UNDERWATER VOCALIZATIONS OF WINTERING PINNIPEDS IN THE HIGH ARCTIC

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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

Underwater vocalizations as a tool for studying the distribution and relative abundance of pinnipeds in the high Arctic

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. This was done to evaluate the potential for using sub-ice vocalizations as a tool for studying the distribution and relative abundance of wintering pinnipeds in the High Arctic. We were able to identify many of the calls made by these 3 species and an initial lexicon is presented. Several preliminary results are discussed. 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 werein late June Vocalization rates of all 3 species were indicative of their distribution and relative abundance in different areas and sea ice habitat types. Recommendations are made of points to be considered if the subject is researched further.

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 1970's, several large-scale industrial proposals were made which would require large specially-constructed ice breaking ships to pass through the Parry Channel and adjoining waterbodies in all seasons. 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 and the Parry Channel en route to an east coast destination as well. Other possibilities include several mines, a methanol plant, ships from Alaska or Japan, an interisland pipeline and extensive shipping just to provide logistic support. On the basis of independent estimates, there may be 900 to 1,000 passages of ships through High Arctic waterways by the turn of the century (CARC 1980; MOT 1981).

If approved, several of these projects may have ships pass through the same areas during the winter, creating the possibility of disturbance and pollution which might have detrimental effects on seals or walruses resident there. During the open water period, these animals could probably avoid disturbance simply by swimming away. During the winter, though, movements of seals and walruses are restricted because they have to either maintain their own breathing holes or use recurring polynyas where currents, wind, or tide keep the sea from freezing. The distribution of the best wintering habitat for each species is fairly localized and so seals are more concentrated there. In addition, seals and walruses tend to mate and give birth to their young in the wintering areas, making them even more important.

There is considerable potential for conflict between ships and pinnipeds during the winter because some of their preferred habitat lies in areas of thinner annual ice, along shoreleads or in recurring polynyas. Some of these areas might be preferred routes for ships because of easier, more economical, and possibly safer passage. 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 short days or continuous 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 in stable annual ice areas, over moderate water depths, in areas where the ice is sufficiently rough to collect snow drifts (McLaren 1958; Smith and Stirling (1975). The seals appear to establish their 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. The best pupping areas are not distributed evenly over the whole area but , on the basis of the data available, appear to be fairly localized. In addition, the distribution and productivity of the most favorable pupping areas appear to vary a certain amount between years (Smith and Stirling 1975, 1978; Smith *et al.* 1978; Stirling and Smith unpublished data). 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 ice is smooth and the low precipitation does not provide sufficient snow cover to form drifts large enough for the construction of birth lairs (Stirling *et al.* 1981; Stirling and Smith, unpublished data). 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 interisland channels. The most productive areas located to date for ringed seals have been in Barrow Strait (Smith *et al.* 1978).

We have undertaken two kinds of studies to evaluate the distribution and abundance of ringed seals in the High Arctic (Fig. 1).

a. Aerial surveys: Aerial surveys of ringed seals are flown in late spring just prior to break-up. The surveys are intended to coincide with the time of day and season when the maximum number are hauled out on the sea ice. Even so, there is no way to

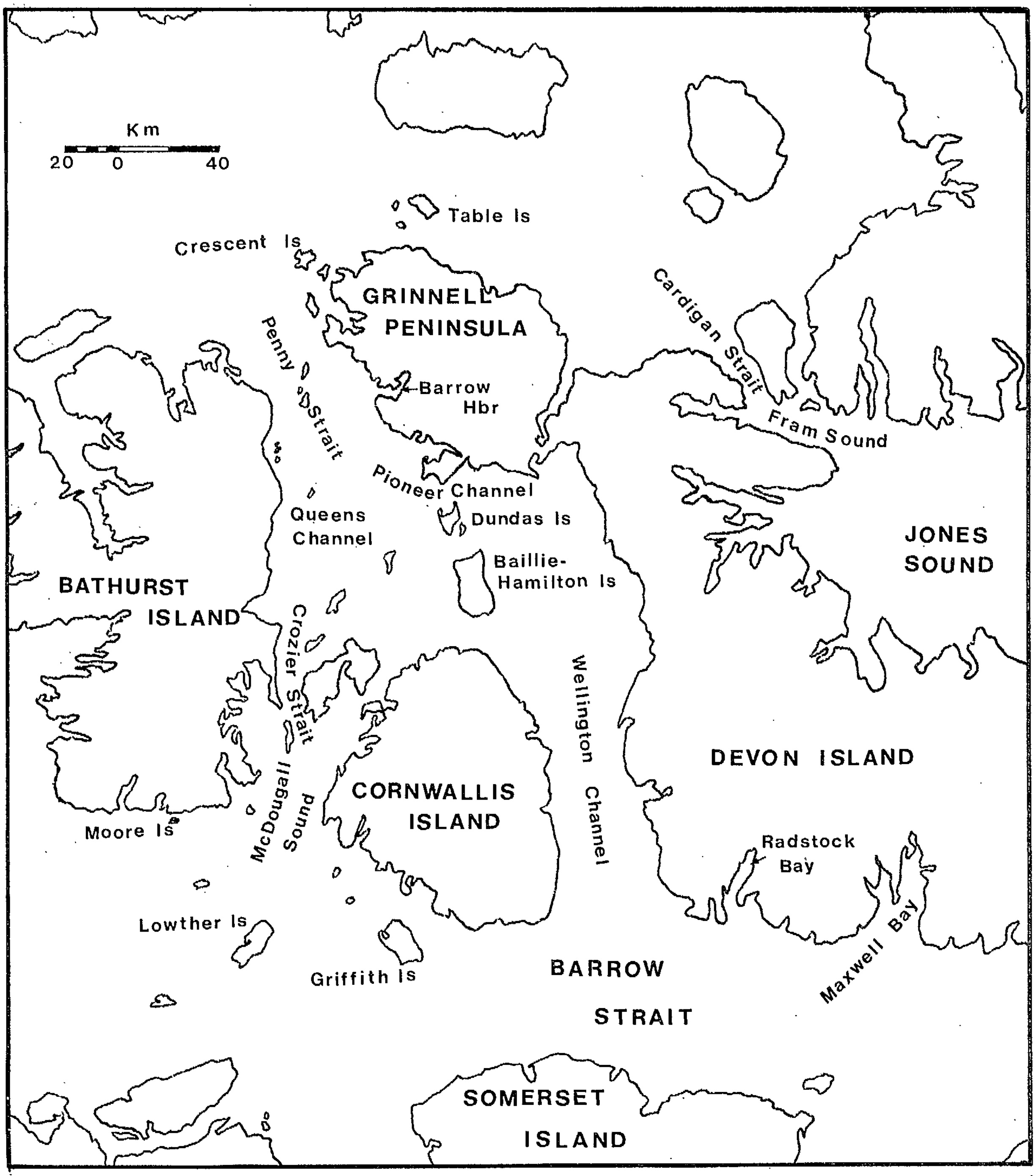

Figure 1. Map of the study area

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 the surveys prior to break-up is that the results will also be more representative of winter distribution. No one has yet evaluated whether that assumption is correct. The most extensive aerial surveys of ringed seals ever done 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.

b. 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 labor-intensive and dogs do not work well in extreme cold. There are few trained dogs and handlers available, and they 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 warmth of the sun causes the roofs of the lairs to cave in, he counted lairs on transects through areas suspected to be productive. In areas such as southeastern Baffin Island, rain in the late spring causes the roofs of birth lairs to cave in, making them easy to see. No attempts have been made to apply this technique in the Canadian Arctic.

<u>Bearded seals</u>

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 in recurring polynyas and in shallow water areas along coastlines, which open up early. In these latter areas they maintain their own breathing holes by abrading the ice with the heavy claws of the foreflippers. Their young are born directly onto the surface of the ice in May. 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 feces on the ice, often around multiyear 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 the 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. It seemed to us that recording sub-ice vocalizations was a technique that had potential for application over wide areas by personnel with less specialized knowledge and experience. The data are collected in a more independent form which can be analyzed, copied, or re-analyzed any number of times by different individuals if desired. Thus, the main objectives of this report are: to summarize the data we have gathered to date on underwater vocalizations; to evaluate the potential of this technique for studying the distribution and abundance of wintering pinnipeds in the High Arctic; and, to make recommendations about future research on this subject.

METHODS

From 1972 through 1979, sub-ice recordings of pinnipeds were made at various locations in the Western and 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 and times at which we chose to record (Fig. 2) in order to examine pinniped distribution and habitat selection. Appendix I summarizes the dates and locations where we made the recordings analysed in this study.

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 a model 6050C hydrophone (International Transducer Corporation). A series of simultaneous recordings were made with the two models of hydrophone to compare their efficacy.

Sound spectrographs were made on a Kay Sona-Graph 7029A set on high shape and using a narrow band (45 cps) filter.

We reached the recording location in a Bell 206 Jet Ranger helicopter, landed, idled for 2 to 3 minutes to allow the engine to cool sufficiently, and then shut down. The hydrophone was lowered through a seal hole or lead if one was available. Otherwise, we drilled a 10 cm hole with a hand auger.

Recordings were usually made between 09:00 and 18:00 local standard time. A duration of 10 minutes was chosen based on our subjective impression that this was long enough to evaluate the amount and type of vocalizing taking place. Tapes were listened to in the laboratory and all the vocalizations catalogued to type and location on the tape. The vocalization rate for ringed and bearded seals was measured as the number of calls heard per minute. We have not yet developed a way to quantify data from our recordings of walruses.

In order to improve the reliability of our lexicon, recordings were made in locations where, to the best of our knowledge at least, only one species would be present and likely to vocalize. In most circumstances, we could not see the animals calling so we could draw no conclusions about

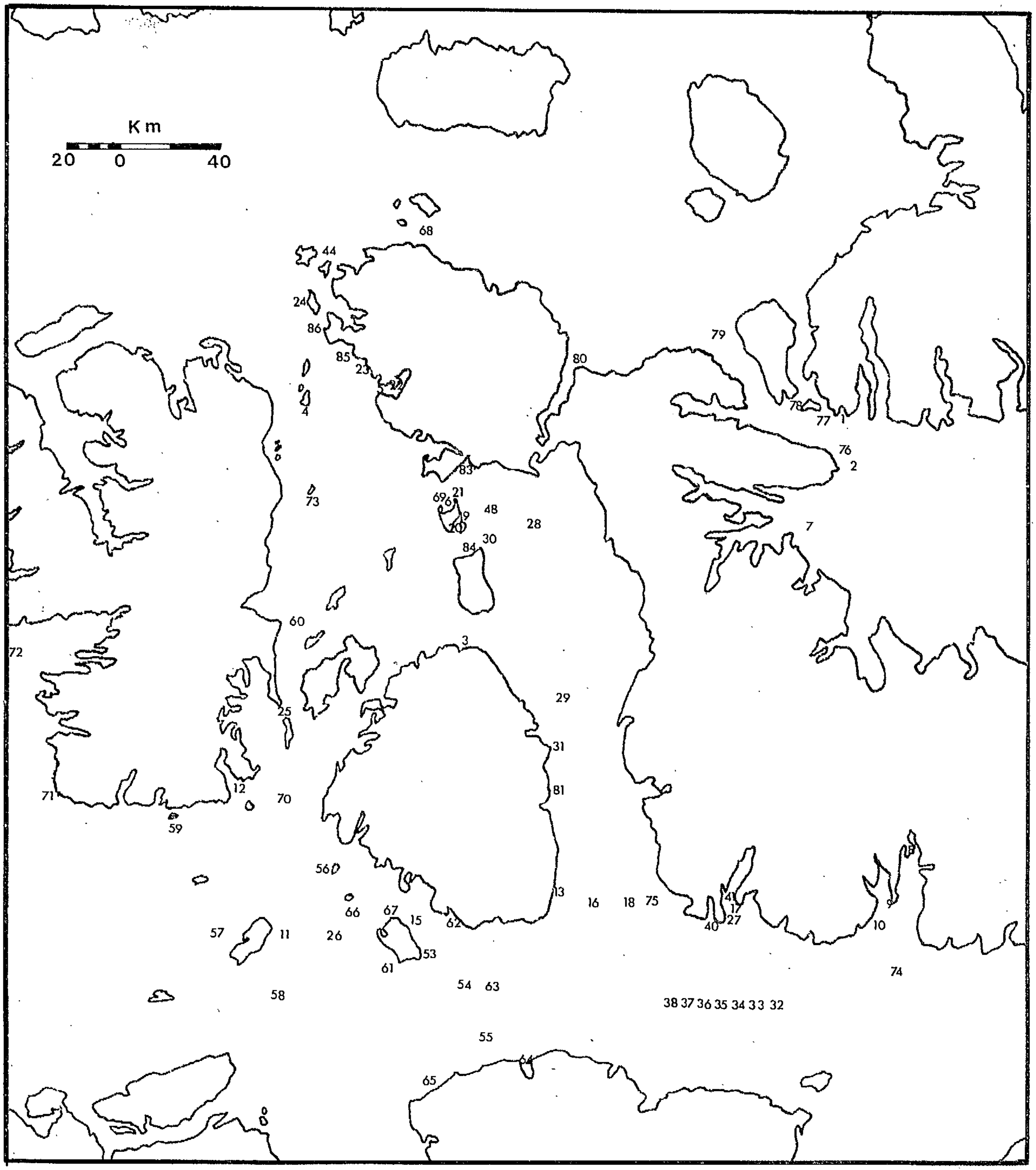

Figure 2. Sites where sub-ice recordings were made in the study area

the function of the calls. However, in 1980 we established a camp at Cape Collins on the northeastern tip of Dundas Island (Fig. 2, site 21) from which to observe polar bears and pinnipeds around the Dundas polynya in Pioneer Channel. In April and early May 1981, we watched individual walruses while they were vocalizing and correlated their behavior with some of the calls.

