NATURAL AND SYNTHESIZED AGGRESSIVE SOUNDS AS POLAR BEAR REPELLENTS

DONALD R. WOOLDRIDGE, Department of Biological Sciences, Pestology Centre, Simon Fraser University, Burnaby, British Columbia V5A 1S6
PETER BELTON, Department of Biological Sciences, Pestology Centre, Simon Fraser University, Burnaby, British Columbia V5A 1S6

Abstract: Aggressive sounds were recorded during a confrontation between 2 male polar bears (*Ursus maritimus* Phipps). These sounds were analyzed for frequency content, envelope, rhythmic patterns, and duration. Nine synthetic versions were generated to simplify, duplicate, or exaggerate components of the original sounds. The behavior of 5 captive polar bears, 2 captive brown bears (*U. arctos* L.), 13 wild black bears (*U. americanus* Pallas), and 18 wild polar bears was observed in response to these sounds. One or more of the variants produced a significant repellent effect in each bear tested. We defined a repellent effect as an immediate and rapid movement away from the speaker, with a continued retreat as long as the sound was produced. The effects of these sounds on the heart rate of captive polar bears were measured with an implanted heart-rate transmitter. The 4 sounds with the greatest apparent effect in the field also produced the greatest increases in heart rate in the captive implanted polar bear.

Many confrontations between man and bears have resulted in death or damage to man or his property. Increased utilization of Canada's arctic regions has increased the numbers of human encounters with polar bears. In January 1975, an employee for Imperial Oil, stationed on an offshore drilling island located in the Beaufort Sea, was attacked and killed by a polar bear. This rig and others are now under the protection of armed Inuit hunters. Since that time, 3 intruding bears have been shot after unsuccessful attempts to drive them away. Pederson (1956) cited 2 cases of attacks on men by polar bears, and Manning (1973), Parker (1974), and Stirling (1975a) report apparently unprovoked attacks on men. Jonkel (1975) reports an attack at Norwegian Bay on a sleeping man and suggests that the bear may have mistaken the man for a loafing seal. He also reports an attack in which an employee of the Department of Energy, Mines and Resources was bitten and hit before the bear was shot by another worker. In August 1975, a reported attack proved to be a probable suicide upon which the bear fed (Jonkel 1975). National Personnel of the Canadian Department of National Defense have had some encounters with curious polar bears in the course of their summer field research camps on Devon Island. Safety in their camps is improved with a trip-wire detection system.

Churchill, Manitoba, experiences a large influx of polar bears each fall for approximately 2 months, but few attacks have been recorded. The area is protected by a 24-hour patrol, manned by personnel from the Department of Renewable Resources. Jonkel (1970a, b) concludes, on the basis of the behavior of captive North American bears, that the polar bear is probably less aggressive than the grizzly bear. One reason for the apparent seasonal change in numbers of man-bear encounters in the Arctic must be the nutritional stress that the polar bears undergo in late fall and winter. Mature males add territorial challenges to the problems facing subadult males, which have proved to be the most common problem animals. These 2 factors combine to produce an animal that is likely to investigate any potential food source.

The use of sound to repel vertebrate pests has been investigated by Frings et al. (1955), Frings and Frings (1957, 1963), Maclean (1974), Stewart (1974), Dracy and Sander (1975), and Belton et al. (1975). Frings et al. (1955:340) and Frings and Frings (1957:91) observed that "biologically significant" sounds were more distressing to birds than simple ultrasonic or sonic sounds. Frings et al. (1955) noted the ability of such sounds to evoke flight in the starling (*Sturnus vulgaris*). Frings also noted an interspecific response to recorded alarm calls of the herring gull (*Larus argentatus*) by both the great black-backed gull (*L. marinus*) and the laughing gull (*L. atricilla*). Maclean (1974) produced repellent sounds to which both laboratory and field-tested rats responded. He employed intense ultrasonic fields (20 kHz at 130 dB) although the repellent effects were permanent only if food and water were alternately accessible. Dracy and Sander (1975) were able to induce anxiety in coyotes (*Canis latrans*) by exposing the test animals to an 18-kHz sound; no intensity was specified. Belton et al. (1975) investigated the use of ultrasonic and sonic sounds as repellents in polar bear control. Some evidence of discomfort was observed in the bears when they were exposed to 7 kHz at 100 dB. Stewart (1974) suggests that his Av-Alarm system operates as an auditory jamming sound, leading to increased levels of psychological stress.

