Net-mortality of Common Murres and Atlantic Puffins in Newfoundland, 1951–81

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1. Abstract

Band recoveries (N = 315) over 26 years (1951–77) and three surveys of seabird bycatch in inshore fishing nets (1972, 1980–81) indicate that there has been a substantial net-mortality of Atlantic Puffins (*Fratercula arctica*) and Common Murres (*Uria aalge*) in Newfoundland coastal waters for the past 2 decades. Offshore (e.g. Grand Banks) gill-netting is limited, but some data suggest that murre net-mortality also occurs offshore at murre wintering areas. The vast majority of inshore net-mortality incidents occur over a 2-week period during the annual inshore spawning migration of capelin (*Mallotus villosus*), the major prey item for alcids in eastern Canada. Most murres (83%) were drowned in bottom-set (30–185 m) cod (*Gadus morhua*) gill nets, whereas more puffins were drowned in surface-set salmon (*Salmo salar*) gill nets or cod traps (55%) than in cod gill nets (45%). Murre band recoveries, colony censuses, and fishing-effort data suggest that at the second largest Common Murre colony in Newfoundland (Witless Bay Seabird Sanctuary, 77 000 breeding pairs) net-mortality was relatively low in the 1950s and early 1960s, but increased during the 1960s as the murre population grew in size and gill-net fishing effort increased in the colony area. By 1971, net-mortality accounted for 70% of murre band recoveries and calculations show that almost 30 000 breeding adults, or about 20% of the local breeding population, were drowned in that year. More reliable estimates of alcid bycatch in the Witless Bay area have been made on the basis of actual bycatch surveys. In 1972 about 20 000 adult murres, or 13% of the breeding stock, were killed in gill-nets. Net-mortality of murres apparently diminished through the 1970s as capelin stocks declined and fewer birds foraged in heavily netted inshore areas. Bycatch surveys in the Witless Bay area in 1980–81 revealed that, relative to previous years, murre net-mortality was greatly reduced and resulted in the loss of only 3–4% of the breeding stock. Even these low mortality rates, however, are cause for concern as adult murre mortality from all sources (including hunting, oil, and natural mortality) should not exceed 6–12% per annum to maintain a stable breeding population. Little is known about the magnitude of net-mortality at other major Newfoundland murre colonies though it is known to be a problem in all colony areas. The bycatch of adult Atlantic Puffins in the Witless Bay area was low compared to murre bycatch and in 3 years of study never exceeded 1.6% of the breeding population. During the 1970s, fishing effort increased five-fold in colony areas and we predict that if capelin spawning stocks return to early 1970s size, then net-mortality of puffins and murres in Newfoundland coastal regions will increase dramatically. Indeed, preliminary examination of 1982 capelin spawning and seabird bycatch data suggests that capelin were much more abundant inshore and murre bycatch increased two- to three-fold over 1981.

2. Résumé

La récupération de bagues (N = 315) pendant 26 années (1951 à 1977) et trois relevés d'oiseaux emprisonnés dans les filets de pêche côtière (1972, 1980–1981) revèlent que la mortalité des Macareux arctiques (*Fratercula arctica*) et des Marmettes communes (*Uria aalge*) dans les filets de pêche côtière a été forte dans les eaux de Terre-Neuve durant ces 20 dernières années. La pêche hauturière aux filets maillants (par exemple à Grand Banks) est limitée, mais certaines données laissent croire que les marmettes se noient egalement dans les filets en haute mer dans leurs zones d'hivernage. La plupart des décès dans les filets de pêche côtière surviennent dans une période de deux semaines durant la migration annuelle, vers les travères du capelin (*Mallotus villosus*), principale proie des alcides de l'est du Canada. La plupart des marmettes (83 %) se sont noyées dans des filets maillants de fond (30 à 185 m) de la pêche à la morue (*Gadus morhua*) tandis que plus de macareux se sont noyés dans des filets maillants de surface de la pêche au saumon (*Salmo salar*) ou dans des trappes à morue (55 %) que dans des filets à morue (45 %). Les données sur les bagues recupérées, les recensements de colonies et l'effort de pêche indiquent que dans la deuxième colonie en importance à Terre-Neuve (Sanctuaire d'oiseaux aquatiques de Witless Bay, 77 000 couples de nicheurs), la mortalité des Marmettes communes dans les filets de pêche a été relativement faible durant les années 1950 et au début des années 1960, mais a augmenté durant la décennie 1960 avec l'accroissement de la taille de la population et de l'effort de pêche aux filets maillants dans la region abritant la colonie. Vers 1971, 70 % des bagues ont été récupérées sur des marmettes emprisonnées dans les filets, et des calculs montrent que près de 30 000 adultes nicheurs, ou environ 20 % de la population nicheuse locale, se sont noyés cette année-là. Des estimations plus sûres des captures d'alcidés à Witless Bay ont été effectuées à partir des données obtenues réellement dans les relevés d'oiseaux capturés. En 1972, environ 20 000 marmettes adultes, soit 13 % de la population nicheuse, se sont tuées dans des filets maillants. La mortalité de cette espèce dans les filets a diminué apparemment durant les années 1970 avec une baisse des stocks de capelan et du nombre d'oiseaux se nourrissant dans les régions côtières où la pêche au filet est intensive. Des relevés

sur les captures dans la région de Witless Bay en 1980–1981 ont révelé que, par rapport aux années antérieures, la mortalité des marmettes dans les filets avait diminué considérablement et n'avait entraîné qu'une perte de 3 à 4 % de la population de reproducteurs. Toutefois, même ces faibles taux de mortalité suscitent certaines préoccupations, car la mortalité des marmettes adultes, quelle qu'en soit la cause (dont la chasse, les déversements de pétrole et la mortalité naturelle), ne doit pas dépasser 6 à 12 % par année pour que l'effectif de la population de nicheurs demeure stable. On ne possède que peu de données sur l'ampleur de la mortalité dans les filets de pêche dans d'autres importantes colonies de marmettes de Terre-Neuve, bien qu'on présume qu'elle constitue un problème dans toutes les régions abritant des colonies. Le nombre de Macareux arctiques adultes capturés dans la région de Witless Bay a été faible comparativement à celui des marmettes, et durant les trois années de l'étude, il n'a jamais dépassé 1,6 % de la population de reproducteurs. Au cours des années 1970, l'effort de pêche a quintuplé dans les régions abritant des colonies, et les auteurs prévoient que si l'effectif des stocks de capelan géniteur revient aux valeurs du début des années 1970, la mortalité des macareux et des marmettes dans les filets de pêche des régions côtières de Terre-Neuve augmentera de façon radicale. De fait, une étude préalable des données de 1982 sur le frai des capelans et les captures d'oiseaux aquatiques laisse croire que les capelans étaient beaucoup plus abondants dans les zones côtières et que le nombre de marmettes capturées a été de 2 à 3 fois plus élevé en 1981.

3. Introduction

Little research has been conducted on seabird mortality associated with commercial fishing operations. Seabirds are known to be drowned in fishing nets in the northeast Atlantic (Holgerson 1961, Bourne 1971, Brun 1979), off Greenland (Tull *et al.* 1972, Christensen and Lear 1977, Evans and Waterston 1976), and in the Pacific (Ogi and Tsujita 1973, DeGange 1978, King *et al.* 1979, Ainley *et al.* 1981), but to date, little is known of the problem in Newfoundland waters where a substantial salmon and cod gill-net fishery coexists with large seabird populations.

