Detection of trawling noise by Atlantic cod

DETECTION OF TRAWLING NOISE BY ATLANTIC

COD (GADUS MORHUA L.)

by

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Abstract

Underwater ambient sea noise and noise produced by fishing with an otter-trawl was measured with a hydrophone on the sea floor. The noise was analysed in 21 1/3-octave bands with center frequencies from 3.15 to 315 Hz. Previously published data on the effect of masking noise on cod hearing, and the measured noise levels were used to calculate the ranges at which cod can detect trawling noise at the different frequencies.

The calculations indicate that even in the noisiest ambient noise likely to occur in the sea, cod can detect trawling noise at .9 miles (1.7 km) in winter, and at .6 miles (1.1 km) in summer. The difference is attributed to seasonal variation of sound transmission characteristics.

Résumé

Le bruit de mer ambiant sous-marin et le bruit causé par la pêche au chalut furent mesurés avec un hydrophone au fond de la mer. Le bruit fut analysé dans 21 1/3 bandes octaves avec fréquences centrales de 3.15 à 315 Hz. Les données déjà publiées sur l'effet du bruit masqué en rapport avec l'ouïe de la morue, et les niveaux du bruit mesuré furent utilisés pour calculer les intervalles de variation du bruit de chalutage que la morue peut percevoir à différentes fréquences.

Les calculs indiquent que malgré le plus bruyant son ambient vraisemblable à se produire dans la mer, la morue peut percevoir le bruit de chalutage à .9 mille (1.7 km) en hiver, et à .6 mille (1.1 km) en été. La différence est attribuée à la variation saisonnière des caractéristiques de la transmission du son.

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Introduction

All modern forms of commercial fish capture employ some knowledge of fish behaviour. The essential information of where and when fish can be found, together with some exploitation of fish responses to stimuli form the basis for the capture process. To a great extent the information used in commercial fishing has accumulated through the generations of development of fishing methods by trial and error. This approach has obviously resulted in many productive catching methods, but the underlying principles of fish behaviour, particularly responses to stimuli were not always understood. As economic pressures made it increasingly advantageous to continue the development of fishing gear and methods on a more scientific basis, this lack of understanding has been brought to attention.

Noise produced by fishing gear, or by the fishing operation, has only recently been recognized as a stimulus for fish reactions to fishing. Shortly after echo-sounders were first used in fish finding the question of whether fish were scared by sounder noise was discussed by Schubert (1950), and by Schärfe (1951). These authors conclude that there is no evidence of pelagic herring reacting to sounder noise, but both remarked that noises in the audible frequency range were known to produce scaring effects in these fish. The differentiation between sounder noise and noise in the audible frequency range, however, is misleading. Sounder noise consists of short pulses of frequencies that may themselves be too high to hear, but the spread of energy due to the pulsing makes the pulses quite audible to man and perhaps to fish also.

In pelagic trawling, noise has been described as a stimulus for avoidance maneuvers of herring and other species by Aslanova (1958) and by Schärfe (1959). The usual reaction seems to be a dive to deeper water.

Habituation to continuing noise was also described.

More recently scaring effects of noise on tuna, herring and
other species have been described in purse seining (Chapman, 1970;
Iversen, 1967; Maniva, 1970; Olsen, 1970, 1971). Noise measurements of a
seiner that was making poor catches compared to other seiners (Hawkins and
Chapman, 1969) showed it to be noisier than average at some frequencies
but not pronouncedly so. The scaring effects described in the above reports
are attributed not so much to steady ship noise as to changes in noise caused
by changes in propeller speed and pitch.

It is clearly established that noise is a stimulus for avoidance
maneuvers of fish in pelagic fisheries. In fisheries for groundfish,
particularly bottom-trawling, there seems to be no·clear evidence of avoid-
ance maneuvers or reactions to noise, despite investigations and discussions
of both aspects in the literature.

The difference in our understanding of responses to fishing
between pelagic fish and groundfish can be attributed to the difficulty of
detecting fish on or near the bottom with echo-sounders. As v. Brandt
(1959) pointed out, in pelagic trawling it is necessary to see fish traces
on the echo-sounder before the gear can be set with any hope of making
catches. In bottom-trawling on the other hand one can hope for catches,
even without fish signs on the sounder. Pelagic trawling therefore provides
a better opportunity to observe fish reactions incidental to fishing than
does bottom-trawling.

The attempt by Schärfe (1956) to observe fish behaviour in re-
lation to the bottom-trawl with an echo-sounder in a rubber boat above the
trawl was unsuccessful. The noise produced by the groundrope caused inter-
ference on the echo-sounder. He concluded that conventional echo-sounders

could not be used for these studies. The level of noise produced by the groundrope was not measured, but was thought to be as loud as ship noise. Because the trawl was a conventional design, and catches of cod and haddock were normal, Scharfe concludes that the noise caused no, or at least no remarkable, flight responses.

To observe groundfish reactions to bottom trawling and to determine the relevant stimuli is obviously a problem that requires special effort and equipment.

Comparative fishing with different modifications of trawls can produce some understanding of fish responses to trawling. Bagenal (1958) compared catches made by otter trawls with catches made by a modification that had bridles between the doors and the wings. He suggested that the larger catches made with the modified trawl were likely due to the vibration of these bridles. To make more positive statements about fish behaviour from the results of comparative fishing would require analysis of the differences in stimuli produced by the modifications as well as the differences in catch.

Diving techniques have been used to observe groundfish behaviour in relation to capture. Hemmings (1967) used free diving to observe fish behaviour in response to the Danish seine. Korotkov (1969) and Martyshevskii et al. (1968) used a diving plane near bottom trawls. All three reports describe a herding of fish in front of the net, and suggest that vision is the stimulus. Martyshevskii et al. go on to state that when fish cannot see the gear, particularly the cloud of turbulence stirred up by the otter boards, the stimulus might be noise.

Lagunov (1955) used a diving chamber suspended from a ship to observe fish and trawls. He saw no response to propeller and engine noise

from the ship in cod and haddock. Similar observations were made by Kiselev (1968) who also used a diving chamber. He noted no responses of cod and haddock to noises made by passing vessels. He did note that in areas where many trawlers were operating the sea floor was stirred up, and cod seemed in a state of agitation. To clarify whether the agitation was due to the turbidity or due to the trawling noise he played back recorded trawling noise. In response, swimming cod became agitated during the first few moments and switched direction of swimming. Repetition of the sounds produced no responses. This suggests a startle response and rapid habituation. It does not clarify whether noises or the turbidity is the stimulus for the observed agitated state of the cod.

A camera attached to the headline of the trawl was used by Parrish et al. (1962). The camera was used in light and dark conditions. There was less uniformity of orientation with the tow of herring and gadoids during dark than during light. Sand eels sometimes oriented with the tow even in the dark. Beamish (1966) also used a headline camera during day and night tows. During the night tows, orientation with the tow was less uniform than during day for both cod and haddock, but most haddock swam with the tow even at night. These results suggest that in visual range and in visual conditions, vision is the stimulus used by fish in their reactions to trawling. But the reports also show that some species can orient with the tow even in the dark.

Although there are no clear indications of groundfish reactions to trawling noise among reported observations, the suggestion that noise could sometimes be a stimulus appears repeatedly. This is no doubt due to the knowledge that trawling generates loud noises, that fish have sensitive hearing, and that noise is a stimulus for pelagic species.

Among groundfish species, hearing has been studied most frequently in cod. Buerkle (1967) used a change in cardiac rhythm as a conditioned response to sound stimuli to determine hearing thresholds of cod in a tank. The thresholds indicated that cod had sensitive hearing at low frequencies (below 400 Hz) and that the sensitivity in this experiment was limited by the background noise in the experimental tank. Olsen (1967) also used condictioning experiments to determine thresholds of cod in a tank. He reported sensitivities that were generally less than those reported by Buerkle (1967) but did not mention any effect of background noise.

The influence of varying levels of background noise on cod hearing thresholds was investigated by Buerkle (1968). Using the same conditioning technique as previously, he determined thresholds at five frequencies in four levels of background noise. The noise in this case was produced electronically in the octave band centered at the relevant signal frequency. The results indicated that thresholds varied directly with noise level and should be measured in terms of threshold to noise ratios.

Another study using cardiac rhythm (Buerkle, 1969) investigated the effect of noise on thresholds in terms of the frequency separation between the noise and the signal at which thresholds were determined. To do this, the apparatus was set up so that the noise and the signal could be produced in any one of five half octave frequency bands. Thresholds were determined in all five signal bands for a constant noise level of 10 db re 1 μ bar in each of the five noise bands. Three cod were tested with each noise band, and each cod was used only with one noise band. Results from the 15 cod tested showed that the masking of signal by noise was most pronounced when signal and noise coincided in frequency, and dropped off as the frequency separation between signal and noise

increased. Masking was calculated in terms of threshold in relation to noise level and varied from about 11 db when signal and noise were at the same frequency to about -19 db when they were furthest removed from each other (separation of about 147 Hz).

The measurements above were made in tanks and might reflect the acoustic characteristics of the tanks as well as the hearing capacities of cod (Freytag, 1967). However, the few measurements of cod hearing that were made in open water in quiet fjords (Hawkins et al. 1969, Olsen, 1969), showed threshold to noise ratios that were quite similar to those determined in tanks. All the reports on hearing in cod support the conclusion that they have sensitive hearing that is probably limited by ocean ambient noise.

A trawling noise spectrum was measured by Chapman et al. (1967). They compared the noise with thresholds of the lythe and concluded that trawling noise can be heard by marine fish "perhaps over considerable distances." In another report (Chapman, 1970) the distance at which ship noise can be heard by fish is estimated at five miles. Olsen (1967) compared thresholds of cod to ship noise spectra and concluded that cod could hear the ship noise "at distances up to at least 70-80 meters".

The transmission loss used in making these estimates is the theoretical "20 log range" due to spherical spreading as described in Urick (1967). In transmission to distances several times the water depth, as it would occur when a fish 'hears' a trawler several miles away, propagation occurs by repeated reflections from the surface and the bottom. Spherical spreading is limited by these boundaries, and the acoustic characteristics of the boundaries are important determinants of the sound field. Application of the spherical spreading value is not strictly valid.

The present project was undertaken to determine more precisely at

what distances cod can detect trawling noise, and to determine which

frequency components of the noise are most important.

Experimental Procedure

A. Recording of trawling noise

i) Procedure

Previous measurements of trawling noise and of ship noise

were made from recordings taken at relatively short ranges (Chapman

et al., 1967; Olsen, 1967). In this investigation, noise from an

approaching trawler was to be measured as it becomes audible to cod

on the sea bottom. To make the recordings, the hydrophone was placed

on the bottom from an anchored recording boat. The recording boat

was allowed to swing with the wind and tide on its anchor line, the

slack hydrophone cable was to prevent the hydrophone from dragging

over the bottom. For each recording, ambient sea noise was recorded

for 10 to 15 minutes while the trawler stood by with engines off

at about one mile (1.8 km) distance (all measurements in miles refer

to nautical miles). The trawler then started the engines, set the

trawl, and towed towards and past the hydrophone while the recording

continued. The trawler passed the recording boat as close as possible

without risking damage to the hydrophone by the trawl, or catching

the anchor of the recording boat. When the trawl was thought to have

passed the hydrophone, the tow and the recording were stopped. A

voice track on the tape recorder was used to record information on

amplifier settings, wind, waves, and trawler operation. Earphones

were used to monitor the recorded signals, and were essential in

detecting disturbances caused by ship traffic and by the dragging

of the hydrophone or anchor.

ii) Recording site

Recordings were made in eastern Passamaquoddy Bay where mean water depth was approximately 60-70 feet (18-21 m) and average lowest low water depth was approximately 50-60 feet (15-18 m). The recording area was chosen to allow tows to be made towards the hydrophone over relatively smooth, flat bottom from a distance of one mile (1.8 km). The bottom consisted of soft, brown mud. Distance of the recording sites was estimated by eye to be between .25 and .5 miles (.46 and .9 km) from shore. Wind and wave conditions during recording did not vary greatly, most recordings were made in light winds and whitecapped waves of approximately one foot (.3 m) height.

iii) The trawler and the trawl

The trawler was the Pandalus II, a research vessel operated by the Department of the Environment (Fisheries and Marine Service) Biological Station, St. Andrews, N. B. Details are given in Table 1.

Tne trawl was a 3/4-35 Yankee otter-trawl made of polyethylene. The groundrope was equipped with 6-inch (15 cm) diameter rubber rollers.

iv) Equipment

The components of the recording and analysis apparatus and their interconnections are shown in Figure 1. The hydrophone system was manufactured by Clevite Corp. (Cleveland, Ohio). It consisted of a sensor type CH-13G(T), a preamplifier module type CE-10H, a housing type CB-31A(T), and 600 ft (183 m) of cable type CU-4A. The specified sensitivity of the sensor was -77 dbv re 1 μ bar. The specified frequency response was flat ±1 db from .38 Hz to

Table 1. Specifications of the trawler.

Ship	M. V. "Pandalus II"
Length (overall)	50 ft (15 m)
Beam	14 ft (4.3 m)
Draught	6.5 ft (2 m)
Gross tonnage	28.9 tons
Engine	Gardner Diesel, 4 cylinder, 76 h.p. at 900 r.p.m.
Auxiliary	Lister 2 cylinder, 10 h.p.
Propeller	Solid, 3 blades, 37" x 30" (94 cm x 76 cm), run through nominal 2:1 reduction gear.
Operation	Trawling is done at 800 to 850 r.p.m. at a speed of 3.0 ± .5 knots (5.6 ± .9 km per hr).
Construction	Wood
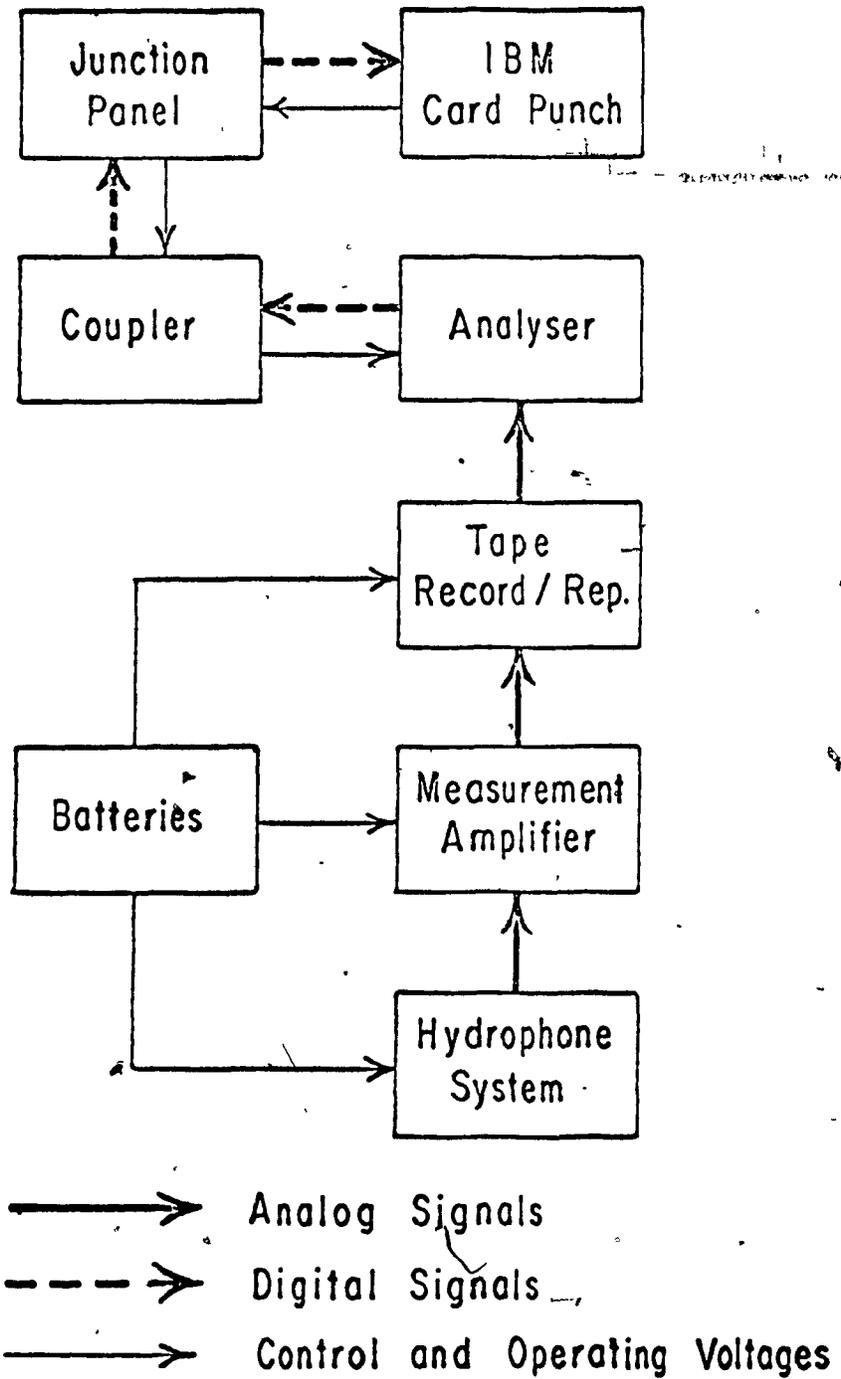
Figure 1. Block diagram of recording and analysis instrumentation.

