OPEN OCEAN ANALYSIS OF A SINK GILLNET

ABSTRACT

Current evidence indicates that the Harbor porpoise (*Phoceana phoceana*) population may be declining because of incidental take caused by sink-gillnet fishing in the Gulf of Maine. The acoustical signature of an open ocean sink-gillnet was compared to the hearing threshold of the harbor porpoise. Results suggest that the gillnet functions as an ambient noise modifier. Increasing the intensity by 5-10 dB at low frequencies and decreasing the intensity at high frequencies. Since there were no obvious differences between the ambient and net noise trends, the harbor porpoise may be unable to distinguish the net from the regular ambient noise. More data is needed to determine the effects of a net holding fish.

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TECH 797 OCEAN RESEARCH PROJECTS

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INTRODUCTION

Harbor porpoise (Phocoena phocoena) incidental take is now a critical problem facing sink-gillnet fisheries in the Gulf of Maine (Potter,1993). Incidental take, or by-catch, is an accidental disturbance or human induced death of marine mammals. In this case, the take is entanglement as a result of commercial fishing. It was found that gillnets were responsible for more than 66% of the 428 marine mammal entanglements that were reported between 1975 and 1989 from the New York Bight to the Gulf of Maine (Kraus, 1978). "Where incidental take has been reported, mortality rates are near 100% for the phocoenids and delphinids and appear to decrease with increasing size of the animal" (Kraus, 1978). The harbor porpoise being one of the smallest cetaceans, with a maximum length of 5 feet and weight of 140 lbs (Katona,1983), possesses the highest mortality rate due to by-catch, 86%. (Kraus, 1978). The actual magnitude of the problem is difficult to quantify since not all takes are reported and the exact size of the harbor porpoise population can only be estimated. The most recent population estimates predict 45,000 harbor porpoise (Confidence Interval 95% therefore, 19,000-80,000) in the Gulf of Maine region. A harbor porpoise by-catch estimate was made at 2,400 (CI 95% therefore, 1,600-3,500)per year for the Gulf of Maine (NOAA/NMFS,1992). This quantity constitutes 4-5% of the population. Due to the increased fishing effort and the high levels of take reports, coupled with the fact that there is a high bias toward not reporting all takes, these values are probably on the conservative side. The annual growth rate is in the area of 2%(Potter,1993), therefore, the Gulf of Maine population of harbor porpoise is in danger of depletion from fishery activities particularly those of gillnets(Read and Gaskin, 1988).

The Marine Mammal Protection Act of 1972 prohibits any take of marine mammals be it intentional or unintentional. However, in 1988, an exemption was passed that permits the incidental take of marine mammals by fishermen as long as log books are kept and observer requirements fulfilled (Seagrant and Marine Law Institute, 1991) This exemption will be in effect until October 1993. NMFS has recommended that harbor porpoise be listed as a threatened species, making the by-catch issue very controversial.

The aim of this research project was to isolate the acoustic signature of a soaking, sink-gillnet in the Gulf of Maine. This was accomplished by recording sounds produced by a gillnet and then comparing them to local ambient noise levels. By isolating the acoustical signature of the net, insight will be gained into the gillnet-harbor porpoise interaction and its potential impact on the incidental take problem. One of the goals was to observe the acoustic signature of a gillnet as it was actively fishing and actually catching fish. The sound of a captured, dying fish would be an interesting component of the harbor porpoise gillnet acoustic interaction.

BACKGROUND

BIOLOGICAL

The harbor porpoise ranges from Cape Hatteras, North Carolina to Greenland in the Western Atlantic with a high concentration in the Gulf of Maine (Katona,1983). Like many other odontocetes it inhabits mostly coastal areas. Relatively little research has been conducted on the harbor porpoise due to observational difficulty as a result of their size. It is known that the harbor porpoise can utilize sonar for navigation and prey location.

Odontocetes, or toothed whales, have a unique method of hearing. A hollow section in the lower jaw bone is filled with a fatty substance or oil. Vibrations of the Pan bone, located amidst the fatty substance alert the Odontocete to propagating sound waves. Directionality of the sound waves is determined by a side to side head movement. The focused sound information is then passed onto the tympanoperiotic bone and to the bulla and the inner ear (Stebbins, 1983) (See Figure 1).

Observations of harbor porpoise in the vicinity of a salmon gillnet led to the conclusion that harbor porpoise have an optimal hearing threshold range from 2 to 40 kHz. If the intensity increases, the margins extend slightly to include frequencies as high as 140 kHz (Hatakeyama et.al., 1988) (see Figure 2).

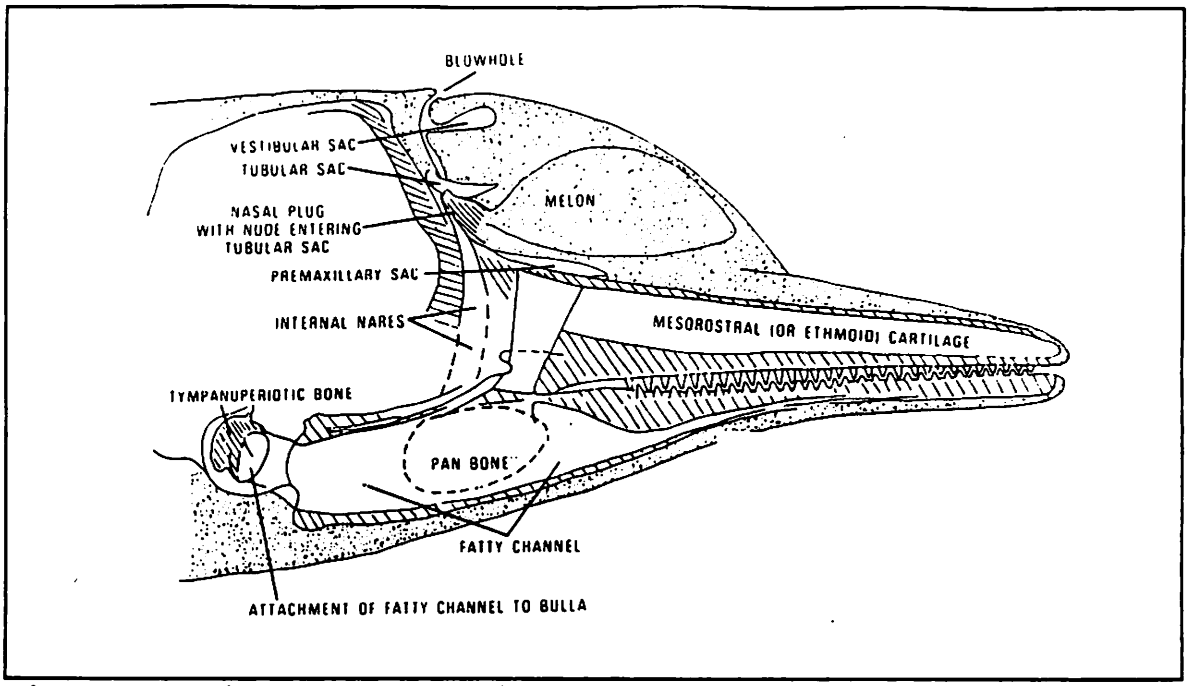
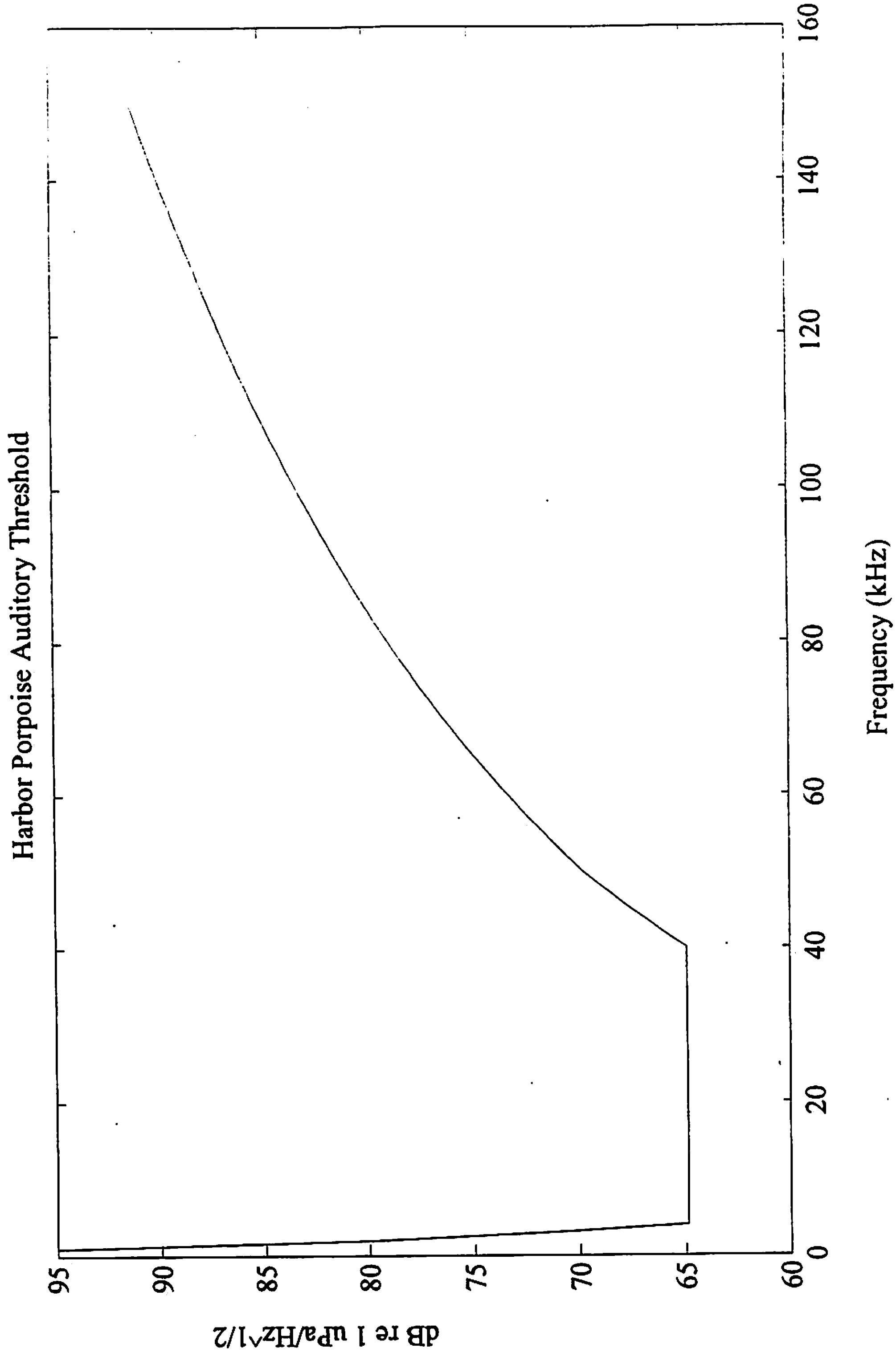


Figure 1. Diagram of hearing structures (Drake, 1968)

Fish are able to detect sound and are particularly sensitive to low frequencies. Low frequency waves can travel long distances with little attenuation and propagate faster than chemical stimuli in the water (Stebbins, 1983). Different species display a variety of sensitivities and hearing ranges. Herring-like fish, the typical prey of harbor porpoise, have a general hearing range of 30 Hz to 4000 Hz (Smith, 1982). The 2000 Hz band is also the upper limit for many fish species. Tavolga (1977) states that "No fish of the North Atlantic coastal waters auditioned to date has exhibited a sound lower than 20 Hz nor higher than 2400-4800 Hz." The most common range is from 75 to 300 Hz.

Figure 2.



Harbor Porpoise Auditory Threshold
dB re 1 uPa/Hz^1/2
95
90
85
80
75
70
65
60
0
20
40
60
80
100
120
140
160
Frequency (kHz)

Harbor porpoise feed on bottom-living fish and invertebrates such as herring, mackerel, capeline, hake, pollack and squid (Katona, 1983). Sink-gillnets are commonly used to harvest many of the same species. It is also known that harbor porpoise provide the beneficial service of eating hagfish, which are scavengers that eat the target species of the nets (Dawson, 1991).

GILLNET FISHING INDUSTRY

Most gillnets in the Gulf of Maine are made of large panels (300^{ft} x 15^{ft}) of monofilament mesh(5.5+ inch minimum), the diameter of the monofilament fiber varies depending on the target species but is typically 0.5mm (Figure 3). These nets are connected together resulting in strings containing up to twenty panels. The nets are deployed along ledges typically found twelve to eighteen miles off shore, in water 250^{ft} to 350^{ft} deep. The nets are hauled in every 24-48 hours contingent upon the weather and the season, and are promptly reset after being emptied (Barnaby, 1992). They function by causing fish who swim into the net to get caught in the monofilament lines by their gills. Size selection of fish is possible by regulation of the mesh size.

"It has been suggested that monofilament nets are acoustically invisible to cetaceans" (Awbrey, 1979). However, the float line, lead line and rope have been proven to be detectable to cetaceans in captivity (Awbrey, 1979). The movement of the net

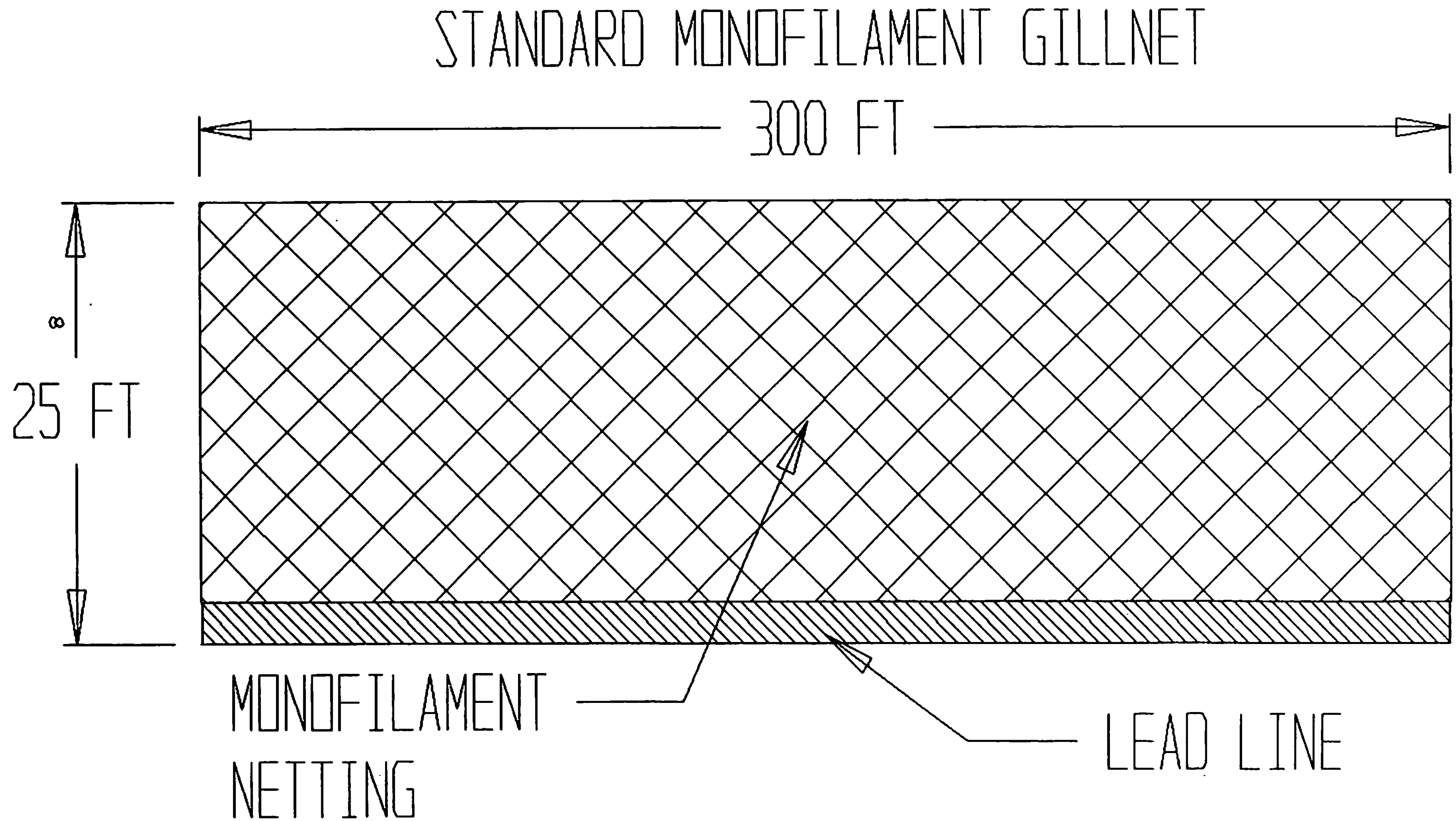

STANDARD MONOFILAMENT GILLNET
300 FT
25 FT
MONOFILAMENT
NETTING
LEAD LINE

FIGURE 3

in the water may cause fluctuations of audible visibility and invisibility. The signal reflected from the net may also be weakened or strengthened depending on the angle of the animal's approach (Nelson, 1990). According to Pence(1986), porpoise are better able to detect the net if their angle of approach is 80 degrees, rather than perpendicular.

There are many theories as to why entanglement occurs. It may be that the net is invisible to them until they are at too close a distance to be able to turn around (Vicedomine, 1991). It is possible that the porpoise are simply attracted to the fish in the net, assuming it is a large group of it's prey (Norris, 1990). Sound produced by the gillnet may be ignored when using echolocation in the pursuit of prey (Nelson, 1990). Observations of bats confirms that echolocating animals are not always able to detect obstacles when chasing prey (Evans et.al, 1988). Studies done on Dall's porpoise (Phocoenoides dalli), also a member of the family Phocoenidae, show that they may sometimes listen for noises created naturally rather than scanning their environment. This would enable them to hunt without revealing their presence (Nelson, 1990); thus decreasing their ability to detect the net. It is also possible that the fish entangled in the net make enough noise to drown out any hint of the net (Pence, 1986; Nelson, 1990). Another possibility is the misinterpretation of the weak signal coming off of the gillnet with dense plankton blooms in the water column, also known as the deep scattering layer. Assuming the gillnet to be the deep scattering layer they may attempt to pass through it (Au et.al., 1991).

With better knowledge of the net's acoustics we will be better able to determine at what points the net is and is not within the hearing threshold of the harbor porpoise and of the prey species in question.

UNDERWATER ACOUSTICS

ECHOLOCATION

The harbor porpoise was first determined to be an acoustic mammal in 1967 when Busnel and Dziedic covered the eyes and ears of a captive harbor porpoise and it was able to avoid obstacles, consisting of wires and pipes. The acoustic sounds produced by harbor porpoise are divided into two main groups; low and high frequency clicks. These clicks are used in echolocation. Echolocation is the means of imaging the surrounding environment by interpreting the sound pulses that are reflected off nearby objects. In this case the hearing mechanism of the harbor porpoise is performing a similar task to the human eye. Where, sound is used instead of light.

The low frequency clicks, or whistles, are used for communication and navigation through unfamiliar territories. The whistles have a duration of about 1 msec. with an amplitude frequency range of 2-8 kHz (Amundin, 1990; Goodson et.al, 1990; Sales & Pye, 1974). Acousticians have been able to differentiate signals on the basis of their acoustic structure. Some researchers believe that this acoustic signature can be easily recognized by other members of its group (Stebbins, 1983). These low frequency whistles have also been associated with different stress situations, such as aggression, fear, and sexual arousal (Sales & Pye, 1974).

The high frequency clicks are utilized during targeting echolocation. These clicks are emitted at 130+ kHz at 20 dB/N/m^2 at 1 meter (Hatakeyama et.al, 1988). The sound wave encountering an object will be reflected if it's wavelength is shorter than the dimensions of the object(Stebbins,1983). Higher frequencies have shorter wavelengths and therefore more vivid acoustic impressions are created. At 130 kHz the wavelength is 0.0115m These clicks emanate from a dense fatty region, called the melon, and dissipate in a pattern similar to that of a flashlight beam, see Figure 4.

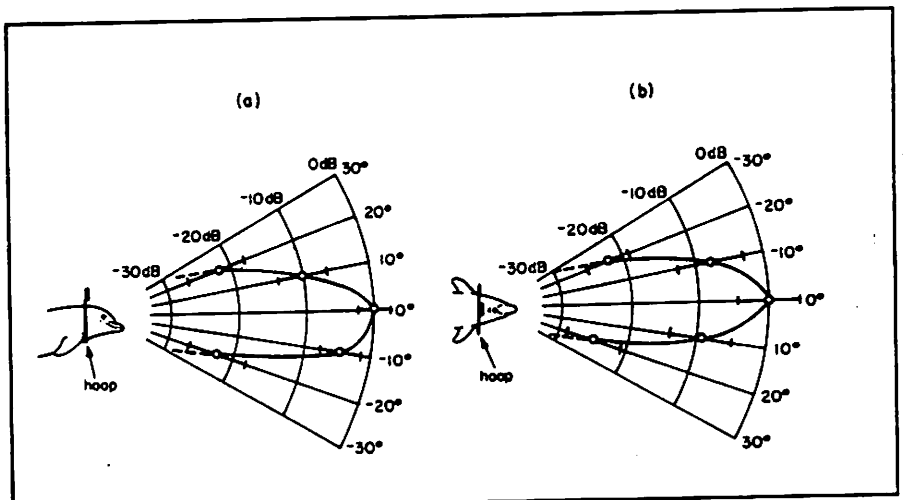


Figure 4. Vertical (a) and horizontal (b) beam pattern for echolocation signal for a bottlenose dolphin. (Stebbins, 1983)

These clicks are produced at a rate of 1-2 per second, while the animal is travelling through a body of water (Kellogg, 1959).

When the harbor porpoise is focusing on a specific target, i.e. a fish, the frequency of the clicks increases to 400-500 per second (Sales & Pye, 1974). Sonar is used even during periods of good visibility (Anderson, 1965), however, a study of Hector's dolphin (Cephalorhynchus Hectori) observed animals swimming in turbid water without emitting sound (Dawson, 1991).

Both the high and low frequency acoustic pulses can be produced simultaneously (Norris, 1968). This creates great speculation into the sources of these clicks.

AMBIENT NOISE

As harbor porpoise travel through different areas of the ocean in search of prey, they experience an ever changing sound environment. Just as humans hear different background sounds as they go about various aspects of their lives, inhabitants of the ocean also experience varying and dynamic sound conditions.

Ambient noise is defined as the combination of the different background sounds found when considering any acoustical system. The most predominant causes underwater include ocean turbulence, precipitation, shipping traffic, wind, seabed flow, wave effects, biological activity and surf action.

Acoustic waves are pressure disturbances that can propagate through a compressible fluid. Sound sources produce pressure waves that travel through the ocean at one or more frequencies. Ambient noise conditions are created when background sources emit different frequency waves which add together and form the ambient noise sound level(NSL). The NSL is a way of describing the intensity versus frequency distribution that comprises ambient noise. As each noise source adds to the sound environment, different sounds mask each other until it becomes difficult to attribute any one noise frequency to a specific source. It is possible, however, to identify the predominant producers of marine ambient noise over a range of frequencies. Figure 5 is a representation of deep water ambient noise over a range of 1 Hz to 1 MHz.

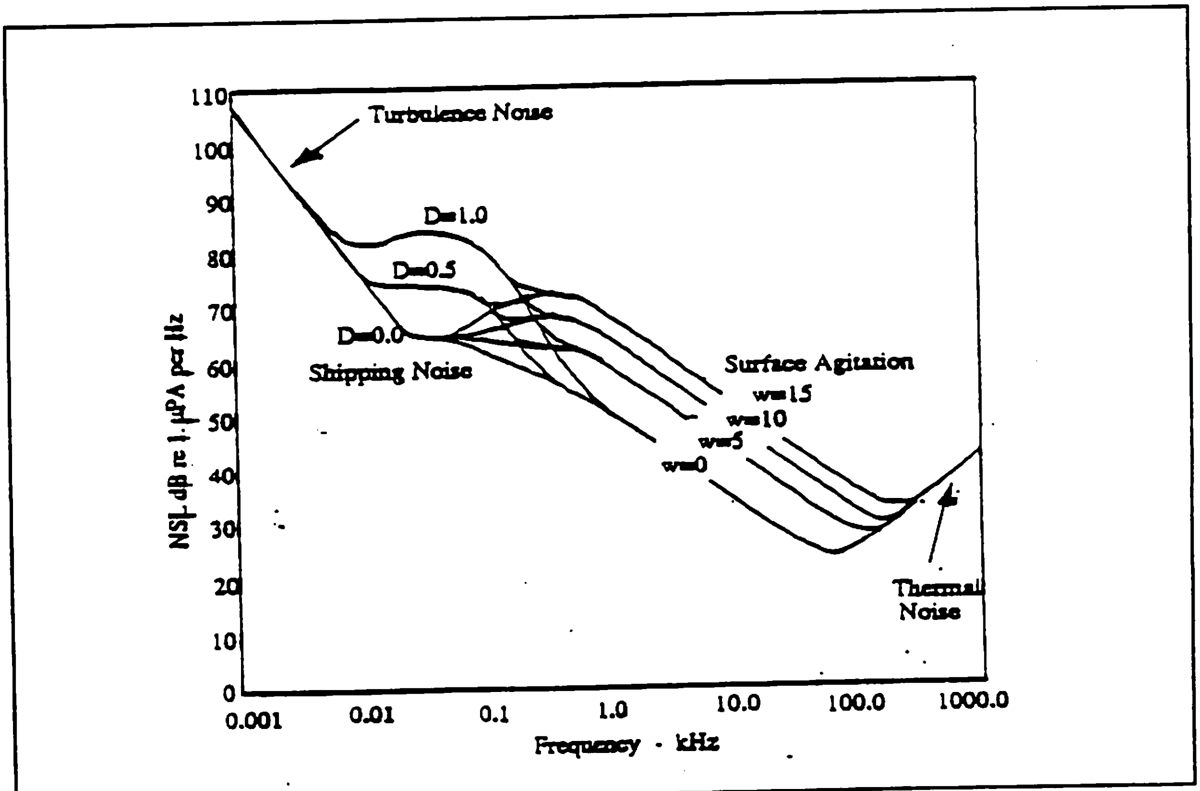


Figure 5. Deep Water Ambient Model (Coates, 1989)

Below 20 Hz, ocean turbulence and seismic activity are responsible for most ambient noise. An empirical equation for this frequency range is:

$$NSL = 17 - 30(\log f). \qquad (1)$$

Above 20 Hz up to 500 Hz, the most ambient noise is created by shipping traffic, biological activity and surf action. Noise levels due to these effects can be considerably higher in shallow water than in deep water. Shipping noise depends greatly on the amount of activity in the area. The noise levels created by shipping can be approximated by:

$$NSL = 50 + 20(D-0.5) + 26(\log f) - 40(\log(f+0.4)) \qquad (2)$$

where D is the shipping density on a scale of 0 to 1 (Coates, 1989). Biological noise levels are dependent on the amount and type of biological activity in the surrounding area.

