Differential Declines among Nesting Habitats of Breeding Herring Gulls (*Larus argentatus*) and Great Black-backed Gulls (*Larus marinus*) in Witless Bay, Newfoundland and Labrador, Canada

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Abstract.—Environmental conditions in eastern Newfoundland have changed considerably since the 1970s, as both bottom-up oceanographic and anthropogenic influences on seabird populations have fluctuated considerably. The diet, reproductive success, and presumably survival of gulls are intrinsically linked to these processes, and breeding populations have declined considerably through the 1980s and 1990s. To assess the populations of breeding large gulls in the Witless Bay Ecological Reserve in eastern Newfoundland and Labrador, Canada, nests were surveyed and clutch size determined for Herring Gulls (*Larus argentatus*) and Great Black-backed Gulls (*L. marinus*) breeding on Great, Gull, and Pee Pee Islands in 2011-2012. The total number of breeding gulls of these two species combined decreased by 41% on Gull Island, 78% on Great Island and 51% on Pee Pee Island since 2000. However, the declines differed among habitat type, with modest declines on puffin slopes (-15% to -52%) and the steepest declines in meadows (-70% to -88%), suggesting that large-scale causative factors are not solely responsible for changes in population size. Clutch size did not differ from that in 2000. Differential recruitment among highly philopatric gulls stemming from bottom-up diet-related variation in breeding success may be responsible for different changes in populations among different habitats. *Received 5 June 2014, accepted 5 June 2015.*

Key words.—clutch size, Great Black-backed Gull, Herring Gull, *Larus argentatus*, *Larus marinus*, nesting habitat, population trend.

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For much of the 20th century, populations of Herring (*Larus argentatus*) and Great Black-backed (*L. marinus*) gulls increased substantially, likely as a result of reduced persecution, increased availability of fisheries discards from industrial operations, and increased availability of other human refuse (Kadlec and Drury 1968; Harris 1970; Rodway and Regehr 1999; Oro *et al.* 2013). As Herring and Great Black-backed gull populations increased, they colonized new nesting habitats, such as inland and urban areas, or new habitats in existing breeding colonies (Goethe 1960, 1964; Monaghan 1979; Robertson *et al.* 2001). Over the past two decades, however, changes in waste management (Pons 1992; Pons and Migot 1995), fisheries discard regulations (Stenhouse and Montevecchi 1999; Votier *et al.* 2004; Bicknell *et al.* 2013), and drastic reductions in fishing effort (Hutchings and Myers 1994) have resulted in many stable or decreasing populations of gulls worldwide (Cotter *et al.* 2012; Oro *et al.* 2013). During the last 40 years in Newfoundland and Labrador, conditions have been altered considerably by such anthropogenic pressures, which have affected several aspects of Herring and Great Black-backed gulls' biology, including breeding populations (Howes and Montevecchi 1993; Robertson *et al.* 2001; Regular *et al.* 2013), nesting habitat (Robertson *et al.* 2001), demography (Rodway and Regehr 1999) and diet (Stenhouse and Montevecchi 1999). Specifically, reductions in the availability of fisheries discards following a groundfish moratorium in 1992 (Hutchings and Myers 1994) and shifts in the phenology of capelin

(*Mallotus villosus*) (Carscadden *et al.* 2001; Obradovich *et al.* 2014) have affected gull diets (Regehr and Rodway 1999; Stenhouse and Montevecchi 1999; Massaro *et al.* 2000), and likely reproductive success and abundance in different breeding habitats within colonies (Pierotti 1982; Pierotti and Annett 1991; Robertson *et al.* 2001).

Previous population studies of Herring Gulls and Great Black-backed Gulls in Witless Bay, Newfoundland and Labrador, found shifts in nesting habitat, which has consequences for diet and breeding success (Pierotti 1982; Pierotti and Annett 1991; Robertson *et al.* 2001). Herring and Great Black-backed gulls in Witless Bay began nesting in forested habitat, and their abundance in rocky and puffin slope habitats decreased considerably between the 1970s and late 1990s, likely as a result of changes in food availability (Massaro *et al.* 2000; Robertson *et al.* 2001). Previous work also found notable differences in clutch size among habitats (Rodway and Regehr 1999; Robertson *et al.* 2001), which is a response to local conditions easily measured when conducting the islandwide population counts. Furthermore, gull populations assessed in Witless Bay in 1999 and 2000 were only at 60-70% of those counted in 1979 (Cairns and Verspoor 1980; Robertson *et al.* 2001), potentially the result of prey limiting predators at multiple trophic levels in the northwestern Atlantic Ocean (Massaro *et al.* 2000; Robertson *et al.* 2001; Obradovich *et al.* 2014).

