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RESPONSES OF RINGED SEALS (*Phoca hispida*) TO NOISE DISTURBANCE

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Abstract

The effects of on-ice industrial noises on ringed seals (Phoca hispida) were investigated to determine the extent to which such disturbance increases the rates at which seals abandon breathing holes and lairs. In the spring of 1982, breathing holes and lairs were abandoned three times as often within 150 m of recent seismic survey lines as were structures at greater distances from the same lines. Subnivean structures were abandoned at equal rates within and beyond 150 m of control lines. Aerial surveys of ringed seals conducted in the Beaufort Sea in 1981 and 1982, however, showed no consistent differences in the density of basking seals in transects centered over seismic survey lines and in intervening transects.

The rate of abandonment of subnivean seal structures was compared over six years. In undisturbed areas, the abandonment rate was 4.0% in shore-fast ice and 12.9% in drifting ice. Among seal structures subjected to industrial noise in the shore-fast ice, the rate was 13.5%, and with the addition of repeated examinations of structures by investigators the rate was 32.5%.

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Radio-tagged seals departed their lairs in response to snow machines within 2.8 km, human footfalls as far away as 600 m, a skier as far away as 400 m, and in response to a helicopter flying 5 km from the lair at an altitude of 152 m, and during helicopter landings or takeoffs as far away as 3 km.

Ringed seals abandon breathing holes and lairs in response to naturally occurring conditions such as minimal snow cover, shifting ice, and the activities of predators. They abandon those sites at higher rates in response to anthropogenic noises. Seals would be most adversely affected by noise disturbance in late March through June when the amount of time they spend out of the water is increasing and movements, especially of females and their dependent young, are limited to small areas.

Introduction

Potential effects on marine mammals of anthropogenic noises include physical harm from extremely loud noises, interference with vocal communication, increased levels of stress, and displacement from local areas (Rausch 1973; Geraci and St. Aubin 1980; Schusterman and Moore 1980; Norris 1981; Stewart 1981; Ronald and Dougan 1982; Mansfield 1983; Kelly et al. 1986). Displacement has the most potential for widespread and long-term effects and has been a focus of our investigations. Ringed seals (Phoca hispida) are the most adapted of northern pinnipeds to inhabiting thick, relatively stable sea ice, and their ability to maintain holes through the ice permits them to occupy areas of complete ice cover year-round. That adaptation allows ringed seals to exploit resources from which other pinnipeds are largely excluded during winter, but it also makes them more vulnerable to predation by polar bears (Ursus maritimus) and arctic foxes (Alopex lagopus). Mortality of ringed seal pups can be substantial due to that predation (Smith 1976; Smith 1987; Kelly et al. 1987). Occupation of areas of extensive ice cover, especially shore-fast ice, also makes ringed seals more vulnerable to human activities; for thousands of years the species was a major resource for coastal Eskimos and it remains important in modern Eskimo culture and economy (Hall 1866; Boas 1888; Stefansson 1913; Manning 1944; McLaren 1958a; Cox and Spiess 1980; Wenzel 1984; Smith 1987). In recent times, petroleum exploration and development activities have taken place in ringed seal habitat. Gravel island construction and exploration for oil using seismic profiling have overlapped spatially and temporally with ringed seal whelping and breeding areas. Both gravel island construction and seismic profiling involve operating heavy trucks and bulldozers on the shore-fast ice. Seismic profiling further entails imparting substantial amounts of low frequency sound energy into the oceanic crust (and incidentally the water column and overlying ice) and recording the reflected signals.

Concern about the effects of disturbance in Alaskan waters was first expressed by subsistence hunters on the Seward Peninsula. They reported decreased harvests of ringed seals in an area subjected to offshore gold exploration in the 1960's (Burns and Kelly 1982). More recently, seismic profiling during oil exploration has presented a greater potential for disturbance since it involves considerable noise energy and affects extensive areas. Explosives were the main signal sources until their offshore use was banned in 1977 by an Administrative Order of the Alaska Department of Natural Resources. Subsequently, "air guns," "water guns," and Vibroseis machines have been used to generate source signals.

