WINTER DISTRIBUTION, ECOLOGY AND MOVEMENTS OF RAZORBILLS *ALCA TORDA* AND OTHER AUKS IN THE OUTER BAY OF FUNDY, ATLANTIC CANADA

FALK HUETTMANN[1,4], ANTONY W. DIAMOND[1], BRIAN DALZELL[2] & KEN MACINTOSH[3]

[1]*Atlantic Cooperative Wildlife Ecology Research Network (ACWERN), University of New Brunswick, PO Box 4511, Fredericton, New Brunswick, E3B 6E1, Canada*
[2]*Grand Manan Bird Observatory, PO Box 179, Castalia, Grand Manan, New Brunswick, E0G 1L0, Canada*
[3]*220 King Street, St. John, New Brunswick, E2L 1H3, Canada*
[4]*Current address: Department of Biology and Wildlife; Institute of Arctic Biology, 419 Irving 1 (EWHALE Lab), University of Alaska Fairbanks, Fairbanks, Alaska, 99775, USA*
(fffh@uaf.edu)

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SUMMARY

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Casual observations between 1992 and 1997 indicated that up to 25 000 Razorbills *Alca torda* may occur around Grand Manan Island, Bay of Fundy, from December to February—numbers far exceeding those of local breeders. Standardized surveys conducted on 26 days between November 1997 and March 1998 revealed up to 52 000 auks of five species, mostly Razorbills, off Grand Manan. Birds were concentrated near the Old Proprietor Shoals. No similar or larger number of wintering Razorbills has been reported for North America. Offshore profile surveys of Old Proprietor Shoals and concurrent land-based counts were carried out during 1998/99 to investigate further the extent of auk distribution and the timing and magnitude of movements in winter. Large numbers of Razorbills (mean: 10 616 per survey) were recorded, especially in mid-January. Bird movement caused wide fluctuations in numbers among surveys. We conclude that a significant proportion of Razorbills breeding in North America spend at least part of the winter in the outer Bay of Fundy and in its coastal zone (i.e. less than eight kilometres offshore). Thus, this population may be more concentrated spatially in winter than during the breeding season. Of 21 Razorbill stomachs collected in 1999, 76% contained krill. We suggest that Razorbills, like many other wide-ranging marine predators in winter, are often concentrated in relatively small areas where predictable concentrations of prey occur.

Key words: Razorbills *Alca torda,* lower Bay of Fundy, Grand Manan Island, wintering auks, Old Proprietor Shoals, coastal seabirds

INTRODUCTION

Razorbills *Alca torda* are the least abundant of North American auks, with a breeding population in eastern Canada of approximately 38 000 pairs, encompassing seven geographic regions and 132 colonies (Chapdelaine *et al.* 2001). The North American population declined during 1960–1985 (Nettleship & Evans 1985), but since then has apparently increased (Chapdelaine *et al.* 2001).

Winter distributions of auks in eastern Canadian, especially Razorbills, are poorly understood (Brown 1985, Gaston & Jones 1998). This contrasts with Europe, where populations are highly variable, but the wintering habits of Razorbills are reasonably well known (Lloyd 1974, Cramp *et al.* 1977, Tasker *et al.* 1987). Most information for the Northwest Atlantic comes from records in the PIROP (Programme Intégré de Recherches sur les Oiseaux Pélagiques) database of the Canadian Wildlife Service (CWS) (Brown *et al.* 1975, Lock *et al.* 1994, Huettmann & Lock 1997; available online at http://seamap.env.duke.edu/datasets/detail/280). PIROP data were collected mainly between 1966 and 1992. Those surveys and several recent studies (Elliott *et al.* 1990, Falk *et al.* 1992, Falk & Durinck 1993, Stenhouse & Montevecchi 1996) show Razorbills predominantly on the Hamilton Banks, in Labrador during late fall and early winter, and in the northern Gulf of Maine later. Brown (1986) reported small numbers of wintering Razorbills off southern Greenland. Powers (1983) and Brown (1985) mentioned waters south of Nova Scotia as wintering grounds for Razorbills, but earlier aerial surveys by CWS found neither Razorbills or murres (*Uria* spp.) in the Bay of Fundy in winter (CWS 1979).

Other sources pertaining to auks in the Bay of Fundy are few (Brown 1985, Nettleship 1996). Most data are either outdated (Pettingill 1939) or qualitative (e.g. Tufts 1961, Squires 1976, Godfrey 1986). A few counts from ferry transects are reported (Finch *et al.* 1978, Huettmann & Diamond 1998), and land-based observations such as Christmas bird counts (CBCs) add some information (Root 1988). Counts of murres and Razorbills at a distance suffer from possible confusion of the three species, whose winter plumages are similar. The usual source of data on auk movements is the recovery of banded birds (Elliott *et al.* 1990, Chapdelaine 1997, Donaldson *et al.* 1997), which is biased by the distribution of sources of mortality (Chapdelaine 1997).

All six Atlantic auk species occur in the Bay of Fundy in winter—Dovekies *Alle alle* and Thick-billed Murres *Uria lomvia* largely in January and February (Finch *et al.* 1978, Powers & Brown 1987, Root 1988); Common Murres *Uria aalge* regularly, though none during CBCs (Root 1988); Black Guillemots *Cepphus grylle* abundantly in coastal waters (Finch *et al.* 1978, Root 1988); Atlantic

Puffins *Fratercula arctica* rarely; and Razorbills throughout the season, with highest numbers in December [Moses 1908 (in Squires 1976), Finch *et al.* 1978]. Monthly counts from ferry transects in the upper Bay of Fundy between Saint John, New Brunswick, and Digby, Nova Scotia, detected few auks during the winters of 1995/96 or 1996/97, suggesting few birds winter in the central or inner Bay of Fundy (Huettmann & Diamond 1998). The Grand Manan CBC, held annually in late December or early January since 1979, has included an average of about 2000 Razorbills, mostly off the north end of the island. The Eastport, Maine, and Campobello, New Brunswick, CBCs have also recorded Razorbills consistently (50–1000 individuals) since the mid-1960s (B. Dalzell, unpubl. data).

