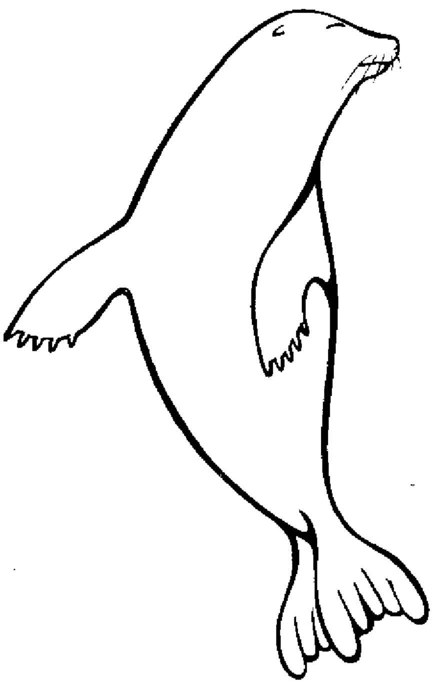
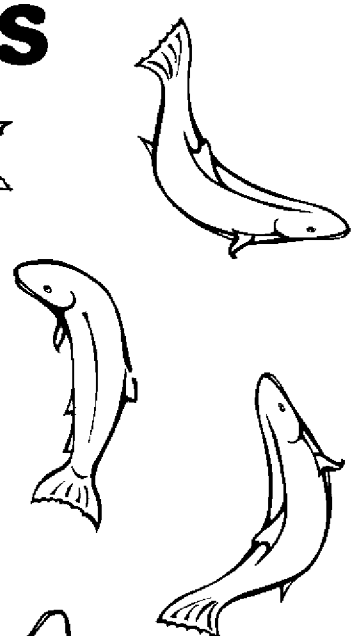


Acoustical Deterrents in Marine Mammal Conflicts with Fisheries



A Workshop Held
February 17-18, 1986
at Newport, Oregon

Bruce R. Mate and James T. Harvey, Editors

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Oregon State University
Sea Grant College Program
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Contents

Introduction

Bruce R. Mate and James T. Harvey
Oregon State Universtiy

Marine mammals have interacted with commercial and sport fisheries for decades (Townsend 1918). The conflicts with fisheries can be classified as direct and indirect types of interactions. Direct interactions involve the incidental mortality, injury, or disruption of marine mammals, together with the damage or loss of fishing gear and catch. Indirect interactions include marine mammal predation on fish resources away from the actual fishery. The concerns of many marine resource users and managers have prompted a number of workshops to review these problems (Mate 1980; Contos 1982; Montgomery 1986).

Incidental mortality of marine mammals is most serious for Stenella dolphins in the tuna purse seine fishery in the eastern tropical Pacific (Perrin 1969, 1970; Perrin and Oliver 1981); for Dall's porpoise in the gill net fishery in the North Pacific (Jones 1984); for harbor porpoise in the gill net fisheries off California and New England (Gilbert and Wynne 1985); for sea lions in trawl fisheries off Alaska (Loughlin and DeLong 1983; Loughlin et al. 1983; West 1983; Loughlin and Nelson 1986; Loughlin et al. 1986); and for fur seals in the purse seine fishery off South Africa (Shaugnessy and Payne 1979). California sea lions are also caught incidentally in the shark gill net fishery off California (DeMaster et al. 1982). Even baleen whales, such as humpback whales off Newfoundland, have fallen victim to net entanglement (Lien and Gray 1980). In some of these areas, the high level of mortality of marine mammals may have severely reduced the population.

In many troll and gill net fisheries, it is pinnipeds that are mainly responsible for damage to the gear and catch. Off the west coast of North America, harbor seals damage salmon catches in gill net fisheries in Alaska (Matkin and Fay 1980), Washington (Everitt and Beach 1982; Beach et al. 1985), and Oregon (Hirose 1977; Mate 1980). Sea lions have principally been involved in conflicts with troll fisheries off California (Briggs and Davis 1972; Miller et al. 1983; Hanan 1986). The damage or take of caught fish, as well as damage to gear, is one of the most controversial and dramatic conflicts of marine mammals with fisheries.