To evaluate seasonal changes in vocalizations of ringed and bearded seals, we recorded at some locations on different dates through the season.

In late June 1981, 2 sets of serial recordings were made in a preliminary attempt to determine if there is a diel cycle in bearded seal vocalizations. Both trials extended over a period of 33 hours with 10 minute recordings made every 2 hours in one set of recordings and every 3 hours in the other. The first trial was conducted on 23–24 June in Dundas polynya. The second trial was conducted two days later approximately 24 km north of the first site in the landfast ice at the mouth of Inglis Bay. (Similar trials were planned for ringed seals but the equipment malfunctioned.) A t–test (Satterwaite's (1946) approximation) was used to compare the mean number of vocalizationss per minute at each site. Difference between the variance in the daily samples were tested using an F–test. Because sample sizes were small, both tests were made at the 5% level.

To determine the patterns of distribution and abundance of a pinniped from its underwater vocalizations, it is necessary to ascertain the distance to which their calls can be heard. However, it is not possible in the field to record within a metre of an individual animal in order to obtain the intensity of a call and extrapolate based on that value. 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 between Cape Liddon (Fig. 2, site 27) and Prince Leopold Island off the northeast corner of Somerset Island. Open water lay to the east. If bearded seals remained where there was open water, then by moving away from the ice, we should gain an approximation of how far the calls travel. Seven 10 minute recordings were made at 8 km intervals beginning at the ice edge and moving westward across the fast ice (Fig. 2, sites 32–38).

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 one end of the scale, low ice ridges or hummocks in stable ice areas with long deep drifts are good for birth lairs while smooth ice with little snow cover or very rough broken areas are not (Smith and Stirling 1975). Upon arrival at each area by helicopter, we evaluated its suitability as ringed seal birth lair habitat on an ascending scale from I to 5 and landed at a spot which appeared representative.

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 a way of quantifying these recordings as we have with ringed and bearded seals. Consequently, at present we can give only a subjective evaluation of the amount of walrus vocalizing at each station with general categories:

a. none heard;
b. present but not abundant, if calls were heard but there was little or no overlapping; and,
c. abundant if calls of different walruses were constantly overlapping each other.

RESULTS AND DISCUSSION

Factors affecting recording quality

The quality of underwater recordings of vocalizations is affected by the type of equipment used as well as 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 between 8 and 12 km/h, the ratio of bearded seal

Table 1. Comparison of the efficacy of the LC–50 and 6050C hydrophones during simultaneous recordings.

Location (site no.)	Weather Conditions	Percent of vocalizations heard on LC–50 compared to 6050C	
		Ringed Seal	Bearded Seal
2 km S of Moore Is (59)	calm, −15°C	40% (34/84)	80% (88/100)
5 km E of Lowther Is (11)	wind, 19 km/h from N, −15°C	10% (19/183)	–
2 km E of Cheyne Pt SE Griffith Is (53)	wind, 12 km/h from N, −13°C	17% (75/441)	–
15 km E of Cape Hotham, Cornwallis Is (16)	wind, 19 km/h from N, −10°C	12% (17/137)	–
3 km E of Cape Majendie (83)	wind, 8 km/h from NE, 7°C	–	64% (43/67)
mouth of Barrow Harbour (5)	wind, 12 km/h from NE, 8°C	–	84% (16/19)

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 between 12 and 19 km/h. These results reflect the need for using caution when comparing total numbers of vocalizations recorded using different equipment. Recordings discussed in this report were made with the 6050C hydrophone.

The quality of underwater recordings is also influenced by the amount of ambient noise from environmental factors such as surface wind, and movement of ice and water. Water movement may result from currents and tides. Like wind, ice and water movements have a marked effect on the ability to record vocalizations clearly. Both sources of ambient noise tend to mask vocalizations. Ice movement in particular makes it difficult to identify ringed seal calls. Based on our experience, we suggest that when possible, underwater recordings should be made under the following conditions:

a. when wind speeds are 8 km/h or less;
b. away from sites where local currents interact with ice edges or where surface melt-water is draining through the sea ice;
c. during slack tide in areas where tides are strong; and
d. at times or sites where ice movement is limited.

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 although there are some interesting variations. In the following sections, we describe the vocalizations we recorded from each species in the Canadian High Arctic.

Ringed seals

High- and low-pitched barks, yelps, 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 overlapping, or follow each other in rapid succession, so that the audile effect is sometimes that of a continuum rather than of clear, discrete sounds. Consequently, these vocalizations are often 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.

The most common calls were yelps and barks, previously described by Stirling (1973). We will also describe some additional calls and variations. Yelps are usually high-pitched and, together with barks, make up the overwhelming bulk of sub-ice vocalizations heard. Figure 3a shows a sonagram of 2 typical high-pitched yelps. Also included in this category are very distinctive high-pitched nasal yelps or screams (Figures 4a,b) which have numerous harmonics associated with the fundamental. All of these high-pitched sounds range in frequency from about 500 to 1100 Hz.

The other predominant category of vocalizations -barks-are generally moderate to low in frequency and shorter in duration than yelps. Figure 3b contains a sequence of 3 moderate-pitched barks followed by a low-pitched growl and then 5 more moderate-pitched barks. Unlike yelps, which consist of a relatively narrow band fundamental with distinct, widely-separated harmonics, barks comprise more continuous bands of frequencies. The width of this band can vary greatly between barks; in Figure 3b several of the barks have a frequency bandwidth of about 400 Hz while in Figure 3c, 2 of the 3 barks have a bandwidth of about 1500 Hz. Frequently, a series of low-pitched barks in rapid succession are interspersed with high-pitched yelps as shown in Figure 3c. (This sonagram permits a visual comparison between the 2 types of vocalizations.) The barks in this sequence average just less than 1/5 s in duration while the yelps range, approximately, from just over 1/5 to 2/3 s. The broad band of frequencies contained within these barks extends between about 1300 and 1550 Hz, while in the yelps the frequency bandwidth averages about 480 Hz from between 700 and 1300 Hz.

We have named calls at the midpoint of the continuum between yelps and barks as bark-yelps. These sounds contain the audile and sound spectrograph characteristics of both barks and yelps. Figure 3d contains 8 bark-yelps; the first 5 are moderate in pitch while the latter 3 are low. Bark-yelps are heard throughout the usual frequency range of vocalizations given by ringed seals (<2000 Hz). The first portion of the bark-yelp contains an indistinct broad band of

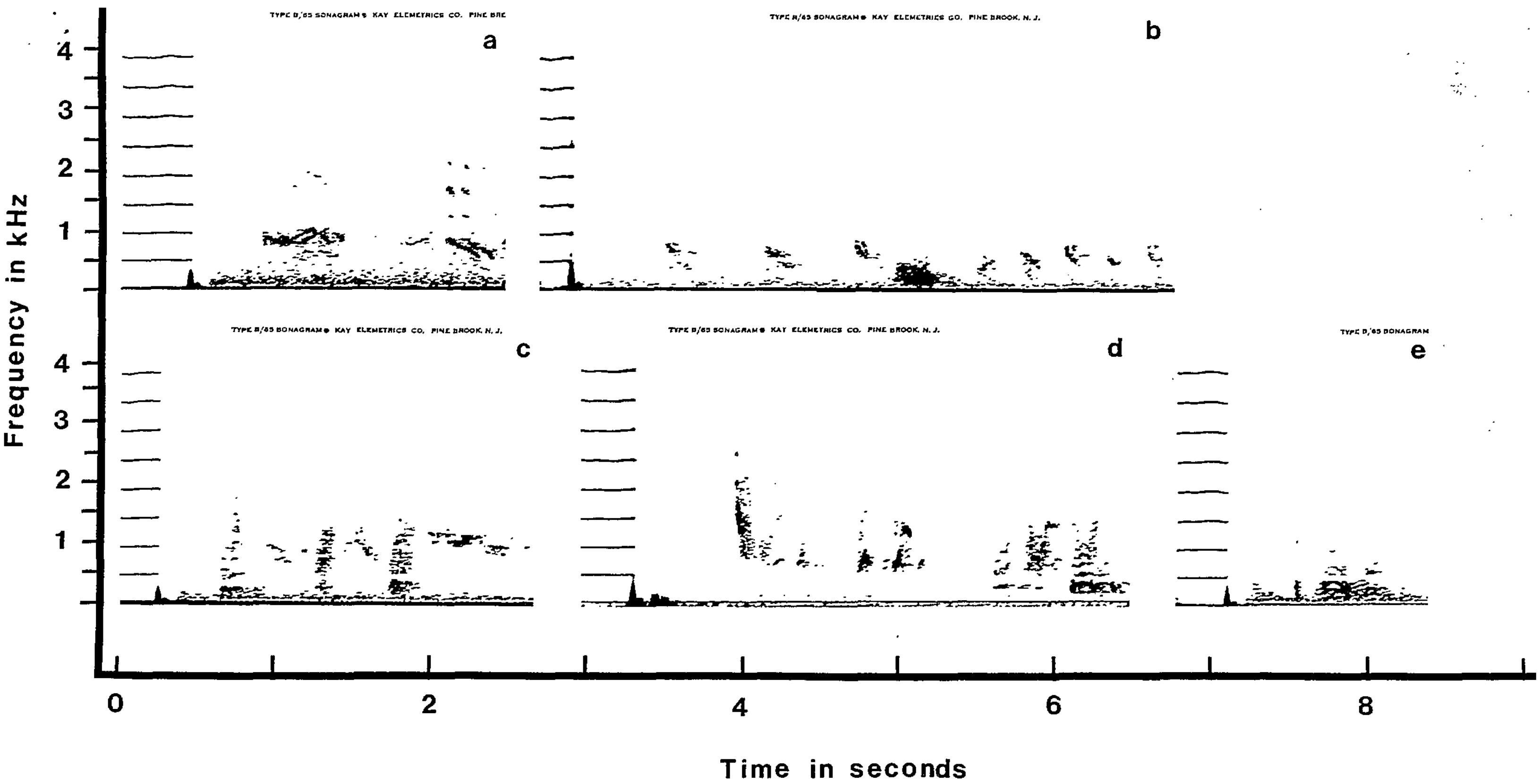

Figure 3. Sonagrams of ringed seal vocalizations:
a. two high–pitched yelps;
b. three moderate–pitched barks followed by a low–pitched growl and 5 more moderate–pitched barks;
c. three low–pitched barks interspersed with 3 high–pitched yelps;
d. five moderate–pitched bark–yelp vocalizations followed by 3 low–pitched bark–yelp vocalizations;
e. low–pitched woof.