In the range of 500 Hz to 20 kHz, ambient noise is primarily caused by agitation of the local sea surface.(Kinsler and Frey, 1990). Noise generation occurs in several different ways and is often shown as a function of local wind speed and sea state. As wind passes across the surface of the water, pressure disturbances cause acoustical energy to be transmitted into the water column. This energy transmission which occurs by the same phenomena that causes surface waves, appears as ambient noise underwater.

The major portion of surface generated noise is caused by breaking waves. As a wave crests, bubbles are created in the water which release acoustical energy as they collapse. A model for surface generated NSL suggested by Coates (1989) states:

$$NSL = 50 + 7.5w^{1/2} + 20(\log f) - 40(\log(f+0.4). \qquad (3)$$

Figure 6 represents deep water noise sound levels as a function of frequency with respect to wind speed. In shallow water, the amount of ambient noise due to surface agitation is also affected by the ocean bottom. As stated by Inenito and Wolf(1988), spectrum levels can vary substantially, often over 10 db, between sand/gravel bottoms and mud over rock bottoms.

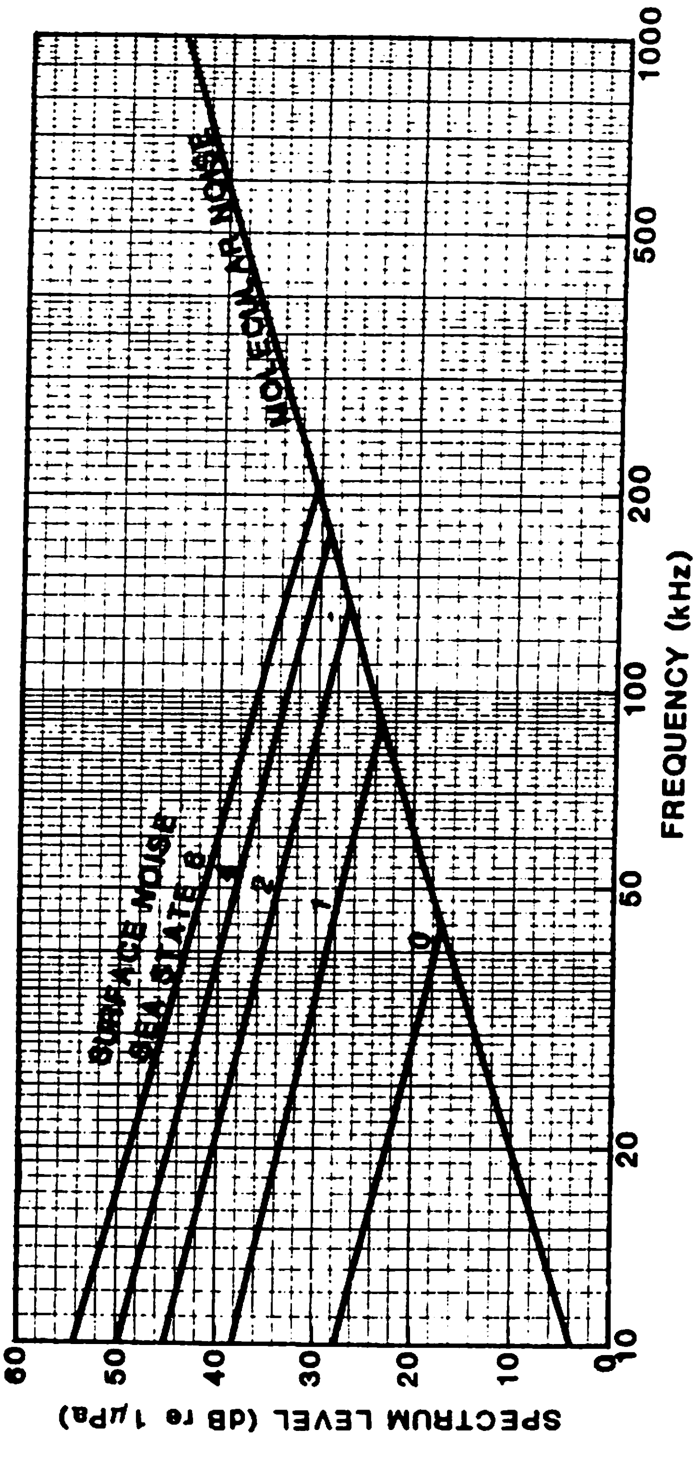
Above 100 kHz thermal agitation of the water molecules becomes the dominant source of ambient noise. Thermal agitation Coates(1989) can be modeled by

$$NSL = -15 + 20(\log f). \qquad (4)$$

Other possible sources of ambient noise include seabed flow and precipitation. When near bed current flow is great enough to cause the movement of sediments, the sound of shifting particles contributes to the ambient noise levels(Thorne,1989). Rainfall, when it occurs, can become the dominant sound source below 15 kHz. The shape of the noise level spectrum is dependent on the drop size while sound levels are dictated by the intensity of the rain(Urick, 1984).

The combination of all the different noise sources creates the ambient sound environment inhabited by the harbor porpoise. Ambient noise levels are dependent on constantly changing criteria, and are never be exactly the same at any two times or locations. Therefore, constantly changing ambient noise levels must be considered when attempting to isolate the acoustical signature of a gillnet.

Figure. 6


MOLECULAR NOISE
SURFACE NOISE
SEA STATE 6
4
2
1
0
FREQUENCY (kHz)
10
20
50
100
200
500
1000
SPECTRUM LEVEL (dB re 1 μPa)
0
10
20
30
40
50
60

METHODS

DESIRED INFORMATION

To assess the ambient noise and gillnet noise it is necessary to know the following: acoustic sound of the gillnet, depth, oceanic current speed and direction and the orientation of the gillnet with respect to the current. These data provide the necessary parameters for quantifying the noise environment. These data were acquired by deploying a mooring with the appropriate instruments and recording the data. The hydrophone had to be hard wired to the surface for magnetic tape recording while the current meter was self contained.

MOORING SYSTEM DESIGN

The basic constraints confronting the mooring design were directly related to the instruments deployed and the data measured by the instruments. Further limitations were set by the ocean environment at the site of deployment.

The mooring system was designed for deployment in 60 fathoms (360 feet) of sea. Since ocean bottom was of unknown texture, the mooring system had to deter overturning. The S4, electromagnetic current meter, produces a magnetic field that could not be disrupted. Any magnetic materials within close proximity of the S4 caused distortion of measurements by the device. Also the instruments were kept as vertical a possible to avoid unnecessary entanglement. This was accomplished by attaching a subsurface float above the hydrophone cage. The floatation kept the instruments vertical in front of the nets. This floatation provided enough buoyancy to offset the weight of the instruments and keep the line taut. The net weight of the instruments and hardware underwater was calculated to be 43 lbs.

The acoustic signal was carried to the surface through a shielded wire. The hydrophone was contained within a cage that protects the instrument from damage. The cage and shielded cable were not capable of withstanding large tension forces. Stresses were avoided during both deployment and recovery.

The final design consisted of a 1/2 inch polydacron rope, with 7% elongation at a maximum stress of 2600 lbs(3% at the 20% working load of 520 lbs). The rope acted as the backbone of the mooring system. The base was a 250 lb. granite block. Stainless steel

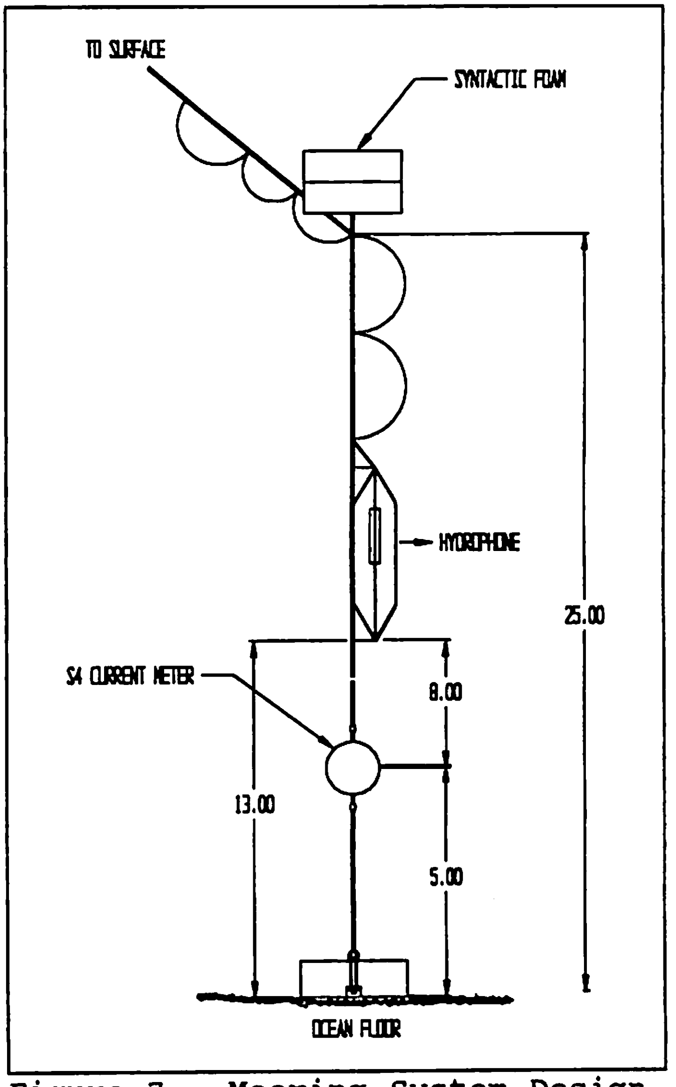


Figure 7. Mooring System Design (dimensions in feet)

was used for the eyebolt of the block and the shackles attached to the S4 current meter, as it did not disrupt the electromagnetic field. To prevent any of the shackles from unscrewing, plastic "zip" ties were attached through the pins and around the body of the shackles. These were chosen because they were electromagnetically invisible.

The hydrophone was attached to the rope, such that no stress was placed on the hydrophone cage. The hydrophone cable was secured to the rope every 3 feet with 4 inches of slack to account for 7% elongation. Two high density syntactic foam blocks with a combined buoyancy of 53.6 lbs were drilled and lashed together with rope. These blocks were donated by Buoy Technologies, Biddeford, Maine.

The 1/8 inch stainless steel winch cable on the Jere A. Chase Research Vessel was attached directly to the eyebolt of the granite block and easily handled the load of 415 lbs. The winch cable supported the full load of the mooring system during deployment and recovery. The 1/2 inch polydacron was not needed during transition but acted as a secondary recovery line in case of accidental disconnection. If disconnection occurred the 1/2 inch rope was able to handle the 415 lb load within its 20% working load.

DATA AQUISITION

PHYSICAL DEPLOYMENT AND RECOVERY

The most crucial design limitation was to determine the simplest method of deployment and recovery. It was in our best interest to explore every opportunity at our disposal. Our final design was obtained after the two trial runs.

Before leaving the mouth of Portsmouth Harbor, all the instruments and hardware were assembled, as the shelter provided by the harbor creates a smoother environment for working. All joints were double checked and then the instruments were tied down for the journey to sea.

Upon reaching the net site, the boat anchored just off the nets. After the anchor was set and the boat was done shifting, deployment began. The 250 lb. granite block was lifted by the stainless steel winch cable and coaxed over the side. Next the instruments were gingerly let into the water. After the syntactic foam block was deployed the mooring system could be quickly lowered. Meanwhile the rope was let out slowly by hand to lessen the possibility of tangling. Markers were placed every 25 feet on the rope to keep constant tabs on the depth. Once the sea bottom was reached, extra winch cable was let out to prevent clanging against the hydrophone cage. A Norfloat buoy was then attached to the rope, with 10 feet of slack. This allowed the boat to shift positions without dragging the granite block. Now the mooring system was completely functional and recording could take place.

After the last second of tape was recorded, recovery began. First, the Norfloat buoy was removed and the block was lifted toward the surface. While the winch was hauling up the block, the rope was pulled up manually. This was a two person project, the first person, using a hand over hand method, piled the rope on the deck. While the second person quickly coiled the rope into a large trash can. When the syntactic foam surfaces the winch was stopped. The block was lifted into the boat and the rest of the cable was pulled up slowly. Stopping for each instrument to be pulled aboard. When the block was finally aboard, the boat anchor was hauled, or maybe not, and the boat headed for home. The equipment was quickly dismantled and packed away for the journey to Portsmouth.

INFORMATION GATHERING AND RECORDING

In order to identify the acoustical signature of a sink gillnet, sound levels around the net must be broken into their frequency components and compared to local ambient noise. Figure 8 is a block diagram of the system used in this project.

Initially, acoustic pressure waves which form local ambient and gillnet sounds were transformed to a voltage signal by the ITC-6050 hydrophone, with a sensitivity of -158 dB re 1 uPa/Hz$^{1/2}$. The relationship between input acoustic pressure(db re uPa) and output voltage(volts)is shown in Figure 9. This transformation can be represented by the empirical formula:

$$\text{Acoustic Pressure(db)} = 138 + 10\log_{10}(v(t)/.01)$$

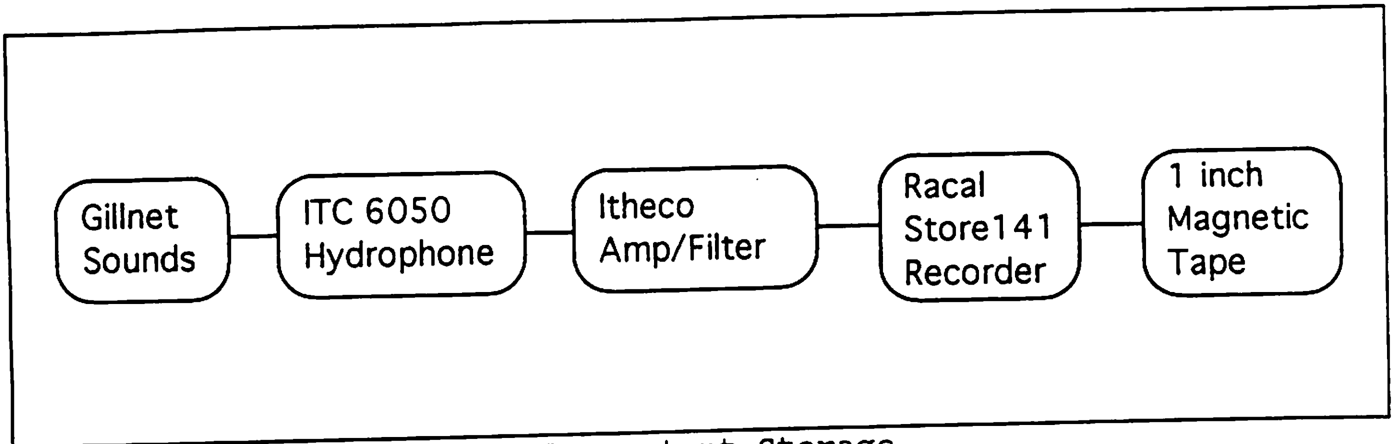
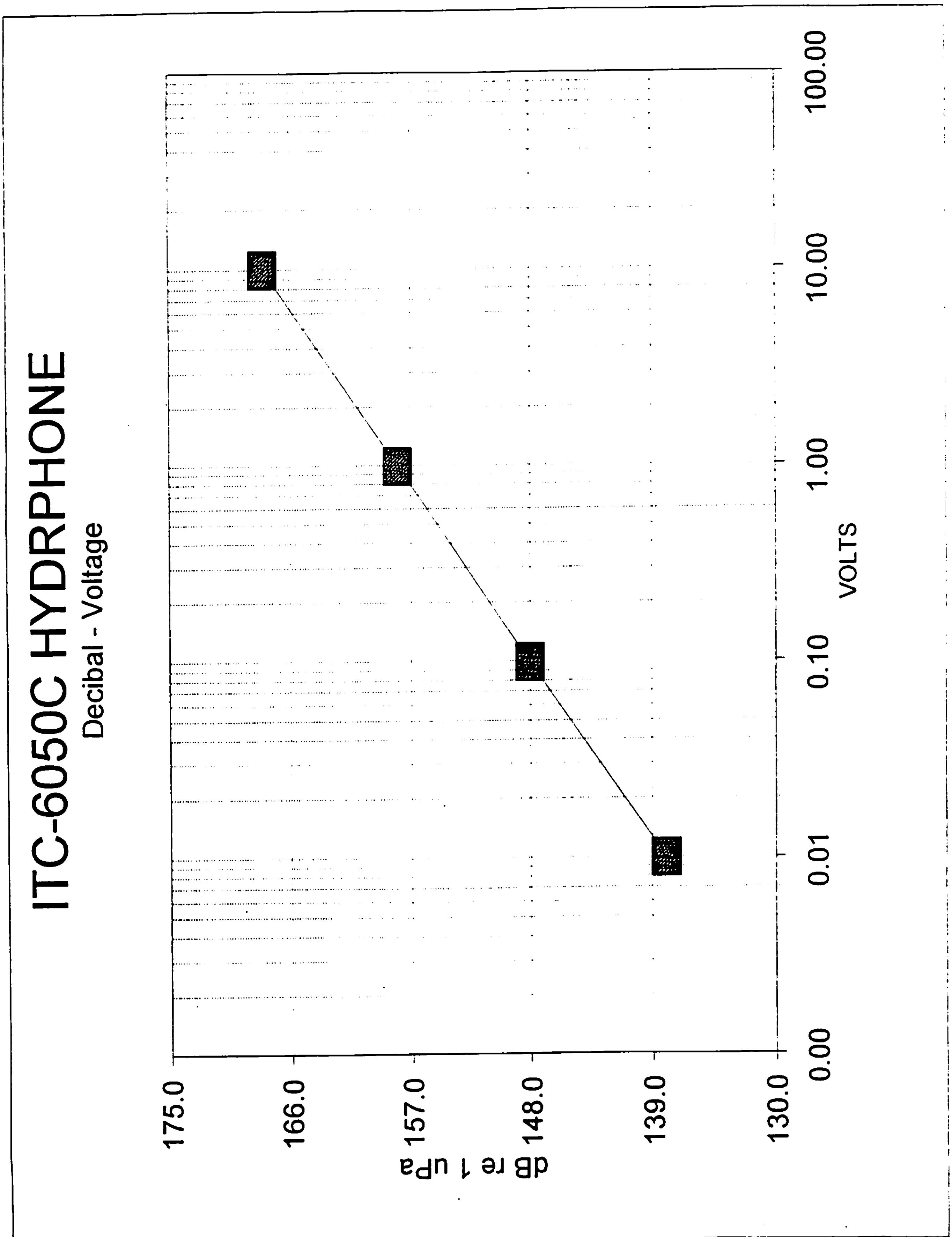


Figure 8. Input Signal to Permantent Storage

The voltage signal produced by the hydrophone was immediately amplified by an Ithaco 451 Data Acquisition Amplifier to the optimum recording level of +/- 1 volt. The amplified signal was then filtered by an Ithaco 4113 Variable Electronic Filter with cut-off frequencies set at 1 kHz and 80 kHz which were dictated by the linear capabilities of the hydrophone. The Ithaco filter applied a first order Butterworth filter at both the high and low pass cutoff points.

After amplification and filtering, the signal was permanently recorded on 1 inch magnetic tape with Racal Store141 tape recorder donated by Racal Recorder Inc. of Irvine, CA. The recorder speed was set to 30 in/sec which provided a useable bandwidth of 200 Hz to 100 kHz. Recorder attenuation was set to the minimum setting in order to provide maximum sound reproduction.

Figure 9.


ITC-6050C HYDRPHONE
Decibal - Voltage
dB re 1 uPa
175.0
166.0
157.0
148.0
139.0
130.0
VOLTS
0.00
0.01
0.10
1.00
10.00
100.00

Continuously recording the sounds produced by the gillnet allowed unlimited sampling of the information back in the lab. Permanently storing the sound signal on tape made it possible to go back and concentrate on specific intervals of recording if it was necessary.

INFORMATION DIGITIZATION AND STORAGE

In the laboratory, the recordings of underwater sounds were digitized and recorded by means of a Phillips 3323 digital oscilloscope. To ensure the recovery of high frequency signal components, the Nyquist criteria was applied to establish the ideal digital sampling rate. Accordingly, the minimum sampling frequency must be greater than or equal to twice the desired message bandwidth of 80 kHZ (Carlson,1986). This was accomplished by digitizing 20 millisecond windows of analog information. By recording the maximum of 4096 discrete points per window a sampling rate of 200 kHz or 1.2 times the Nyquist rate will be achieved, ensuring the complete transformation of the entire desired bandwidth.

Samples were taken at random, and exported onto a PC via a software package DSOCOM, provided with the Phillip's Oscilloscope. Each 20 millisecond window was stored in ASCII format on the PC hard drive for later manipulation by math processing software.

To determine the acoustical signature of a sound source, it is necessary to calculate the Power Spectral Density (PSD) of the sound signal. This assumes any periodic signal (acoustic pressure waves) contains some finite amount of energy. The PSD function shows how that finite amount of energy is distributed over a range of frequency, or in the case of this project, 1 kHz to 80 kHz.