The indirect effects of marine mammal predation on fishery products involve interactions at aquaculture facilities and in rivers and the ocean. The marine mammals in these instances are considered competitors with humans. Pinnipeds, in particular, damage or consume valuable salmonids in natal streams (Hirose 1977; Everitt et al. 1981; Gearin et al. 1986) and the ocean (Fiscus 1980) and those returning to aquaculture facilities (Brown and Mate 1983). Other fishes of commercial importance, such as hake (Fiscus 1979) and halibut (Bell 1961), are eaten as well. Many other marine mammals may compete with man for limited marine resources (Brooks 1955; Costa 1978; Lowry 1982). Conversely, fisheries harvesting marine mammal prey species may limit marine mammal populations.

In the past, states have attempted to regulate specific pinniped populations by using bounties or by hiring a hunter (Lensink 1958; Pearson and Verts 1970; Johnson and Jeffries 1977). These actions decreased the number of pinnipeds, but did not often remove the specific individual pinnipeds which were interacting with fisheries. The Marine Mammal Protection Act (MMPA) of 1972, however, provided complete protection to all marine mammals with a few exceptions. In the context of marine mammal-fisheries conflicts, these exceptions were the return of management to states and the issuance of permits to fishermen for takng marine mammals incidental to commercial fishing operations. States can regain the authority to manage (including lethal taking) specific marine mammal populations if they can show reasonable evidence that the population is above the maximum net productivity (MNP) and if the effects of management will not reduce it below MNP. Only Alaska has attempted to obtain the return of management for some species of marine mammals, but differences in State and Federal regulations regarding the definition of a subsistence hunter prevented implementation. The required data would be difficult and expensive to procure for many states. The return of management strictly for the lethal taking of marine mammals to reduce fisheries would also be unpopular and would be opposed by many public interest groups. The inability to effectively regulate populations of marine mammals has led to many discussions regarding alternative solutions to the conflicts.

Possible solutions to the problem of incidental take of marine mammals and damage to gear and catch are (1) modifications of fishing gear, methods, or locations, (2) the use of systems designed to repel marine mammals from areas of fishing or to condition them to avoid these areas, and (3) removal of specific individual animals by capture and translocation or killing. Modification of methods and gear used in the tuna fishery have substantially reduced mortality of cetaceans in the eastern tropical Pacific (University of Oregon Law School 1977). Troll and gill net fisheries, however, have not been able to make any changes in gear or methods which have reduced the conflicts with pinnipeds. On the other hand, ocean drift gill net closures around areas of pinniped concentrations (e.g., San Miguel Island) have reduced California sea lion mortalities in California. It has become apparent that in many fisheries a small number of individuals are responsible for a larger portion of the interactions. Removing or repelling these individuals has proven difficult (S. J. Jeffries, personal communication). Since 1977, researchers have attempted to develop a system for repelling pinnipeds from specific fishing areas. Such a system would be an appropriate solution to the problem of seals taking fish from fishermen and to the incidental take of marine mammals by fisheries.

The production of underwater sounds, as warnings or irritants, has often been considered a promising method of repelling marine mammals. Most marine mammals have excellent hearing and live in a medium which efficiently transmits sound. At first, sounds of a predator (killer whales) where used to repel belugas (Fish and Vania 1971) and gray whales (Cummings and Thomson 1971). Without positive reinforcement (sighting a killer whale), however, the animals soon learned that no killer whales were in the area. Another choice was to develop a high-amplitude acoustic signal to repel marine mammals, either by disturbing them or by causing auditory pain.