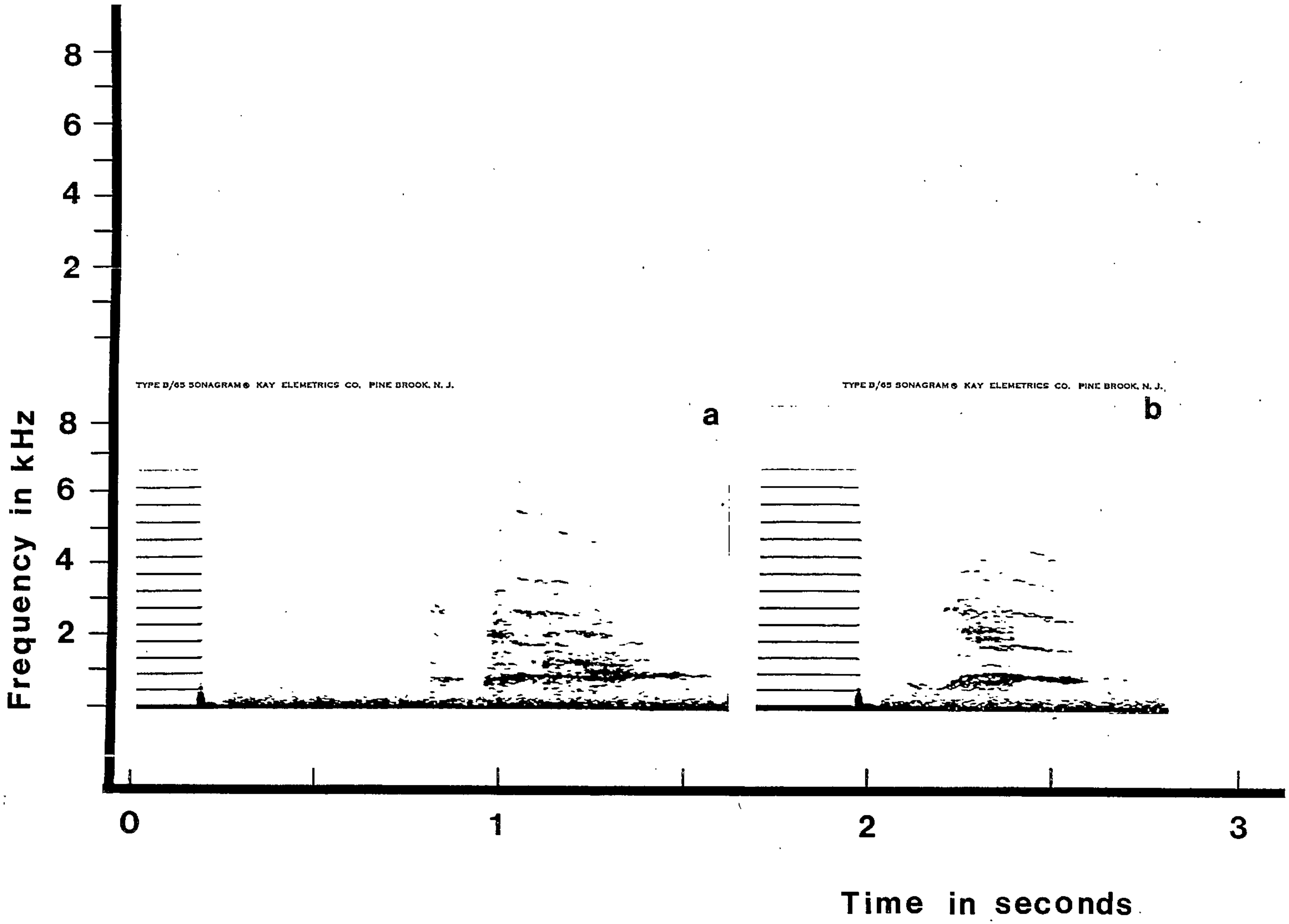

Figure 4. Sonagrams of ringed seal vocalizations:
a. and b. representative examples of high-pitched yelps.

frequencies characteristic of barks. In the latter portion of the vocalization, the fundamental tends to be narrow and longer in duration, like a typical yelp. Because bark–yelps represent the middle of a continuum, there is variability in their structure as illustrated by Figure 3d.

A woof (Fig. 3e) sounds like a bark but is lower pitched and lacks the higher pitched harmonics.

We have tentatively identified 3 other vocalizations: chirps, grunts, and growls. Chirps are high–pitched while grunts and growls, like barks, tend to be moderate to low– pitched. Grunts are relatively common whereas growls and chirps are less frequent. Figure 3b illustrates a low–pitched growl in a series of moderate–pitched barks. The growl consisted of a broad band of frequencies (approximately 900 Hz in width) extending from about 50 to 950 Hz and lasting just over 1/5 s. In contrast, the mid–points of barks in this sequence range from about 500 to 850 Hz with an average bandwidth about 350 Hz, and last between just less than 1/10 s to 1/4 s. No sonagrams of chirps or grunts were suitable for reproduction.

Bearded seals

During the late winter and spring, bearded seals have been reported to produce a distinct song often referred to as a trill (Dubrovskii 1937; Chapskii 1938; Burns 1967; Ray *et al.* 1969). In the Canadian High Arctic, their loud, distinctive songs are heard as early in the year as the last week of March. We do not know how much earlier in the season they may begin calling.

Ray *et al.* (1969) first described the song of the bearded seal as a "long oscillating frequency–modulated warble that may be more than a minute in duration, followed by a short unmodulated low–frequency moan." As our analysis did not reveal a low–frequency moan, the following discussion will be limited to the frequency–modulated warbles or trills. Figures 5a–c illustrate the characteristic pattern of 3 descending trills, as well as an indication of the types of differences between calls. This diversity includes differences in: a. the maximum and minumum frequency of the fundamental; b. slope; c. degree of modulation; d. presence or absence of harmonics; e. duration of the vocalization; and f. dialect. Each of these aspects will be discussed briefly below.

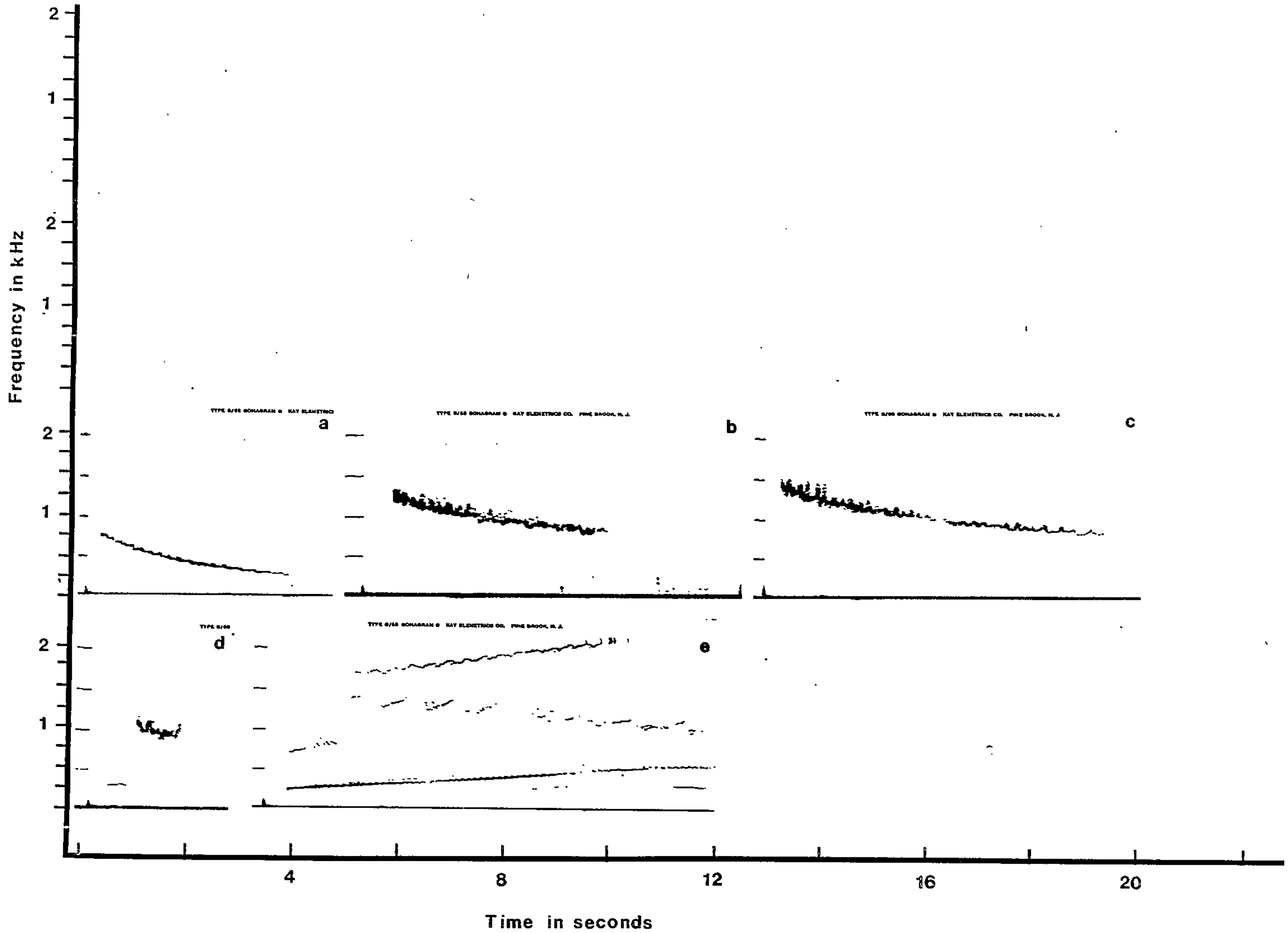

Figure 5. Sonagrams of bearded seal vocalizations:
a., b., and c. typical examples of descending trills;
d. short descending trill;
e. two ascending trills and one descending trill recorded in the Western Arctic.

a. Maximum and minimum frequency of the fundamental

Figure 6a shows a 2 s segment of a 17 s descending trill in which the maximum frequency attained in the fundamental is 6000 Hz. The peak frequency occurred approximately 3.5 s after the trill began, unlike most descending trills which begin with the highest frequency. The trill shown in Figure 5a shows the more typical pattern although the maximum frequency for this vocalization is about 750 Hz. The minimum frequency of the fundamental also varies from one trill to another as is readily seen between Figure 5a (min. frequency approximately 500 Hz) and Figure 6b (min. frequency approximately 2000 Hz).

b. Slope

The slope refers to the rate of rise (in ascending trills) or fall (in descending trill) in frequency of the trill over time. The trill illustrated in Figure 7a, for example, initially shows a precipitous descent in frequency after which the subsequent decline is very gradual. Figure 7b, on the other hand, contains 3 segments taken from a sonogram of a typical bearded seal showing a gradual decline in frequency throughout the vocalization.

c. Modulation

The degree of modulation may vary greatly between trills. For example, the maximum extent of modulation exhibited in the trill shown in Figure 5a is about 50 Hz, while in Figure 6a the maximum modulation of the fundamental is about 2500 Hz. Rythmicity of the modulation may also differ noticeably between trills. Figures 7c–e show segments taken from several trills recorded at one site in which the rhythm of modulation was not only very regular, but also more drawn out.

d. Presence or absence of harmonics

Many sonagrams of trills reveal harmonics associated with the trill fundamental. These may vary in intensity and duration both between trills and within one trill if more than one is present. Although it did not reproduce well, Figure 7f is a nice example of harmonic differences within one trill.

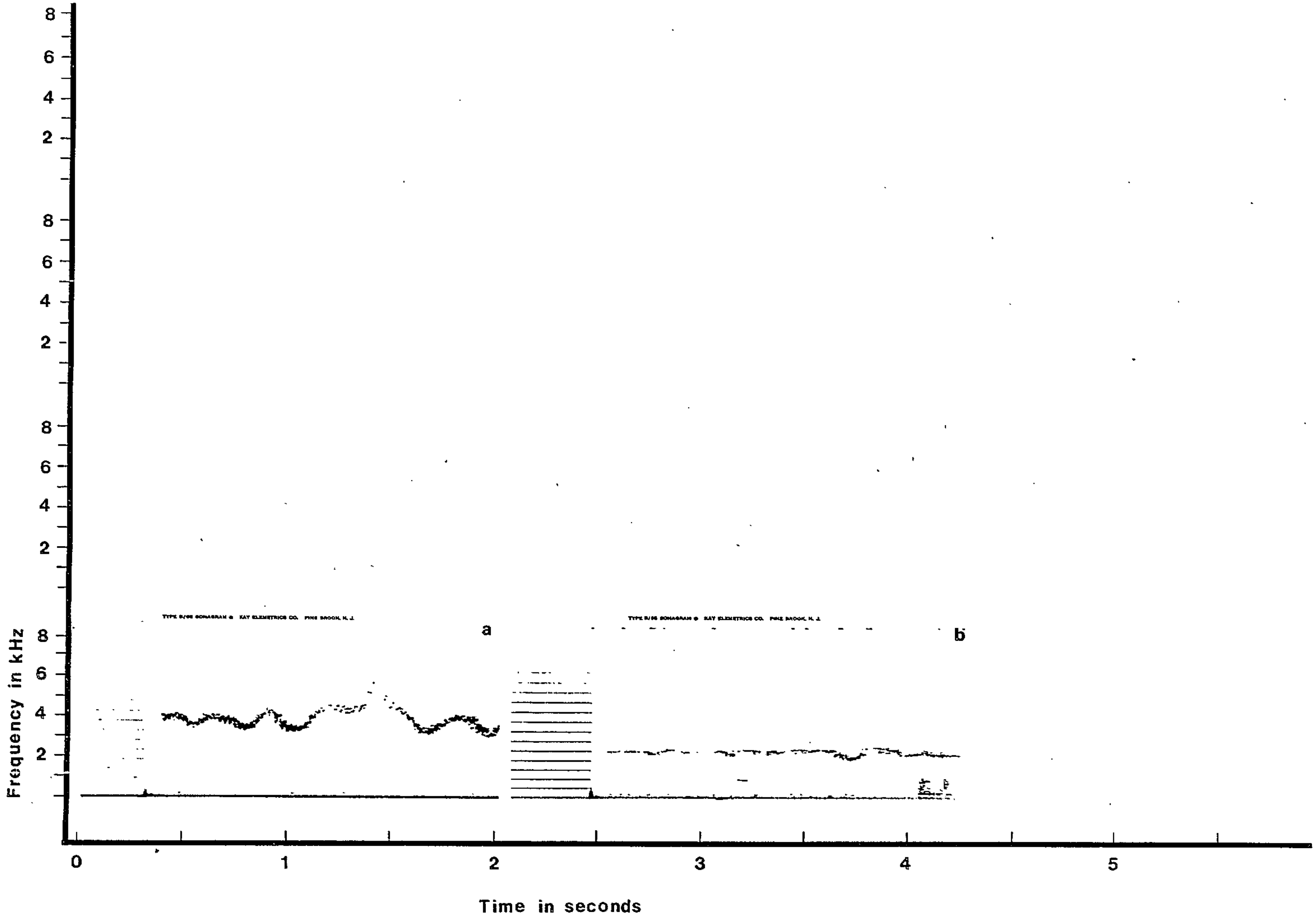

Figure 6. Sonagrams of bearded seal vocalizations:
a. section of a 17–second descending trill taken 3.5 seconds after the trill commenced;
b. last two seconds of the same descending trill.

