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GRAY WHALES (*Eschrichtius robustus*) IN THE BEAUFORT, CHUKCHI, AND NORTHERN BERING SEAS: DISTRIBUTION AND SOUND PRODUCTION a)

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ABSTRACT

Gray whale distribution and sound production has been studied while conducting aerial surveys for endangered whales in arctic waters. Gray whale distribution extends from Bristol Bay in the Bering Sea, to the Baille Islands in the eastern Beaufort Sea. A concentration of feeding whales occurs seasonally in the northern Bering Sea between St. Lawrence Island and the Bering Strait, with estimated densities to 0.26 whales/nmi^2. There is an indication that smaller, juvenile gray whales may migrate further north and be less involved in feeding than adults. Sounds recorded in the presence of feeding gray whales were primarily metallic knocks emitted in series. These knocks averaged 963 Hz, 106 ms with an average 1/140 ms repetition rate. Other sounds included grunts, moans and miscellaneous high frequency pops. Grunts and moans averaged 388 Hz, 344 ms and 325 Hz, 913 ms, respectively. Miscellaneous sounds were few in number and not systematically analysed. A complex moan is presented having divergent tonal components within one sound.

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INTRODUCTION

Gray whales (Eschrictius robustus) migrate into the Bering, Chukchi and Beaufort Seas each summer, primarily to feed. Gray whales are frequently sighted as far northeast as Pt. Barrow, Alaska (71° 23′ N, 156° 25′ W) with rarer sightings along the northern coast of Alaska to Barter Island (70° 08′ N, 143° 35′ W) (Maher, 1960). The extreme easterly site record in arc-tic waters was 3 gray whales seen between Tuktoyaktuk, Canada and the Baille Islands in the eastern Beaufort Sea (Rugh and Fraker, 1981).

Sounds produced by gray whales have been recorded and described for migrating, captive and feeding whales (Eberhardt and Evans, 1962; Asa-Dorian, 1967; Cummings et al, 1968; and Fish et al, 1974), and have been onomatopoeically -termed growls, grunts, moans, blow sounds, bubble-type signals, clicks and metallic knocks. Dahlheim and Schempp provide a detailed review of published gray whale acoustical reports in this volume.

The distribution and sound production of gray whales has been studiedby the Naval Ocean Systems Center (NOSC) while conducting aerial surveys for endangered whales in are-tie waters in 1980 and 1981 under the auspices of the Bureau of Land Management (BLM) (Ljungblad, 1981; Ljungblad et al, 1982). Sounds produced by gray whales feeding in the northern Bering and Chukchi Seas have been recorded in the course of these studies. The recorded sounds described here are the first for gray whales in arctic waters. These data provide valuable information on gray whale habitat utilization patterns and behavioral ecology in its northerm most range.

METHODS

Study area and aerial surveys

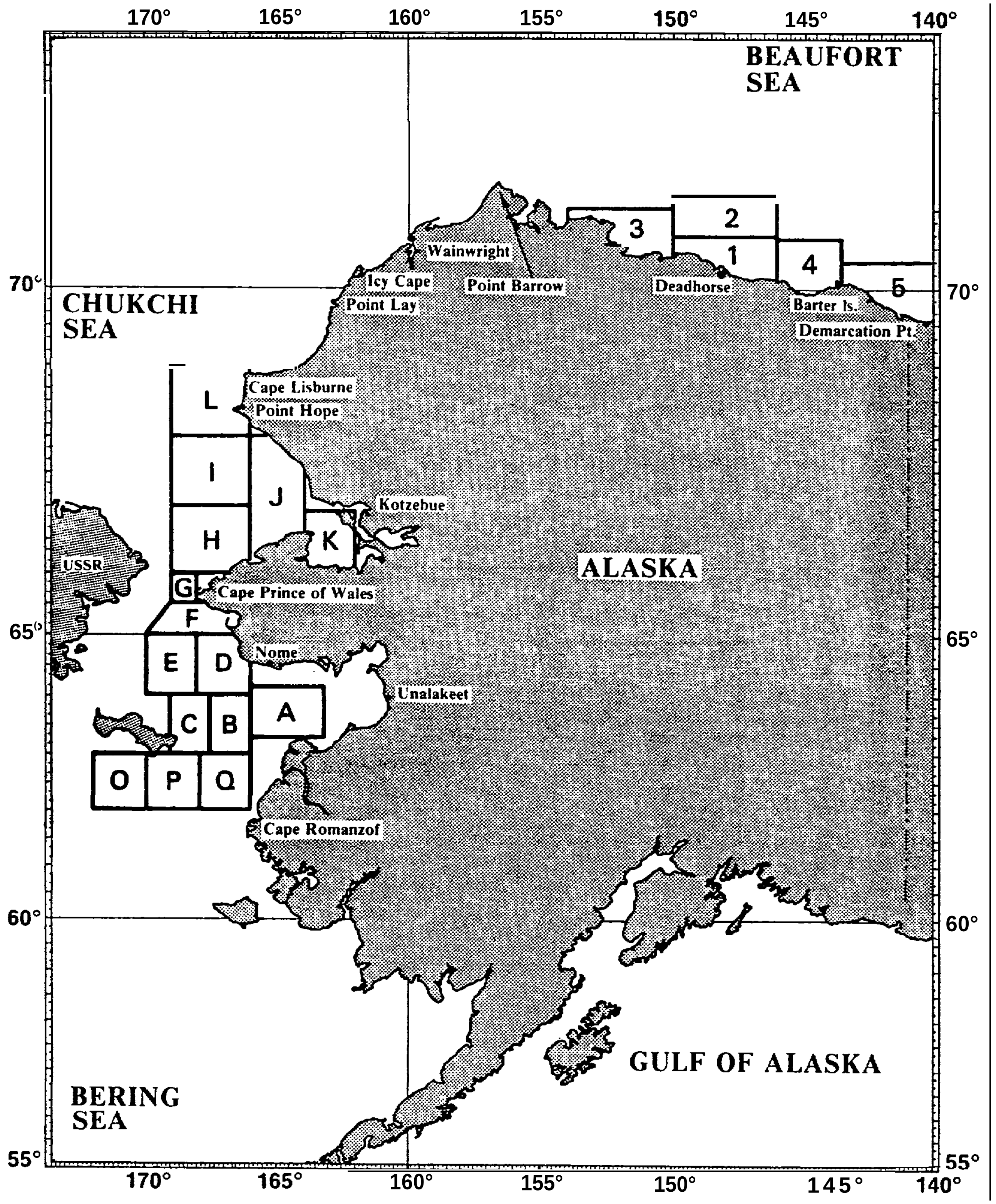
The BLM has funded NOSC to determine occurrence, distribution and relative abundance of endangered whales in the Beau fort, Chukchi and northern Bering Seas since 1980. These studies have been primarily focused on the bowhead whale (*Balaena mysticetus*), though data have been gathered on gray whales whenever possible.