When we began this study in 1981, the only data available with which to examine the hunters' suggestion that ringed seals were displaced by noise disturbances were the results of aerial surveys conducted between 1970 and 1977 (Burns and Harbo 1972; Burns and Eley 1978). In those surveys, lower densities of seals were observed in the vicinity of coastal settlements than in adjacent near-shore areas. They believed that those differences were greater than could be accounted for by removal of seals, since hunting of ringed seals was greatly reduced compared to earlier times. They speculated that human activity, especially snow machine travel, was displacing seals from those areas. Examination of the aerial data from the Beaufort Sea for indications of differences in seal densities inside and outside of areas affected by seismic exploration has yielded conflicting results. Burns and Harbo (1972) reported similar densities of seals in both areas during the 1970 survey, but Burns et al. (1981) re-examined the data from 1975-1977 and concluded that densities of seals in "seismic" areas were consistently lower than in undisturbed areas. None of those surveys were designed to test for indications of displacement, however, and the retrospective partitioning of the data into disturbed and undisturbed areas was unsatisfactory.

For the present study, we combined on-ice surveys of subnivean seal structures (breathing holes and lairs) using trained Labrador retrievers, aerial surveys of basking seals, and radio telemetry to quantify the reactions of ringed seals to seismic profiling that employed the Vibroseis method and to other anthropogenic noises. Our objectives were to (1) determine the effect of seismic profiling activities on ringed seal distribution, (2) determine the behavioral responses of ringed seals occupying lairs to anthropogenic noise, (3) compare the rates of abandonment of subnivean structures in disturbed and undisturbed areas, and (4) assess the significance of abandonment of subnivean structures in terms of the numbers and distribution of alternative structures available to individual seals. Our primary measures of disturbance were the relative densities of basking seals along and immediately adjacent to seismic "shot lines," the rate of abandonment of subnivean structures as a function of distance from seismic lines, and changes in haulout frequency and duration in areas subjected to seismic profiling. Rates of short-term and long-term displacement resulting from noise disturbance were assessed relative to natural rates established using surveys and telemetric studies conducted between 1981 and 1987.

Methods

Aerial surveys

Aerial surveys were conducted along the Beaufort Sea coast of Alaska (Figure 1) between 2 and 9 June 1981 and between 25 May and 4 June 1982. The 1981 surveys were conducted from a twin engine fixed-wing aircraft (Grumman Goose) equipped with a Global Navigation System (GNS). A Bell 204 helicopter, also with GNS, was used for the 1982 surveys. Two observers counted all seals visible within 0.5 nm of each side of the aircraft while flying at an altitude of 500 ft.

Between 2 and 9 June 1981, we surveyed 2,880 nm of transect lines divided into three groups; those parallel to the coast between Smith Bay (70°55'N, 154°20'W) and Barter Island (70°08'N, 143°40'W), those centered over seismic lines that had been surveyed during the previous few months, and control lines centered between those seismic line transects. In 1982, we conducted aerial surveys between 25 May and 4 June. The total length of those transects was 1,083 nm, again divided into those along seismic trails, those along control transects, and a series duplicating some of the transects surveyed in June 1981.

Subnivean seal structure surveys

Trained Labrador retrievers were used to find seal-made structures (subnivean lairs and breathing holes) in 10 surveys between