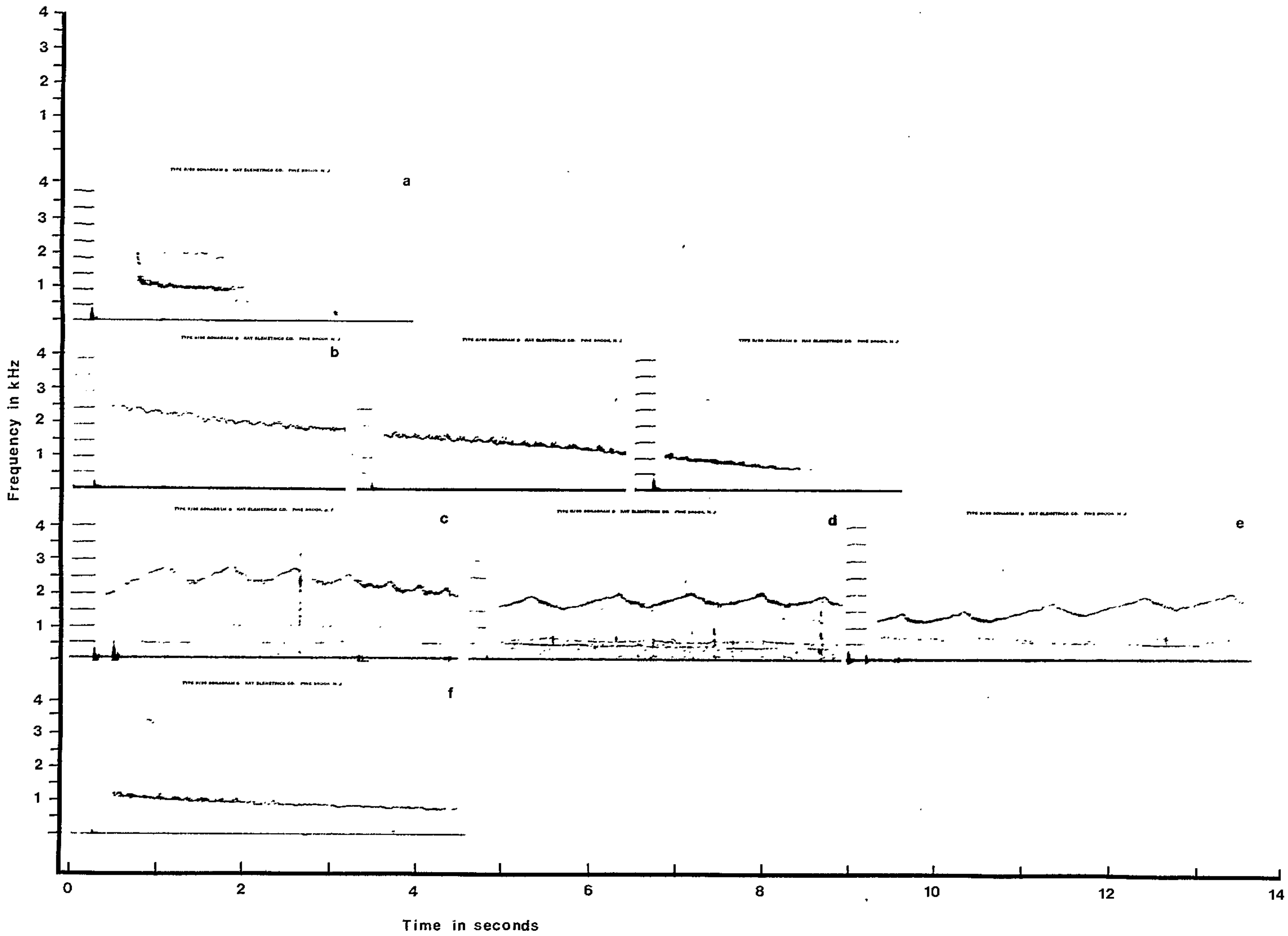

Figure 7. Sonagrams of bearded seal vocalizations:
a. descending trill showing a short precipitous descent followed by a very gradual decline;
b. three segments taken from a typical trill vocalization showing a constant and gradual decline in frequency throughout the vocalization;
c., d., and e. segments taken from different trills showing a very regular pattern of modulation and an unusually long periodicity;
f. descending trill accompanied by two harmonics.

e. Duration of trill

Trills vary in duration from less than one second (Fig. 5d) to at least 73 s. The mean duration appears to be 10–15 s.

f. Dialect

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 5e. Our data suggest that bearded seals may also produce other sounds in addition to the trills described above. 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.

Walruses

The presence of vocalizing walruses in March and Arpil was easy to detect by monitoring with a hydrophone. Their calls were loud, distinct, and usually numerous.

We observed adult male walruses going through stereotyped cycles of underwater singing. For example, one male observed continuously for 1.5 h went through 10 such cycles. The mean time underwater was 6 min 41 s ± 98.5 s (n=10, range= 215 to 511 s) while the mean time at the surface was 2 min 34 s ± 11.5 s (n=11, range=136 to 179 s). When the animal was at the surface, it gave the same calls in the same order between individual breaths each time it came to the surface. Similarly, this individual gave 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 singing 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). Stirling and Siniff (1979) reported a similar pattern of singing 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 (*Leptonychotes weddelli*) and the bearded seal also have fairly stereotyped singing cycles.

Most of the underwater vocalizations recorded were made up of one or more short pulses that had a sharp rather monotonous sound. Some calls were a few hundred pulses long and lasted for 60 to 80 s. In order to have a working terminology, we assigned descriptive names to the sounds, following those of other workers when possible.

a. Taps and knocks

These are by far the most abundant vocalizations (Fig. 8) and appear to equate to what Ray and Watkins (1975) call pulses. Although there is a gradation between taps and knocks, we have given them two names because, in general, they are recognizably different to the human ear. Taps sound higher in pitch and lighter in intensity than knocks. In comparing Fig. 8a with Fig. 8c, it appears that in the knock, more sound is released overall, as well as in the lower frequencies. The rate at which taps and knocks are given may vary between calls or within the same call from about 6/s to 1.25/s (Fig. 8a,c). One particularly distinctive variation is the double knock (Fig. 8d) which is given by at least some males before surfacing to breath during a stereotyped singing cycle.

b. Bell

This call, one of the most distinctive and best known, 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. 9a), in a short series (Fig. 9b) or, often, at the end of a series of taps or knocks. Structurally, the bell is similar to the knock except for a continuing pure tone at about 700 to 800 Hz. In sound spectrographs of knocks, traces of this pure tone are sometimes present (eg. Fig. 8b,c) though not always detectable to the human ear. The bell sound is usually about a second in duration (Fig. 9b) although it may last for as long as 2 s (Fig. 9a).

c. Strum

This call (Fig. 9c,d),not given during the stereotyped cycles and heard only at irregular intervals, was reminiscent of fingers being strummed over the higher notes of a guitar or zither. Structurally, the call is similar to the bell but has several harmonics above the fundamental, some of which approach 2000 Hz.

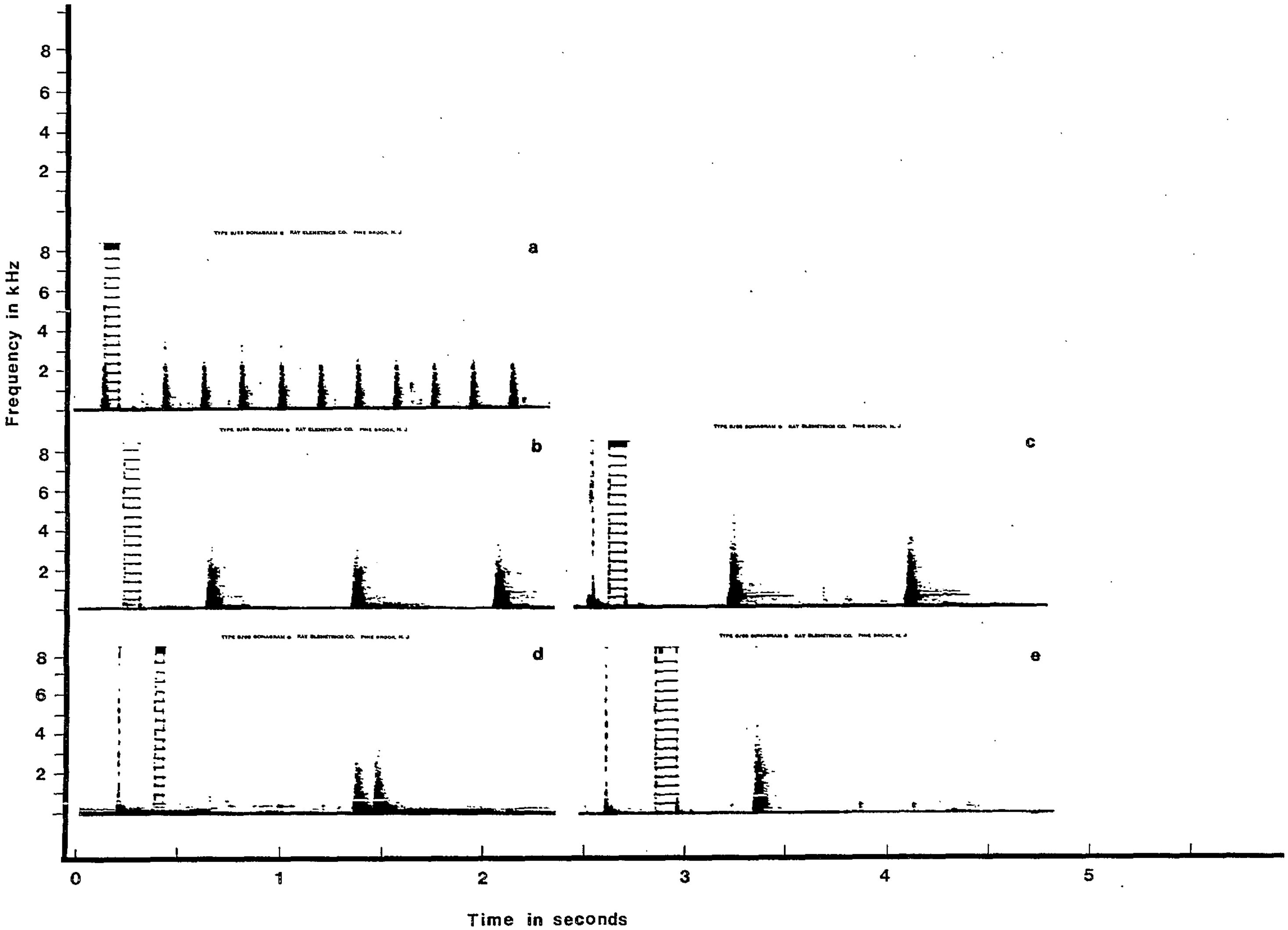

Figure 8. Sonagrams of walrus vocalizations:
a. series of rapid taps;
b. taps given more slowly; c. two knocks; d. double knock; and,
e. single knock given between breaths at the surface.