Recent land-based observations of wintering Razorbills suggested that large numbers occur regularly near Grand Manan Island—e.g. 3000 birds off the north end on 1 December 1996 (A. Clavette, pers. comm.), 2200 birds between Machias Seal Island and the south end of Grand Manan on 3 January 1997 (R. Maker, pers. comm.), 1000 birds off the north end (J. Wilson, pers. comm.), more than 5000 off the south end on 18 January 1995 (D. Christie, pers. comm.), and about 25 000 birds flying low to the north off White Head Island in a 30-minute period on 7 February 1997 (B. Dalzell, unpubl. data). These reports prompted the present study.

Preliminary estimates indicated that a substantial, but so far never described, proportion of the North American population of Razorbills might spend at least part of the winter in the vicinity of Grand Manan Island. The region is known for high marine productivity (Johnston *et al.* 2005), is used intensively by several fisheries (Cohen & Langton 1992), and is a major shipping lane for oil tankers and other commercial vessels (Brown *et al.* 1975, Lock *et al.* 1994, Brown *et al.* 1995). Our study was undertaken to assess the distribution and numbers of Razorbills and other auks off Grand Manan in late fall and winter.

METHODS

The Bay of Fundy is characterized by strong tidal currents and geographic features such as shoals, submarine ledges and a steep shelf break that make the waters surrounding Grand Manan a richly productive marine environment (Hachey 1961, Canadian Hydrographic Service 1997, Johnston *et al.* 2005). Tidal ranges in the Bay of Fundy are among the largest in the world (Swift 1966, Loder & Greenberg 1986). Details of the bathymetry and oceanography of the Grand Manan region are available in Jovellanos & Gaskin (1983), Gaskin *et al.* (1985) and Johnston *et al.* (2005).