Our objectives were to: 1) estimate the population of breeding Herring and Great Black-backed gulls on the three accessible islands in the Witless Bay Ecological Reserve, Newfoundland and Labrador (Gull, Great, and Pee Pee Islands) in 2011/2012; 2) determine whether the habitat shifts observed in 1999 and 2000 continued in the intervening decade; and 3) assess whether there have been any associated changes in clutch size over time or with habitat type.

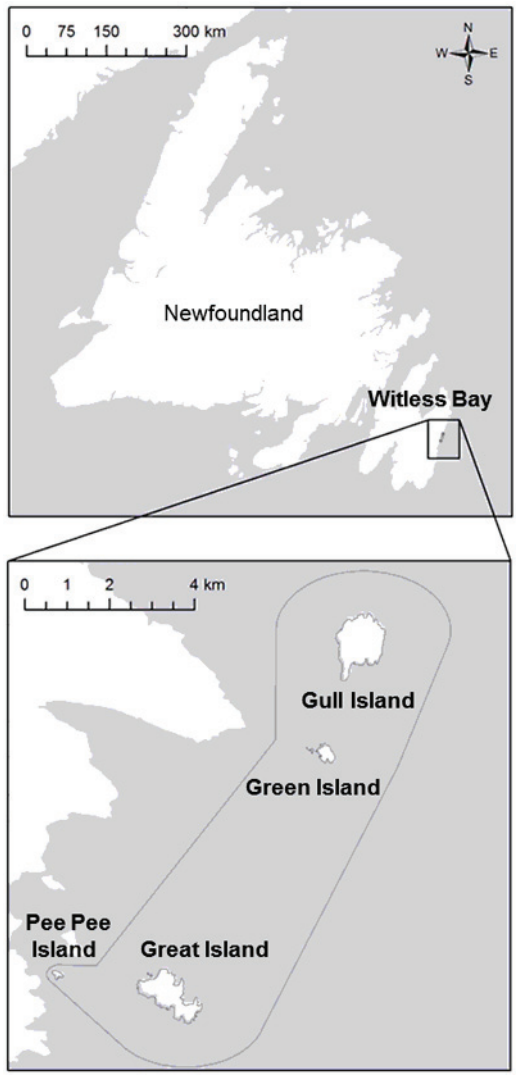

Figure 1. Map of Newfoundland showing the Witless Bay Ecological Reserve and locations of Great, Gull, and Pee Pee Islands.

METHODS

Our study sites were islands in the Witless Bay Ecological Reserve, which comprises four islands (Gull, Green, Pee Pee, and Great Islands; Fig. 1). We did not survey Green Island to avoid disturbing the large colony of Common (*Uria aalge*) and Thick-billed (*U. lomvia*) murres, which number > 250,000 pairs (Canadian Wildlife Service, unpubl. data), and because the steep cliffs make the flat plateau where gulls nest difficult to access. In 1979, there were 304 Herring Gull nests and 51 Great Black-backed Gull nests on Green Island (Cairns and Verspoor 1980). Descriptions of the Gull, Great, and Pee Pee Islands are provided elsewhere (Nettleship 1972; Haycock 1973; Cairns and Verspoor 1980; Robertson *et al.* 2001).

We surveyed breeding Herring and Great Black-backed gull populations from 22-24 May 2012 on Great Island, from 19 May-6 June 2011 on Gull Island, and on 22 May 2012 on Pee Pee Island; no other *Larus* spp.

gulls breed on the islands. We walked in lines across the islands and systematically recorded the nesting habitat (except on Pee Pee Island where all Herring and Great Black-backed gulls nest in meadow habitat) and clutch size of each nest, and then marked the nest with a colored wooden stick to prevent repeated counting following established methods (Nettleship 1976; Robertson *et al.* 2001). In 2011, Herring and Great Black-backed gulls in Witless Bay completed their clutches by late May, so our estimates would fail to account for eggs lost prior to clutch completion, though this is a very small number (A. L. Bond, unpubl. data), and Herring Gulls can continue to lay eggs until they have a full clutch of three eggs if eggs are lost prior to clutch completion (Pierotti 1982). The timing of our census was similar to those in previous years, and the methods were identical (Nettleship 1976; Robertson *et al.* 2001). We classified nesting habitat into four categories: rocky (largely unvegetated areas around the periphery of the islands), meadow (grass, sedge, and tussock), puffin slope (vegetated areas with burrowing Atlantic Puffins (*Fratercula arctica*)), and forest (in association with coniferous or deciduous trees). For detailed methods and descriptions of the different habitats, see Robertson *et al.* (2001). We identified Great Black-backed Gulls using a variety of methods, including the presence of an adult defending a nesting territory, the size of the nest cup and the relative size of the eggs. As in previous surveys, misidentification could greatly affect the estimates for Great Black-backed Gulls, so we urge caution when interpreting results specific to Great Black-backed Gulls.