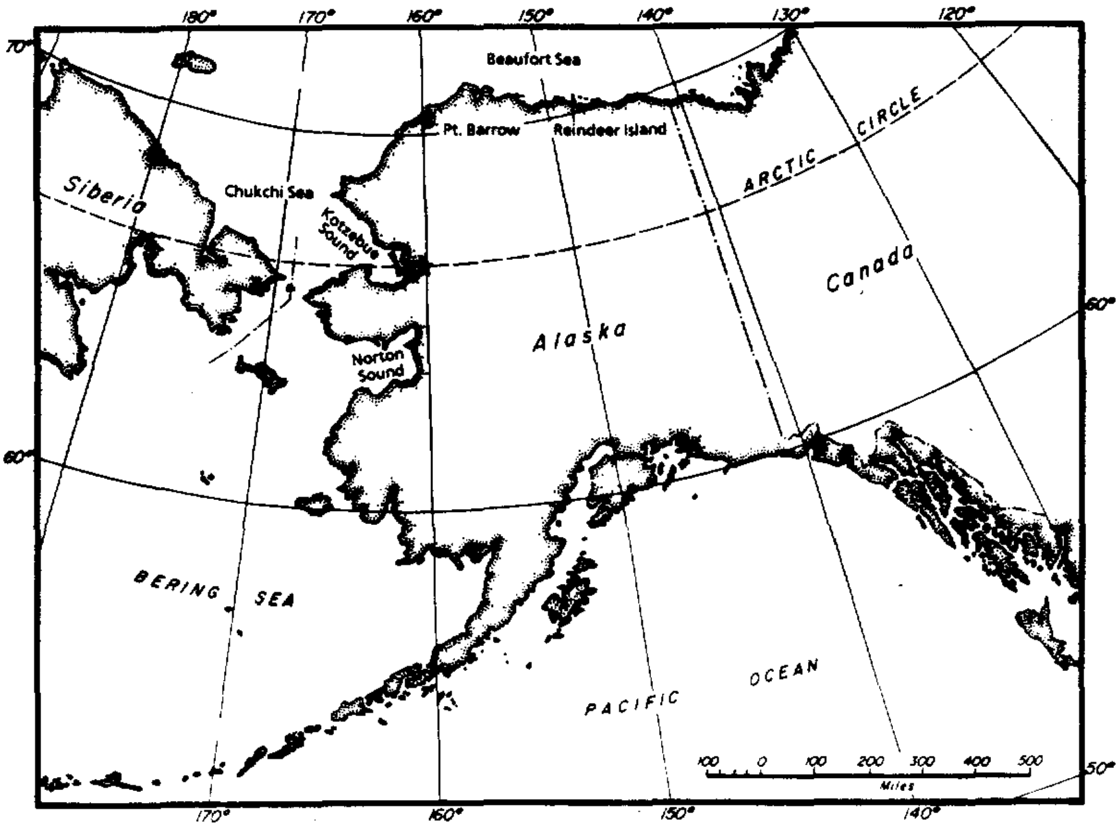

Figure 1. Map of Alaska showing locations mentioned in text.

1982 and 1987. The method was similar to the way Eskimo hunters used sled dogs to locate seal holes (Hall 1866). Canadian workers adapted the method for biological sampling (Smith and Stirling 1975) and one of us (BPK) learned the method from them in 1981. The dogs ran in front of a snow machine at the direction of the dog handler. When they detected seal odor, they followed the scent to its source and indicated the location of the seal structure by digging in the snow above it. Generally, the dogs were directed to run perpendicular to the wind direction to maximize the area of detection.

The search pattern varied depending on the objectives of work during the different field efforts. The dogs generally searched either along lines established by heavy equipment and snow machines or at random within pre-selected areas, usually near field camps or stations established to monitor radio-tagged seals. An exception was in a drift ice survey in 1987 when the dogs searched along tracks of polar bears.

Seal structure surveys in 1982 were limited to the shore-fast ice of the Beaufort Sea, primarily in the vicinity of Reindeer Island and Seal Island, a man-made gravel island (Figure 2). In that effort, searches were primarily along seismic lines or control lines delineated by snow machine tracks. Surveys in 1983 were conducted again in the Reindeer Island area and at numerous shore-fast ice locations from Norton Sound in the Bering Sea north to Point Barrow in the Chukchi Sea (Figure 1). In 1984, shore-fast ice was surveyed in Kotzebue Sound and drifting ice was surveyed elsewhere in the Chukchi Sea. Shore-fast ice was surveyed in the vicinity of Point Barrow in 1985, 1986, and 1987. The 1987 surveys also included efforts in the Beaufort Sea east of Point Barrow; on shore-fast ice between the man-made gravel island, Tern Island (70°17'N, 147°28'W) and Narwhal Island (70°24'N, 147°30'W) and at several locations in drifting ice.

At a minimum, each structure was probed with an aluminum rod, 1 cm in diameter. Most structures were partially uncovered to permit examination and measurements after which they were carefully re-covered. When examined, structures were classified as breathing holes, simple resting lairs, multi-chambered lairs, or birth lairs, and notations were made of the dimensions, physical setting, and indications of predator activity. The status of each structure was recorded as **open**, if the hole through the ice was maintained by the seal to its maximal diameter; **frozen**, if the entire hole was refrozen; or, in the case of lairs as **altered**, if access to the lair was obstructed by partial freezing of the access hole or by a collapsing ceiling. Structures that were classified as frozen were considered to have been abandoned by the seals.

In most instances, structures were examined when first located. In 1982, however, many structures were probed when first located, but they were not examined further until a subsequent revisit. In that year, approximately 72% of the structures were visited two or more times.

The examination of a structure was considered to constitute a disturbance, thus all examinations subsequent to the initial one were of structures previously exposed to anthropogenic disturbance and were categorized as such.