Seal bombs (underwater explosives), which produce a flash of light and a high amplitude sound, have been used in some cases to successfully frighten pinnipeds from fishing activities. Cracker shells (airborne explosives) are shot from a shotgun, usually over the heads of pinnipeds in the water. Both explosives have been intermittently used in fisheries, with some degree of success. To use them, however, requires a person to continually interrupt his or her fishing activities or dedicate someone completely to the task of discharging explosives. The signal produced from these devices is also not well matched to the more sensitive portions of the range of pinniped hearing.

The increasing number of conflicts of pinnipeds with salmon gill net fisheries and aquaculture facilities in the Pacific Northwest and the lack of an adequate repellent provided the impetus for the development of a new underwater acoustic deterrent (Mate et al, in this volume). The use of an irritating or potentially harmful underwater, nonbiological signal was first attempted by by Anderson and Hawkins (1978), but the signal was unsuccessful in deterring seals. The use of high-frequency (greater than 2 kHz) sounds to repel marine mammals has the advantage of localized application, since they are attenuated more rapidly than low-frequency sounds and they may be targeted to individuals directly involved in conflicts with the fishery. In addition, the use of acoustical deterrents is at the whim of the operator and can be intermittent. These characteristics made this technique a logical choice to develop, even though earlier attempts by Anderson and Hawkins had not been successful. The result was an acoustical harassment device (AHD) which produced randomly spaced pulses of 12- to 17-kHz tones.

The papers in this volume were presented at a workshop to review the results of six years of experimentation and use of the AHD. The meeting brought together acousticians, aquaculturists, behaviorists, and biologists to evaluate the current state of acoustical harassment of marine mammals (see the list of participants in the appendix). The objectives of the workshop were to assess the effectiveness of the AHD, review other forms of acoustical harassment, recommend future research needs and possible modifications to the AHD, and review other techniques of marine mammal harassment.

The first two papers are a review of sound propagation in water by Greenlaw and Thomas. The third paper, by Mate et al., is a description of the AHD and the results of its first testing in laboratory and field settings. The subsequent papers are divided into research and applied uses of the AHD. Geiger and Jeffries report the results of three years of testing the AHD in Washington. Hanan and Scholl describe the use of the AHD and alternative forms of harassment in fisheries off California. Harvey et al. tested the use of the AHD as a barrier to seals entering an Oregon bay.

The AHD has been used at a number of aquaculture facilities along the west coast of North America. The results of the use of the AHD at the OreAqua facility in Newport, Oregon, and at the Anadromous facility in Coos Bay, Oregon, are presented by Rivinus and by Greenke and Vanslyke, respectively.

Awbrey and Thomas report on the acoustical testing of the sound propagation from the AHD, seal bombs, and cracker shells. Pryor, a behavioral biologist, discusses the factors involved in conditioning animals. And Greenlaw reviews the highlights of the workshop. Greenlaw's assessment of future application strategies should be especially noted by any future researchers. The use of conditioning stimuli and variable reinforcement schedules will reduce habituation by prolonging the effectiveness of negative reinforcements like the AHD and create anxiety for the animals. These effects may be compounded by using multiple AHDs in different locations. AHDs may best be used as operant conditioning tools to "train" (dissuade) nuisance animals from target areas in conjunction with other negative stimuli.

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Executive Summary

Many fisheries have been affected by interactions with marine mammals. Most studies of the conflicts of marine mammals and fisheries have concluded that a relatively small number of individuals are responsible for damage to gear and catch. Unfortunately, there have been no nonlethal methods which have successfully kept marine mammals from disturbing fishing operations. The detrimental activities of marine mammals with regard to fisheries occur in the water; therefore, acoustical forms of deterrence seem appropriate because sound transmits so efficiently in water. Furthermore, acoustical harassment is used only locally, targeting on only those individuals involved. Sounds, however, are affected by the frequency and amplitude of the signal, and the temperature, salinity, and depth of the water. Background noise, such as water turbulence, rain, or man-made noises, will affect the perceived sound levels of animals in the water. Bottom topography and the characteristics of the basin will also affect sound propagation, as will water surface reflections, bottom reflections, and the location of the subject relative to the sound source. All of these factors need to be evaluated in designing and using acoustical methods.

