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Underwater Vocalizations as a Tool for Studying the Distribution and Relative Abundance of Wintering Pinnipeds in the High Arctic

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ABSTRACT. Recordings of the underwater vocalizations of ringed seals, bearded seals and walruses were made in the High Arctic between late March and late June 1980 and 1981, to evaluate the potential for using sub-ice vocalizations to study the distribution and relative abundance of wintering pinnipeds. Most of the calls made by these three species are identified and an initial lexicon is presented. Ringed seal vocalizations were more frequent in late April than earlier in the season or in late June, whereas the highest vocalization rates recorded for bearded seals were in late June. Vocalization rates of all three species were indicative of their distribution and relative abundance in different areas and sea ice habitat types. We conclude that underwater vocalizations have the potential for giving more precise information on the relative abundance of wintering pinnipeds than techniques previously used. It may be possible, provided the necessary information on the vocal behaviour of these species is acquired, to use this technique for censusing.

Key words: vocalizations, ringed seal, bearded seal, walrus, distribution

RÉSUMÉ. Les vocalisations sous-marines de phoques annelés, de phoques barbus et de morses ont été enregistrées dans le nord de l'Arctique entre la fin-mars et la fin-juin 1980 et 1981 en vue d'évaluer l'usage possible des vocalisations subglaciaires pour l'étude de la distribution et de l'abondance relative de pinnipèdes en hivernage. La plupart des cris de ces trois espèces sont identifiés et un premier lexique est présenté. Les vocalisations de phoques annelés sont plus fréquentes vers la fin-avril que plus tôt au cours de la saison ou à la fin-juin, tandis que le taux maximal de vocalisations pour les phoques barbus était enregistré à la fin-juin. Les taux de vocalisation des trois espèces indiquaient leur distribution et leur abondance relative dans diverses régions et dans divers types d'habitats sur la glace maritime. L'étude conclut que les vocalisations sous-marines peuvent peut-être signaler des renseignements plus précis sur l'abondance relative de pinnipèdes en hivernage que le peuvent les méthodes employées jusqu'à présent. Si les données nécessaires portant sur le comportement vocal de ces espèces sont obtenues, il serait peut-être possible d'employer cette technique pour des recensements.

Mots clés: vocalisations, phoque annelé, phoque barbu, morse, distribution
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INTRODUCTION

Three species of pinnipeds winter in the Canadian High Arctic: ringed seals (*Phoca hispida*), bearded seals (*Erignathus barbatus*), and Atlantic walruses (*Odobenus rosmarus rosmarus*). Until recently, their populations have been relatively undisturbed during the winter except for a limited amount of hunting. However, in the 1970s, proposals were made for several large-scale industrial projects which would require large, specially constructed, ice-breaking ships to pass through Barrow Strait and adjoining waterbodies in all seasons (Fig. 1). For example, the Arctic Pilot Project proposes to liquefy natural gas at Bridport Inlet on Melville Island and transport it to an east coast terminal. Dome Petroleum proposes to ship oil from the Beaufort Sea through Prince of Wales Strait, Viscount Melville Sound, Barrow Strait, and Lancaster Sound, also en route to an east coast destination. Other possibilities include several mines, a methanol plant, ships from Alaska and/or Japan, an inter-island pipeline, and extensive shipping just to provide logistic support. On the basis of independent estimates, there may be 900 to 1000 passages of ships per year through High Arctic waterways by the turn of the century (CARC, 1980; MOT, 1981).

If approved, each of several projects may have ships passing through the study area during the winter. There is potential for conflict between pinnipeds and ships because some preferred wintering habitat lies in areas of thinner annual ice, along shoreleads or in recurring polynyas; these are often preferred routes for ships because of easier, more economical, and possibly safer passage. During the open-water period, pinnipeds could probably avoid disturbance from ship traffic simply by swimming away. During the winter, however, movements of seals and walruses are restricted because they must either maintain breathing holes or use recurring polynyas where currents, wind, or tides maintain areas of open water. The distribution of the best wintering habitat for each species is fairly localized and pinnipeds are concentrated within it. Wintering areas are also important because seals and walruses mate and give birth to their young there in the spring. At this stage, we feel it is critical to determine where the most important wintering areas for seals and walruses are so that they may be protected as much as is practical when shipping lanes are being determined.

Defining the problem and the objectives is considerably easier than gathering data to address them. Trying to determine the distribution of seals or walruses during the winter is confounded by darkness, cold and inclement weather, and by seals hauling up and maintaining breathing holes under the snow, where they are not visible. The few seals or walruses which may be seen on the ice or in the water by the end of April give little quantitative indication of their winter distribution patterns or abundance.

Ringed Seals

Ringed seals prefer to winter over moderate water depths, in

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areas where the stable annual ice is sufficiently rough to collect snow drifts (McLaren, 1958; Smith and Stirling, 1975). Adult seals appear to establish territories at freeze-up in the fall (Smith and Hammill, 1981) and remain in the same area through the winter. In the spring, the pregnant females give birth to their young in subnivean lairs. Favourable pupping areas appear to be fairly localized and their distribution and productivity can vary considerably between years (Smith and Stirling, 1975, 1978; Smith *et al.*, 1978). Preliminary findings indicate that, in contrast to the western or eastern Arctic, bays in the High Arctic do not appear to be particularly productive areas for ringed seals, apparently because the smooth ice and low precipitation do not facilitate snowdrifts large enough for birth lairs (Stirling *et al.*, 1981). If so, it means that the greatest portion of the pupping takes place in the rougher ice areas along the coastlines of the islands and in the inter-island channels. The most productive areas located to date for ringed seals in the High Arctic have been in Barrow Strait (Smith *et al.*, 1978).

In the past, we have undertaken two kinds of studies to evaluate the distribution and abundance of ringed seals in the High Arctic.

1) *Aerial surveys*. Aerial surveys of ringed seals are flown in late spring just prior to breakup. The surveys are intended to coincide with the season and time of day when the maximum number are hauled out on the sea ice. Even so, there is no way to correct for the number of seals under the ice so the results are indices of abundance rather than total population estimates. Another reason for conducting aerial surveys prior to breakup is that the results may also be representative of winter distribution. No one has yet evaluated whether that assumption is correct. The most extensive aerial surveys of ringed seals in the High Arctic were conducted in late June and early July of 1980 and 1981 (Kingsley *et al.*, 1982). These identified Barrow Strait and southern Wellington Channel as having the greatest numbers and densities of ringed seals in the late spring and early summer.
2) *Birth lair surveys*. Smith and Stirling (1975, 1978) used a trained dog to search for the subnivean breathing holes and birth lairs of ringed seals and made tape recordings of their vocalizations (Stirling, 1973) in order to assess the relative importance of different areas to ringed seals. The dog searches revealed data on the number and kinds of structures present, which could not have been determined any other way. The tape recordings provided information on the relative abundance of seals. Both types of data correlated fairly well with habitat data such as snow depth and the presence and type of pressure ridges. The disadvantages of the dog searches are that they are labour-intensive, and dogs do not work well in extreme cold; there are few trained dogs and handlers available; and the dogs may be subject to variability that we are unable to detect or measure.

Pastukov (1965) described another method of surveying birth lair distribution and density using motorized ground transport. In the late spring, when the sun's warmth caused the roofs of the lairs to cave in, he counted lairs on transects through areas suspected to be productive. No attempts have been made to apply this technique in the Canadian Arctic. Finley (1979) used aerial photographs of drainage patterns on the ice to count and calculate the density of seal holes in two bays in the High Arctic.

Bearded Seals

Bearded seals are much less abundant than ringed seals in the High Arctic and their distribution appears to be much more localized (Kingsley *et al.*, 1982). They appear to winter near recurring polynyas and in shallow water areas along coastlines, where, like ringed seals, they maintain breathing holes by abrading the ice with the heavy claws of their foreflippers (Stirling, 1977). Their young are born unsheltered onto the surface of the ice in May (Burns and Frost, 1979). Details of possible seasonal movements are unknown.

Walruses

Undetermined numbers of walruses winter in various locations in the High Arctic (Davis *et al.*, 1978; Kiliaan and Stirling, 1978; Stirling *et al.*, 1981). Their presence can be detected from the air by locating their large haul-out holes and faeces on the ice, often around multi-year floes frozen into the annual ice. Walruses appear to winter annually at the recurring polynyas of the Cardigan Strait-Fram Sound and Penny Strait-Queens Channel areas. However, even though we suspect they are present during the winter in these or adjacent areas, it is difficult, using conventional aerial survey methods, to confirm or even gain a subjective impression of abundance because the animals do not usually come out of the water.

In summary, the techniques used to date for assessing the winter distribution and abundance of pinnipeds in the High Arctic have a number of disadvantages. Insufficient numbers of seals haul out during cold winter weather to make aerial surveys worthwhile. Using trained dogs to search for birth lairs and breathing holes is probably the best technique available for ringed seals but it requires experienced field personnel and dogs, both of which are in short supply. Several biologists have noted that recording underwater vocalizations may have potential for censusing marine mammals (Ray, 1970; Winn *et al.*, 1975; Thomas and DeMaster, 1982). It seemed to us that this technique had potential for application in the Arctic by personnel with unspecialized knowledge and experience. The data are collected in a form which can be analyzed, copied, or re-analyzed any number of times by different individuals if desired. Our main objectives are to summarize our data on underwater vocalizations and to evaluate the potential of this technique for studying the distribution and abundance of wintering pinnipeds in the High Arctic.