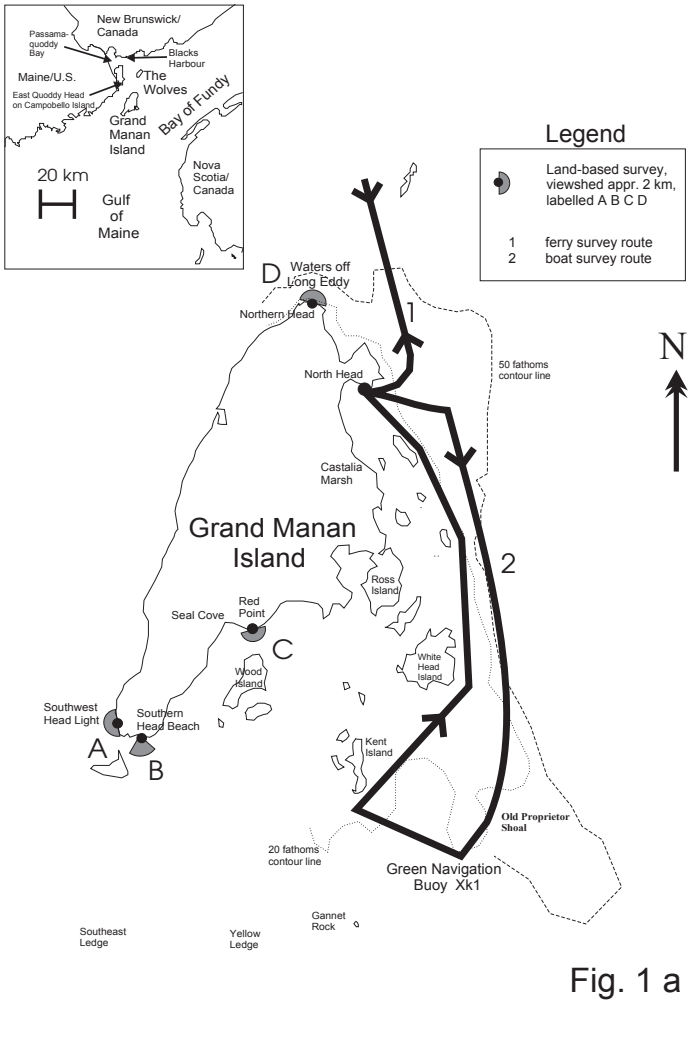

Fig. 1 a

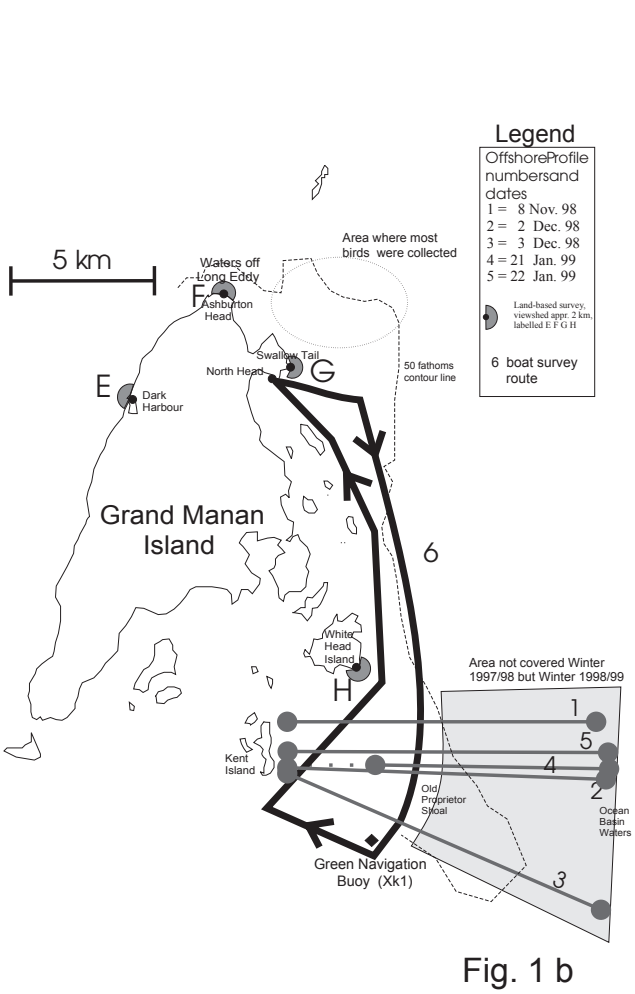

Fig. 1 b

Fig. 1. (a) Map of Grand Manan region, New Brunswick and survey locations 1997/98. Numbers denote at-sea surveys: 1 = ferry survey, 2 = vessel transect. Letters denote land-based surveys: A = Southwest Head Light, B = Southern Head Beach, C = Red Point, D = Northern Head (Long Eddy Point). (b) Map of survey locations 1998/99. Note: Survey on 21 January started on Old Proprietor Shoals, returning to Kent Island.

Between 1 December 1997 and 31 March 1998, we counted auks (and other waterbirds, reported elsewhere) on transects off Grand Manan [Fig. 1(a)] following the PIROP protocol (Brown *et al.* 1975) using a 10-m "Cape Island" boat. Two observers, one on each side of the boat, detected and counted birds in a 150-degree arc (total coverage 300 degrees instead of the normal 360 degrees, because of viewing restrictions caused by boat type). To avoid double counting, counts were confirmed and recorded to the nearest minute by a third observer (FH). Vessel speed was usually five knots. The observers' platform was about three metres above sea level. Seven surveys were conducted over the same offshore route, which took about five hours to complete. Each survey began around 08h00 from North Head harbour, followed the 50-fathom depth contour south through Old Proprietor Shoals, turned northwest toward Kent Island at green navigation buoy XK1, and then returned north and northeast to North Head [Fig.1(a)]. We followed the 50-fathom isobath because earlier sightings (BD & FH, unpubl. data) suggested that that zone was a major movement corridor for auks. To capture extremes of the lunar tidal cycle, surveys were planned at 14-day intervals. Actual timing varied from 12 days to 16 days according to weather conditions. Storms prevented any survey being conducted during March.

Because most auks could not be identified to species, they were recorded simply as "large auks" (including Common Murre, Thick-billed Murre, Razorbill and Atlantic Puffin). Species were identified where possible, however, and ratios of those data were used to estimate the percentage of Razorbills among the large auks recorded. To investigate whether concentrations of auks were related to those of potential prey, fish targets were recorded at 15-minute intervals using the vessel's sonar fishfinder. Waters north of Grand Manan were surveyed from the ferry between Blacks Harbour and North Head (15-km transect, eight-metre-high platform, 90-degree field of view oriented toward The Wolves archipelago, duration *c.* 90 minutes). Two ferry transects were completed in conjunction with each of our vessel counts—one starting at 13h30 the day before, and another beginning at 08h00 on the day following a survey [Fig.1(a)].

To supplement the boat surveys, 30-minute counts from land of a defined "viewshed" (300-m view of the sea) were carried out in 1997 and 1998. Observers made visual scans, unassisted by spotting scopes or binoculars, except to confirm species identification. Such observations were made immediately after our boat transect from four locations on Grand Manan: Long Eddy, Red Head, Southern Head Beach and the Southwest Head Lighthouses [Fig. 1(a)].
Additional boat and land surveys were carried out opportunistically in 1997 and 1998:

- From the Grand Manan ferry (Blacks Harbour to North Head and return) on 27 December 1997, 23 January 1998, 1 and 24 February 1998
- From lobster boats on 12 January 1998 (around Machias Seal Island), 2 February 1998 (North Head to Seal Cove), and 3 February 1998 (Seal Cove to Southeast Ledge, Yellow Ledge and return to Seal Cove)
- From land on 18 and 23 January 1998 (simultaneously from North Head and Swallow Tail), and on 4 January, 23 January and 23 February 1998 (from East Quoddy Head overlooking Head Harbour Passage)

To address uncertainties resulting from the winter surveys of 1997/98, our focus in late fall and winter of 1998/99 was on the broader extent of auk distribution, patterns of movement and collection of specimens. In the previous season, only small sections of Old Proprietor Shoals, known "hot spots," and the 50-fathom contour were surveyed. In 1998/99, we determined how far the marked concentration of auks extended on either side of the 50-fathom isobath, an indication of birds missed the previous year [Fig 1(b)]. We ran geo-referenced transects perpendicular to the 50-fathom isobath across Old Proprietor Shoals using a global positioning system (GPS). This method allowed us to compute a ratio of animals inside and outside the 50-fathom contour zone and to estimate how many auks were in the region overall, based on data obtained in 1997/98. From general observations, we felt justified in assuming that Razorbills were distributed consistently in various years relative to the 50-fathom contour zone.

Patterns of movement over the waters off Long Eddy were investigated using land-based surveys from Ashburton Head [Fig. 1(b)], where auks appeared to concentrate at times. In addition, concurrent land-based counts were made from four locations (Dark Harbour, Ashburton Head, Swallow Tail and White Head Island) to clarify patterns of auk movements around the island [Fig. 1(b)].

Razorbills (n = 21) were collected at sea to determine stomach contents. The proventriculus and stomach were removed from each bird immediately and were frozen or preserved in 95% ethanol for later analysis.