Statistical Analysis

We calculated the percent change in Herring and Great Black-backed gull populations and changes in habitat use between three census periods: 2011-2012, 1999-2000, and 1979. To account for slight differences in the number of years between surveys, we also determined the percent change per year for each species on each island as the *n*th root of the overall change, where *n* is the interval between surveys. We examined changes in Herring Gull clutch size using a generalized linear model, with habitat type and year as predictors. We used a Poisson error distribution, and a likelihood ratio test against a null model in statistical program R (R Development Core Team 2014), and effects were considered significant when $P < 0.05$.

Results

Population Trends

We recorded 1,608 Herring Gull nests and 32 Great Black-backed Gull nests on Gull Island in 2011, representing a decrease of 42% and 64%, respectively, since 2000, or a 1.4% and 1.5% decline per year, respectively (Table 1). On Great Island, there were

Table 1. Summary of previous census results for Herring and Great Black-backed gulls in Witless Bay, Newfoundland and Labrador.

	Great Island		Gull Island		Pee Pee Island		
Year	Great Black-backed Gull	Herring Gull	Great Black-backed Gull	Herring Gull	Great Black-backed Gull	Herring Gull	Data Source
1968	40	1,500		1,983			Nettleship 1972[1]; Threlfall 1978
1969			36	2,033			Haycock 1973; Threlfall 1978
1970			40	2,544			Haycock 1973; Threlfall 1978
1971				2,663			Threlfall 1978
1976	40	2,104					Pierotti 1982[2]
1979	80	2,771	118	3,852			Cairns and Verspoor 1980[3]
1984					3	75	Cairns *et al.* 1989
1999			115	2,794			Robertson *et al.* 2001
2000	28	1,640	88	2,786	7	134	Robertson *et al.* 2001
2011			32	1,608			this study
2012	9	358			7	62	this study

[1]Rough estimate only.
[2]The ratio of Herring Gulls to Great Black-backed Gulls is not reported; we assumed 40 Great Black-backed Gulls and the remainder Herring Gulls.
[3]Counts of Great Black-backed Gulls on Great Island may be biased; see Robertson *et al.* (2001).

358 Herring Gull nests and nine Great Black-backed Gull nests in 2012, for a decrease of 78% (-1.4% per year) and 68% (-1.4% per year), respectively, from the 2000 census (Table 1). The number of Great Black-backed Gull nests on Pee Pee Island was stable from 2000 to 2012 (7 nests), but the number of Herring Gull nests decreased by 54% from 134 to 62, or -1.4% per year (Table 1).

Compared to the earliest reliable assessments (Gull Island: 1969; Great Island: 1976; Pee Pee Island: 1984), Herring Gulls have declined by 21% (-1.1 % per year), 83% (-1.1% per year), and 17% (-1.1% per year), respectively (Table 1). Great Black-backed Gulls also declined at Gull Island (-13%; -1.1% per year) and Great Island (-78%; -1.1% per year), and increased at Pee Pee Island (+233%; +1.2% per year), though these represent smaller changes in real terms because of the small number of Great Black-backed Gull nests overall (Table 1).

Habitat Use

There were marked changes in habitat use between 2000 and 2011/2012 throughout Witless Bay. Although the overall population of breeding Herring and Great Black-backed gulls declined, the west side of Gull Island saw an increase in nesting numbers of Herring Gulls since 1979, while the decline on the east side was disproportionately steep (Table 2). While this was driven by changes before 2000, the pattern continued through 2011-2012. The decline in Herring and Great Black-backed gull nests was least on puffin slope (-15% on Gull Island, -52% on Great Island). The number of nests in forest (-21% on Gull Island, -77% on Great Island) and rocky habitat (-42% on Gull Island, -88% on Great Island) were essentially half that in 2000, while there was a 70% decrease in the number of nests in meadow habitat between 2000 and 2011/2012 on Gull Island, and a 87% decrease on Great Island (Table 3).

Clutch Size

Using a likelihood ratio test, we found a significant effect of census period (χ^2_6 =

Table 2. Number of Herring Gull and Great Black-backed Gull nests in different areas of Gull, Great and Pee Pee Islands in 1979, 1999/2000 and 2011/2012. Overall change is the percent difference from 1979 to 2011/12. Recent change is the percent difference from 1999/2000 to 2011/2012. Predominant nesting habitats for each area are given in parentheses.