Acoustic Harassment Device (AHD)

The acoustic harassment device (AHD) was originally designed to harass harbor seals (*Phoca vitulina*) in fisheries of the Pacific Northwest. The AHD has a number of advantages over other methods of acoustical harassment. It avoids the uncertainties and hazards of using explosives, (e.g., cracker shells and seal bombs). The frequencies used (12 to 17 kHz) lie in the range of maximum sensitivity for pinnipeds. The signals embody those characteristics which seem unpleasant, being of relatively high amplitude, pulsed, and irregular. Finally, sounds from the AHD are not heard by fish, and therefore fish are not frightened; neither do these frequencies affect fish egg or sperm viability.

In most cases, the AHD has not appeared to be effective in disturbing Califonnia or Steller sea lions (*Zalophus californianus* and *Eumetopias jubatus*). In some cases the sea lions have been observed to be frightened initially, but within minutes return to the area. An AHD, used in Alaska near beluga whales, seemingly drove them from the area, and the effects lasted for days (L. Lowry, personal communication). In other areas cetaceans appeared to be unaffected by the sounds from an AHD.

The preliminary tests of the AHD with harbor seals were encouraging. The AHD significantly reduced the number of salmon damaged and increased the number of fish caught in a gill net test fishery for salmon in the Columbia River. The AHD also was used to successfully reduce the number of returning salmon eaten by seals at an experimental salmon hatchery. The AHD seemed to be effective out to about 100 m; thereafter, its effectiveness decreased. These same observations of the effectiveness of the AHD with harbor seals were recorded at two other aquaculture facilities in Oregon. In some of these locations, the AHD proved to be an economically efficient device, which was less labor intensive than alternative forms of harassment.

The effectiveness of the AHD, however, appeared to decline over the years. Eventually, the proportion of damaged salmon in the test fishery was greater when the AHD was operating than when it was off. Four years after the initial use of the AHD at the experimental hatchery, predation rates were equal for periods with and without the AHD in use. Commercial hatcheries also reported that greater numbers of seals appeared to be unaffected by the sounds produced from AHDs.

There are at least four possible reasons for this decline in the effectiveness of the AHD: (1) individual seals are deaf or have impaired hearing; (2) seals have become habituated to the sounds; (3) the AHD now serves as a conditioning reinforcer, signaling the seals where fish are being caught; and (4) the sounds produce only an initial startle response because sounds from the AHD are insufficient to cause pain.

Improvements in the AHD which would increase the perceived loudness are (1) increasing the power (e.g., by decreasing broad band frequencies, increasing the pulse length, or focusing the sound,) (2) increasing the number of sound sources and using them in a random schedule, and (3) building in a conditioning stimulus, such as a buzzer, which would be activated to train culprit animals before the AHD's pulsed signal was applied (on a random schedule) to prolong its effectiveness as a negative stiumlus.

The AHD has not proved to be an effective deterrent over long periods of use. Harbor seals are extremely wary animals, and the AHD may only serve to disrupt their normal activities until they become familiar with it. It has, however, been the most successful nonlethal method used to date in alleviating or lessening some marine mammal conflicts with fisheries.

Alternative Methods of Deterrence

Killer whale (Orcinus orca) sounds have been used to deter some marine mammals from fishing areas and activities. Some initial success has been reported, but the technique is not effective over the long term for several reasons: there is no reinforcement, some pinnipeds can differentiate between the actual killer whale sounds and recordings, and the killer whale sounds may also scare salmon. Killer whale sounds may be used effectively in small channels for short periods of time, but not in large estuaries or the ocean for prolonged periods. Coupling the sounds with the silhouettes of killer whales has not increased the effectiveness of this technique.