Monitoring of haulout activity

Fourteen ringed seals were live-captured at breathing holes in the shore-fast ice; three in the Beaufort Sea in 1982, six in the Beaufort Sea in 1983, and five in Kotzebue Sound in 1984 (Kelly et al. 1986). The weight, sex, and minimal age, as determined by claw annuli (McLaren 1958b), of each seal was recorded. VHF radio transmitters were glued to the pelage of the dorsum, midway between the base of the tail and the region of maximal girth, before each seal was released at its capture site.

The unique frequency of each deployed transmitter was monitored from a nearby camp every half-hour in 1982 and every hour in 1983 and 1984 for up to 2.5 months between March and early June. Signals could be received only when the transmitters were above the ice surface, thus indicating that the seals were out of the water. Haulout bouts of 13 of the radio-tagged seals were monitored after their release; no signals were received from one of the seals tagged in 1983. Whenever feasible, the exact location of the signal sources, indicating the location of lairs or other haulout sites, was determined. Those determinations were accomplished by skiing or walking around the signal source while monitoring the signal with a hand-held, directional antenna.

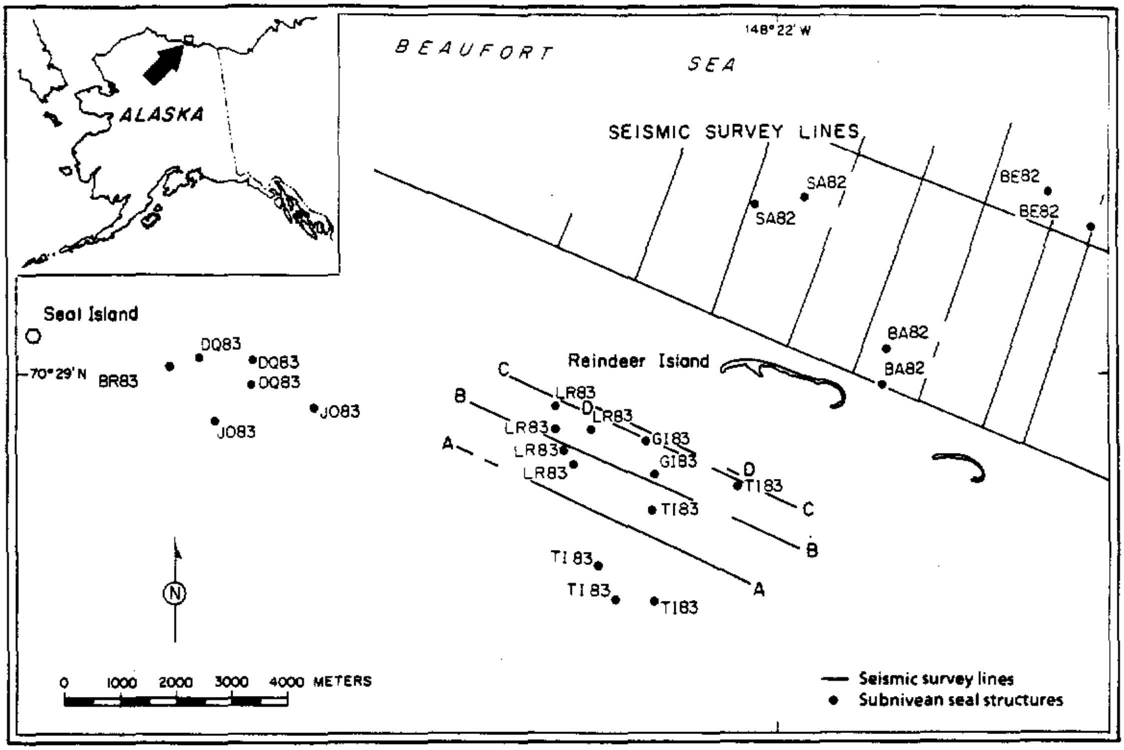

Figure 2. Subnivean structures used by radio-tagged ringed seals and seismic survey lines in 1982 (north of Reindeer Island) and 1983 (south of Reindeer Island). (After Kelly et al. 1986.)

When radio-tagged seals were in their lairs and subjected to anthropogenic sounds, notations were made of their behavioral responses (departed or remained in lair). In April 1983, a simulated seismic survey was conducted near Reindeer Island in an area occupied by radio-tagged seals. The survey consisted of four seismic lines; A, B, C, and D depicted in Figure 2. Four machines travelled over each seismic line. A drill truck used a power auger to bore holes through the ice, generally every 67 m along the survey lines. A bulldozer (D6 Caterpillar) then leveled the ice along the survey lines. Every 67 m, the ice surface was vibrated ten times in 16 second sweeps from 10 to 70 Hz by a Vibroseis machine. A fuel truck followed at the end of the convoy. Lines A and B were vibrated on 21 April, lines C and D were vibrated on 22 April, and line A was vibrated a second time on 27 April. Additionally, the behavioral responses of seals in lairs to the sounds of helicopters, snow machines and other equipment operating on the ice, and people walking or skiing on the ice were documented opportunistically.