METHODS

From 1972 through 1979, sub-ice recordings of pinnipeds were made at various locations in the western or High Arctic, mainly on an opportunistic basis while conducting other studies. In 1980 and 1981, we concentrated our recording in the High Arctic and were more selective about the locations (Fig. 1) and times at which we chose to record in order to examine pinniped distribution and habitat selection. We recorded at some locations on different dates through the season to evaluate seasonal changes in vocalizations.

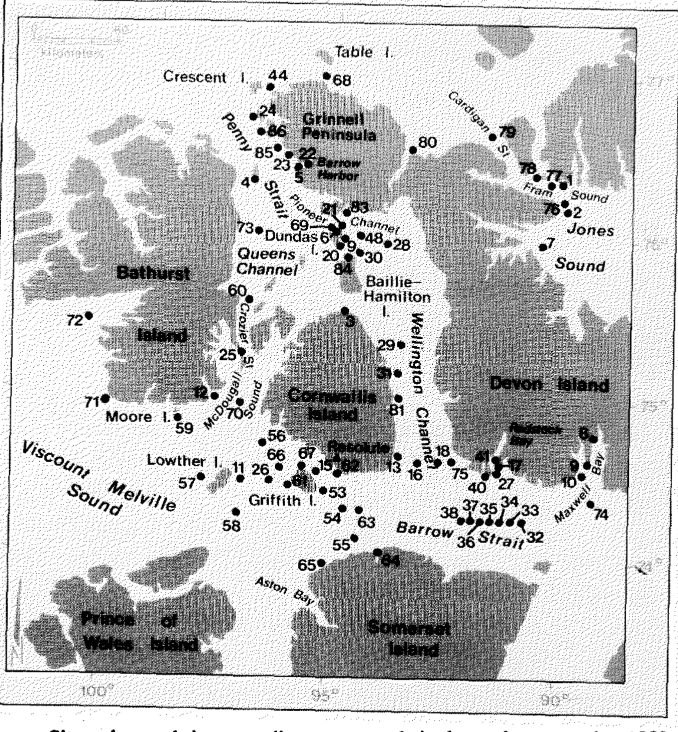

FIG. 1. Sites where sub-ice recordings were made in the study area spring 1980 and 1981.

Recordings from 1972 through 1979 were made with a Uher 4000 Report-L tape recorder using Ampex, Sony, and BASF tapes and a model LC-50 hydrophone with an LG-1324 preamplifier (Atlantic Research Corporation). In 1980 and 1981, recordings were made with Uher 4000 Report-L and 4000 Report IC tape recorders, BASF tapes and both the model 6050C hydrophone (International Transducer Corporation) and model LC-50 hydrophone. A series of simultaneous recordings was made to compare the two models of hydrophone. Sound spectrograms were made on a Kay Sona-Graph 7029A set on 13 db high shape and using a narrow-band filter (45 Hz at the 80-8000 Hz setting and 22.5 Hz at 40-4000 Hz).

We reached the recording locations in a Bell 206 Jet Ranger helicopter, landed, idled for 2-3 min to allow the engine to cool sufficiently, and then shut down. The hydrophone was lowered at an ice edge or through a seal hole if one was available. Otherwise, we drilled a 10 cm hole with a hand auger. The hydrophone hung 3-5 m below the bottom of the ice.

We recorded under different sea ice habitats in representative areas in both years to see if vocalization rates might reflect the importance of those habitats and areas to ringed seals. Annual ice can be subjectively evaluated from the air and on foot for its potential suitability as ringed seal birth-lair habitat. On the high end of the scale, low ice ridges or hummocks in stable ice areas with long deep drifts are good for birth lairs while smooth areas with little snow cover or very rough broken areas are not (Smith and Stirling, 1975). Upon arrival at each area by helicopter, we evaluated it on an ascending scale from one to five and landed at a spot which appeared representative.

The recordings analyzed for this report were made 13 April-13 May 1980 and 26 March-29 June 1981. Recordings were usually made between 09:00 and 18:00 CST. A duration of 10 min was chosen, based on our subjective impression that this was long enough to evaluate the amount and type of vocalizing. In the laboratory, vocalizations were catalogued to type and location on the tape. The vocalization rates for ringed and bearded seals were quantified as the number of calls heard per minute.

The vocalizations of walruses are often long and repetitive; if several animals are vocalizing simultaneously, it may be impossible to identify the start or finish of individual calls. We have not yet developed an adequate way of quantifying walrus vocalizations. Consequently, at present we can give only a subjective evaluation of the amount of walrus vocalizing at each station in general categories: 1) none heard; 2) present but not abundant, if calls were heard but there was little or no overlapping; and 3) abundant, if calls of different walruses were constantly overlapping each other.

In order to improve the reliability of our lexicon, several recordings were made in locations where, to the best of our knowledge, only one species would be present and likely to vocalize. In most circumstances, we could not see the animals so we could draw no conclusions about the function of the calls. However, in April and early May 1981, we were able to observe individual walruses while they were vocalizing and correlate their behaviour with some of the calls.

To determine the patterns of distribution and abundance of pinnipeds from underwater vocalizations, it is necessary to ascertain the distance to which calls can be heard. The usual technique is to record the intensity of a call within 1 m of an individual animal and extrapolate source levels, but this was not possible in the field. However, by using our knowledge of the habitat preferences of bearded seals (moving ice interspersed with areas of open water) the following simple test was conducted. On 13 May 1980, the eastern edge of the fast ice covering Barrow Strait lay in a line which curved to the west between Cape William Herschel (Fig. 1, site 10) and Prince Leopold Island off the northeast corner of Somerset Island. Open water lay to the east. If bearded seals remained in or near the open water, then by moving away from the ice edge and recording, we could estimate how far the calls travelled. We made seven 10-min recordings at 8-km intervals beginning at the ice edge and moving westward across the fast ice (Fig. 1, sites 32-38).

RESULTS AND DISCUSSION

Factors Affecting Recording Quality

The quality of underwater recordings of vocalizations is af-

TABLE 1. Comparison of the efficacy of the LC-50 and 6050C hydrophones during simultaneous recordings

Location	Weather conditions	Percent of vocalizations heard on LC-50 compared to 6050C	
		Ringed seal	Bearded seal
2 km S of Moore Is (59)[1]	calm, −15°C	40% (34/84)	80% (88/110)
5 km E of Lowther Is (11)	wind 19 $km \cdot h^{-1}$ from N, −15°C	10% (19/183)	—
2 km E of Cheyne Pt SE Griffith Is (53)	wind 12 $km \cdot h^{-1}$ from N, −13°C	17% (75/441)	—
15 km E of Cape Hotham, Cornwallis Is (16)	wind 19 $km \cdot h^{-1}$ from N, −10°C	12% (17/137)	—
3 km E of Cape Majendie (83)	wind 8 $km \cdot h^{-1}$ from NE, 7°C	—	64% (43/67)
Mouth of Barrow Harbour (5)	wind 12 $km \cdot h^{-1}$ from NE, 8°C	—	84% (16/19)

[1]Numbers in brackets are recording sites on Figure 1.

fected by the type of equipment used as well as by several environmental factors. Because of improvements in the equipment available during recent years, higher quality recordings can be produced. To compare the LC-50 hydrophone to the 6050C hydrophone, we conducted simultaneous recordings at different sites and under various weather conditions during late winter and spring of 1980 and 1981 (Table 1). Under calm conditions, the LC-50 hydrophone picked up 40% of the total number of ringed seal vocalizations and 80% of bearded seal vocalizations recorded by the 6050C hydrophone. When surface wind speeds were 8-12 $km \cdot h^{-1}$, the ratio of bearded seal vocalizations recorded by the LC-50 hydrophone dropped to an average of 69%. Ringed seal vocalizations decreased markedly to an average of 15% when surface winds increased to 12-19 $km \cdot h^{-1}$. These results reflect the need for using caution when comparing data from recordings made using different equipment. Unless otherwise noted, recordings in 1980 and 1981 were made with the 6050C hydrophone.

Ambient noise from environmental factors, such as surface wind, and movement of ice and water resulting from currents and tides, has a marked effect on the ability to record vocalizations clearly, since noise tends to mask vocalizations. Ice movement in particular makes it difficult to identify ringed seal calls.

Identity of Vocalizations

Some preliminary papers have already been published on the underwater calls of ringed seals, bearded seals, and walruses (Dubrovskii, 1937; Schevill *et al.*, 1966; Ray *et al.*, 1969; Stirling, 1973; Ray and Watkins, 1975). Our results are in general agreement with those data, though there are some interesting variations. In the following sections, we describe the vocalizations we recorded in the Canadian High Arctic from each species.