RESULTS

Year 1 (1997/98)

Boat transects

Common Murres, Thick-billed Murres, Razorbills and Atlantic Puffins were observed almost exclusively on the offshore transect between North Head harbour and Old Proprietor Shoals (Table 1). Numbers of auks varied over the winter, with a peak of 52 128 individuals on 23 January 1998. Razorbill numbers were high from late November through December, peaked on 23 January and declined thereafter. Common Murres were less numerous than Razorbills, peaking in February. Dovekies occurred regularly in small numbers from late December through February, peaking on 23 January. Dovekies were widely distributed, but tended to aggregate between Old Proprietor Shoals and Kent Island. Few Thick-billed Murres were recorded on our surveys at any time; small numbers occurred close to shore in harbours and around wharfs from late January to March. Atlantic Puffins were also scarce throughout the survey period. Black Guillemots resided close to shore all winter, mostly between Old Proprietor Shoals and Kent Island; peak numbers occurred in early February.

The proportion of auks identified to species varied greatly among transects (1%–96%) because of weather, sea conditions and the distances at which birds were seen. Razorbills appeared to dominate between late November and late January, comprising about 85% of all large auks identified (Table 1). After December, as Razorbill numbers declined, Common Murres increased, and auks were concentrated mainly on the Old Proprietor Shoals. At locations other than Old Proprietor Shoals and waters off Long Eddy, most auks were observed flying rapidly toward or away from those sites. We found no obvious coincidence of either Razorbills or other auk species with fish presence as indicated by the fishfinder. In November and December, Razorbills were aggregated near the shelf edge (i.e. 20- and 50-fathom contour lines, Fig. 1), and in mixed feeding flocks with Herring Gulls *Larus argentatus,* Great Black-backed Gulls *L. marinus* and Black-legged Kittiwakes *Rissa tridactyla.*

Auks in flight occurred in both mixed and single-species flocks. Auks on the water normally flew when approached by the boat—although some dived. On 23 January and later, birds in breeding plumage were observed occasionally. The flight style and wing-beat frequency of auks changed after mid-February, possibly because the birds had completed wing-moult. Birds also became more responsive to disturbance at that time—they abandoned the Old Proprietor Shoals entirely when our vessel passed through, a behaviour not seen on earlier cruises.

Ferry transects

On ferry transects between Blacks Harbour and North Head (Grand Manan), auk numbers were highest in November and December, declining sharply after early January (Fig. 2). Most auks occurred at Long Eddy, within five kilometres of Northern Head (Fig. 1). Near the mainland and off Grand Manan, the birds closest to shore were mostly Black Guillemots. Birds observed in late November were identifiable only as "large auks"; Razorbills were identified on 19 December, 20 December and 19 January only. Dovekies were seen once, on 2 January, and none of the other three auk species was identified.

Land-based counts

Fewer auks were counted from land than at sea. The distribution of Razorbills at Northern Head was similar to that detected from the ferry—most birds were seen sitting or flying over Long Eddy between late December 1997 and mid-January 1998 (Fig. 3). All birds observed were large auks, but only about half, mostly Razorbills, could be identified to species. A few Common Murres were recorded on 19 January, and a single Thick-billed Murre was seen on 21 February. The only auks observed from Red Point and Southwest Head Lighthouse were Black Guillemots, plus a single Dovekie in Seal Cove on 3 February. Three surveys of Head Harbour Passage from East Quoddy Head [Fig. 1(a)], recorded only one auk, a Thick-billed Murre. Two observations from land at Liberty Point at the southern tip of Campobello Island and regular surveys from Southwest Head Lighthouse on Grand Manan detected no auks, and no previous records exist for auks at those locations.

Year 2 (1998/99)

Profiles of Old Proprietor Shoals

On east–west transects over Old Proprietor Shoals, auk numbers were highly variable, even those tallied one hour apart on the same round trip (Table 2). Dovekies were more abundant, but auks in general—and Razorbills in particular—were less abundant than in the previous season. The profiles were designed to provide correction factors (species distribution relative to the 50-fathom contour) for data obtained in the previous season. Application of those ratios would suggest that boat surveys off Grand Manan in 1997/98, which surveyed waters shallower than 50 fathoms, detected between 66% and 82% of the Razorbills in the region (Table 2).

Activity patterns near Long Eddy

Our observations indicated that the waters off Long Eddy, as well as those of the Old Proprietor Shoals, play an important role for wintering auks around Grand Manan. During two all-day surveys of the waters off Long Eddy (10 and 14 December 1998), auks were sparse in the early morning and abundant by mid-morning and late morning (09h00–13h00), remaining stable in number during the afternoon (Table 3). Most auks leaving the area in the early

TABLE 1
Auks counted on seven transects between 29 November 1997 and 3 April 1998 along the east coast of Grand Manan Island, New Brunswick

Date	Individuals counted[a]						Unidentifed "large auks"	Total auks	Auks identified to species (%, rounded)	Total Razorbills[b]
	DOVE	COMU	TBMU	RAZO	BLGU	ATPU				
29 Nov 1997[c]	0	0	0	3250	134	0	113	3 497	3 384	3 358
				(96%)	(4%)				(97%)	
20 Dec 1997	57	301	1	5 806	89	2	3247	9 503	6 256	8 825
	(1%)	(5%)	(0%)	(93%)	(1%)	(0%)			(66%)	
3 Jan 1998	68	30	1	104	52	4	933	1 192	259	477
	(26%)	(12%)	(0%)	(40%)	(20%)	(2%)			(22%)	
23 Jan 1998	231	25	0	7 045	211	5	45 278	52 795	7 517	49 153
	(3%)	(0%)		(93%)	(3%)	(0%)			(14%)	
2 Feb 1998	156	918	1	15	344	2	3 091	4 527	1 436	324
	(11%)	(64%)	(0%)	(1%)	(24%)	(0%)			(32%)	
21 Feb 1998	19	305	7	103	211	0	9 124	9 769	645	1 562
	(3%)	(47%)	(1%)	(16%)	(33%)				(7%)	
3 Apr 1998	0	15	0	13	269	0	160	457	297	77
		(5%)		(4%)	(90%)				(65%)	

[a] Percentage of auks identified to species in parentheses.
[b] Number of identified Razorbills, plus *pro rata* share of unidentified large auks.
[c] Incomplete transect; cancelled after 2 h due to storm.
DOVE = Dovekie; COMU = Common Murre; TBMU = Thick-billed Murre; RAZO = Razorbill; BLGU = Black Guillemot; ATPU = Atlantic Puffin.

morning flew south-westward, whereas those departing around noon flew to the southeast. Numbers of auks sitting on the water increased during the morning, suggesting feeding or resting. No large movements were observed after 15h00, but morning numbers were low, suggesting that movements occurred at other times, possibly at night.