11 kHz. The preamplifier module was calibrated to have a gain of 35 db with the CU-4A cable, its frequency response was measured to be flat ±3db from about 3Hz to 20 kHz. At the low frequencies, response was down 10 db at 1Hz. The system response was -42 dbv re 1 μ bar with the frequency response of the preamplifier. This system was used for recordings made before January 15, 1971. It was extremely sensitive to overloads by low frequency pressure fluctuations caused by surface waves. To reduce this difficulty it was recommended by Clevite Corp. engineers, to reduce the sensitivity of this system by shunting the sensor with a 330 pF capacitance. This was done, the sensitivity was then -52 dbv re 1 μ bar. The modified system was used for recordings made after January 15, 1971. It seemed somewhat less sensitive to overloads, but the problem was not entirely solved. Correction for the new sensitivity was made during analysis. The output from the hydrophone system was connected to a calibrated instrumentation amplifier (Eastech Industries, Dartmouth, N. S., model 329). The gain of the amplifier could be switched in 10 db steps from 0 to 80 db. Because of the large dynamic range of noise pressures that occurred between the beginning and the end of a tow, it was necessary to reduce the amplifier gain as the trawling noise became louder, so that the signal remained compatible with the input sensitivity of the tape recorder. The output of the amplifier (i. e. input to the tape recorder) was kept between 0 and -20 db re 1 volt. The changes in amplifier gain were recorded on the voice track so that corrections could be made at the appropriate times during analysis.

The tape recorder/reproducer was a Lockheed model 417 using 1/2" (1.27 cm) tape. It had 2 direct tracks, 2 FM tracks and

12.

a voice track. It was used at a tape speed of 3 3/4 ips (9.53 cm
per sec.). At this speed the frequency response of the direct system
was flat ± 3 db from 100 to 12,500 Hz, the frequency response of the
FM system was flat $\pm .5$ db from 0 to 1,250 Hz. In the direct system,
signal to RMS noise ratio over the pass band of the recorder was
35 db. In the FM system, it was 37 db. Input sensitivity of the
direct system was readjusted to 0 db gain. Input sensitivity and out-
put voltage of the FM system was 1 volt RMS for full carrier deflection
($\pm 40\%$). Recordings were made simultaneously in one direct and one
FM track. During the recording, the input level was monitored on a
meter on the recorder. Earphones were used to monitor the recording
on the tape in the simultaneous record/reproduce mode.

v) Results

Ten recordings were made from July to October 1970 with a
20 ft (6 m) long wooden seine skiff as the recording boat. Eight
recordings were made during January 1971 with a 57 ft (17 m) long
wooden trawler as the recording boat. Difficulties occurred during
six tows and the recordings were discarded because they were not
representative of normal conditions. Two were discarded because the
hydrophone dragged over the sea bed. Two were discarded because the
tows were not continued long enough for the trawl to pass the hydro-
phone. One was discarded because of interfering noise from ship
traffic. One was discarded because it contained frequencies that,
for undiscovered reasons, did not show the characteristic rise in
pressure as the trawler approached.

Of the twelve recordings remaining for analysis, six were
made during summer (July to October 1970), and six were made in

winter (January 1971).

B. Data processing

i) Aim

To determine at what frequencies and at what distance
trawling noise becomes detectable to cod, the change in noise level,
at different frequencies, with time was to be measured over the whole
length of each recording. The upper frequency limit of sensitive
hearing in cod is about 300 Hz. The FM track recordings were there-
fore analysed in 1/3 octave bands using a real-time spectrum analyser.

ii) Equipment

The recordings were reproduced on the Lockheed model 417
recorder/reproducer previously described. The output from the recorder/
reproducer was coupled to a Hewlett Packard (HP) model 8054A Real Time
Spectrum Analyser (Figure 1). The analyser was coupled to an HP
model 2547A coupler which was coupled through an HP model 2780A
junction panel to an IBM 526 summary card punch.

The function of the system was to filter the output from
the recorder/reproducer into 1/3 octave bands, and to punch the band
voltages on computer cards sequentially and continuously during the
analysis.

The analyser filtered the analog voltage from the recorder/
reproducer into 24 1/3 octave bands (Table 2). It stored the voltage
of each band for sequential scanning and conversion to digital form.
The output was in db re 1 μ volt and was programmed on the coupler
patch-board to consist of a 3 digit whole number in each band. The
card punch was programmed by its control card and patch-board to
punch 24 3-digit numbers in sequence in the first 72 columns of every

Table 2.   The 1/3 octave bands, band widths and power ratios.

Band number	Center frequency (Hz)	Band width(a) (Hz)	Power ratio(b) db
1	3.15	.73	-1.4
2	4	.92	- .4
3	5	1.15	.6
4	6.3	1.45	1.6
5	8	1.84	2.6
6	10	2.30	3.6
7	12.5	2.87	4.6
8	16	3.66	5.6
9	20	4.60	6.6
10	25	5.75	7.6
11	31.5	7.30	8.6
12	40	9.20	9.6
13	50	11.5	10.6
14	63	14.5	11.6
15	80	18.4	12.6
16	100	23.0	13.6
17	125	28.7	14.6
18	160	36.6	15.6
19	200	46.0	16.6
20	250	57.5	17.6
21	315	73.0	18.6
22	400	92:0	19.6
23	500	115	20.6
24	630	145	21.6

(a) band width = .231 center frequency (Albers 1965)

(b) power ratio = $10 \log \frac{\text{band width}}{1 \text{ Hz band width}}$ (Albers 1965)

card and to skip the remaining 8 columns. In synchronisation with the analyser it punched the 24 band levels making up one spectrum on one card, and started a new card for each new spectrum. The speed of the analysis was limited by the punching speed of the punch to 14 spectra per minute. A measurement was thus made in each band every 4.3 seconds during the whole analysis.

iii) Procedure

Because the amplifier gain was varied during the recordings, compensation for the gain shifts had to be made during the card-punching operation. It was done by inserting a cue card among the cards punched whenever an amplifier gain shift was announced on the voice track. In subsequent analysis the cue cards programmed the computer to compensate for amplifier gain changes, and to convert the db re 1 μ volt output on the cards to db re 1 μ bar of sound pressure in the water. The cue card correction for different amplifier gains that were subtracted from the db re 1 μ volt on the cards are given in Table 3. They are the sum of the amplifier gain, the hydrophone system sensitivity and the 120 db conversion factor to change the db re 1 volt amplifier output to db re 1 μ volt analyser output.

During the process of converting the recordings to numbers on computer cards, the various control and synchronisation voltages between card punch, coupler and analyser had to be initiated in correct sequence. The sequence was worked out with Hewlett Packard engineers and was used in setting up the following procedure.

(1) Hook up analyser, coupler, junction panel and card punch as outlined in the respective operation manuals.

(2) Connect the output of the recorder/reproducer to input B on

Table 3. Calculation of cue card correction.

	Before Jan. 15, 1971					After Jan. 15, 1971				
Amplifier gain db	0	10	20	30	40	0	10	20	30	40
Hydrophone system sensitivity dbv re 1 bar	-42	-42	-42	-42	-42	-52	-52	-52	-52	-52
Amplifier output dbv re 1 bar	-42	-32	-22	-12	-2	-52	-42	-32	-22	-12
Cue card correction db re 1 volt	78	88	98	108	118	68	78	88	98	108

See text for explanation

the analyser.

(3) Turn on power to all instruments.

(4) On the card punch:

- Put the control card on the drum, and the drum on the spindle.

- Close control card contacts.

- Switch to automatic feed and automatic print.

- Load cards, release a card and address a card.

(5) On the coupler:

- Set REM.-LOC. switch to LOC.

- Set ON-OFF switch to OFF.

(6) Start recorder/reproducer on playback, and listen to the voice track with headphones for amplifier gain setting.

(7) Insert the appropriate amplifier gain cue card into the output hopper of the punch.

(8) On the analyser:

- Push EXTERNAL INHIBIT button.

- Select sensitivity range to avoid overloads.

- Push RESET button.

(9) Rewind the tape on recorder/reproducer.

(10) Switch coupler REM.-LOC. to REM.

ON-OFF to ON.

(11) Start tape on playback.

(12) At "zero time" signal on voice track push EXT. INHIBIT button on analyser.

(13) Remove the first card that comes off card punch carriage.

(14) Check for correct synchronisation:

As the storage in the analyser is scanned, a bright trace

moves from band to band on the oscilloscope display of the analyser. When synchronized correctly the bright trace hesitates on band 2 during a card change. If it hesitates on any other band, synchronisation is not correct. To correct it, push RESET button and go back to step (9).

(15) While cards are being punched, monitor the analyser for overloads and listen to the voice track continuously to the end of the recording.

- Whenever overloads occur, push RESET on analyser, stop tape, release card, switch analyser range higher, and start tape. When display is stable, push EXT. INHIBIT, and remove incomplete card as it comes off punch carriage. Check synchronisation (step 14).

- Whenever amplifier gain shifts are announced on the voice track, push RESET, stop tape, release card, insert appropriate amplifier gain cue card at bottom of output hopper of punch, and start tape. When the display is stable push EXT. INHIBIT and remove incomplete card as it comes off the punch carriage. Check synchronisation (step 14).

iv) Results

During the punching of the cards, it was found that trawling noise at close range contained over 40 db more pressure at frequencies above 20Hz than at frequencies below 25Hz. Since the dynamic range of the analyser at any one range setting was 40 db, it was necessary to punch 2 sets of cards for each recording. One set was punched with the analyser range adjusted so that frequency bands 1 to 9 (3.15 to 20Hz) were within the dynamic range of the analyser. The other set

was punched so that bands 10 to 21 (25 to 315Hz) were within the
dynamic range of the analyser. Subsequent analysis for each frequency
was done in the appropriate set of cards. The 24 sets of cards for
the 12 recordings under consideration contained a total of 13,650 cards.

C. Data analysis

i) Data reduction and smoothing.

Hearing in cod is insensitive to frequencies above about
300Hz (Buerkle, 1967). For this reason, analysis was done in frequency
bands 1 to 21 (3.15 to 315Hz) and not at higher frequencies. There
were more than 143,000 3-digit numbers in these bands in the 12 re-
cordings to be analysed. On the average, each frequency band was
represented by approximately 570 measurements.

To reduce and smooth the data, moving averages were calculated.
Each average was the average of 14 measurements and represented a time
period of 1 minute because the card punch produced 14 spectra per minute.
Succeeding averages overlapped preceding averages by 7 measurements
making a time difference of 30 seconds between averages (see Figure 2).
This resulted in a mean of 80 averages in each frequency band in each
recording, or a total of approximately 20,000 averages to be analysed.

Examples of the change in averages with time are shown in
Figure 3. They show little change in level during the time that ambient
ocean noise was measured before trawling started. When trawling started,
the noise levels in some bands began to rise and continued to rise as
the trawler approached the hydrophone. Equations to describe mean
trawling noise in relation to distance along the tow path were calculated
and are drawn for the example in Figure 3.

Measurement Numbers
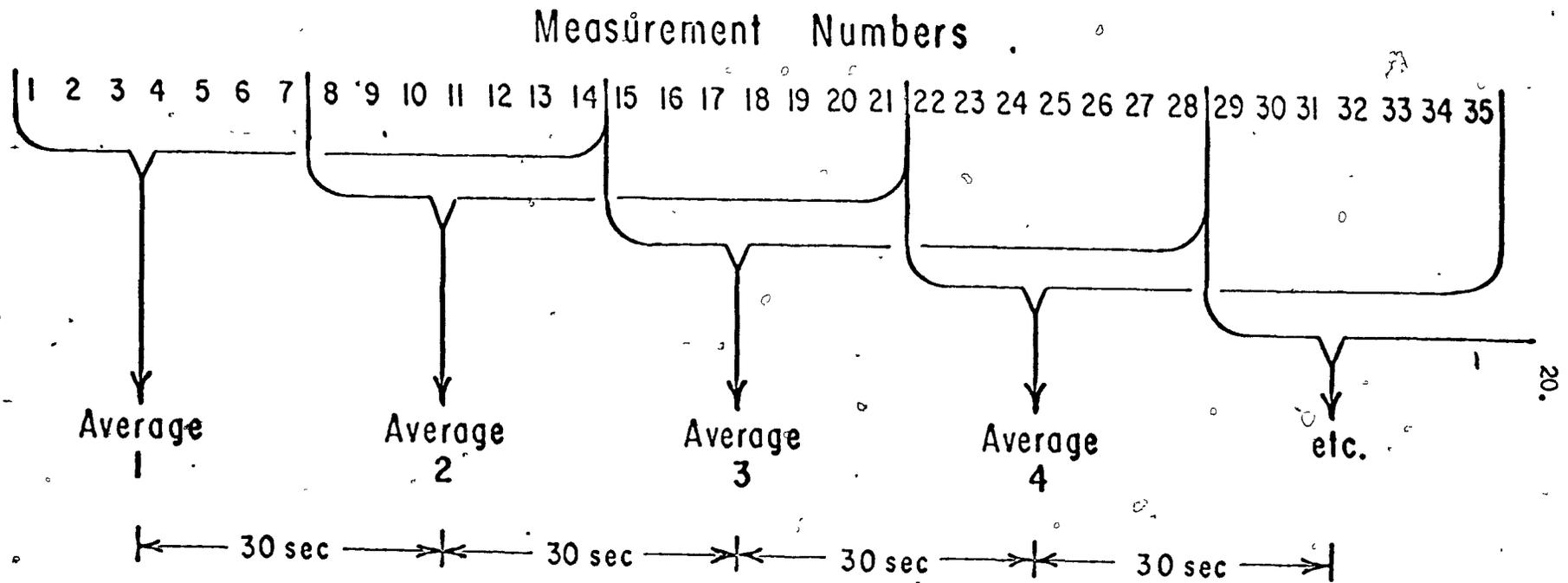
Figure 2. Relationship between moving averages and measurement numbers and time.
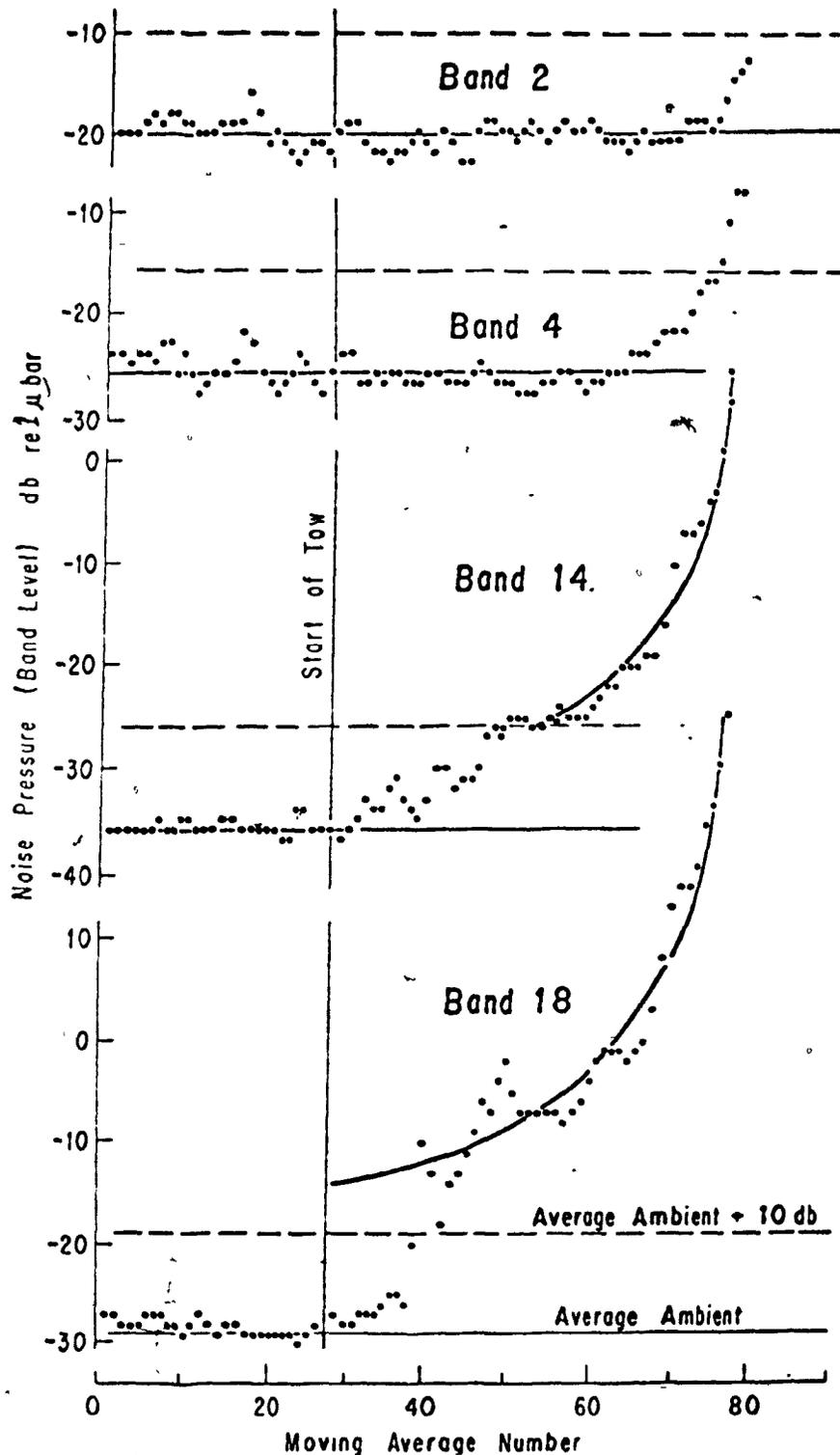
Figure 3.   Moving averages of 4 frequency bands (from recording 3, August 29, 1970).

