | n/a | n/a | 693 | Horn <i>et al.</i> 2003 |
| | 2006 ² | 17-21 Jun | photography/flush count | n/a | n/a | n/a | n/a | > 425 | Toms <i>et al.</i> 2006 |
| | 2007 | 24 Jun | photography/flush count | n/a | n/a | n/a | n/a | 731 | Dillon 2007 |
| | 2008 | 15 Jun | quadrats (10 x 10 m) | 8 | 2,560 | 1,300 | 1.34 | 3,430 (2,223-4,638) | Dillon 2008 |
| | 2009 | unknown | quadrats (10 x 10 m) | 4 | 2,030 | 1,140 | 1.34 | 2,720 (1,223-4,217) | Sable Island Preservation Trust 2009 |
| | 2012 | 14 Jun | quadrats (5 x 5 m) | 10 | 1,680 | 1,080 | 1.34 | 2,251 (1,354-3,148) | this study |
| | 2013 | 10 Jun | direct count (0.70 ha) | n/a | 1,506 | n/a | 1.34 | 2,018 | this study |

¹Three plots were 20 x 20m; two extras were of other dimensions not reported.

²Possible underestimate due to methodology.

Table 2. Estimates of Common, Arctic, and Roseate tern populations on Sable Island from 1969 to 2013. Most surveys between 1969 and 2002 counted the total number of individuals at colonies, which were converted using a factor of 1.5 to estimate breeding pairs. Where possible, separate counts are provided for species. n/a = not applicable.

| Year | Number of Colonies | | | Estimate of Breeding Pairs | | | | | | Source | |
|-------------------|----------------------|--------------|----------------------|----------------------------|-------------|-------|-------------|-------|--------------|--------|---|
| | Common / Arctic Tern | Roseate Tern | Common / Arctic Tern | Roseate Tern | Common Tern | | Arctic Tern | | Roseate Tern | | |
| | | | | | Common | Tern | Arctic Tern | Tern | Common | | Roseate Tern |
| 1969 ¹ | n/a | unknown | 2,600 | 120 | n/a | n/a | n/a | 1,733 | n/a | n/a | Lock 1989, as cited in Horn 1998 |
| 1971 ¹ | n/a | unknown | 2,585 | 250 | n/a | n/a | n/a | 1,723 | n/a | n/a | McLaren 1981 |
| 1979 | n/a | 2+ | n/a | 10-30 | n/a | n/a | n/a | n/a | ~15 | n/a | McLaren 1981 |
| 1983 | 10 | unknown | 1,356 | n/a | n/a | n/a | n/a | 904 | n/a | n/a | A. R. Lock, unpubl. data as cited in Horn 1998 |
| 1984 | 20 | 2 | 1,734 | 36 | 1,050 | 85 | 365 | 1,156 | n/a | n/a | A. R. Lock, unpubl. data as cited in Horn 1998 |
| 1985 | 10 | unknown | 2,112 | 40 | 1,040 | n/a | n/a | 1,408 | 10-20 | n/a | A. R. Lock, unpubl. data as cited in Horn 1998 |
| 1993 | 13 | 2 | 2,200 | 8 | n/a | n/a | n/a | 1,467 | 4 | n/a | Boates and Sam, unpubl. data, as cited in Horn 1998 |
| 1995 | 20 | 2 | 2,146 | 4 | 1,290 | 135 | 135 | 1,431 | 2 | 2 | Z. Lucas, unpubl. data, as cited in Horn 1998 |
| 1998 | 21 | 1 | 2,640 | n/a | 1,545 | 200 | 200 | 1,760 | 3 | n/a | Horn and Shepherd 1998 |
| 2000 | 19 | 1 | n/a | 4 | 1,348 | 142 | 142 | 1,490 | n/a | n/a | Horn and Taylor 2000 |
| 2001 | 16 | 1 | n/a | n/a | 1,474 | 57 | 57 | 1,531 | 1 | 1 | Taylor <i>et al.</i> 2001 |
| 2002 | 18 | 0 | 1,715 | n/a | 1,050 | 93 | 93 | 1,143 | 0 | 0 | Horn <i>et al.</i> 2003 |
| 2006 ² | 12 | 1 | n/a | 3 | n/a | n/a | n/a | 3,024 | n/a | n/a | Toms <i>et al.</i> 2006 |
| 2007 ² | 15 | 1 | n/a | n/a | 1,534 | 470 | 470 | 2,004 | 4 | 4 | Dillon 2007 |
| 2008 | 9 | 1 | n/a | n/a | n/a | na | na | 9,557 | 5 | 5 | Dillon 2008, corrected in this study |
| 2009 | 11 | 1 | n/a | n/a | 7,065 | 1,801 | 1,801 | 8,866 | 5 | 5 | Sable Island Preservation Trust 2009 |
| 2012 | 4 | 1 | n/a | 5 | n/a | n/a | n/a | 6,447 | n/a | n/a | this study |
| 2013 | 3 | 1 | n/a | n/a | n/a | n/a | n/a | 4,242 | 3 | 3 | this study |