Cracker shells have been used to repel seals and sea lions. They are marginally successful in frightening animals for short periods of time (approximately 3-4 min.). Unless the animal has its head out of the water or is directly under the explosion, it may not hear the device or respond to it. Cracker shells also are somewhat dangerous and labor intensive.

Seal bombs, which explode 2-3 m underwater, produce a signal which is less than 2 kHz in frequency and approximately 190 dB at the source. They also generate some light when they explode. These explosives, like the cracker shells, have been used for years in certain fisheries. They also can be dangerous and somewhat labor intensive. Some evidence exists that seal bombs also scare salmon because the frequency produced is within the hearing range of fish.

The use of lights to deter pinnipeds and possibly to attract fish has been discussed. Flashing blue and green lights scare fish, while red and amber lights attract fish. The urge to migrate for fish, however, may override any deleterious effects of flashing lights. The disadvantages of this method are that light is poorly transmitted in most nearshore waters and estuaries and that the presence and location of the animal underwater needs to be known to activate the lights, unless the system runs continually.

Recently, there has been some interest in chemical deterrence. Tests of taste aversion have used lithium chloride (LiCl) which has been injected into fish. These dosed fish are then inadvertently taken by pinnipeds feeding on caught fish off sportfishing boats in California. This method has the advantages of being individual specific, nonlethal, and applied only occasionally. It may be coupled with an acoustic signal which would act as the conditioning stimulus. This method may be hazardous if fish dosed with LiCl are inadvertently consumed by humans. Taste aversion may not reduce the number of conflicts if the number of new pinnipeds arriving in the fishery is equal to the number being conditioned. This method may prove to be effective in reducing the incidences of predation only on line-caught fish.

Lethal means of removing individual marine mammals from interacting with fisheries may remain the most effective method in many cases. It is probably the most cost-effective. The potential for death is the strongest enforcer, and this has lead to pinnipeds being conditioned to activities of certain boats used by seal hunters. The use of a conditioning stimulus, such as a signal from an AHD, may strengthen the effectiveness of the periodic use of a gunshot. Lethal methods, however, have strong disadvantages, which include safety and public reaction.

Negative Conditioning

A great deal of time and money has been spent on assessing marine mammal-fishery interactions and devising possible solutions to the problem. The general consensus is that in some cases there may be little economic loss to the fishery and that in most cases a small number of marine mammals are involved in the conflicts. The solution is, therefore, to deal with these few individuals, if a cost and time-effective method can be devised. The individuals can be removed using lethal means. This is both permanent and sometimes the only method which is practical. Marine mammals, however, are also a source of concern for much of the public, and for this reason nonlethal methods were sought to alleviate conflicts. It has proven difficult to produce an effective nonlethal method of deterring marine mammals from fisheries because these animals are highly intelligent, mobile, and difficult to observe. It has become obvious that with all the nonlethal methods used, the animals become habituated to or tolerant of the deterrent, rendering the method ineffective. Keeping the negative stimulus effective is the main challenge, and effectively administered behavioral conditioning is the most likely solution.

Behavioral conditioning makes use of either positive or negative reinforcement. Positive reinforcement would not be useful in this case, because there is nothing the marine mammal wants more than the fish. A negative reinforcement is needed to alter the marine mammal's behavior in taking caught fish. Perhaps the most powerful form of negative reinforcement involves the use of a variable schedule, conditioning stimulus. A conditioning stimulus (i.e., threat) is presented, which is sometimes followed by a negative stimulus (e.g., pain). The animal learns to associate the conditioning stimulus with the negative stimulus.

In the case of taste aversion, the conection between conditioned and negative stimuli is stronger if the time between ingestion of the food and illness is short, if the illness is severe, and if the food is exotic. Variable scheduling may be more effective because the animals will have less exposure to the negative stimulus and therefore less time to become habituated. The effectiveness of the conditioned response can be tested by measuring the time between the conditioning and administration of negative stimuli. As the animals associate the conditioning stimulus with the negative stimulus, they will become more sensitized to the conditioning.