	Great Black-backed Gulls							Herring Gulls						
Location	1979	1999	2000	2011	2012	Recent Change	Overall Change	1979	1999	2000	2011	2012	Recent Change	Overall Change
Gull Island														
East (puffin slope)	28	13	8	3		-63%	-89%	1,048	400	377	164		-56%	-84%
Finger (rocky-meadow)	59	64	52	19		-63%	-68%	508	394	373	349		-6%	-31%
North (mix)	2	18	9	3		-67%	+50%	653	585	579	255		-56%	-61%
South (rocky-puffin slope)	29	11	12	4		-67%	-86%	1,259	623	608	347		-43%	-72%
West (forest-puffin slope)		9	7	3		-57%	+∞	384	792	761	493		-35%	+28%
Great Island														
North (forest)	6		7		2	-71%	-67%	317		410		73	-82%	-77%
South (puffin slope-rocky)	66		14		6	-57%	-91%	1,666		774		208	-73%	-88%
Middle (meadow-puffin slope)	8		7		1	-86%	-88%	788		456		77	-83%	-90%

Table 3. The decline in breeding large gulls in the Witless Bay Ecological Reserve differs among nesting habitat types.

	Number of Nests			Percent Change		
Island, Habitat	1976	2000	2011/2012	1976-2000	1976-2011/2012	2000-2011/2012
Gull Island	—	2,786	1,640	—	—	-41%
Forest	—	409	322	—	—	-21%
Meadow	—	836	253	—	—	-70%
Puffin slope	—	629	536	—	—	-15%
Rocky	—	912	529	—	—	-42%
Great Island	2,154	1,668	367	-23%	-83%	-78%
Forest	10	268	62	+2,680%	+620%	-77%
Meadow	585	838	105	+43%	-82%	-87%
Puffin slope	1,083	369	177	-66%	-84%	-52%
Rocky	476	193	23	-59%	-95%	-88%

53.4, $P < 0.001$) and habitat type ($\chi^2_3 = 10.7$, $P = 0.014$) on clutch sizes of Herring Gull nests; the habitat × census period interaction was not significant ($\chi^2_{13} = 8.7$, $P = 0.79$). Clutch sizes were universally lower in the early 1990s than during other censuses. In 2011/2012, nests in meadow and puffin slope habitat on Gull Island tended to have smaller clutches than those in forested areas. This trend was less pronounced on Great Island (Table 4).

DISCUSSION

Anthropogenic waste from fisheries and other human refuse contributed little to gull diets historically (Haycock and Threlfall 1975; Pierotti 1982), so the reduction in fisheries waste from groundfish fisheries closures (Hutchings and Myers 1994) and centralization and modernization of municipal waste management facilities in eastern Newfoundland are not solely responsible for the reductions in breeding gull populations. The closure of the groundfish fishery in 1992 and subsequent reduction in discards, however, did influence gull populations (Regular *et al.* 2013). Discards were likely of varying importance throughout the year, and their contribution to gull diets differed among age classes. The decrease in gull populations from the 1970s to 2000 was largely attributed to delayed spawning by capelin (Regehr and Rodway 1999; Carscadden *et al.* 2001, 2002; Davoren and Montevecchi 2003), which has remained late through the 2000s (Fisheries and Oceans Canada 2013).

Gulls have adapted to this food shortage by shifting to more seabird prey, including Black-legged Kittiwakes (*Rissa tridactyla*) and Leach's Storm-petrels (*Oceanodroma leucorhoa*), particularly early in the breeding season to compensate for the late arrival of capelin (Regehr and Montevecchi 1997; Stenhouse and Montevecchi 1999; Massaro *et al.* 2000). On Great Island, gulls are estimated to depredate on the order of 10^5 Leach's Storm-petrels per year (Stenhouse *et al.* 2000), a level that is expected to have a demographic effect on the population.

On Great Island, the proximate cause of the severe decrease in the breeding gull population in 2012 was likely due to an increase in the number of loafing Bald Eagles (*Haliaeetus leucocephalus*) on the island (authors' pers. obs.). Bald Eagles loafing on Great Island have caused significant numbers of breeding seabirds to abandon breeding attempts (Hipfner *et al.* 2012) or shift to Gull Island. Gull Island hosts a breeding pair of Bald Eagles, which appears to minimize the presence of loafing Bald Eagles and therefore their density. Bald Eagles in Newfoundland consume significant numbers of seabirds (Dominguez *et al.* 2003), so the recovery of Bald Eagle populations will likely continue to affect gulls and other seabird populations in eastern Newfoundland and elsewhere.