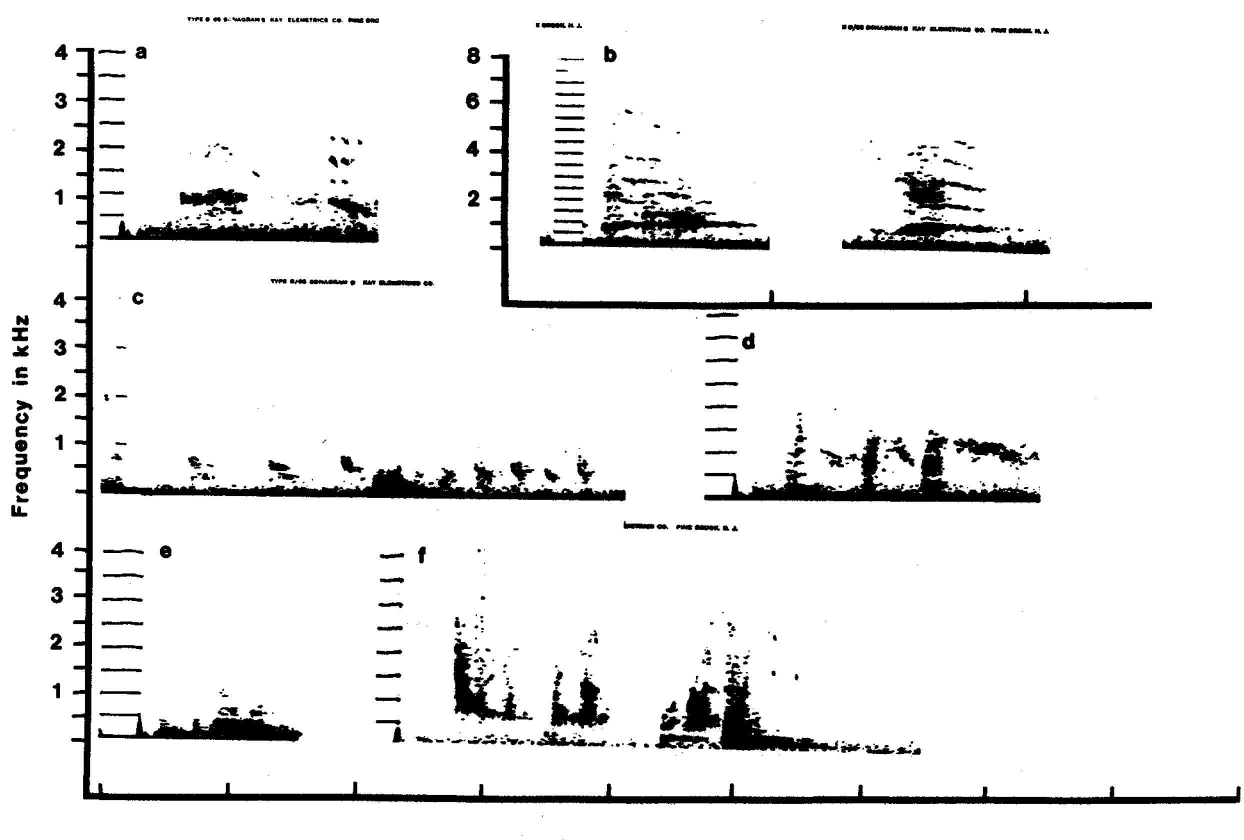

FIG. 2. Sonagrams of ringed seal vocalizations: a. two high-pitched yelps; b. two nasal yelps; c. three medium-pitched barks followed by a low-pitched growl then five medium-pitched barks; d. three low-pitched barks alternating with three high-pitched yelps; e. woof; f. five medium-pitched bark-yelps followed by three low-pitched bark-yelps.

Ringed seals. High- and low-pitched yelps, barks, growls, and chirps were first recorded and described by Stirling (1973). Unlike the loud distinctive vocalizations of bearded seals and walruses, the calls of ringed seals are often faint, or follow each other in rapid succession, so that the audile effect is sometimes that of a continuum rather than of discrete, categorically distinct sounds. Consequently, these vocalizations are difficult to catalogue. Because of this, and because the calls are more easily masked by ambient noise, their occurrence is probably underestimated. Our records of their vocalizations are probably less accurate than those of the other two species.

Yelps and barks made up the majority of sub-ice vocalizations heard. There are structural and audile variations within these categories. Yelps (Fig. 2a) are usually high-pitched. Some yelps sound nasal and their sound spectrograms (Fig. 2b) show additional and more distinct sidebands.

Barks are generally moderate to low in frequency and shorter in duration than yelps (Fig. 2c,d). The barks in Figure 2d average approximately 0.2 s duration while the yelps range from 0.2 to 0.7 s. Unlike yelps, which consist of a relatively narrow-band fundamental with distinct, widely separated sidebands, barks have a broader frequency range. The width of this band can vary greatly between barks. Frequently, a series of low-pitched barks in rapid succession in interspersed with high-pitched yelps (Fig. 2d). A woof (Fig. 2e) sounds

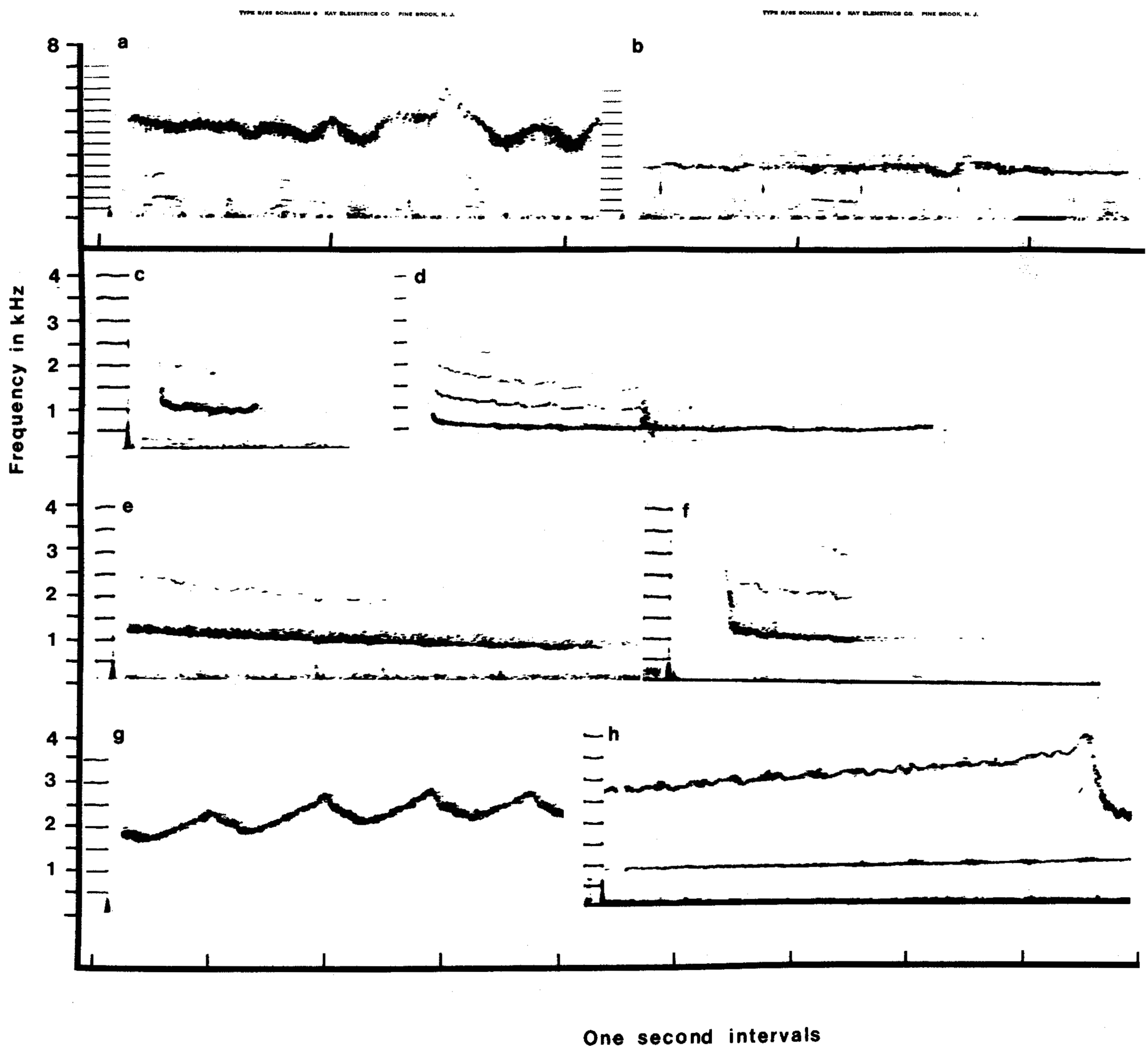

FIG. 3. Sonagrams of bearded seal vocalizations: a. high-frequency trill; b. ending of high-frequency trill; c. short descending trill; d. low-frequency trill with several sidebands; e. slowly-descending trill; f. rapidly-descending trill; g. trill with regular, long-period modulation; h. two ascending trills, one ending with a descending trill, recorded in the western Arctic.

like a bark, but is lower-pitched and lacks the higher-pitched sidebands.