¹May include non-breeders of all species; Roseate Tern numbers likely overestimated (McLaren 1981; A. R. Lock, pers. commun.).

²Possible underestimate at large colonies using flush count method (see Table 1).

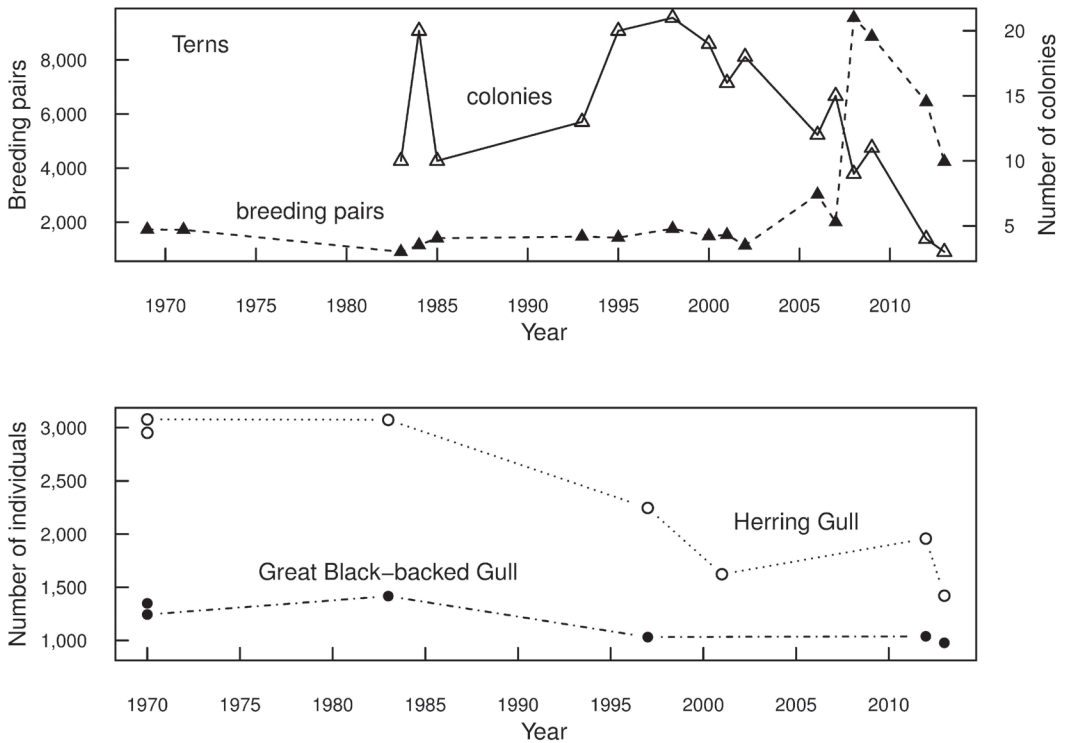


Figure 2. Trends in numbers of Herring and Great Black-backed gulls, and mixed colonies of Common and Arctic terns (Terns) nesting on Sable Island, Canada, between 1969 and 2013.