The most comprehensive data on net bycatch have been obtained from research on the west Greenland salmon (*Salmo salar*) drift-net fishery. Tull *et al.* (1972) estimated an average Thick-billed Murre (*Uria lomvia*) bycatch of 500 000 ± 50% birds per year for the years 1969–71 by extrapolating from an observed ratio of murres to salmon in research vessel drift nets to the total west Greenland drift-net salmon catch.

Christensen and Lear (1977) re-examined seabird bycatch in the Greenland fishery during the course of joint International Council for the Exploration of the Seas – Internation Commission on North Atlantic Fisheries (ICES/ICNAF) salmon-tagging experiments in 1972. They found the relationship between seabird bycatch and salmon catch to be weak and consequently derived their estimates of seabird mortality solely on a catch-per-unit-effort basis. They estimated that in 1972 about 207 000 Thick-billed Murres drowned in drift nets along with 19 other seabird species including 10 000 Dovekies (*Alle alle*), 2000 Black Guillemots (*Cepphus grylle*), and 2000 Greater Shearwaters (*Puffinus gravis*). In addition, they concluded that the probability of seabird net-entrapment depends on many factors associated with the birds themselves, particularly their activity pattern, size, shape, and feeding behaviour, and that the relative abundance of a seabird species in bycatch did not necessarily reflect its abundance at sea. Also, the most accurate measure of fishing effort with which seabird mortality could be correlated was the product of the quantity of nets (total length in kilometres) multiplied by fishing time (in hours), or kilometre-hours of effort. This approach has some drawbacks, however, as it does not take into account the variable effects of wind, tide, currents, and sea-surface conditions, or prey fish species abundance and distribution, on seabird net-entrapment.

More recently, Ainley *et al.* (1981) found that for some seabird species (e.g. Thick-billed Murre and Short-tailed Shearwater (*Puffinus tenuirostris*)), there was a positive correlation between abundance at sea and net entrapment in high seas salmon gill nets in the North Pacific Ocean and Bering Sea. The highest densities and catch rates of seabirds occurred within 100 km of the Aleutian Islands and in the productive waters of the Alaskan Stream and Bering Current. The most commonly caught species were those that fed beneath the ocean surface by diving or pursuit plunging. They estimated that 266 500 birds were killed annually in the offshore Japanese salmon gill-net fishery between 1952 and 1979 and, of particular relevance to the Newfoundland situation, they demonstrated that bird catch rates increased logarithmically as distance to major seabird colonies decreased.

Newfoundland alcids, especially the Common Murre (*Uria aalge*) and Atlantic Puffin (*Fratercula arctica*) are predominantly capelin (*Mallotus villosus*) predators (Tuck 1961, Nettleship 1972). In summer, an estimated one million Common Murres and 500 000 Atlantic Puffins breed in Newfoundland (Nettleship 1980) and forage for capelin in coastal waters also intensively fished by people (Nettleship 1977). Until recently little has been known of the impact of the Newfoundland inshore fishery on seabirds. King *et al.* (1979) stated:

> There are as yet no estimates of the total alcid mortality from this fishery, although the annual catch of birds is believed to be smaller during the present (1970s) than during the last decade (1960s) because the fishing effort is reduced and fishermen in the area now avoid setting nets near alcid concentrations because of the annoyance of having to remove birds from their nets.

In this paper, we will present evidence that there were and still are large numbers of alcids being killed in the inshore fishery. Many alcids are drowned in fish nets set close to their breeding colonies as well as many kilometres away. Although alcid bycatch has diminished in recent years, this is not due to a decreased fishing effort: the inshore fishery has increased five-fold between 1973 and 1980 (as judged by the number of person-hours fished and the number of gill nets in use). Instead, it is related to changes in capelin biomass and interyear differences in inshore spawning by capelin.

The offshore gill-net fishery in Newfoundland may also result in significant alcid mortality. In addition to resident alcid populations, an estimated four million Thick-billed Murres from the eastern Canadian Arctic and several million Dovekies from Greenland arrive in autumn to spend the winter foraging along the east coast of Newfoundland and on the Grand Banks (Brown *et al.* 1975, Gaston 1980). Although the offshore cod gill-net fishery in Newfoundland

is relatively small (about 6000–9000 nets in use between May and December, D. Kulka, pers. comm., Department of Fisheries and Oceans [DFO], Enforcement Branch, St. John's), it is concentrated in areas known to be important to wintering populations of alcids (Brown *et al.* 1975). Preliminary data from DFO salmon-tagging experiments in 1979 and 1980 (D. Reddin, unpubl. data) indicate that alcid bycatch is associated with gill-netting operations in these areas.

The purpose of this paper is to review the available data on net-mortality of alcids breeding at major colonies in Newfoundland, attempt a preliminary assessment of its importance as one of several mortality factors affecting alcid populations, examine its possible relationship to capelin abundance, predict future trends, and reveal what research is required in the future.

4. Capelin

Prior to 1966, capelin research centred on life history, distribution, and racial studies (Templeman 1948, Pitt 1958, Winters 1966). Consequently, little is known about capelin abundance before this time, although reports of unusually low inshore capelin spawning efforts do not appear in the literature. Between 1950 and 1971 anywhere from 3000 to 20 000 t of capelin were harvested annually by inshore fishermen for use as fertilizer and bait (Campbell and Winters 1973). In anticipation of future large-scale exploitation, an assessment of capelin abundance was iniated in the mid 1960s (Templeman 1967) and an offshore fishery was opened in 1972 (Pinhorn 1976) with landings for that year totalling 70 800 t. These offshore landings rose to 360 500 t in 1976 and declined to only 11 000 t in 1979 (Akenhead *et al.* 1981). Estimates of total capelin biomass in the Newfoundland region are available (Carscadden and Winters 1980) for 1972–79 and show a peak of capelin biomass in 1975 and 1976 of about 1.3 million metric tons for both years and a decline to 350 000 t in 1979.

In summary, in the late 1960s and early 1970s capelin were abundant throughout their range in Newfoundland and southern Labrador (Jangaard 1974), but in recent years (1977–81) there has been a marked decline (five- to ten-fold) in capelin numbers both off shore (Carscadden and Miller 1980, 1981; Carscadden *et al.* 1981; Miller and Carscadden 1981; Carscadden, this volume) and inshore (J. Carscadden, pers. comm.). Although historical information on inshore spawning effort is largely qualitative, it is correlated with the size of offshore stocks because it is the mature fish from offshore stocks that move inshore to spawn (Jangaard 1974). (For a more complete analysis of historical capelin population trends, see Carscadden, this volume.)

5. Inshore net-mortality

5.1. Introduction

From all data collected, it is evident that most inshore alcid net-mortality coincides with the presence of capelin in fishing areas. Given the historical trends in capelin abundance and the correlation between alcid net-mortality and capelin presence, one can assess the relative significance of the inshore alcid net-mortality estimates given in Table 1 from band recoveries of Common Murres between 1951 and 1977 (Canadian Wildlife Service [CWS] files) and surveys of net-mortality made in 1972 (D.N. Nettleship), 1980, and 1981 (J. Piatt) in the Witless Bay Seabird Sanctuary area (Fig. 1*b*). Details of these data sets now follow with explanations of (1) how the net-mortality estimates were derived, and (2) what these results suggest considering the timing and distribution of net-mortality and the types of fishing gear involved.