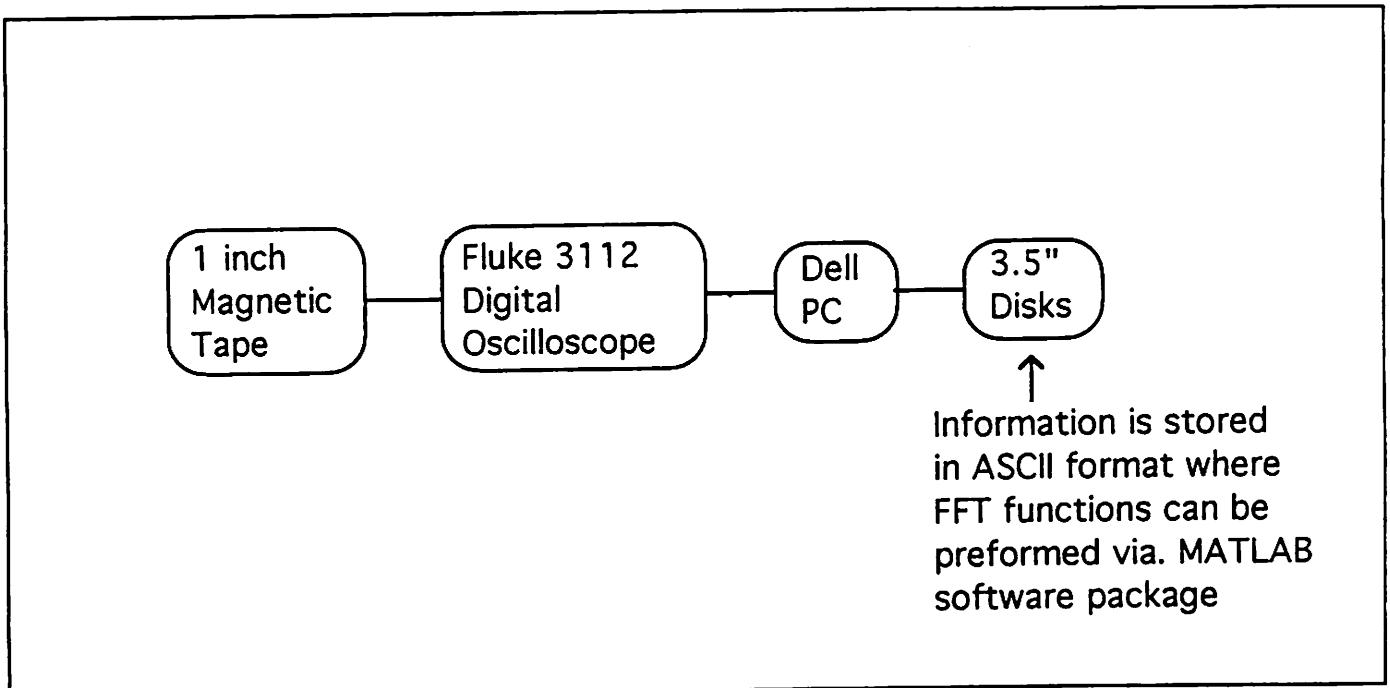
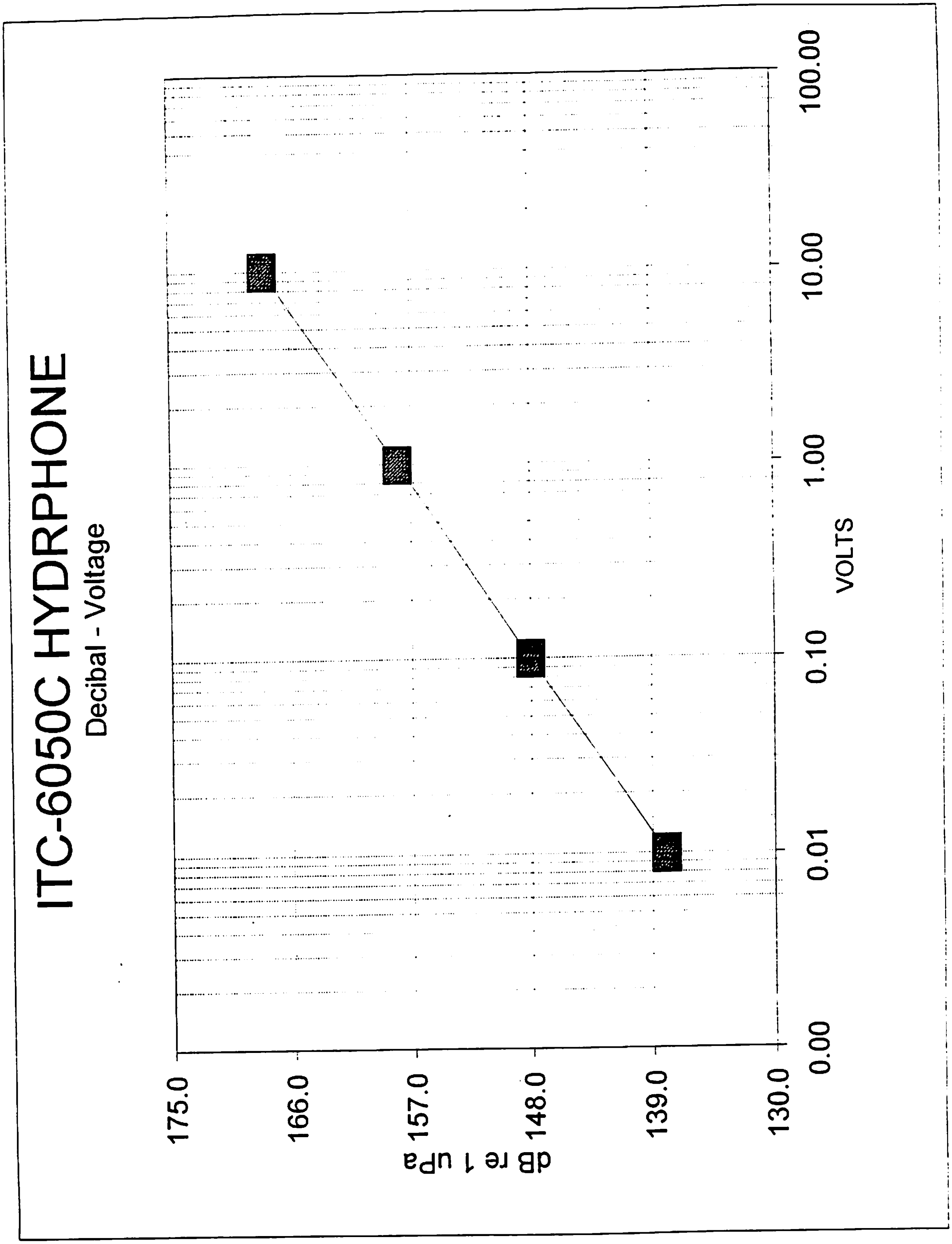


Figure 10. Signal Digitization and Storage

The PSD function of the samples was stored in the PC, by using a Simulab software package by Math Works. This was accomplished by first finding the Fast Fourier Transform (FFT) of the voltage signal (V(t)) produced by the hydrophone and then taking the autocorrelation of the FFT function. This is

Figure 11.


ITC-6050C HYDRPHONE
Decibal - Voltage
dB re 1 uPa
175.0
166.0
157.0
148.0
139.0
130.0
VOLTS
0.00
0.01
0.10
1.00
10.00
100.00

represented by the formula:

$$PSD = FFT\ (V(t))*\ \text{complex conjugate}\ (FFT(V(t)). \qquad (5)$$

The PSD was then converted to terms of dB re 1 $uPa/Hz^{1/2}$. Initially, the output signal was divided by the gain used when recording the sound to tape (100v/v or 20 dB) and then calculating the resulting pressure from the voltage to pressure characteristic of the hydrophone shown in Figure 11.

In order to find the acoustical signature, the analog recording was sampled as described earlier in 25 window sections. Each sample window was digitized approximately every 5-10 seconds without consideration to the contents of the window. After importation into the computer, 25 consecutive (4096 points) windows were stored in matrix form. Storage in matrix form made it possible to do multiple mathematical processes on 25 different samples at one time. The number of 25 windows stored in one matrix was dictated by the storage and processing capabilities of the PC. Limiting the number of samples ensured that complex storage of the matrices was possible on one 3.5" floppy disk.

After each 4096 x 25 matrix was formed, the PSD of each separate window was found, and the average PSD of all 25 windows calculated. The resulting function corresponds to the average PSD of 0.5 seconds (25 x 20 msec). From the average PSD graphs, insight into the finite power distribution of the gillnet and ambient sound levels was determined.

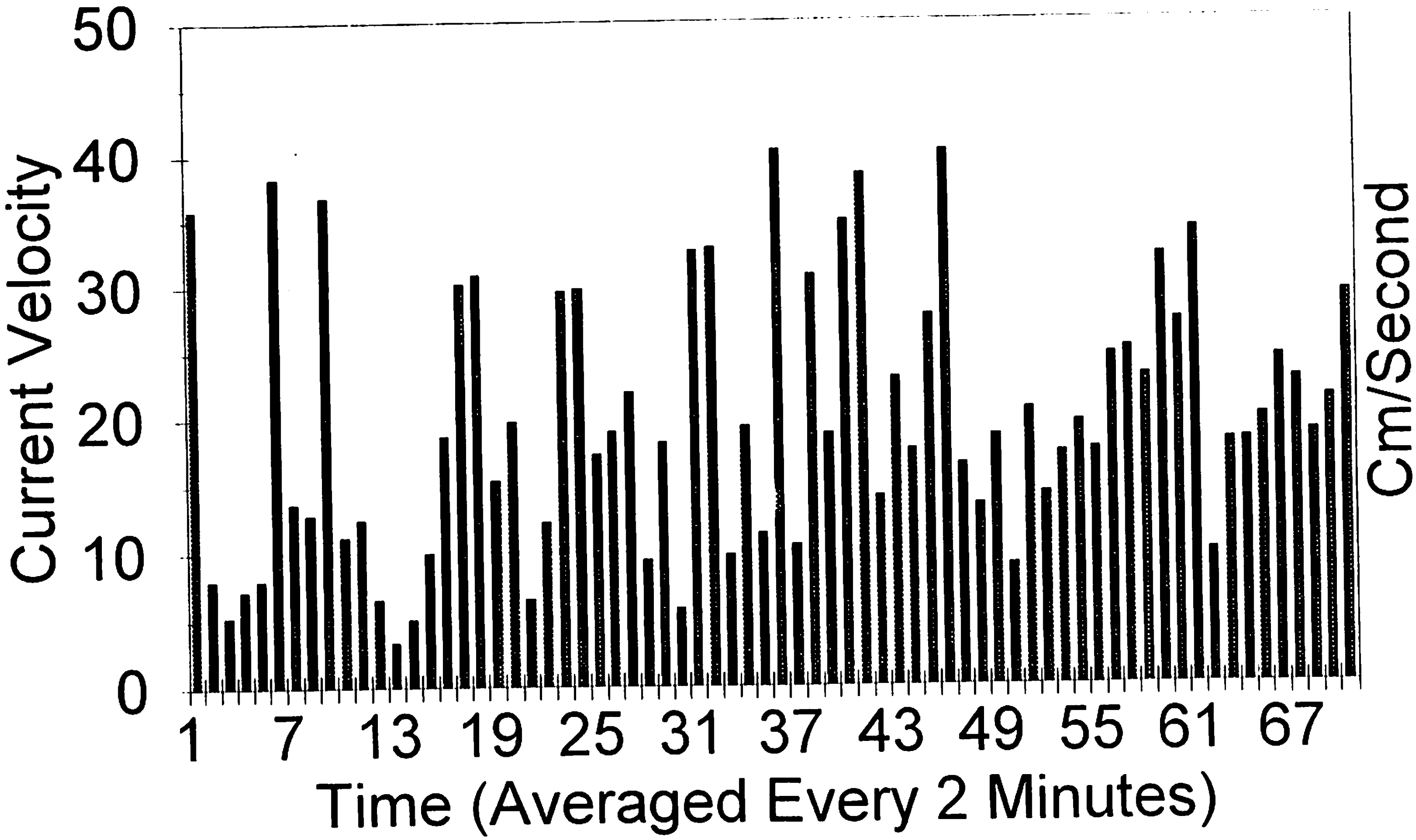
CURRENT INFORMATION GATHERING AND PROCESSING

The S4 current meter, from InterOcean Systems Inc., was programmed to record data on all eight analog channels. The channels measure: Voltage, x and y compass values, conductivity, temperature, depth, and x and y axis tilt. Using the data obtained, current speed and salinity can be calculated. The S4 was programmed to sample data continuously and record the average at two minute intervals in the internal CMOS RAM memory. After the mooring was recovered, the information stored inside the S4 was down loaded onto the hard drive of a Dell 316 LT. Using the software provided with the S4, graphs of current speed and direction could be created.

Two types of graphs were plotted current velocity vs. time and current velocity vs. change in orientation. The latter displays the effects of twisting of the S4 current meter.

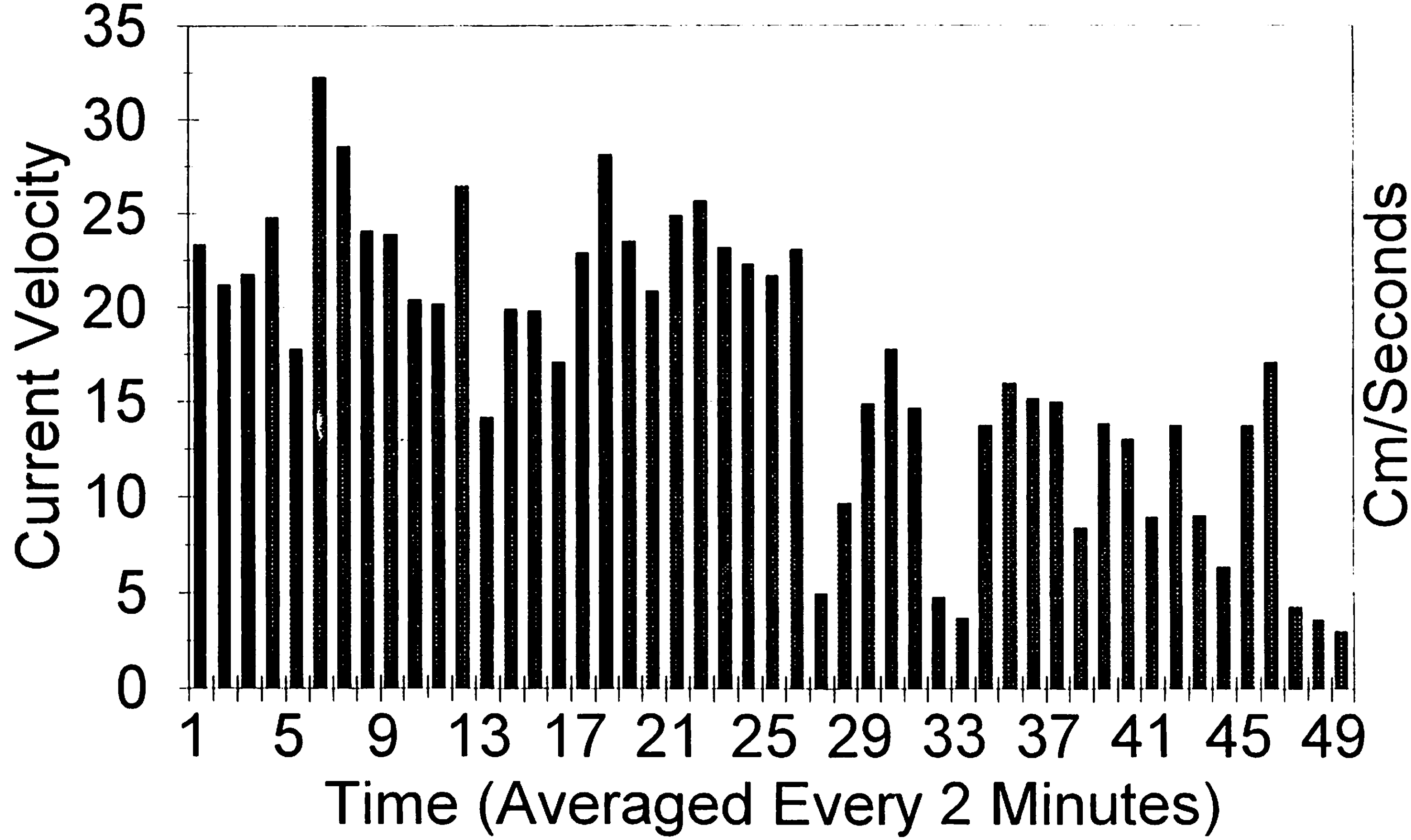
Current Velocity vs. Time

Gillnet Location



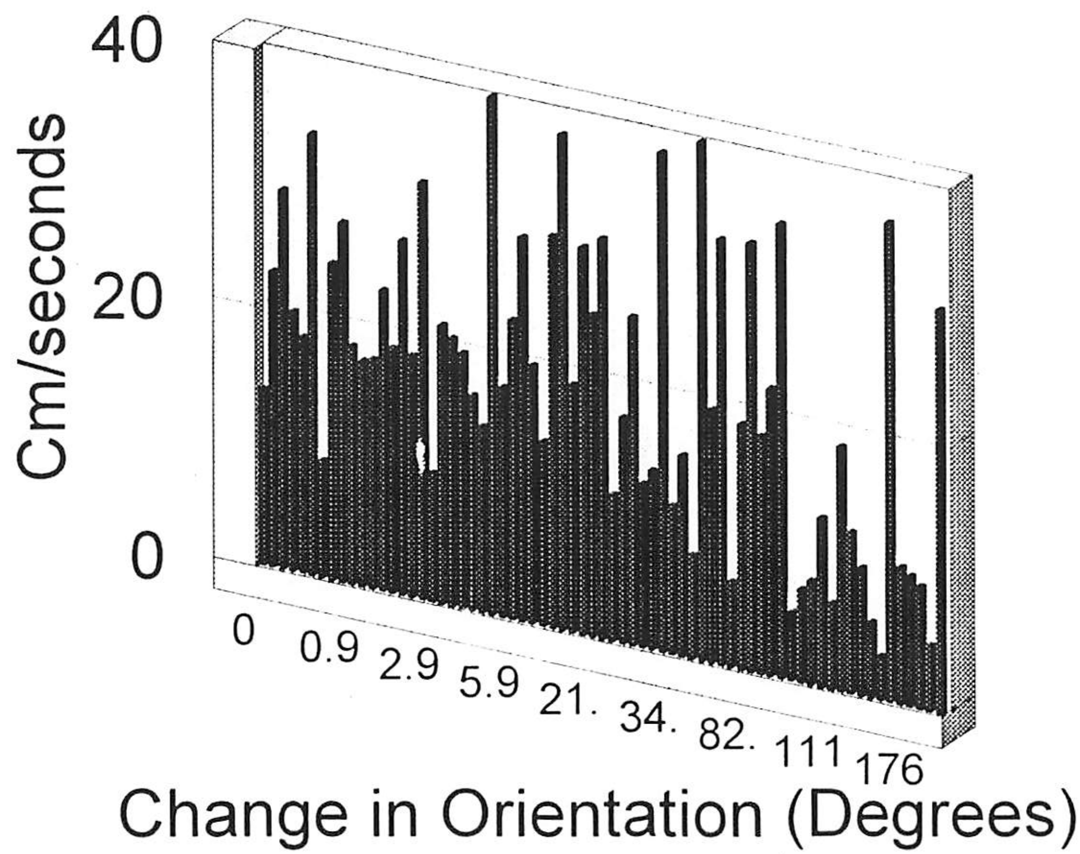
Current Velocity vs. Time

Ambient Location



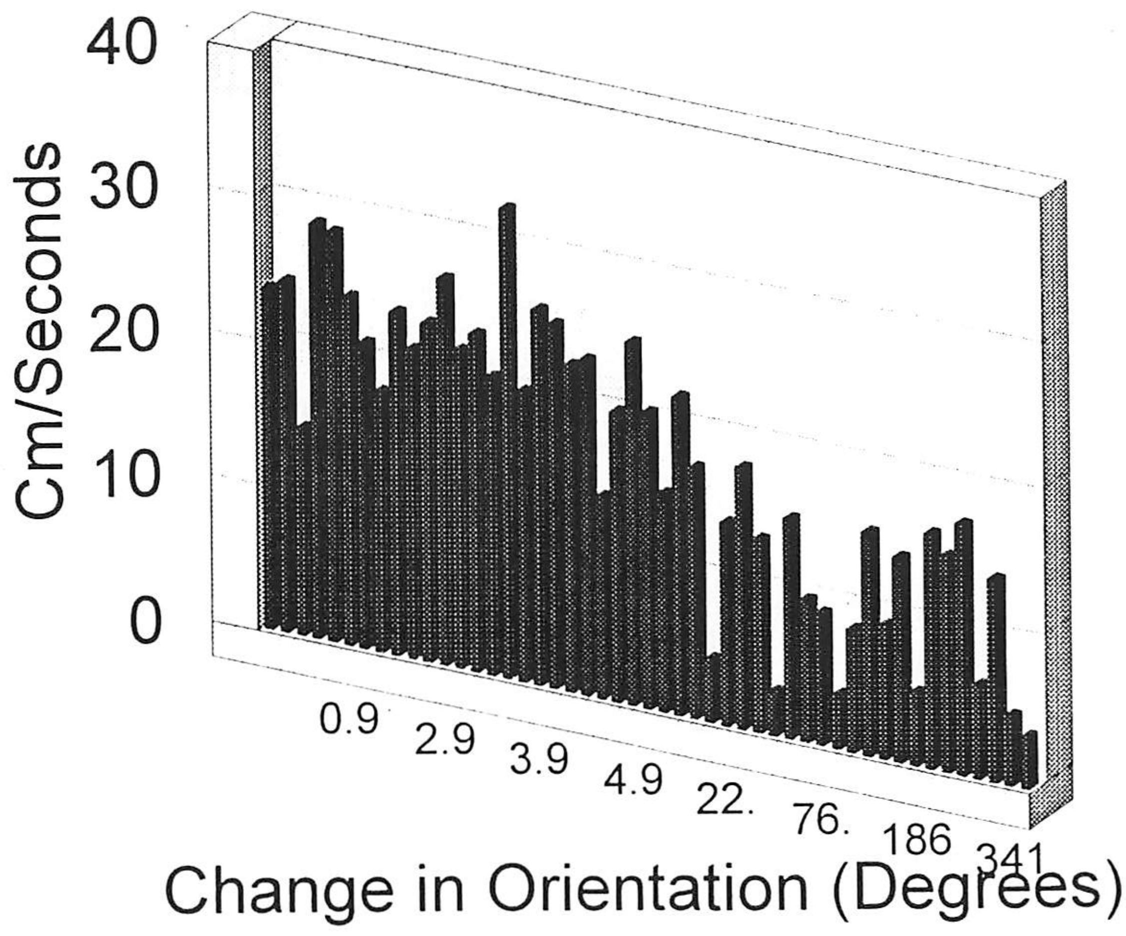
Current Velocity

Gillnet Location



Current Velocity

Ambient Location



RESULTS

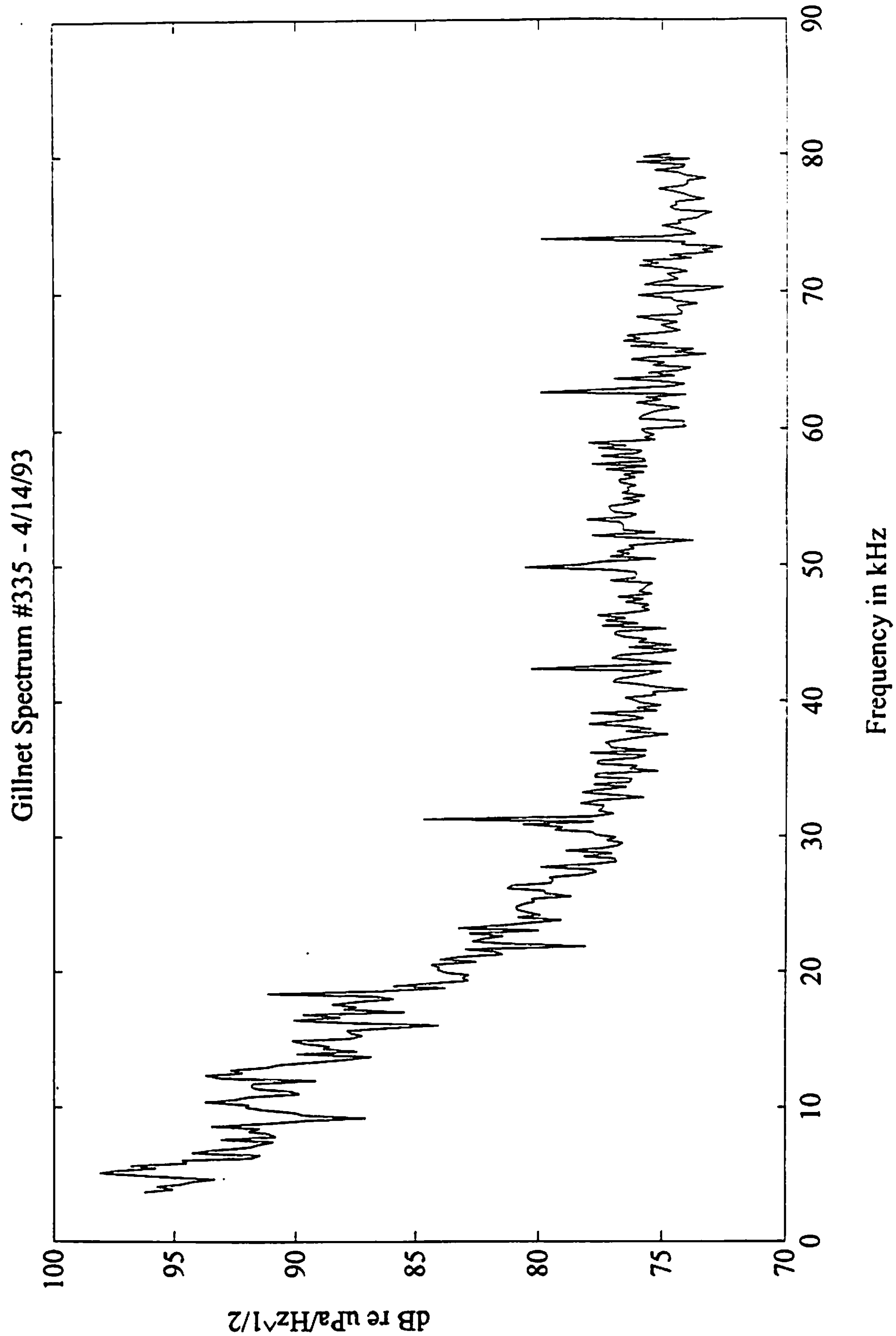
After digitizing random sections of analog gillnet recordings, a total of 27 different average PSD conversions were made (April 8: 5 gillnet, 10 ambient; April 14: 8 gillnet and 4 ambient). An example of a PSD function is shown in Figure 12.

In order to make trends, more understandable the PSD plots were smoothed by averaging frequency blocks of 1000 Hz. The averaged result of Figure 12 is displayed in Figure 13. The remaining PSD plots can be found in the appendix. To show similarities, between the two sample days, seperate mesh plots were generated to combine ambient(Figure 14) and gillnet(Figure 15) noise.

On the two separate recording occasions, a total of 153 minutes of gillnet sounds and 45 minutes of ambient noise were recorded. From these recordings, over 700 twenty millisecond samples were digitized and converted into average PSD form.

Investigation of the ambient noise PSD plots shows substantial peaks at 11, 22, 33, and 66 kHz (See Figure 16.). In depth research into possible natural causes has provided no logical explanations. The creation of the peaks as an artifact of the recording and digitization system can be ruled out because of the lack of similar intensity peaks in the gillnet recordings. The lower intensity peaks, found in the gillnet recordings of the same frequency can be explained as the transmission and resulting

Figure 12.



Gillnet Spectrum #335 - 4/14/93
Frequency in kHz
dB re uPa/Hz^1/2
0
10
20
30
40
50
60
70
80
90
100
95
90
85
80
75
70

Figure 13.