Bark-yelps are at the midpoint of the continuum between yelps and barks and contain the audile and sound spectrogram characteristics of both barks and yelps (Fig. 2f). Because bark-yelps represent the middle of a continuum, there is considerable variability in their structure.

We have tentatively identified some other vocalizations. Figure 2c illustrates a low-pitched growl in the middle of a series of medium-pitched barks. The growl consists of a broad band of frequencies approximately 900 Hz in width lasting just over 0.2 s. No recordings of other vocalizations were suitable for analysis.

Bearded seals. Bearded seals have been reported to produce a distinct vocalization during the late winter and spring, often referred to as a trill (Dubrovskii, 1937; Chapskii, 1938; Burns, 1967; Ray *et al.*, 1969). Our data suggest bearded seals may also give other calls, but to date we have not been able to confirm this.

Trills vary in duration. Portions of a 73-s trill are shown in Figure 3a,b, while Figure 3c shows a trill lasting less than 1 s.

The maximum frequency of a trill may range from about 750 Hz (Fig. 3d) to 6000 Hz (Fig. 3a). The minimum frequency may range from about 500 Hz (Fig. 3d) to 2000 Hz (Fig. 3b). The frequency of trills usually changes gradually (Fig. 3e), but occasionally will change rapidly (Fig. 3f). Some trills have sidebands which may vary in intensity and duration (Fig. 3c-f).

The degree and rhythmicity of modulation may vary greatly between trills. For example, the maximum modulation in Figure 3d is about 50 Hz, while in Figure 3a the maximum modulation of the fundamental is about 2000 Hz. Figure 3g shows a segment of a trill in which the rhythm of modulation was not only very regular, but also more drawn out than in the other trills shown.

Virtually all the trills heard in the High Arctic descend in frequency, while in the western Arctic a number also ascend in frequency, such as the two shown in Figure 3h.

During 703 minutes of recordings made from 1972-75 in the western Arctic, 18.8% (172/914) of the total number of trills heard ascended in pitch. Many ascending trills begin or end with descending trills. The higher trill in Figure 3h illustrates the sharp descent that often follows an ascending trill.

Walruses. Walrus vocalizations are loud, distinct, and usually numerous, making them easy to detect by monitoring with a hydrophone. Most of the underwater vocalizations recorded consisted of one or more short pulses that had a sharp repetitious sound. We have termed these taps and knocks (Fig. 4a), which appear to equate to what Ray and Watkins (1975) call pulses. Although there is a gradation between taps and knocks, taps generally sound higher in pitch and lighter in intensity than knocks (first two pulses in Fig. 4a). In contrast, it appears that knocks are slightly longer, and contain more energy, especially below about 1000 Hz (last three pulses in Fig. 4a).

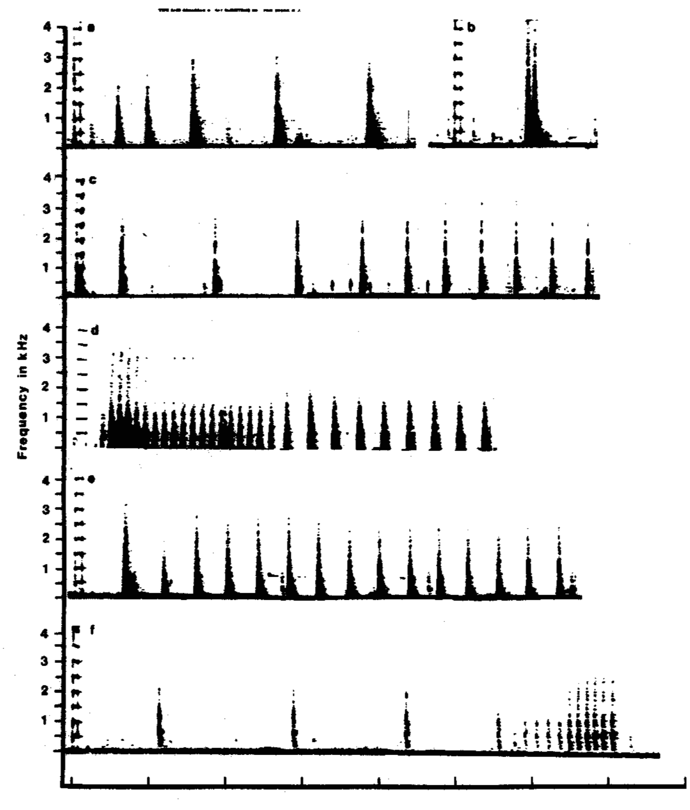

FIG. 4. Sonagrams of walrus vocalizations: a. two taps then three knocks; b. double knock; c. slow start of sequence of pulses; d. rapid start of sequence of pulses in a diving vocalization; e. diving vocalization given by a different male than Fig. 4d; f. coda preceded by a few slow pulses.

The rate at which taps and knocks are given may vary between calls or within calls from $1\cdot s^{-1}$ to a maximum of about $15\cdot s^{-1}$. They may occur in sequences of up to several hundred pulses, lasting 60-80 s, or in short abrupt sequences of six to eight pulses, or as single pulses. Taps and knocks are given in at least four different patterns which we have termed double knock, tapping or knocking sequence, coda, and diving vocalization.

The double knock (Fig. 4b) is a particularly distinctive call given by at least some males before surfacing to breathe during a stereotyped vocalizing cycle.

In long tapping or knocking sequences, pulses are usually given at a rate of about $1\text{-}3\cdot s^{-1}$ but can increase to about $6\cdot s^{-1}$. They may start slowly (Fig. 4c) or quickly (Fig. 4d). Toward the end of a sequence, the taps may deepen and become knocks. The last few pulses are often given as a rapid burst of knocks (termed a coda by Ray and Watkins, 1975) and are sometimes followed by a bell call (see below). We also found codas being given as separate calls, preceded by only a few pulses (Fig. 4f).

During stereotyped vocalizing cycles, the male always gives a distinct call, which we termed the diving vocalization, immediately after taking his last breath and descending from the surface. Some began with a rapid burst of knocks (up to $10\text{-}15\cdot s^{-1}$) then slowed down to about $3\text{-}4\cdot s^{-1}$ and continued for well over 100 pulses. There is some indication that the div-

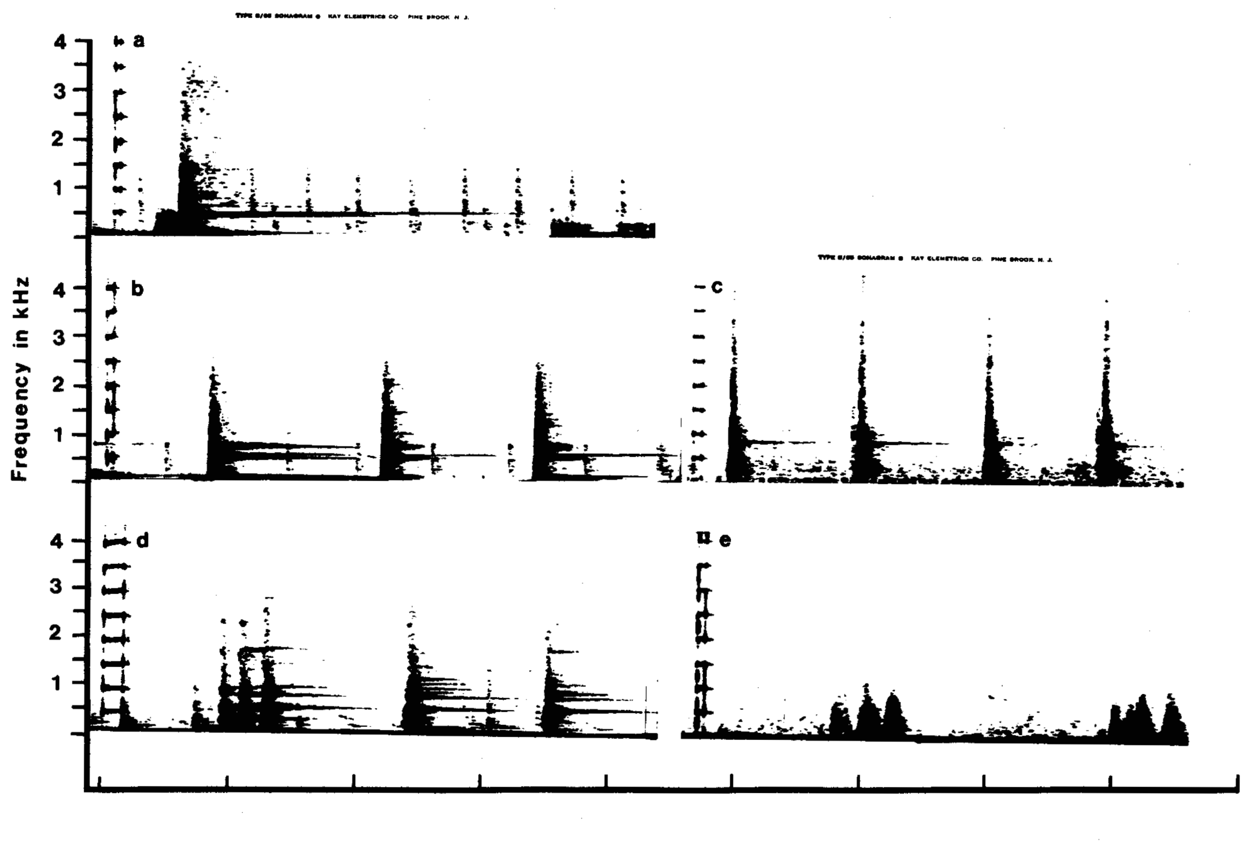

FIG. 5. Sonagrams of walrus vocalizations: a. single bell call with 2-s long fundamental (faint knocks in background); b. series of three bells; c. four knocks, first and second sound metallic; d. five strums; e. low-pitched grunts.