R. Lock, unpubl. data). From 1984 through the 1990s, surveys consistently reported that Arctic Terns comprised about 10% of the total tern population (Horn 1998; Horn and Taylor 2000). Since then, Arctic Terns were present in many of the small colonies on the island (Toms *et al.* 2006), but most of these colonies have disappeared in recent years. Surveys in 2007 and 2009 suggested that the two largest colonies contained about 20% Arctic Terns (Dillon 2007; Sable Island Preservation Trust 2009), though our impression is that both the Main Station and East Light colonies likely contained less than 5% Arctic Terns as of 2013.

Roseate Terns. In 2013, we spent 6.5 hr observing the northeast portion of the East Light colony for signs of Roseate Tern nesting activity. Adults were observed landing in the tall grass in three different locations, implying that at least three nesting pairs were present. We did not search for nests. On 10 June 2013, two observers spent an additional 8 hr scanning for Roseate Terns throughout the rest of the colony, but none were ob-

served. Numerous counts of Roseate Terns have been recorded over the past 45 years (Table 2). Although methodological differences preclude a statistical analysis of trends, there has been an obvious decline from 250 birds in 1971 to fewer than six pairs at a single colony in the 1990s and 2000s.

Herring and Great Black-backed Gulls

Estimates of nesting pairs. In 2013, we counted 45 Herring Gull colonies, ranging in size from three to 65 standing adults. For Herring Gulls, the ratio of standing birds to nests was 1.41 in 1970 ($n = 315$ nests; Lock 1973), 1.71 in 2012 ($n = 35$ active and empty nests at one colony), 1.52 for active nests in 2013 ($n = 99$ active nests, nine colonies), and 1.36 for all nests in 2013 ($n = 110$ active and empty nests, nine colonies). Counts of adult Herring Gulls on the “consolidated part of the island” were 2,858, 1,627, and 1,281 in 1970, 2012, and 2013, respectively. When the ratios were applied to their respective counts, estimates of breeding birds were

2,025 pairs in 1970, 951 pairs in 2012, and 843 to 942 pairs in 2013. In 1983, 2,520 individuals were counted in “breeding areas” (A. R. Lock, unpubl. data), but the number of nests was not estimated. In 2001, during an island-wide search, 1,634 individuals were counted and 573 nests were located in 36 colonies ranging in size from five to 49 nests (Taylor *et al.* 2001).

For Great Black-backed Gulls, Lock (1973) applied an adult to nest ratio of 2.13 to 1,121 adults (excluding birds from loafing areas and the spits), yielding an estimate of 527 pairs in 1970. In June 1983, 902 individuals were counted in “breeding areas” (A. R. Lock, unpubl. data), but estimates of nests were not obtained. Great Black-backed Gulls were hatching by the time we arrived at the colony in 2012 and 2013, thus making estimates of adult to nest ratios ineffective. However, during island-wide counts, we frequently observed adults in pairs much more often than singly, suggesting that both parents were typically guarding young at the time of the survey; thus, a ratio of about two adults per nest would be roughly consistent with Lock (1973). Applying Lock’s ratio of 2.13 adults per nest to “consolidated” counts of 1,004 and 847 adults, yields estimates of 472 and 398 pairs in 2012 and 2013, respectively.

Trends in abundance and distribution. Island-wide surveys of gulls in 2012/2013 counted between 1,400 and 2,000 Herring Gulls and approximately 1,000 Great Black-backed Gulls (Table 3). Current estimates are directly comparable to those made in May and June of other years (Table 3) showing declines in abundance (Fig. 2) and changes in distribution on the island (Table 4). Both Herring Gulls (linear model: $n = 6$ surveys, $P = 0.004$, $R^2 = 0.796$) and Great Black-backed Gulls ($n = 5$ surveys, $P = 0.039$, $R^2 = 0.621$) have experienced significant declines in numbers since 1970, although the numbers of both species appeared to be stable at least until the mid-1980s (Fig. 2). As of 2013, there were approximately 33 to 50% fewer Herring Gulls and 23% fewer Great Black-backed Gulls than observed in 1970 (Fig. 2). Both species showed declines in the central