Table 4. Clutch sizes of Herring Gulls in different nesting habitats on Great and Gull Islands. Data are mean ± SD (*n*).

Island	Habitat	1976[1]	1977[1]	1978[1]	1992[2]	1993[2]	2000[3]	2011/2012[4]
Great	Forest	—	—	—	—	—	2.63 ± 0.60 (265)	2.46 ± 0.62 (61)
	Meadow	2.15 ± 0.72 (87)	2.48 ± 0.65 (98)	2.51 ± 0.67 (93)	2.14 ± 0.75 (64)	2.08 ± 0.67 (49)	2.58 ± 0.63 (812)	2.13 ± 0.86 (103)
	Puffin slope	2.22 ± 0.75 (72)	2.67 ± 0.59 (134)	2.67 ± 0.62 (137)	1.84 ± 0.73 (68)	1.88 ± 0.54 (43)	2.57 ± 0.63 (366)	2.12 ± 0.81 (171)
	Rocky	2.40 ± 0.72 (67)	2.60 ± 0.60 (117)	2.57 ± 0.64 (120)	2.06 ± 0.78 (70)	1.89 ± 0.69 (65)	2.52 ± 0.66 (191)	2.35 ± 0.71 (23)
Gull	Forest	—	—	—	—	—	2.68 ± 0.55 (409)	2.63 ± 0.59 (322)
	Meadow	—	—	—	—	—	2.55 ± 0.68 (836)	2.65 ± 0.63 (233)
	Puffin slope	—	—	—	—	—	2.51 ± 0.69 (629)	2.43 ± 0.72 (526)
	Rocky	—	—	—	—	—	2.52 ± 0.70 (912)	2.54 ± 0.66 (527)

[1]Pierotti 1982.
[2]Rodway and Regehr 1999.
[3]Robertson *et al.* 2001.
[4]This study.

Though Herring and Great Black-backed gull populations in all nesting habitats have decreased in Witless Bay, the decline has not been uniform and is not the same as observed between the 1970s and 2000. This suggests that large-scale ecosystem changes (e.g., Drinkwater 1996) are not solely responsible for changes in breeding gull populations in Witless Bay. In terms of recent trends, the largest decrease was in meadow habitat, where there were only 21% of the nests in 2000 as were found in 2011/2012 on Gull Island. Historically, Herring and Great Black-backed gulls nesting in meadow habitat tend to have smaller eggs, lower hatching and reproductive success, and reduced chick growth compared with those in other habitats (Pierotti 1982). They also tend to specialize on depredating Leach's Storm-petrels to a greater degree than Herring and Great Black-backed gulls nesting in other habitats (Pierotti and Annett 1991), and meadow habitat is more likely to be where Bald Eagles loaf. Unlike Herring Gulls, Great Black-backed Gull diet and reproductive success seem to be unaffected by nesting habitat (Veitch 2003), though there are only tens of pairs of breeding Great Black-backed Gulls compared to the thousands of Herring Gulls, so a trend is difficult to detect.

Rocky habitat was the first to be colonized on Great Island in the 1940s (Pierotti 1982), and generally has the highest hatching success, greatest chick mass at hatching, fastest growth, densest nests, and greatest capacity for egg production by females, leading Pierotti (1982) to suggest that rocky areas were the preferred nesting habitat for Herring Gulls in Witless Bay. Herring and Great Black-backed nesting in rocky habitat tended to have a diet composed mainly of blue mussels (*Mytilus edulis*) (Pierotti 1982), though mussel consumption has declined markedly across Gull Island in recent years (Bond 2016). It is possible that the high densities observed by Pierotti (1982) were artificially high, but the reliance on natural foods and overall better breeding performance compared with other habitats runs counter to this hypothesis.

Since 2000, the number of large gulls nesting in forest habitat decreased. Indeed, this nesting behavior was so rare it was not described as a separate habitat type until the census in 1999 (Robertson *et al.* 2001). Forested areas provide cover from predators and shelter for chicks (Pierotti 1982), and may facilitate access to high-energy prey (Leach's Storm-petrels), though the predation rate on storm-petrels was not found to be significantly different between open and forested areas when it was last studied in 1996/1997 (Stenhouse and Montevecchi 1999). The forested area on Great Island has decreased considerably from 562,000 m^2 in 1979 to 462,000 m^2 in 2012, a decrease of 18% (Canadian Wildlife Service, unpubl. data), while that on Gull Island has remained relatively constant. This change in habitat might partially explain the decline in forest-nesting gulls, but would not be the sole driver of the observed population trends.