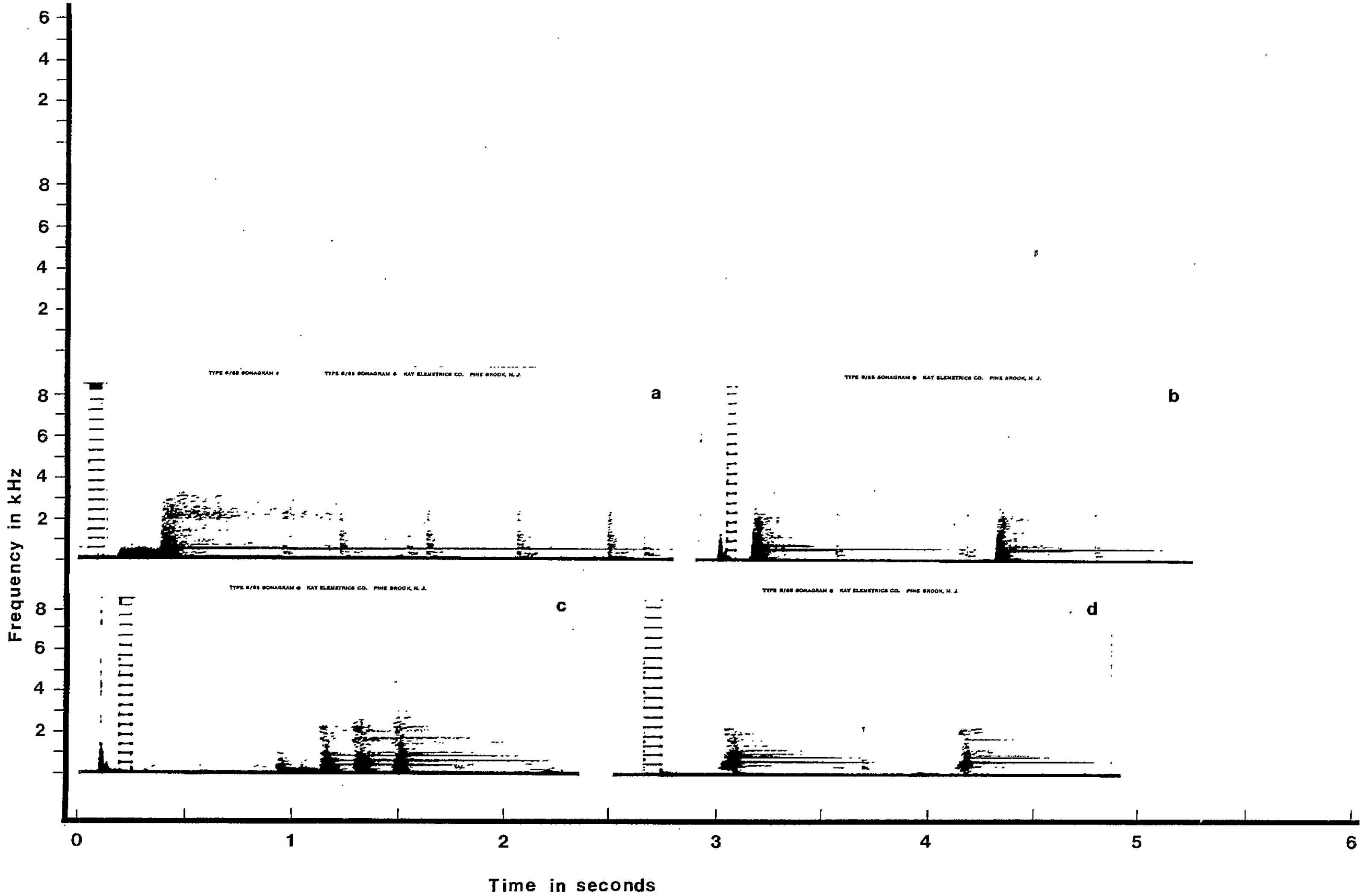

Figure 9. Sonagrams of walrus vocalizations:
a. single bell call with two second long fundamental (faint knocks in background);
b. two bells; c. strum; and, d. two strums.

d. Diving vocalization

During the stereotyped singing cycles we observed, the male always gave a distinct call immediately after taking his last breath and descending from the surface. It begins with a rapid burst of knocks which then slows down and continues for well over 100 pulses. There is some indication the diving vocalizations given by the same individual are constant and that there are recognizable differences between individuals. For example, Figures 10a and b are sonograms of the diving vocalizations of two different animals. The diving vocalizations of the male that made the call illustrated in Figure 10b remained constant through the 10 singing 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 vocalizations of male northern elephant seals *(Mirounga leonina)* remained constant between years. If individual male walruses can be recognised in different years because of natural markings we may be able to determine if they can be identified by their vocalizations.

Sometimes when listening to several walruses vocalizing, we heard low sounds in the background almost like mumbling voices in the distance. On some occasions at least, we knew that females and their yearling calves were present although we do not know if they were producing the sounds. None of our recordings were clear enough to facilitate making sound spectrographs.

We did not hear the rasp call reported from the Atlantic walrus by Schevill *et al.* (1966, Fig. 1). However, on a few occasions, we did record a similar sounding call which was given in a series like a tapping sequence. We did not obtain any good quality recordings of this vocalization.

Diel effects

We have no information on the presence or absence of a diel cycle in the vocalizations of ringed seals or walruses.

Bearded seals

During the 33 h recordings, the mean numbers of bearded seal vocalizations heard for each set of 10 minute recordings were significantly different between the Dundas polynya and

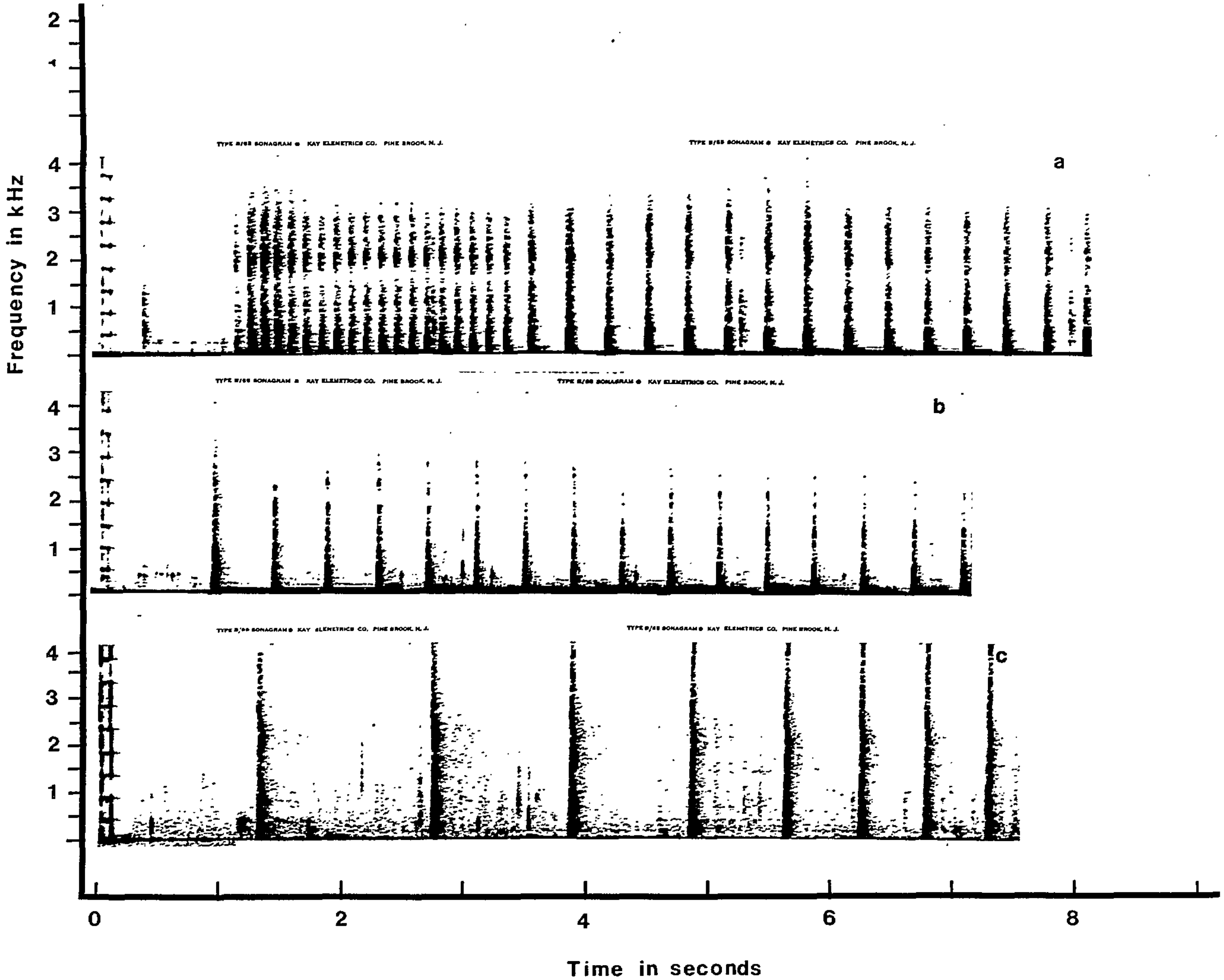

Figure 10. Sonagrams of walrus vocalizations:
a., b. stereotyped diving vocalizations given by two different males;
c. beginning of a tapping sequence given between breaths at the surface showing change in frequency of pulses as call progresses.

Inglis Bay sites, however the variances in daily samples were not. The patterns of vocalization rates within the two sets of recordings also varied significantly. Using a runs test to examine the order in which the vocalization rate values appeared in the recordings, the set of Dundas polynya recordings did not reveal any difference from a random arrangement (Fig. 11). In contrast, the Inglis Bay recordings showed a sequential trend over the 33 hour period. In this trial the vocalization rate was lower between 16:30 and 20:30 than it was at other times. However, at this point, we have too few data to facilitate drawing any conclusions.

To permit comparison of recordings made at one or more sites at different times of the day and season, it will be necessary to ascertain whether or not a diel cycle exists in the pattern of vocalizing in the bearded seal. This would require recording at two or more different habitat types over a period of at least 5 to 7 days per trial on 2 or more occasions. If a diel cycle exists, data from past recordings will have to be adjusted accordingly while future recordings can be planned for optimal times.

Distance travelled by calls

Bearded seals

At the ice edge, bearded seal calls were loud and numerous (about 14/min). Moving west, the intensity and number of vocalizations declined (Fig. 12) to such an extent that at the last recording site (48 km west of the ice edge) the tape recorder, set at maximum gain, picked up only 17% of the total number heard at the ice edge. 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 a maximum of 45 km from the source under ideal conditions (i.e. no wind, ice or water movement, or submarine obstacles). These results also suggest that recording sites should not be less than 60 km apart to reduce the chance of the same animals being heard at both sites since we cannot identify individual bearded seals from their vocalizations.

Although we have not conducted similar preliminary 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

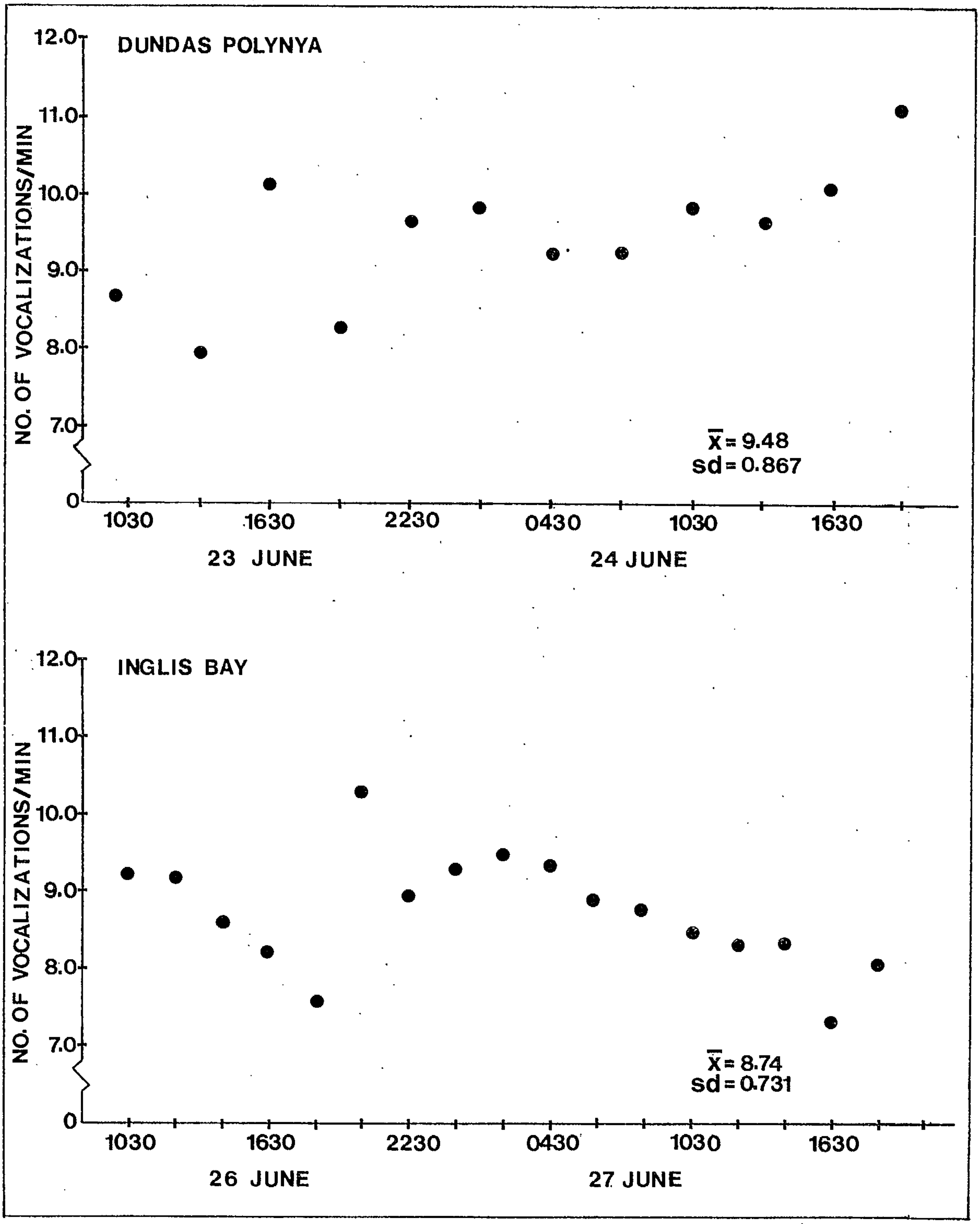

Figure 11. Diel patterns of bearded seal vocalizations in late June as recorded during two 33-hour periods in the High Arctic.