ing vocalizations given by the same individual are constant but that there are recognizable differences between individuals, such as between Figure 4d and 4e. The diving vocalizations of the male that made the call illustrated in Figure 4e remained constant through 10 vocalizing cycles. We do not know if an individual gives the same diving vocalization throughout a single season and possibly between years. However, LeBoeuf and Petrinovich (1975) reported that individual variability in the threat vocalizations of male northern elephant seals (*Mirounga leonina*) remained constant between years. If individual male walruses can be recognized in different years because of natural markings, we may be able to determine if they can also be identified by their vocalizations.

The bell, one of the most distinctive and best known calls, was first reported by Schevill *et al.* (1966) from a captive male Atlantic walrus in the New York Aquarium. As its name suggests, it sounds like a church bell. It may be given singly (Fig. 5a), in a short series (Fig. 5b) or, often, at the end of a series of taps or knocks. Although it may last for as long as 2 s (Fig. 5a), the bell sound is usually about 1 s long (Fig. 5b). Structurally, the bell is similar to the knock except for a narrow band of sound at about 700 to 800 Hz. In sound spectrograms of knocks, traces of this sound are sometimes present (the latter two pulses in Fig. 5c), though not always detectable to the human ear. Some knocks do sound metallic, and inspection of a sound spectrogram indicates that it is because the duration of sound in the frequency range of the fundamental of the bell is extended (first two pulses in Fig. 5c).

The strum (Fig. 5d), not given during the stereotyped cycles and heard only at irregular intervals, is reminiscent of fingers being strummed over the strings of a guitar or zither. Structurally, the call is similar to the bell but has three or more narrow bands spaced throughout the total frequency band width and extending beyond the main pulse.

We are able to confirm that females with calves, though we do not know which, made low-pitched grunts (Fig. 5e). If several animals were vocalizing simultaneously, it sounded like mumbling voices in the distance.

On a few occasions, we recorded a call similar to the rasp call reported from the Atlantic walrus by Schevill *et al.* (1966: Fig. 1). We did not obtain good recordings of this vocalization.

Distance Travelled by Calls

At the ice edge, (Fig. 1, site 32), bearded seal calls were loud and numerous (about 14·min^{-1}). Moving west, the intensity and number of vocalizations declined until we recorded 17% as many calls 48 km to the west (Fig. 1, site 38). If few of the vocalizing seals were located in the stable ice-covered waters to the west of the ice edge, the results would suggest that at least some of the vocalizations might be heard 45 km from the source under ideal conditions (i.e. no wind, ice or water movement, or submarine obstacles).

Although we have not conducted similar tests with walruses, our impression is that their calls do not travel as far as those of bearded seals. The ubiquitous distribution of ringed seals precludes conducting a similar field test. However, because their calls seem to be so much fainter, we suspect they travel only a few kilometres at the most.

Function and Seasonality of Calls

Ringed seals. Ringed seals appear to be territorial during the breeding season in April and May (Smith and Hammill, 1981). Vocalizing probably serves an important role in the reproductive behaviour of this species, as it does in the ringed seal's ecological counterpart, the Weddell seal (*Leptonychotes weddelli*) in the Antarctic (Kaufman *et al.*, 1975; Stirling, 1977). We suspect that vocalizations in association with reproductive behaviour occur in addition to calls used for social organization and determining access to breathing holes. This may explain the increase in vocalization rates observed in late April. In most cases, vocalization rates increased by 2 to 13 times from late March — early April to late April (Table 2). Stirling (1973) reported an 11% increase in the number of vocalizations$\cdot$min^{-1} from January to April 1972 in Amundsen Gulf, which he suggested might be related to an increase in agonistic behaviour during the breeding season. We suspect that the higher vocalization rates continue through much of May as well. The rate of vocalizing probably varies with the density of the seals and with the amount of access to naturally maintained breathing areas.

By late June, the breeding season is well over and the ice in most areas is beginning to crack and break up. This provides more access to naturally occurring breathing areas resulting in less need to maintain a sub-ice social structure around breathing holes. This may explain the drop in vocalization rates recorded in late June (Table 2). More ringed seals also haul out for longer periods of time in June (Finley, 1979) but we feel this behavioural change is inadequate to explain the drop in vocalizations, since Stirling (1973) also reported a very low vocalization rate in August 1972 in the open water offshore from Sachs Harbour on Banks Island in the western Arctic, although many seals were present in the area at the time.

Bearded seals. Ray *et al.* (1969) suggested that male bearded seals produce loud, distinctive vocalizations during the spring courtship season, which they believed functioned as a proclamation of either territory or breeding condition. Burns and Frost (1979) suggested that female bearded seals may vocalize as well but this has not been confirmed.

Bearded seal vocalizations have been recorded as early as 26 March and as late as 15 July in the Canadian High Arctic. We have not documented how much earlier or later in the year these calls are given. In 1981, we recorded at 13 sites between two and four times each. Generally, vocalization rates increased from late winter to early summer (Table 2). This suggests that either individual seals were vocalizing more, or there were more seals within range of the hydrophone. One exception to this pattern of an increasing vocalization rate occurred 2 km south of Moore Island (Fig. 1, site 59). In early April, the vocalization rate at this site declined to 24% of the value recorded 10 days earlier (Table 2). Seventeen days after the second recording was made, the vocalization rate increased nearly nine times, and was still high two months later, in June. All four recordings were made under calm wind and water conditions and within an hour of the same time of day, and ice conditions were constant through April. We think it is unlikely that the observed changes in vocalization rates reflected movements of seals during the fast-ice period, and therefore there may be some daily variability in the vocalization rate.

Another exception to the trend of increasing numbers of vocalizations occurred 2 km east of Cape Liddon (Fig. 1, site 27). Overall, the vocalization rates remained low and, in contrast to the other sites, declined through the spring and early summer. The annual ice along the southern coast of Devon Island and in eastern Barrow Strait breaks up earlier than at the

TABLE 2. Vocalization rates (calls$\cdot$min^{-1}) of ringed seals and bearded seals during spring and early summer 1981

Locations	Ringed seals 26 Mar -1 Apr	9-13 Apr	21-28 Apr	21-29 June	Bearded seals 26 Mar -1 Apr	9-13 Apr	21-28 Apr	21-29 June
3 km S Resolute Bay (62)[1]	5.4	—	16.5	—	0.0	—	1.9	—
2 km E Cape Liddon (27)	1.9	2.5	23.6	3.5	0.7	1.3	1.0	0.4
S Patrol Pt Radstock Bay (17)(41)	0.8	—	10.1	6.9	0.0	—	0.9	2.3
3 km SE Cape Wm Herschel (10)	1.5	1.4	—	—	1.8	17.4	—	—
5 km E Lowther Is (11)	8.3	—	15.7	3.2	0.3	—	0.2	9.0
6 km W Griffith Is (61)	5.8	—	13.2	5.3	0.8	—	2.0	11.9
2 km E Cheyne Pt (53)	7.9	—	45.9	8.2	0.0	—	0.0	8.4
3 km S Somerville Is (66)	7.9	—	7.9	—	2.4	—	2.3	—
2 km E Separation Pt (81)	—	—	19.4	0.3	—	—	0.0	3.0
Freemans Cove (12)	0.6	—	—	0.2	0.6	—	—	4.5
2 km S Moore Is (59)	10.5	4.4	6.7	0.0	5.5	1.3	11.3	10.7
Mid-Barrow Strait (63)	5.8	—	15.4	—	0.0	—	0.0	—
1 km N Dundas Is (6)(21)	0.0	0.0	0.0	0.0	0.0	0.1	2.6	9.5

[1]Numbers in brackets are recording sites on Figure 1.

other sites on Table 2. We suspect that as new leads form, and breakup moves westward through Barrow Strait, bearded seals move west as well. In April 1982, the floe edge was about 150 km east of Cape Liddon and almost no bearded seal calls were recorded, which also suggests that the distribution of open water is the main factor influencing winter distribution of bearded seals along the south coast of Devon Island.