Table 3. Numbers of Herring and Great Black-backed gulls counted during island-wide surveys of Sable Island, 1970 to 2013. n/a = not applicable.

| Year | Date | Adults | | Immatures | | Notes | Source |
|------|-----------|--------------|-------------------------|--------------|-------------------------|-------------------------------|---|
| | | Herring Gull | Great Black-backed Gull | Herring Gull | Great Black-backed Gull | | |
| 1970 | 3/5 Jun | 2,952 | 1,349 | 0 | 0 | whole island census | Lock 1973 |
| 1970 | 14/15 Jun | 3,078 | 1,244 | 0 | 0 | whole island census | Lock 1973 |
| 1970 | 10 Jul | 2,524 | 1,015 | 0 | 174 | whole island census | Lock 1973 |
| 1970 | 22/23 Aug | 1,785 | 1,878 | n/a | n/a | whole island census | Lock 1973 |
| 1971 | 12/15 Jul | 2,765 | 1,131 | 0 | n/a | whole island census | Lock 1973 |
| 1983 | 22-24 Jun | 3,074 | 1,417 | n/a | n/a | whole island census | A. R. Lock, unpubl. data |
| 1997 | n/a | 2,246 | 1,032 | n/a | n/a | count method and area unknown | Z. Lucas, unpubl. data, as cited in Horn 1998 |
| 2001 | 22-28 May | 1,623 | n/a | n/a | n/a | counts in nesting areas only | Taylor <i>et al.</i> 2001 |
| 2012 | 5/6/7 Jun | 1,958 | 1,039 | 45 | 227 | whole island census | this study |
| 2113 | 5/6 Jun | 1,421 | 978 | 5 | 247 | whole island census | this study |

portions of the island and increases near the island tips, especially for Great Black-backed Gulls in the most western sector (Table 4).

DISCUSSION

The majority of the Common and Arctic tern population comprises two distinct breeding colonies, both of which have grown considerably since the early 2000s. At the Main Station colony, differences in survey methodology have likely contributed to uncertainty and variability in abundance estimates. Nevertheless, the lower confidence intervals suggest that minimum population estimates have been greater than 1,200 pairs since 2008, compared with 150-200 pairs counted in 1998 and 2002 (Taylor *et al.* 2001; Horn *et al.* 2003). The current occupied area, estimated to be ~11 ha, is vast compared to the three sub-colonies here in the late 1990s (A. G. Horn, pers. obs.), suggesting that the colony growth is real and not an artifact of methodological differences. Though small in area, the fenced region of the East Light colony has supported the largest or second largest colony of terns on the island for several decades, with nest densities three to five times greater than at the Main Station colony. Moreover, the East Light colony is the only confirmed nesting area of Roseate Terns since 1993, emphasizing the importance of this site. In contrast to the increase of these large tern colonies, many of the island's smaller colonies have been aban-

doned in recent years and the total number of terns nesting in small colonies has been declining since 1998.

The recent growth of the large colonies on the island and disappearance of smaller colonies may be explained by Common Tern meta-population dynamics, whereby large colonies may attract individuals from smaller colonies during periods of population growth (Schippers *et al.* 2011), a pattern that has been observed in the fluctuations of populations on mainland Nova Scotia (Regular *et al. in press*). On Sable Island too, large colonies have higher rates of reproductive success than do small colonies (Horn and Shepherd 1998; Horn and Taylor 2000; Taylor *et al.* 2001). Alternatively, several extrinsic factors may be influencing tern population dynamics on the island, including wind and wave exposure, availability of perch sites, exposure to predation by gulls (Horn and Shepherd 1998; Taylor *et al.* 2001), impacts from horses by trampling (as observed at gull nests; Lock 1973) or by displacement to less favorable habitat (e.g., high density vegetation inside the East Light colony; Freedman *et al.* 2011), vegetation type and dynamics (influenced by wind, waves, and horses; Catling *et al.* 1984; Freedman *et al.* 2011), and other resource limits external to the island, such as the availability of food (Horsman and Shackell 2009). Habitat availability is also an important factor influencing tern population dynamics and the establishment of new colonies (Schippers *et al.* 2009; Cabot and Nisbet 2013), though breeding habitat does not appear to be limited on Sable Island.