Concurrent land-based counts off Grand Manan

During concurrent land-based surveys (5 January, 09h00 to 13h00) from Dark Harbour, Ashburton Head, Swallow Tail and White Head Island, most auk sightings were birds on the sea off Long Eddy observed from Ashburton Head. In early morning (09h00–10h00), a large movement occurred at Dark Harbour (5927 flying auks, of which 4028 flew toward Long Eddy). That movement diminished sharply after 10h00 (40 birds in the last survey hour, 12h00–13h00), when large movements were seen at Swallow Tail (5654 flying auks, of which 4417 came from the direction of Long Eddy). Auks sitting on the water were recorded at Dark Harbour (maximum 20 birds), Swallow Tail (maximum 91 birds) and Ashburton Head (maximum 100 birds). Only 145 auks (showing no predominant flight direction) were recorded from White Head Island during the entire survey. During a second concurrent survey (7 February), relatively few auks were sighted (maximum 114 birds at Ashburton Head between 09h00 and 13h00). Most movement (172 birds) occurred off White Head Island on that date.

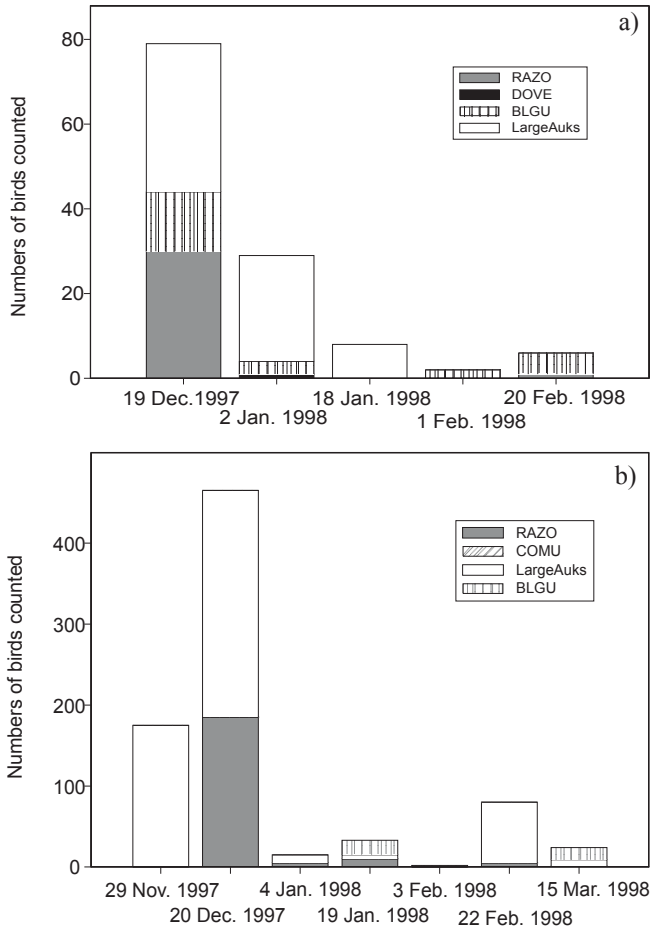

Fig. 2. Counts of auks during 12 ferry surveys conducted 29 November 1997–15 March 1998 between Blacks Harbour, New Brunswick, and North Head, Grand Manan Island. (a) Blacks Harbour to Grand Manan. (b) Grand Manan Island to Blacks Harbour. RAZO = Razorbill; COMU = Common Murre; TBMU = Thick-billed Murre.

Razorbill specimens

Razorbills were collected northeast of Grand Manan Island between 09h00 and 13h00 on 23 January 1998 and 21–22 January 1999 (Table 4). Two birds were in breeding plumage, all others in winter plumage. None were in primary moult. Few could be sexed with confidence because of internal deterioration between collection and freezing. A total of 21 Razorbill stomachs were examined. Two of the three stomachs of birds collected in January 1998 were empty, the other contained a ball of digested crustaceans, largely euphausiids (*Meganyctiphanes norvegica*) and decapods, with some fish or squid tissue. Of stomachs sampled in 1998/99 76% contained krill, mostly *M. norvegica,* with one stomach containing 420 individuals (68 cm^3 by volume). Fish occurred less frequently (eight stomachs); species identified were Three-spined Stickleback (*Gasterosteus aculeatus*) and Atlantic Herring (*Clupea harengus*). Some polychaetes were also found.

DISCUSSION

Razorbills

The waters off Grand Manan are difficult to survey in winter because of strong tides, rough weather, complex coastal topography and widely dispersed marine "hotspots." Wintering auks had not been surveyed previously, but our study confirms that large numbers of auks winter in the region. Of the 79 886 large auks (murres, Razorbills and Atlantic Puffins) we counted, 20% could be identified as Razorbills. However, Razorbills accounted for 91% of all large auks identified to species, so there can be no doubt that tens of thousands of Razorbills resided off Grand Manan in winter, probably in both winters 1997/98 and 1998/99.