    Band 2.   No averages above average ambient + 10 db

    Band 4.   4 averages above average ambient + 10 db, no equation calculated.

    Band 14.   Equation calculated for 30 averages.

    Band 18.   Equation calculated for 38 averages.

ii) Calculation of mean trawling noise in relation to distance along
the tow path.

(a) Effect of ambient noise.

When measured trawling noise is less than 10db above
ambient sea noise, the measurement is not of trawling noise
alone but of the sum of trawling noise and ambient noise.
When trawling noise is 10db or more above ambient noise, the
ambient noise has no effect on the measurement of trawling
noise (Albers, 1965, Appendix 3). Before equations were
calculated, therefore, trawling noise measurements that were
less than 10 db above average ambient sea noise were eliminated.
The average ambient sea noise of each band in each recording
was calculated from the moving averages of measurements made
before trawling began (Figure 3). The equation for any band
was calculated from the averages that were 10 db or more above
the average ambient noise and that followed the last average
below that level. No equation was calculated for bands that
had less than 5 averages that met this criterion.

(b) Calculation of distance intervals.

The averages were fitted to logarithmic equations
of the form $db = A + b \log \frac{distance}{reference\ distance}$ because noise
levels of a noise source at distances from the source are
inversely proportional to the log of the distance. For this
form of equation, the 30 second time interval between the
moving averages had to be changed to distance.

The distance scale was calculated from timing cues
recorded on the voice tracks of 5 recordings when distances
between the trawler and the recording boat were estimated by

radar to be .75, .50, .25 and 0 miles (1.4, .9, .5 and 0 km). During the punching of the cards for these recordings, cue cards were inserted whenever the voice track indicated a distance. The number of data cards between the cue cards were later counted and used in the calculations in Table 4.

The distances of 146 ft (44 m) and 131 ft (40 m) are the upper and lower 95% fiducial limits of the mean distance along the tow path between adjacent moving averages. They were used in each recording in every band with sufficient averages to calculate one equation with the maximum and one with the minimum intercept respectively. A total of 324 equations were calculated, their intercepts (A) and slopes (b) are listed by recording and band number in the Appendix.

The two equations in each of the 162 bands of the Appendix describe mean maximum and mean minimum trawling noise relative to distance along the tow path in each band. They were used to calculate the maximum and minimum range at which trawling noise becomes detectable for cod in each of the bands.

iii) Calculation of masking levels.

For cod to detect trawling noise at sea, their auditory apparatus must be able to separate the tonal stimulation caused by the trawling noise from that caused by the ambient sea noise. That is, the trawling noise must not be masked by ambient sea noise.

To determine the masking level, the level at which ambient noise masks trawling noise, in each frequency band of each recording, the measurements of auditory masking in cod made by Buerkle (1969) were used. Figure 4 reproduces Figure 2 from Buerkle (1969). It shows the

Table 4.   Calculation of towing speed and of distance between moving averages.

Distance (radar)	.75		.5		.25		0	mi.
	1.4		.9		.5		0	km.
Number of cards		77		80		79		
between distances		79		88		59		
in 5 recordings		87		78		71		
		–		83		67		
		67		76		76		

Mean number of cards per 1/4 mile   = 76.2
Standard error of the mean   = 2.1

95% fiducial = 321.6 to 288.0 cards per mile interval
    limits
             = 131 to 146 feet per average*
        (40 m)   (44 m)

towing speed = 2.6 to 2.9 knots[+]
        (4.8 to 5.4 km per hr)

* feet per average $= \dfrac{\text{feet per nautical mile}}{\text{cards per mile}} \times 7$

+ knots $= \dfrac{\text{cards per hour (=840)}}{\text{cards per mile}}$
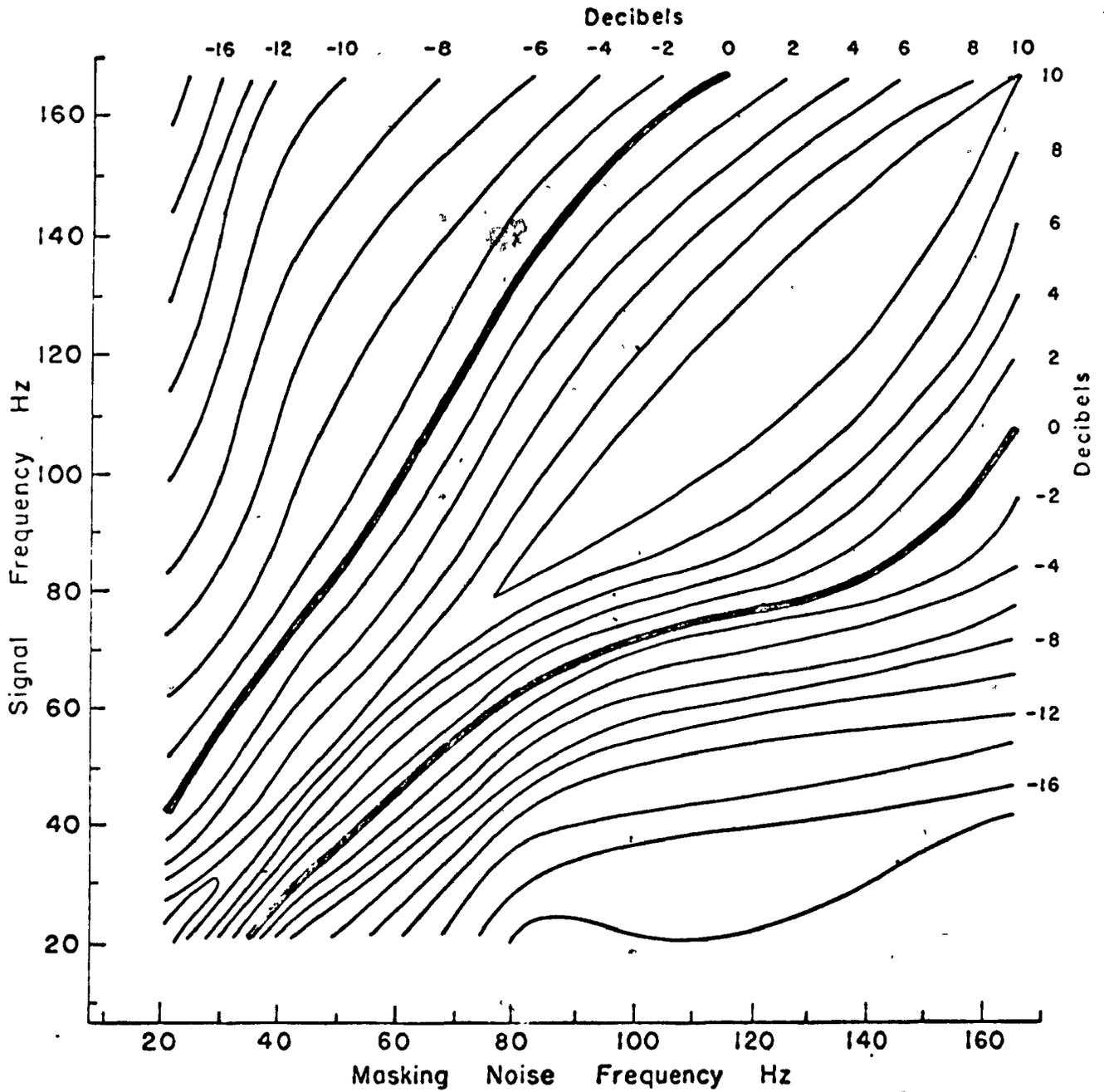
Figure 4. Contour plot of masking in decibels of signal threshold in relation to masking noise level (Fig. 2 in Buerkle 1969).

relationship, by signal frequencies and noise frequencies, of thresholds and masking noise in decibels. To determine the slopes by which threshold re masking noise decrease with increased separation between signal frequency and masking frequency, the values of Table 5 were interpolated from Figure 4. For each noise frequency, two regressions of threshold re masking noise versus signal frequency were calculated, one for signal frequencies higher than the noise frequency, the other for signal frequencies lower than the noise frequency. The slopes of each regression, and the mean slope for signal frequencies higher than noise frequency and for signal frequencies lower than noise frequency are shown in Table 6.

The masking level of each frequency band was calculated from the mean slopes and from the average ambient noise level in each recording. For every signal band, the frequency of each of the 21 noise bands was subtracted from the frequency of the signal band. Positive sums were multiplied by -.2 db per Hz, negative sums were multiplied by -.4 db per Hz. Because signals at the same frequencies as masking noise are detected only when they are a minimum of 10 db above the masking noise (Figure 4 and Table 5), the product for each noise band was added to the average ambient noise +10 db level of the noise band. The maximum of the 21 sums obtained for each signal band was the masking level of that band. The masking levels for the 162 bands in the Appendix are listed there under "Masking level".

iv) Calculation of range at which cod can detect trawling noise.

A distance D at which trawling noise equals masking level can be calculated from each intercept (A), slope (b), and masking level (ML) of the Appendix. By substituting masking level for decibels in the

Table 5. Cod thresholds relative to masking noise level in decibels (interpolated from Fig. 4).

Noise frequency Hz	Signal frequencies Hz							
	20	40	60	80	100	120	140	160
20	10	0	-4	-7	-10	-13	-15	-18
40	-4	8	3	2	-5	-6	-9	-11
60	-12	-2	7	4	0	-3	-5	-8
80	-18	-12	-1	10	6	2	-1	-5
100	-18	-14	-6	6	10	8	4	-1
120	-18	-16	-9	-2	9	10	8	3
140		-16	-10	-1	5	9	10	7
160		-18	-12	-4	0	4	8	10

Table 6. Slopes of threshold or masking noise for signal
          frequencies higher than noise frequencies, and for
          signal frequencies lower than noise frequency.

Noise frequency	Signal frequency	
	higher than noise (db/Hz)	lower than noise (db/Hz)
20	-.179	
40	-.138	-.600
60	-.150	-.475
80	-.185	-.475
100	-.185	-.380
120	-.175	-.323
140	-.150	-.276
160		-.236
Mean	-.2	-.4

general equation db = $A + b \log \frac{D}{Dreff.}$, the equation becomes ML =
$A + b \log D$ and D = antilog $\frac{ML - A}{b}$, when Dreff. = 1. The D re-
presents the distance back along the tow path from the intercept of
the equation to where trawling noise equals masking level. At shorter
distances, trawling noise is above the masking level, at longer distances
it is below the masking level. The intercept of the equations, however,
is a theoretical point at distance = 0, and does not represent the point
at which the noise source was actually closest to the hydrophone. To
correct for this, the closest point along the tow path between the noise
source and the hydrophone was determined as follows.

As noise sources move along the tow path towards the hydrophone
and pass it, the noise levels at the hydrophone should rise to a peak
as the distance between the source and the hydrophone becomes minimum.
The peak represents the closest point along the tow path between the
noise source and the hydrophone. The peak moving average in each of the
162 bands in the Appendix was determined. For a number of bands the
loudest moving average was also the last moving average of the series
(Figure 3). In such cases, the loudest moving average cannot properly
be called a peak. Examination of the measurements from which the moving
averages were calculated, however, revealed that in all these cases
included in this report the measurements did rise to a peak and decrease
again. Therefore, when the loudest moving average was the last of the
series, there were simply not enough decreasing measurements to lower
the average below the previous one, but the loudest average does represent
the peak noise pressure.

The distance (d) between the peak moving average and the inter-
cept of each equation was calculated from the number of distance increments

between them and the relevant increment size of 146 ft (44m) or 131 ft (40 m). These distances (d) are shown in the Appendix in feet.

The range (r) along the tow path between the closest point to the hydrophone and the masking level was then r = D-d or, r = antilog $\frac{ML - A}{b}$ - d. The r is always greater for the equation based on the 146 ft (44m) increments than for the equation based on the 131 ft (40 m) increments. The range r, however, is still not the range at which cod can detect trawling noise because the hydrophone and thus the hypothetical cod were not located on the tow path. Figure 5 illustrates the geometry of the recording situation. As described previously, the recording boat swung on its anchor line and excess hydrophone cable was used to prevent the hydrophone from dragging over the sea floor. This permitted the hydrophone to be located anywhere within a radius of several hundred feet of the recording boat. The tow paths were straight lines that passed the recording boat at distances with a maximum of about 300 ft (90 m). Because the minimum water depth was about 50 ft (15 m), this meant that a noise source moving along the tow path at the surface could be anywhere from about 50 ft (15 m) to about 500 ft (150 m) from the hydrophone at the closest point (Figure 5).