5.2. Magnitude of net-mortality based on recoveries of banded Common Murres

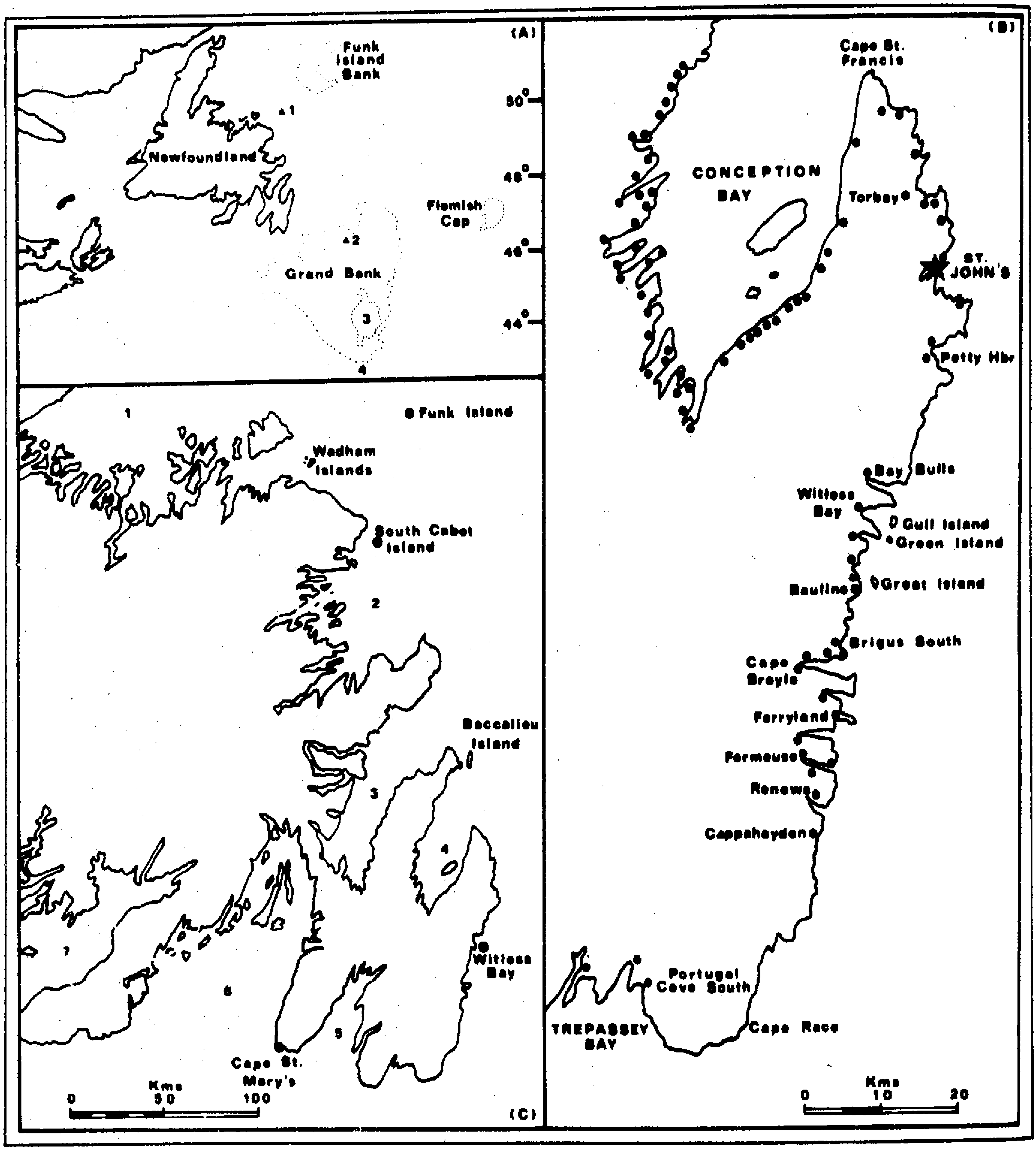
Common Murre chicks (N = 9740) on Green Island, Witless Bay (Fig. 1*b*) were banded by L.M. Tuck and co-workers of the CWS during 1951–56 and 1966–70 and band recoveries were made during 1951–62 and 1966–77 (CWS files). Over 90% of all band recoveries from the 1950s and 1960s banding efforts were made between 1953 and

Table 1
Inshore net-mortality of Common Murres and Atlantic Puffins in the Witless Bay Seabird Sanctuary area, 1954–81

Time period	Study method	Assessment of mortality	Est. no. of birds killed: Common Murre	Est. no. of birds killed: Atlantic Puffin	% breeding population killed: Common Murre	% breeding population killed: Atlantic Puffin
1954–56	Band-recovery analysis: Common Murre*	Population size × % mortality (3-year average)	7800 ± 4900	—	6.2	
1967–71	Band-recovery analysis: Common Murre*	Population size × % mortality (5-year average)	27 200 ± 9700		14	
1970	Band-recovery analysis: Common Murre*	Population size × % mortality	35 600	—	18	
1971	Band-recovery analysis: Common Murre*	Population size × % mortality	38 000	—	20	
1972	Daily record of net-mortality through fishing season by one fishing crew†	No. birds drowned/net/season × total no. nets in foraging area	25 200	2400	13	0.59
1980	Daily record of net-mortality by 8 fishermen and 5 qualitative reports‡	No. birds drowned/net/season × total no. nets in fishing area, summed for 5 communities	4200	7900	2.7	1.6
1981	Daily record of net-mortality by 20 fishermen and 71 qualitative reports‡	No. birds drowned/net/season × total no. nets in fishing area, summed for 15 communities	6260–8100	1210–2104	3.3–4.2	0.25–0.13

*Data from CWS files and Threlfall and Tuck (in prep.).
†Data from D.N. Nettleship (unpubl.).
‡Data from J. Piatt (unpubl.).

Figure 1
(*a*) Offshore areas where alcid mortality in nets is known to occur: 1, Funk Island; 2, Virgin Rocks; 3, Southeast Shoal; and 4, Tail of the Banks. (*b*) Southeastern inshore area showing the distribution of fishing communities around the Witless Bay Seabird Sanctuary (Gull, Green, and Great islands). (*c*) Other inshore fishing areas where alcid net-mortality occurs are as follows: 1, Notre Dame Bay; 2, Bonavista Bay; 3, Trinity Bay; 4, Conception Bay; 5, St. Mary's Bay; 6, Placentia Bay; and 7, Fortune Bay. Also shown are the six seabird colonies in Newfoundland (names given)



1958 and 1967 and 1972, respectively. Due to band loss (Tuck 1961), few recoveries were made later than 3 years after banding effort had ceased.

Analysis of murre band recoveries (Table 2) clearly shows the magnitude of net-mortality for Green Island murres. Ninety-three of 315 murres (30%) recovered over 26 years were found in fishing nets. This is a very high proportion compared to murre recoveries in Britain where only 3.8% of all British murre recoveries ($N = 552$) up to 1972 were from "fishing tackle" (Birkhead 1974). In addition, many murres in the "found dead" category may have been discarded after removal from nets (Tuck 1961), which raises the net-kill to possibly 40%. No murres banded as adults ($N = 453$) were ever recovered in nets and of all the immature murres recovered from nets ($N = 93$) about 25, 50, and 25% were 1–2, 2–3, and 3–4 year-class birds, respectively.