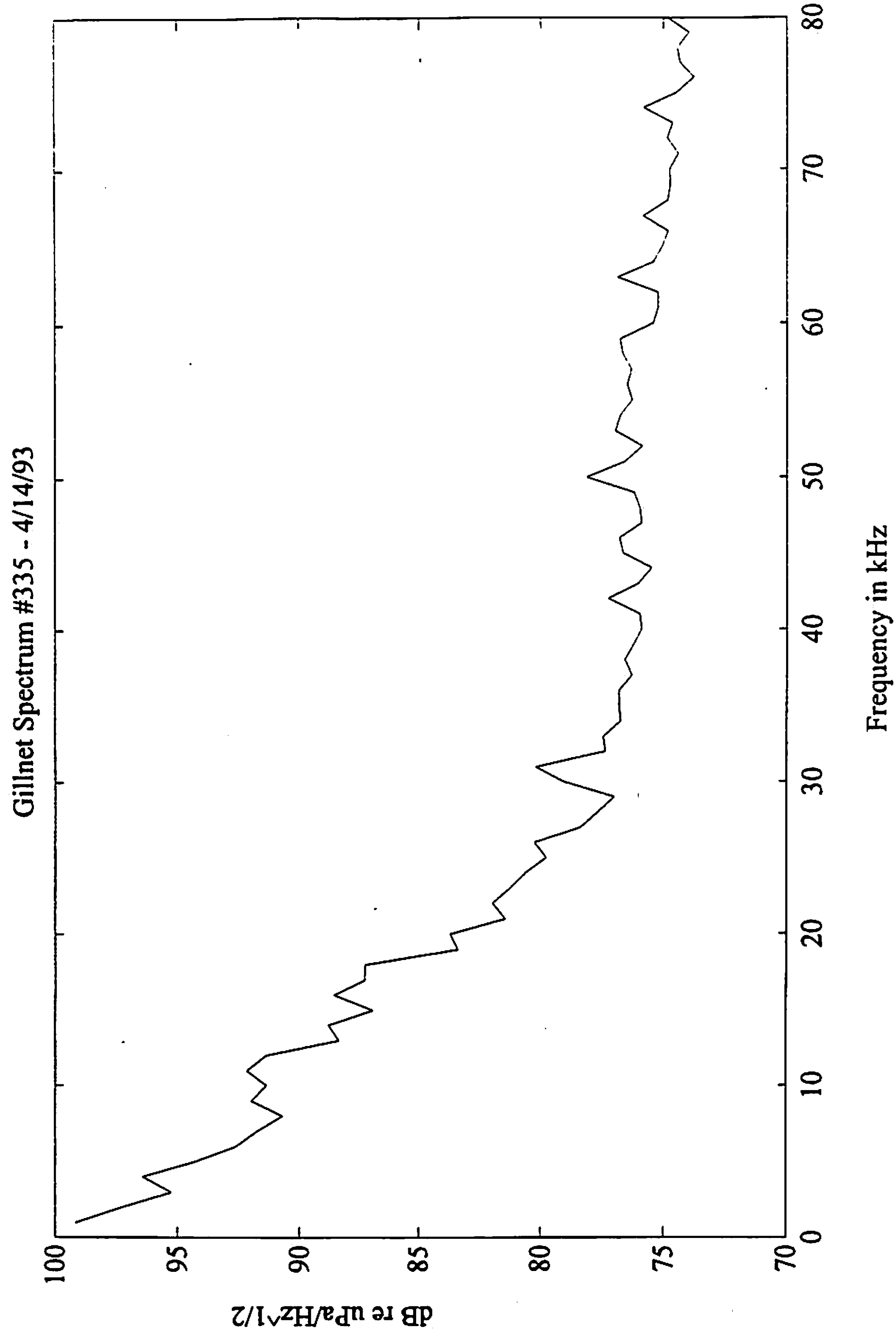

Gillnet Spectrum #335 - 4/14/93
dB re uPa/Hz^1/2
Frequency in kHz
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80

Figure 14.

Comparison of 4/8/83 and 4/14/93 Ambient Noise

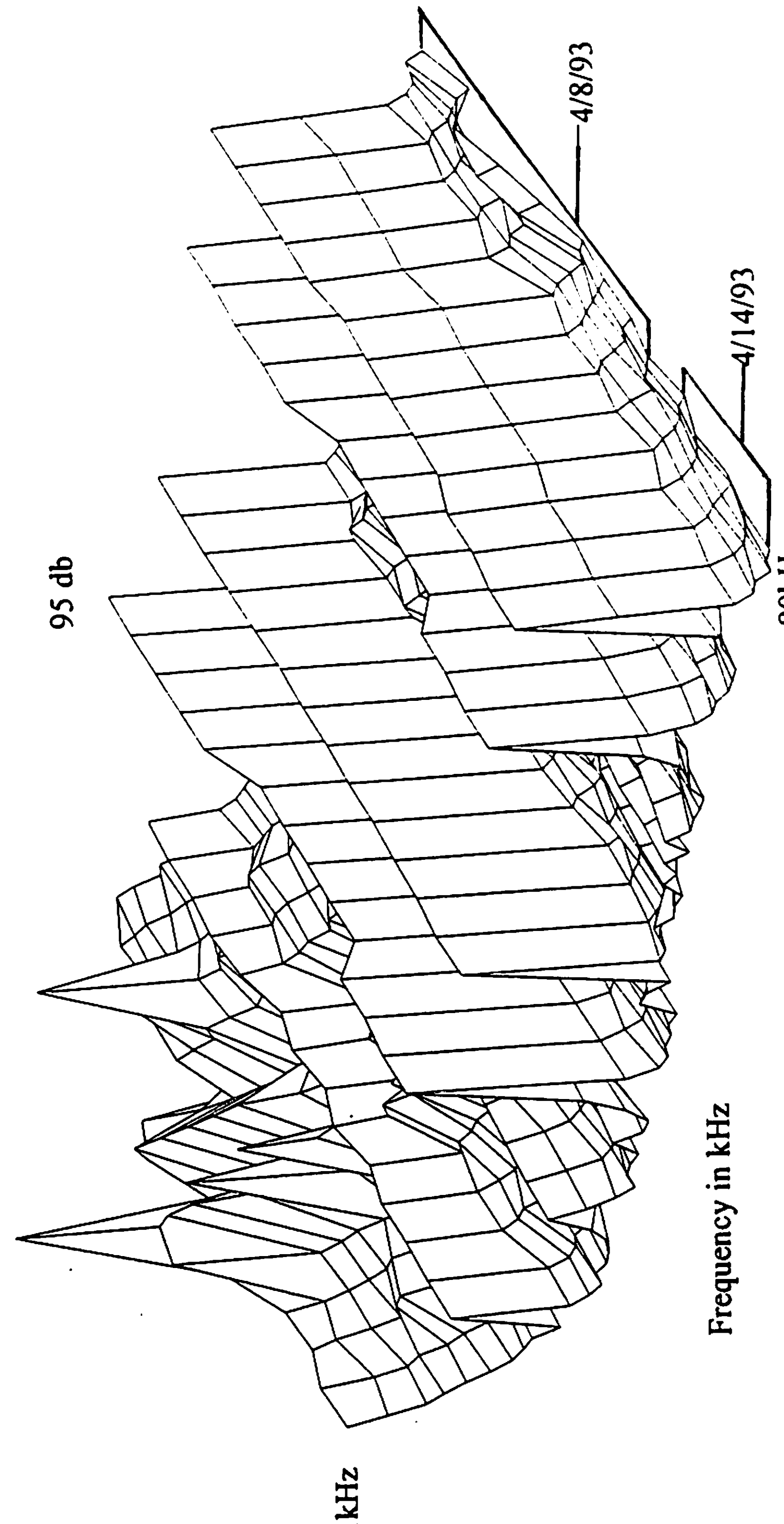


Figure 15.

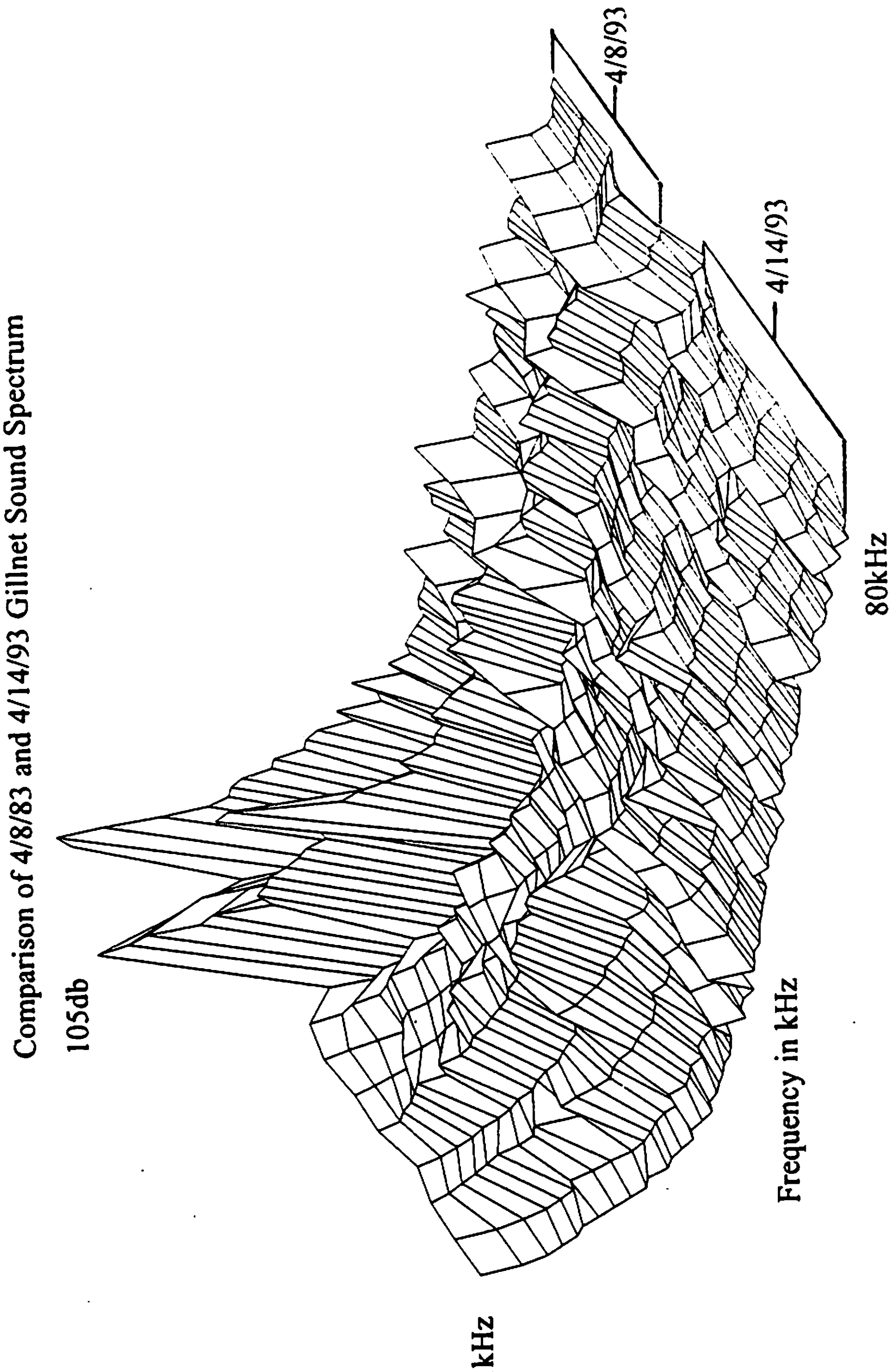
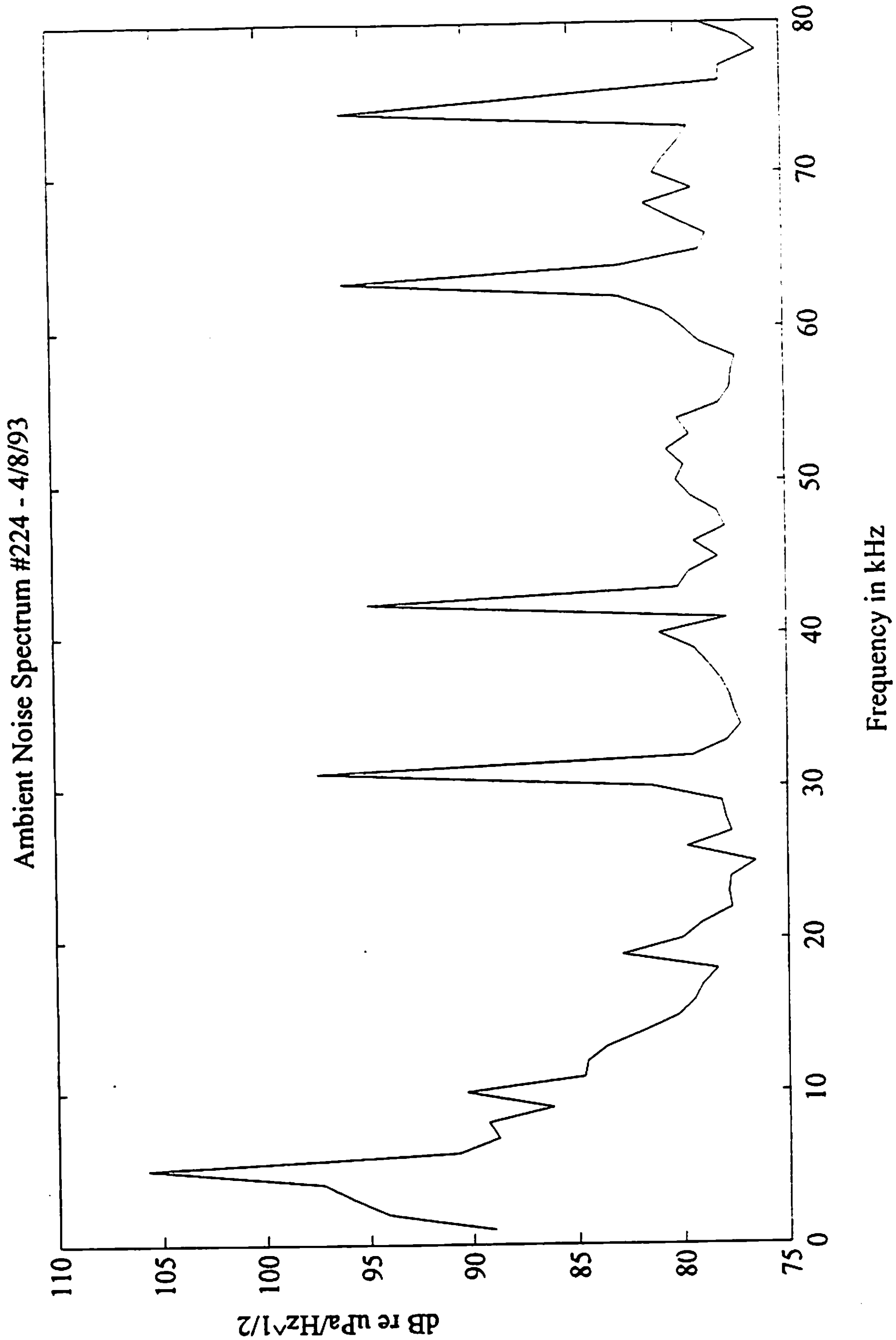

Comparison of 4/8/83 and 4/14/93 Gillnet Sound Spectrum
105db
4/8/93
4/14/93
80kHz
Frequency in kHz
1kHz

Figure 16.



Ambient Noise Spectrum #224 - 4/8/93
Frequency in kHz
dB re uPa/Hz^1/2
0
10
20
30
40
50
60
70
80
75
80
85
90
95
100
105
110

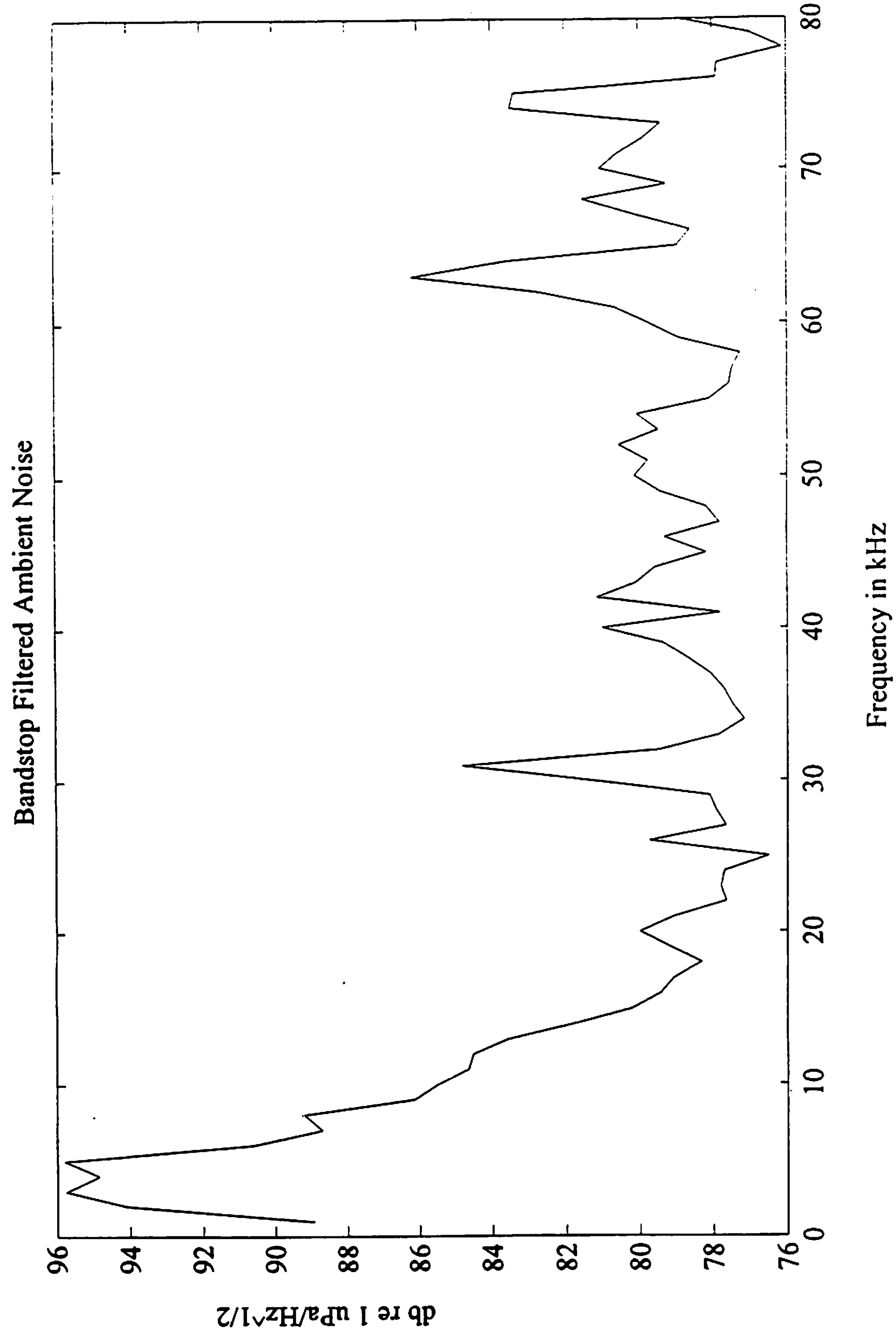
attenuation of the sound from the ambient sight. As a result, the large 100+ dB peaks can only be attributed to a human source. Similarities to PSD levels seen when operating the onborad depth sounder suggest possible the high intensity interference maybe nearby fishermen operating a depth sounder or fish finder. However, trends are still visible when comparing ambient and gillnet signals.

To make the information more clear, the ambient noise PSD was filtered by bandstop filter at each of the large peaks and then smoothed with the same method as before (See Figure 17.). By eliminating the peaks an idea of a more natural ambient PSD is gained. Figure 18 is a comparison of ambient noise PSD, gillnet sounds and harbor porpoise hearing thresholds.

This comparison reveals very similar PSD distributions.The gillnet PSD shows no real change in the abrupt changes from the ambient noise distribution in the range of optimal harbor porpoise hearing range. There is, however, a general shift of energy distribution from higher (+30 kHz) in the ambient noise to lower frequencies in the gillnet noise. This is seen in Figure 18 where gillnets PSD levels are generally greater than ambient PSD levels above (approx. 30 kHz), at which time the gillnet levels fall below ambient levels. This would suggest that the net is producing sounds below 30 kHz and damping high frequency energy.

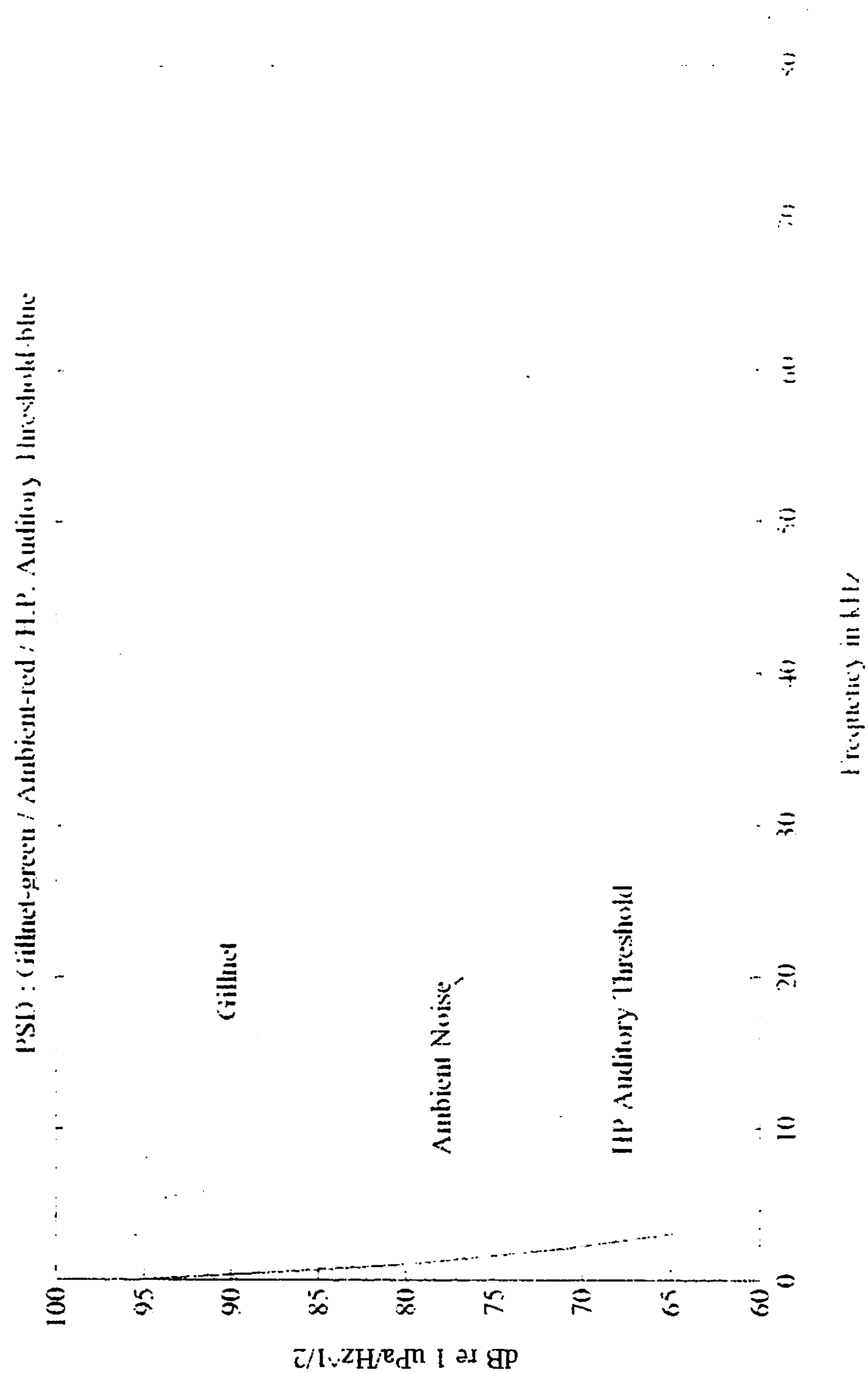
Comparing the PSD of this year's gillnet recordings with the gillnet recording of last year's project shows very similar energy distributions for the empty gillnet which helps to verify the

Figure 17.



Bandstop Filtered Ambient Noise
Frequency in kHz
db re 1 uPa/Hz^1/2
96
94
92
90
88
86
84
82
80
78
76
0
10
20
30
40
50
60
70
80

Figure 18.


PSD : Gillnet-green / Ambient-red / H.P. Auditory Threshold-blue
Gillnet
Ambient Noise
HP Auditory Threshold
dB re 1 uPa/Hz^1/2
100
95
90
85
80
75
70
65
60
0
10
20
30
40
50
60
Frequency in kHz

results found in this project(Atwood et al., 1992). This suggests that the sounds emitted by the net would be interpreted as just a change in ambient noise levels, and would not alert the harbor porpoise to the presence of the net. However, due to the lack of fish in the net on either recording day, it is impossible to identify any changes in the sound spectrum due to the addition of expiring fish in the net.

TRIP LOG

February 11, 1993

The goal of our first excursion was to test the improved deployment and recovery method and acquire data. We chose a 75 foot deep basin in the mouth of Portsmouth Harbor that would best simulate the experimental conditions. Using the R.V. Jere A. Chase, the instruments were deployed and recovered using our initial design. The initial design was determined to be awkward and inefficient, although the data system operated as planned. Changes had to be made to the deployment/recovery system.

February 25, 1993

Cancelled/Bad Weather

March 11, 1993

Cancelled/Bad Weather

March 12, 1993

Cancelled/Bad Weather

March 16, 1993

Cancelled/Bad Weather

March 18, 1993

Cancelled/Bad Weather

March 25, 1993

Returned to the mouth of Portsmouth Harbor to test the mooring design. This time the deployment and recovery was simple and required little wasted energy or time. This design was adopted as our, previously mentioned, final design.