We found no change in clutch size between the 2000 and 2011/2012 censuses. Changes in clutch size of Glaucous-winged Gulls (*Larus glaucescens*) in western North America, which declined continuously from 2.82 eggs/clutch in the 1960s to 2.25 eggs/clutch in 2009, has been attributed to changes in the availability of high-quality forage fish during egg formation (Blight 2011). Our results generally agree, as the marine environment in eastern Canada changed considerably more in the 1990s than it has since 2000 (Baillie and Jones 2004; Hedd *et al.* 2009; Farmer and Leonard 2011).

Clutch size is unlikely to change over a wide range of prey availability (Cairns 1987; Piatt *et al.* 2007). Because gulls are "income" breeders that use locally-acquired nutrients for egg production (Drent and Daan 1980; Hobson *et al.* 1997) and can easily replace eggs lost early in incubation (Pierotti 1982), clutch size would only be affected by a significant prey shortage. Clutch size is not expected to be significantly affected by predation, as such events are rare in Witless Bay, and when they do occur, result in the loss of the entire clutch (A. L. Bond, unpubl. data). Herring and Great Black-backed gulls nesting in the forest habitats showed slightly larger clutches, possibly a function of good pre-laying foraging conditions, an over-representation of experienced breeders nesting in this habitat, or an almost complete lack of early partial clutch predation because the nests are well concealed.

In conclusion, the number of breeding gulls in Witless Bay, Newfoundland and Labrador, has continued to decline at ~1.0-1.5% per year, differing among the four nesting habitat types, which suggests that the causative factors are not uniform across the population (Robertson *et al.* 2001). Decreases in fisheries discards are unlikely to have been a major influence, especially to explain the recent trends, as recent research indicates that these are not significant food sources for gulls in Witless Bay during the breeding season (Bond 2016; Veitch *et al.* 2016). The overall decline from the 1970s to 2000 was likely related to larger-scale ecosystem changes in eastern North America. The recent decline in gulls breeding in Witless Bay is not typical of recent trends for either species breeding along the Atlantic coast of Newfoundland, which have shown stable or increasing trends throughout the 2000s (Thomas *et al.* 2014), again highlighting that local conditions, likely related to available food resources and diet selection, play a role in the dynamics of gull colonies.

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Literature Cited

Baillie, S. M. and I. L. Jones. 2004. Response of Atlantic Puffins to a decline in capelin abundance at the Gannet Islands, Labrador. Waterbirds 27: 102-111.

Bicknell, A. W. J., D. Oro, K. Camphuysen and S. C. Votier. 2013. Potential consequences of discard reform for seabird communities. Journal of Applied Ecology 50: 649-658.

Blight, L. K. 2011. Egg production in a coastal seabird, the Glaucous-winged Gull (*Larus glaucescens*), declines during the last century. PLOS ONE 6: e22027.

Bond, A. L. 2016. Diet changes in breeding Herring Gulls (*Larus argentatus*) in Witless Bay, Newfoundland and Labrador, Canada, over 40 years. Waterbirds 39 (Special Publication 1): 152-158.

Cairns, D. K. 1987. Seabirds as indicators of marine food supplies. Biological Oceanography 5: 261-271.

Cairns, D. K. and E. Verspoor. 1980. Surveys of Newfoundland seabird colonies in 1979. Unpublished report, Canadian Wildlife Service, Dartmouth, Nova Scotia.

Cairns, D. K., W. A. Montevecchi and W. Threlfall. 1989. Researcher's guide to Newfoundland seabird colonies. Memorial University of Newfoundland Occasional Papers in Biology 14: 1-34.

Carscadden, J. E., K. T. Frank and W. C. Leggett. 2001. Ecosystem changes and the effects on capelin (*Mallotus villosus*), a major forage species. Canadian Journal of Fisheries and Aquatic Sciences 58: 73-85.

Carscadden, J. E., W. A. Montevecchi, G. K. Davoren and B. S. Nakashima. 2002. Trophic relationships among capelin (*Mallotus villosus*) and seabirds in a changing ecosystem. ICES Journal of Marine Science 59: 1027-1033.

Cotter, R. C., J.-F. Rail, A. W. Boyne, G. J. Robertson, D. V. C. Weseloh and K. G. Chaulk. 2012. Population status, distribution, and trends of gulls and kittiwakes breeding in eastern Canada, 1998-2007. Occasional Paper No. 120, Canadian Wildlife Service, Ottawa, Ontario.

Davoren, G. K. and W. A. Montevecchi. 2003. Signals from seabirds indicate changing biology of capelin stocks. Marine Ecology Progress Series 258: 253-261.