Walruses. We observed adult male walruses going through stereotyped cycles of underwater vocalizing. For example, one male observed continuously for 1.5 h went through 10 such cycles. The mean time underwater was 6 min 41 s $\pm$ 98.5 s ($n = 10$, range = 215 to 511 s) while the mean time at the surface was 2 min 34 s $\pm$ 11.5 s ($n = 11$, range = 136 to 179 s). Each time this animal came to the surface, it gave the same calls in the same order between individual breaths. Similarly, this individual tended to give the same calls in the same order when it was underwater although there was more variability in this part of the cycle. Ray and Watkins (1975) reported a similar stereotyped pattern of breathing and vocalizing from the Pacific walrus (*O.r. divergens*) in the Bering Sea, except that the durations were much shorter (mean = 23 s at the surface and mean = 2 min 2 s underwater). Ray and Watkins (1978) and Fay (1982) interpreted these vocal displays as an advertisement to females of the male's reproductive status and as a deterrent to other males in the area.

Stirling and Siniff (1979) reported a similar pattern of vocalizing cycle from the leopard seal (*Hydrurga leptonyx*). Although it has not been demonstrated, we suspect that the males of other highly vocal species such as the Weddell seal and the bearded seal may also have stereotyped vocalizing cycles.

Schevill *et al.* (1966) reported that a male walrus in captivity gave bell calls while copulating. Ray and Watkins (1975) and Fay and Ray (1979) suggested that the stereotyped vocalizing observed in the Pacific walrus was probably related to social organization during the breeding season. We suspect this interpretation is correct and applies as well to the Atlantic walrus.

From histological evidence, it appears that the mating season for Pacific walruses in the Bering Sea, between about 57°N and 65°N, is from January to April (Fay and Ray, 1979; Fay, 1982). The mating season of the Atlantic walrus in the High Arctic likely takes place during a similar period although it may be slightly later at higher latitudes (>75°N). Although we found underwater vocalizing by walruses to be a constant occurrence from late March through April, we do not know whether this behaviour occurs only during the breeding season or goes on throughout the year.

During our direct observations of adult male walruses, we were able to confirm that they give all the calls listed earlier. We have not been able to confirm whether or not female walruses give any of these calls.

Winter Distribution

Ringed seals. Table 3 compares vocalization rates recorded at the mouths and inner areas of three bays. The sample is small but the vocalization rates are consistently higher at the mouths of the bays, suggesting that more seals are present there. Our unpublished data on polar bear hunting behaviour also indicate that, during the spring, bears spend much more time hunting in the drifted rough ice in the mouths of bays than in the smooth ice of the inner bays where there is little snow cover.

TABLE 3. Comparison of vocalization rates (calls·min^{-1}) of ringed seals in the mouths of bays versus inner portions of bays

Location	Date	Recording site	Vocalization rate
Barrow Harbour	25 April 1980	inner bay (22)[1]	0.2
	16 April 1980	bay mouth (5)	1.6
Maxwell Bay	30 March 1981	inner bay (8)	1.2
		mid-bay (9)	0.8
		bay mouth (10)	1.5
Radstock Bay	30 March 1981	mid-bay (17)	0.8
		bay mouth (27)	1.9
	28 April 1981	inner bay (41)	10.1
		bay mouth (27)	23.6

[1]Numbers in brackets are recording sites on Figure 1.

Figure 6 summarizes the data on relative abundance of sub-ice ringed seal vocalizations, recorded mainly between 26 March and 13 April 1981 (Table 2). In general, the vocalization rates of ringed seals were higher in the areas of most suitable pupping habitat between Cornwallis, Griffith, and Lowther islands, suggesting the presence of more seals there than elsewhere.

Smith *et al.* (1978) conducted ringed seal birth-lair surveys in eastern Viscount Melville Sound and western Barrow Strait and reported high densities east of Lowther Island and around Griffith and Browne islands. We recorded high vocalization rates around Lowther and Griffith islands (Fig. 6) and Kingsley *et al.* (1982) also reported high densities of seals hauled out on the ice there in early summer.

We rated mid-Barrow Strait and the southern end of Wellington Channel as being unsuitable for pupping habitat in 1981 because of insufficient snow for birth lairs, yet they had higher vocalization rates than we expected (Fig. 6). In aerial surveys of ringed seals flown over most of the High Arctic in late June and early July of 1980 and 1981 (Kingsley *et al.*, 1982: Fig. 7), the highest densities of ringed seals in both years were in Wellington Channel and Barrow Strait. The results of our preliminary surveys, using vocalization rates, also suggest higher numbers of ringed seals in these areas relative to other locations in the study area. If this interpretation is correct, it suggests that Barrow Strait and Wellington Channel have high numbers of ringed seals during the winter. If this area is consistently less suitable for pupping, the seals present are likely to be predominantly immature and non-breeding animals, which suggests that they also vocalize, perhaps at rates similar to adults in other areas.

Vocalization rates were also high near the northwest coast of Somerset Island and southern Bathurst Island (Fig. 1, sites 65, 59, 71). These sites were all near rough ice or some pressure ridges and were within 3 km of the coast. We know from our unpublished studies that one of the preferred hunting areas of

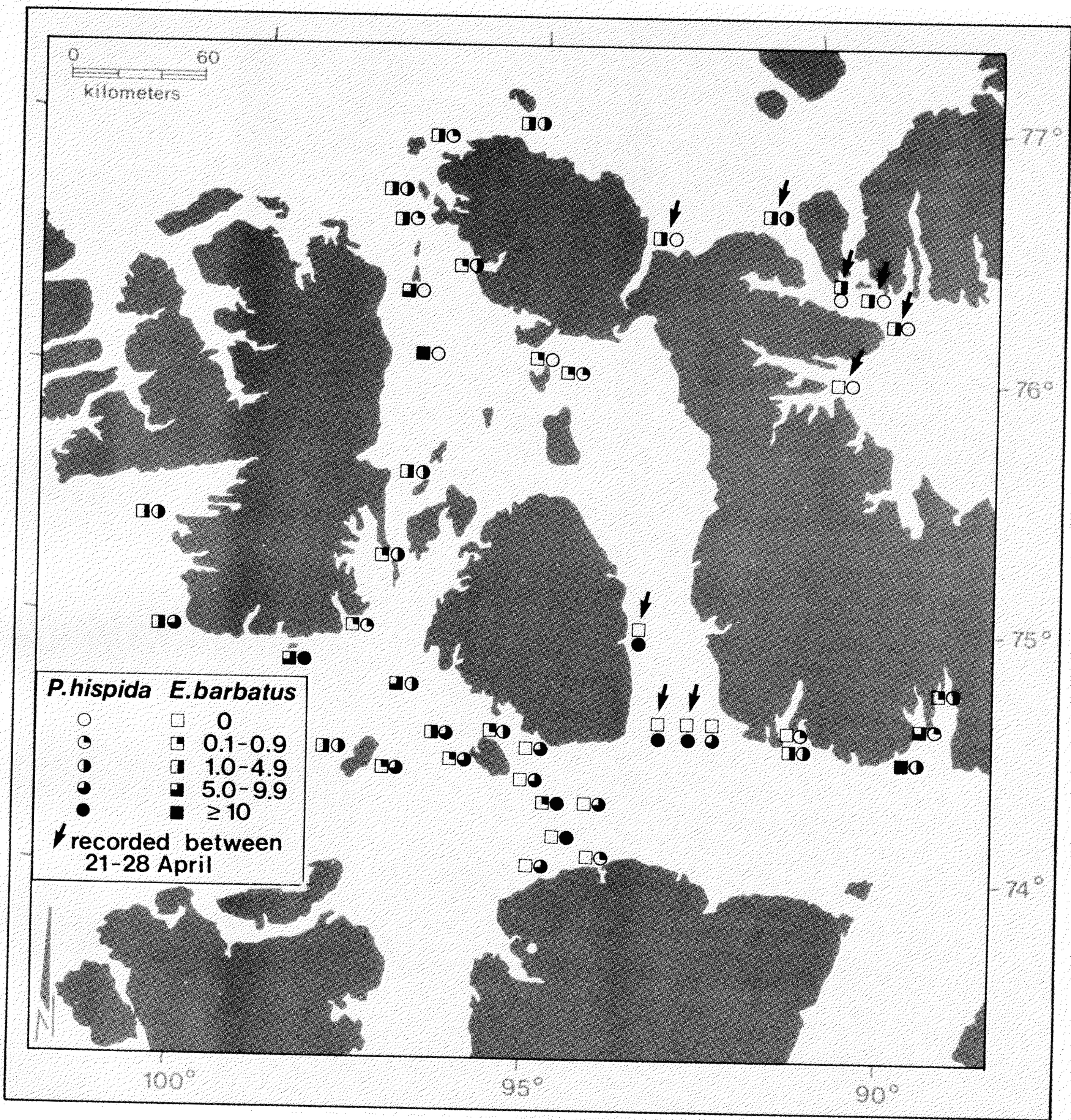

FIG. 6. Abundance of vocalizations (calls·min^{-1}) of ringed seals and bearded seals in spring 1981 at recording sites in the High Arctic. Except where noted, the recordings were made between 26 March and 13 April.

polar bears is the rough ice parallel to coastlines, suggesting that seals are either more abundant or more accessible there. Snowdrifts on these ridges appeared as if they might be suitable for construction of birth lairs but we have no information on this aspect.