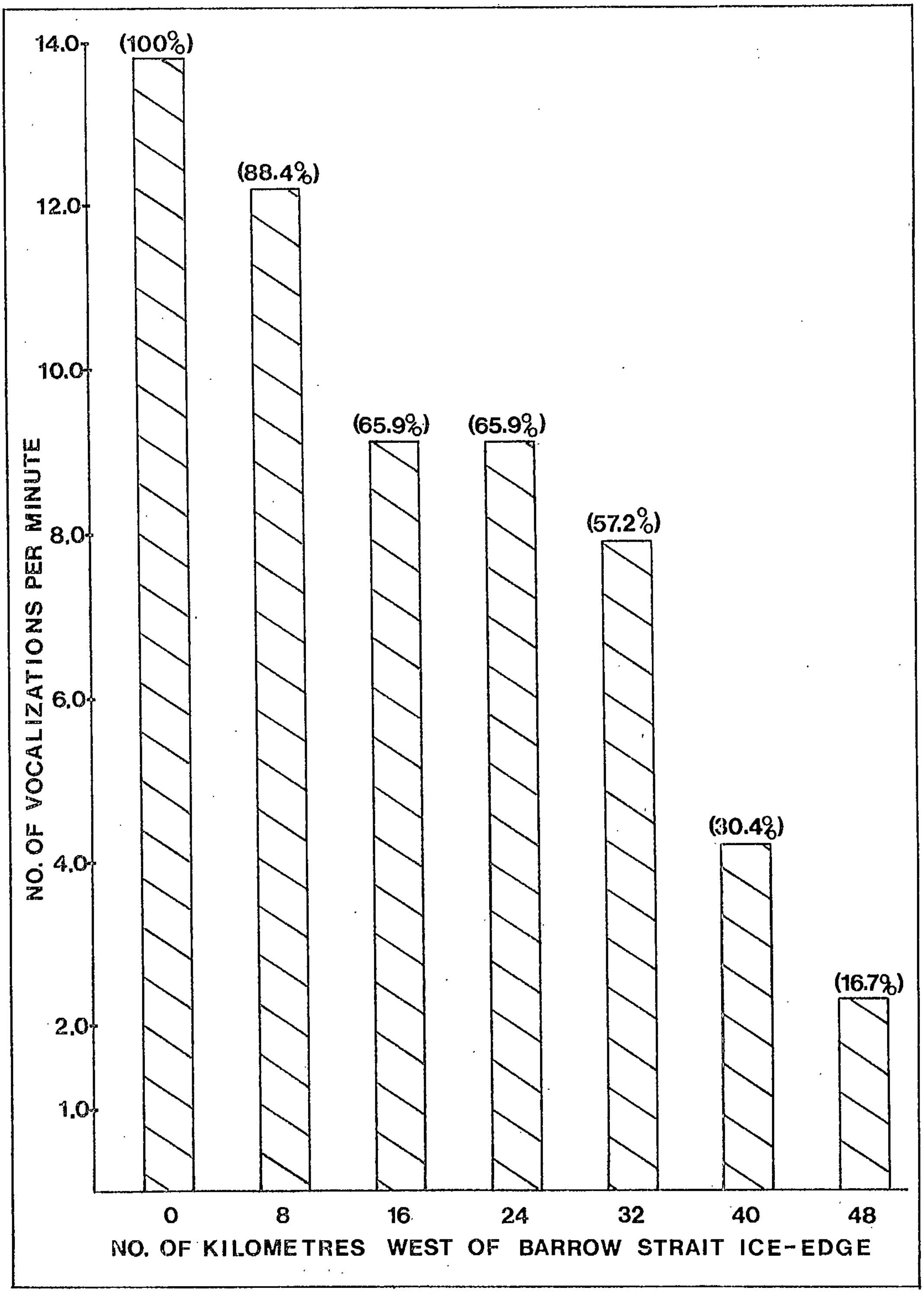

Figure 12. Distance travelled by bearded seal vocalizations as determinedfrom vocalizations per minute recorded at 6 sites back from open water. Percentages in brackets are numbers of vocalizations heard compared to the ice-edge site.

fainter, we suspect they do not travel for more than a few miles.

Function and seasonality of calls

Ringed seals

Table 2 gives the vocalization rates of ringed seals recorded at a number of locations in the High Arctic in the spring and early summer of 1981. At some sites, recordings were made during 2 or more of the recording periods. Despite the small sample size and lack of continuity, there is a fairly clear trend for vocalization rates to be higher in late April than either earlier in April or at the end of June.

We have not observed the underwater behavior of ringed seals when they are vocalizing so we cannot confirm the function of their calls. However, based on Stirling (1973), there appear to be at least two purposes to be served by these calls:

a. maintenance of social order around, or hierarchy of access to, the limited supply of self-maintained breathing holes during the winter; and,

b. part of the repertoire of agonistic and reproductive displays used to organize social behavior during the breeding season.

During much of the winter and spring, the sub-ice movements of ringed seals are limited by the availability of self-maintained breathing holes. Access to these holes is probably limited to a certain number of individuals. If so, there would be a minimum amount of vocalizing under the fast ice during the winter to maintain social order around breathing holes. The amount of vocalizing probably varies with the density of the seals and with the amount of access to naturally maintained breathing areas.

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 behavior of this species, as it does in its ecological counterpart, the Weddell seal *(Leptonychotes weddelli)* in the Antarctic (Kaufman *et al.* 1975). We suspect vocalizations in association with reproductive behavior 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. Stirling

Table 2. Vocalization rates of ringed seals during spring and early summer 1981 in areas subjectively evaluated as being suitable or unsuitable for ringed seal pupping habitat. Numbers in brackets are locations on Figure 2.

	Recording period			
Locations	26 Mar –1 Apr	9–13 Apr	26–28 Apr	21–29 June
Suitable pupping habitat				
3 km S Resolute Bay (62)	5.3	–	11.1	–
2 km E Cape Liddon (27)	1.9	2.5	22.7	3.5
1 km S Patrol Pt (17) (41)	0.8	–	9.5	6.9
3 km SE Cape William Herschel (10)	1.4	1.3	–	–
5 km E Lowther Is (11)	7.1	–	14.9	3.2
10 km W Lowther Is (57)	4.4	–	–	–
16 km SE Lowther Is (58)	8.9	–	–	–
6 km W Griffith Is (61)	5.7	–	12.8	5.3
2 km E Cheyne Pt (53)	8.7	–	44.7	–
3 km S Somerville Is (66)	10.5	–	7.9	–
2 km W Browne Is (56)	3.9	–	–	–
8 km E Limestone Is (65)	7.8	–	–	–
3 km W Cape Cockburn (71)		6.5	–	–
2 km E of Separation Pt (81)	–	–	21.3	0.4

Table 2. (concluded).

Locations	Recording period			
	26 Mar –1 Apr	9–13 Apr	26–28 Apr	21–29 June
<u>Unsuitable pupping habitat</u>				
Freemans Cove (12)	0.7	–	–	0.2
2 km S Moore Is (59)	10.8	4.0	7.8	0
6 km E Black Pt (60)	3.7	–	–	–
Graham Moore Bay (72)		3.1	–	–
N of Cornwallis Is (3)	0.6	–	–	–
McDougall Sound (70)		1.6	–	–
mid–Barrow Strait (54)	12.3	–	–	–
mid–Barrow Strait (55)	6.2	–	–	–
mid–Barrow Strait (63)	15.0	–	14.5	–
S end Wellington Channel (16)	–	–	15.6	–
S end Wellington Channel (18)	–	–	24.7	–
S end Wellington Channel (75)	–	7.4	–	–

(1973) reported an 11% increase in the number of vocalizations/min from January to April 1972 in Amundsen Gulf, which he suggested might be related to an increase in agonistic behavior during the breeding season (April–May). In most cases, the increases in vocalization rates we recorded in late April, compared to late March and early April, were much greater than 11% (Table 2). We suspect that the higher vocalization rates continue through much of May as well.

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 rate recorded in late June (Table 2). 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.

If sub–ice vocalizations are to be used to measure the relative abundance of ringed seals, then the seasonal variation in vocalization rate needs to be clarified. In this way, recordings could be made when the seals are most vocal. Furthermore, it is likely that if one wishes to compare the results from different areas, the recordings should probably be made in as short a period as is practical.

Bearded seals

As stated earlier, male bearded seals produce loud, distinctive songs during the spring courtship season which are believed to function either as a proclamation of territory or breeding condition (Ray *et al.* 1969). 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. In 1981, we recorded at 12 sites between 2 and 4 times each; the results for the 5 sites which had the most data are shown in Figure 13. With two exceptions, vocalization rate increased from late winter to early summer. This suggests that either individual seals were vocalizing more, or there were more seals. One exception to this pattern of an increasing vocalization rate occurred 2 km south of Moore Island (Fig. 2, site 59). In early April, the vocalization rate at this site declined to 34% of the value recorded 10 days previously (Fig. 13).

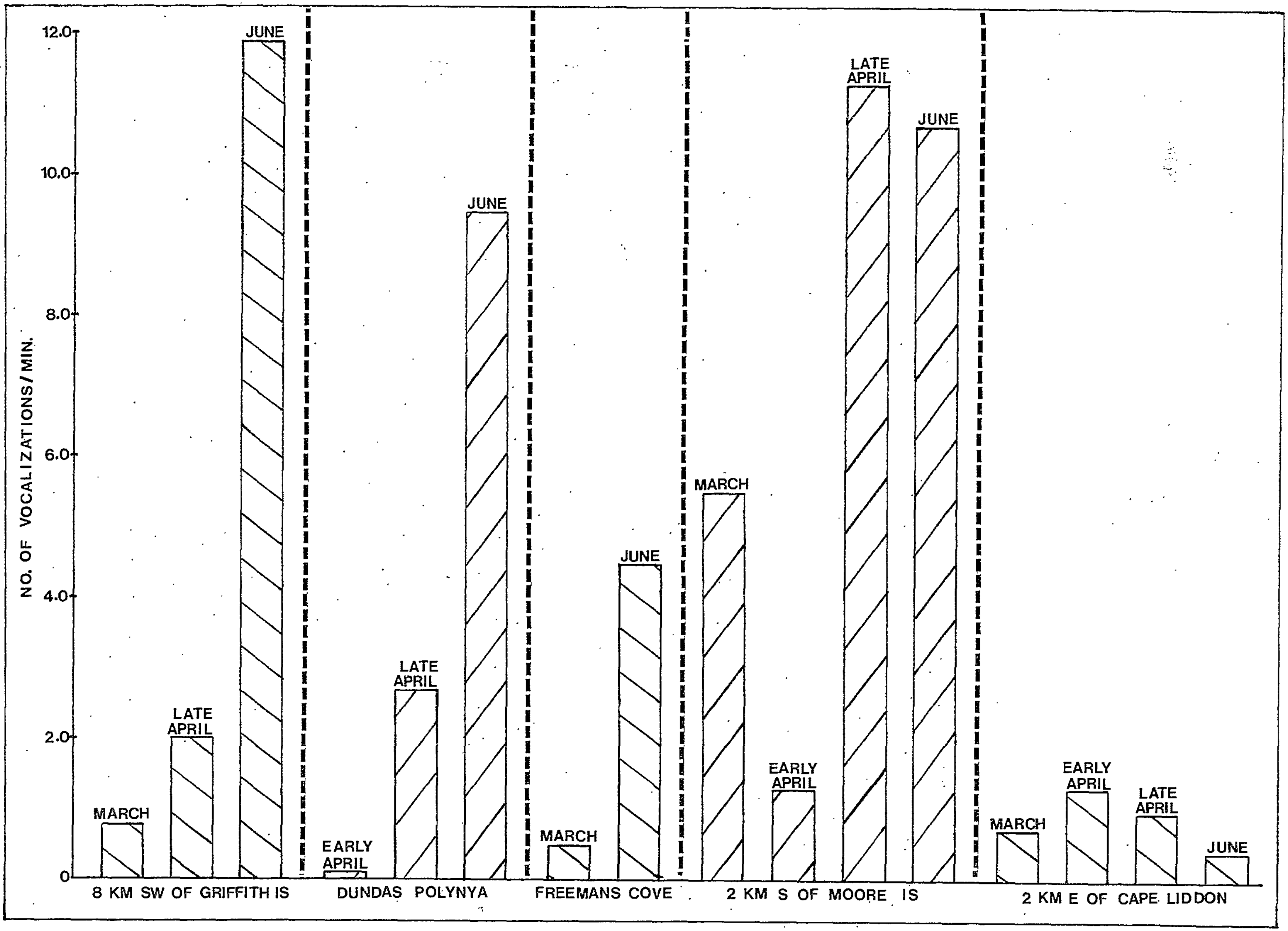

Figure 13. Seasonal changes in vocalization rates of bearded seals at five sites in 1981.

Seventeen days after the second recording was made, the vocalization rate increased nearly 900%. The decline in the vocalization rate should not be an artefact of the collection method as all 4 recordings were made under calm wind and water conditions and within an hour of the same time of day. There were either fewer bearded seals present or fewer of them were vocalizing. Another exception to the trend of increasing numbers of vocalizations occurred 2 km east of Cape Liddon (Fig. 2 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 sooner than at the other sites in Figure 13. As new leads form and break-up moves westward through Barrow Strait, bearded seals may move west as well. This may explain the pattern in vocalization rate observed at Cape Liddon.