Separation of these data into the appropriate recovery periods (1951–1962 and 1966–1977), however, better illustrates the more recent situation. The Witless Bay murre population has increased from roughly 20 000 pairs in 1953 (Tuck 1961) to 77 000 pairs in 1972 (Brown *et al.* 1975), while fishing effort has increased markedly (since the 1950s) along with an increase in the use of cod and salmon gill nets (D. Wells, pers. comm., Department of Fisheries and Oceans [DFO], Econ. Br., St. John's). Accordingly, there was an increase in the proportion of net-related mortality from 6% in the 1950s to 49% in the 1960s and early 1970s. If the "found dead" murres are added to this, the proportions become 16 and 60%, respectively. Fish-net recoveries peaked in 1970 and 1971, with 66 and 70% of all recovered murres drowned in fish nets, respectively.

Using these band-recovery figures we calculated the actual number of murres drowned in nets in 1971 in the following manner. Assuming that in each of the years 1966–1971 there were 77 000 breeding pairs of Common Murres at the Witless Bay Seabird Sanctuary (Gull, Green, and Great islands, Brown *et al.* 1975) and that productivity was 0.70 chicks/pair (Birkhead and Hudson 1977, Mahoney 1979), then in each given year 53 900 chicks were fledged. Although Newfoundland band recoveries have yet to be analysed for the construction of life tables, the mortality of murre chicks (0–1 year-class) to first year (1–2 year-class) is considered to be high (Birkhead 1974, Mead 1974) and for the purpose of these calculations at least 50%. Since no 0–1 year-class murres were recovered in nets and few murre fledglings returned in the next year to their natal colonies (Birkhead and Hudson 1977), we attributed none of this first-year mortality ($0.5 \times 53\,900 = 26\,950$ murres) to drowning in nets. If we consider that 4–5 year-class murres are breeders and that survival to this age class is about 30% (Birkhead and Hudson 1977), then about 16 200 chicks ($0.3 \times 53\,900$) produced in any given year would have survived to breeding age. Thus, the number of immature murres (1–2, 2–3, and 3–4 year-classes) dying between their second and fifth years of life would be approximately 10 800 (27 000–16 200). In 1971, 70% of this mortality was due to drowning in nets, which means about 7600 immature murres drowned. From recent bycatch surveys (section 5.6), however, it appears that the ratio of immature to adult murres caught in nets is about 1:5 respectively. Thus, the total number of murres killed in nets at Witless Bay in 1971 may have equalled 38 000.

Similar calculations were made for each year in which more than 15 murre band recoveries were made

Table 2
Comparison of recoveries of Common Murres banded on Green Island, Witless Bay, for different time periods

Time period	Total no. of banded birds recovered	Cause of death: Drowned in fishing gear No.	Drowned in fishing gear %	"Found dead" No.	"Found dead" %	Other No.	Other %
1951–77	315	93	30	32	10	190	60
1951–62	144	9	6	14	10	121	84
1966–77	171	84	49	18	11	72	40
1970	29	19	66	1	3	9	31
1971	33	23	70	0	0	10	30

(Table 1). In 1970, about 35 600 murres may have drowned in nets. For the years 1967–1971 inclusive, the calculated number of murres killed in nets was 27 200 ± 9700. Again, for 1954–56 (and assuming a murre population of 50 000 pairs: Tuck 1961), 7800 ± 4900 murres were killed in fishing nets.

There is little doubt that these estimates of murre bycatch are excessive because the return of bands from birds recovered in fishing gear is likely to be proportionately higher than band recoveries from birds killed in other ways (e.g. oil, hunting, or natural mortality, Mead 1974). Nonetheless, compared to the estimates in sections 5.4–5.6 and Table 1, these figures appear to be of the right order of magnitude and provide a relative assessment of murre net-mortality in Newfoundland from 1954 to 1971. Based on these figures it appears that murre net-mortality was low in the 1950s and early 1960s resulting in an annual adult mortality equivalent to about 6% of the breeding population (number of murres killed × proportion of adults ÷ total number of individuals breeding, i.e. $7800 \times 0.8 \div 100\,000$). Net mortality increased in the late 1960s and adult mortality averaged about 14% of the breeding population during 1967–71 inclusive. In 1970 and 1971, the calculated adult mortality peaked at about 18 and 20% of the breeding population, respectively. Insufficient band recoveries were made during 1972–77 to assess net-mortality, but more reliable surveys of actual bycatch (sections 5.4–5.6) and trends in capelin abundance indicate that net-mortality declined through the 1970s.

5.3. Net-mortality of banded Common Murres: type of fishing gear, timing, and distribution

In Newfoundland, Common Murres are concentrated at their colonies from April to July and most are found offshore by August (Tuck 1961, Mahoney 1979). Thus murres are abundant in the periphery of their colonies during the time of major inshore fishing effort (LeMessurier 1980) for herring (*Clupea harengus*) in April, salmon in mid May to July, and cod in early June to October.

In addition to the Green Island band returns, there are data on net-recoveries of Common Murres ($N = 21$) which were banded as chicks on Funk Island. Together, these recoveries ($N = 114$) indicate the types of fishing gear responsible for murre net-mortality (Table 3). The ratio of murres killed in cod gill nets to salmon gill nets is about 2:1 and 89.5% of all recoveries were made from gill nets. The remaining 10.5% of recoveries were evenly distributed between cod traps, trawl lines, and herring nets.

The majority of band recoveries ($N = 114$) occurred in the months of May (12%), June (50%), and July (24%) with the remaining 14% spread evenly over the other 9 months of the year. The 86% of recoveries in May–June correspond to the known pattern of inshore capelin spawning in Newfoundland which typically peaks in June (Jangaard 1974). The 14% of recoveries outside this period may provide a biased estimate of non-capelin associated mortality since banded murres would less likely be noticed during the times when large numbers were being removed from nets (May–July) than at other times of the year when murre bycatch was unusual (August–April).

Only 12 (11%) of the recoveries were made outside a 70 km radius (estimated foraging range) of a major seabird colony (Fig. 1c) and half of these ($N = 6$) were also outside the May–July period. Most of these strays ($N = 9$) were caught in fishing gear on the southwest coast of Newfoundland and in Placentia Bay.

5.4. Net bycatch survey, 1972

In 1972, a fisherman in Bauline East, 2 km from Great Island (Fig. 1*b*), recorded the number of birds caught in his fishing gear (Table 4) throughout the fishing season (16 May – 2 November). A kill of 561 birds was recorded (502 Common Murres, 12 Thick-billed Murres, 46 Atlantic Puffins, and 1 Black Guillemot), with only one bird (Black Guillemot) caught outside the time capelin were judged to be present by the fisherman (17 June – 2 August). Murres were caught ($N = 464$) in cod gill nets (monofilament nylon, 140 mm mesh) and cod traps ($N = 50$), but never in salmon gill nets (nylon, 140 mm mesh) which were in the water from 16 May to 16 June (i.e. before the arrival of capelin in the inshore area). Mortality of Common Murres in gill nets was highest (15.7 birds/net/day, $N = 224$) during the first week of capelin spawning (17–23 June) with reduced numbers of birds (3.6 birds/net/day, $N = 228$) caught in nets during the remaining 40 days of the capelin period. Common Murres were caught four times in cod traps ($N = 30$, 10, 6, 4) and puffins were only caught in gill nets on 2 days ($N = 40$, 6) in July. No birds were killed in nets after 17 July, although cod gill nets and cod traps were in daily use until 10 August and 2 November, respectively.