Results

Aerial surveys

Results of our aerial surveys were conflicting with regard to the effects of seismic survey activities on seal distribution. In 1981, we observed an average of 1.3-1.4 ringed seals per nm^2 on the shore-fast ice between Point Barrow (71°23.2'N, 156°27.2'W) and Oliktok Point (70°30.0'N, 149°52.6'W) and an average of 1.1 ringed seals per nm^2 between Oliktok Point and Barter Island (70°08.1'N, 142°24.7'W), similar to the densities observed in four surveys conducted between 1970 and 1978 (Burns et al. 1981).

The observed densities of basking seals along seismic lines and intermediate control lines on three days are shown in Table 1. Densities along the two sets of lines differed significantly only on 3 June when densities along the seismic lines were 58% of those along control lines.

Concentrations of seals basking along newly opened cracks (as opposed to at breathing holes) appeared unexpectedly early in June 1981 and increased from 13.9% of all seals sighted on 4 June to 16.5% on 7 June and 22.8% on 8 June. The indication was that seals were leaving breathing holes and lairs maintained through the winter in favor of haulout sites along newly opened cracks. Therefore, we suspected that the 5 and 9 June surveys were less representative of the early spring distribution of seals than was the 3 June survey. Thus, in 1982, we scheduled aerial surveys to begin in late May in the hope of obtaining relative densities that were more representative of early spring distribution.

A replicated survey track from Cape Halkett (70°48'N, 152°11'W) to a point offshore of Prudhoe Bay yielded 1.28 seals per nm^2 in 1981 and 1.84 seals per nm^2 in 1982, not a significant difference ($t = 1.03$, $df = 32$, $p > 0.10$). The 1982 effort also included eight flights in which a series of seismic and control lines were surveyed (Table 2). Observed densities along seismic and control lines did not differ significantly, except on 26 May when more seals (1.00 per nm^2) were observed along seismic lines than along control lines (0.48 seals per nm^2) ($t = 2.24$, $df = 13$, $p < 0.05$).

Responses of seals to anthropogenic noises

Haulout bouts of the radio-tagged ringed seals were monitored for 3 to 10 weeks (Table 3), and we documented the behavioral responses of seals that were hauled out in lairs when exposed to a variety of anthropogenic noises. Single observations were obtained during the approach of a seismic convoy, a hovercraft, and a dog. A seal (GI83) departed his lair when a seismic convoy was 0.64 km away. On another occasion, the same seal departed his lair when a dog approached within 5 m of the lair. Another seal (SA82) remained in her lair when a hovercraft passed at a distance of 2.5 km.

Responses of seals to helicopter noise was variable. Responses to helicopters landing and taking off (i.e., when the helicopters were applying maximal power and lift close to the surface) were noted six times. On two occasions, at distances of 1.0 and 3.0 km, the seal departed. On four occasions, all at distances greater than 2.5 km, the seals remained in their lairs. Seals departed lairs in five of 14 cases in response to airborne helicopters. In one case, the helicopter was directly over the lair at an altitude of 152 m, and in another case it was 5 km away at that same altitude when the seal departed. The closest approaches of airborne helicopters that were tolerated by seals in lairs were 0.6 km at an altitude of 122 m and directly overhead at an altitude of 762 m.

Nine observations of the seals' responses to operating snow machines were obtained. One seal remained in its lair on two occasions when snow machines were operating 0.5 km distant. Three other seals departed on seven occasions when snow machines passed within 0.5 to 2.8 km of their lairs.

Twenty-one approaches of people walking on ice in the vicinity of occupied

Table 1. Ringed seal densities observed along adjacent seismic and control transects during aerial surveys in 1981.

	Seismic Transects		Control Transects		
Date	Density (seals/nm^2)	Length (nm)	Density (seals/nm^2)	Length (nm)	T Test
3 June	0.82	47.6	1.41	41.2	$p<0.05$
5 June	1.37	81.8	1.70	48.2	$p>0.10$
9 June	1.12	130.0	0.89	91.0	$p>0.10$

Table 2. Ringed seal densities observed along adjacent seismic and control transects during aerial surveys in 1982.