Walruses

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 singing cycles observed in the Pacific walrus were 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). 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 if this behavior 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.

There seemed to be some differences between the vocalizations recorded after landing with a helicopter and those recorded at the Dundas polynya where the walruses were, in general, less disturbed and some adult males were giving stereotyped singing cycles. For example, in the recordings made from the helicopter, few diving vocalizations were heard and the mean number of pulses in a sample of tapping and knocking sequences was significantly less (mean = 31.5 ± 27.5 vs mean = 110.3 ± 102.1, t= 8.93, df = 276, $p < .001$). The longest tapping sequence recorded in a sample from the helicopter surveys was 149 pulses (n = 186) while in a sample from the Dundas polynya, 30.8% (28/91) were longer than 150 pulses. These long tapping sequences at the Dundas polynya were recorded during the stereotyped singing cycles. Their absence from the samples taken during the helicopter surveys suggests we were not recording singing cycles.

There are at least 3 possible explanations for the apparent absence of calls associated with the stereotyped singing cycles in the samples collected by helicopter. If the breeding portion of the wintering walrus population is concentrated in the area of Penny Strait and Queens Channel, animals recorded elsewhere might be non-breeders and not give these vocal displays. Although males usually display for several hours at a time, we may, by chance, have not recorded while any males were giving their stereotyped singing cycles. The third possibility is that walruses in the area were disturbed enough by the helicopter to stop stereotyped singing displays. The data are equivocal. When we carefully and slowly approached the Dundas polynya on foot to record walruses, the singing males sometimes stopped vocalizing and either left the area or moved further away and continued to dive but without vocalizing. Although the walruses would not usually have been able to see us, they could have heard us through the water as we crossed the ice. The walruses seemed easily disturbed, yet, when we landed the helicopter 2 to 3 km away from the Dundas polynya, we heard diving vocalizations. Consequently, we cannot be sure of the possible effects of disturbance on the vocalization patterns of walruses but we suggest it should be examined further.

Winter distribution

Ringed seals

Table 3 compares vocalization rates recorded at the mouths and inner areas of 3 bays. The sample is small but the vocalization rates are consistently higher at the mouths of the bays suggesting more seals are present there. Our unpublished data on polar bear hunting behavior also

Table 3. Comparison of vocalization rates of ringed seals in the mouths of bays versus inner portions of bays. Numbers in brackets are locations on Figure 2.

Location	Date	Recording site	Vocalizations /minute
Barrow Harbour	16 April 1980	inner bay (22)	0.25
	25 April 1980	bay mouth (05)	1.62
Maxwell Bay	30 March 1981	inner bay (8)	1.20
		inner bay (9)	1.02
		bay mouth (10)	1.40
Radstock Bay	30 March 1981	inner bay (17)	0.77
		bay mouth (27)	1.90
	28 April 1981	inner bay (17)	9.54
		bay mouth (27)	22.65

indicate that, during the spring, bears spend much more time hunting in the drifted rough ice in the mouths of bays than they do in the smooth ice of the inner bays where there is little snow cover. Stirling *et al.* (1981) suggested there were more seals at the mouths of the bays because the deeper snow drifts there made the area more suitable for construction of birth lairs and protection of breathing holes.

Table 2 gave vocalization rates of ringed seals in areas subjectively rated as being suitable or unsuitable for ringed seal pupping habitat in 1981. In general, the vocalization rates were higher in the areas of most suitable pupping habitat, suggesting the presence of more seals. However, there were two interesting exceptions: mid-Barrow Strait and the southern end of Wellington Channel. In 1981, these areas had very little suitable snow for birth lairs. Much of the ice was smooth and, even where there were pressure ridges, the snow was not deep enough for seals to dig birth lairs. Yet, vocalization rates recorded in these areas were consistently as high or higher than were recorded in the most suitable pupping habitat. 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 present on a year-round basis. If this area is consistently less suitable for pupping, the seals present are more likely to be immature and non-breeding animals.

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 also recorded higher vocalization rates in these areas (Table 2) and Kingsley *et al.* (1982) reported high densities of seals hauled out on the ice there in early summer.

<u>Bearded seals</u>

Table 4 presents vocalization rates of bearded seals for 36 sites where we recorded on one or more occasions during the spring and early summer of 1981. Because the vocalization

Table 4. Vocalization rates of bearded seals during spring and early summer 1981. Numbers in brackets are locations on Figure 2.

Locations	Recording period 26 Mar –1 Apr	9–13 Apr	26–28 Apr	21–29 June
SE coast Devon Is				
5 km SE of Cape William Herschel (10)	1.80	17.38	–	–
2 km E of Cape Liddon (27)	0.69	1.26	0.97	0.40
1 km S of Patrol Pt, Radstock Bay (17) (41)	0	–	0.90	2.28
Wellington Channel				
30 km E of Cape Hotham, Cornwallis Is (18)	–	–	0	–
15 km E of Cape Hotham, Cornwallis Is (16)	–	–	0	–
2 km E of Separation Pt, Cornwallis Is (81)	–	–	0	2.95
S and mid–Barrow Strait				
Mouth of Cunningham Inlet (64)	0	–	–	–
8 km E of Limestone Is (65)	0	–	–	–
40 km SSE of Resolute Bay (63)	0	–	–	–
48 km SSE of Griffith Is (55)	0	–	–	–
24 km SE of Griffith Is (54)	0.11	–	–	–

Table 4. (continued).

Locations	Recording period 26 Mar –1 Apr	9–13 Apr	26–28 Apr	21–29 June
NW Barrow Strait				
3 km S of Resolute Bay (62)	0	–	1.89	–
2 km NE of Cheyne Pt, Griffith Is (53)	0	–	0	8.41
8 km SW of Griffith Is (61)	0.78	–	2.00	11.90
2 km N of Dobell Pt, Griffith Is (67)	0.14	–	–	–
8 km E of Lowther Is (11)	0.30	–	0.19	9.03
10 km W of Lowther Is (57)	1.10	–	–	–
3 km S of Somerville Is (66)	2.40	–	2.28	–
2 km W of Browne Is (56)	6.76	–	–	–
S and SW coast Bathurst Is				
2 km S of Moore Is (59)	5.53	1.31	11.28	10.70
3 km W of Cape Cockburn, Bathurst Is (71)	–	3.72	–	–
12 km SE Bradford Is, Graham Moore Bay (72)	–	2.40	–	–
McDougall Sound and Crozier Channel				
Mouth of Freemans Cove (12)	0.58	–	–	4.54
Between Brooman Pt and Truro Is (25)	0.81	–	–	–
6 km E of Black Pt, Crozier St (60)	1.83	–	–	–

Table 4. (concluded).

Locations	Recording period 26 Mar −1 Apr	9−13 Apr	21−28 Apr	21−29 June
Penny Strait and Queens Channel				
16 km E of Dundas Is (48)	0.60	–	–	–
Between Cape Collins and Pt Little (6) (21)	0	0.11	2.65	9.52
2 km S of Des Voeux Is (73)	–	13.46	–	–
3 km S of Hyde Parker Is (4)	–	6.28	–	–
Mouth of Barrow Harbour (5)	0.60	–	–	–
3 km W of Cape Sir John Franklin (86)	1.41	–	–	–
5 km W of Spit Is (24)	–	2.31	–	–
N side Grinnell Peninsula				
6 km E of Crescent Is (44)	–	1.90	–	–
6 km S of Table Is (68)	–	3.22	–	–
Fram Sound				
3 km N of St Helena Is, Fram Sd (76)	–	–	3.11	–
4 km S of Calf Is, Fram Sd (77)	–	–	7.78	–

rates tend to increase through the spring and early summer, comparisons between areas should be made over as short a time as practical when using the calls to evaluate relative abundance in different areas. The absence of calls during a full recording period at any location probably indicates there are few, if any, bearded seals in the area.

In the Beaufort Sea, bearded seals prefer areas with incomplete ice cover over shallow water (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 (unpublished data).

The ice cover in the High Arctic is essentially the same 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. From Table 4, bearded seals were heard along the southwest coast of Devon Island, near the islands in northwestern Barrow Strait, along the southern and southwestern coast of Bathurst Island, McDougall Sound, Crozier Strait, Queens Channel, Penny Strait, north of the Grinnell Peninsula, and in Fram Sound. 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 March or April in Wellington Channel or in southern to mid-Barrow Strait (Table 4). These areas are characterized by deep water and later break-up than locations where bearded seal calls were heard, probably indicating few bearded seals winter there.

After the beginning of break-up 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 the late spring and early summer (Finley 1976; Kingsley *et al.* 1982), and unpublished observations made during 8 years of polar bear surveys in the High Arctic show bearded seals are most concentrated in the same general areas listed above.

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

Walruses

Figure 14 summarizes the data on the relative abundance of sub-ice walrus vocalizations recorded in the study area from late March through early May in 1980 and 1981. These 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. Within those general areas, the greatest numbers of sub-ice vocalizations were recorded at Pioneer Channel, northeastern Penny Strait and Fram Sound. In general, the abundance was lower and more variable between years in eastern Penny Strait and Queens Channel, south of Dundas Island, and in Fram Sound.

No walruses were heard in Wellington Channel (Fig. 2, sites 29, 31, 81) or McDougall Sound (Fig. 2, site 70) in either year, although distant vocalizations were heard in 1981 at Black Point at the northern end of Crozier Stait (Fig. 2, site 60). In the summer, Crozier Stait 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. 2, site 25) is only about one metre thick in April, so it is one of the first areas to open. However, it appears few, if any, walruses winter there.

We recorded at only 4 sites along the northern coast of the Grinnell Peninsula and northeastern Devon Island in the spring of 1981 (Fig. 2, sites 44, 68,79, and 80) but heard walruses only east of Crescent Island (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 and unpublished data). The largest numbers of walruses counted have been in Fram Sound, Pioneer Channel and northeastern Penny Strait where, in general, the greatest numbers of sub-ice vocalizations were recorded as well.

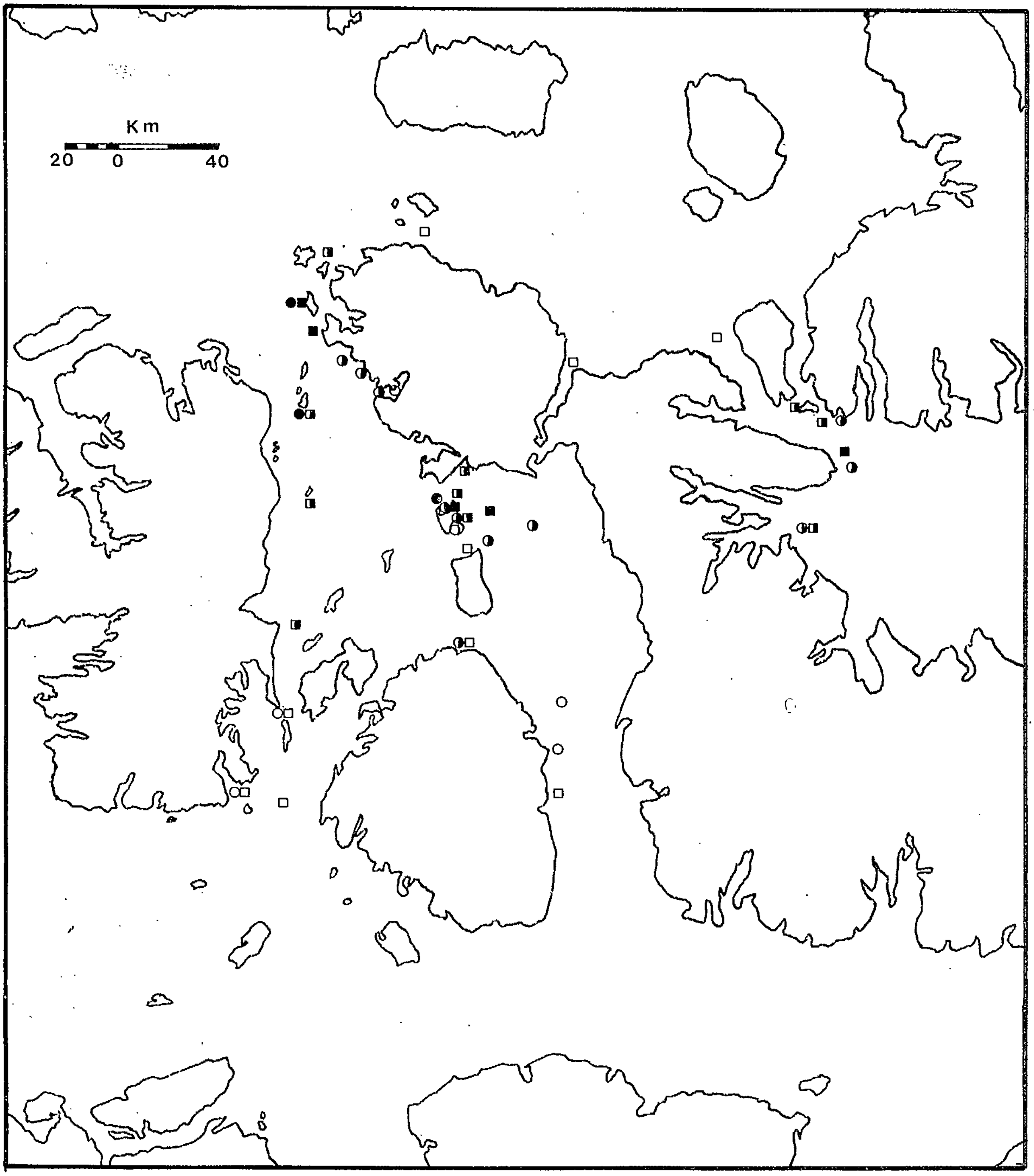

Figure 14. Locations where recordings for walruses were made. Circles indicate sites from 1980 and squares indicate 1981. Empty units indicate an absence of calls, half-filled units indicate a few calls and solid units indicate many.