Based on an average effort of 5.4 nets/day in use during the capelin period, the estimated rate of alcid mortality in 1972 for the Great Island area was 84 murres/net/season and nine puffins/net/season. In 1972 there were probably about 300 gill nets in operation (D. Wells, pers. comm., DFO, Econ. Br., St. John's) within the area used for feeding by alcids breeding at the Witless Bay Seabird Sanctuary. If we assume that the kill at each net was equal, then the total number of murres and puffins drowned in 1972 may have been as high as 25 200 and 2700, respectively. As before (section 5.2), we calculate that this represents an adult murre and puffin mortality of 13 and 0.6%, respectively, of the local alcid breeding populations. Note that this estimate of murre net-mortality (13% of breeders) is very close to the average murre net-mortality calculated from murre band recoveries for 1967–71 inclusive (14% of breeders, section 5.2). This method of extrapolation, however, may be subject to considerable error. Bycatch surveys in 1980–81 (sections 5.5 and 5.6) indicate that bycatch rates can vary markedly between fishing areas (Tables 4 and 5) and it is impossible to speculate on whether the 1972 bycatch rate observed was typical, low, or high. We can, however, compare maximum murre bycatch rates between years. The maximum observed cod gill-net bycatch rates in 1980 and 1981 of 10.8 and 19.4 murres/net/season, respectively (for Witless Bay, Tables 4 and 5), are only 13 and 23%, respectively, of the 1972 rate of 84 murres/net/season. Similarly, the 1980 and 1981 total bycatch estimates (Table 1), which are based on much more data, are only 16 and 25–32%, respectively, of the 1972 total bycatch estimate. Thus, working back from 1980–81 surveys and

Table 3
Comparison of net-mortality of 114 Common Murres banded as chicks on Green Island or Funk Island, Newfoundland, and recovered between 1951 and 1977, by type of fishing gear

Type of fishing gear	Banded birds, no.	Recovered, %
Gill nets		
Unspecified*	52	46
Salmon	17	15
Cod	33	29
Total	102	89.5
Others		
Cod trap	4	3.5
Trawl-line	4	3.5
Herring net	4	3.5
Total	12	10.5

*Unspecified gill nets were probably all salmon or cod gill nets judging by the date of net-mortality.

Table 4
Summary of alcid bycatch in salmon gill nets and cod gill nets and traps in the Witless Bay Seabird Sanctuary area, 1972 and 1980

				Bird mortality in cod gill nets and traps								Bird mortality in salmon gill nets				Estimated kill for all nets	
						No. birds drowned		$\bar{x}$ no. birds/net				No. birds drowned		$\bar{x}$ no. birds/net			
Community	No. fishermen reporting	Minimum distance of nets from nearest colony, km*	Time period kill recorded	Total number of nets	No. nets Sampled	Common Murre	Atlantic Puffin	Common Murre	Atlantic Puffin	Total no. of nets	No. nets sampled	Common Murre	Atlantic Puffin	Common Murre	Atlantic Puffin	Common Murre	Atlantic Puffin
1972																	
Bauline	1	0–2	17 June – 2 August	300	6	502	46	84.0	8.0	?	2	0	0	0	0	25 200	2400
1980																	
Witless Bay	4	0–3	5 July – 16 July	107	65	700 ± 50%	11 ± 25%	10.8	0.17	?	0	—	—	—	—	1156	18
Tors Cove	1	0–3	28 June – 18 July	70	11	88 ± 5%	0	8.0	0	?	0	—	—	—	—	560	0
Bauline	3	0–3	3 July – 10 July	400	47	108 ± 50%	0	2.3	0	?	16	0	350 ± 50%	0	21.8	230	350
Brigus South	1	9–11	24 June – 10 July	0	0	—	—	—	—	44	3	88 ± 5%	57 ± 5%	29.3	19	1289	836
Cape Broyle	4	13–15	23 June – 4 July	23	23	10 ± 5%	0	0.4	0	200	6	28 ± 5%	200 ± 50%	4.7	33.3	950	6660
1980 totals																4185	7864

*Colonies and population sizes (breeding pairs) (from Nettleship 1980):

	Common Murre	Atlantic Puffin
Great Island	2800	148 000
Green Island	74 000	17 000
Gull Island	680	74 000

considering the high bycatch estimates from murre band recoveries (section 5.2) in 1967–71, we feel that the 1972 bycatch estimate is reasonably accurate.

5.5. Net bycatch survey, 1980

In summer 1980 a survey of alcid bycatch in fishing gear was carried out by collecting information (Table 4) from 13 fishermen actively fishing in inshore waters around the Witless Bay Seabird Sanctuary (Fig. 1*b*). The reliability of data collected has been subjectively estimated and is believed to vary from ± 5% (kill recorded daily by reliable fisherman) to ± 50% (based on personal interviews before and after the season). Alcid bycatch was recorded from 23 June to 19 July in the survey area and because fishermen had most of their gear in operation throughout this period, the total murre and puffin kill was estimated by multiplying the average number of birds killed per net times the total

Table 5a
Fishing effort, sampling effort, and reported alcid bycatch in the Witless Bay Seabird Sanctuary area in 1981

	No. of nets* used			No. of nets sampled			Bird mortality in nets (No. birds drowned): Common Murre			Atlantic Puffin		
Community	CN	SN	CT	CN(†)	SN(†)	CT(†)	CN(†)	SN(†)	CT(†)	CN(†)	SN(†)	CT(†)
Pouch Cove	82	75	20	24	16	11	0	8	0	0	0	0
Flat Rock	42	37	22	16	17	6	0	0	0	0	1	0
Torbay	15	30	20	0	8	5		4	0		0	0
St. John's	70	24	10	50	20	4	10	4	0	0	0	0
Petty Harbour	0	217	62	0	27(5)	7(1)		22(10)	10(0)		5(5)	0(0)
Bay Bulls	167	205	35	167	69	9	517	54	0	20	59	0
Witless Bay	114	24	3	114(102)	24(7)	3(1)	2076(1978)	191(56)	15(0)	174(153)	74(35)	0(0)
Tors Cove	70	10	5	60(35)	4(4)	5(3)	192(185)	25(25)	2(2)	4(2)	7(5)	0(0)
Bauline	64	5	5	64	5	1	190	4	0	29	43	0
Brigus South	30	70	8	10(4)	32(10)	7(2)	4(4)	89(80)	3(3)	7(0)	99(94)	19(19)
Cape Broyle	80	135	37	52(34)	21(10)	18(4)	81(81)	39(15)	15(15)	15(15)	30(23)	21(8)
Calvert	107	75	33	33(20)	20(8)	8(2)	175(175)	190(172)	1(1)	0(0)	21(16)	2(2)
Ferryland	59	28	27	20	19	11	2	0	3	0	1	0
Aquaforte	0	33	17	0	8(4)	5(2)		5(5)	0(0)		10(10)	0(0)
Fermeuse	310	35	20	310(25)	14(4)	1	132(0)	16(2)	1(0)	0(0)	2(0)	0
Renews	200	25	24	68	10	11	64	2	0	0	0	0
Portugal Cove	150	30	30	30	4	2	0	0	0	0	0	0
Totals	1560	1058	378									
All reports ($N = 91$)				1018	318	111	3413	653	40	243	350	42
Type 1 reports ($N = 20$) only				220	52	15	2423	165	24	177	190	29

*Nets used were cod gill nets (CN), salmon gill nets (SN), and cod traps (CT).
†Numbers in parentheses indicate the values obtained from type 1 reports only (most accurate data; see text for details).