The objectives of this study were to determine the response of captive and free-ranging black, brown, and polar bears to natural and synthetic aggressive sounds.

The intent of these experiments is the development of an acoustic repellent system that might reduce or prevent dangerous bear-man encounters.

This research, conducted from 1975 to 1977, was supported in part by grants from Imperial Oil and the National Research Council of Canada. B. Hodges of the Olympic Game Farm; N. Oritsland and C. Jonkel of Churchill, Manitoba; B. Haagensen and T. Melnyck of Imperial Oil; J. Lay of the British Columbia Department of Fish and Wildlife; and C. Mueller of Simon Fraser University are gratefully acknowledged.

METHODS AND MATERIALS

Recording Natural Aggressive Vocalizations

Natural aggressive vocalizations of 2 male polar bears were recorded at the Olympic Game Farm, near Sequim, Washington. Both bears were positioned in 1 cage and were offered a single piece of raw beef, vocalizations included hisses and throaty growls. Loud directed roars were recorded with a Uher 4000-L Reprt recorder and a Grampion parabolic reflector. The bears were approximately 5 m from the microphone during recording.

Analysis of the Natural Aggressive Vocalizations

Sounds were analyzed for frequency content on a Kay Elemetrics Co. Type 8/65 Sonagram that gives a plot of frequency versus time on a calibrated drum. The sounds were also analyzed on a Bruel & Kjaer Third-Octave Band-Pass Filter Analyser that verified the Sonagram analysis and gave a more accurate indication of the relative amplitudes of each of the frequencies within the vocalizations (i.e., the amplitude envelope).

Synthesis of Aggressive Sounds

The analysis of the natural vocalizations yielded information on frequency, rhythmic patterns, and duration, which allowed us to synthesize analogs of the natural sounds. The synthesis was achieved through modulation and modification of 3 basic sounds: a foghorn and 2 types of automobile engines. These basic sounds were chosen because of the ease with which we could alter their characteristics.

Modulation of each base sound was carried out by passing the sound content through a series of electronic devices that shaped and clarified the content into that which we desired. The basic sounds were passed through a filter bank that smoothed the sounds. This low-level input was then amplified and passed through a ring modulator, an additive unit that produced a preprogrammed modification of the sine wave components of the base sound. F_1 sine wave frequencies of the base sound were added to by specific chosen F_2 frequencies, according to our program formula:

$$(F_1 \pm F_2) + (3F_1 \pm F_2) + (5F_1 \pm F_2).$$

It is apparent from this program that larger values of F_2 (which were specified) resulted in a wider but emptier sound, whereas smaller values of F_2 generated a denser sound. it was therefore possible to create sounds loaded around the base sound frequencies or to create lightly loaded sounds with a greater overall spectrum.

Finally, the resultant complex sound was passed through a Krohn-Hite 3100R Band-Pass Filter, adjusted so as to limit the harmonics and the upper and lower limits of the sound and to produce the sharp attack or initiation of the sound, which we had noted in natural vocalizations. The resultant sounds were analyzed on the Bruel & Kjaer equipment to verify their fit with respect to our original intentions.

The F_2 modulation frequencies supplied to the ring modulator program were (1) foghorn: 220, 20, 150 Hz; (2) auto source 1: 160, 25 Hz; and (3) auto source 2: 150 Hz.