Date	Seismic Transects Density (seals/nm2)	Seismic Transects Length (nm)	Control Transects Density (seals/nm2)	Control Transects Length (nm)	T Test
26 May	1.00	83.7	0.48	71.4	$p<0.05$
29 May	0.41	48.9	0.76	52.3	$p>0.10$
30 May	1.38	55.1	0.48	16.8	$p>0.10$
31 May	1.27	15.8	1.29	29.5	$p>0.10$
31 May	1.16	13.8	1.41	14.2	$p>0.10$
1 June	1.97	50.8	1.99	56.3	$p>0.10$
3 June	1.62	40.7	2.14	103.7	$p>0.10$
4 June	1.69	37.8	1.69	11.8	$p>0.10$

lairs were noted. In nine cases, the seals remained in the lairs, including four cases in which the people approached to within 0.2 km. In 12 cases where the seals responded by departing, people were walking 0.1 to 0.6 km from the lairs. In each of four cases in which a person walked within 0.1 km, the seal departed from its lair.

People on skis approached lairs 26 times. Seals remained in lairs during five of six approaches by skiers to within 0.2 km. Four departures were observed, one at 0.2 km, two at 0.3 km, and one at 0.4 km.

In all instances in which seals departed lairs in response to noise disturbance, they subsequently reoccupied the lair. The breathing holes and lairs known to have been used by the three female seals radio-tagged in 1982 (SA82, BA82, BE82) were within an extensive grid of seismic lines that had been vibrated a few weeks before the

Table 3. Ringed seals radio-tagged in the Beaufort Sea and Kotzebue Sound . (After Kelly et al. 1986.)

Seal no.	Sex	Age (yrs) indicated by claws	Weight (kg)	Date tagged	First signal received	Last signal received	Known minimal no. of lairs
BA-82	F	2	~46	4/17/82	4/19/82	6/04/82	2
SA-82	F	5	~68	4/22/82	4/23/82	6/03/82	1
BE-82	F	1	~40	4/25/82	4/26/82	6/04/82	1
TI-83	M	8	~135	3/22/83	4/09/83	6/02/83	3
GI-83	M	8	~110	3/23/83	3/24/83	4/26/83	2
DQ-83	M	8	68	3/30/83	4/11/83	5/19/83	2
BR-83	M	7	68	3/31/83	--	--	--
JO-83	M	8	73	3/31/83	4/23/83	5/20/83	1
LR-83	F	7	60	5/08/83	5/09/83	6/04/83	4
LK-84	F	5	77	3/04/84	3/07/84	5/11/84	3
LU-84	F	5	73	3/04/84	3/07/84	4/24/84	2
HU-84	M	5	68	3/05/84	3/06/84	4/19/84	3
ZO-84	M	7	72	3/13/84	3/15/84	5/14/84	1
NA-84	M	7	~77	3/26/84	3/27/84	5/15/84	2

seals were tagged (Figure 2). Each seal maintained at least one lair and one breathing hole within the grid of seismic lines. The breathing holes and lair access holes passed through 2 m of ice and presumably had been maintained since freeze up, or shortly thereafter. The breathing holes ranged from 19 to 129 m from the nearest seismic line; the lairs ranged from 250 to 700 m from the nearest seismic line. All of those structures remained in active use until at least early June, approximately two months after the seismic convoy had left the area.

Of the seals radio-tagged in 1983, three (two males and one female) occupied lairs within the grid of simulated seismic survey lines (Figure 2). One of the males (TI83) tended to haul out late at night in April and was never in his lair during the daytime hours that the seismic convoy operated (Kelly et al. 1986). The frequency and duration of his haulout bouts and their locations showed no significant changes in relation to the seismic operation.

The second male (GI83) was in his lair when the seismic equipment approached on 21 April and his departure, when the convoy was 0.64 km distant, was mentioned earlier. The next signal from him was heard on 23 April when he briefly hauled out at a different site than the one he departed two days earlier. Thereafter, five additional haulout bouts by that seal were recorded, at least two of them from the lair he departed in response to the convoy. No signals were received from his transmitter after 26 April when he hauled out briefly (less than one hour). On 17 May, examination of the lair he had occupied during the seismic survey indicated its continuing use as a haulout site, but we were unable to ascertain whether he or some other seal was using the lair at that time.