To calculate the maximum and minimum range (R) at which cod can detect trawling noise, this distance between the hydrophone and the closest point had to be corrected for. Figure 6 illustrates the relationship between R, r, and the hydrophone distance from the closest point. As described previously, each of the 162 bands in the Appendix has a maximum and a minimum r. It can be seen in Figure 6 that the maximum and minimum R (ft) in each band will be $(r \max.^2 + 500^2)^{1/2}$ and $(r \min.^2 + 50^2)^{1/2}$ respectively. The maximum and minimum range R
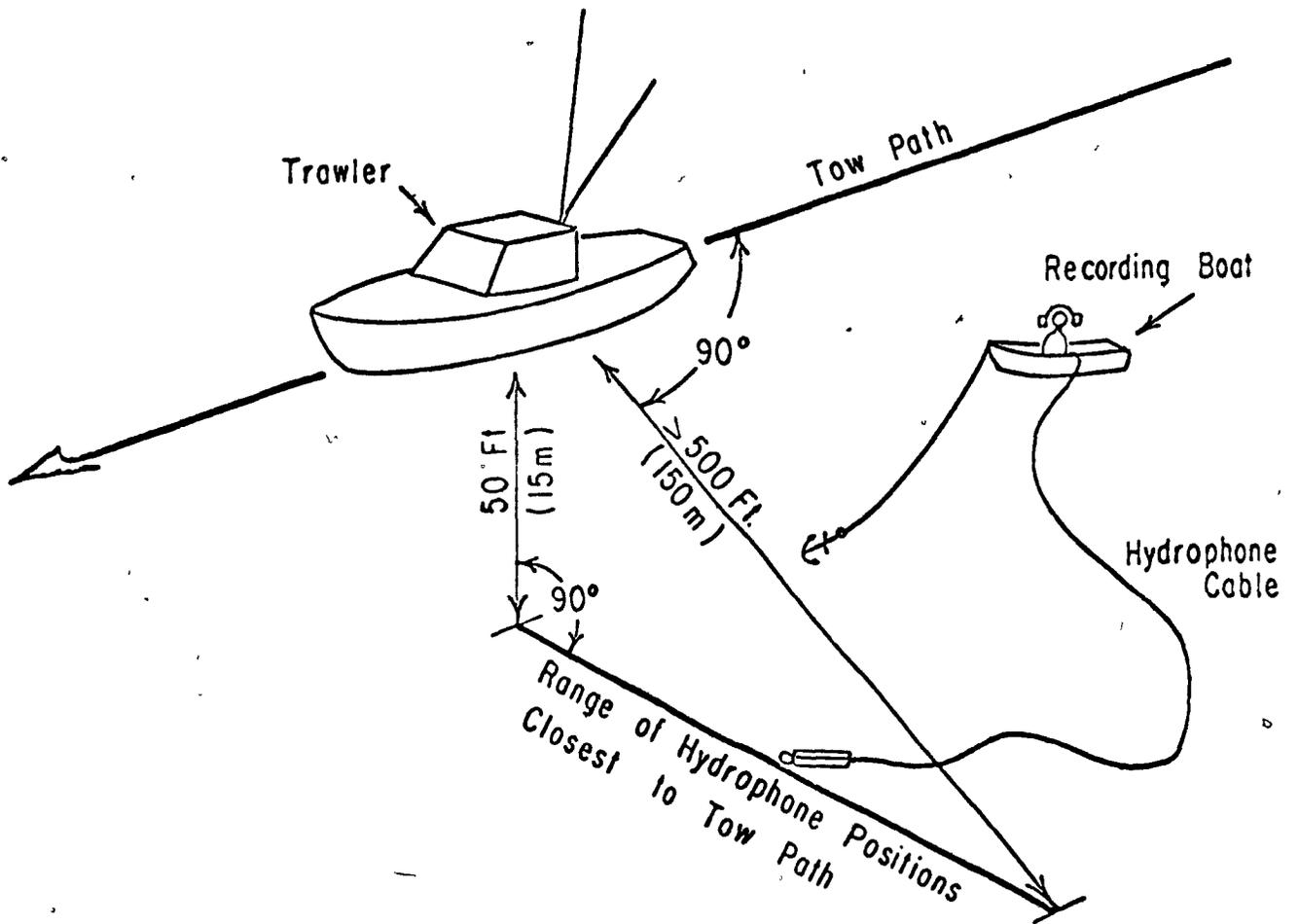
Figure 5. Recording geometry.
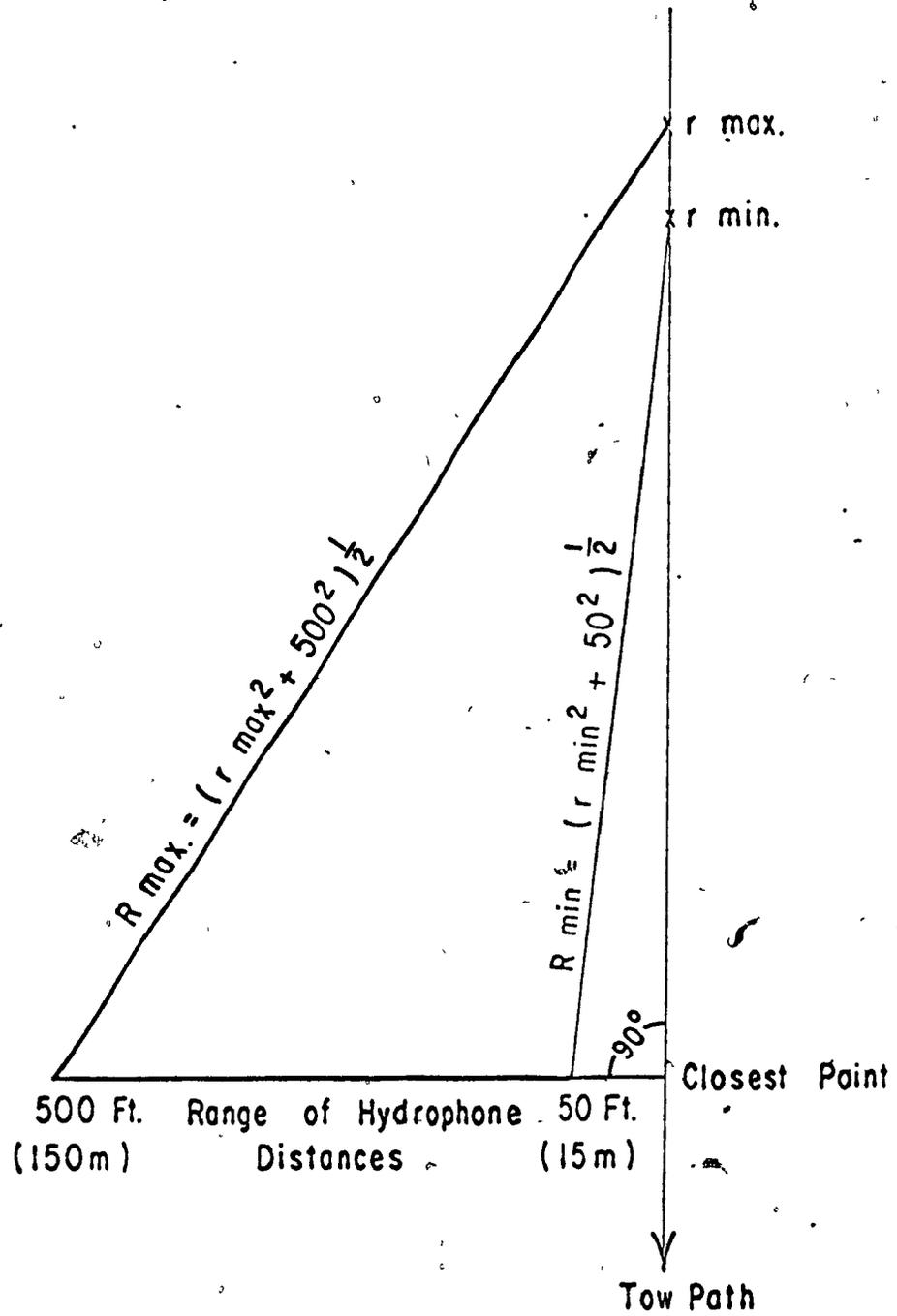
Figure 6. Relationships of maximum and minimum R, r, and hydrophone distance (explanation in text).

in feet at which cod can detect trawling noise in each band of each recording is listed in the Appendix.

Results and Discussion

A. Ambient sea noise

Table 7 shows the band level of average ambient sea noise in each band for each of the 6 summer recordings and for each of the 6 winter recordings. The mean in each band and its 90% fiducial limits is calculated for the summer recordings and the winter recordings and is shown as spectrum level (spectrum level = band level - power factor of Table 2). The mean spectrum levels and their 90% fiducial limits are illustrated on a logarithmic frequency scale in Figure 7.

The differences between the summer and winter mean noise levels were significant at the 90% level ('t' test) in all frequency bands except bands 4, 5 and 6. Higher noise levels in winter were also reported by Piggott (1964) for shallow waters of the Scotian Shelf. He attributes the higher noise levels in winter to the difference in vertical sound velocity profile, The vertical sound velocity profile is defined as the variation of sound velocity with depth (Urick, 1967). A positive vertical velocity profile means that sound velocity increases with depth and a negative vertical velocity profile means that the sound velocity decreases with increased depth. On the Scotian Shelf, the vertical velocity profile in winter is positive, and attenuation coefficients are smaller than in summer when the vertical velocity profile is negative (Piggott, 1964). Measurements of velocity profiles in Passamaquoddy Bay have not been reported, the temperature structure, however, is warmer at the surface in summer and warmer near the bottom in winter while salinity is always higher near the bottom (Forgeron, 1959). Since

Table 7. Average ambient noise in db re 1 μ bar.

Band	Average ambient noise (band levels) summer recordings						Mean and 90% fiducial limits (spectrum level)		
								$\bar{x}$	
1	-21	-12	-14	-16	-18	-24	-19.1	-16.1	-13.1
2	-28	-15	-20	-21	-21	-23	-23.8	-20.9	-18.1
3	-31	-19	-23	-22	-23	-23	-26.8	-24.1	-21.4
4	-32	-20	-24	-20	-24	-22	-28.2	-25.3	-22.3
5	-28	-24	-23	-24	-25	-22	-28.3	-26.9	-25.6
6	-27	-24	-24	-26	-24	-23	-29.3	-28.3	-27.3
7	-25	-25	-28	-28	-25	-24	-31.6	-30.4	-29.3
8	-23	-28	-29	-31	-29	-26	-35.1	-33.3	-31.4
9	-29	-32	-31	-35	-32	-30	-39.5	-38.1	-36.7
10	-35	-35	-33	-35	-34	-32	-42.4	-41.6	-40.8
11	-39	-36	-33	-35	-35	-34	-45.3	-43.9	-42.6
12	-37	-34	-31	-33	-35	-33	-44.8	-43.4	-42.1
13	-34	-31	-32	-33	-36	-32	-44.8	-43.6	-42.4
14	-35	-29	-30	-30	-36	-30	-45.3	-43.3	-41.3
15	-34	-29	-31	-29	-36	-29	-45.9	-43.9	-41.9
16	-32	-28	-30	-27	-35	-29	-45.7	-43.8	-41.8
17	-35	-28	-30	-24	-33	-29	-47.0	-44.4	-41.8
18	-37	-28	-29	-22	-29	-30	-48.0	-44.8	-41.6
19	-35	-29	-28	-20	-27	-33	-48.8	-45.3	-41.8
20	-33	-27	-25	-17	-23	-35	-48.7	-44.3	-39.8
21	-30	-25	-23	-15	-21	-35	-48.1	-43.4	-38.7

winter recordings

1	-9	-10	-9	-16	-16	-5	-12.3	-9.4	-6.5
2	-12	-14	-10	-21	-22	-7	-18.0	-13.9	-9.9
3	-15	-17	-12	-24	-25	-8	-21.9	-17.4	-13.0
4	-20	-23	-16	-28	-29	-13	-27.4	-23.1	-18.8
5	-20	-27	-18	-29	-30	-12	-30.0	-25.3	-20.5
6	-20	-25	-18	-27	-28	-16	-29.3	-25.9	-22.6
7	-21	-25	-20	-24	-24	-17	-28.5	-26.4	-24.4
8	-21	-26	-21	-27	-25	-18	-31.0	-28.6	-26.2
9	-22	-27	-21	-30	-29	-15	-34.4	-30.6	-26.8
10	-21	-27	-21	-28	-29	-16	-34.7	-31.3	-27.8
11	-21	-27	-21	-31	-32	-19	-37.5	-33.8	-30.0
12	-21	-23	-21	-27	-31	-20	-36.3	-33.4	-30.5
13	-17	-15	-20	-7	-17	-14	-28.6	-25.6	-22.6
14	-21	-24	-17	-20	-27	-18	-35.3	-32.8	-30.2
15	-20	-22	-18	-26	-31	-17	-38.5	-34.9	-31.4
16	-19	-23	-17	-27	-28	-17	-38.7	-35.4	-32.1
17	-18	-20	-15	-24	-29	-17	-38.6	-35.1	-31.6
18	-17	-17	-14	-22	-28	-15	-38.0	-34.4	-30.9
19	-15	-16	-12	-21	-27	-14	-37.8	-34.1	-30.4
20	-13	-15	-10	-19	-25	-12	-37.0	-33.3	-29.6
21	-11	-14	-9	-20	-24	-11	-37.4	-33.4	-29.5
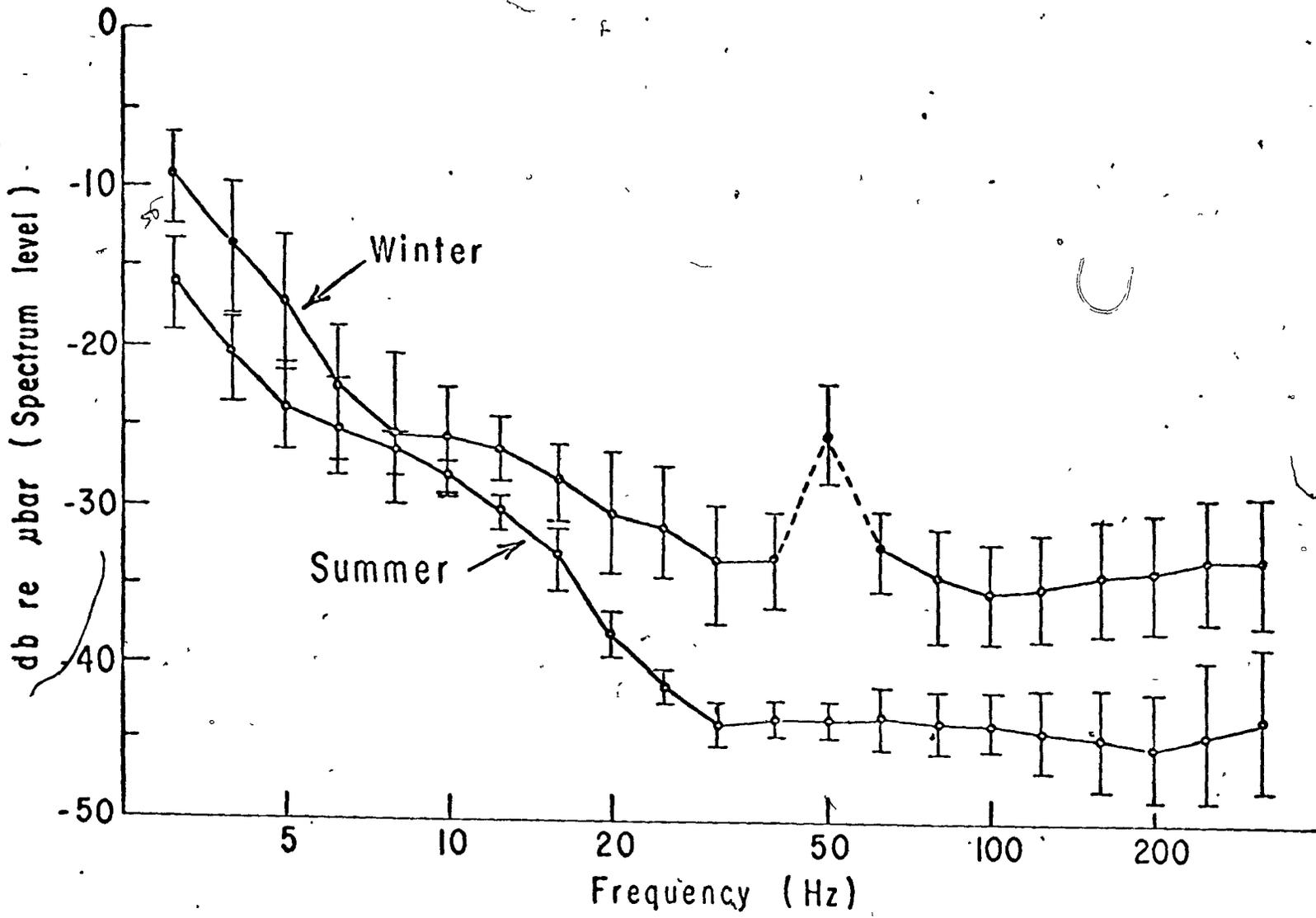
Figure 7. Mean ambient noise spectrum level.

sound velocity increases with increased temperature at 2.7 ft (.82 m) per second per °C and increases with increased salinity at 4 ft (1.22 m) per second per 1 ppt., a positive vertical sound velocity profile in winter is most certain and a negative vertical sound velocity profile in summer is quite probable in Passamaouoddy Bay. This difference no doubt accounts for the difference between summer and winter ambient noise.

The peak in winter ambient noise in band 13 (50 Hz) is probably due to electrical interference produced by the recording boat. As described previously, winter recordings were made from a trawler. It had radio and radar equipment in operation during the recording. The equipment was operated so that the measurements of range between the trawler and the recording boat that were needed to estimate the towing speed could be made. Such equipment often emits electrical noise to which a tape recorder could be sensitive.

Recordings were made during periods when the wave height was about 1 ft (.3 m) and there were white caps. Periods of calm surface were not encountered, and when the waves were large, recordings could not be made because the recording boat then generated noise by slapping on the waves. The resulting small range of sea states during which recordings were made, does not permit comparison of ambient sea noise at different sea states.

Pigott (1964) describes sea noise spectrum level on the Scotian Shelf in relation to wind speed. The combined summer-winter average ambient noise spectrum level measured in this project corresponds approximately in level to the combined summer-winter average noise reported by Piggott at wind speeds of 6 to 9 miles per hour.