The most recent census of Razorbills in North America indicates a breeding population of about 38 000 pairs (Chapdelaine *et al.* 2001). If we assume the nonbreeding age classes comprise 43% of the total population (Diamond *et al.* 1993), Razorbills would number about 140 000 individuals in North America. We encountered up to 35% (49 153 birds) of that total, based on the extrapolation of our maximum count on 23 January 1998. Most Razorbills occupied the

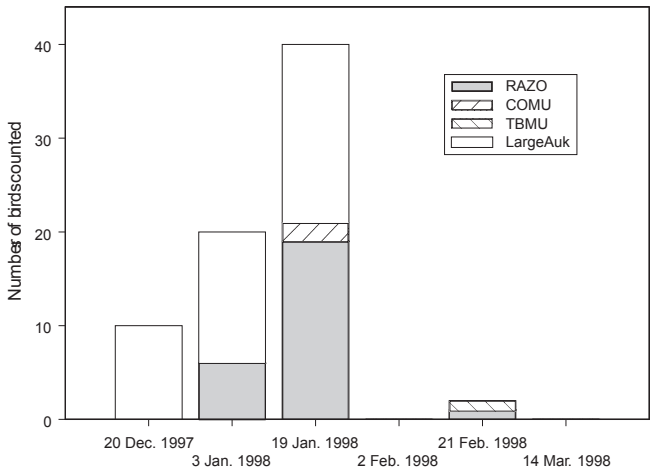

Fig. 3. Count of auks within a 30-minute period during land-based observations from Northern Head (Long Eddy Point), Grand Manan, 20 December 1997–14 March 1998. RAZO = Razorbill; DOVE = Dovekie; BLGU = Black Guillemot).

TABLE 2
Number of auks per survey 1998/99 on Old Proprietor Shoals, proportion of Razorbills and proportion (%) counted within the 50-fathom contour

Date	Species	Depth range		
		Proportion of birds within 50 fathoms[a] (%)	≤50 fathoms	>50 fathoms
8 Nov 1998	Black Guillemot	30	0	100
	Atlantic Puffin	3	13	19
	Common Murre	1	0	100
	Razorbill	28	93	23
	Unidentified large auks	135	52	72
	% Razorbills[b]	88	88	
	Total Razorbills[c]	146	139	51
8 Nov 1998	Dovekie	4	0	100
(return trip)	Black Guillemot	42	1	97
	Atlantic Puffin	29	28	50
	Razorbill	372	402	48
	Unidentified large auks	98	26	79
	% Razorbills	93	93	
	Total Razorbills	462	426	52
2 Dec 1998	Black Guillemot	5	0	100
	Atlantic Puffin	1	0	100
	Common Murre	0	10	0
	Razorbill	147	0	100
	Unidentified large auks	38	3	93
	% Razorbills	99		
	Total Razorbills	184	0	100
3 Dec 1998	Dovekie	2	1	66
	Black Guillemot	6	0	100
	Razorbill	40	3	93
	Unidentified large auks	291	42	87
	% Razorbills	100	100	
	Total Razorbills	331	45	88
3 Dec 1998	Dovekie	2	1	66
(return trip)	Black Guillemot	10	0	100
	Atlantic Puffin	0	1	0
	Razorbill	16	0	100
	Unidentified large auks	179	3	98
	% Razorbills	89		
	Total Razorbills	175	0	100
21 Jan 1999	Dovekie	118	168	41
	Common Murre	11	6	65
	Razorbill	10	0	100
	Unidentified murres	6	0	100
	Unidentified large auks	461	532	46
	% Razorbills	37		
	Total Razorbills	180	0	100
21 Jan 1999	Dovekie	2117	345	86
(return trip)	Common Murre	0	1	0
	Razorbill	8	0	100
	Unidentified large auks	298	1686	15
	% Razorbills	100		
	Total Razorbills	306	0	100
22 Jan 1999	Dovekie	4	984	0
	Black Guillemot	12	0	100
	Common Murre	2	14	13
	Thick-billed Murre	0	1	0
	Razorbill	27	7	79

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Date	Species	Depth range		
		Proportion of birds within 50 fathoms[a] (%)	≤50 fathoms	>50 fathoms
	Unidentified murres	0	1	0
	Unidentified large auks	86	479	15
	% Razorbills	93	32	
	Total Razorbills	106	159	40
22 Jan 1999	Dovekie	175	6	97
(return trip)	Common Murre	2	0	100
	Razorbill	20	0	100
	Unidentified large auks	5	1	83
	% Razorbills	83		
	Total Razorbills	24	0	100

[a] Percentage of birds observed inshore (within 50-fathom depth contour) versus offshore (beyond 50-fathom depth contour, calculated as: 100 × (number within 50 fathoms / all birds).

[b] Percentage of Razorbills among identified large auks (Common and Thick-billed Murre, Atlantic Puffin).

[c] Total Razorbills estimated as sum of identified Razorbills and number extrapolated as *pro rata* share of unidentified large auks.

relatively small area of Old Proprietor Shoals. The occurrence of such a large proportion of North American Razorbills in one place is noteworthy, especially in comparison to the wide dispersion of this species in the breeding season. It suggests that a common assumption—seabirds are more concentrated spatially during than outside of the breeding season—is not always true.

Auks are often described as wintering far offshore (e.g. National Geographic Society 1999), with special reference to records as far from land as Flemish Cap, 700 km off Newfoundland, and Georges Bank (Tuck 1961, Brown 1986, Nettleship 1996). Tuck (1961) and Godfrey (1986) described the wintering habitat of Razorbills as "offshore," but the account of Gaston & Jones (1998)—"... continental shelf waters, usually somewhat closer to shore than murres ... tidally induced upwellings in coastal areas"—fits better with what we observed in the Bay of Fundy. The main concentrations of Razorbills were less than 10 km from the coast, in the tidal upwelling zones of Old Proprietor Shoals and off Long Eddy. Most sightings were within Ashmole's (1971) definition of the "inshore" zone (i.e. less than eight kilometres from shore). Because Razorbills breed on land in summer, feed within a few kilometres of the colony (Gaston & Jones 1998), migrate near land (e.g. Newfoundland) and are evidently close to shore for much of the winter, we suggest that Razorbills should be viewed not so much as pelagic birds, but as a true component of coastal ecosystems.