Aerial surveys have been used as the best means for sampling such a large area over a short period of time. Aerial surveys may be classified into one of three types: 1) transect surveys in predetermined blocks (Figure 1) with randomly determined turning points, flown to assess distribution and estimate relative density, 2) search surveys, flown in areas of maximum probability of sighting whales to observe behavior and record sounds and 3) coastal surveys, primarily flown to assess distribution and when relocating to a new field station.

The aircraft used was a Grumman Turbo Goose provided by the Office of Aircraft Services, Department of the Interior, Anchorage, Alaska. It was equipped with a Global Navigation System (GNS) which has 0.37 km/h precision providing continuous position updating and transect turning point programming. Surveys were usually flown at 153m, but were adjusted with weather to maximize visibility. Altitude while circling to observe behavior and record whale sounds averaged 300m. Air speed varied between 222 and 296 km/h.

For all gray whales sighted the following information was recorded whenever possible: time, position coordinates, aircraft altitude, number of animals, true heading, estimated swimming speed and behavior of the whales. An inclinometer angle, used when deriving an index of abundance, was taken when the sighting was abeam of the aircraft. Photographs were routinely taken to catalogue distinctive markings and to record behavior patterns.

Figure 1. Predetermined transect blocks in -the Beaufort, Chukchi and northern Bering Sea.



170°
165°
160°
155°
150°
145°
140°
BEAUFORT SEA
CHUKCHI SEA
3
2
1
4
5
Wainwright
Icy Cape
Point Lay
Point Barrow
Deadhorse
Barter Is.
Demarcation Pt.
70°
L
Cape Lisburne
Point Hope
I
J
H
K
Kotzebue
USSR
ALASKA
G
Cape Prince of Wales
F
65°
E
D
Nome
C
B
A
Unalakeet
O
P
Q
Cape Romanzof
60°
GULF OF ALASKA
BERING SEA
55°

Sound Recording and Analysis Equipment

Sonobuoys were used successfully to record gray whale sounds in the northern Bering and Chukchi Seas. A sonobuoy is a passive listening system which contains a hydrophore array and a VHF transmitter. Sonobuoys are designed to be dropped from the aircraft by means ofa rotochute or parachute. Once in contact with water, a seawater-activated battery energizes the unit. The parachute assembly then jettisons and the hydrophore array drops to a preselected depth of 18.2 to 91.4 m (60 to 300 ft.). Two types of sonobuoys, AN/SSQ-41A and AN/SSQ-41B with respective frequency responses of 10 Hz to 4 kHz arid 10 Hz to 15 kHz were used.

Most sonobuoys were dropped near gray whales that were feeding and monitored for 0.5 to 1.5 hours. Feeding activity was inferred by frequent diving and mud plumes evident as the whales brought bottom sediments to the surface. The sounds picked up by the hydrophores were amplified and transmitted to a VHF broadband receiver (Defense Electronics GPR-20) on the aircraft, -the output of which was coupled to a NAGRA SJ recorder with a frequency response of 30 kHz. Recordings were make at 9.5 cm/s (3 3/4 ips).

Sounds were first aurally reviewed at recorded speed. Those sounds judged to be of sufficient intensity to permit analysis (signal/noise ≥ 10 dB) were converted to continuous hard copy spectrograms using a Spectral Dynamics 350 real time analyser. Analyzing bandwidth was 0 to 5 kHz. Gain settings from 0 to +30 dB were used to maximize spectral clarity. The response of the analyzing system was flat from 50 Hz to 20 kHz. Sound frequency and duration parameters were measured from the spectrograms.

RESULTS

Gray Whale Distribution

Gray whales were sighted from Bristol Bay to Pt. Barrow in 1980 and 1981. A total of 326 grays were seen in 1980 (Figure 2); 546 whales were counted in 1981 (Figure 3). More gray whales were seen in 1981 than 1980 primarily due to aerial survey effort. In 1980 more surveys were concentrated in areas off Alaska's north slope, while in 1981 aerial survey effort was more equally divided between the Beaufort Sea and the Chukchi and northern Bering Seas. Additional sightings made in 1980 and 1981 on aerial surveys of Bristol Bay conducted by Alaska Fish and Game biologists (per. comm., Lowry, 1982) were added to our sightings (Figures 2 and 3) to supplement the distribution data for both years. Total gray whale sightings in Bristol Bay on these surveys were 32 whales seen between 16 April and 23 June 1980, and 41 whales sighted between 7 April and 7May 1981.