Captive Polar and Brown Bears

Captive polar and brown bears at the Olympic Game Farm were subjected to our test sounds and to the original natural vocalizations. An interval of approximately 15 minutes was allowed between each test. We defined a positive response as an immediate and rapid reaction resulting in the swift retreat of the target animal. The bear had to continue to respond in this way for the duration of the test. Free-ranging animals tested later were required to continue their retreat for a distance of 100 m. Any response less than our defined response was discarded as not being of value in an actual situation. Captive subjects, because they were unable to run away, required careful evaluation. Obvious behavioral changes were noted in these instances.

Wild Black Bears

The responses of free-ranging black bears to our test sounds were evaluated at a dump in the lower mainland area of British Columbia and at 3 dump sites and a fire suppression camp in the eastern interior of the province. Seven- to 10-minute intervals were maintained between acoustic tests. Bears that could be visually identified and that were frightened by a specific sound were tested with different sounds the next day. Because more than 1 sound proved effective with particular animals, some bears did not return after 2 or 3 tests, and it was therefore impossible to try all sounds on each animal. A 20-W amplifier, cassette, and 0.5 m reflex horn were used to produce test sounds.

Wild Polar Bears

The dump area and the incinerator site at Churchill, Manitoba, were the sites of our field tests on free-ranging polar bears. Attractant stations were maintained at suitable locations. Gainsburger dogfood patties soaked in sardine oil were used to bring the bears close to our test apparatus. A 20-W public address system, a 0.5 m double reflex horn, and a cassette deck were used to generate sounds. The open country allowed us to test bears over long ranges, and sounds were played to animals up to 250 m away.

Captive Polar Bears: Telemetry

A recently captured polar bear from the Churchill area was fitted with an implanted heart-rate transmitter. The device was a silicon-wax embedded FM transmitter, and was placed under the skin in the ventral thorax region. Two stainless steel electrodes ran laterally from this unit and picked up cardiac electrical impulses. The FM signal, picked up on an FM receiver, was then placed on a Gould-Brush Accuchart recorder for permanent record. Three tests of each sound were run, and average heart-rate increases were subjected to a 1-tailed *t*-test for significance at the 0.95 level. A level of 60 dB (measured on a sound meter 1 m from the speaker) was used in all tests.

On-site Installation: Beaufort Sea Drilling Rig

In December 1975, Wooldridge installed an acoustic repellent system on one of Imperial Oil's offshore drilling rigs. The system consisted of 4 speakers, a cassette player, and a 70-W amplifier. The speakers were positioned so as to broadcast the sounds outward from the rig. The sound level was adjusted to approximately 120 dB measured 1 m from the speaker.

RESULTS

Analysis and Synthesis of Sounds

Sonogram analysis (Fig. 1) gave us the frequency spectrum of an aggressive polar bear roar. We analyzed several of these plots in order to establish all of the required frequencies inherent in the vocalization. Apparent frequencies were in the ranges of 80, 100, 150, 200, 220, 300, 400, and 600 Hz, with some hiss sounds

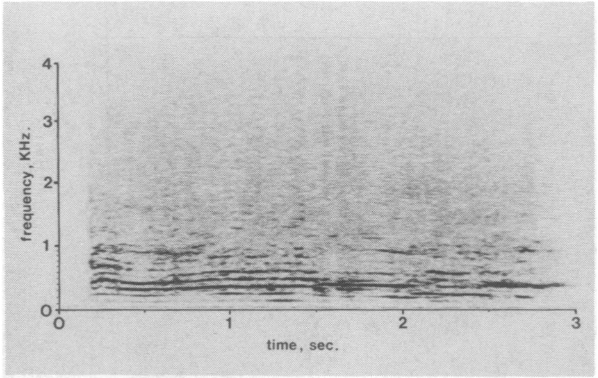

Fig. 1. Sonogram of a typical polar bear aggressive vocalization.