Bearded seals. In the Beaufort Sea, bearded seals prefer areas with shallow water and incomplete ice cover (Burns, 1967; Stirling *et al.*, 1981). Although they are capable of maintaining their own breathing holes in fast ice (Stirling and Smith, 1977), they tend to do so only in areas which freeze up late and open early.

The ice cover in the High Arctic is essentially constant through the winter to the end of April. Thus, we can use the presence and rates of bearded seal vocalizations in April to make some preliminary statements about the winter distribution of this species (Fig. 6). Bearded seals were heard along

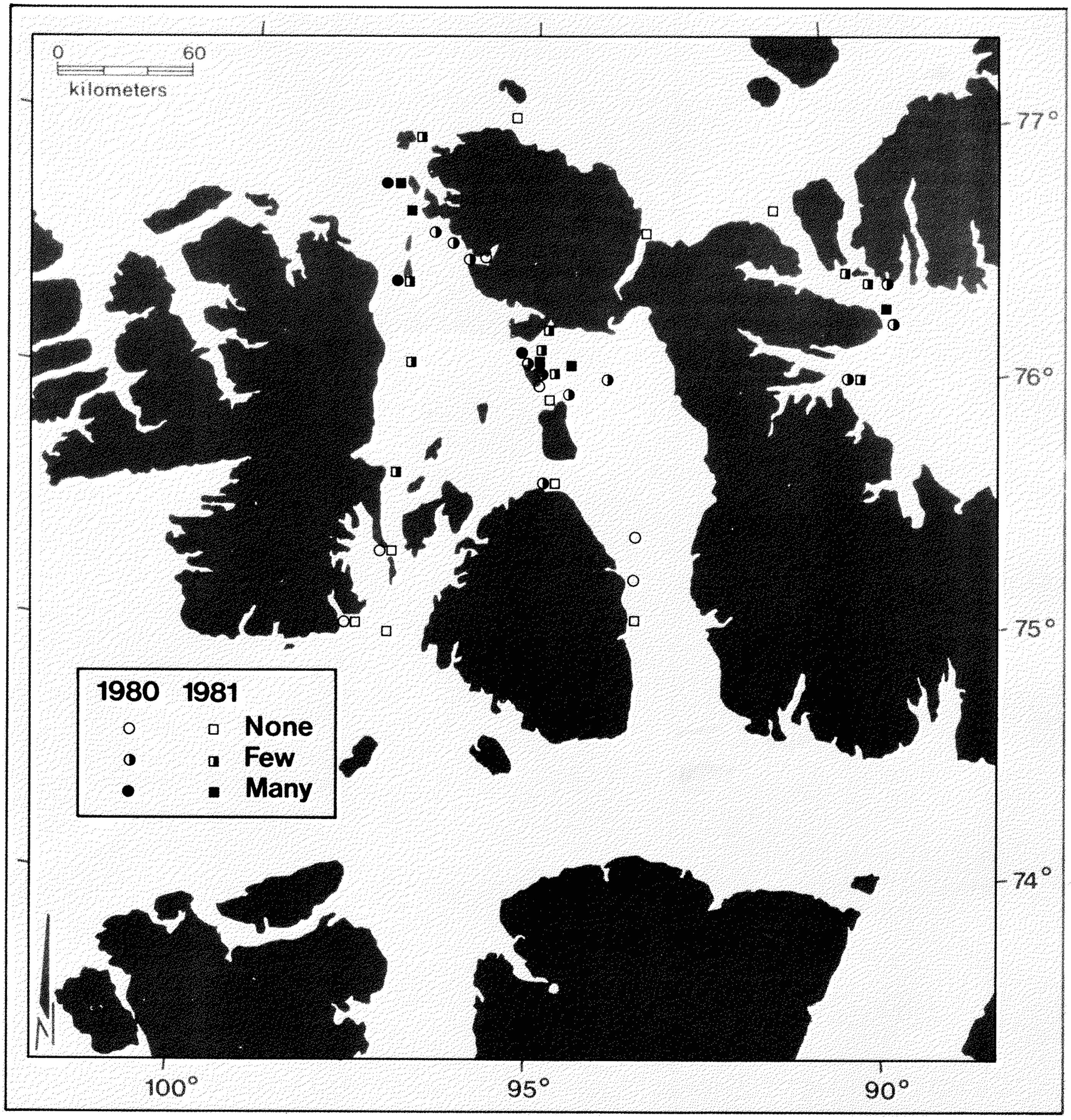

FIG. 7. Abundance of walrus vocalizations in spring 1980 and 1981 at recording sites in the High Arctic.

the southwest coast of Devon Island, near the islands in northwestern Barrow Strait, along the southern and southwestern coasts of Bathurst Island, McDougall Sound and Crozier Strait, Queens Channel and Penny Strait, north of the Grinnell Peninsula, and in Fram Sound (Fig. 6). These locations are shallow and tend to break up earlier than adjacent areas; some areas, such as Fram Sound, Penny Strait, and Queens Channel, have recurring polynyas as well (Smith and Rigby, 1981), which shorten the period of ice cover in those areas, making them more suitable for bearded seals.

Bearded seal vocalizations were not heard in late April in Wellington Channel nor in late March in southern to mid-Barrow Strait (Fig. 6). These areas are characterized by deep water and later breakup than locations where bearded seal calls were heard, probably indicating that few bearded seals winter there.

After the beginning of breakup in late spring and early summer, bearded seals have more freedom of movement and their distribution may be more extensive. However, sightings of bearded seals made during aerial surveys conducted in late spring and early summer (Finley, 1976; Kingsley *et al.*, 1982), and unpublished observations made during eight years of polar bear surveys in the High Arctic, show bearded seals most often occur in the general areas listed above.

Overall, bearded seals are not abundant in the High Arctic, at least in comparison to ringed seals (Kingsley *et al.*, 1982). The absence of bearded seal calls from large areas also suggests their winter distribution is localized.

Walruses. Our results suggest that, during winter, the distribution of walruses in the High Arctic is restricted to the general areas of Cardigan Strait-Fram Sound and Penny Strait-Queens Channel (Fig. 7). Within those general areas, the greatest numbers of sub-ice vocalizations were recorded at Pioneer Channel and northeastern Penny Strait. Since the polynyas there are near shallow feeding areas, they are the most important wintering sites for walruses. In general, the abundance was lower and more variable between years in western Penny Strait, Queens Channel south of Dundas Island, and in Fram Sound. We recorded at four sites along the northern coast of the Grinnell Peninsula and northwestern Devon Island in spring of 1981 (Fig. 1, sites 44, 68, 79, and 80), but heard walruses only east of Crescent Island (Fig. 1, site 44). The calls were distant, and probably came from Penny Strait. In 1981 at least, the walrus populations of Fram Sound and Penny Strait seemed to be geographically isolated during the winter. The data on the relative abundance of walruses, based on sub-ice recordings, are in general agreement with the data available from aerial surveys and anecdotal reports (Bissett, 1967; Davis *et al.*, 1978; Kiliaan and Stirling, 1978; Stirling *et al.*, 1981).

No walruses were heard in Wellington Channel (Fig. 1, sites 29, 31, 81) or McDougall Sound (Fig. 1, site 70) in either year. Distant vocalizations were heard in 1981 at Black Point at the northern end of Crozier Strait (Fig. 1, site 60). In summer, Crozier Strait is an important feeding area for walruses (Davis *et al.*, 1978). The water is shallow and the ice in areas such as Brooman Point (Fig. 1, site 25) is only ~1 m thick in April, so it is one of the first areas to open. However, it appears that few, if any, walruses winter there.

The numbers and distribution of walruses wintering in the Fram Sound area varied more than we expected, considering the extent and reliability of open water there. Kiliaan and Stirling (1978) reported 100 walruses in May 1972 and Davis *et al.* (1978) counted 48 on 19 April 1977. Underwater recordings in April 1980 and 1981 suggested that few walruses were present. On 17 and 21 April 1981 we saw 0 and 30 respectively. The 30 walruses seen on 21 April were widely distributed in small numbers from eastern Fram Sound to southern Cardigan Strait, suggesting, like the vocalization data, that they were not concentrated.

From late March to early May, walruses seem to prefer to haul out in the afternoon on calm clear days. Even so, the number hauled out can be quiet variable. For example, during four weeks of day-long observations at the Dundas polynya in April 1981, the number of walruses hauled out varied from <5 to >50 on apparently similar days. From the air, on 28 March, 29 March, and 9 April 1981, we counted 5, 1, and 2 walruses respectively, even though it became apparent from our ground-based daily observations that there were at least 60 individuals present. Even from these few data, the potential for large errors in aerial surveys of walruses in late winter and early spring is obvious. While counts of walruses hauled up on the ice are certainly useful, we think it is essential to include sub-ice recordings when trying to assess the winter distribution and relative abundance of this species.

CONCLUSIONS

Underwater recordings give information on wintering pinnipeds in the Arctic which cannot be obtained using other techniques. Because we can identify most vocalizations, we can confirm the presence of a species. At present, we cannot state that the absence of underwater vocalizations confirms the absence of a species.