Gray whales were seen both near shore and in offshore pelagic waters throughout the summer of 1981. Gray whales were seen within 0.5 km of shore on both deep and shallow gradient beaches, such that they were in water from 3m to 40m deep. Some places were so shallow the whales appeared to be lying on the bottom. Deep water coastal areas where grays were seen include areas just north of Cape Prince of Wales, Cape Lisburne and Icy Cape. Grays were also sighted in pelagic waters 40 to 60 m deep and in up to 3/10 ice concentrations.

The headings of feeding whales were random, but the headings of swimming whales in pelagic waters were generally north (330° to 30° true) or south (150° to 210° true). Whales sighted near the coast were usually heading along the coast swimming either north or south.

Most gray whales in the northern Bering and southern Chukchi Seas (below 69° N latitude) were seen with mud plumes indicating feeding (Figure 4). Mud plumes became useful sighting cues, as association of these trails with gray

Figure 2. Gray whale sightings in 1980.

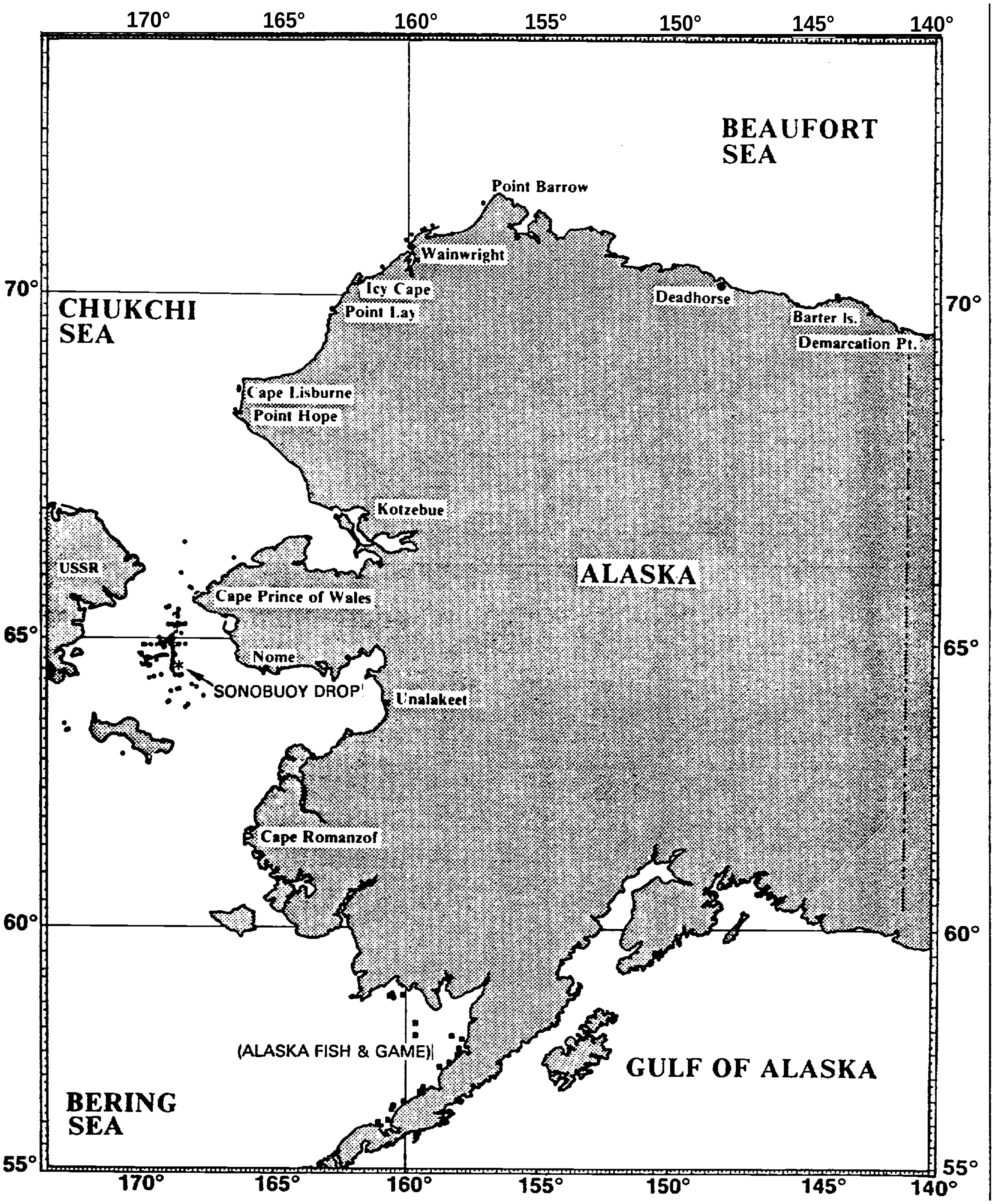
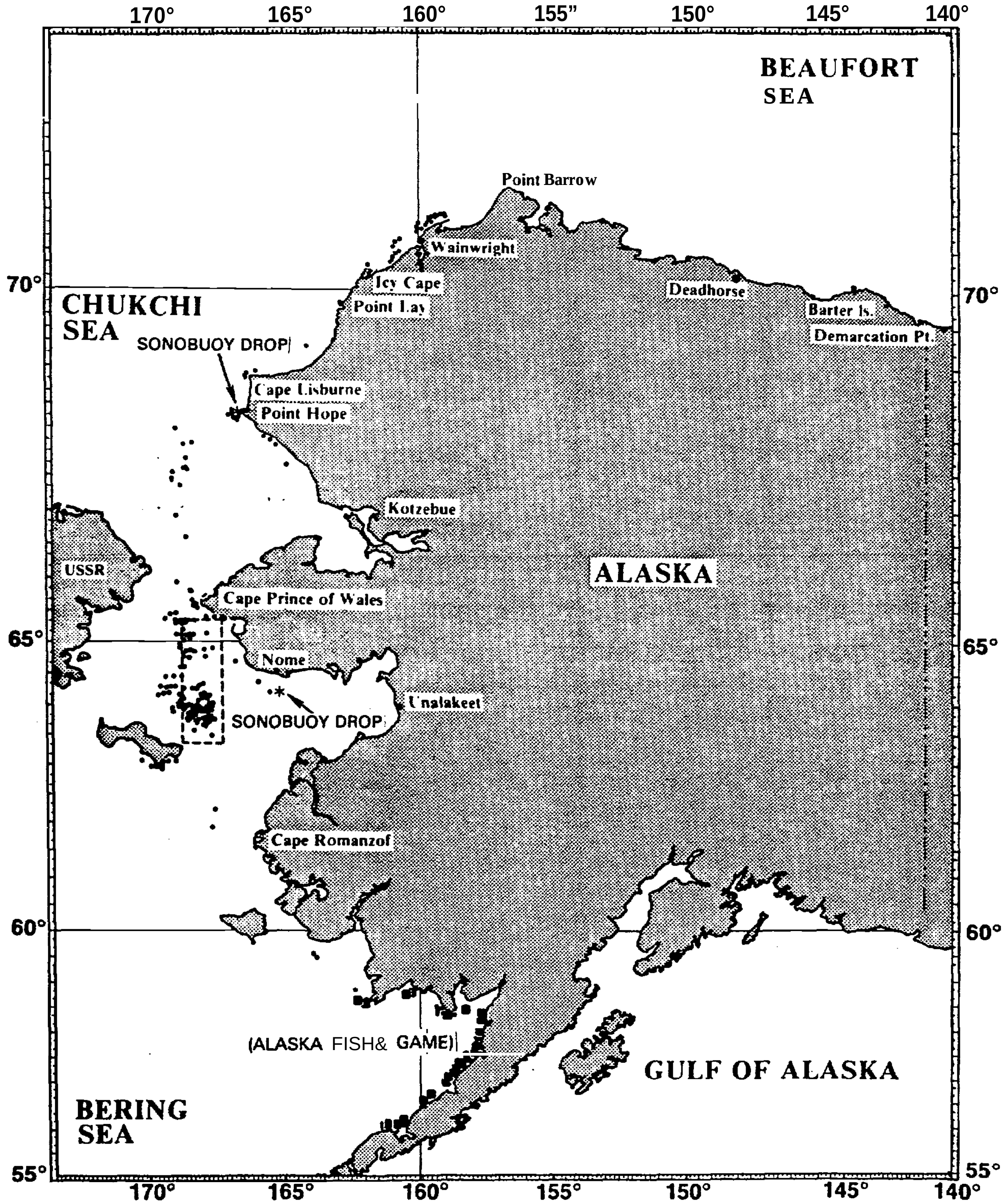