Table 4. Changes in numbers and distribution of Herring and Great Black-backed gulls counted during June surveys on Sable Island. Counts were divided into approximately equal sectors from west to east (numbers correspond to Fig. 1). Longitude denotes the degrees bisecting the island at the most eastern portion of each sector. % change is calculated by the following formula: (mean count from 2012 and 2013 – mean count from 1970) / mean count from 1970 x 100.

| Sector | Longitude | Herring Gull Counts | | | | | Great Black-backed Gull Counts | | | | |
|--------------|---------------|---------------------|--------------|--------------|--------------|------------|--------------------------------|--------------|--------------|------------|------------|
| | | 1970a | 1970b | 2012 | 2013 | % Change | 1970a | 1970b | 2012 | 2013 | % Change |
| 1 | 60° 04' 23" W | 71 | 116 | 287 | 208 | 165 | 37 | 30 | 272 | 171 | 561 |
| 2 | 60° 00' 18" W | 642 | 642 | 381 | 436 | -36 | 110 | 102 | 148 | 225 | 76 |
| 3 | 59° 53' 06" W | 1,291 | 1,267 | 417 | 349 | -70 | 553 | 520 | 178 | 236 | -61 |
| 4 | 59° 48' 36" W | 625 | 724 | 348 | 163 | -62 | 345 | 344 | 179 | 134 | -55 |
| 5 | 59° 45' 07" W | 252 | 269 | 261 | 183 | -15 | 209 | 145 | 146 | 131 | -22 |
| 6 | eastern spit | 71 | 60 | 264 | 82 | 164 | 95 | 103 | 116 | 81 | -1 |
| Total | | 2,952 | 3,078 | 1,958 | 1,421 | -44 | 1,349 | 1,244 | 1,039 | 978 | -22 |

Despite the decline in small tern colonies after a period of relative stability from the 1970s to early 1990s (Horn and Shepherd 1998), the total population on Sable Island has grown rapidly since 2002, with a decline during the most recent surveys. Likewise, tern populations in other parts of Canada have also been increasing (Morris *et al.* 2012). The mainland population of terns in Nova Scotia experienced a period of growth from 1995 to 2003, reaching a maximum level of ~6,700 pairs before declining again to ~5,300 and 5,200 pairs in 2007 and 2011, respectively (Regular *et al. in press*). While the population growth on Sable Island mirrors that on the mainland with a lag of about 5 years, the recent exponential increase at the Main Station and East Light colonies seems improbable from intrinsic population growth alone, especially considering low rates of reproductive success recorded at Main Station in recent years (Sable Island Preservation Trust 2009). Immigration is a strong contributor to the growth rate of tern colonies (Szostek *et al.* 2014); thus, the rapid increase of Sable Island colonies suggests that immigration from mainland colonies is occurring and that Sable Island is part of a larger metapopulation of terns in Nova Scotia and the Bay of Fundy (Schipper *et al.* 2011; Regular *et al. in press*). Moreover, the “crash” observed on Sable Island sometime between the 1940s and 1969 (Kress *et al.* 1983) also mirrors broad-scale regional patterns in most of eastern North America (Drury 1973, 1974; Kress *et al.* 1983; Nisbet *et al.* 2013), further suggesting that colonies are interdependent.

Despite the overall increasing trend of the total tern population, both Roseate and Arctic terns appear to have continued to decline since the 1980s. The decline of Roseate Terns is particularly evident, with fewer than six pairs breeding on the island in the past two decades. For Arctic Terns, total abundance estimates remain uncertain, but the proportion, relative to Common Terns, has declined from > 60% (in the late 1800s to early 1980s) to < 5% at present. The causes of these apparent declines are unknown.