The measured ambient noise also fits well within the limits of prevailing noise described by Wenz (1962). Sources of noise described

by Wenz that could contribute to the measured noise levels are:
turbulent pressure fluctuations due to surface waves for frequencies
1 to 10 Hz, turbulent pressure fluctuations due to siesmic background
for frequencies 1 to 100 Hz, distant oceanic traffic for frequencies
12 to 315 Hz, and bubbles and spray due to surface agitation for
frequencies 100 to 200 Hz. In addition, there could be intermittent
sources such as ships, industrial activity, and biological sources.
These, however, would not be major contributors to the noise described
here because care was taken to record only when there were no known
intermittent disturbances.

B. Masking

Auditory masking in cod was measured in the frequency range
of 20 to 160 Hz (Buerkle, 1969). Ambient noise measured in this project
was loudest at frequencies below 20 Hz. The possible masking of trawling
noise by these low frequencies can either be ignored because nothing
definite is known about masking at frequencies below 20 Hz, or it can be
quantified by extrapolations of the published data on masking. The
latter approach was chosen because it seemed unreasonable that the high
noise levels below 20 Hz should have no masking effect.

To illustrate the masking effect, the mean masking for summer
and winter recordings is described. Figure 8 shows the relationship
of the spectrum levels of mean ambient noise +10 db, mean masking levels,
and the slope of masking of higher frequencies by lower frequencies.
The mean masking levels were calculated from the previously described
band level masking levels, the slope of the masking effect was also
previously described as -.2 db (band level) per Hz. Although the masking
levels and the masking slope were previously described as band levels
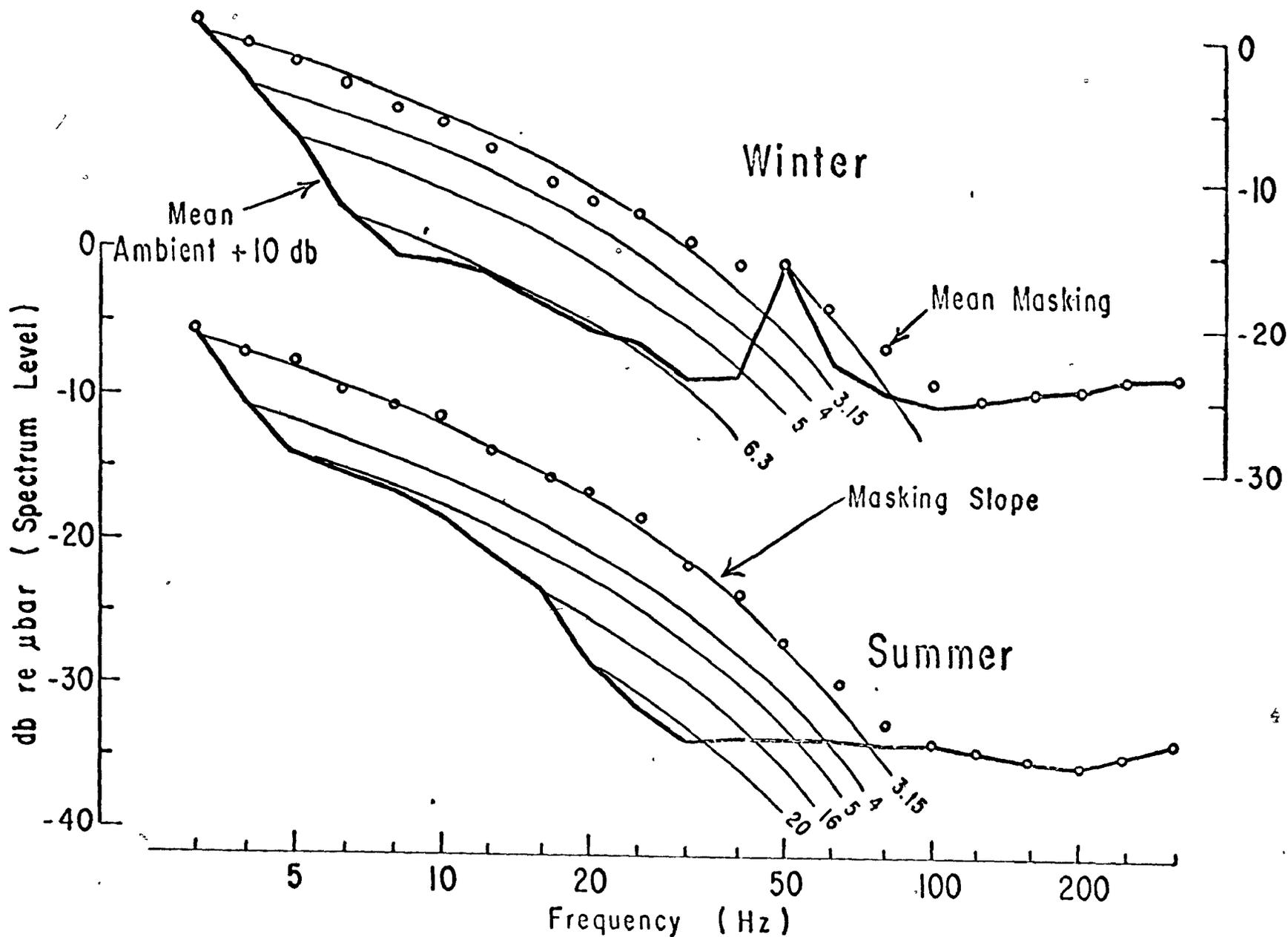
Figure 8. Relationship of mean ambient noise + 10 db, mean masking levels and slope of masking of higher frequencies by lower frequencies.

and were used as such in the calculation of the range (R), Figure 8 shows the relationship in terms of spectrum level because the mean ambient noise was previously described as spectrum level. The conversion does not affect the relationships.

The masking effect of low frequencies is illustrated by the family of curves of masking slope originating at some of the low frequencies. For example, the curve marked 3.15 is the level at which the mean ambient noise at 3.15 Hz masks higher frequencies, and the curve marked 4 is the level at which the mean ambient noise at 4 Hz masks higher frequencies. It can be appreciated that the mean masking level at any frequency in summer or winter, is the mean of the highest masking effect in each of the 6 relevant recordings.

In winter, the mean ambient noise between 3.15 and 4 Hz masks frequencies up to about 40 Hz. Then the peak of noise at 50 Hz, previously described as electrical interference, masks a few frequencies above and below 50 Hz. From about 100 Hz up, each frequency is masked only by noise of the same frequency. In summer, noise at 3.15 Hz masks frequencies up to about 80 Hz. Since there was no electrical interference at 50 Hz, this is probably the correct situation for winter also. As in winter, frequencies above about 100 Hz are masked only by noise of the same frequency.

Figure 8 also shows that should the low frequency masking not occur, and all frequencies are masked only by noise of the same frequency, masking levels of frequencies between 3.15 and 100 Hz would on the average be about 7 db lower. At 25 Hz the difference would be about 9 db in winter and about 13 db in summer.

C. The noise source

During trawling, noise can conceivably be generated by any part of the trawling gear from the trawler itself to the trawl 450 feet (137 m) behind. The sources of noise in the different frequency bands in this project are unknown, but a measure of their location can be obtained from the data. If noise in the different frequency bands was produced by sources that are spatially separated from each other, the peak noise pressure in the different bands should occur at different times, and the difference should occur in all tows. Time differences between the peak noise in each band can be obtained from the distances d of the Appendix. It will be remembered that d is the distance from the intercept of each equation to the point at peak noise pressure. The maximum and minimum d in each band are reflections of the distance interval of 146 ft (44 m) and 131 ft (40 m) between moving averages respectively. The time relationship between peak noise in the different frequency bands is the same for both distance intervals, calculations will be done with the maximum d of each band. The d's in each recording can be put on a relative scale of time by the relationship 146 ft (44 m) = 30 seconds. The relationships of peak noise pressure in the bands of each of the 12 recordings are shown in Figure 9. It can be seen that there is no consistent time pattern between frequency bands. It can be concluded that any spatial separation between noise sources of the different frequency bands is too small to detect by examination of time differences between peak moving averages. If the trawl were a major noise source in any frequency band, the 450 foot (137 m) separation between the trawler and the trawl should cause a peak of about 1.5 minutes in that band in all recordings. The absence of any
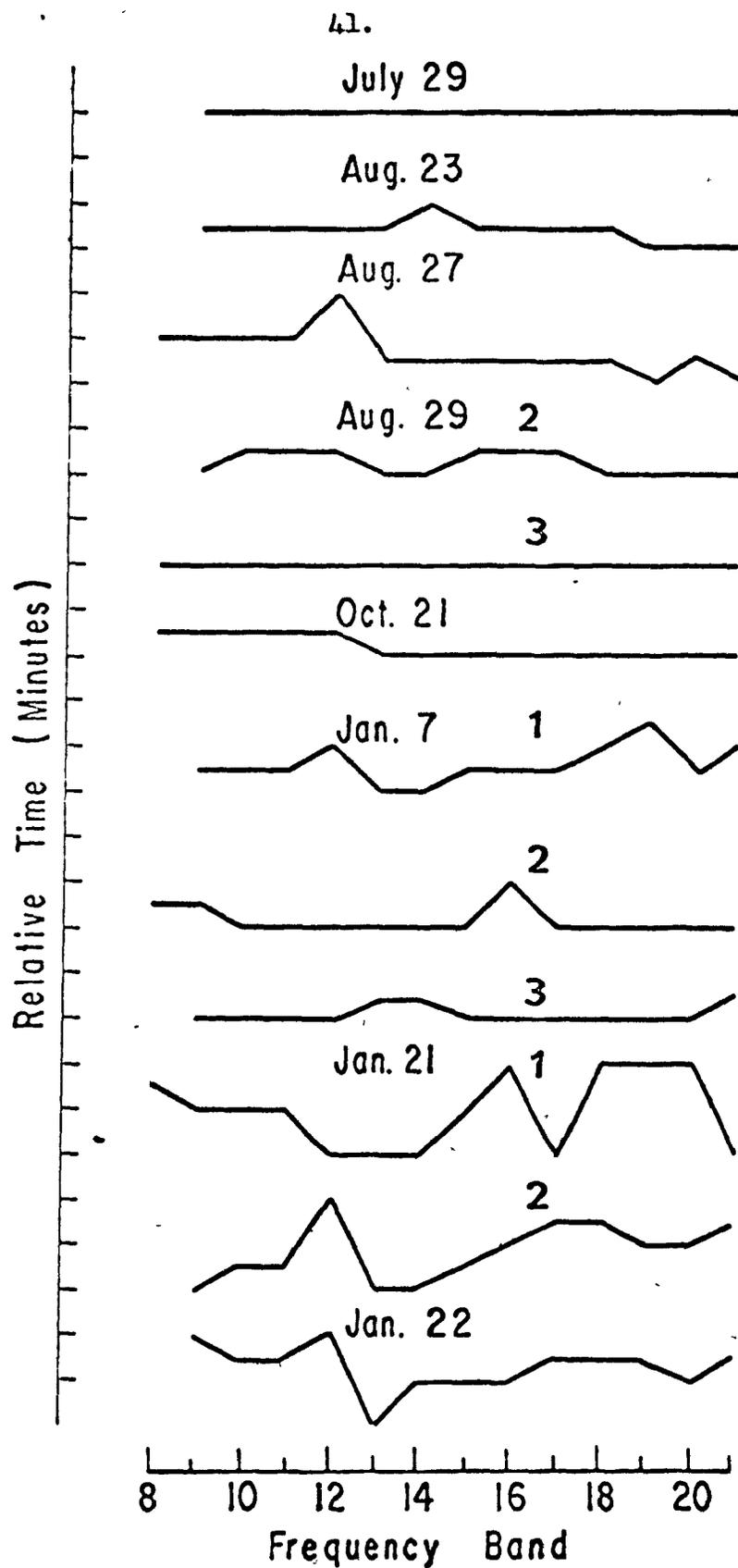
Figure 9. Relative time of peak noise pressure by frequency bands.

such consistent pattern in Figure 9 leads to the conclusion that the major noise source, in all frequency bands, is the trawler. On a sea floor of soft mud as occurred in this project, the trawl would not be expected to produce much noise. This finding also agrees with the statement of Shiskova (1958) that trawls produce little noise compared to trawlers. On a hard sea floor of rocks or gravel on the other hand the trawl could generate loud intermittent noises as its hard parts, such as doors and rollers, strike against the hard bottom.

D. Index value of trawling noise

Recent recommendations (Gjestland, 1971) suggest that ship noise and trawling noise should be described in terms of an index value that is the decibels in 1 Hz band widths at 1 meter from the source. In this project, distances between the noise source and the hydrophone were not determined precisely, and index values can therefore only be estimated. Urick 1967 (p. 266) states that "spherical or inverse spreading is a good rule of thumb for expressing the variation of ship noise with range at close distances, even for low frequencies in shallow water". This "rule of thumb" was used to calculate index values of trawling noise for the summer and the winter data.

The mean noise level db_{cp} at the closest distance between the hydrophone and the noise source and the mean noise level db_{cp+131} at 131 ft (40 m) further than that were calculated from the minimum intercept (A), the slope (b) and the minimum distance (d) in each of the frequency bands of the Appendix. They were averaged in each band of the 6 summer recordings and in each band of the 6 winter recordings, the averages and their standard errors are shown in Table 8. The

Table 8. Index values of summer data.

Band	db_{cp}	$s\bar{x}$	db_{cp} + 131	Dcp (ft)	(m)	Index value -90%	mean	+90%
8.	3.7	1.3	.2	262	80	33.9	36.1	38.3
9	18.7	4.2	11.4	101	31	34.9	41.9	48.9
10	34.8	5.8	28.4	119	36	49.7	59.3	68.9
11	16.5	4.1	10.9	146	44	34.2	40.9	47.6
12	8.6	2.2	4.9	262	80	33.4	37.0	40.6
13	16.2	2.0	10.9	164	50	36.2	39.6	43.0
14	17.7	2.4	11.6	131	40	34.1	38.1	42.1
15	21.0	1.6	15.3	146	44	38.8	41.4	44.0
16	20.2	1.6	15.0	164	50	37.9	40.6	43.3
17	29.9	2.5	23.8	131	40	43.1	47.3	51.4
18	39.4	3.6	32.4	109	33	48.3	54.2	60.1
19	45.2	3.0	36.8	82	25	51.7	56.6	61.5
20	38.9	2.5	31.3	94	29	46.4	50.5	54.6
21	33.7	1.9	26.5	101	31	41.8	44.9	48.0

Index values of winter data.

Band	db_{cp}	$s\bar{x}$	db_{cp} + 131	Dcp (ft)	(m)	-90%	mean	+90%
8	-7.9	6.1	-8.6	1310	400	28.6	38.5	48.4
9	6.7	3.5	4.3	437	133	36.8	42.5	48.2
10	34.5	5.3	29.0	146	44	51.2	59.9	68.6
11	18.0	3.8	14.4	262	80	41.7	47.4	53.1
12	2.4	3.5	.3	655	200	33.1	38.8	44.5
13	13.6	1.6	10.8	327	100	40.3	43.0	45.7
14	7.5	1.6	5.0	437	133	35.7	38.3	40.9
15	10.0	3.2	7.0	327	100	32.2	37.4	42.6
16	12.2	2.9	10.0	437	133	36.2	41.0	45.8
17	24.3	3.3	20.1	218	66	40.6	46.1	51.6
18	22.7	5.0	19.3	262	80	36.9	45.1	53.3
19	17.8	4.4	15.0	327	100	34.0	41.2	48.4
20	15.4	4.1	12.7	327	100	31.1	37.8	44.5
21	15.6	3.4	12.8	327	100	31.5	37.0	42.5

db_{cp} = average decibels at closest point
$s\bar{x}$ = standard error
db_{cp} +131 = average decibels at closest point + 131 feet
Dcp = distance at closest point
± 90% = upper and lower 90% fiducial limits.

average values were used to calculate a distance (Dcp) between the closest point and the hydrophone in the following manner.

The slope between the two averages in any band is (according to Urick's "rule of thumb") - 20 log distance. In any band, therefore,

$$db_{cp} = A - 20 \log D_{cp}$$

$$db_{cp} + 131 = A - 20 \log (D_{cp} + 131).$$ These equations can be subtracted and reduced to

$$D_{cp} = \frac{131}{antilog \dfrac{db_{cp} - db_{cp} + 131}{20} - 1}.$$

Since db_{cp} ($\pm$ standard error) and D_{cp} are now known, the decibels at 1 meter (dbm) can be calculated by the following equation

$$dbm \ (\pm \text{ standard error}) = db_{cp} \ (\pm \text{ standard error}) - 20 \log \frac{3.28}{D_{cp}}$$

(1 meter 3.28 feet.) These distances Dcp are also listed in Table 8. The decibels at 1 meter are band levels and can be converted to levels in 1 Hz band widths by subtracting, in each band, the appropriate power ratio of Table 2. The converted values are index values of trawling noise and are shown in Table 8 and Figure 10.