170°
165°
160°
155°
150°
145°
140°
BEAUFORT SEA
Point Barrow
Wainwright
Icy Cape
Point Lay
Deadhorse
Barter Is.
Demarcation Pt.
70°
CHUKCHI SEA
Cape Lisburne
Point Hope
Kotzebue
USSR
ALASKA
Cape Prince of Wales
65°
Nome
SONOBUOY DROP
Unalakeet
Cape Romanzof
60°
(ALASKA FISH & GAME)
GULF OF ALASKA
BERING SEA
55°

Figure 3. Gray whale sightings in 1981.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Cape Prince of Wales
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Nome
Unalakeet
SONOBUOY DROP
Cape Romanzof
60°
(ALASKA FISH& GAME)
GULF OF ALASKA
BERING SEA
55°

Figure 4. Gray whales with mud plume made while feeding.

whale sightings was approximately 85% over the course of our surveys. These brown plumes also attract feeding birds (Harrison, 1979) that aid sightability, but dissociate within five minutes and so are a very temporary sighting cue.

We occasionally saw mud plumes in semi-circular rings (Figure 5) indicating a patterned feeding strategy on the part of the grays. We do not know if the rings are formed by one animal, or several foraging together. A circular or semi-circular feeding pattern might serve to concentrate benthic infauna. Hypothetically, motile crustacea (primarily amphipods) once disturbed may jump away from a gray whale feeding "pit" and so become more concentrated inside a gray whale feeding ring. This strategy may parallel the bubble-net feeding pattern of humpback whales (Megaptera novangeliae), which serves to concentrate their planktonic prey.

A concentration of feeding gray whales was seen in late October and early November 1980, in the northern Bering Sea between St. Lawrence Island and the Bering Strait. This area is called the Chirikov Basin. A similar concentration of feeding gray whales was noted in the same area from May through August, 1981 (see Figures 2 and 3). This gray whale feeding ground covered approximately 344 km^2 (100 nmi^2) ranging from 63° 30′ N to 66° 00′ N latitude and 167° 00′ W to 170° 00′ W longitude. A special transect survey block was flown over a section of this area (65° 12′ N - 63° 28′ N / 167° 20′ W - 168° 40′ W ; see dashed line rectangle, Figure 3) in 1981.

Relative Density and Abundance in the Chirikov Basin

Relative abundance and density estimates were derived for gray whales in the Chirikov Basin using strip transect, method 1 described in Estes (1978). Estimates were calculated by blocked areas (see Figure 1) to better utilize all flight effort. A conservative strip width of approximately 0.5 km (463 m) was used to maximize the probability that all individuals were counted within the strip boundaries.