in the background. Frequency amplitude envelopes for the natural and synthesized sounds are given in Fig. 2; T refers to *sound type* in this figure. Some roars consisted of 2 or 4 roars; the majority of vocalizations consisted of 3 bursts. The lung capacity of a polar bear may be the upper limiting factor in the number of roars produced. This possibility suggested the synthesis of longer and more frequent roars, thereby producing a suprastimulus. T_2, T_4, and T_6 are all of longer duration than T_1, the natural sound. The rapid attack seen in the amplitude envelopes of T_2, T_4, and T_5 exaggerate this characteristic. T_5, T_6, and T_7 show a level of background "white" noise similar to that in natural sounds. T_7 attempted to duplicate the general rhythmic and amplitude patterns of the T_1 sound.

Frequency envelopes show good correlation with natural vocalizations and indicate that the synthesized sounds closely approximated natural sounds.

Captive Polar and Brown Bears

A total of 5 polar and 2 brown bears were subjected to our test sounds. The 2 polar bears that were the original source bears for our recordings of natural vocalizations responded the least of all captive animals. One polar bear did not react to any of the sounds and exhibited typical signs of "zoo neurosis." The 3 other polar bears were either younger, female, or both, and were apparently intensely frightened by our tests. They attempted to escape through the wire at the rear of their cages by running at it. Unable to escape, they cowered in the far corners of their cages. The brown bears gave the most dramatic responses; both of them tried to run through the wire backs of their cages and then attempted to climb up and out through the bars. Towards the end of our tests, our mere approach caused these bears to retreat. They had rapidly become conditioned to the fact that we produced the repellent sounds.