The index value for the summer and the winter data should be the same if the "rule of thumb" used in their calculation is valid for both situations. At frequencies up to 125 Hz the index values for the summer and winter are very close, but at frequencies between 125 and 315 Hz the calculated values for winter are from 8 to 15 db lower than those of summer. If it can be taken for granted that the trawler generates an equal amount of noise in winter as in summer, the difference indicates that the "rule of thumb" does not apply to both summer and

45.
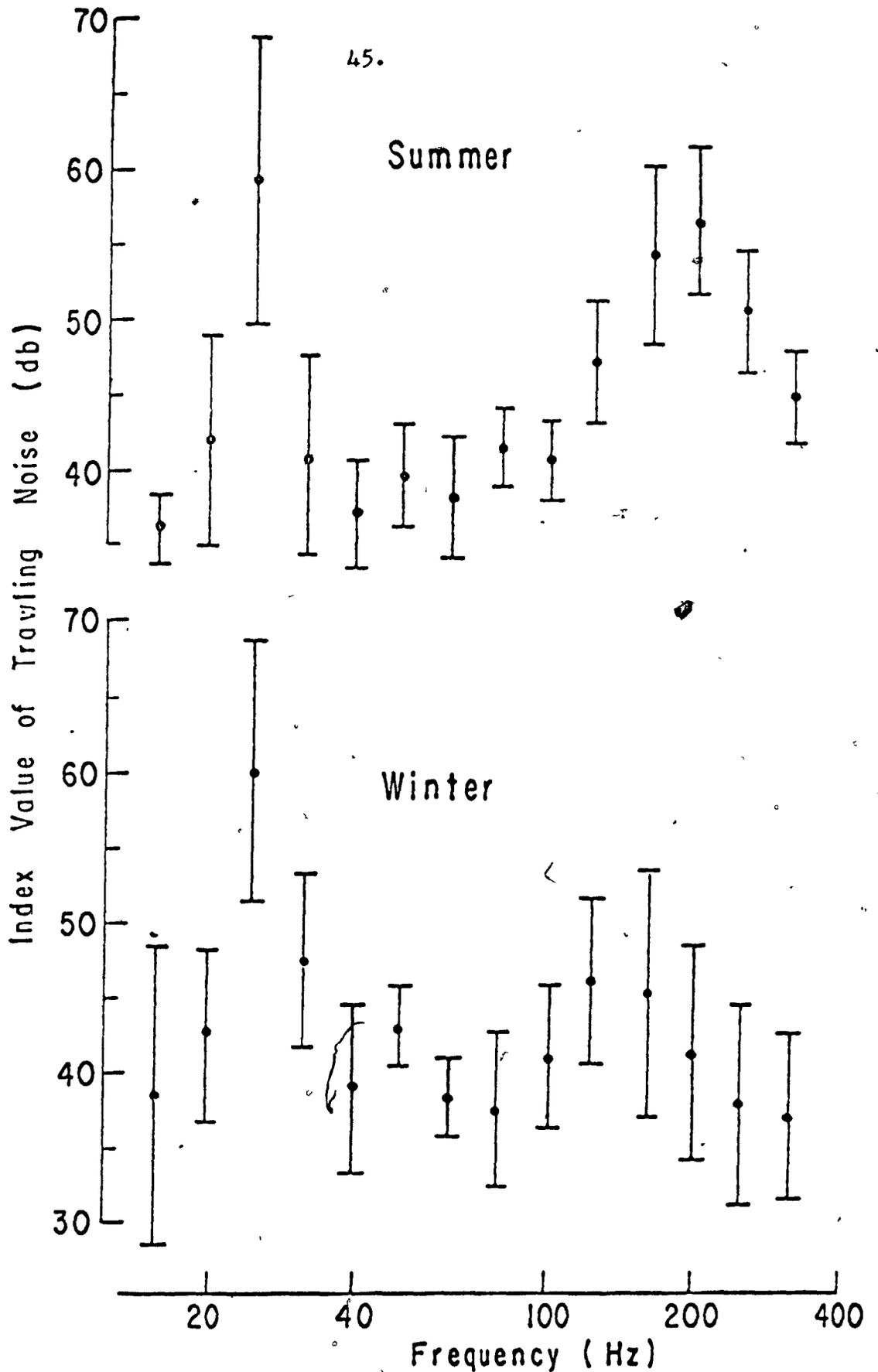
Figure 10. Index values of trawling noise for winter and
summer data.

winter conditions.

At frequencies between 125 and 315 Hz the transmission loss of 20 log distance does not fit both the summer and the winter conditions. If it is appropriate for summer, the winter loss should be about 35 log distance. If it is appropriate for winter, the summer loss should be about 12 log distance. Which of these cases, if either, is correct, cannot be determined from the data. It is correct to conclude, however, that transmission loss in winter, at close range and at frequencies between 125 and 315 Hz, is more than in summer.

The spectrum of index values calculated here shows similarities to those reported by Olsen (1967) and by Hawkins et al. (1972). The spectrum of the vessel R/V Johan Hjort (Olsen, 1967) shows a decrease in level at around 40 Hz and a peak at around 125 Hz that is similar to the distribution presented here. Olsen does not report a peak at 25 Hz in the 1/3 octave band analysis of the Johan Hjort noise, but he does show a 68 db noise level in a 1 Hz band width at 25 Hz. If this 68 db in a 1 Hz band width were measured in a 1/3 octave band width with a center frequency of 25 Hz, the level would be about 60 db. This is almost exactly the level of the peak at 25 Hz in this report, and suggests that the peak is due to high noise intensity in a very narrow band around 25 Hz.

The spectra of the other vessels reported on by Olsen (1967) and Hawkins et al. (1972) do not show a peak in noise level between 100 and 200 Hz. They show a decrease in noise with increasing frequency of about 6 db per octave at frequencies above 100 Hz.

The highest mean noise level described by Hawkins et al. was about 50 db and occurred below 100 Hz. The highest mean noise level

reported by Olsen was about 65 db at about 40 Hz.

At 200 Hz the average noise of the 2 vessels reported on by Olsen, and the average of the 2 vessels reported on by Hawkins et al. were about 45 and 40 db respectively.

In the present work, the average at 200 Hz was 56 and 41 db in summer and winter respectively. This might be regarded as evidence that the winter spectrum is more representative of average conditions and that the winter transmission loss at close range really is 20 log distance.

In general, the noise levels determined by Olsen (1967), Hawkins et al. (1972) and in this project are surprisingly similar when one considers the differences in conditions under which measurements were made, and the differences in vessel size, type and propulsion. It shows that smaller wooden vessels can be as noisy as the larger steel vessels, but it cannot be regarded as a general rule.

E. Transmission loss

Transmission loss describes the weakening of sound between a reference distance from a sound source and other distances. If I is the intensity of a source at a reference distance, and I_2 is the intensity of another distance, the transmission loss between the two distances is $10 \log \frac{I_1}{I_2}$ db. Transmission loss is the sum of loss due to spreading and of loss due to attenuation. Spreading loss is a geometrical effect representing the regular weakening of a sound signal as it spreads outward from a source. If a source generates sound in an unbounded homogeneous medium, the power is radiated equally in all directions so as to be equally distributed over the surface of a sphere surrounding the source. This is called spherical spreading. If there

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is no loss in the medium, the power crossing all such spheres must be
the same. Since power equals intensity times area,

$$P = 4\pi r_1^2 I_1 = 4\pi r_2^2 I_2 = ----$$

(P = power, r = range, I = intensity)

If $r_1 = 1$ the transmission loss to r_2 will be $10 \log \dfrac{I_1}{I_2} = 10 \log r_2^2 =$

20 log r_2 db.

If the medium has plane and parallel upper and lower bounds
such as in shallow water, the spreading is no longer spherical. It is
called cylindrical spreading because beyond a certain range the power
radiated by a source is distributed over the surface of a cylinder with
radius (r) equal to the range, and height (H) equal to the distance
between the bounding planes. The power crossing such surfaces at range
r_1 and r_2 is

$$P = 2\pi r_1 H I_1 = 2\pi r_2 H I_2 = ----$$

If $r_1 = 1$ the transmission loss is

$$10 \log \frac{I_1}{I_2} = 10 \log r_2$$

In the ocean the distinction between spherical and cylindrical
spreading is never quite so clear. In fact, spherical spreading often
occurs under trapping conditions in sound channels where it has no
right to occur (Urick, 1967).

Attenuation, the other factor that adds to transmission loss,
is the reduction in intensity due to discontinuities, absorption, and
variations in temperature and salinity. It thus includes all factors
other than spreading loss. It is not a constant, and cannot be accurately
predicted from theoritical considerations.

Transmission loss in this project was not measured but the

slopes (b) of the Appendix are functions of the transmission

characteristics of trawling noise for the prevailing conditions. They

do not express the real magnitude of the transmission losses because they

were calculated from an assumed distance between the last moving average

and the hydrophone. They do express the relative transmission loss

between frequencies. It was shown previously that there was no evidence

of spatial separation between noise sources of the different frequency

bands. The distance between the hydrophone and closest point in the

tow path, therefore, can be expected to be the same for all bands of

any one recording. The difference between this distance and the assumed

distance from which the slopes were calculated is, therefore, constant

and the error in slope also is constant for all bands in any one recording.

The slopes in each band of the 6 summer recordings and of the

6 winter recordings were averaged and are shown with their 90% fiducial

limits in Figure 11.

It can be seen that the relationship between slopes and frequencies

is the same in summer and winter, but that the slopes in winter are

approximately 10 db higher. Greater transmission loss in summer has

also been reported for the Scotian Shelf by Macpherson et al. (1962).

Their data indicate that a difference between summer and winter of 10

log distance is not unreasonable. They attribute the difference to the

positive vertical velocity profile of winter, which as already discused

also occurs in Passamaquoddy Bay.

The variations of transmission loss with frequency seen in

Figure 11 may be due to several causes, singly or in combination. The

patterns could reflect an interaction between the wave lengths of the

frequencies and the physical characteristics of the transmission channel,
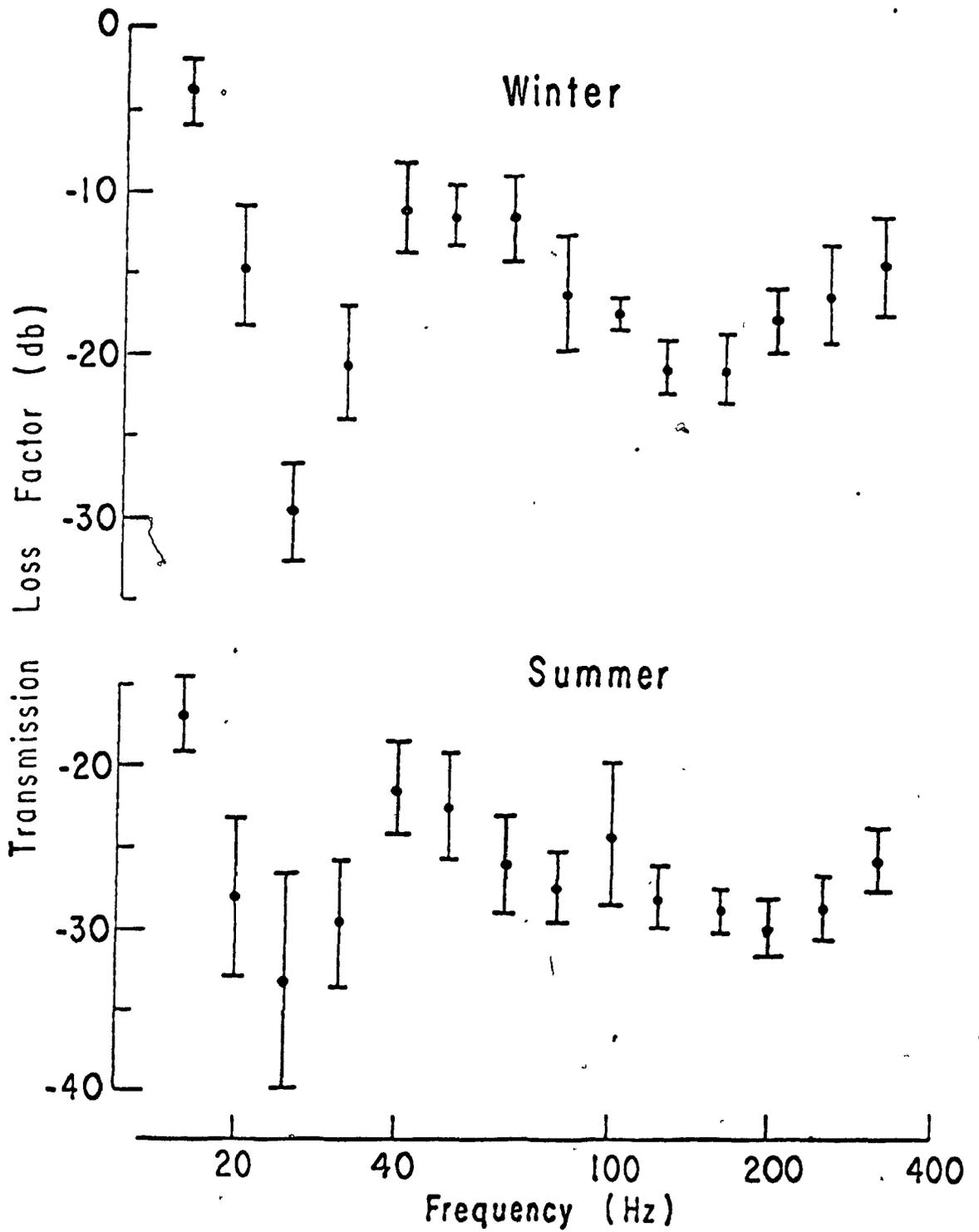
Figure 11. Mean relative transmission loss by frequencies.

or they could be caused by the characteristics of the noise fields
generated by the sources of the different frequency bands. Whatever
the cause, it is important to note that transmission loss does vary with
frequency by as much as 26 log distance in the frequency range covered
in this report.

F. Range at which cod can detect trawling noise

The maximum and minimum range (R in the Appendix) at which cod
can detect trawling noise in each band were averaged for the six summer
recordings and the six winter recordings. The means of summer and winter
in each band are listed with their standard deviation in Table 9.
Winter ranges are significantly greater at 25 and 31.5 Hz ('t' test).
Summer ranges are significantly greater at 20, 40, 200 and 250 Hz.
At other frequencies, the differences are not significant. The mean
maximum and minimum range of each band and their upper and lower 90%
fiducial limits respectively are shown in Figure 12 for the summer
recordings, and in Figure 13 for the winter recordings.

In summer the trawling noise at 200 Hz can be detected at the
longest range. It can be detected at about 1.5 miles (2.8 km) in 90%
of the tows made under conditions similar to those during this project.
In 10% of the tows it can be detected as far as 2.5 miles (4.6 km).
In winter the frequency that can be detected at the longest range is
125 Hz. It can be detected at about .5 miles (.9 km) and at about
2.5 miles (4.6 km) in 90% and 10% of the tows respectively.

Except for the increased ranges at frequencies 20, 25 and
31.5 Hz the range at frequencies below 200 Hz decreases with frequency
at about 66 ft (20 m) per Hz in summer. In winter this decrease is not
as clear because of the large difference in range between 40 and 50 Hz.

Table 9. Mean range at which cod can detect trawling noise in summer and winter.