Numbers of Razorbills around Grand Manan in winter can vary considerably from year to year (B. Dalzell, pers. obs.; Root 1988), perhaps in response to the abundance of herring (Jovellanos & Gaskin 1983) or krill. We found no consistent relationship between the presence of Razorbills or other auks and the occurrence of fish schools as indicated by echo-sounding, but such correlations are perhaps not to be expected at the spatial scale we viewed (Schneider & Piatt 1986) or in consideration of the behaviour types we included during the transects (i.e. sitting, flying and diving birds). The presence of fresh undigested krill in our 1998/99 sample indicated that Razorbills were feeding in the waters off Long Eddy where they were collected, consistent with our observation of birds feeding in the flocks from which the specimens were taken. The clumped distribution of auks in early winter suggested that young Atlantic herring (10–20 cm in length) were a possible attractant, yet stomach contents revealed that Razorbills fed mostly on krill, and to a lesser degree on fish (mainly sticklebacks). Only a few stomachs contained identifiable remains of herring. The only previous account of the winter diet of Razorbills in North America is that of Tuck (1961), who reported that crustaceans were the major prey off Newfoundland. Thus, these auks appear at times to feed mainly on the zooplankton that support herring or other fish, not on the fish themselves. Nevertheless, the stable-isotope signature of bone collagen from the birds we collected was very close to that of herring, suggesting that krill are taken occasionally, or perhaps only briefly in winter, not consistently (A.W. Diamond, F. Huettmann & R. Doucette, unpubl. data). In this context, we note that Elliott *et al.* (1990) describe Thick-billed Murres in Newfoundland shifting from fish to crustaceans in mid-winter, and Braune & Gaskin (1987) reported a zooplankton peak in the Bay of Fundy in November and December.

Razorbills may move widely in the Gulf of Maine in winter, given that they are regularly reported east of Cape Cod and Nantucket Shoals in Massachusetts (Veit & Petersen 1993; Chapdelaine 1997; S. Pollock & K. Gammons, pers. comm.). In some years they move farther south, as indicated by a count of 9000 Razorbills off the outer banks of North Carolina in February 2004 (Davis 2004: 215).

The geographic origins of Razorbills wintering off Grand Manan are unclear. All the large Canadian breeding colonies may contribute birds. Chapdelaine (1997) presented recoveries of Razorbills banded on breeding colonies in Quebec and Labrador, and cautioned that band recoveries provide only a biased assessment of wintering areas. Most recoveries of banded Razorbills arise from shooting during the winter hunt for murres ("turre hunt") in Newfoundland, giving the impression that most Razorbills winter there rather than in areas where there is no hunt. On the contrary, our data suggest that a large proportion of the Razorbills breeding in North America concentrate southeast of Grand Manan for at least a few weeks in mid-winter, and are probably present between there, Georges Bank and the southern Gulf of Maine for most of the winter.

Other auks

Brown (1984, 1988) suggested that the Scotian Shelf is a wintering ground for the North Atlantic population of Dovekies. Our data for the 1998/99 season show their occurrence more widely in the region. Donaldson *et al.* (1997) and Huettmann & Diamond (2000) did not mention the lower Bay of Fundy as a wintering ground of Thick-billed Murres, and our observations confirm that this area is not an important wintering ground for either species of murre. We

assume that the Black Guillemots encountered during our winter surveys were resident birds, breeding in the Grand Manan area during summer. However, Brown (1986) noted that some Black Guillemots probably migrate further south in winter.

Survey limitations

The tidal processes that concentrate plankton, and consequently herring and their predators such as porpoises, in the "island wake" off Long Eddy (Johnston *et al.* 2005) would be expected to operate year-round and may explain the concentrations of Razorbills we observed there. Other prime offshore feeding areas may exist (Smith *et al.* 1984; P. Wilcox, pers. comm.) that would not have been detected by either our land- or boat-surveys. Systematic surveys of another upwelling area on the east side of the Bay of Fundy (Brier Island, Nova Scotia; Brown & Gaskin 1989) have not been done, but we are unaware of any observations of significant numbers of auks in that area. Several auk sightings had been reported from Head Harbour Passage (Campobello Island) and Point Lepreau, New Brunswick. Although we did no systematic surveys in those areas, our occasional visits detected few or no Razorbills.

Although the offshore and inshore (land-based) data show distinctly different patterns, the offshore counts were characterized by very high variances, and by differences between species of auks through the season. We suspect that tidal cycles and seafloor topography are important in driving both the short-term movements around Grand Manan Island and possibly also the larger-scale movements between that location and other parts of the Gulf of Maine where Razorbills have been reported in large numbers (e.g. Georges Bank, Cape Cod). Systematic surveys timed to coincide with spring and neap tides are needed to test that hypothesis. The extreme temporal variation in numbers suggests either that we were sampling only a small part of the birds' patchy distribution at any one time, or that movements continued throughout the winter such that periods of concentration off Grand Manan were relatively short-lived. In that case, any single count could miss most of the Razorbills actually using the area.

We counted very different numbers of auks in two winters. Much of the difference was attributable to changes in location, study objectives and design of the surveys. In the first winter, our transect was a linear pass along the 50-fathom isobath, which turned out to be a major travel route used by Razorbills moving between Old Proprietor Shoals and Long Eddy. Many of the birds counted were flying along the same orientation as the boat. In the second winter, our transects were at right-angles to that line, so that birds in flight were moving across our bow rather than parallel to it. We would expect to record many fewer birds in that situation (Gaston *et al.* 1987a, 1987b). We cannot evaluate that sampling effect because we did not systematically record the direction in which birds were flying. We feel sure, however, that the effect was large enough that the lower number counted in 1998/99 does not mean that the higher number in 1997/98 was exceptional.