Dominguez, L., W. A. Montevecchi, N. M. Burgess, J. Brazil and K. A. Hobson. 2003. Reproductive success, environmental contaminants, and trophic status of nesting Bald Eagles in eastern Newfoundland, Canada. Journal of Raptor Research 37: 209-218.

Drent, R. and S. Daan. 1980. The prudent parent: energetic adjustments in avian breeding. Ardea 68: 225-252.

Drinkwater, K. F. 1996. Atmospheric and oceanic variability in the northwest Atlantic during the 1980s and early 1990s. Journal of Northwest Atlantic Fishery Science 18: 77-97.

Farmer, R. G. and M. L. Leonard. 2011. Long-term feeding ecology of Great Black-backed Gulls (*Larus marinus*) in the northwest Atlantic: 110 years of feather isotope data. Canadian Journal of Zoology 89: 123-133.

Fisheries and Oceans Canada. 2013. Assessment of capelin in SA2 + Div. 3KL in 2013. Canadian Science Advisory Secretariat Science Advisory Report 2013/011, Fisheries and Oceans Canada, Dartmouth, Nova Scotia.

Goethe, F. 1960. Felsbrütertum und weitere beachtenswerte Tendenzen bei der Silbermöwe. Pages 252-258 *in* Proceedings of the XII International Ornithological Congress (G. Bergman, K. O. Donner and L. von Haartman, Eds.). Tilgmannin Kirjapaino, Helsinki, Finland. (In German).

Goethe, F. 1964. Lenkung der Möwenbestände an der deutschen Nordseeküste mit Hilfe der Einschläferung erwachsener Möwen durch Glukochloralose-α. Berichte Internationaler Rat für Vogelschutz. Deutsche Sektion 4: 53-57. (In German).

Harris, M. P. 1970. Rates and causes of increases of some British gull populations. Bird Study 17: 325-335.

Haycock, K. A. 1973. Ecological studies on Gull Island, Witless Bay, with particular reference to avifauna. M.S. Thesis, Memorial University of Newfoundland, St. John's, Newfoundland and Labrador.

Haycock, K. A. and W. Threlfall. 1975. The breeding biology of the Herring Gull in Newfoundland. Auk 92: 678-697.

Hedd, A., W. A. Montevecchi, G. K. Davoren and D. A. Fifield. 2009. Diet and distributions of Leach's storm-petrel (*Oceanodroma leucorhoa*) before and after an ecosystem shift in the Northwest Atlantic. Canadian Journal of Zoology 87: 787-801.

Hipfner, J. M., L. K. Blight, R. W. Lowe, S. I. Wilhelm, G. J. Robertson, R. T. Barrett, T. Anker-Nilssen and T. P. Good. 2012. Unintended consequences: how the recovery of sea eagle (*Haliaeetus* spp.) populations in the northern hemisphere is affecting seabirds. Marine Ornithology 40: 39-52.

Hobson, K. A., K. D. Hughes and P. J. Ewins. 1997. Using stable-isotope analysis to identify endogenous and exogenous sources of nutrients in eggs of migratory birds: applications to Great Lakes contaminant research. Auk 114: 467-478.

Howes, L.-A. and W. A. Montevecchi. 1993. Population trends and interactions among terns and gulls in Gros Morne National Park, Newfoundland. Canadian Journal of Zoology 71: 1516-1520.

Hutchings, J. A. and R. A. Myers. 1994. What can be learned from the collapse of a renewable resource? Atlantic cod, *Gadus morhua*, of Newfoundland and Labrador. Canadian Journal of Fisheries and Aquatic Sciences 51: 2126-2146.

Kadlec, J. A. and W. H. Drury. 1968. Structure of the New England herring gull population. Ecology 49: 644-676.

Massaro, M., J. W. Chardine, I. L. Jones and G. J. Robertson. 2000. Delayed capelin (*Mallotus villosus*) availability influences predatory behaviour of large gulls on Black-legged Kittiwakes (*Rissa tridactyla*), causing a reduction in kittiwake breeding success. Canadian Journal of Zoology 78: 1588-1596.

Monaghan, P. 1979. Aspects of the breeding biology of herring gulls *Larus argentatus* in urban colonies. Ibis 121: 475-481.

Nettleship, D. N. 1972. Breeding success of the common puffin (*Fratercula arctica* L.) on different habitats at Great Island, Newfoundland. Ecological Monographs 42: 239-268.

Nettleship, D. N. 1976. Census techniques for seabirds in Arctic and eastern Canada. Occasional Paper No. 25, Canadian Wildlife Service, Ottawa, Ontario.