The colonization and growth of gull populations on Sable Island between the 1920s and 1970s echoes the growth and expansion of gull colonies in New England, USA (Kadlec and Drury 1968). Current population estimates of gulls on Sable Island are about 450 and 900 breeding pairs of Great Black-backed and Herring gulls, respectively, and total numbers of individuals are down by about 23% and 50%, respectively, of 1970 levels. This also resembles patterns in the eastern USA, where Herring Gull populations probably peaked prior to 1980 and have decreased by > 50% since then, while Great Black-backed Gull populations likely peaked in the 1990s and have since been declining (Nisbet *et al.* 2013). Mainland populations of both species in Nova Scotia showed increases between the 1970s and 1980s, but declines to the 2000s, presumably associated with the reduction in fisheries offal available and the closure of open landfills (Boyne and Beukens 2004; Cotter *et al.* 2012; Wilhelm *et al.* 2016). Since limited survey data are available for Sable Island in the 1980s and 1990s, it is unclear if the Sable Island population follows the short-term rise and fall seen on the mainland.

Though long-term population trends may be similar to some mainland regions, factors influencing these trends remain unknown. In contrast to mainland areas, Sable Island is isolated from terrestrial food sources (e.g., intertidal areas, landfills, fishery discards at processing sites), and it was thought that most of the regional fishery activities during the 1970s were beyond reach (> 90 km) of breeding gulls (Lock 1973). Thus, landfill closures and decreased availability of fisheries offal are unlikely to have affected the Sable Island gull population, raising questions about widespread assumptions of factors affecting mainland population declines (Boyne and Beukens 2004; Cotter *et al.* 2012; Wilhelm *et al.* 2016). Other factors that may be influencing Sable Island's gull populations include low reproductive success (Lock 1973), low adult survival (as has been observed for other populations of Herring Gulls in eastern Canada; Robertson *et al.* 2016), dietary shifts (Ronconi *et al.* 2014)

that may be related to fluctuating local prey availability (Horsman and Shackell 2009), and contaminant loads found in eggs (Geb-bink *et al.* 2011; Burgess *et al.* 2013); these hypotheses remain untested. Alternatively, a portion of the observed decline may be associated with local changes in suitable nesting habitat since we also documented a shift in nesting distribution on the island. These changes reflect the erosion and establishment of vegetated dunes during the past 20 years (D. Bowen and J. McMillan, pers. commun.), which have caused previous gull colonies to be abandoned (Lock 1973) and new ones to form.

Over the past century, Sable Island's gull and tern populations have fluctuated asynchronously, raising questions about the possible influence of gulls on terns (Lock *et al.* 1993; Horn and Taylor 2000) that have been raised elsewhere (Becker and Erdelen 1987; Suedbeck *et al.* 1998). Increasing gull populations and resultant predation on tern eggs and young have been suggested as one possible factor contributing to the decline of tern populations on Sable Island and elsewhere (Lock *et al.* 1993; Becker 1995). Gulls do depredate tern eggs and young on Sable Island (Lock 1973) and have been implicated with low rates of reproductive success (Horn and Shepherd 1998) and abandonment of small colonies (Taylor *et al.* 2001). However, the evidence of gull predation having a large impact on terns "is not overwhelming" (Becker and Erdelen 1987; Howes and Montevecchi 1993; Taylor *et al.* 2001; Cabot and Nisbet 2013), and recent dietary estimates from pellets suggest that terns are virtually absent in gull diets during the incubation period (Ronconi *et al.* 2014). Moreover, the recent development of very large tern colonies on Sable Island may also offer better defense against predatory gulls (Burger and Gochfeld 1991; Hernández-Matías and Ruiz 2003).

Historical records and population estimates of terns and gulls from the past century suggest a dynamic system on Sable Island. The declines in gull numbers and recent recovery of tern colonies on the island could be interpreted as a return to a previous ecosystem state when gulls were absent and

terns were abundant; however, recent inter-annual variability in total breeding pairs suggests that this population is still in a state of flux. Regardless of the causes of population growth and declines, the current tern population on Sable Island is at least as large as the entire population of mainland Nova Scotia (Regular *et al. in press*), and historically this site was one of the largest aggregations of terns recorded anywhere in the Temperate Zone, emphasizing the importance of this colony site to the western North Atlantic ecosystem.

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