Table 5b
Net bycatch rates and total estimated numbers of alcids killed in nets in the Witless Bay Seabird Sanctuary area in 1981*

	Min. dist. of nets from colonies, km†	No. of birds killed/net‡/season: Common Murre			Atlantic Puffin			Estimated kill in nets: Common Murre			Atlantic Puffin			Estimated kill for all nets	
Community		CN(§)	SN(§)	CT(§)	CN(§)	SN(§)	CT(§)	CN(§)	SN(§)	CT(§)	CN(§)	SN(§)	CT(§)	Common Murre	Atlantic Puffin
Pouch Cove	60–80	0	.50	0	0	0	0	0	37	0	0	[illegible]	0	37	[illegible]
Flat Rock	60–70	0	0	0	0	.06	0	0	0	0	0	2	0	0	2
Torbay	50–60	—	.50	0		0	0		15	0		0	0	15	0
St. John's	30–40	.20	.20	0	0	0	0	14	5	0	0	0	0	19	0
Petty Harbour	25–30	—	.81	0		.19	0		176	0		41	0	176	41
			(2.0)	(0)		(.50)	(0)		(434)	(0)		(109)	(0)	(434)	(109)
Bay Bulls	1.5	3.1	.78	0	.12	.86	0	517	160	0	20	176	0	677	196
Witless Bay	0–3	18.2	8.0	5.0	1.5	3.1	0	2076	191	15	174	74	0	2282	248
		(19.4)	(8.0)	(0)	(1.50)	(5.0)	(0)	(2212)	(192)	(0)	(171)	(120)	(0)	(2404)	(291)
Tors Cove	0–3	3.2	6.2	.4	.1	1.3	0	224	312	2	[illegible]	13	0	538	18
		(5.3)	(6.2)	(.7)	(.11)	(1.3)	(0)	(370)	(312)	(35)	(4)	(13)	(0)	[illegible]	(17)
Bauline	0–3	3.0	.8	0	.5	8.6	0	190	4	0	29	43	0	194	72
Brigus South	9–11	.4	2.8	.4	0	3.1	2.7	12	195	3	0	[illegible]	[illegible]	210	[illegible]
		(1.0)	(8.0)	(1.5)	(0)	(9.4)	[illegible]	(30)	(560)	(12)	(0)	[illegible]	[illegible]	(602)	[illegible]
Cape Broyle	13–15	1.6	1.9	.8	.3	1.4	1.2	125	251	31	23	[illegible]	43	407	[illegible]
		(2.4)	(1.5)	(3.8)	(.44)	(2.3)	(2.6)	(190)	(202)	(138)	(35)	(310)	[illegible]	(530)	(419)
Calvert	15–20	5.3	9.5	.1	0	1.1	.3	567	712	4	0	[illegible]	8	1283	[illegible]
		(8.8)	(2.1)	(0)	(0)	(2.0)	(1.0)	(936)	(1612)	(0)	(0)	(150)	(33)	(2548)	(183)
Ferryland	20–25	.1	0	.3	0	.1	0	6	0	7	0	[illegible]	0	13	[illegible]
Aquaforte	20–25	—	.6	0		1.2	0		20	0		41	0	[illegible]	41
			(1.3)	(0)		(2.5)	(0)		(44)	(0)		(83)	(0)	(44)	(83)
Fermeuse	30–50	.4	1.1	1.0	0	.1	0	[illegible]	40	20	0	[illegible]	0	193	[illegible]
		(0)	(.5)		(0)	(0)		(0)	(17)		(0)	(0)		(17)	(0)
Renews	30–50	.9	.2	0	0	0	0	188	5	0	0	0	0	193	0
Portugal Cove	70–80	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals using															
All reports ($N = 91$)								4052	2123	82	[illegible]	[illegible]	[illegible]	[illegible]	1213
Type 1 reports ($N = 20$) and for Bay Bulls and Bauline, type 2 reports ($N = 13$).								4415	[illegible]	153	259	1062	[illegible]	[illegible]	2104

*Bycatch rates and estimated kills calculated from data in Table 5a.
†See footnote, Table 4, for colony population statistics.
‡Nets used were cod gill nets (CN), salmon gill nets (SN), and cod traps (CT).
§Numbers in parentheses are values based on type 1 reports only (most accurate data; see text for details).

number of nets operating in the community fishing area and summing the estimates for the five communities surveyed.

Most murres were caught ($N = 906$) in cod gill nets (140 mm mesh, nylon monofilament) set at depths ranging from 30 to 100 m; a few birds were also caught ($N = 116$) in salmon gill nets (nylon, 140–152 mm mesh) set 6–10 m deep. Puffins were rarely caught ($N = 11$) in cod gill nets, but large numbers were drowned ($N = 607$) in salmon gill nets. High net-mortalities were recorded near the colonies as well as up to 15 km away and there was a large variation in alcid bycatch from day to day as well as between fishing areas (Table 4). Alcid net-mortality was recorded during similar time periods in all areas surveyed and was correlated with the presence of capelin in each area (as judged by the presence of capelin in cod stomachs).

In summary, it appears that alcids were drowned in fish nets while feeding on capelin and that most murres and puffins were killed in cod and salmon gill nets, respectively. The observed difference in the type of nets responsible for murre and puffin mortality may be due to differences in the feeding behaviour of the two species, with murres feeding at greater depths than puffins. The daily and geographic variation in mortality may be largely due to fluctuations in the capelin spawning effort, influenced by oceanographic and meteorological factors (Jangaard 1974).

Taken together, the data indicate that a minimum of 4200 murres and 7900 puffins were killed in gill nets in 1980 in the area sampled. As calculated previously (section 5.2), this represents an adult murre and puffin mortality of 2.7 and 1.6%, respectively, of the local alcid breeding populations. This was the lowest mortality rate of murres observed over the years studied (Table 1). This estimate is probably low as fishing activities were not sampled at all communities (about 14) within foraging distance of the colonies and the overall estimates of fishing gear are known to be conservative. Furthermore, salmon nets were not sampled in two of the five communities surveyed and cod traps were not sampled at all. On the other hand, the estimates of puffin net-mortality may be very high since a large part (85%) of the estimated mortality is derived from the observations of a single fisherman in Cape Broyle (see Table 4).

The year 1980 probably represents a low-point for net-mortality in the Witless Bay Seabird Sanctuary area due to a decline of capelin in inshore waters (J. Carscadden, pers. comm.) and a provincial strike of the Fishermen's Union, which resulted in a major reduction of fishing effort during the 1980 fishing season. This contention is supported by the data (Table 4) which show that there was a marked decline in the time period in which alcid mortality was recorded in Bauline between 1972 and 1980 (17 June – 2 August and 3–10 July, respectively) and, as discussed previously, in the mean number of murres caught per net per season (84.0 and 10.8, respectively).