April 1, 1993

Cancelled/Bad Weather

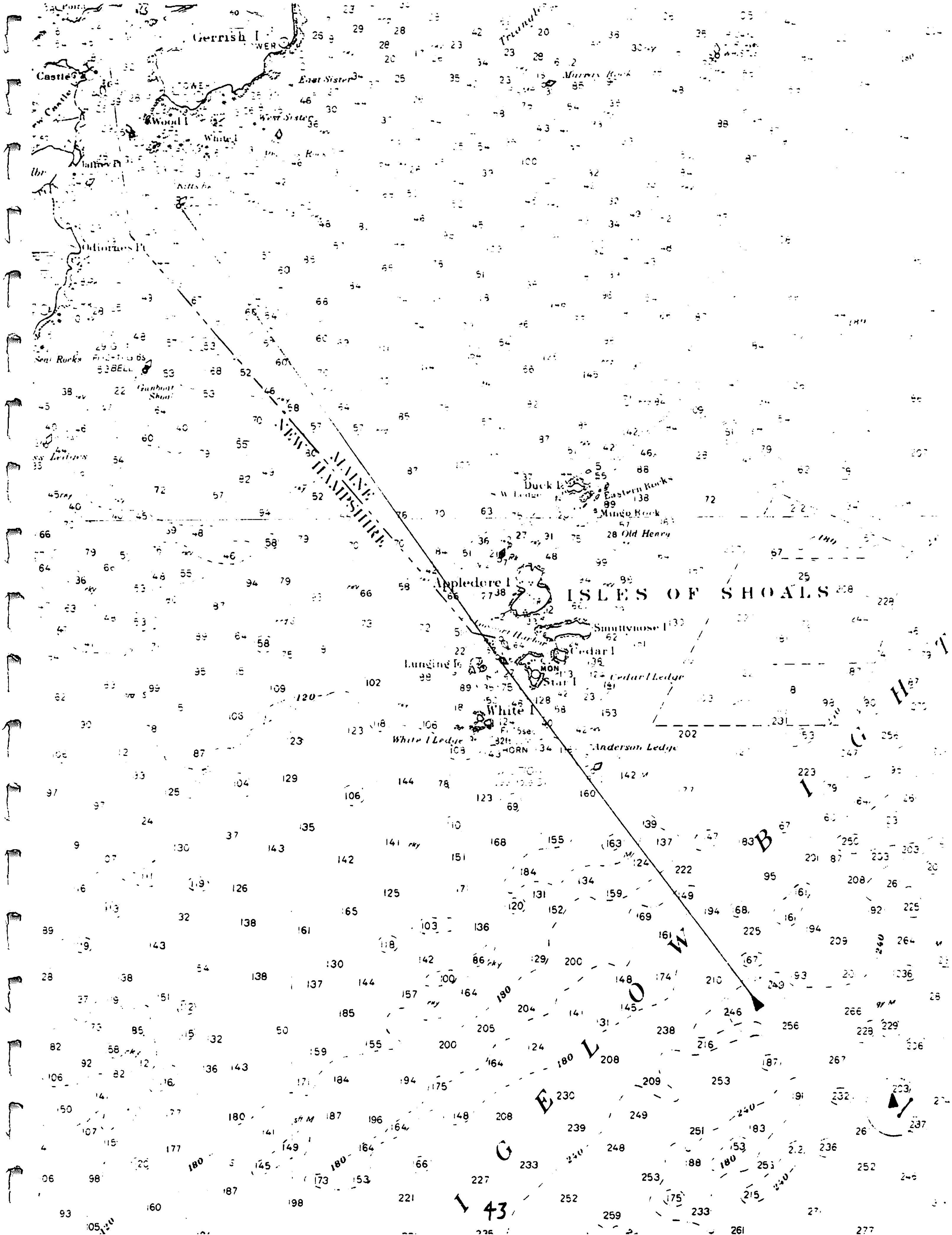
April 6, 1993

Cancelled/Bad Weather

April 8, 1993

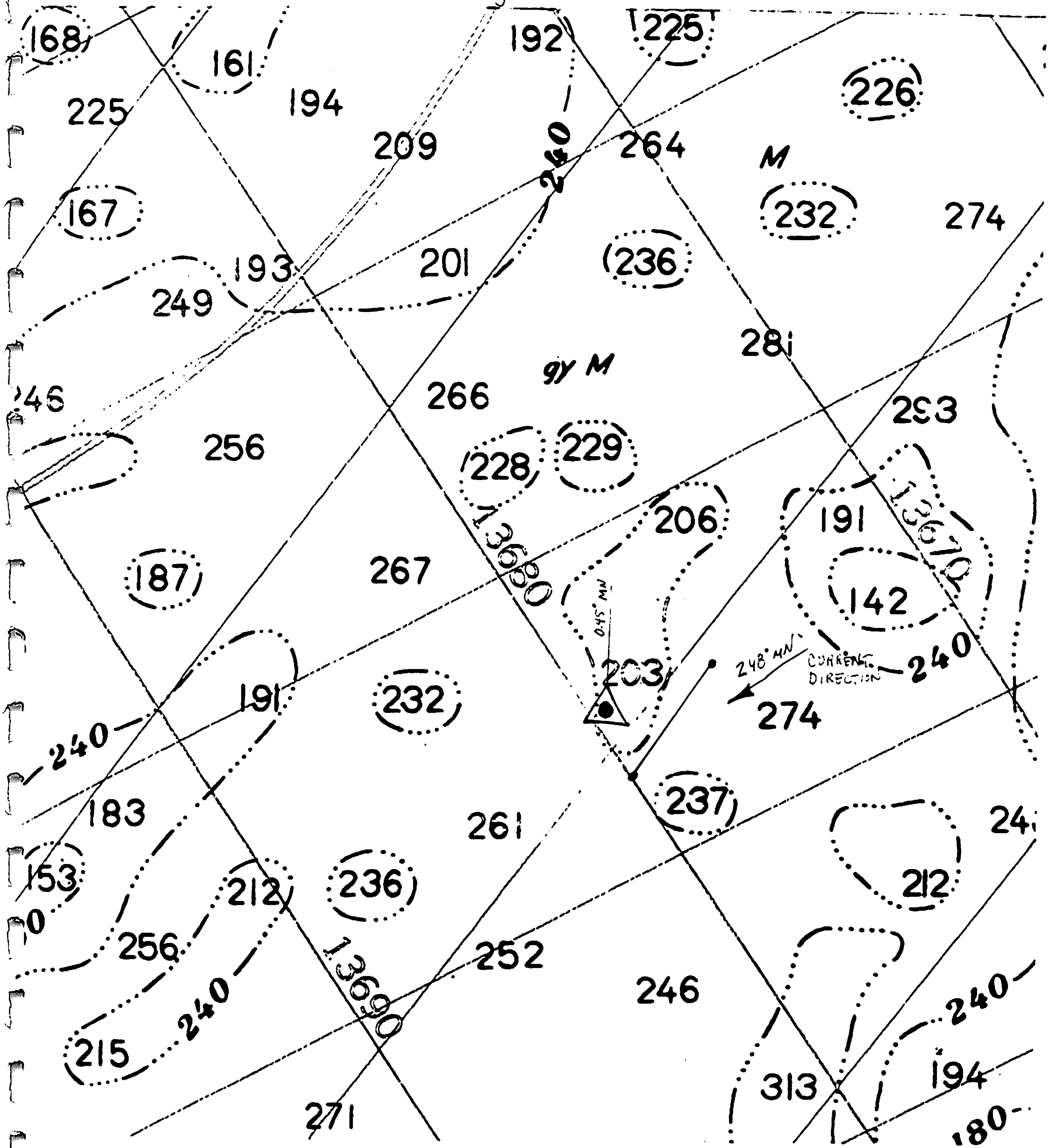
Departed Portsmouth Harbor aboard the Jere A. Chase at 7AM, for Latitude N 42° 54'45" and Longitude W° 32'02". Figure 19 displays the location of the gillnets compared to Portsmouth, NH. Upon reaching the site, the Jere A. Chase anchored 0.04 NM away from the north bouy and 0.088 NM from the south bouy, at a distance of 0.0138 NM (85 ft.). Figure 19 shows the orientation of the mooring system with reference to the gillnet.

Ambient readings were taken at Latitude N 42° 55'16" and


Gerrish I
Castle
Wood I
White I
East Sister
West Sister
Triangle
Murrays Rock
Odiornes Pt
Seal Rocks
Gunboat Shoal
MAINE
NEW HAMPSHIRE
Duck I
Eastern Rocks
Mingo Rock
Old Henry
Appledore I
ISLES OF SHOALS
Smuttynose I
Cedar I
Lunging I
Star I
Cedar I Ledge
White I
White I Ledge
Anderson Ledge
IGELOW BIGHT

43

Figure 19.


168
161
192
225
226
225
194
209
264
M
167
232
274
193
201
236
249
281
gy M
246
266
293
256
228
229
206
191
13670
187
267
13680
142
0.45 MN
203
248° MN
CURRENT DIRECTION
240
191
232
274
240
183
261
237
24
153
212
236
212
256
252
13690
246
240
215
240
313
194
271
180

Longitude W 70° 34'48", at a distance of 0.466 NM from the north buoy and 0.343 NM from the south buoy. Two Harbor Seals (Phoca vitelline) were observed in the vicinity of the net.

Once the mooring system was deployed, the boat engine and on board depth sounder were shut down. The engine was transmitting large amounts of low frequency (<1000 Hz) noise, thus making recording impossible. Similarly, the depth sounder was emitting a 50.5 Hz signal which was overpowering the local ambient noise. Amplification levels were set at 20 dB with the Itheco filter cut-off points at 1000 Hz and 100 kHz.

At the site, eight tracks of tape were recorded at a tape speed of 30 inch/sec. This resulted in 125 minutes of recorded gillnet sounds with a usable bandwidth of 1 kHz to 100 kHz.

After moving to the ambient noise location 31 minutes of sound were recorded following the same operational procedure with respect to gain level, tape speed, cut-off frequencies and engine/depth sounder operation. Recording conditions for this day were 1-2 ft seas with 10 mph winds.

Data was successfully recorded by the S4 on this trip. The Jere A. Chase returned to Portsmouth at 5 PM.

April 10, 1993

Departed Portsmouth at 6 AM for the same location. Upon arrival the Jere A. Chase lowered her anchor chain to secure our position away from the net. At this time the chain failed and we were forced to return without collecting data.

April 15, 1993

Departed Portsmouth Harbor at 7 AM, for a net located in the vicinity of Latitude N 42° 54'45" and Longitude W 70°32'02". The mooring system was approximately 150 ft away from the net. Ambient readings were taken at Latitude N 42° 55'16" and Longitude W 70° 34'48". One Harbor seal was observed in the vicinity of the net. Following the same operating procedure as April 8, 30 minutes of gillnet sounds and 15 minutes of ambient sounds were recorded. Sea conditions were 2-4 ft. seas with a wind speed of 10 mph with gusts up to 20 mph. Unfortunately, the S4 did not record data on this trip. The Jere A. Chase returned to Portsmouth at 2 PM.

Summary

Harbor porpoise incidenal take is a prominent issue in the Gulf of Maine. The goal of this project was to provide insight into the relationship between the auditory threshold of the harbor porpoise and the sound created by a working gillnet.

This investigation suggests that the empty net serves to alter the intensity of the ambient noise, but has no clearly defined acoustic signature. Comparisons of the ambient noise and net noise showed a close relation in trend and differed by only 5-10 dB. Because the nets were empty, the effect of fish in the net would only be speculation.

This is an excellent area for future research. Using a similar design method, the acoustic signature of a net full of fish could be analyzed. From the comparison of this and future research a better understanding of the acoustical environment experienced by harbor porpoise.

Acknowledgements

We would like to extend our appreciation to people who have assisted us at various stages of our project. We would like to thank our advisor, Dr. Ken Baldwin, for his guidance throughout the entire scholastic year. Dr. K. Sivaprasad, Dave Potter(NMFS), Rollie Barnaby, Eric Anderson and Wally Fournier who all had major roles in assisting our project. Thanks to all the Ocean Engineering graduate students for their assitance during the final stages. Also thanks to the Captain and first mate of the Jere A. Chase, Paul Pelittier and Ken Houtler, for their countless hour of patience.

Two corporations made donations that were pivitol to the success of this project; Racal Recorder Inc. and Buoy Tchnologies. This project was funded by Sea Grant.

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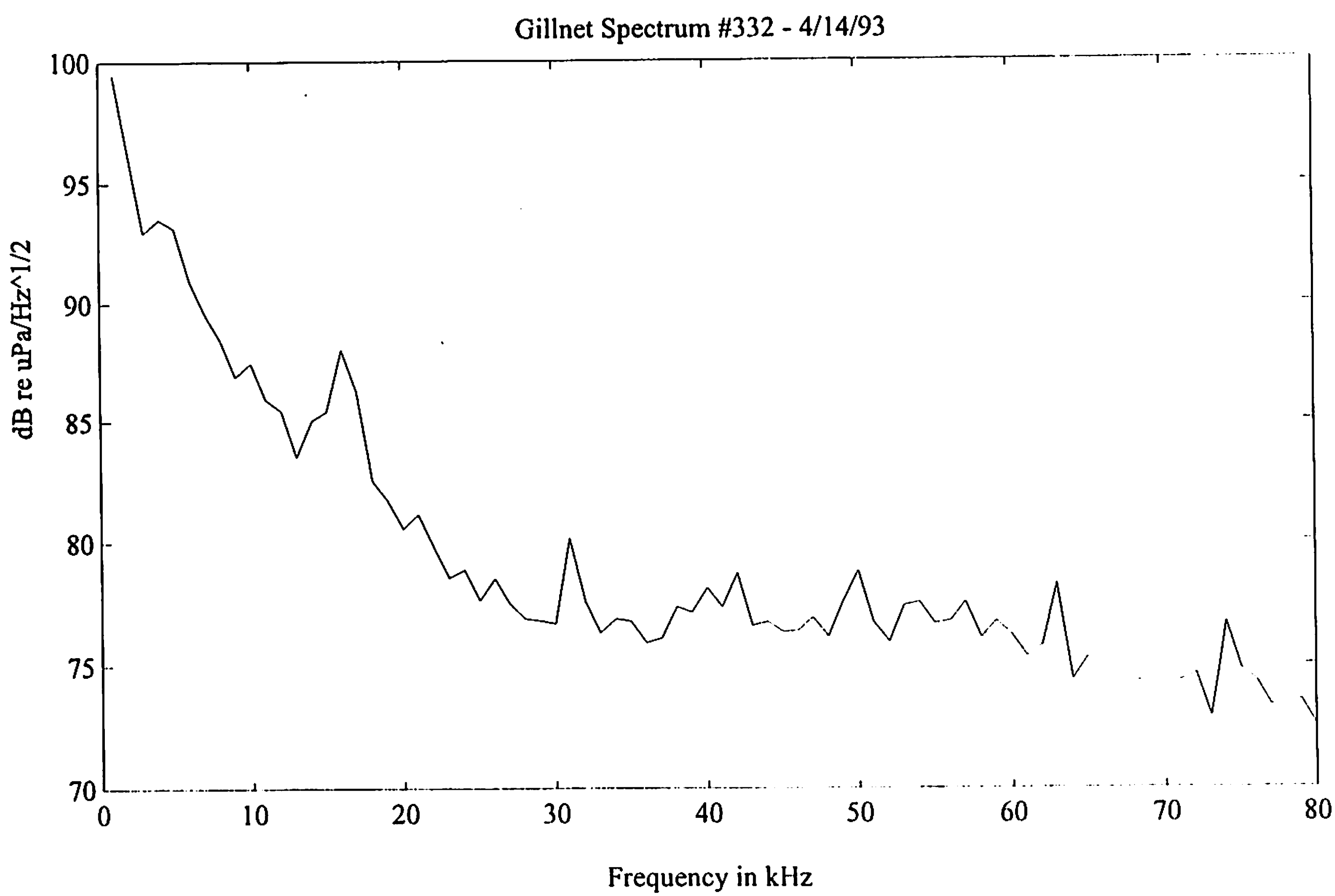
Appendix

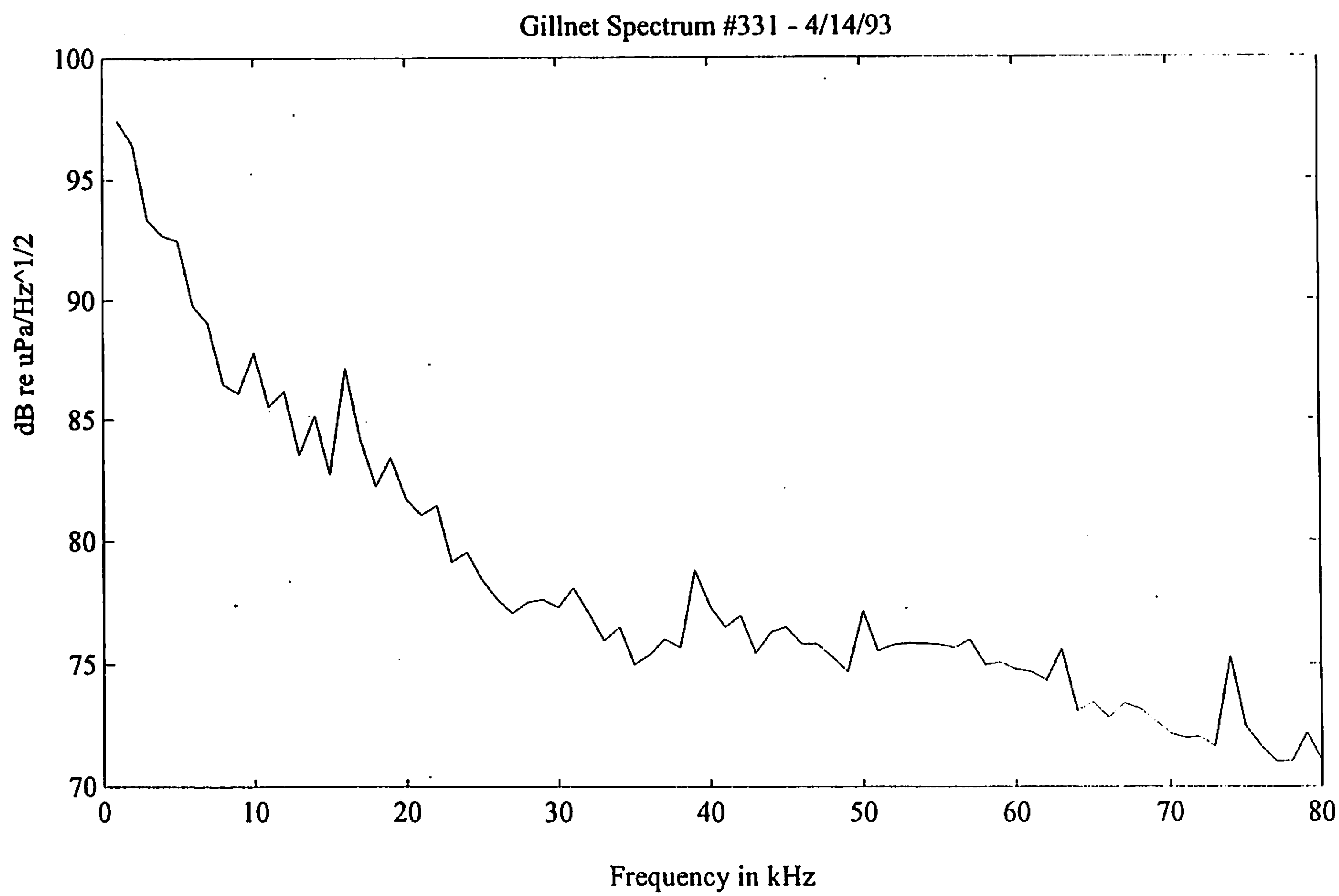
The flow of water (a conductor) past the electromagnetic field created by the S4 current meter causes a voltage to result. This voltage is proportional to the velocity of the current past the sensors on the meter. The S4 uses an internal flux-gate compass to reference current direction to magnetic north.

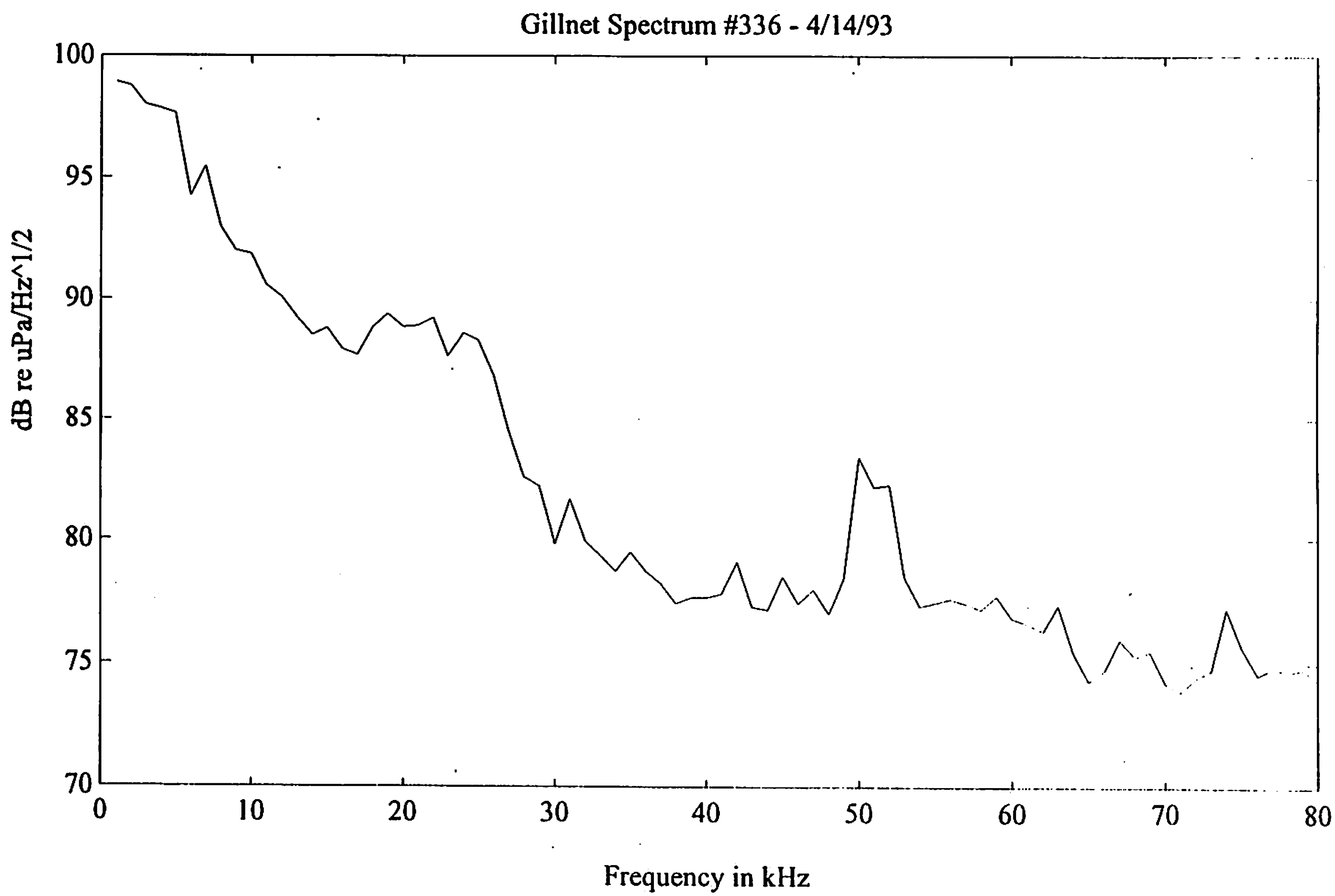
There is a 2 cm Titanium shaft running through the middle of the S4. This enabled us to keep the S4 in line with the rest of the mooring. It was strong enough to handle the forces of both deployment and recovery. The S4 is capable of recording data in water up to 1000m deep and can be equipped to handle depths up to 6000m.