The female (LR83) using the 1983 seismic area was tagged after the survey was completed. Her four haulout sites were within the seismic line grid, and her birth lair probably was in use prior to the seismic survey (Figure 2). She continued to use that lair as late as 4 June, more than one month after the survey.

Fate of seal structures in areas of industrial activity

While lair use by the radio-tagged seals appeared to be interrupted only briefly by anthropogenic disturbance, we did observe cases of abandonment in our examination of other structures. We found evidence that the examination by investigators and the activities associated with seismic profiling and gravel island construction increased the rates of abandonment. Data on these points were obtained in 1982 on the shore-fast ice of the Beaufort Sea.

Of 37 structures that were opened and examined when first found, 46% were frozen or altered when revisited. Another 59 structures were only probed when first found, and 22% of those structures were frozen or altered when revisited. The difference in the proportion of structures frozen or altered was significant ($G = 6.35$, $df = 2$, $p < 0.05$).

The fate of 110 structures was investigated as a function of their distance from seismic lines and a gravel island under construction. Within 150 m of the seismic lines, 14/48 (29.2%) structures were abandoned, compared to 4/37 (10.0%) of the structures beyond 150 m of the same lines. The difference was statistically significant ($G = 5.53$, $df = 1$, $0.01 < p < 0.025$).

Within 8 km of the Seal Island construction site, the incidence of abandonment was 8/25 (32.0%), similar to the rates close to seismic lines. Near the island construction site, no differences were detected in abandonment rates within and beyond 150 m of the search lines.

We observed varying rates of abandonment in over 700 seal structures examined between 1982 and 1987. Our samples were grouped according to ice type, the amount of anthropogenic disturbance, and the number of examinations by the investigators. That breakdown resulted in the four samples shown in Table 4. They are; (1) 93 structures from the drifting ice, not subjected to unnatural noise disturbance; (2) 471 structures from shore-fast ice and not subject to human disturbance; (3) 148 structures from shore-fast ice and subjected to "on-ice" industrial activity; and (4) 107 of the above 148 structures after being subjected to two or more investigator examinations as well as industrial activities.

On the shore-fast ice with no significant anthropogenic disturbances (sample 2), only 4.0% of the structures were

Table 4. Rates of abandonment (freezing of breathing or access holes) of ringed seal structures in four samples collected between 1982 and 1987.

	Sample	Anthropogenic disturbance	N	Number frozen	Percent frozen
1.	Drifting ice Chukchi & Beaufort seas 1984 & 1987	None	93	12	12.9%
2.	Shore-fast ice Bering, Chukchi, & Beaufort seas 1983-1987	None	471	19	4.0%
3.	Shore-fast ice Beaufort Sea 1982	Seismic surveys, island building	148	20	13.5%
4.	Shore-fast ice Beaufort Sea 1982	Seismic surveys, island building, & investigator examinations	107	35	32.7%

frozen. This represents what we consider to be the natural rate of abandonment on shore-fast ice during our study.

Of the structures in the shore-fast ice that were subjected to industrial noise (sample 3), 13.5% were abandoned when first examined. The difference in abandonment rates between the industrially disturbed sample (3) and the undisturbed sample (2) was highly significant ($X^2 = 17.14$, df = 1, $p < 0.001$). In sample 4, which includes 107 of the structures from sample 3 that were subjected to multiple examinations as well as to industrial activities, the abandonment rate was 32.7%, indicating a significant increase due to the investigator's activities ($X^2 = 12.42$, df = 1, $p < 0.001$).

Sample 1 includes 93 structures from the drifting ice and is included for comparison with the shore-fast ice samples. Compared to the latter habitat, the drifting ice is less stable. Furthermore, a high proportion of ringed seal structures in the drifting ice are opened by polar bears, a source of natural disturbance similar to that of our opening a lair. In the 1987 drift-ice sample, 22/39 (56.4%) of the structures had been visited by bears, but that proportion was biased since the sample was collected while following bear tracks (Kelly et al. 1987). The 1984 drifting ice sample was random, however, and of 54 structures in that sample, nine (16.6%) were visited by bears. The rate of abandonment of structures in the drift ice (sample 1) was 12.9%, similar to that found on the shore-fast ice in 1982 (sample 3). Only one other sample not subjected to industrial disturbance showed rates of abandonment similar to those in the drifting ice. One of seven undisturbed, shore-fast ice samples exceeded 5% abandonment. That sample, collected near Barrow in 1986, had a 12.8% abandonment rate and was associated with a very high incidence of arctic fox activity.