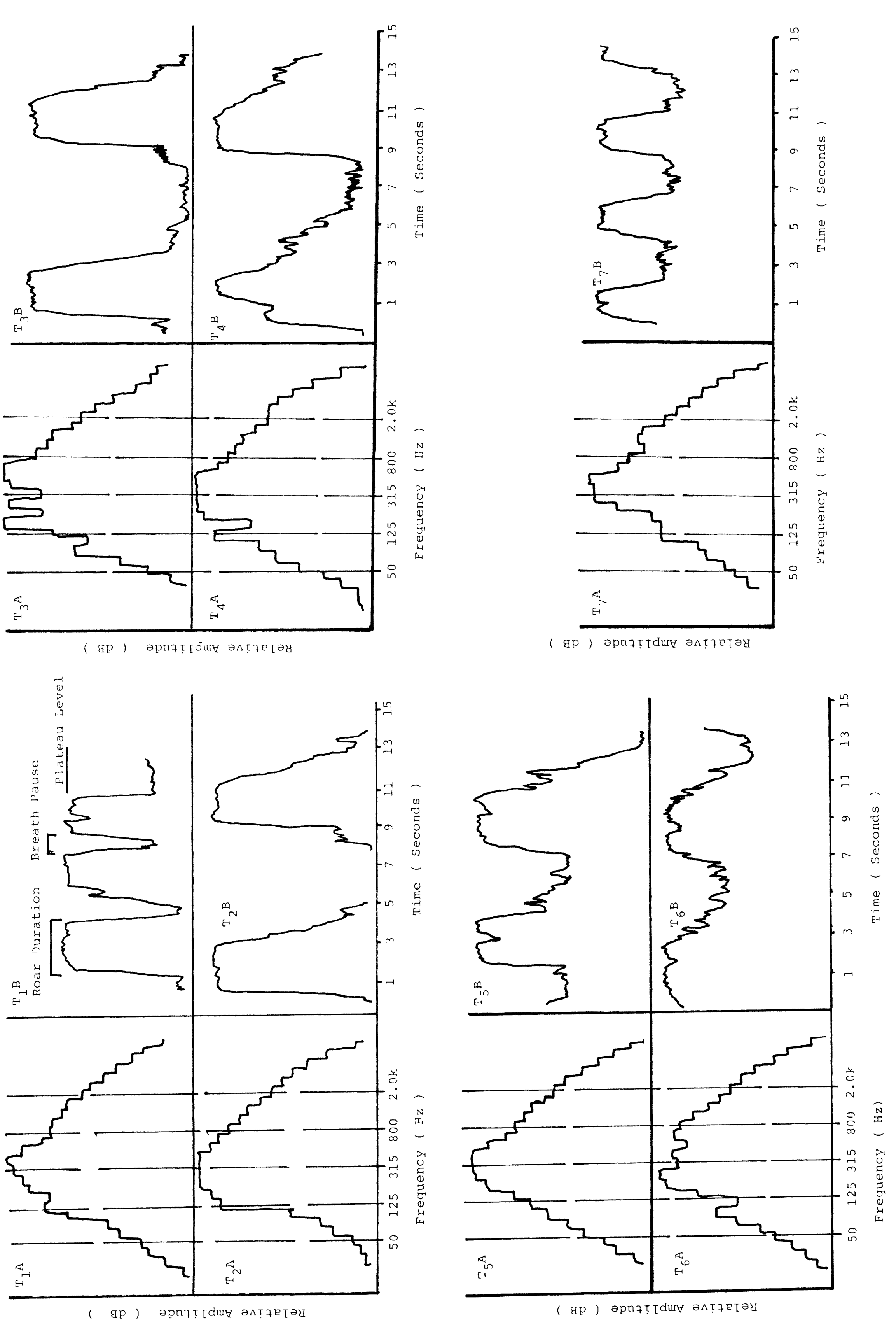

Fig. 2. Amplitude vs. frequency and amplitude vs. time. T_1 = natural sounds: $T_{2\text{-}7}$ = synthetic sounds. Relative amplitudes for frequencies are given for natural (T_1) and synthesized ($T_{2\text{-}7}$) sounds in "A" on these plots. Relative amplitudes vs. time are given in "B" on these plots.

Wild Black Bears

A total of 13 free-ranging black bears were exposed to our test sounds. All responded significantly to at least 1 of the sounds, and most responded to 3 or more (Fig. 3). We were able to carry out multiple tests at dumps, because the bears at those sites seemed to be permanent residents. Insignificant responses were characterized by hesitation and apparent indecision to leave the area. Often, ineffective sounds resulted in the immediate return of the bears. We were then able to try other sounds. Effective responses were characterized by the rapid retreat of bears, followed by their absence from the area for at least 2 hours. In most instances the bears did not return while we were at the test site. We observed no aggressive reactions to the sounds.

Wild Polar Bears

A total of 19 wild polar bears were subjected to our test sounds. One female, with 2 cubs, reacted aggressively towards sound type T_2. This same bear was exposed to T_1 3 days later, and she retreated rapidly after initial hesitation. All other polar bears tested retreated upon exposure to an effective sound. One bear, sleeping at an estimated distance of 250 m, was awakened by T_6; he retreated rapidly until he was out of our sight and range. Four polar bears were subjected to repeat tests carried out on subsequent days.

Telemetry Studies

Table 1 summarizes our heart-rate data. Percent increases were greatest for sound types 1, 3, 5, and 6 with corresponding values of 54, 75, 138, and 180 percent increases. Types 4 and 10 gave values of 30 and 31 percent. Rates before and after initiation of each test were averaged for the 3 experiments, and these values were tested for significant differences at the $P = 0.95$ level of significance. Percentage increases over 50 percent generally resulted in apparent fear responses involving movement away from the sound source and, on several occasions, attempts by the test animal to climb out of the small barred window at the rear of the holding cage. The level of increase diminished over the 3 days of tests, indicating a degree of habituation to the sounds, probably compounded by the inability of the bear to escape them and the lack of any reinforcement accompanying the aggressive vocalizations.