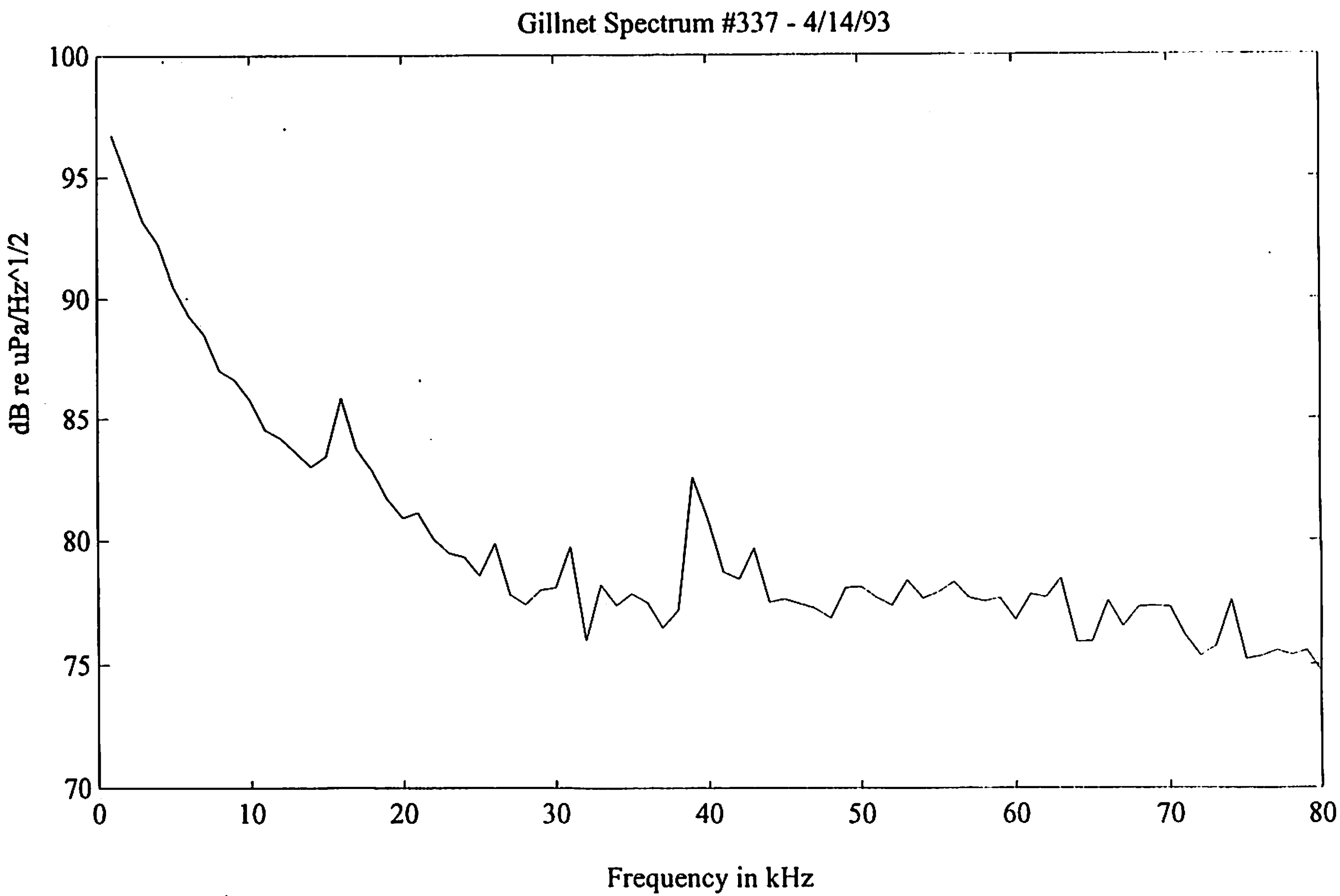
A standard feature of the meter is automatic tilt compensation. This ensures that our data is accurate even if the subsurface float doesn't keep the mooring system exactly vertical.

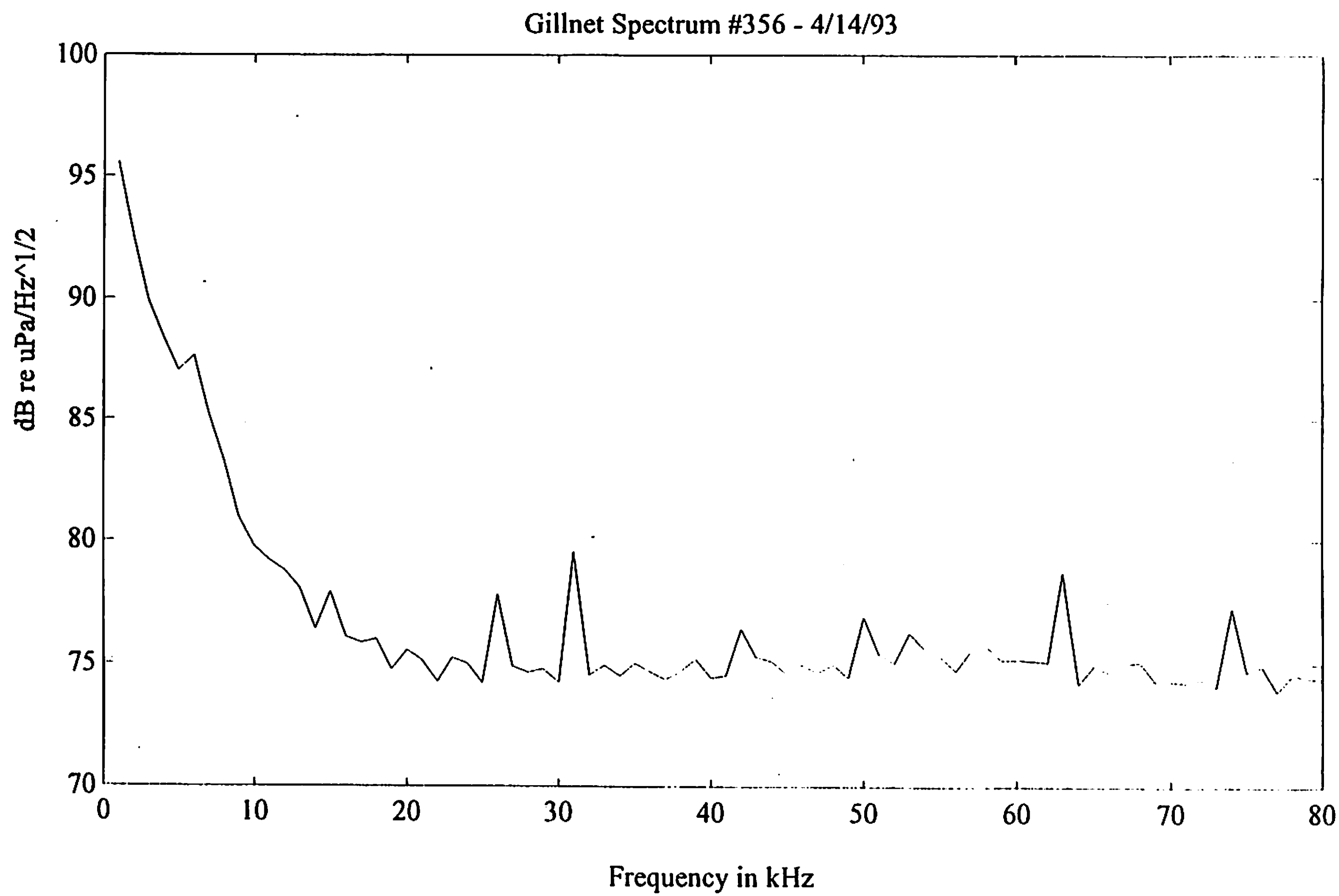
Data was retrieved from the non-restricted lithium battery protected memory using a model S110 RS232C interface unit and was transferred to the hard drive of the Dell 316 Lap Top. The process of data retrieval is non-destructive and may be repeated several times. (We are fortunate to have 3 copies of the same days data due to the sporadic functioning of the S4.)

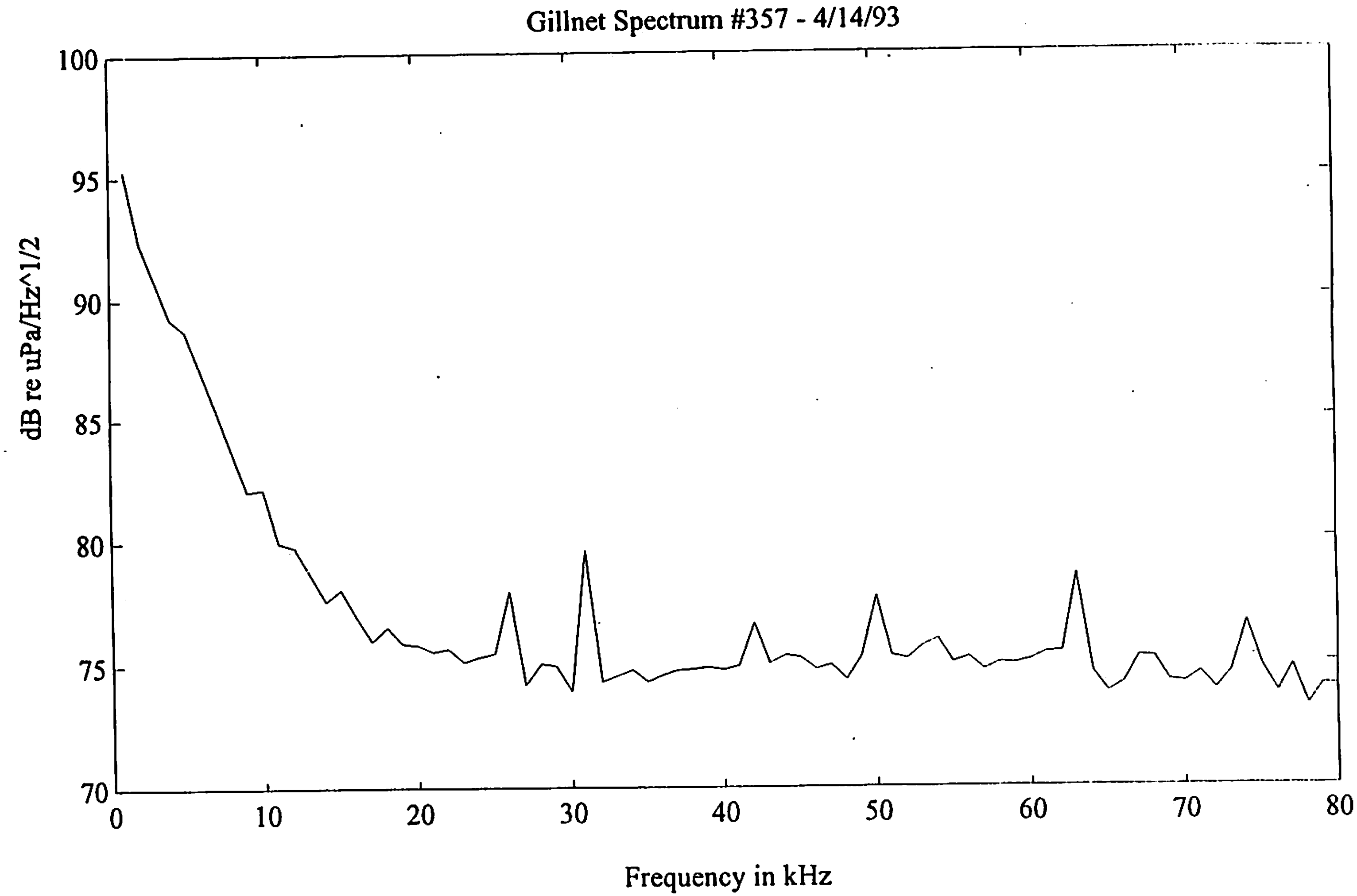

Gillnet Spectrum #332 - 4/14/93
dB re uPa/Hz^1/2
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency in kHz

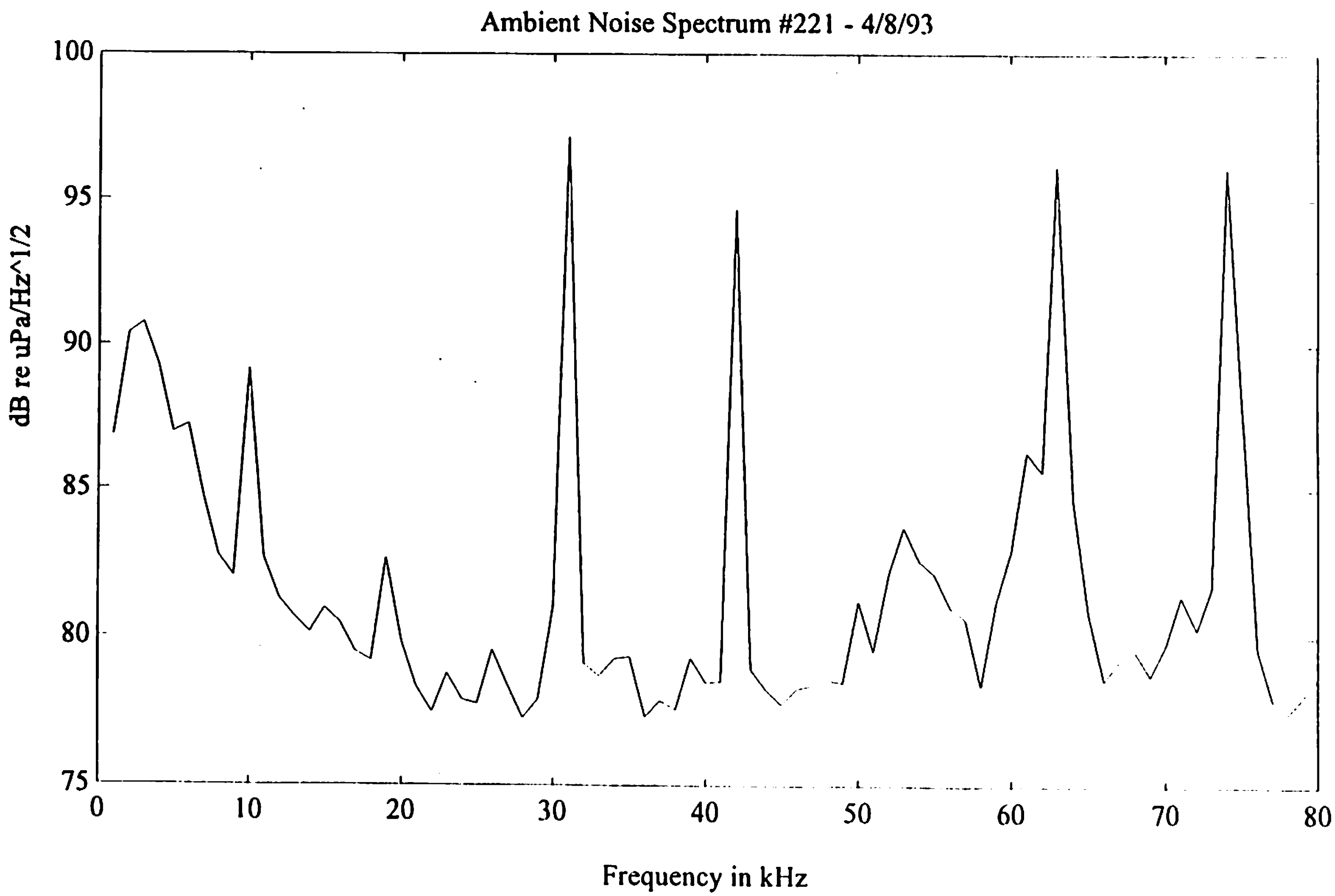

Gillnet Spectrum #331 - 4/14/93
dB re uPa/Hz^1/2
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency in kHz


Gillnet Spectrum #336 - 4/14/93
dB re uPa/Hz^1/2
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency in kHz


Gillnet Spectrum #337 - 4/14/93
dB re uPa/Hz^1/2
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency in kHz

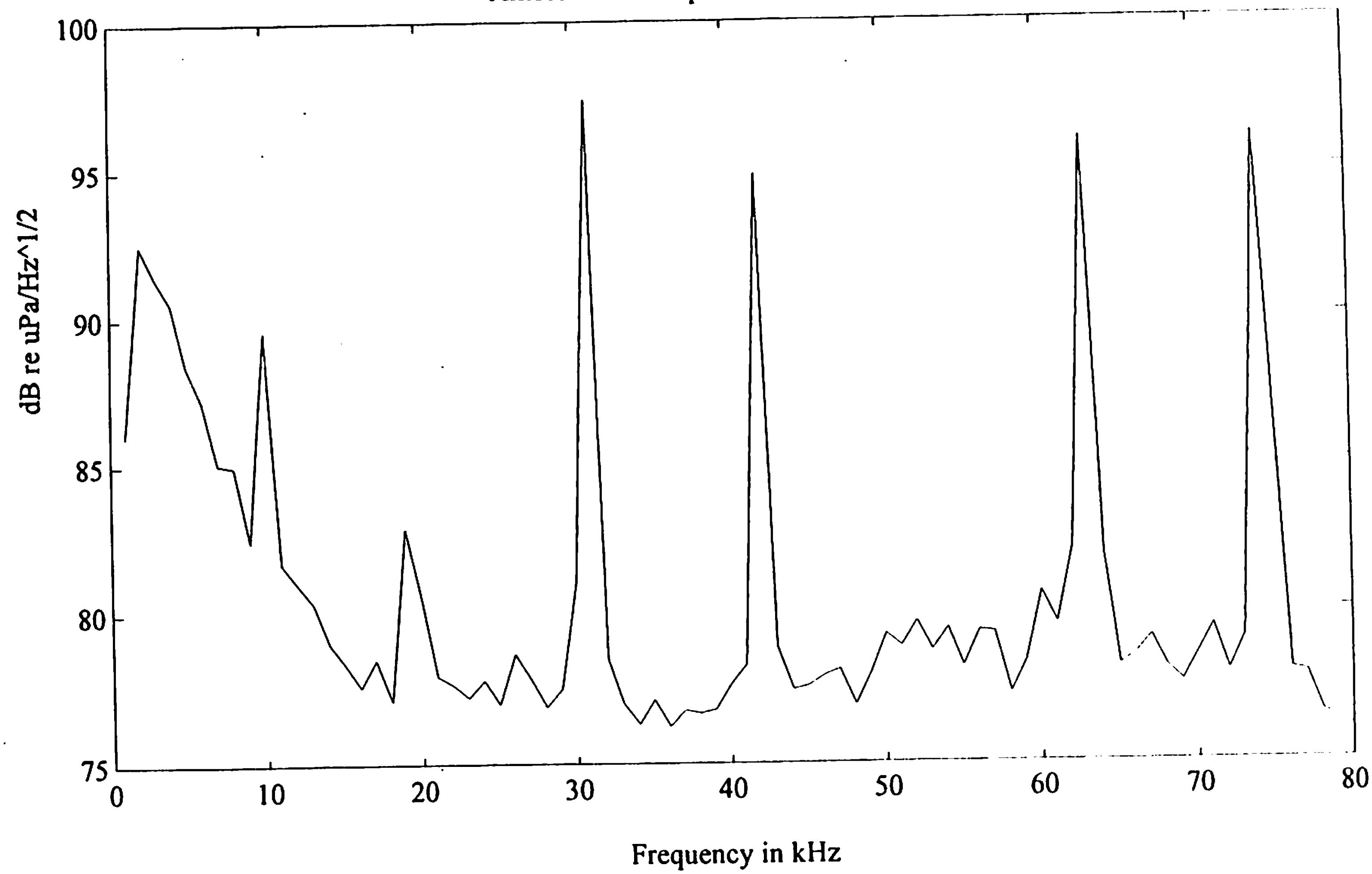

Gillnet Spectrum #356 - 4/14/93
dB re uPa/Hz^1/2
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency in kHz


Gillnet Spectrum #357 - 4/14/93
dB re uPa/Hz^1/2
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency in kHz

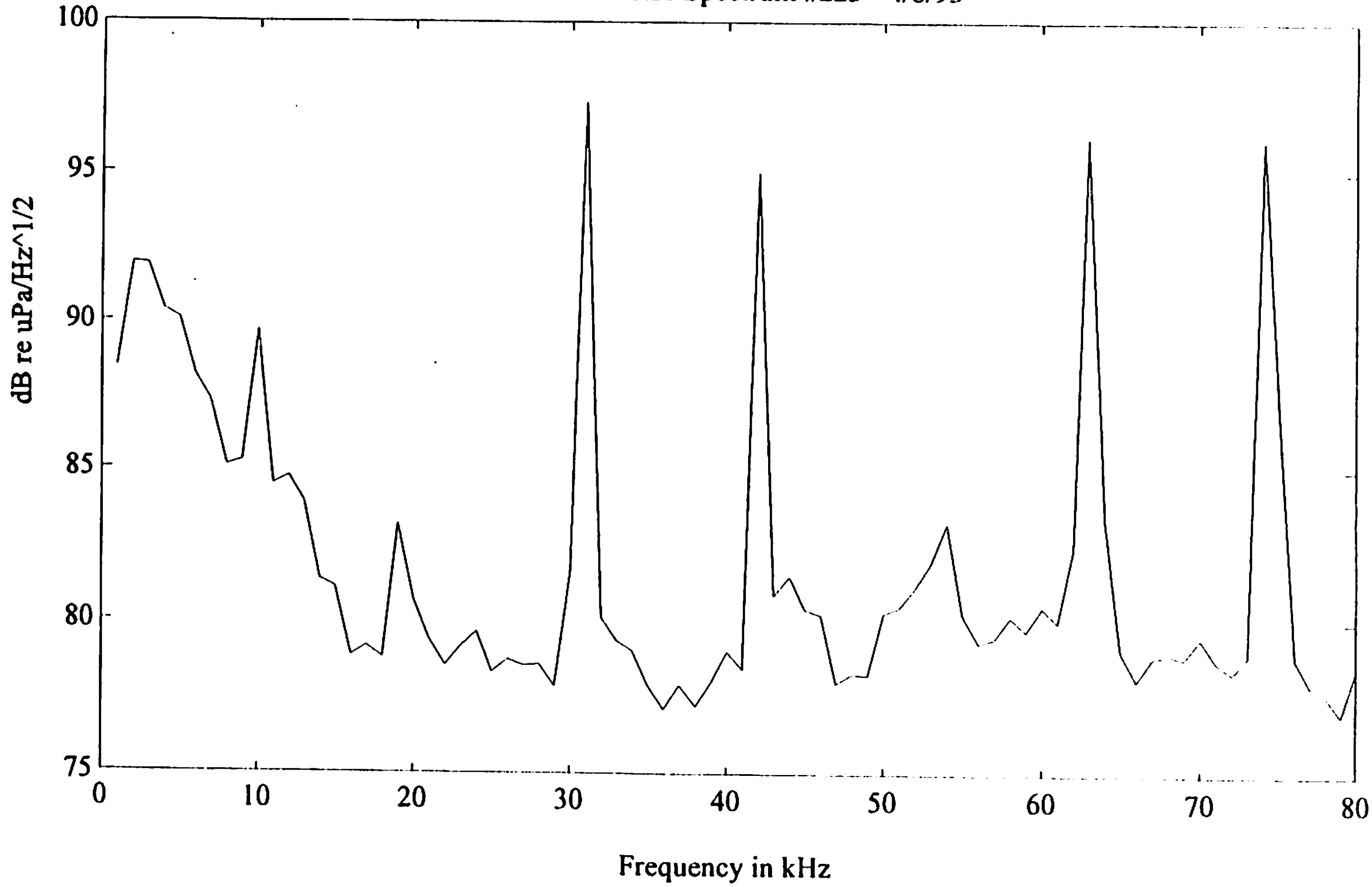


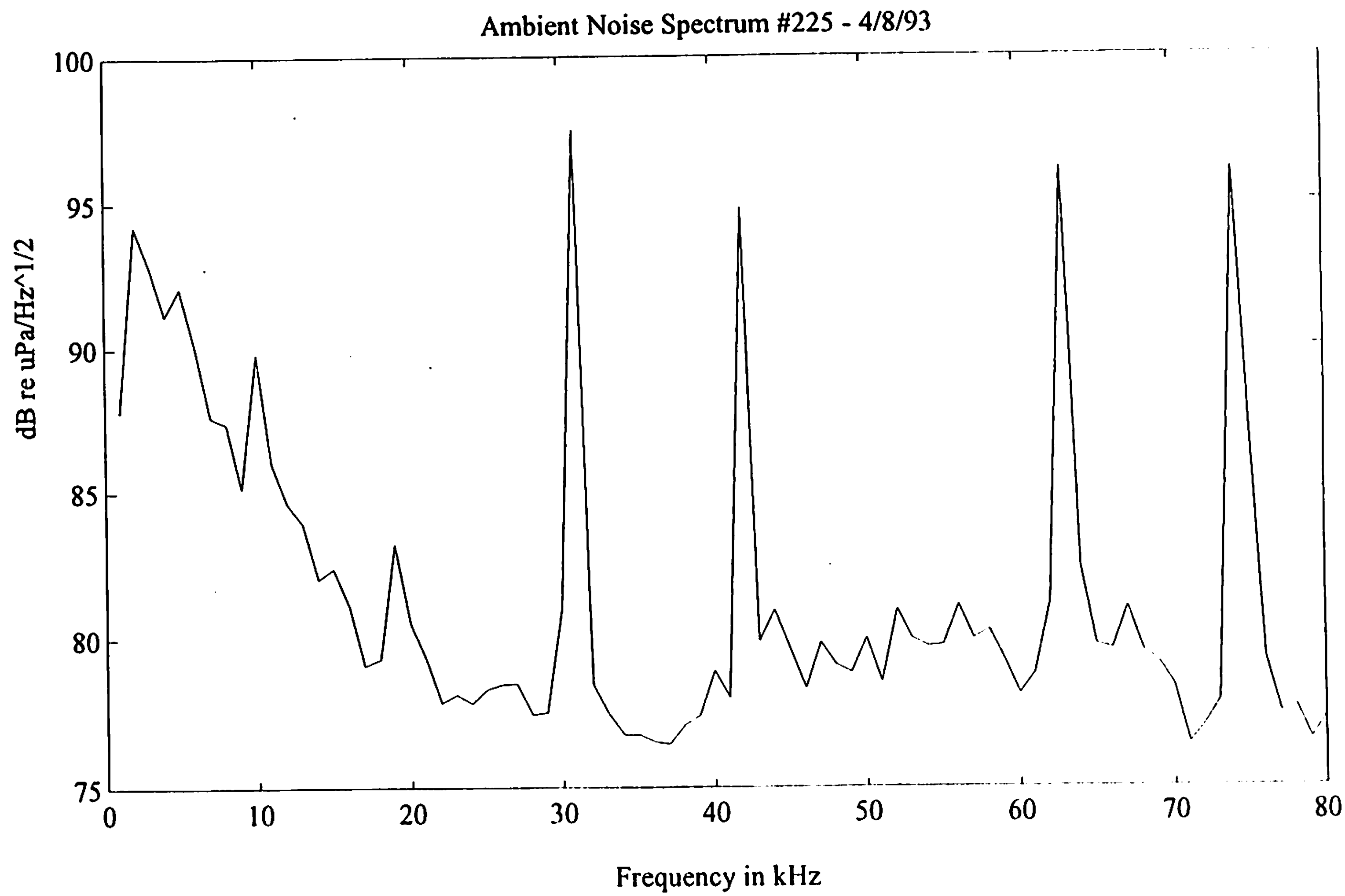
Ambient Noise Spectrum #221 - 4/8/93
100
95
90
85
80
75
0
10
20
30
40
50
60
70
80
dB re uPa/Hz^1/2
Frequency in kHz