Discussion

The responses of ringed seals to noise disturbance were quite variable as indicated by the behavior of radio-tagged seals and by the rates of abandonment of seal structures near and at various distances from human activities. Some structures remained in active use despite close proximity to seismic survey lines, snow machine trails, gravel island construction, and helicopter flight paths. Other structures were abandoned quickly when exposed to noises at greater distances. That variation probably is due in part to differences in the noise environment that are difficult to measure. For example, helicopter noise is muffled on warm, cloudy, snowy, or windy days and is loudest in clear, calm, cold conditions. A snow machine, or person on foot or skis, produces different kinds and levels of noise when the snow is very cold and hard or windblown compared to newly fallen, relatively warm or soft snow. Snow machines travelling over smooth ice sound different than those over rough ice. Also, the seals' sensitivity to anthropogenic noise may lessen when background noise, such as from wind-driven snow or ice movement is high.

In spite of an array of variables not accounted for, it is apparent that ringed seals in lairs are aware of sound intrusions, and they generally react to mechanical conveyances at greater distances than they do to people on foot or on skis. The individual variation in their reactions, however, makes it difficult to define "critical" distances for noise disturbances. Although we found fewer active seal structures within 150 m of seismic lines than beyond that distance, we cannot say how the rate of abandonment changed within that range, which was chosen on the basis of sample size, rather than distance per se.

Gravel island construction appeared to result in displacement of ringed seals at rates similar to those observed close to seismic survey lines. Our data suggested that the radius of disturbance was greater around Seal Island when it was under construction than was the radius around seismic exploration, but the data are insufficient for determining the distance from the island at which the incidence of abandonment began to decrease.

The displacement of some seals within two hundred meters of seismic lines probably results in little, if any, increased mortality since, as we reported elsewhere (Kelly 1985; Kelly et al. 1986), individual seals use more than a single lair and as many as four or five lairs each. Our telemetric studies indicated that the distances between lairs used by individual seals averaged 572 m for females and 2,018 m for males (Kelly et al. 1986). We do not know if mortality would be likely to occur if individual seals were displaced completely from the areas containing all of their lairs. At the very least, such an event would be likely to increase intra-specific strife by forcing displaced seals to use structures maintained by other seals.

That ringed seals respond to noise disturbances by fleeing into the water probably is the result of their subjection to predation by polar bears and arctic foxes. Weddell seals (Leptonychotes weddelli), which breed on the shore-fast ice of Antarctica, have evolved in the absence of surface predators and are much less readily disturbed (Stirling 1977; Kooyman 1981). The rates of ringed seal structure abandonment that we observed in areas of noise disturbance were more than three times greater than the overall rates in undisturbed areas but similar to the rates in areas of frequent predator activity.

Increasing the frequency with which ringed seals flee lairs may increase stress levels and energy demands at times when rest is important to their well-being. Lair occupation becomes increasingly frequent and longer in duration throughout the spring months (Kelly et al. 1986), apparently due to the seals' need to maintain high epidermal temperatures while replacing their pelage (Feltz and Fay 1966).

Of potentially greater importance are the effects of disturbances that cause structures to be completely abandoned. That occurrence would be deleterious especially for nursing pups. Furthermore, females with nursing young are more susceptible to disturbance in lairs by virtue of their more frequent and extended haulout bouts (Kelly et al. 1986). Short of abandoning a pup, female seals can take them through the water to alternate lairs (Smith and Stirling 1975; Taugbøl 1982). If a newborn pup is forced into the water, however, it may not survive the resultant heat loss. At birth, ringed seal pups do not have the insulating blubber layer that protects older seals from excessive heat loss when submerged. Pups that do survive swimming through the water to an alternate lair would have to expend significant amounts of their energy reserves in order to maintain core temperature while drying (Taugbøl 1982). Those pups would be easier prey for polar bears and arctic foxes and would be less able to withstand other stresses.

Our investigation focused on the effects of noise disturbance on the seals' use of lairs and breathing holes. From our telemetric studies, we know that seals spend the majority of the time in the water under the ice (Kelly et al. 1986). Little is known about their activities under the ice, although much of it must involve feeding and, perhaps, territorial defense. Sound is readily conducted through the ice into the water, and the effects of noise disturbance on seals under the ice remains unknown. Recent experiments with captive ringed seals suggest that ambient noise provides a critical navigational cue to seals swimming under ice in total darkness (Wartzok et al. 1987).

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