From satellite photographs, it is clear that these 3 areas have the most reliable recurring polynyas in the central High Arctic (Smith and Rigby 1981). Since these polynyas are near shallow feeding areas, they are the most important wintering sites for walruses.

Numbers of walruses were both lower and more variable in eastern Penny Strait and Queens Channel. In April 1980, small groups of walruses (up to 5) were seen near the southern tips of the Cheyne, Des Voeux, and Baring islands and near grounded multiyear floes in Queens Channel. No walruses were seen near eastern or northern Baillie-Hamilton Island (Fig. 2, site 84) though small numbers were heard. In 1981, no walruses were seen in eastern Penny Strait or Queens Channel. Walruses were heard near Des Voeux and Hyde Parker islands (Fig. 2, sites 73,4) but not near northern Baillie-Hamilton Island. In March 1982, R.W. Prach (personal communication) saw 15 and 11 walruses near northern Baillie-Hamilton Island and one near Baring Island. Clearly, the winter distribution of walruses south of Dundas Island is variable between years.

The underwater recordings of walrus calls made in Fram Sound (Fig. 14) are of particular interest because they suggest few walruses were present in April 1980 and 1981. There is usually considerable background noise when recording in this area because of the strong currents and moving ice. This may obscure some vocalizations but, since walrus calls are loud, numerous, and distinctive, it seems doubtful that background noise would mask the presence of a substantial number of animals. The Fram Sound area is fairly large so more widely spread recording points may be needed to sample it adequately. However, it may also be that the numbers of walruses wintering in this area may be more variable than was previously thought. Kiliaan and Stirling (1978) reported 100 walruses in May 1972 and Davis *et al.* (1978) counted 48 on 19 April 1977. In comparison, we counted 0 and 30 on 17 April and 21 April 1981 respectively. The 30 walruses seen April 21 were widely distributed in small numbers from eastern Fram Sound up into southern Cardigan Strait, suggesting, like the vocalization data, that they are not concentrated.

During 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 quite variable. For example, during 4 weeks of day-long observations at the Dundas polynya in April 1981, the number of walruses hauled out varied from less than 5 to over 50 on apparently similar days. From the air, on 28

March, 29 March, and 9 April 1981, we counted 5, l, 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 recording when trying to assess the winter distribution and relative abundance of this species.

RECOMMENDATIONS

The underwater vocalizations of all 3 species of arctic pinnipeds appear to be potentially useful for studying their distribution and relative abundance during the winter. If this subject is to be researched further, we have several recommendations:

a. evaluate the minimum recording time required to obtain a representative sample of the vocalizations of each species in different seasons;

b. quantify the pattern of seasonal change in vocalization rates and whether or not a diel pattern exists. With these results, it would be easier to plan the optimum dates for underwater recording surveys to be done and possibly the time of day as well;

c. establish a series of survey sites for each species so that annual variability in distribution and abundance could be assessed (probably most important for ringed seals);

d. under c. above, for ringed seals, coordinate sub-ice recording with dog searches for numbers of breathing holes and birth lairs in each area;

e. attempt to observe animals whenever possible to determine the function of these vocalizations. Understanding this behavior would greatly aid the interpretation of recordings in terms of the distribution and abundance of different age and sex classes;

f. attempt to measure distances travelled by calls and, if possible, measure source levels (possibly using captive animals); experiment with artificially synthesized calls to estimate distances travelled by calls; and

g. evaluate the effect, on vocalization rates, of disturbance resulting from both research and industrial activities.

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Appendix I. March to June recording sites in the High Arctic.

Site no.	Location	Date
1	1 km S Bay of Woe, Hell Gate	80 Apr 13
2	8 km E Cape Vera	80 Apr 13
3	2 km N north end Cornwallis Is	80 Apr 13
	4 km N Cornwallis Is	80 Apr 16
	10 km N Lady Hamilton Bay	81 Mar 28
4	1 km S Hyde Parker Is	80 Apr 16
	3 km S Hyde Parker Is	81 Apr 09
	3 km S Hyde Parker Is	81 Apr 09
5	Mouth Barrow Harbour	80 Apr 16
	Mouth Barrow Harbour	80 Apr 16
	Mouth Barrow Harbour	81 Mar 29
6	N Dundas Polynya	80 Apr 16
	.5 km W Dundas Polynya	81 Mar 28
	Between Cape Collins and Pt Little	81 Apr 09
	Between Pt Little and Cape Collins	81 Apr 26
7	13 km NE Boat Pt, West Fd	80 Apr 17
	10 km NNE Boat Pt, West Fd	81 Apr 21
8	Small inlet in E arm Maxwell Bay	80 Apr 19
	W inlet in E arm Maxwell Bay	81 Mar 30
9	W tip central peninsula Maxwell Bay	80 Apr 19

Appendix I. (continued).

Site no.	Location	Date
10	2 km E Cape William Herschel, Maxwell Bay	80 Apr 19
	5 km SE Cape William Herschel, Maxwell Bay	81 Mar 30
	3 km SW Maxwell Bay peninsula	81 Mar 30
	5 km E Cape William Herschel, Maxwell Bay	81 Apr 13
11	3 km E Lowther Is	80 Apr 20
	8 km E Lowther Is	81 Mar 27
	5 km E Lowther Is	81 Apr 27
	5 km E Lowther Is	81 Apr 27
	8 km E Lowther Is	81 Jun 21
12	Freemans Cove	80 Apr 20
	Mouth Freemans Cove	81 Mar 31
	Mouth Freemans Cove	81 Jun 21
13	100 m in mouth of Barlow Inlet	80 Apr 23
15	3 km NE Griffith Is	80 Apr 23
16	SW Wellington Channel	80 Apr 24
	15 km E Cape Hotham, Cornwallis Is	81 Apr 28
	15 km E Cape Hotham, Cornwallis Is	81 Apr 28
17	Between Patrol Pt – Waldegrave Bluff	80 Apr 24
	1 km S Patrol Pt, Radstock Bay	81 Mar 30
18	S Wellington Channel	80 Apr 23
	26 km W Cape Riddle, Devon Is	80 Apr 24
	30 km E Cape Hotham, Cornwallis Is	81 Apr 28

Appendix I. (continued).

Site no.	Location	Date
19	N channel between Margaret and Dundas Is	80 Apr 25
	Between Margaret and Dundas Is	81 Mar 28
20	W channel between Margaret and Dundas Is	80 Apr 25
	W channel between Margaret and Dundas Is	80 Apr 25
21	Dundas Polynya	81 Apr 05
	Dundas Polynya	81 Apr 07
	Dundas Polynya	81 Apr 08
	Dundas Polynya	81 Apr 16
	Dundas Polynya	81 Apr 18
	Dundas Polynya	81 Apr 19
	Dundas Polynya	81 Apr 19
	Dundas Polynya	81 Apr 19
	Dundas Polynya	81 Apr 20
	Dundas Polynya	81 Apr 20
	Dundas Polynya	81 Apr 23
	Dundas Polynya	81 Jun 23
22	Bay 5 km NW Domville Is, Barrow Harbour	80 Apr 25
23	1 km E northern Fairholme Is	80 Apr 25
24	2 km W Spit Is	80 Apr 25
	5 km W Spit Is	81 Apr 09
25	Between Brooman Pt and Truro Is	80 Apr 25
	Between Brooman Pt and Truro Is	81 Mar 31

Appendix I. (continued).

Site no.	Location	Date
26	26 km E Lowther Is	80 Apr 27
27	2 km E Cape Liddon, Radstock Bay	80 Apr 28
	2 km E Cape Liddon, Radstock Bay	80 Apr 28
	2 km E Cape Liddon, Radstock Bay	81 Mar 30
	2 km E Cape Liddon, Radstock Bay	81 Apr 13
	3 km E Cape Liddon, Radstock Bay	81 Apr 28
	2 km E Cape Liddon, Radstock Bay	81 Jun 29
28	26 km E Margaret Is	80 May 02
29	16 km E Copeland Pt, Cornwallis Is	80 May 03
30	3 km NE Surprise Pt, Baillie–Hamilton Is	80 May 03
31	Advance Bluff, NE Cornwallis Is	80 May 13
32	1 km W floe edge, Barrow St	80 May 13
33	8 km W floe edge, Barrow St	80 May 13
34	16 km W floe edge, Barrow St	80 May 13
35	24 km W floe edge, Barrow St	80 May 13
36	32 km W floe edge, Barrow St	80 May 13
37	40 km W floe edge, Barrow St	80 May 13
38	48 km W floe edge, Barrow St	80 May 13
40	2 km SW Cape Ricketts, Devon Is	81 Apr 28
41	2 km W Patrol Pt, Radstock Bay	81 Apr 28
	1 km SSW Patrol Pt, Radstock Bay	81 Jun 29
44	6 km E Crescent Is	81 Apr 09
	6 km E Crescent Is	81 Apr 09

Appendix I. (continued).

Site no.	Location	Date
48	16 km E Dundas Is	81 Mar 28
53	2 km NE Cheyne Pt, Griffith Is	81 Mar 26
	2 km E Cheyne Pt, SE Griffith Is	81 Apr 27
	2 km E Cheyne Pt, SE Griffith Is	81 Apr 27
	2 km NE Cheyne Pt, SE Griffith Is	81 Jun 21
54	24 km SE Griffith Is, Barrow St	81 Mar 26
55	48 km SSE Griffith Is	81 Mar 26
56	2 km W Browne Is	81 Mar 27
57	10 km W Lowther Is	81 Mar 27
58	16 km SE Lowther Is	81 Mar 27
59	2 km S Moore Is, SE Bathurst Is	81 Mar 31
	2 km S Moore Is, SE Bathurst Is	81 Apr 10
	2 km S Moore Is, SE Bathurst Is	81 Apr 27
	2 km S Moore Is, SE Bathurst Is	81 Apr 27
	4 km S Moore Is, SE Bathurst Is	81 Jun 21
60	6 km E Black Pt, Crozier St	81 Mar 31
61	8 km SW Griffith Is	81 Mar 31
	6 km W Griffith Is	81 Apr 27
	8 km SW Griffith Is	81 Jun 21
62	4 km S Resolute	81 Apr 01
	3 km S Resolute	81 Apr 27
63	Between Resolute and Cunningham Inlet	81 Apr 01
	40 km SSE Resolute	81 Apr 27

Appendix I. (continued).

Site no.	Location	Date
64	Mouth Cunningham Inlet	81 Apr 01
65	8 km E Limestone Is, Somerset Is	81 Apr 01
66	5 km S Somerville Is	81 Apr 01
	3 km S of SW tip Somerville Is	81 Apr 27
67	2 km N Dobell Pt, Griffith Is	81 Apr 01
68	6 km S Table Is	81 Apr 09
69	250 m NE Pt Little, Dundas Is	80 Apr 25
	250 m NE Pt Little, Dundas Is	80 Apr 25
70	mid S McDougall Sd	81 Apr 10
71	3 km W Cape Cockburn, Bathurst Is	81 Apr 10
72	12 km SE Bradford Is, Graham Moore Bay	81 Apr 10
73	2 km S Des Voeux Is	81 Apr 10
74	16 km S mouth Maxwell Bay	81 Apr 13
75	10 km W Beechey Is	81 Apr 13
76	3 km N St Helena Is, Fram Sd	81 Apr 21
77	4 km S of E End Calf Is, Fram Sd	81 Apr 21
78	2 km S Prince Edward Pt, N Kent Is	81 Apr 21
79	10 km ENE Cape Derby, Cardigan St	81 Apr 21
80	8 km N Cape Separation, Arthur Fd	81 Apr 21
81	2 km E Separation Pt, Cornwallis Is	81 Apr 26
	2 km SE Separation Pt, Cornwallis Is	81 Jun 29
82	2 km W Dyer Is, Inglis Bay	81 Jun 26
83	Bay E of Cape Majendie	81 Apr 26

Appendix I. (concluded).

Site no.	Location	Date
84	4 km NE Cape Fitzjames, Baillie–Hamilton Is	81 Apr 26
85	1 km SE Cracroft Is	80 Apr 25
86	3 km W Cape Sir John Franklin	81 Mar 29

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