Ambient Noise Spectrum #222 - 4/8/93

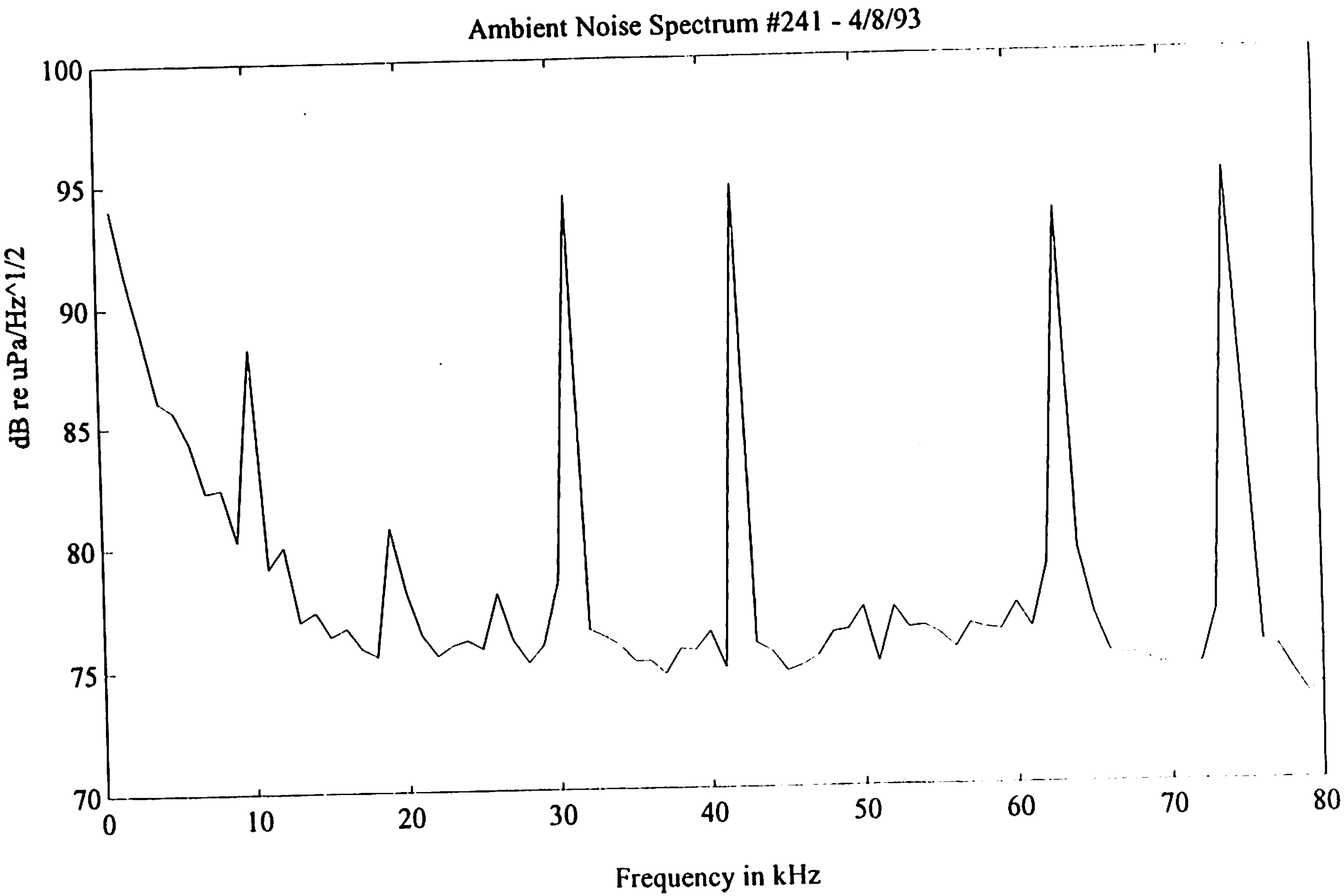


Ambient Noise Spectrum #223 - 4/8/93

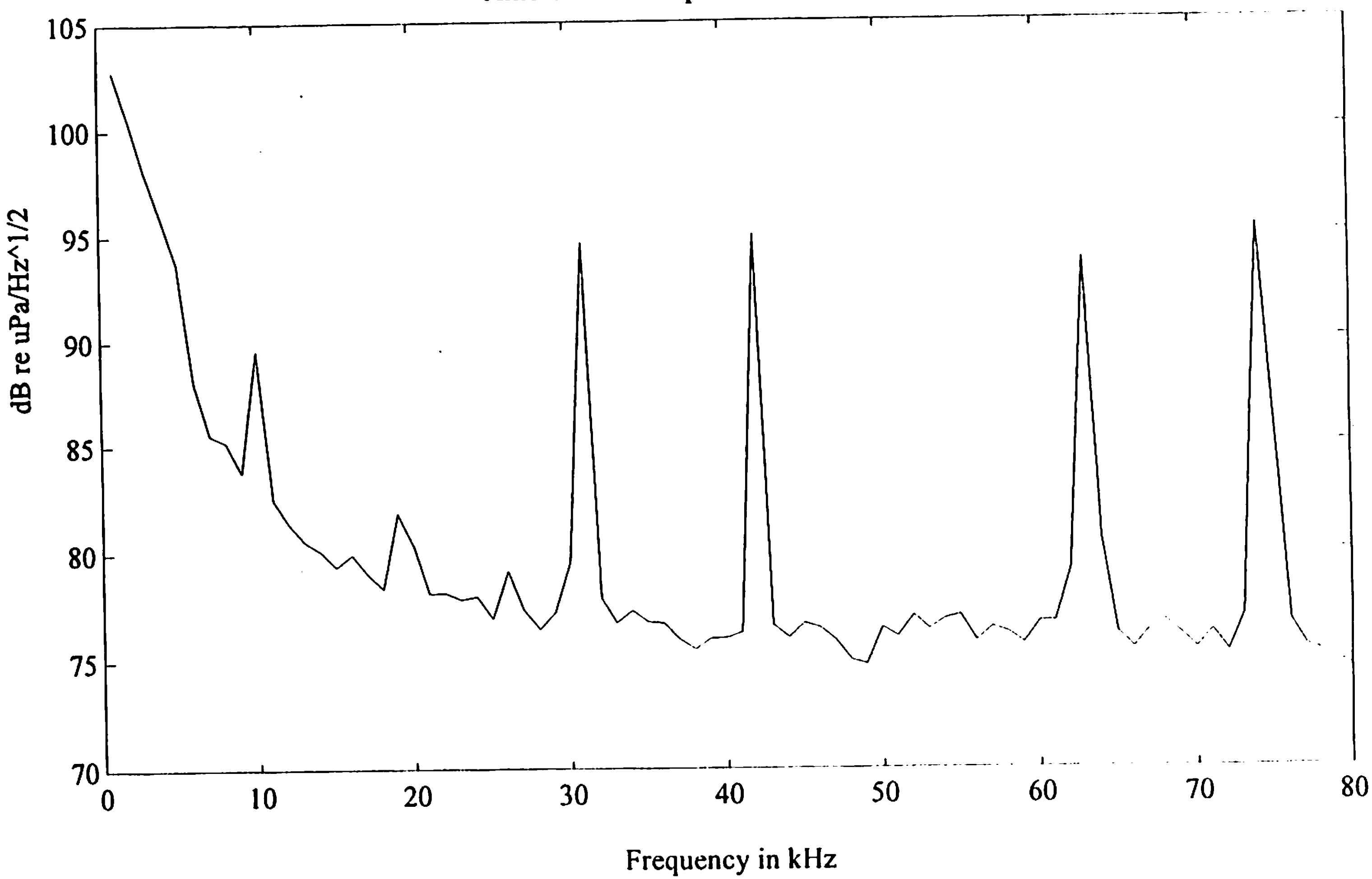


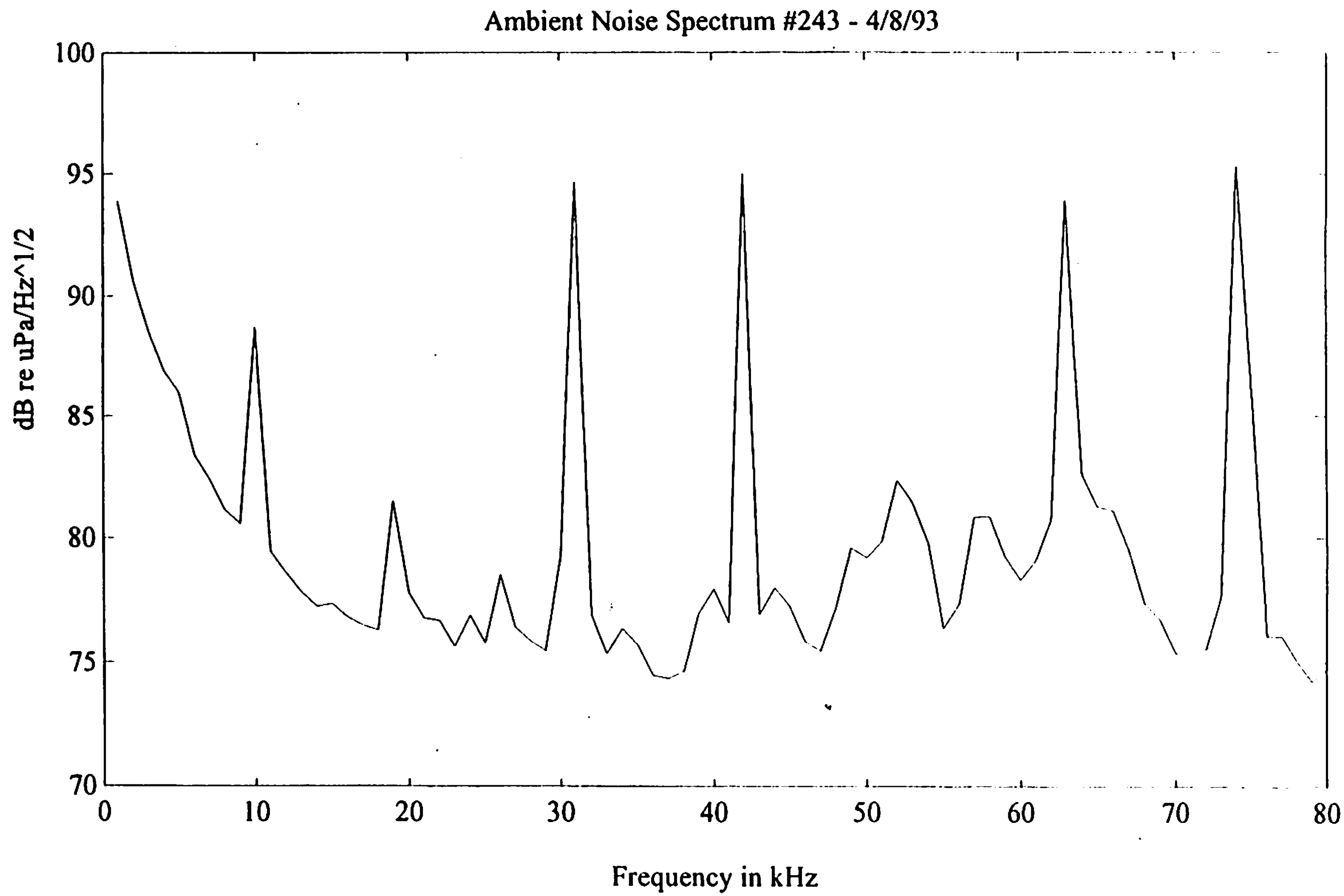


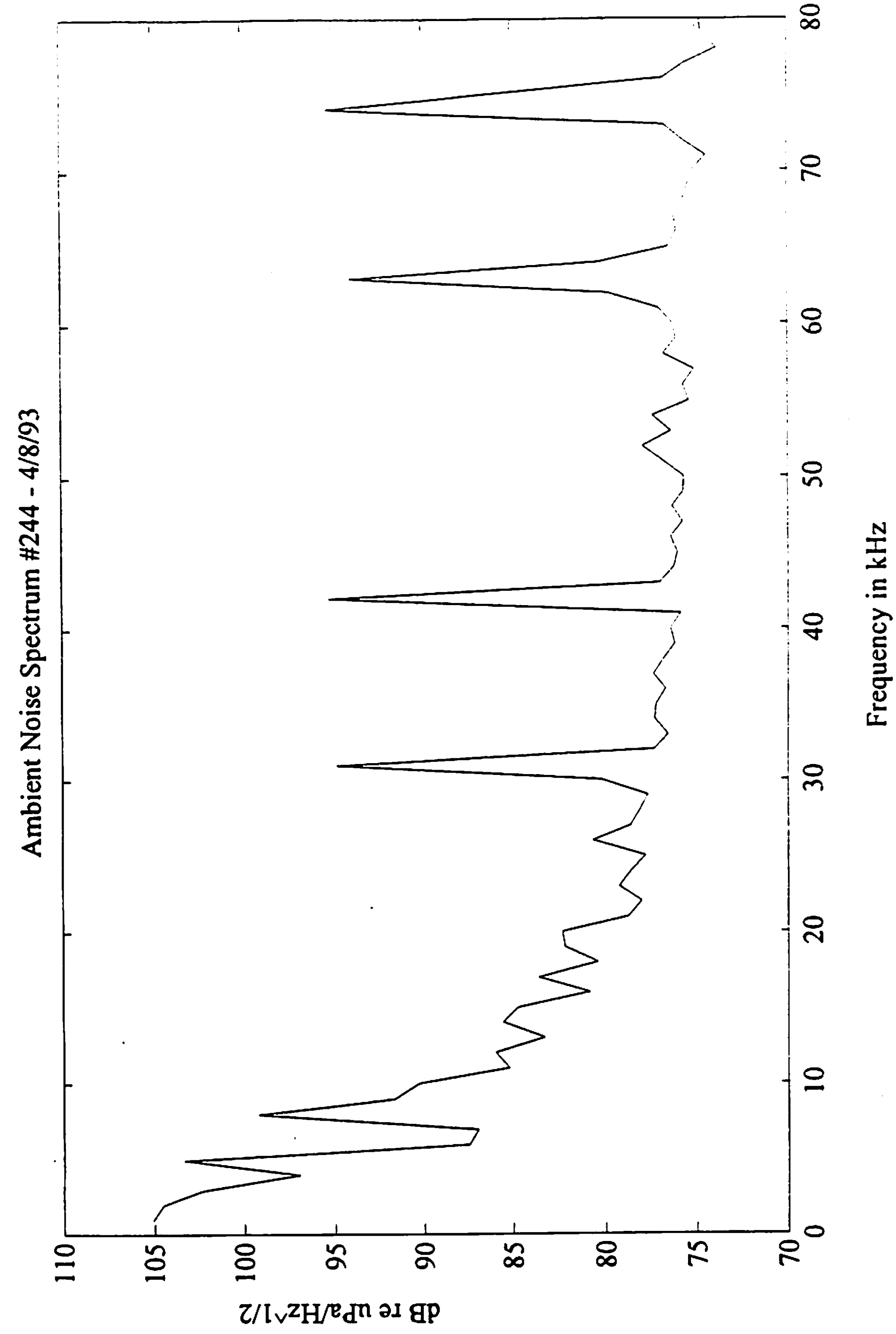
Ambient Noise Spectrum #225 - 4/8/93
100
95
90
85
80
75
dB re uPa/Hz^1/2
0
10
20
30
40
50
60
70
80
Frequency in kHz


Ambient Noise Spectrum #241 - 4/8/93
dB re uPa/Hz^1/2
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency in kHz

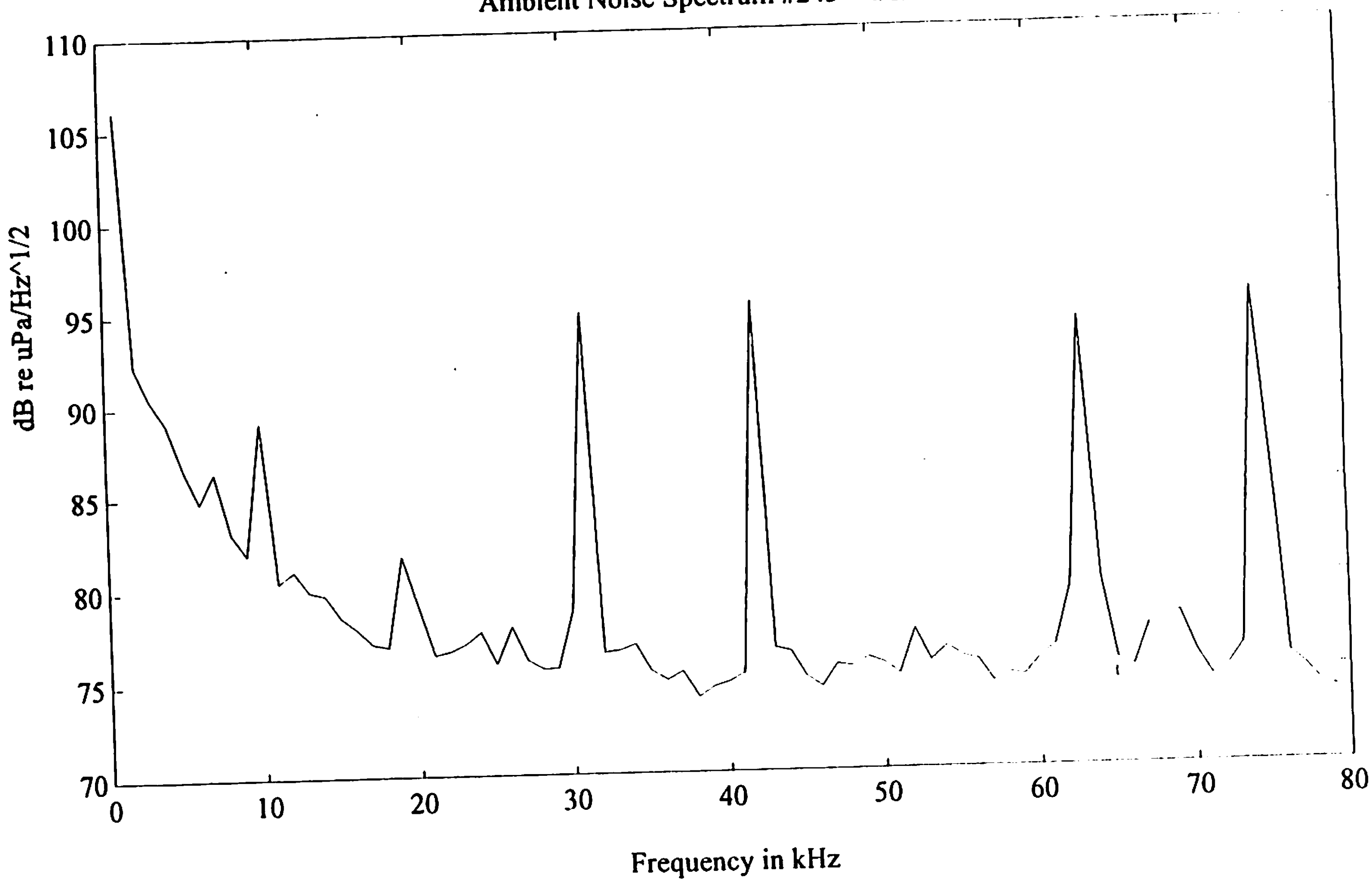
Ambient Noise Spectrum #242 - 4/8/93



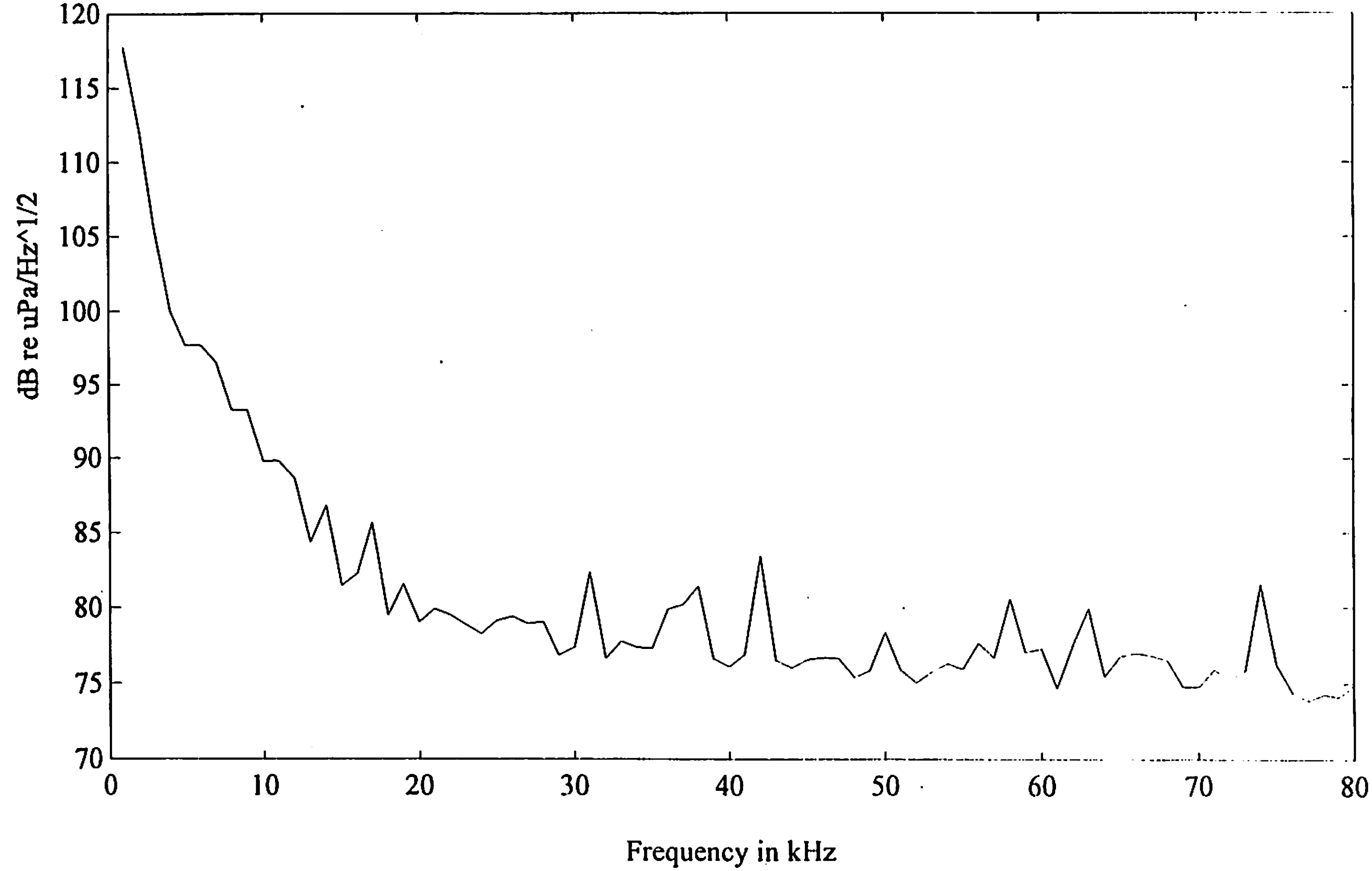

Ambient Noise Spectrum #243 - 4/8/93
dB re uPa/Hz^1/2
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency in kHz


Ambient Noise Spectrum #244 - 4/8/93
dB re uPa/Hz^1/2
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency in kHz