Figure 5. Gray whale with semi-circular mud plume ring.

The abundance estimates calculated for the nine areas ranged from a low of 0 to a high of 447 gray whales for block F (Table 1). Estimated density in block F was 0.26 whales/nmi^2.

Size, Behavior and Distribution

Most gray whales seen in the northern Chukchi Sea (north of 69°N) in 1981 were swimming or resting rather than feeding. Estimated swimming speeds averaged 2 to 3 knots. Moreover, the gray whales seen in the northern Chukchi appeared smaller then those seen feeding in the Chirikov Basin.

To compare size and behavior of whales, we divided our 1981 gray whale sightings into a northern group (north of 69°N) and a southern group (63°N to 69°N). The mean estimated size of the northern group was 11.11 m $\pm$ 1.72, that of the southern group, 12.22 m $\pm$ 1.98. Unfortunately,. size was estimated on only 6 animals in the northern group, thus statistical comparison was forfeit due to small sample size.

Behavioral comparisons were limited to relative percentages also because of small sample size in the norhtern group. Table 2 presents behaviors seen in the two groups. If sightings where no behavior was noted are removed, we find: 88% of the whales in the northern group were swimming, 11% were resting and none were seen feeding; while in the southern group, 63% were noted as feeding and only 34% were swimming. From these preliminary data we hypothesize that smaller juvinile whales migrate further morth in summer and are less involved in feeding than full grown adults.

Sounds Recorded Near Feeding Gray Whales

Gray whales were recorded in the northern Bering and Chukchi Seas in 1980 and 1981. Sound recordings made of gray whales feeding near King Island in 1980, and in the Chukchi Sea (20 km SW of Pt. Hope) and Norton Sound in 1981 were chosen for analysis because they contained relatively little ambient

Block	Area (nmi^2)	Track survey (nmi)	Gray whales counted in strip	Density ($\hat{R}$) (no./nmi^2)	Variance $S^2(\hat{R})$	Abundance Var ($\hat{T}$)	Variance Var ($\hat{T}$)	95% confidence internal around $\hat{T}$
B	2388	50.3	0	O*O	o	0±0	0	(0-0)
c	2388	573.8	46	.049*.018	.00031	117*36.8	1357,0	(40-193)
D	3071	559.9	5	.005*.O12	.00016	16±34.6	1194.4	(-54-87)
E	3071	469.9	71	.094*.033	.00106	288?92.2	8500.7	(97478)
F	1707	400.7	131	.262*.102	.01048	447*152.9	23375.0	(1 17-778)
G	736	178.0	9	.028*.020	.00039	21±12.7	160.1	(-7-49)
o	3296	372.8	0	0±0	o	0±0	o	(o-o)
P	3296	341.0	2	.003*.002	.00000	10±6.0	36.6	(-4-23)
Q	3296	372,7	2	.003*.002	.00000	9±5.7	32.9	(4-21)

Table *1*. Gray whale relative abundance and densit y estimates for nine survey blocks in the Chirikov Basin. Strip with used = 463 m.

Table 2. Comparative behaviors of gray whales north of $69^{O}N$, and between $63^{O}N$ and $69^{O}N$.

	Behavior Missing	Feeding	Resting	Dove	Swimming	N
NORTH GROUP (north of 69°)	12 57% A-	0 - -	1 5% 11%	0 - -	8 38% 88%	21 9
SOUTH GROUP ($63^{O}N$ - $69^{O}N$)	54 26% &.-	96 46% 63%	3 1% 2%	2 1% 1%	52 25% 34%	207 153

(*removed)

noise. Sonobuoy locations for these recordings are no-ted in Figures 2 and 3.

Sounds were classified to four types: metallic knocks, grunts, moans and miscellaneous sounds. Metallic knocks were usually emitted in series called bursts. Bursts were defined as a series of metallic knocks with inter-knock silent breaks of less than one second. The frequency at maximum amplitude (aural frequency) and duration was measured on metallic knocks. Inter-knock interval, burst duration and number of knocks per burst were measured on metallic knock bursts. Grunts were belch-like sounds which occurred alone, in pairs and sometimes at the end of a metallic knock burst. The duration and frequency of maximum amplitude was measured on grunts. Initial, mid-sound and end frequency, and duration were measured on moans. Miscellaneous sounds were the few that could not be called moans, grunts or knocks and were not systematically analysed. They consisted mainly of short, higher frequency pops. Table 3 presents range mean and standard deviation for all measured parameters on each sound type.

Metallic knocks far outnumbered any other type of sound. These sounds were short ($\bar{x}$ = 106 ins), broadband (to 4 kHz), with a mean maximum-amplitude frequency of 963 Hz (Figure 6). Inter-knock intervals were quite variable (0-955 ins). but averaged 140 ms. Metallic knock bursts lasted as long as 19 s, averaged less than 3 s and were as short as 0.25 s. Bursts were comrised of 2 to 69 seperate knocks and averaged about 12 knocks per series.

When the metallic knocks recorded from gray whales near King Island in 1980 were compared with those recorded from whales in the Norton Sound in 1981, difference: were noted in frequency of maximum amplitude and inter-knock interval, but not in sound duration. The metallic knocks recorded in Norton Sound were higher in maximum-amplitude frequency and had a shorter inter-knock interval than those recorded from grays near King Island. The results ofa t-test (Table 4) show these differences to be significant at the .001 level.

Table 3. Frequency and duration measures on four gray whale sound types.