Band	Summer				Winter			
	Mean range		Standard deviation		Mean range		Standard deviation	
	(ft.)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)
8	270	82.4	149.5	45.6				
	592	180.6	92.7	28.3				
9	781	238.2	388.1	118.4	480	146.4	97.5	29.7
	1021	311.4	328.8	100.3	733	223.6	82.1	25.0
10	2661	811.6	536.4	163.6	3994	1218.2	1447.8	441.6
	3010	918.0	607.4	185.3	4481	1366.7	1603.3	489.0
11	850	259.2	366.8	111.9	2401	732.3	749.2	228.5
	1087	331.5	307.9	93.9	2727	831.7	865.8	264.1
12	754	230.0	352.1	107.4	295	90.0	196.9	60.1
	983	300.0	228.6	69.7	625	190.6	116.1	35.4
13	1688	514.8	793.1	241.9	2909	887.2	1704.9	520.0
	1958	597.2	851.3	259.6	3302	1007.1	1885.2	575.0
14	1666	508.1	439.5	134.0	1694	576.7	1523.4	464.6
	1945	593.2	420.7	128.3	2014	614.3	1609.2	490.8
15	2529	771.3	530.1	161.7	2015	615.6	1342.1	409.3
	2863	873.2	581.4	177.3	2434	742.4	1444.4	440.5
16	4647	1417.3	2344.6	715.1	4236	1292.0	3197.9	975.4
	5191	1583.2	2603.6	794.1	4775	1456.4	3547.2	1081.9
17	5585	1703.4	1763.6	537.9	8165	2490.3	7441.6	2269.7
	6248	1905.6	1958.5	597.3	9122	2782.2	8291.4	2528.9
18	9003	2745.9	2646.3	807.1	7542	2300.3	5509.5	1680.4
	10049	3064.9	2945.0	898.2	8424	2569.3	6135.9	1871.4
19	10570	3223.8	3107.3	947.7	5363	1635.7	3365.8	1026.6
	11819	3604.8	3352.0	1022.4	6002	1830.6	3739.1	1140.4
20	6515	1987.1	3516.4	1072.5	3175	968.4	1713.2	522.5
	7616	2322.9	3914.4	1193.9	3582	1092.5	1891.7	577.0
21	4711	1436.8	2022.3	616.8	3537	1078.8	2368.8	722.5
	5404	1648.2	2402.1	732.6	3986	1215.7	2616.8	798.1
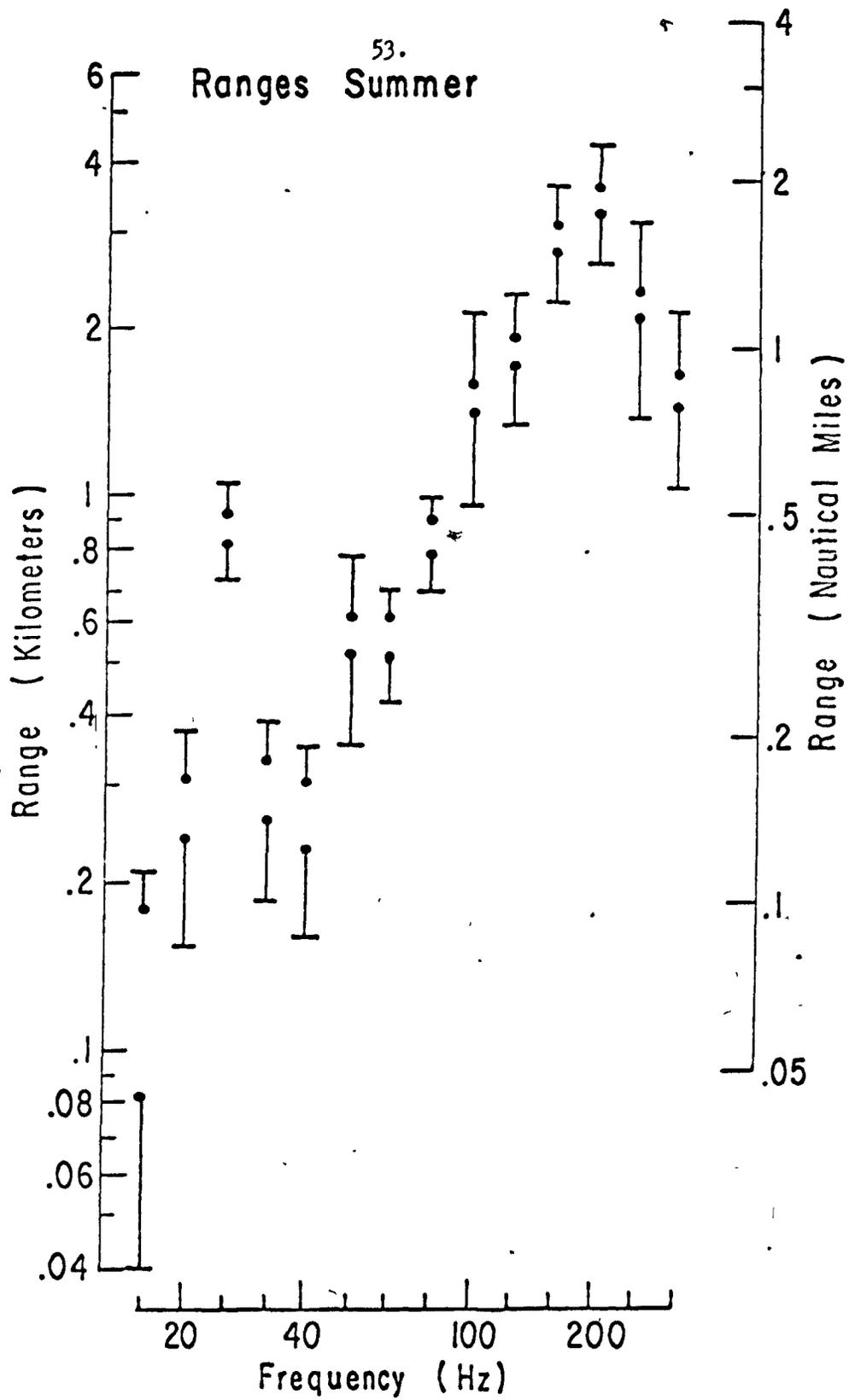
Figure 12. Mean maximum and minimum range at which cod can detect trawling noise in summer and their upper and lower 90% fiducial limit respectively.
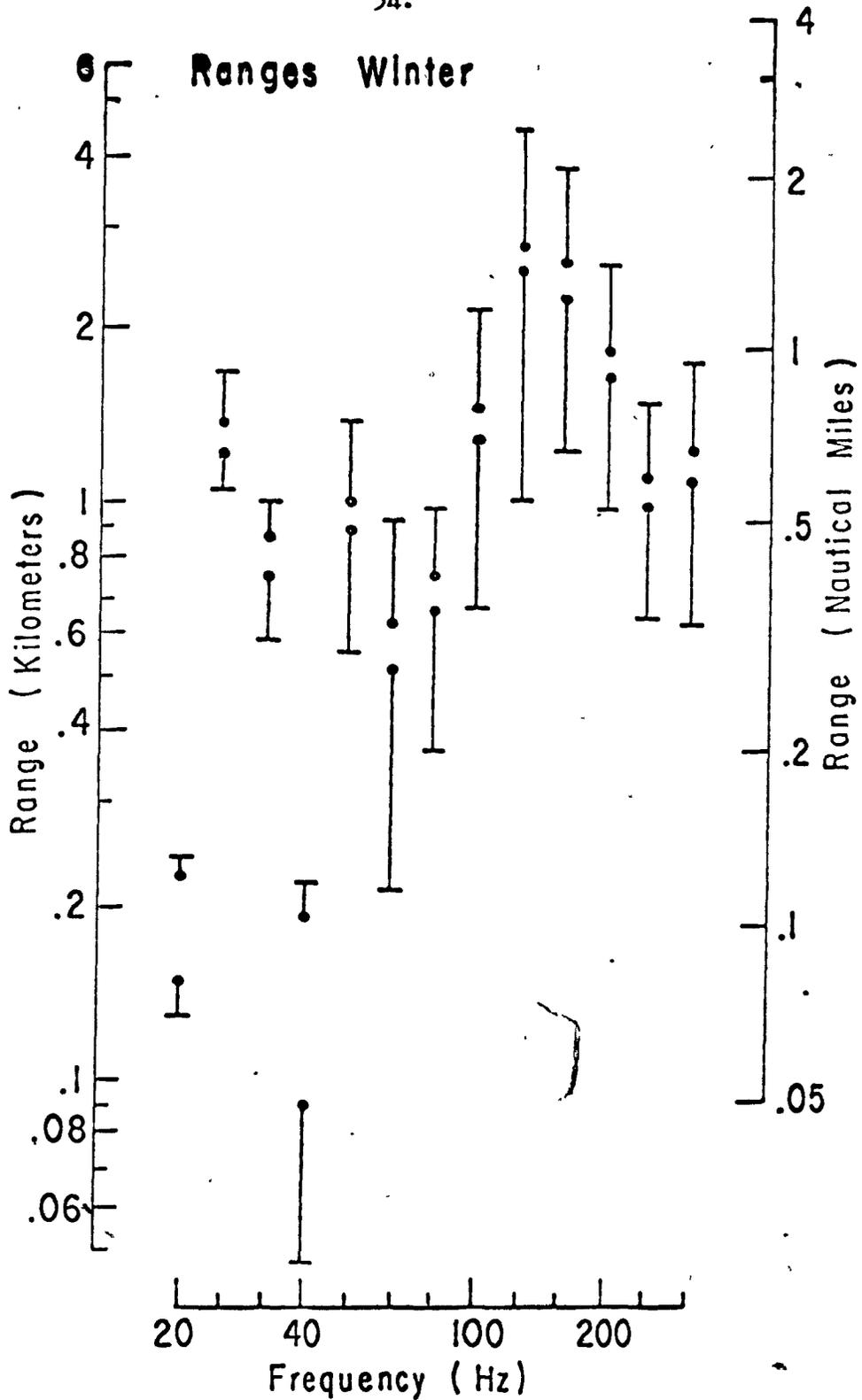
Figure 13. Mean maximum and minimum range at which cod can detect trawling noise in winter, and their upper and lower 90% fiducial limit respectively.

At frequencies above 200 Hz the range decreases with increasing frequency at about 40 ft (12 m) per Hz in winter and in summer.

The shape of the spectrum of range versus frequency is different from the spectrum of index values (Figure 10). The index values were highest at 25 Hz in summer and winter. The fact that 25 Hz is not the frequency that is detected at the longest range can be attributed to the greater transmission loss at 25 Hz than at 125 and 200 Hz (Figure 11). This points out that the theoretical values for transmission loss whether for spherical spreading (20 log distance) or for cylindrical spreading (10 log distance) should not be used in calculations involving transmission of noise over long ranges in shallow water.

As mentioned, the frequencies of trawling noise that cod can detect at the longest ranges are 125 and 200 Hz in winter and summer respectively. Since range is a function of masking level, and masking level depends on the ambient noise level, the effect of ambient noise level on range can be determined.

To simplify these calculations the mean of the average maximum and average minimum range (from Table 9) were calculated for 125 Hz in winter and for 200 Hz in summer. Because this mean range was calculated from a masking level based on the mean average ambient noise level, the mean range changes with ambient noise level by a factor equal to

$$
\text{antilog} \ \frac{\text{ambient noise level - mean ambient noise level}}{\text{average slope (from Figure 11)}}
$$

when all factors except ambient noise level remain the same.

The relationship of range versus ambient noise was calculated for the mean ranges and the lower 90% fiducial limits of the average minimum ranges of 125 Hz for winter and of 200 Hz for summer. They

are shown in Figure 14. The range of ambient noise levels shown in Figure 14 includes the maximum, mean and minimum average ambient noise measured in this project, and extends lower to -50 db because that is about the lowest level of ambient noise at these frequencies, that occurs in the ocean (Pigott, 1964; Wenz, 1962).

It can be seen that the steeper slope (-30) of summer results in less change of range with change in ambient noise level than does the less steep slope (-21) of winter. It can also be seen that at any noise level likely encountered in the ocean, winter ranges are larger than summer ranges.

Under the most quiet condition of ambient noise, cod can detect trawling noise at a mean range of about 35 miles (60 km) in winter and about 10 miles (18 km) in summer.

In 90% of tows made under such conditions, cod can detect the noise at about 14 miles (25 km) in winter and at about 7 miles (13 km) in summer.

Even at the loudest ambient noise level of -15 db that is likely to occur in the ocean at these frequencies (Wenz, 1962), the range at which cod can detect trawling noise is appreciable. In winter the mean range is about .9 miles (1.7 km); in summer it is about .6 miles (1.1 km).

In summary, the mean detection range of trawling noise for cod ranges from .9 miles (1.7 km) to 35 miles (60 km) in winter and from .6 miles (1.1 km) to 10 miles (18 km) in summer as the ambient noise level ranges from the loudest to the least loud.

Conclusion

It has been shown that the ambient noise measured in this project is similar to, and well within the limits of ambient noise in other reports
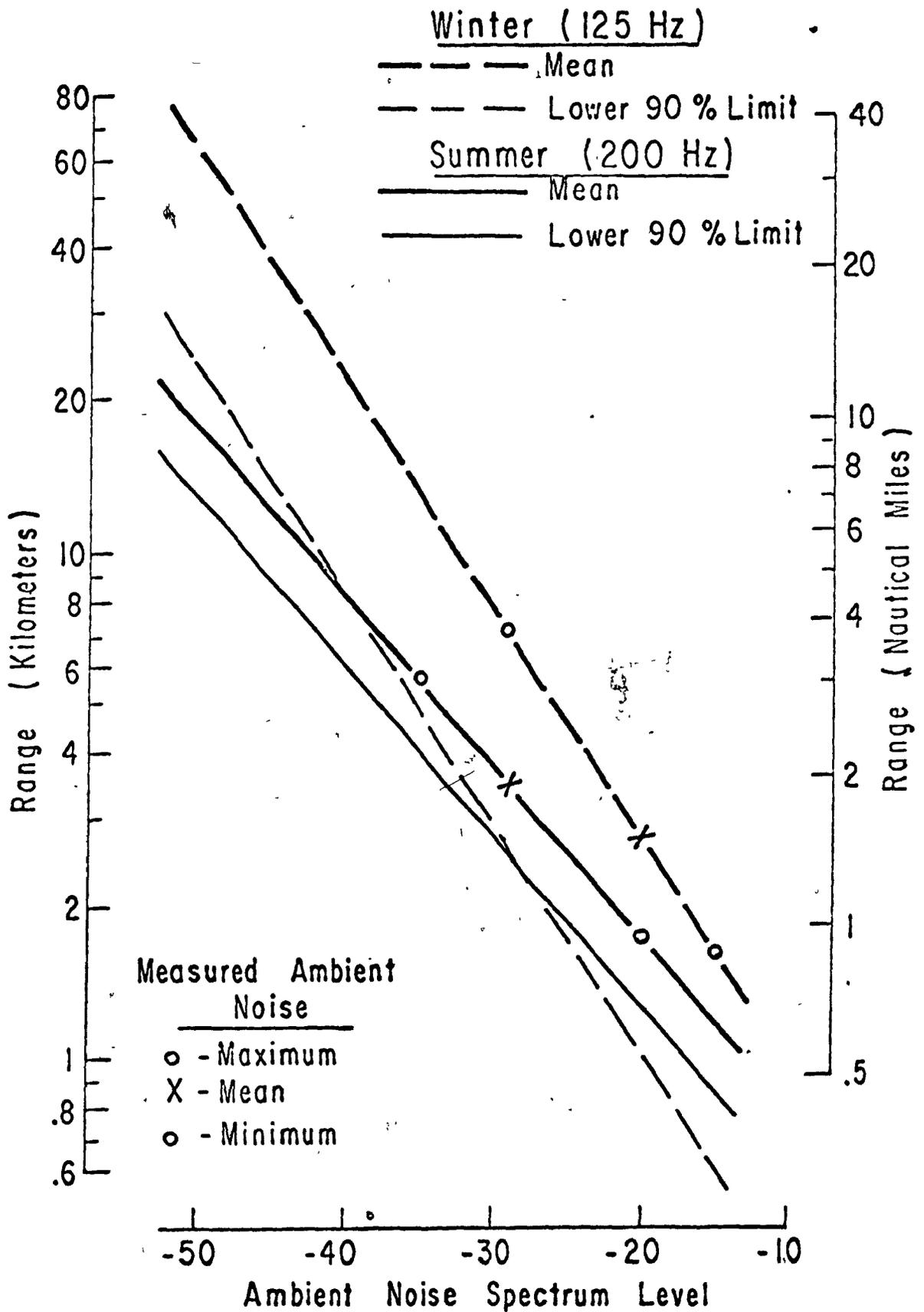
Figure 14. Effect of ambient noise level on range at which cod can detect trawling noise in summer and winter.

(Piggott, 1964; Wenz, 1962). It has been shown that the index value of trawling noise (and thus the noise generated by trawling) estimated in this report is similar to that reported for both trawlers and seiners (Hawkins et al. 1972; Olsen, 1967). The transmission loss estimated in this report showed variations with frequency that have not been shown before but was similar in magnitude to that described for broadband sources on the Scotian Shelf (Macpherson et al. 1962).

These considerations can lead to the conclusion that although the measurements were made under a specific range of conditions, they do reveal generalities that have a more universal application.