The use of behavioral conditioning is just now being applied to marine mammal conflicts with fisheries. Coupling an auditory signal with a negative stimulus (e.g., acoustical pulse, LiCl in fish) may keep the negative stimulus novel, reduce habituation, and successfully deter most individual marine mammal conflicts.

Psychoacoustics and Pinnipeds

Charles F. Greenlaw, CMI-Cascade, Philomath, Oregon

Early in the development of acoustic aversion techniques for seals, it was thought that the sounds produced might be painful to the animal and thus induce it to remove to some "effective" distance from the sound source. The effective range of the unit would then be adjustable by changing the output level. This opinion is not uncommon among users even today. The purpose of this note is to discuss the concept of loudness versus sound intensity and to suggest that it is very unlikely that pain reactions are responsible for the success of acoustic aversion. In doing so, I hope to offer some insight into potential causes of failure when acoustic aversion is not successful.

Part I: Estimates of Hearing Thresholds

A voluminous body of experimental data exists on the human ear. Numerous measurements permit the establishment of "average" characteristics of human hearing such as thresholds of audibility, thresholds of pain, and critical bands. The sum total of equivalent data for pinnipeds appears to be measurements (often on a single animal) of the threshold of audibility as a function of frequency.

Pinniped ears are basically terrestrial ears, only partly adapted to water (compared, say, to odontocete cetacean ears). They are similar in structure to human ears although the frequency range is slightly different. For the purposes of this analysis I shall assume that pinniped ears are substantially identical to human ears. This assumption is not critical to the analysis; I have estimated only plausible bounds here and I make no pretense of absolute accuracy. The major reason for assuming similarity is to permit extrapolation from the vast body of pyschoacoustical research on human ears.

To begin, it is worthwhile to understand the relationships among acoustic variables and the medium that carries sound waves. Most acoustic sensors measure pressure, converting pressure changes in the medium to voltage changes that may be displayed or recorded. It is also possible to design acoustic sensors that respond to the motion of water particles (e.g., the lateral line system of fishes) or to the intensity of the sound (e.g., the Rayleigh disk). Pressure, particle motion amplitude, and intensity are all possible descriptors of sound waves. They are related to each other as follows:

$$P = \rho c \omega A$$
$$I = P^2/\rho c$$

where P is pressure, A is particle motion amplitude, I is intensity, ρ is the density of the medium, c is sound speed in the medium, and ω is 2π times the frequency of the sound. If A is in meters, ρ in kg/m^3, and c in m/sec, then P is in units of Pascals ($Newtons/m^2$) and I is in units of $watts/m^2$. The plethora of units used in acoustics is confusing; I will attempt to remain consistent in the use of these units here.

The common unit for pressure in underwater sound is the μPa (micro-Pascal or 10^{-6} Pascals). Because of the wide range of sound pressures found in acoustics, a logarithmic scale (decibels, or dB) is generally employed. The level of a sound is defined as

$$L = 20 \text{ Log } (P/Po)$$
$$= 10 \text{ Log } (I/Io)$$

where Po is the reference pressure (1 μPa) and Io is a reference intensity. Logarithms to the base 10 are used. The pressure level corresponding to a pressure of 20 μPa would be expressed as +26 dB//μPa, where the // means "referred to" and the reference pressure is stated as 1 μPa. The reference intensity in air is commonly taken as 10^{-12} W/m^2; in water the reference intensity is usually taken as the intensity of a 1 μPa pressure sound, approximately 6.7×10^{-19} W/m^2. Intensity is seldom used explicitly in underwater acoustics.