5.6. Net bycatch survey, 1981

In 1981, a more extensive survey of alcid bycatch around the Witless Bay Seabird Sanctuary was carried out (Tables 1, 5*a*, and 5*b*). The most accurate data were obtained from fishermen recording bycatch and/or from personal observations of bycatch on a daily basis during the capelin spawning period (report type 1, $N = 20$). The remaining reports (type 2, $N = 71$) of bycatch were obtained through personal interviews of fishermen before, during, and after the capelin spawning period. Personal observations (J.P.) of seabird bycatch in many communities along the coast (Fig. 1*b*) permitted an evaluation of the reliability of type 2 reports. Coverage of fishing effort in the 17 fishing communities along the coast was extensive (Table 5*a*). Out of an estimated 1560 cod gill nets, 1058 salmon gill nets, and 378 cod traps used from Cape St. Francis to Portugal Cove South (Fig. 1*b*), bycatch was reported (type 1 and 2 reports) from 65, 30, and 30%, respectively, of this gear. Type 1 reports covered 14, 5, and 4% of all fishing gear, respectively, although this coverage was concentrated in areas of high net-mortality from Petty Harbour to Calvert (Table 5*b*).

Considering only type 1 reports, it was observed (Table 6) that most murres (83.3%) were caught in cod gill nets at depths of 30–185 m, whereas relatively few were caught in surface-set salmon gill nets (16.0%) or cod traps (0.7%). In terms of the number of murres caught per net, however, salmon nets were almost as effective in catching murres (8.9 murres/net) as cod gill nets (11.0 murres/net). These data are in rough agreement with the murre band-recovery data discussed previously (Table 3). Almost equal numbers of puffins were caught in salmon (48.0%) and cod (44.7%) gill nets, but in terms of puffins caught per net, more birds were caught in surface-set salmon nets (3.6 puffins/net) and cod traps (1.9 puffins/net) than cod gill nets (0.8 puffins/net). The discrepancy between the rate of bycatch per net and the actual number of birds caught in

Table 6
Comparison of net mortality of Common Murres and Atlantic Puffins in 1981 by type of fishing gear*

Type of fishing gear	No. of nets	Common Murres drowned† No.	%	$\bar{x}$ no./net	Atlantic Puffins drowned‡ No.	%	$\bar{x}$ no./net
Cod gill net (138 mm mesh)	220	2423	83.3	11.0	177	44.7	0.8
Salmon gill net (125–138 mm mesh)	52	465	16.0	8.9	190	48.0	3.6
Cod trap (138–200 mm mesh)	15	21	0.7	1.3	29	7.3	1.9
Totals		2909	100		396	100	

*Based on type 1 data only, bycatch recorded daily (see text).
†Maximum depth at which murres were caught = 185 m.
‡Maximum depth at which puffins were caught = 60 m.

Table 7
Summary of the alcid bycatch in the Witless Bay Seabird Sanctuary area in 1981

Report type	No. of reports	No. of birds caught (all nets): Common Murre	Atlantic Puffin
A. Reported bycatch*			
Type 1	20	2909	396
Type 1 and 2	91	4136	635
B. Total bycatch†			
All type 1 and 2	91	6257	1213
Type 1 (8 communities)	20		
and selected type 2 (2 communities)	13	8132	2104

*Type 1 reports more reliable than type 2 (see text for details).
†Total bycatch extrapolated by calculating $\bar{x}$ bycatch per net (for each net type) in each community and multiplying this value by the estimated amount of fishing gear in the corresponding community, and then summing for all communities surveyed.

each net type is due to the high ratio of cod gill nets to salmon gill nets and cod traps (4.1:2.8:1, respectively). The fact that more murres were caught in bottom-set cod gill nets than puffins is most likely due to differences in foraging depths between the species.

As in 1972 and 1980, most of the 1981 net-drownings occurred during the inshore spawning migration of capelin (approximately 22 June – 20 July, as judged by the presence of capelin in cod stomachs). Capelin were observed to be the dominant food item (by % occurrence) in murre (97.2%, $N = 71$), puffin (93%, $N = 14$), and cod (48–100%, $N = 259$) stomachs during this period. Most (76%, $N = 1978$) murres in Witless Bay were caught during the first week of the capelin spawning period and the remainder (24%) were caught regularly, but in smaller numbers, for the remainder of time capelin were present. Examination of alcids retrieved from fishing gear revealed that the majority of murres (83.0%, $N = 481$) and puffins (98.4%, $N = 123$) caught were breeding adults (as judged by the presence of well developed brood patches or from autopsies).

The distribution of net-mortality around the Witless Bay Seabird Sanctuary was concentrated within a 60-km zone north and south of the colonies (Table 5*b*). There were few obvious patterns of bycatch observed; rather, there was a great deal of variation in bycatch per net between and within communities. These differences were probably related to capelin distribution, weather conditions, the location of fishing nets, and bathymetric features. If the number of birds caught per net is a valid measure of foraging activity, the data in Table 5*b* suggest that the foraging ranges of murres and puffins are similar (less than 20–30 km) during the capelin spawning period, although small numbers of murres were consistently caught in fishing areas up to 60 km away.

On the basis of reported bycatches, it was possible to extrapolate a total bycatch for the entire southeastern shore fishing area in 1981 (Table 7). Total bycatch was extrapolated (Table 5*a* and 5*b*) as in 1980 and the total amount of fishing gear in use was determined from estimates by fishermen in each community. If all reports ($N = 91$) are considered, about 6300 murres and 1200 puffins were caught in nets in 1981. However, on the basis of observations in the field, it was apparent that some qualitative type 2 reports underestimated actual bycatch. Thus if only the most reliable bycatch reports (all type 1, $N = 20$ and selected type 2, $N = 13$) are used to extrapolate to total bycatch, then about 8100 murres and 2100 puffins were killed in nets in 1981. As before (section 5.2), we calculate that 1981 net-mortality represents an adult murre and puffin mortality equivalent to 3.3–4.2 and 0.25–0.43%, respectively, of the local alcid breeding populations. Murre bycatch was higher than in 1980 (2.7% of breeders), but like 1980, it was substantially less than bycatch observed in the early 1970s (13–20% of breeders). Puffin bycatch in 1981 was markedly lower than in 1980, but, because of extreme intra- and inter-year bycatch variability, it is impossible to evaluate the reliability of the 1980 puffin bycatch estimate. Both the 1972 and 1981 data suggest, however, that puffin net-mortality is usually low relative to murre net-mortality and the 1980 puffin bycatch estimate may therefore be extreme. As discussed previously, the relatively low bycatch rates observed in 1980–81 were probably due to a marked decline in the abundance of capelin spawning stocks inshore (Carscadden, this volume).

5.7. Inshore net-mortality at other seabird colonies

Little is known about alcid net-mortality at the other five major seabird colonies in Newfoundland (Fig. 1*c*) except for anecdotal information which indicates that net-mortality occurs wherever fishing activities coincide with large seabird populations. Capelin are widely distributed around the Newfoundland coast during their spawning migration with major concentrations moving inshore from the southern Labrador – Funk Island Bank region towards the northeast coast (Fig. 1*a*) in June–July (Jangaard 1974) where a large proportion (55%) of gill nets in use in the inshore fishery are located (D. Wells, pers. comm., DFO, Econ. Br., St. John's) in addition to the major seabird populations (Nettleship 1980) at Funk Island (*ca.* 400 000 pairs Common Murres), the Wadham Islands (10 000 pairs Atlantic Puffins), and the Cabot Islands (3000 pairs Common Murres).