Sound Type		Measured Parameter	N	Range	x ± SD
Metallic Knock		Maximum amplitude (Hz)	330	238-2584	962.62 ± 652.66
		Duration (ins)	1530	45-227	106.38 ± 23.20
		Interval (ins)	1379	0-955	139,64 ± 161.34
		Burst duration (s)	127	0.25-19.05	2.76 ± 2.84
		Number knocks/burst (n)	127	2-69	11.86 ± 11.30
Grunt		Maximum amplitude (Hz)	19	136-748	388.3 ± 143.0
		Duration (ins)	19	245-588	344.4 ± 86.1
Moan		Initial (Hz)	14	102-578	308.4 ±154.1
		Middle (Hz)	14	102-544	352.1 ± 121.2
		End (Hz)	14	170-544	325.62145.3
		Duration (ins)	14	621-1519	91 3.4? 259.8
Complex Moan	Upper	Initial (Hz)	2	442-578	510 ± 96.2
		Middle (Hz)	2	374-476	425 ± 72.1
		End (Hz)	2	544	544 ± o
		Duration (ins)	2	686	686 ± O
	Lower	Initial (Hz)	2	238-272	255.0 ± 24.0
		Middle (Hz)	2	308-340	289.0 ± 24.0
		End (Hz)	2	272-306	324.0 ± 22.6
		Duration (ins)	2	735-882	808.5 ± 103.9

Figure 6. *Spectrogram* of metallic *knock series*. Note *broadband character (to 4 kHz) and short duration ($\bar{x}$ = 106 ins). The frequency at maximum amplitude averaged 550 Hz in the 4 NOV sample (6a), 1853 Hz in the 17 MAY sample (6b), and 963 Hz averall.*

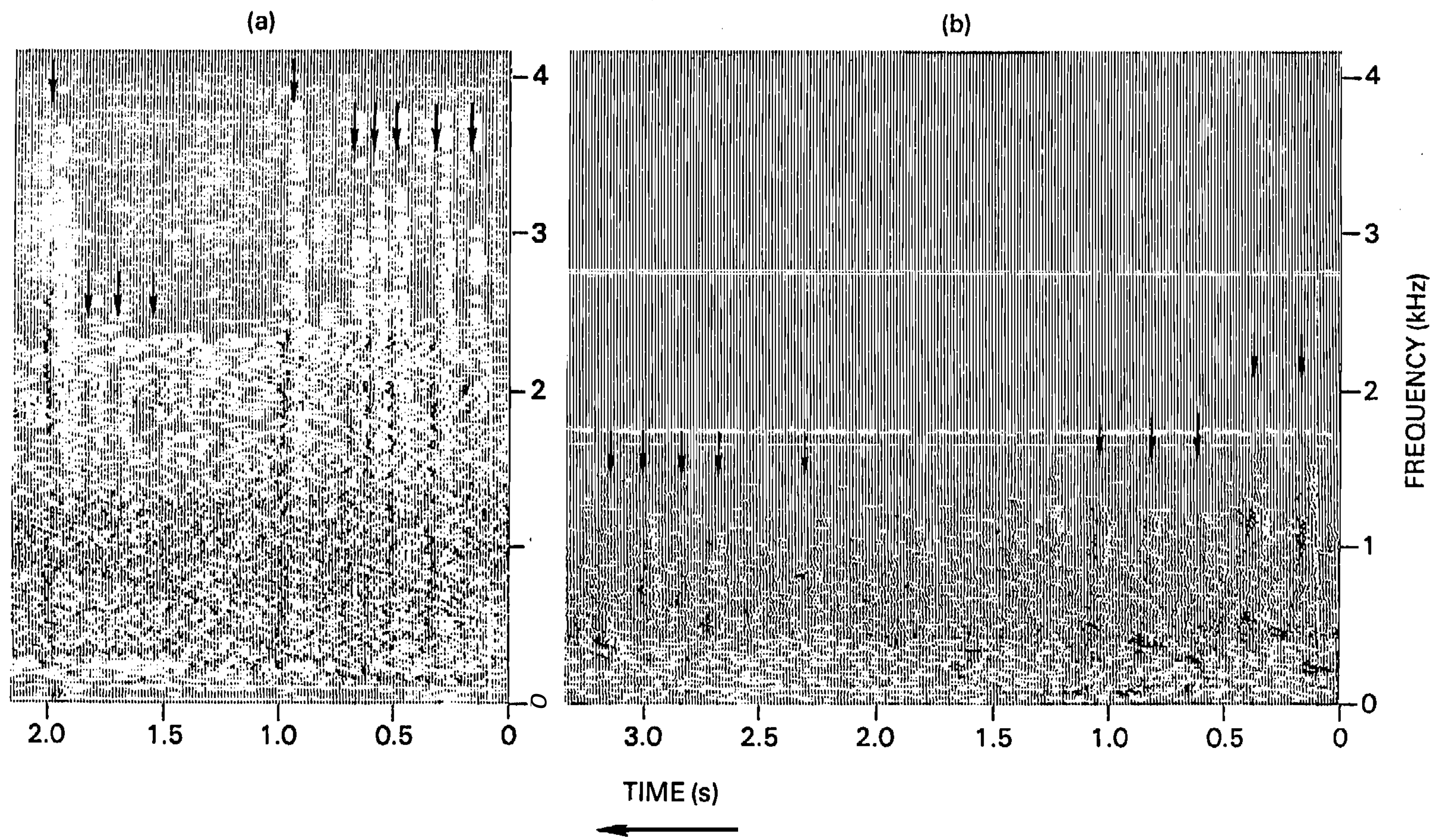

(a)
(b)
0
0.5
1.0
1.5
2.0
2.5
3.0
TIME (s)
0
1
2
3
4
FREQUENCY (kHz)