Our results indicate that there are seasonal and daily variations in vocalization rates, that there is geographic variation in vocalizations, and that bearded seal calls may be recorded up to 45 km from the source. The vocalization rates appear to give a measure of relative abundance.

We believe that underwater vocalizations have the potential to give more precise information on the relative abundance of wintering pinnipeds and may eventually be usable for censusing. However, in order to approach this goal, specific research is required on each species to determine: diel, between-day, and seasonal patterns of vocalizing in order to determine the optimum recording times; the length of the recording period required to obtain a representative sample; the age, sex, and social status of calling individuals; variability in vocalization rates and repertoires of individuals; how far from the source vocalizations can be recorded; and how much pinnipeds move underneath the ice during the winter. We recognize the difficulty of conducting such research and recommend that all opportunities be taken to relate data obtained through recordings with direct observations on pinnipeds.

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REFERENCES

BISSETT, D. 1967. Resolute. An Area Economic Survey. A.E.S.R. 66/4. Ottawa: Department of Indian Affairs and North Development. 175 p.

BURNS, J.J. 1967. The Pacific bearded seal. Federal Aid in Wildlife Restoration Project Covering Investigations completed by 31 December 1966. 3:1-66.

______ and FROST, K.J. 1979. The natural history and ecology of the bearded seal, *Erignathus barbatus*. Final Report RU 230. Boulder, CO: Outer Continental Shelf Assessment Program. 77 p.

CARC (Canadian Arctic Resources Committee). 1980. Marine traffic forecast, Northwest Passage. Appendix to CARC submission to EARP review of the Arctic Pilot Project. April 1980. Ottawa. 71 p.

CHAPSKII, K.K. 1938. The bearded seal (*Erignathus barbatus* Fabr.) of the Kara and Barents Seas. Translation from Arkticheskii Institut. Leningrad. Trudy. 123:7-79. (Canadian Fisheries and Marine Service Translations Series 3162, M. 145 p.)

DAVIS, R.A., KOSKI, W.R. and FINLEY, K.J. 1978. Numbers and distribution of walruses in the central Canadian High Arctic. Report by LGL Limited. Toronto: Polar Gas Project. 50 p.

DUBROVSKII, A.N. 1937. On the nuptial cry of the bearded seal *Erignathus barbatus*. Leningrad: Priroda No. 4: 124 p. (Canadian Wildlife Service Translation, 1973).

FAY, F.H. 1982. Ecology and biology of the Pacific walrus, *Odobenus rosmarus divergens* Illiger. North American Fauna No. 74. 279 p.

______ and RAY, G.C. 1979. Reproductive behavior of the Pacific walrus in relation to population structure. In: Melteff, B.R. (ed.). Alaska Fisheries: 200 Years and 200 Miles of Change. Proceedings of the 29th Alaska Science Conference, 1978. Fairbanks, AK: Sea Grant Program, University of Alaska. 409-410.

FINLEY, K.J. 1976. Studies of the status of marine mammals in the central District of Franklin, N.W.T. June-August, 1975. Report by LGL Limited. Toronto: Polar Gas Project. 183 p.

______. 1979. Haul-out behaviour and densities of ringed seals *Phoca hispida* in the Barrow Strait area, N.W.T. Canadian Journal of Zoology 57:1985-1997.

KAUFMAN, G.W., SINIFF, D.B. and REICHLE, R.A. 1975. Colony behaviour of Weddell seals, *Leptonychotes weddelli*, at Hutton Cliffs, Antarctica. In: Ronald, K. and Mansfield, A.W. (eds.). Biology of the Seal. Charlottenlund Slot, Denmark: Rapports et Procés-Verbaux des Reunions. Conseil International Pour l'Exploration de la Mer. 169:228-246.

KILIAAN, H.P.L. and I. STIRLING. 1978. Observations on wintering walruses in the eastern Canadian High Arctic. Journal of Mammalogy 59:197-200.

KINGSLEY, M.C.S., STIRLING, I. and CALVERT, W. 1982. The distribution and abundance of seals in the high Arctic, 1980-1981. Report prepared for the Arctic Islands Operating Advisory Committee, Department of Indian and Northern Affairs, and Department of Fisheries and Oceans. Edmonton: Canadian Wildlife Service. 68 p.

LeBOEUF, B.J. and PETRINOVICH, L.F. 1975. Elephant seal dialects: are they reliable? In: Ronald, K. and Mansfield, A.W. (eds.). Biology of the Seal. Charlottenlund Slot, Denmark: Rapports et Procés-Verbaux des Reunions. Conseil International pour l'Exploration de la Mer. 169:213-218.

McLAREN, I.A. 1958. The biology of the ringed seal (*Phoca hispida*) in the eastern Canadian Arctic. Journal of the Fisheries Research Board of Canada Bulletin 118. 97 p.

MOT. 1981. Arctic Marine Services Policy. Discussion paper by Ministry of Transport. Ottawa. 32 p.

PASTUKOV, V.D. 1965. A contribution to the methodology of counting Baikal seals. In: Pavlovskii, E.N., Zenkovich, B.A., Kleunenbery, S.E. and Chapskii, K.K. (eds.). Moscow: Morski Mlekopiaiushchie, Nauka. 100-104. (Fisheries Research Board of Canada Translation Series No. 3408).

RAY, C., WATKINS, W.A. and BURNS, J. 1969. The underwater song of *Erignathus* (Bearded seal). Zoologica 54:79-83.

RAY, G.C. 1970. Population ecology of Antarctic seals. In: Holdgate, M.W. (ed.). Antarctic Ecology. New York: Academic Press. 398-414.

______ and WATKINS, W.A. 1975. Social function of underwater sounds in the walrus *Odobenus rosmarus*. In: Ronald, K. and Mansfield, A.W. (eds.). Biology of the Seal. Charlottenlund Slot, Denmark: Rapports et Procés-Verbaux des Reunions. Conseil International pour l'Exploration de la Mer. 169:524-526.

SCHEVILL, W.E., WATKINS, W.A. and RAY, C. 1966. Analysis of underwater *Odobenus* calls with remarks on the development and function of the pharyngeal pouches. Zoologica 51:103-105.

SMITH, M. and RIGBY, B. 1981. Distribution of polynyas in the Canadian Arctic. In: Stirling, I. and Cleator, H. (eds.). Polynyas in the Canadian Arctic. Ottawa: Canadian Wildlife Service Occasional Paper No. 45:7-28.

SMITH, T.G. and HAMMILL, M.O. 1981. The ecology of the ringed seal in its fast ice breeding habitat. Canadian Journal of Zoology 59:966-981.

SMITH, T.G., HAY, K., TAYLOR, D. and GREENDALE, R. 1978. Ringed seal breeding habitat in Viscount Melville Sound, Barrow Strait and Peel Sound. Final Report to Arctic Islands Pipeline Project. Ottawa: Department of Environment ESCOM Report No. A1-22. 85 p.

SMITH, T.G. and STIRLING, I. 1975. The breeding habitat of the ringed seal (*Phoca hispida*): the birth lair and associated structures. Canadian Journal of Zoology 53:1297-1305.

______. 1978. Variation in the density of ringed seal (*Phoca hispida*) birth lairs in the Amundsen Gulf, Northwest Territories. Canadian Journal of Zoology 56:1066-1070.

STIRLING, I. 1973. Vocalization in the ringed seal (*Phoca hispida*). Journal of the Fisheries Research Board of Canada 30:1592-1594.

______. 1977. Adaptations of Weddell and ringed seals to exploit polar fast ice habitat in the presence or absence of land predators. In: Llano, G.A. (ed.). Adaptations Within Antarctic Ecosystems. Proceedings of the Third Symposium on Antarctic Biology. Houston, TX: Gulf Publishing Co. 741-748.

______, CLEATOR, H. and SMITH, T.G. 1981. Marine mammals. In: Stirling, I. and Cleator, H. (eds.). Polynyas in the Canadian Arctic. Ottawa: Canadian Wildlife Service Occasional Paper No. 45:45-48.

STIRLING, I. and SINIFF, D.B. 1979. Underwater vocalizations of leopard seals (*Hydrurga leponyx*) and crabeater seals (*Lobodon carcinophagus*) near the South Shetland Islands, Antarctica. Canadian Journal of Zoology 57:1244-1248.

STIRLING, I. and SMITH, T.G. 1977. Interrelationships of Arctic Ocean mammals in the sea ice habitat. Section II. In: Circumpolar Conference on Northern Ecology. Ottawa: National Research Council. 129-136.

THOMAS, J.A. and DeMASTER, D.P. 1982. An acoustic technique for determining diurnal activities in leopard *(Hydrurga leptonyx)* and crabeater *(Lobodon carcinophagus)* seals. Canadian Journal of Zoology 60:2028-2031.

WINN, H.E., EDEL, R.K. and TARUSKI, A.G. 1975. Population estimate of the humpback whale *Megaptera novaeangliae* in the West Indies by visual and acoustic techniques. Journal of the Fisheries Research Board of Canada 32:499-506.