Implications for conservation

Our maximum count of Razorbills adds to the reputation of the lower Bay of Fundy as a marine ecosystem of international significance (Brown *et al.* 1995, Conkling 1995, Wallace &

TABLE 3
Assembled day profile of shore-based observations of auks from Ashburton Head, Grand Manan Island, on two dates in 1998[a]

Auk activity	Date and time									
	10 Dec				14 Dec					
	08h01–09h00	09h01–10h00	10h01–11h00	11h01–12h00	12h01–13h00	13h01–14h00	14h01–15h00	15h01–16h00	16h01–17h00	Total
Flying west	64	931	1413	890	150	0	648	69	0	4165
Flying east	0	0	3	397	0	0	731	51	0	1182
Sitting[a]	10	360	200	1500	1000	3000	247	2500	2500	3000[a]
Enter from west, landing	0	3168	220	0	0	0	0	33	0	3421
Enter from east, landing	0	160	0	0	0	0	0	0	0	160
Sitting, depart to west	0	20	40	432	165	0	0	0	0	657
Sitting, depart to east	12	0	0	0	1030	100	233	725	0	2100
Total	86	4639	1876	3219	2345	3100	1859	3378	2500	14685

[a] Only a conservative estimate is used (= maximum counts), because local turnover rate is not well known.

TABLE 4
Measurements of Razorbills collected off Grand Manan Island in winter

Age class[a]	N	Weight (g)	Flattened wing (mm)	Tarsus[b] (mm)	Head-bill (mm)	Bill depth (mm)[c]
Adult[d]	21	734.5 (19.2)	209.7 (1.0)	41.6 (0.3)	95.3 (0.5)	21.8 (0.3)
Immature	2	630, 510	202, 187	41.8, 40.2	92.6, 87.3	16.2, 17.0

[a] Aged by number of bill ridges: ≥2 = adult; 0–1 = immature.
[b] From heel joint to joint between toes and tarso-metatarsus.
[c] At gonys.
[d] Adult measurements shown as mean (standard error); immature measurements in full.

Braasch 1996). The area has the highest bird species richness in the Canadian Atlantic (F. Huettmann, unpubl. CWS-PIROP data), is an important moulting ground for Bonaparte's Gulls *L. philadelphia* (Braune & Gaskin 1987, Huettmann *et al.* 2000) and is a noted fall staging area for migrating Grey and Red-necked Phalaropes *Phalaropus fulicarius* and *P. lobatus* (Brown & Gaskin 1988). The feeding ground used by Razorbills is also of major importance to Black-legged Kittiwakes and other waterbirds in winter (Root 1988; Huettmann *et al.,* in press). In summer, large numbers of Wilson's Storm-Petrels *Oceanites oceanicus*, Great Shearwaters *Puffinus gravis* and Sooty Shearwaters *Puffinus griseus* reside in the bay (Brown *et al.* 1981), as do numerous marine mammals such as North Atlantic Right Whales *Eubalaena glacialis* (Murison & Gaskin 1989; Brown *et al.* 1995), Fin Whales *Balaenoptera physalus* (Woodley & Gaskin 1996), Harbour Porpoises *Phocoena phocoena* (Gaskin 1992), and seals *Phoca vitulina* and *Halichoerus grypus* (Colbourne & Terhune 1991).

Our observations show that the Bay of Fundy is vitally important to wintering auks, Razorbills in particular. Implications for the conservation of this species are considerable. We identified two main areas of concentrated feeding activity, Old Proprietor Shoals and Long Eddy. The area of the Old Proprietor Shoals would qualify as a Marine Protected Area (Nettleship 1998), especially given its proximity to the summer habitat of Right Whales (Gaskin 1987, Murison & Gaskin 1989, Brown *et al.* 1995). A protected area there, and around Long Eddy, need not have much impact on fishing, given that fishermen generally avoid those locations because of their shallow waters and treacherous tidal currents. However, we also noted auks departing Old Proprietor Shoals and Long Eddy, using the shelf edge as a corridor and dispersing widely in the Grand Manan Archipelago and around The Wolves islands.

The Newfoundland murre hunt has been cited as a major threat to Razorbills outside the breeding season (e.g. Evans & Nettleship 1985, Nettleship 1996), but data in Chapdelaine (1997) and our observations suggest that Razorbills are vulnerable to that hunt only briefly as northern breeders pass through Newfoundland en route to more southerly wintering areas. The Gulf of Maine as a whole, and the Bay of Fundy in particular, is already harmed (Lotze & Milewski 2001) and remaining parts are threatened by overfishing and contamination (Loring 1982, Wilson & Addison 1984, Backus & Bourne 1987, Cohen & Langton 1992, Nelson *et al.* 1998). Waters east of Grand Manan are on a major shipping route for freighters and tankers bound for the port of Saint John, New Brunswick (Lock *et al.* 1994). This traffic accounts for considerable mortality to endangered North Atlantic Right Whales (Gaskin 1987, Brown *et al.* 1995) and poses a substantial threat of oil spills to wintering auks (Lock *et al.* 1994).

Oceanic processes off Grand Manan, driven mostly by sea-floor topography, strong tides and wind mixing, are known to concentrate the availability of plankton and herring (Loder & Greenberg 1986). We believe that fine-scale oceanographic features (such as Long Eddy and Old Proprietor Shoals) concentrate prey predictably and serve periodically to concentrate predators, including Razorbills, that would otherwise disperse over a broader range in winter. The physical and biologic mechanisms behind the periodic concentration of one of North America's least abundant seabirds deserve focused research.

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