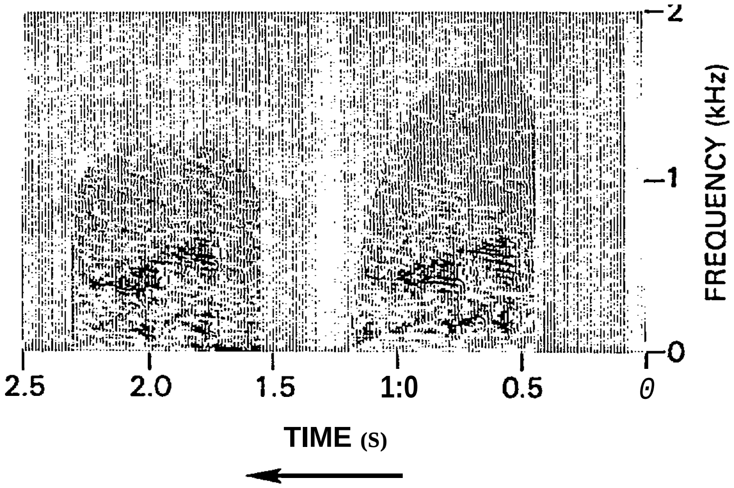
Table 4. Comparison of metallic knocks recorded 4 NOV 1980 and 17 May 1981, using t-test.

	4 NOV		17 MAY		t-test		
	N	$\bar{x} \pm SD$	N	$\bar{x} \pm SD$	t	df	P
Frequency at maxim amplitude (Hz)	229	550 ± 190	104*	1853 ± 338	44.83	331	<<.001
Duration (ms)	228	109.5 ± 23	880	114 ± 25	1.39	1106	>.100
Interval (ins)	183	240.4 ± 227	801	138 ± 146	7.19	982	<.001

*This parameter could not be measured on all knocks due to masking of sounds by bearded seal (Erignathus barbatus) calls.

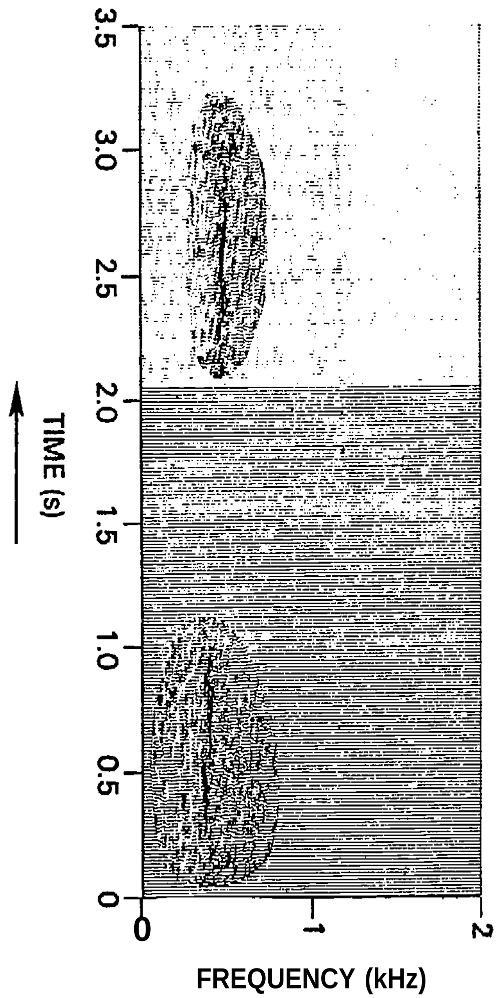
Grunts were longer ($\bar{x}$ = 344 ms) pulsive sounds of narrower frequency bandwidth (to 1.2 kHz), with a lower mean frequency ($\bar{x}$ =388 Hz) than the metallic knocks (FIG 7.) Moans were tonal, frequency modulated (FM) sounds with fundamental energy a-t about 325 Hz and an average duration of just under 1 s($\bar{x}$=913 ms) (Figure 8). There were two moans we called complex moans that looked, but did not sound, quite different from other moans. Complex moans consisted of two divergent fundamental bands with an approximate 100 ms shift in onset of these components (Figure 9). The lower frequency band averaged 300 Hz and 808 ms, while the higher frequency component averaged 525 Hz and 686 ms. Each FM band appears to be an independent component and not a harmonic component of the complex moan. This suggests either dual sound generation on the part of one whale, or nearly-simultaneous moans produced by two whales. We believe this is the first report of this type of moan for gray whales.

Figure 7. Spectrogram of two pairs of grunts. Note narrow bandwidth (to 1.2 kHz), longer duration ($\bar{x}$ = 344 ms) and lower mean frequency ($\bar{z}$ = 388 Hz.).



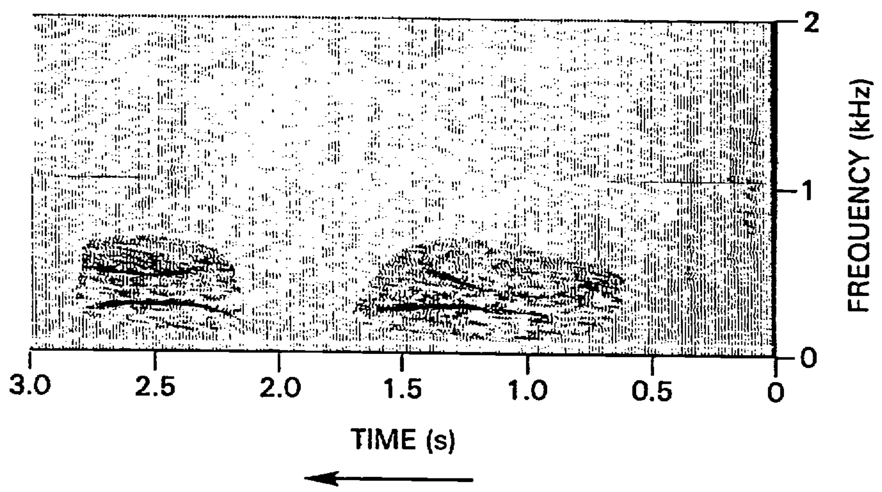
2
1
0
FREQUENCY (kHz)
2.5
2.0
1.5
1:0
0.5
0
TIME (S)

Figure 8. Spectrogram of two moans. Note mean fundamental frequency about 325 Hz and approximate 1 s duration.