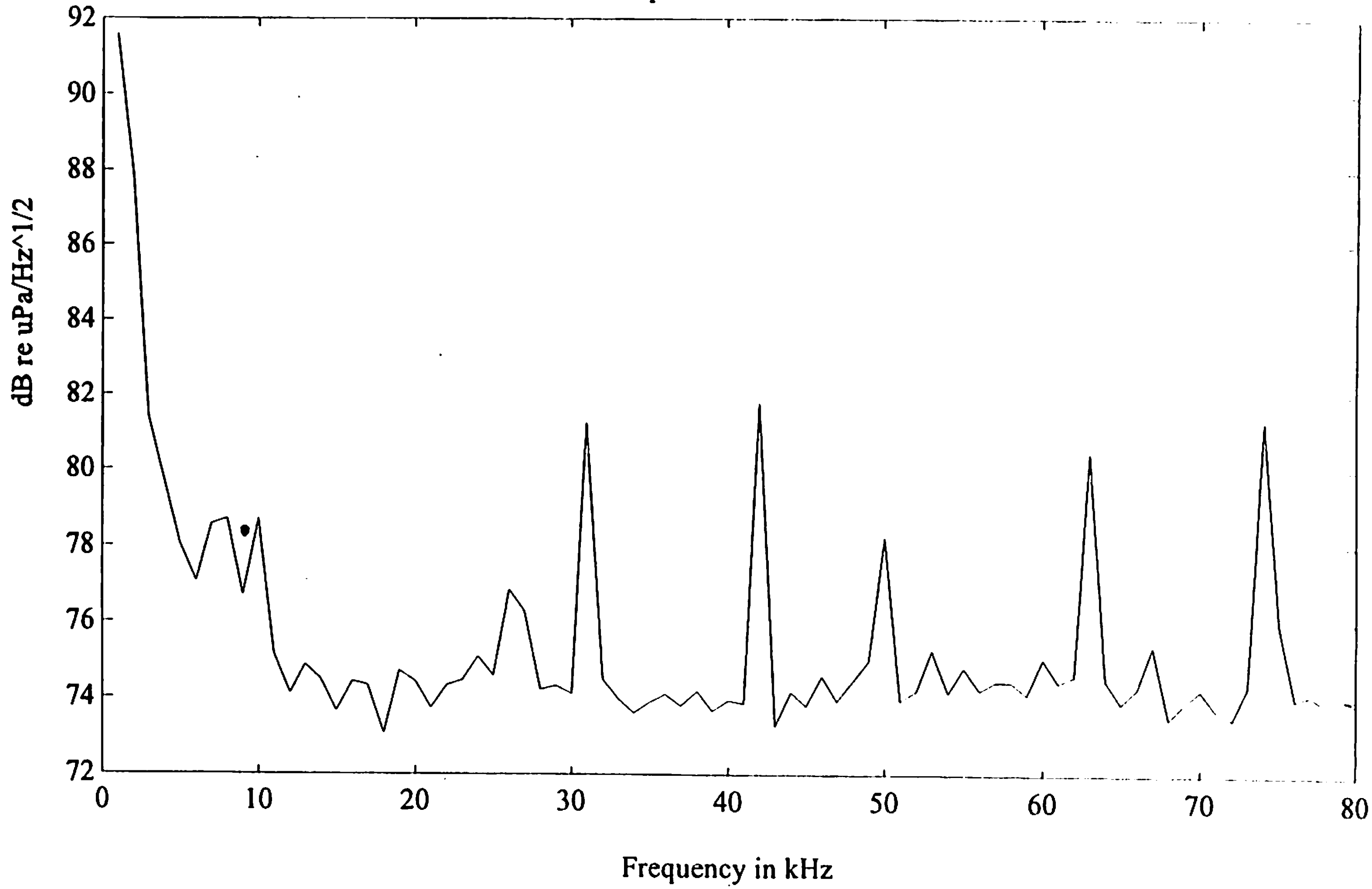
Ambient Noise Spectrum #245 - 4/8/93



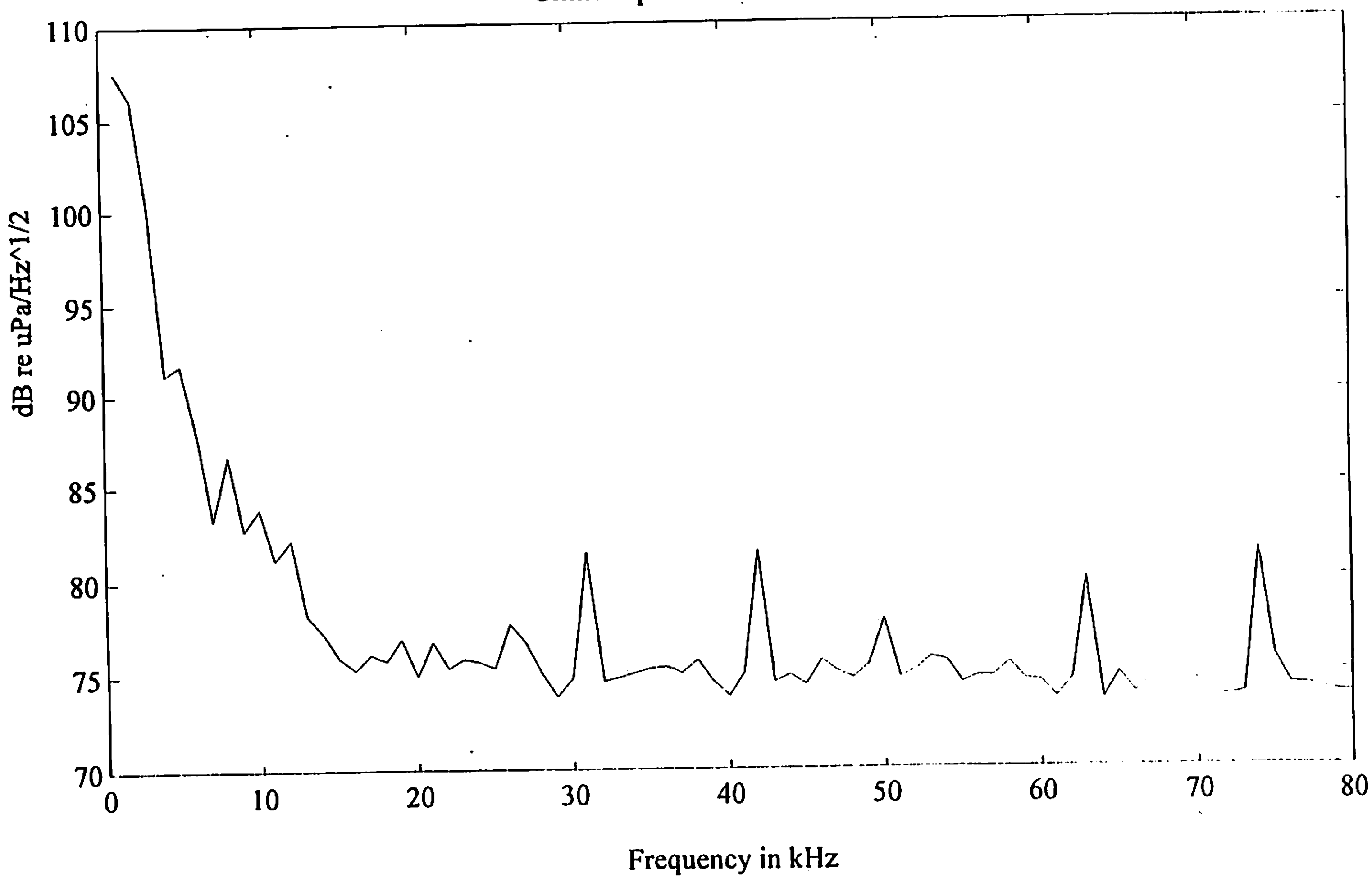
Gillnet Spectrum #251 - 4/8/93

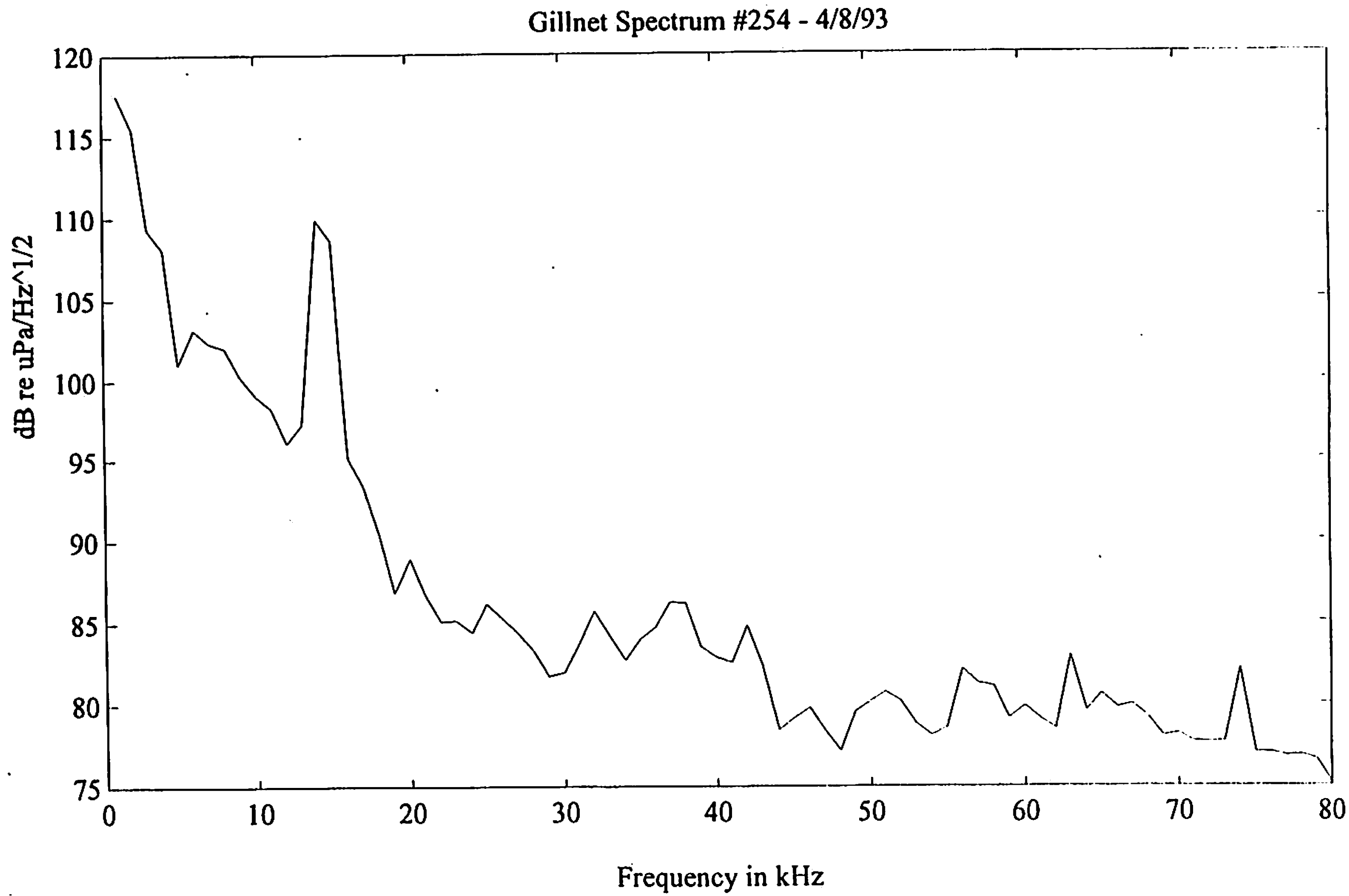


Gillnet Spectrum #252 - 4/8/93

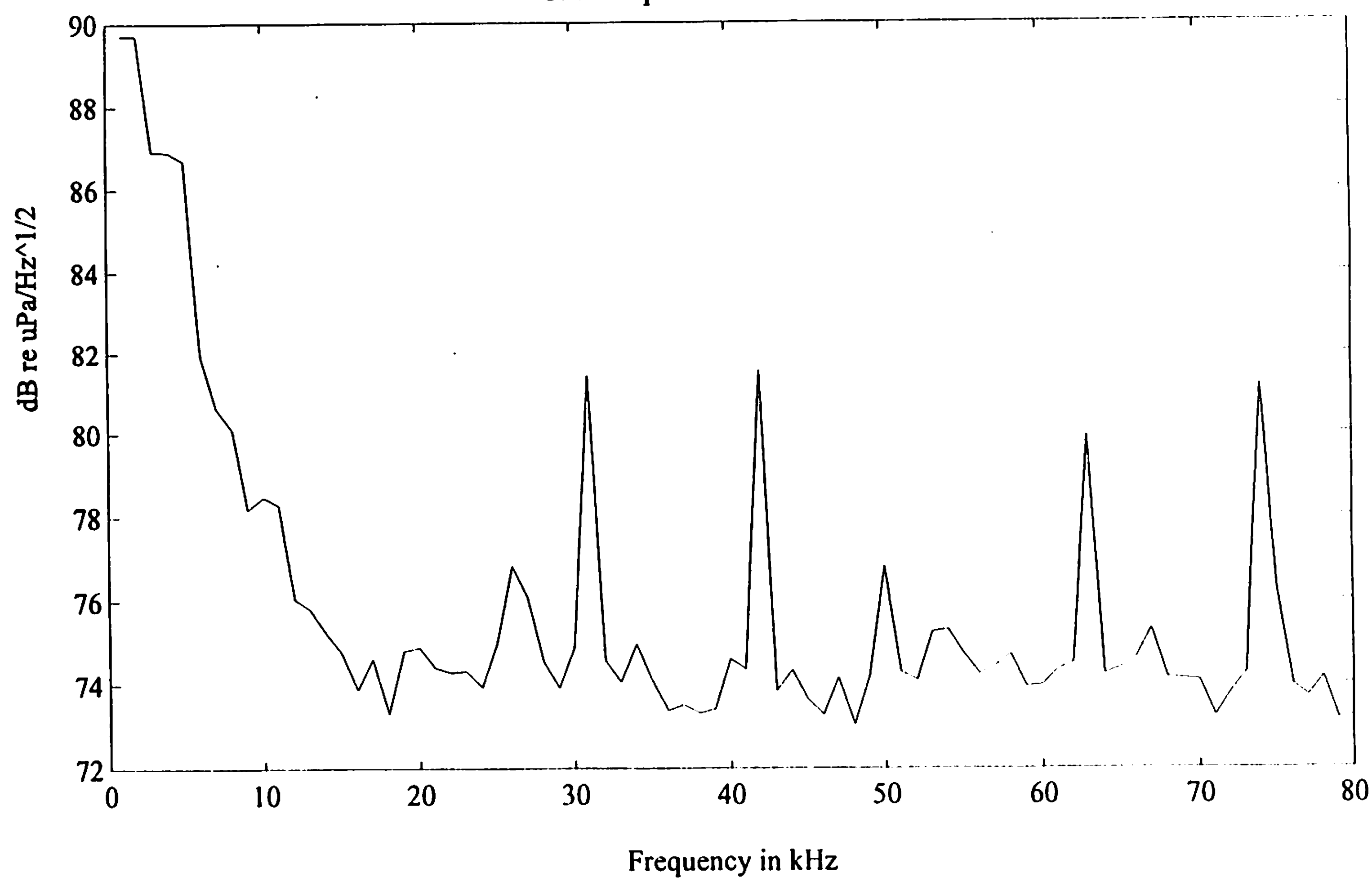


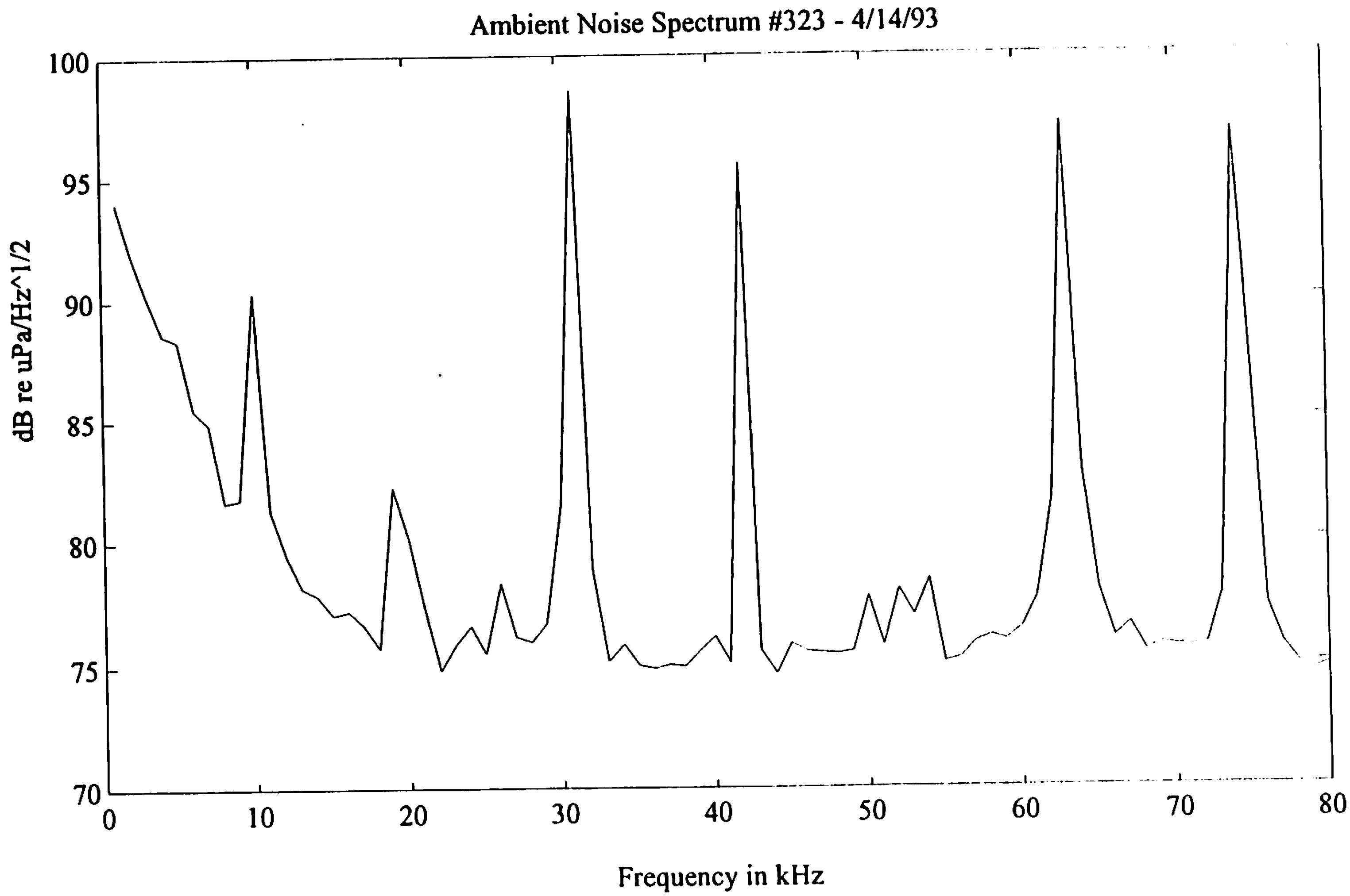
Gillnet Spectrum #253 - 4/8/93



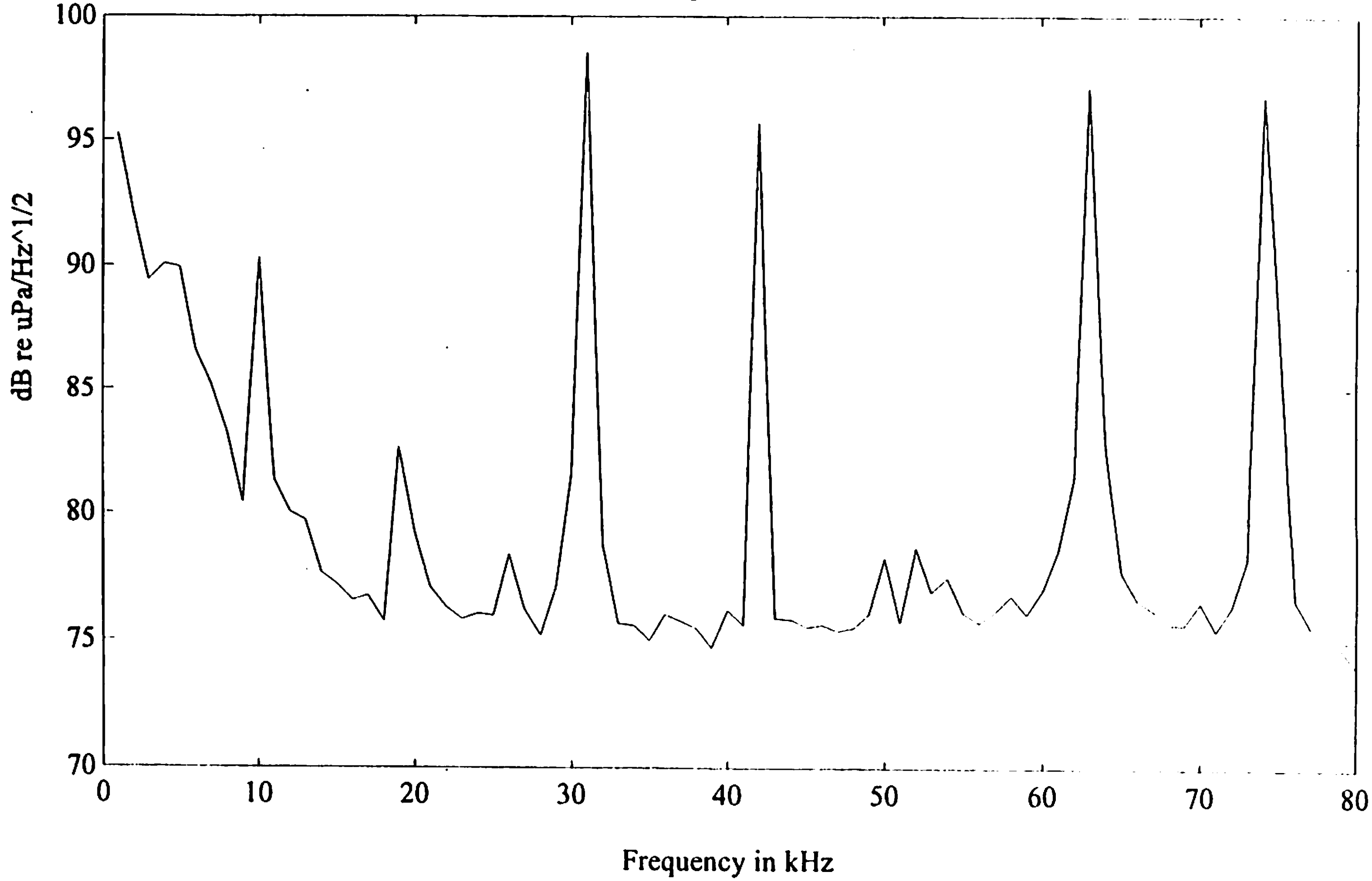

Gillnet Spectrum #254 - 4/8/93
dB re uPa/Hz^1/2
120
115
110
105
100
95
90
85
80
75
0
10
20
30
40
50
60
70
80
Frequency in kHz

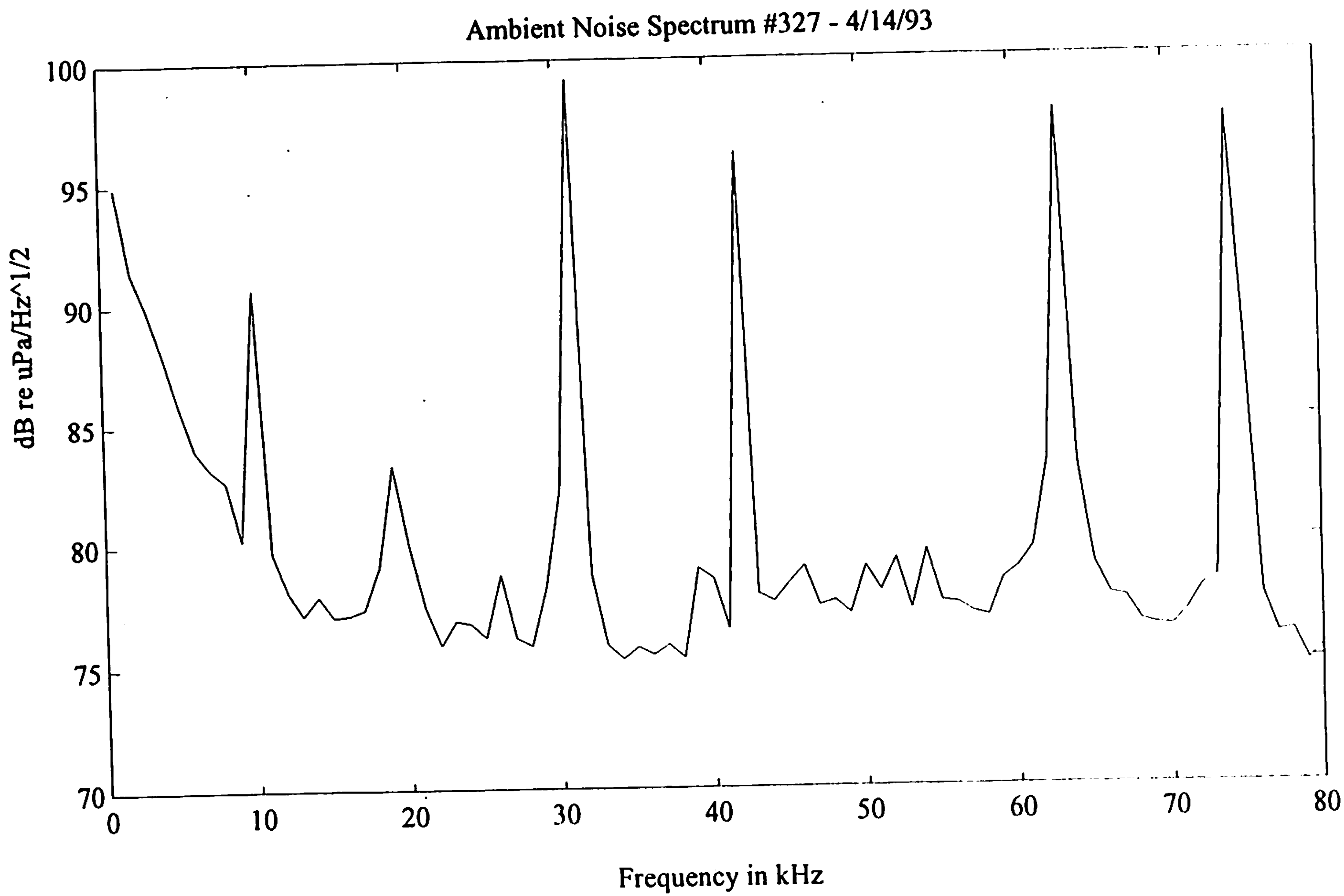
Gillnet Spectrum #255 - 4/8/93




Ambient Noise Spectrum #323 - 4/14/93
dB re uPa/Hz^1/2
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency in kHz

Ambient Noise Spectrum #324 - 4/14/93




Ambient Noise Spectrum #327 - 4/14/93
dB re uPa/Hz^1/2
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency in kHz