Of all Common Murre band recoveries ($N = 334$) over a 26-year period (1951–77) from murres banded as chicks on Funk Island, only 5.8% ($N = 21$) were recovered from fishing gear (CWS files); unfortunately, data are not available to compare bycatch between 10-year periods. Because the murre population on Funk Island has increased dramatically from about 40 000 pairs in 1951 (Tuck 1961) and because there has been an increase in the number of longliner fishing vessels capable of travelling the 60–100 km distance from mainland communities to the Funk Island area (LeMessurier 1980), it is possible that the net-mortality of Funk Island murres is now much greater than the 26-year average band-return figure suggests.

In the Cabot Islands region, net-mortality may also be significant. For example, 340 Common Murres were drowned in six cod gill nets which had been set in the vicinity of South Cabot Island in July 1980 (J. Lien, pers. comm.).

There are no data at present available on alcid net-mortality for the populations (Nettleship 1980) at Baccalieu Island (10 000 pairs of Atlantic Puffin, 1500 pairs of Common Murre) and Cape St. Mary's (11 000 pairs of murre {spp.}). However, personal observations and conversations with local fishermen indicate that net-mortality is common during the inshore capelin spawning period.

A systematic survey of all colony areas is required to evaluate the significance of net-mortality for these other alcid populations.

6. Offshore net-mortality

The potential number of alcids killed in the offshore gill-net fishery is quite high. In 1980, 15 Portuguese gill-netting vessels were licensed to operate within the Canadian 320-km territorial limit from June to December. Of this total, six to 12 boats normally operated (Fig. 1*a*) on the Virgin Rocks (49% of effort), Southeast Shoal (19% of effort), and southwest slope of the Grand Banks (33% of effort), while an equal number of unlicensed vessels operated outside the 320-km limit on the Tail of the Bank and Flemish Cap (D. Kulka, pers. comm., DFO, Econ. Br., St. John's).

This distribution of vessels encompasses all known major alcid wintering grounds in eastern North America. Large numbers of alcids move into these areas between September and December and they remain through to May or June with only small numbers present from July to

September (Brown *et al.* 1975). Thus, there is a 6-month overlap (May–June, September–December) in the use of these biologically productive areas by alcids and commercial gill-net operators. No records of the bycatch associated with these fishing activities are maintained, but qualitative reports from DFO observers (D. Kulka, pers. comm., DFO, Econ. Br., St. John's) and evidence of the bycatch observed during a salmon-tagging exercise conducted by DFO on the Grand Banks in 1979 suggest that it may be high. From 30 April to 20 May 1979, numerous alcids were drowned in salmon gill nets (monofilament nylon, 140–152 mm mesh, 100 m length) placed on the southwest slope of the Grand Banks, Virgin Rocks, Southeast Shoal, and the Tail of the Bank (D. Reddin, unpubl. data). During 384 km-hours of fishing effort, 162 Dovekies, 26 Common Murres, and 2 Atlantic Puffins were recovered from nets set at 6–10 m depths.

The licensed fishing effort of Portuguese gill-netting vessels on the Grand Banks in 1980 for the months of June and September–December is estimated at 132 960 km-h (Table 8). Using the DFO research vessel's ratio of alcids caught per unit fishing effort in May 1980 (Dovekie 0.42, murre 0.068, puffin 0.0052), it is possible that 56 000 Dovekies, 9000 murres, and 700 puffins were killed in offshore gill nets operated within the 320-km limit in 1980. Although the estimates for the kill of murres may be correct, the numbers of Dovekies and puffins drowned are probably much lower than the estimates because cod gill nets are usually set at depths (50–200 m) beyond the normal foraging ranges of these species. However, if a similar net-mortality was associated with the unlicensed gill-netting operations on the Tail of the Bank and Flemish Cap, then the estimated alcid net-mortality would be doubled because the fishing effort in these zones was known to be similar to the effort inside the 320-km limit in 1980.

Table 8
Estimates of gill-net fishing effort by Portuguese vessels on the Grand Banks in 1980*

Month	No. of days on fishing ground (all vessels combined)	Estimate of gill-net fishing effort, km/h†
June	33	15 840
July	124	59 520
August	157	75 360
September	82	39 360
October	74	35 520
November	63	30 240
December	25	12 000
Total	558	267 840

*Does not include fishing effort outside the Canadian 320-km limit which is estimated to be either greater or equal to the fishing effort within Canadian waters (D. Kulka, pers. comm.).
†Calculated by multiplying vessel-days-on-fishing-ground × 24 × number of nets in use per day (x = 200) × total length of nets (0.1 km).

7. Discussion and conclusions

On the basis of murre band recoveries made over 26 years (1951–77) and three surveys of alcid bycatch in fishing nets in the vicinity of the Witless Bay Seabird Sanctuary (1972, 1980, and 1981), as well as numerous qualitative reports, it is apparent that a large bycatch of adult Common Murres and Atlantic Puffins occurs in the area and probably at all other major seabird colonies in Newfoundland. There is some evidence that a substantial alcid bycatch also occurs in offshore fishing regions.

Murre net-mortality appears to have increased dramatically from the 1950s and peaked in the early 1970s as murre populations increased in size and fishing effort intensified in the vicinity of major colonies. In recent years (1977–80), alcid net-mortality has apparently decreased due to a marked decline in the abundance and inshore spawning effort of capelin, the major summer prey item of murres and puffins in Newfoundland.

Meanwhile, there has been a steady increase in effort by the Newfoundland fishery. In 1973 the total number of person-months fished was 59 100 and 55 400 gill nets were in use, whereas in 1979 the numbers of person-months and gill nets were estimated to be 320 000 and 180 400 respectively. During the same period in the fishing zones encompassing the seabird colonies in eastern Newfoundland the number of gill nets in operation increased from 22 500 to 113 500. Thus, there has been a five-fold increase in fishing effort and fishing gear over the last decade. Moreover, traditional fishing grounds are still being exploited and there has been little change in the overall inshore fishing pattern since 1970 (LeMessurier 1980).

It is possible that in past years murre bycatch exceeded the limit allowable for maintaining a stable population, especially for the Witless Bay colonies where band recovery and survey data indicate that 13 to 20% of the breeding population were killed annually in the early 1970s. Even the relatively low murre net-mortality rates observed in 1980–81 (*ca.* 3–4% of breeders) are cause for concern since the total adult murre mortality from all sources (including oil, hunting, and natural mortality) should not exceed 6–12% per annum to maintain stable breeding populations (Birkhead 1974, Mead 1974). Net-mortality of alcids is especially significant because it occurs during the peak of the breeding season and the rearing of young by one bird is difficult, if not impossible (Nettleship 1972).

If capelin stocks recover, it is reasonable to expect that a high alcid bycatch will be seen in coming years, particularly in view of the increased emphasis on and participation in the inshore fishery in Newfoundland. Indeed, preliminary analysis of the 1982 capelin spawning effort in Newfoundland suggests that it was much larger than in recent years (J. Carscadden, pers. comm.). Correspondingly, murre bycatch in fishing nets increased two- to three-fold in the Witless Bay area, and increased bycatch was noted at other seabird colonies as well.

Clearly, more research is required to elucidate the impact of net-mortality on seabirds in Newfoundland, as well as a concerted effort to better understand the population biology of the seabirds most vulnerable and their major summer prey, capelin, a fish species that forms the basis of the food web in temperate water regions of Atlantic Canada (Brown and Nettleship, this volume).

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