Fig. 3 presents a general summary of the effects of all of the sound types. In general, wild polar bears responded most strongly to their own and our synthesized aggressive sounds. Wild black bears also reacted strongly, whereas captive polar and brown bears appeared to be less affected by loud aggressive sounds. This result is understandable as they are always in close association with men and human sounds. Heart-rate increases correlated well with field observations. Some differences existed; however, these may have been due to the acoustics of the small room (introducing changes in the sound parameters) and the various factors associated with the confinement of the test bear. Replication in field experiments was possible in 4 instances. Bears so tested appeared to react more strongly in subsequent tests.

On-site Drilling Rig Tests

In late February 1976, a polar bear approached the Beaufort Sea drilling rig that had been fitted with our acoustical repellent system. The sounds were initiated when the bear was at least 800 m away. The animal hesitated, and then moved away after approximately 1 minute. Observations on the response of this bear were reported by several individuals, but the reports were not in general agreement. The bear was subsequently chased and shot and was reported to be in a semistarved condition, which is not uncommon in this region in the middle of winter. No distinction between known effective and ineffective sounds was made by rig personnel, and it is possible that a less effective sound may have been broadcast to the animal.

DISCUSSION

Initial studies of the responses of free-ranging and captive black, brown, and polar bears to biologically significant sounds suggest that these sounds may be effective in repelling nuisance bears. Comparison of response and sound type has allowed us to speculate on the required components of an effective bear-scaring sound. The frequency content should be within the range of 100-600 Hz, with frequency distribution in predominant bands at approximately 100, 125, 150, 200, 250, 400, and 600 Hz. These frequencies must fit within a frequency envelope that emphasizes those bands between 150 and 300 Hz. The amplitude-time plot, or amplitude envelope, must conform to a shape that is characterized by a relatively sharp *attack* (a near vertical slope), a plateau region of 2-4 seconds duration, and an attenuation of sound less severe than the attack. Finally, each roar, as described above, should be repeated 3 or 4 times in a series, at intervals of approximately 1-4 seconds.

The amplitude of the sounds in actual field use should be 100 dB, which is extremely loud at short