Obradovich, S. G., E. H. Carruthers and G. A. Rose. 2014. Bottom-up limits to Newfoundland capelin (*Mallotus villosus*) rebuilding: the euphausiid hy-

pothesis. ICES Journal of Marine Science 71: 775-783.

Oro, D., M. Genovart, G. Tavecchia, M. S. Fowler and A. Martínez-Albraín. 2013. Ecological and evolutionary implications of food subsidies from humans. Ecology Letters 16: 1501-1504.

Piatt, J. F., A. M. A. Harding, M. T. Shultz, S. G. Speckman, T. I. van Pelt, G. S. Drew and A. B. Kettle. 2007. Seabirds as indicators of marine food supplies: cairns revisited. Marine Ecology Progress Series 352: 221-234.

Pierotti, R. 1982. Habitat selection and its effect on reproductive output in the herring gull in Newfoundland. Ecology 63: 854-868.

Pierotti, R. and C. A. Annett. 1991. Diet choice in the herring gull: constraints imposed by reproductive and ecological factors. Ecology 72: 319-328.

Pons, J.-M. 1992. Effects of changes in the availability of human refuse on breeding parameters in a Herring Gull *Larus argentatus* population in Brittany, France. Ardea 80: 143-150.

Pons, J.-M. and P. Migot. 1995. Life-history strategy of the herring gull: changes in survival and fecundity in a population subjected to various feeding conditions. Journal of Animal Ecology 64: 592-599.

R Development Core Team. 2014. R: a language and environment for statistical computing v. 3.1. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org, accessed 30 October 2014.

Regehr, H. M. and W. A. Montevecchi. 1997. Interactive effects of food shortage and predation on breeding failure of Black-legged Kittiwakes: indirect effects of fisheries activities and implications for indicator species. Marine Ecology Progress Series 155: 249-260.

Regehr, H. M. and M. S. Rodway. 1999. Seabird breeding performance during two years of delayed capelin arrival in the northwest Atlantic: a multi-species comparison. Waterbirds 22: 60-67.

Regular, P. M., W. A. Montevecchi, A. Hedd, G. J. Robertson and S. I. Wilhelm. 2013. Canadian fishery closures provide a large-scale test of the impact of gillnet bycatch on seabird populations. Biology Letters 9: 20130088.

Robertson, G. J., D. A. Fifield, M. Massaro and J. W. Chardine. 2001. Changes in nesting-habitat use of large gulls breeding in Witless Bay, Newfoundland. Canadian Journal of Zoology 79: 2159-2167.

Rodway, M. S. and H. M. Regehr. 1999. Habitat selection and reproductive performance of food-stressed Herring Gulls. Condor 101: 566-576.

Stenhouse, I. J. and W. A. Montevecchi. 1999. Indirect effects of the availability of capelin and fishery discards: gull predation on breeding storm-petrels. Marine Ecology Progress Series 184: 303-307.

Stenhouse, I. J., G. J. Robertson and W. A. Montevecchi. 2000. Herring Gull *Larus argentatus* predation on Leach's Storm-petrel *Oceanodroma leucorhoa* breeding on Great Island, Newfoundland. Atlantic Seabirds 2: 35-44.

Thomas, P. W., L. A. MacFarlane Tranquilla, B. E. Toms, A. W. Boyne, G. J. Robertson, P. M. Regular and S. I. Wilhelm. 2014. Second census of terns, gulls, kittiwakes and cormorants along the coast of insular Newfoundland, 2005-2007. Technical Report Series No. 531, Canadian Wildlife Service, Atlantic Region, Dartmouth, Nova Scotia.

Threlfall, W. 1978. Dispersal of Herring Gulls from the Witless Bay sea bird sanctuary, Newfoundland. Bird Banding 49: 116-124.

Veitch, B. G. 2003. Diet choice and reproductive success of Great Black-backed Gulls (*Larus marinus*) and impacts on local breeding seabird populations. M.S. Thesis, Memorial University of Newfoundland, St. John's, Newfoundland.

Veitch, B. G., G. J. Robertson, I. L. Jones and A. L. Bond. 2016. Great Black-backed Gull (*Larus marinus*) predation on seabird populations at two colonies in eastern Canada. Waterbirds 39 (Special Publication 1): 235-245.

Votier, S. C., R. W. Furness, S. Bearhop, J. E. Crane, R. W. G. Caldow, P. Catry, K. Ensor, K. C. Hamer, A. V. Hudson, E. Kalmbach, and others. 2004. Changes in fisheries discard rates and seabird communities. Nature 427: 727-730.