It may be concluded that in areas where the vertical sound velocity profile is positive in winter and negative in summer, the range at which cod can detect trawling noise is longer in winter than in summer when the ambient noise is the same. The longer range in winter is probably due to surface duct transmission in which sound propagates by upward refraction and repeated reflections off the sea surface where there is little reflection loss. In summer, refraction is downward and reflection loss at the bottom is generally higher than at the surface.

The frequencies of trawling noise that are propagated the furthest also differ between winter and summer. In winter, frequencies in the third octave band centered at 125 Hz can be detected at the longest range, while in summer, frequencies in the third octave band centered at 200 Hz can be detected furthest. This difference also must be attributed to the different propagation characteristics between winter and summer.

In both winter and summer, the range at which cod can detect trawling noise varies inversely with ambient noise level. During the most quiet conditions likely encountered in the ocean, cod should be able to detect

trawling noise as far as 35 miles (60 km) away in winter, and as far as 10 miles (18 km) away in summer. Under the most noisy conditions likely encountered in the ocean, the range at which cod can detect trawling noise is still appreciable. On the average, cod can detect the noise of tows made under such conditions at about .9 miles (1.7 km) in winter, and at about .6 miles (1.1 km) in summer.

It is obvious that trawling generates auditory stimuli that should, in theory, allow cod to make avoidance maneuvers well in front of the trawl under all conditions of ambient noise. The fact that cod are captured by trawls at all could mean that they do not respond to the stimuli, or that some respond in a way that does not lead to avoidance.

To determine which of these interpretations, if either, is correct is not within the scope of this report. It is hoped that the results presented here will aide in the design of experiments to determine the behaviour of cod in relation to fish capture processes.

Acknowledgements

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APPENDIX

Intercept (A), slope (b), masking level (ML), distance (d)
for 6 summer and 6 winter recordings (R and d in feet).

July 29, 1970, recording 1.

Band	Intercept (A)	Slope (b)	Masking level (ML)	Distance (d)	Range (R)
9	28.12	-15.05	-14	262	370
	28.83	"	"	292	646
10	64.16	-23.79	-15	262	1864
	65.16	"	"	292	2110
11	35.46	-19.76	-16	262	149
	36.39	"	"	292	524
12	44.99	-20.65	-18	262	862
	45.96	"	"	292	1082
13	75.87	-28.18	-20	262	2262
	77.19	"	"	292	2568
14	91.00	-33.64	-22	262	2025
	92.58	"	"	292	2310
15	93.20	-32.97	-24	262	3-326
	94.76	"	"	292	3742
16	86.21	-31.54	-22	262	2436
	87.69	"	"	292	2758
17	81.45	-29.12	-25	262	4263
	82.82	"	"	292	4776
18	81.65	-26.86	-27	262	10831
	82.91	"	"	292	12077
19	90.69	-27.81	-25	262	14193
	92.00	"	"	292	15827
20	83.31	-25.79	-23	262	12986
	84.53	"	"	292	14489
21	74.45	-24.59	-20	262	6672
	76.61	"	"	292	8207

Appendix (continued)

August 23, 1970, recording 1.

Band	Intercept (A)	Slope (b)	Masking level (ML)	Distance (d)	Range (R)
9	62.81	-23.53	-4	262	432
	63.91	"	"	292	691
10	118.95	-35.61	-5	262	2764
	120.63	"	"	292	3121
11	72.57	-25.76	-7	262	966
	73.18	"	"	292	1122
12	39.48	-17.93	-8	262	189
	40.33	"	"	292	540
13	54.64	-21.01	-10	262	932
	55.63	"	"	292	1152
14	52.81	-21.08	-13	393	822
	53.80	"	"	438	1152
15	67.92	-25.47	-16	262	1710
	69.12	"	"	292	1970
16	53.60	-20.29	-18	262	3118
	54.55	"	"	292	3508
17	73.91	-24.40	-18	262	5583
	75.06	"	"	292	6243
18	85.20	-26.57	-18	262	7396
	86.46	"	"	292	8264
19	87.16	-27.86	-19	131	6332
	89.07	"	"	146	7440
20	85.16	-28.66	-17	131	3538
	86.50	"	"	146	3972
21	75.51	-25.58	-15	131	3323
	76.71	"	"	146	3735

Appendix (continued)

August 27, 1970, recording 1.

Band	Intercept (A)	Slope (b)	Masking level (ML)	Distance (d)	Range (R)
8	31.76	-15.1	-8	393	
	32.49	"	"	438	
9	80.49	-28.79	-8	393	
	81.85	"	"	438	1014
10	134.50	-41.16	-9	393	2672
	136.44	"	"	438	3020
11	84.22	-30.53	-11	393	923
	85.66	"	"	438	1143
12	35.84	-15.81	-12	524	540
	36.58	"	"	584	780
13	64.72	-22.57	-14	262	2313
	65.79	"	"	292	3177
14	58.26	-22.74	-17	262	1778
	59.33	"	"	292	2043
15	68.97	-24.83	-17	262	2638
	70.14	"	"	292	2982
16	69.15	-24.32	-20	262	4370
	70.29	"	"	292	4893
17	88.33	-27.80	-20	262	7622
	89.64	"	"	292	8511
18	96.97	-28.15	-19	262	12912
	98.30	"	"	292	14405
19	100.83	-28.80	-18	131	13236
	102.19	"	"	146	14765
20	90.77	-27.13	-15	262	7657
	92.05	"	"	292	8550
21	72.97	-22.74	-13	131	5903
	74.04	"	"	146	6597

Appendix (continued)

August 29, 1970, recording 2.

Band	Intercept (A)	Slope (b)	Masking level (ML)	Distance (d)	Range (R)
8	42.24	-20.97	-9	131	155
	43.23	"	"	146	526
9	91.21	-34.03	-9	131	751
	92.81	"	"	146	973
10	50.80	-17.67	-10	262	2498
	51.63	"	"	292	2827
11	89.02	-32.96	-12	262	900
	90.57	"	"	292	1120
12	61.47	-24.34	-13	262	886
	62.62	"	"	292	1106
13	26.74	-13.86	-15	131	897
	27.39	"	"	146	1116
14	70.66	-27.01	-18	131	1786
	71.93	"	"	146	2051
15	70.44	-25.85	-19	262	2622
	71.66	"	"	292	2965
16	84.29	-27.26	-17	262	4935
	85.38	"	"	292	5429
17	96.90	-31.74	-14	262	2857
	98.39	"	"	-292	3222
18	98.37	-29.42	-12	131	5512
	99.76	"	"	146	6166
19	115.02	-30.77	-10	131	11432
	116.25	"	"	146	12541
20	96.76	-28.99	-7	131	3664
	98.12	"	"	146	4112
21	81.07	-25.65	-5	131	2137
	82.28	"	"	146	2434

Appendix (continued)

August 29, 1970, recording 3.

Band	Intercept (A)	Slope (b)	Masking level (ML)	Distance (d)	Range (R)
8	27.51	-14.81	-10	131	216
	28.21	"	"	146	552
9	83.87	-30.18	-10	131	1159
	85.29	"	"	146	1384
10	126.28	-39.89	-11	131	2633
	128.16	"	"	146	2977
11	87.63	-33.31	-13	131	920
	89.19	"	"	146	1139
12	54.87	-23.12	-14	131	823
	55.96	"	"	146	1043
13	55.66	-22.94	-16	131	1200
	56.74	"	"	146	1427
14	61.36	-24.79	-19	131	1614
	62.52	"	"	146	1865
15	77.48	-28.93	-22	131	2615
	78.83	"	"	146	2954
16	75.81	-27.92	-25	131	3949
	77.12	"	"	146	4428
17	89.40	-29.52	-23	131	6290
	90.79	"	"	146	7028
18	102.03	-31.02	-19	131	7843
	103.49	"	"	146	8755
19	106.38	-31.77	-17	131	7517
	107.88	"	"	146	8395
20	91.70	-27.93	-13	131	5475
	93.01	"	"	146	6120
21	78.08	-25.16	-11	131	3341
	79.26	"	"	146	3755

Appendix (continued)

October 21, 1970, recording 1.

Band	Intercept (A)	Slope (b)	Masking level (ML)	Distance (d)	Range (R)
8	35.29	-17.33	-14	262	439
	36.11	"	"	292	698
9	93.37	-34.59	-16	262	1191
	95.00	"	"	292	1417
10	130.36	-40.85	-16	262	3565
	132.28	"	"	292	4004
11	95.39	-35.37	-17	262	1244
	97.06	"	"	292	1473
12	65.57	-26.92	-19	262	1224
	66.84	"	"	292	1348
13	66.58	-26.27	-21	131	2027
	67.81	"	"	146	2311
14	70.19	-27.14	-20	131	1974
	71.46	"	"	146	2254
15	73.14	-27.27	-19	131	2262
	74.42	"	"	146	2568
16	47.20	-16.70	-19	131	9075
	47.99	"	"	146	10132
17	80.13	-25.77	-19	131	6895
	81.35	"	"	146	7706
18	101.82	-30.57	-20	131	9529
	103.26	"	"	146	10632
19	110.72	-33.14	-23	131	10709
	112.28	"	"	146	11945
20	105.90	-33.??	-25	131	7571
	107.49	"	"	146	8455
21	95.51	-31.33	-25	131	6891
	96.98	"	"	146	7694

Appendix (continued)

January 7, 1971, recording 1.

Band	Intercept (A)	Slope (b)	Masking level (ML)	Distance (d)	Range (R)
9	46.20	-17.43	-3	262	406
	47.02	"	"	292	672
10	87.59	-23.87	-4	262	6609
	88.71	"	"	292	7380
11	68.07	-21.11	-6	262	2965
	69.06	"	"	292	3340
12	33.91	-13.82	-7	393	522
	34.56	"	"	438	764
13	40.26	-14.01	-7	131	2232
	40.92	"	"	146	2537
14	23.92	-10.39	-10	131	1709
	24.41	"	"	146	1969
15	52.65	-19.09	-10	262	1652
	53.55	"	"	292	1908
16	55.37	-18.32	-9	262	3002
	56.23	"	"	292	3381
17	76.11	-23.38	-8	262	3697
	77.21	"	"	292	4150
18	80.30	-24.02	-7	393	3917
	81.43	"	"	438	4394
19	64.83	-19.95	-5	524	2641
	65.77	"	"	584	2985
20	55.63	-17.61	-3	262	1873
	56.46	"	"	292	2147
21	46.32	-14.21	-1	393	1746
	46.99	"	"	438	2009

Appendix (continued)

January 7, 1971, recording 2.

Band	Intercept (A)	Slope (b)	Masking level (ML)	Distance (d)	Range (R)
8	9.50	-5.14	-4	262	169
	9.74	"	"	292	531
9	53.52	-20.15	-4	262	456
	54.47	"	"	292	711
10	111.49	-33.61	-5	131	2793
	113.07	"	"	146	3152
11	67.40	-22.57	-7	131	1848
	68.46	"	"	146	2119
12	38.30	-16.60	-8	131	487
	39.08	"	"	146	736
13	19.53	-7.01	-5	131	3026
	19.86	"	"	146	3409
14	25.76	-12.00	-8	131	522
	26.32	"	"	146	765
15	55.16	-21.36	-11	131	1121
	56.76	"	"	146	1431
16	51.47	-18.06	-13	393	3321
	52.32	"	"	348	3823
17	65.83	-20.56	-10	131	4747
	66.80	"	"	146	5315
18	77.76	-23.58	-7	131	3801
	78.86	"	"	146	4261
19	66.09	-20.77	-6	131	2327
	67.06	"	"	146	3186
20	60.23	-19.97	-5	131	1716
	61.17	"	"	146	1976
21	57.04	-18.94	-4	131	1540
	57.93	"	"	146	1787

Appendix (continued)

January 7, 1971, recording 3.

Band	Intercept (A)	Slope (b)	Masking level (ML)	Distance (d)	Range (R)
9	29.54	-11.94	-3	131	403
	30.10	"	"	146	670
10	95.30	-27.31	-3	131	3845
	96.58	"	"	146	4312
11	35.56	-11.42	-5	131	3431
	36.10	"	"	146	3858
12	14.40	-7.99	-6	131	232
	14.77	"	"	146	560
13	36.96	-13.67	-8	262	1683
	37.60	"	"	292	1940
14	25.32	-10.70	-7	262	788
	25.83	"	"	292	1010
15	20.14	-8.33	-8	131	2258
	20.53	"	"	146	2564
16	41.27	-14.08	-7	262	2419
	41.93	"	"	292	2740
17	55.28	-16.67	-5	131	4001
	56.06	"	"	146	4483
18	59.75	-17.39	-4	131	4503
	60.56	"	"	146	5037
19	46.07	-13.58	-2	131	3335
	46.71	"	"	146	3750
20	29.68	-8.86	0	131	2108
	30.10	"	"	146	2403
21	30.12	-8.86	+1	262	1674
	30.54	"	"	292	1932

Appendix (continued)

January 21, 1971, recording 1.

Band	Intercept (A)	Slope (b)	Masking level (ML)	Distance (d)	Range (R)
8	-6.59	-2.72	-9	524	
	-6.47	"	"	584	
9	42.17	-16.96	-9	393	649
	42.97	"	"	438	878
10	113.39	-34.74	-7	393	2528
	115.03	"	"	438	2862
11	84.28	-27.57	-4	393	1200
	85.57	"	"	438	1426
12	13.10	-7.11	-1	131	
	13.44	"	"	146	
13	37.43	-11.44	+3	131	893
	37.97	"	"	146	1112
14	23.81	-9.40	0	131	216
	24.25	"	"	146	552
15	53.39	-19.13	-3	262	627
	54.29	"	"	292	857
16	56.06	-18.97	-7	655	1455
	56.95	"	"	730	1696
17	68.60	-21.00	-12	131	6757
	69.59	"	"	146	7548
18	55.41	-16.81	-12	655	9580
	56.20	"	"	730	10687
19	48.28	-15.08	-11	655	7876
	48.98	"	"	730	8778
20	54.97	-18.10	-9	655	2767
	55.82	"	"	730	3123
21	53.67	-17.95	-10	131	3394
	54.51	"	"	146	3812

Appendix (continued)

January 21, 1971, recording 2.

Band	Intercept (A)	Slope (b)	Masking level (ML)	Distance (d)	Range (R)
9	38.43	-15.97	-9	393	542
	39.18	"	"	438	782
10	109.24	-32.59	-10	524	4034
	110.77	"	"	584	4522
11	70.42	-23.62	-12	524	2563
	71.54	"	"	584	2902
12	31.27	-13.85	-11	917	216
	31.92	"	"	1022	552
13	51.52	-16.06	-7	593	4011
	52.27	"	"	438	4494
14	57.90	-19.40	-10	393	2770
	58.81	"	"	438	3125
15	49.43	-17.91	-13	524	2537
	50.28	"	"	584	2873
16	55.18	-17.86	-17	655	10346
	56.03	"	"	730	11556
17	69.84	-20.29	-19	786	23121
	70.80	"	"	876	25787
18	68.84	-20.33	-18	786	17900
	69.80	"	"	876	19963
19	60.50	-19.06	-17	655	10989
	61.40	"	"	730	12262
20	58.95	-19.40	-15	655	5829
	59.86	"	"	730	6513
21	56.26	-18.37	-14	786	5893
	57.13	"	"	876	6592

Appendix (continued)

January 22; 1971, recording 1.

Band	Intercept (A)	Slope (b)	Masking level (ML)	Distance (d)	Range (R)
9	16.25	-5.03	+1	655	424
	16.49	"	"	730	687
10	97.63	-26.60	0	524	4157
	98.88	"	"	584	4658
11	59.45	-17.73	-2	524	2400
	60.28	"	"	584	2718
12	17.83	-7.24	-3	655	110
	18.17	"	"	730	512
13	30.28	-9.12	-4	131	5607
	30.74	"	"	146	6319
14	23.11	-8.26	-7	262	4157
	23.50	"	"	292	4661
15	36.44	-11.83	-7	262	4437
	37.00	"	"	292	4974
16	57.75	-17.45	-7	262	4874
	58.57	"	"	292	5453
17	80.05	-22.57	-7	524	6669
	81.11	"	"	584	7447
18	82.25	-23.06	-5	524	5552
	83.33	"	"	584	6204
19	65.60	-18.80	-4	524	4513
	66.48	"	"	584	5050
20	46.29	-13.01	-2	393	4757
	46.91	"	"	438	5332
21	35.27	-9.36	-1	524	6975
	35.71	"	"	584	7788