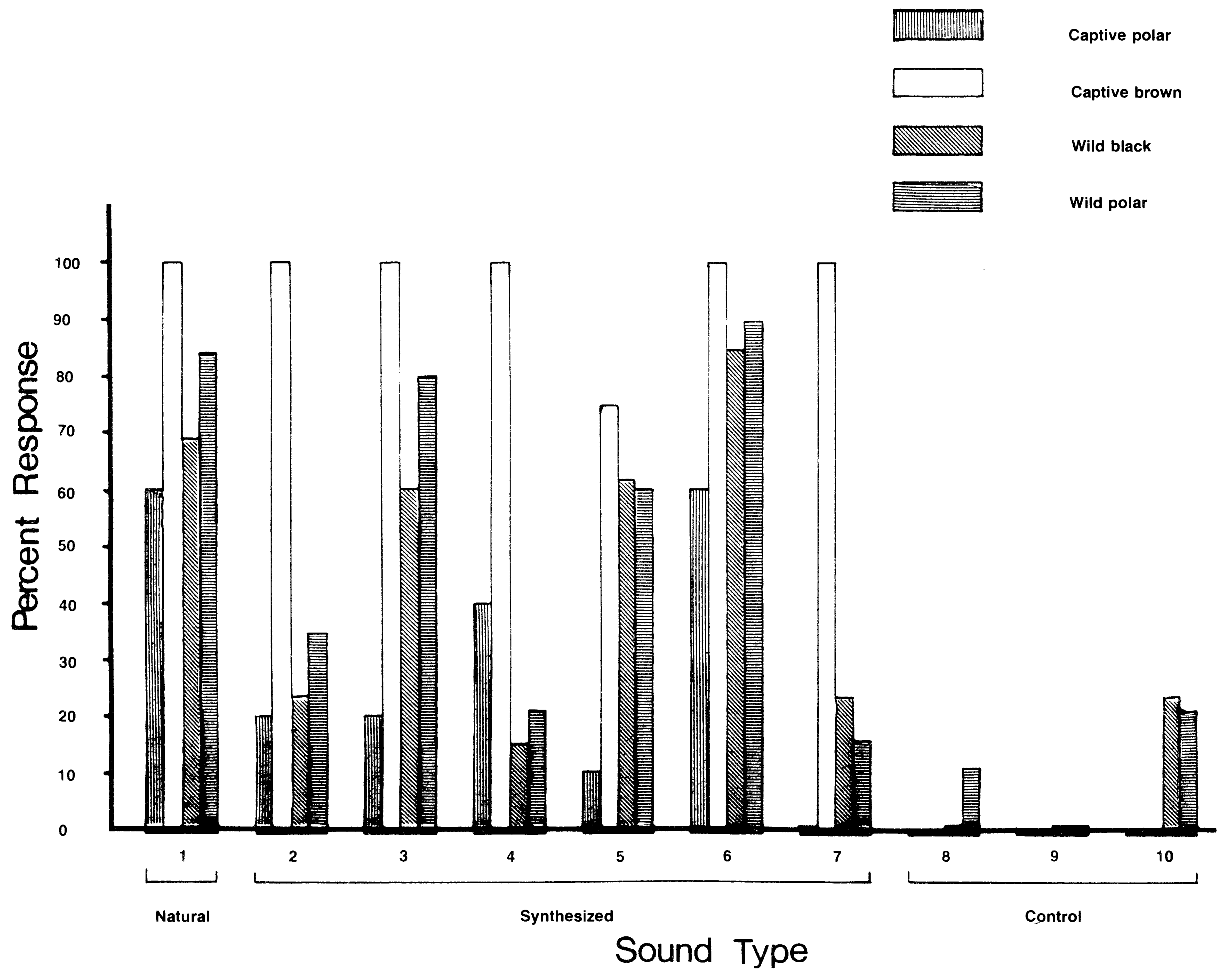

Fig. 3. Response vs. sound type. Frequency distribution of the total number of avoidance responses (expressed as a percentage) to each sound type, including the 3 control types (T_8, T_9, T_{10}) for captive polar and brown bears and for free-ranging black and polar bears.

Table 1. Effects of natural and synthesized sounds on the heart rate of a captive polar bear. Test 1, mean heart rate after sound = 129.0 bpm. Test 3, mean heart rate after sound = 110.6 bpm (14 percent decrease). One-tailed t-test for ($n_1 \pm n_2 - 2$) = 4 df at 0.05 level of probability is significant if $t > 2.13$.

Sound type	Test 1		Test 2		Test 3		X_b	X_a	Percent increase	t value	Rank
	Before sound	After sound	Before sound	After sound	Before sound	After sound					
1	105	170	110	168	100	150	105	163	54	8.26	2
2	120	135	105	110	100	98	108	114	5	0.48	
3	100	160	65	140	75	120	80	140	75	3.86	4
4	90	125	80	95	100	130	90	117	30	2.16	6
5	105	175	60	155	36	150	67	160	138	4.30	3
6	55	170	45	160	72	150	57	160	180	10.51	1
7	72	88	80	90	110	98	87	92	5	0.39	
8	60	72	85	87	95	100	80	86	8	0.48	
9	70	100	90	96	100	110	87	102	17	1.57	
10	70	95	95	120	80	110	82	108	31	2.60	5
Mean heart rates:		129.0				121.6					

distances from the speaker source and may in itself effect a retreat. At our test amplitude of 120 dB, we successfully rousted a bear at a distance of 250 m; continued application of the sounds resulted in the retreat of the bear to an estimated 500 m, at which point the test was discontinued.