TIME (s)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0
1
2
FREQUENCY (kHz)

Figure 9. Spectrogram of two *complex* moans. Note *nearly simultaneous double fundamental* component; the *lower band* averaging 300 *Hz* and 808 ms, the upper band *averaging* 525 *Hz* and 686 ms.


2
1
0
FREQUENCY (kHz)
3.0
2.5
2.0
1.5
1.0
0.5
0
TIME (s)

DISCUSSION

Gray Whale Distribution and Density

Gray whales have a patchy distribution over their northern range. This distribution probably reflects patchiness of their favored food source, benthic amphipods. Stomach contents of gray whales taken in the northern Bering and Chukchi Seas consist primarily of benthic amphipods belonging to twelve different genera (Rice and Wolman, 1971: Zimushko and Ivashin, 1979). Nerini (1980) states that summer distribution of gray whales in the central Chirikov Basin is eons-trained by the distribution of prey items. Dense beds of amphipods, to 22,450/m^2 for Ampelisca macrocephala, have been samp Zeal. Combining this amphipod abundance dirts with our gray whale, Chirikov Basin peak density estimate of 0.26/nmi^2, a simple two-tier food pyramid may be contructed with the dense amphipod community forming the broad base.

Size, Behavior and Distribution

Our preliminary size-distribution and behavioral data suggests that smaller gray whales may travel further north and spend less -time feeding. Smaller size generally reflects a younger age-class (Rice and Wolman, 1971), thus we may hypothesize a different behavioral ecology for juvenile and adult gray whales: juvenile whales swim further north and spend less time feeding in are-tie waters than do adult whales.

Alternatively, juvenile gray whales may simply be utilizing a more northerly and coastal food source than the adults. Zimushio and Ivashin (1979) report that gray whales taken nearshore were smaller and feeding mainly on the amphipod Pontoporeia, while larger whales taken further offshore were feeding on Ampelisca. Both paradigms would complement the late arrival of juvenile gray whales at their tropical calving lagoons off Baja California.

In contrast, two of the three gray whales reported by Rugh and Fraker (1981) in the eastern Beaufort Sea were associated with mud plumes, apparently feeding. These whales were very close to shore in 35 to 40 m deep water, near areas of relatively dense zoobenthos. Whale size was not estimated on these sightings. Zimushio and Ivashin (1979) report gray whale abundance along the Soviet coast to be annually more variable than. that in the central Chirikov Basin region. Perhaps juvinile gray whales exploit coastal amphipod communities (and travel as far north as they need to do so) while adults return to predictable dense amphipod-bed feeding areas.

Sounds Recorded Near Feeding Whales

This report is the first on sound production by gray whales on their arctic feeding grounds. The sounds described are very similar to the knocks, grunts and moans reported for this species in other parts of their range. Metallic knock bursts were the most prevalent sound recorded near feeding gray whales. This corresponds with the "metallic-sounding pulse train" and "clicks" described by Fish et al (1974) for a captive gray whale and for gray whales feeding off Vancouver Island, Canada. The repeated nature of metallic knocks suggests a possible echolocatory function. Gray whales, being primarily benthic amphipod grazers, would most likely use sound cues for bottom topography scanning rather than prey capture. These short duration, pulsed signals, emitted in series may serve some orientation function for the feeding whale. It is noteworthy that gray whales feeding in Norton Sound emitted higher frequency metallic knocks with a faster repetition rate than those produced by whales feeding in the Chirikov Basin. Perhaps the whale alters these characteristics of the sound with changing bottom topography or sediment type.

The grunts and moans may be social-whale sounds. Both sounds are rarely produced and are longer and of lower mean frequency than metallic knocks. Hypothetically, these sounds may be emitted when foraging gray whales encounter one another. Cummings (1968) reports that moans were the most common sound recorded from migrating whales. The metallic knock sounds were not reported from the migrating grays. The complex moans, composed of two nearly simultaneous non-harmonic(divergent) tonal bands, suggest dual sound generation by one animal or nearly simultaneous sound production by two whales. Until more sounds of this type are available for analysis however, we can only guess as to their production or function.

Summary

Gray whales feed duping the summer months in the northern Bering and Chukchi Seas with rare sightings in the Beaufort Sea. Large adult whales return annually to forage over dense beds of Ampelisca amphipods in the Chirikov Basin. Smaller whales appear to swim further north and may be less involved in feeding, or exploiting an alternate coastal food source. Feeding whales some times leave semi-circular mud plume rings that indicates a pattern to their foraging.

A short metallic knock produced in series is the sound most often produced by feeding gray whales in arctic waters. The few grunts and moans emitted are longer, lower frequency sounds that may or may not serve some social function. As in the case of miscellaneous higher frequency sounds, there are too few grunts and moans yet analysed to infer function. Continued study of gray whale distribution, density and behavior in its northern range will help elucidate habitat utilization patterns and 'lead to more effective management of this population.

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