Some positive responses by target bears were considered to be of minimal practical value in bear-man confrontations and were therefore disregarded in our observations. About 30 percent of our observed negative responses were in fact weak positive responses and were characterized by hesitation in an advance or by a slow retreat. No habituation was observed in the field. Four bears subjected to repeat tests at Churchill, Manitoba, appeared to respond more readily on second exposure to our test sounds. This readier response was probably due to the reinforcement that these animals sometimes receive from other, dominant animals. Such real aggressive encounters are often coupled with either a visual display or actual physical blows. Our sounds may act as releasers of responses that have been learned in the bears' daily life. Habituation appeared to be occurring in the responses of the captive polar bear fitted with an FM transmitter. His overall heart-rate increase for all sounds presented decreased from a mean of 129 beats per minute to 110.6 beats per minute, 14 percent over 3 days of tests. The conditions of his confinement and his continued exposure to the presence of people may have reduced his responsiveness to frightening sounds.

Repellent sounds offer advantages over conventional methods of bear control. They are nondestructive and require no actual contact between bear and equipment. They appear to be effective over moderately long ranges (250-500 m), probably because of their significance to the target animal. As a result of their electronic origins, they are easily interfaced with devices designed to detect the intrusion of bears. In the severe arctic environment, such detection devices may prove to be the only truly effective equipment capable of warning of the approach of an intruding polar bear.

Research is continuing at the time of writing. Field tests under arctic conditions, simulating actual field installations, should lead to definitive conclusions about the efficacy of this technique. Incorporation of repellent-sound devices offers the potential of reducing the numbers of dangerous bear-man encounters and of protecting polar bears in their home environment from destructive removal techniques in those instances where other alternatives exist.

LITERATURE CITED

BELTON, P., C. MUELLER, AND D. WOOLDRIDGE. 1975. Can sound be used to repel polar bears? Rep. to Imperial Oil. 7pp.

DRACY, A. C., AND D. R. SANDER. 1975. The effect of sound as a deterrent to coyote predation. South Dakota State Univ. Annu. Rep. WC 123.

FRINGS, H. W., AND M. FRINGS. 1957. Recorded calls of the eastern crow as attractants and repellents. J. Wildl. Manage. 21(1):91.

———, AND ———. 1963. Sound: a better way to control. Electronics 36(2):24-26.

———, ———, B. COX, AND L. PEISSNER. 1955. Recorded calls of herring gulls (*Larus argentatus*) as repellents and attractants. Science 121(4):340-341.

JONKEL, C. J. 1970a. Some comments on polar bear management. Biol. Conserv. 2(2):115-119.

———. 1970b. The behavior of captive North American bears. BioScience 20(21):1145-1147.

———. 1975. Summaries of several unreported polar bear-man encounters in the Canadian Arctic. Can. Wildl. Serv. Polar Bear Proj. Spec. Rep. 90. 3pp.

MACLEAN, K. 1974. The effects of ultrasound on the behavior of commercial rodents with a discussion of its potential in management and control programs. M. S. Thesis. Simon Fraser Univ., Burnaby, B. C. 180pp.

MANNING, T. H. 1973. Polar bear killed in self-defense. Can. Wildl. Serv. Polar Bear Proj. Spec. Rep. 86. 2pp.

PEDERSON, A. 1956. Der eisbar, rastloser wanderer in nordpolargebeit. Kosmos, Jahorg. 52(12):554-559.

STIRLING, I. 1975a. Polar bear attack, Mackenzie Delta 1972? Can. Wildl. Serv. Polar Bear Proj. Spec. Rep. (In prep.)

———. 1975b. Summary of fatality involving a polar bear attack in the Mackenzie Delta, January, 1975. Can. Wildl. Serv. Polar Bear Proj. Spec. Rep. 89. 2pp.

STEWART, J. L. 1974. Experiments with sounds in repelling mammals. Proc. Vert. Pest Conf. 6:222-226.