The decibel is a convenient measure for another reason as well. It happens that 1 dB is just about the minimum detectable difference for pure tones in humans. That is, humans can fairly reliably determine that one tone is louder than another tone of the same frequency if the louder tone is about 1 dB greater in intensity. This level-discrimination threshold is termed a "just noticable difference," or JND.

It is important to note the effect of the medium on the properties of the sound. For example, the product ρc in air is 415 rayls while the corresponding value in water is 1,500,000 rayls. Thus a given pressure produces a sound of much higher intensity in air than in water. The particle motion in air is nearly 4000 times that of a sound of equal pressure in water.

Measurements of human hearing in air have shown that the maximum sensitivity to sounds occurs in the frequency range of 1-6 kHz. Within this frequency range, sounds as faint as 20 μPa pressure are just audible. The intensity of this sound is about 10^{-12} W/m^2 and the particle motion is about 10^{-11} m. At very low and very high frequencies, this threshold of audibility increases by several orders of magnitude. For example, the minimum detectable sound intensity at 50 Hz is nearly a million times as great as it is at 3000 Hz. At the most sensitive frequency, the minimum detectable sound is very close to the sound levels produced by thermal agitation of air molecules.

The sound levels that cause pain (this definition is clearly subjective) tend not to be strongly influenced by frequency; the threshold of pain is about 20×10^6 μPa over the entire frequency range of the ear. The corresponding sound intensity is about 1 W/m^2 and the particle motion amplitude is ca. 10^{-5} m. Damage to the ear occurs at sound intensities of about 10,000 w/m^2.

The levels given above refer to sound field properties impinging upon the outside of the ear. Levels at the eardrum can be as much as 20 dB higher because of resonance in the ear canal. The ear canal forms a closed tube with the eardrum at one end and the sound source at the open end. Resonance in the ear canal produces a broad resonance centered at about 6 kHz in air. This resonance phenomenon amplifies the sound intensity (pressure, amplitude) at the eardrum. When the human ear is submerged in water, the resonance of the ear canal occurs at around 13-14 kHz. The resonant gain may partially offset the loss in response at these frequencies.

Thresholds of audibility have been measured for divers submerged in water but these data are not readily available. For present purposes, it is instructive to estimate these values from the accepted standard values in air. It will also provide some insight into which descriptor of sound is pertinent to terrestrial ears.

If the ear responds to pressure, then the only difference between the thresholds of audibility in air and water would be the effects of ear canal resonance. Resonance would still occur, but at a frequency of about 13-14 kHz, where the threshold of audibility is much higher than at lower frequencies. Thus we would expect the threshold of audibility in water to be about 10-20 dB higher than in air, ca. 63-200 μPa or +36-46 dB//μPa at 1000 Hz. Mechanical mismatch effects between the eardrum and the water could raise this threshold even higher. Ambient noise at 1000 Hz is about +62 dB//μPa (in one "critical bandwidth"). The difference between the ambient noise level and this (presumed) threshold of audibility is about equal to the average noise level in a quiet office.

If the ear responds to intensity, then the threshold of audibility in water corresponding to 10^{-12} W/m^2 would be a pressure level of +72 dB//μPa. This is a plausible conservative estimate.

If the ear responds to particle motion amplitude, then the pressure level corresponding to 10^{-11} m is +109 dB//μPa. The intensity of this sound would be about 6×10^{-9} W/m^2. This is probably an upper limit estimate.

Measurements of pinnipeds suggests maximal sensitivities on the order of +65 dB//μPa for seals and about +80 dB//μPa for sea lions. The values for sea lions are consistent with the estimate for humans above, assuming intensity to be the relevant parameter, suggesting a close similarity with human ears. Seals appear to have ears better adapted to underwater hearing and are some 15 dB more sensitive to faint sounds.

Humans

Now, if we assume that the threshold of pain is still about +120 dB above the threshold of audibility, then we can estimate the lower bound for this threshold, in water, to be approximately +192 dB//μPa. Recall that the threshold of damage is perhaps 40 dB higher still.

This lower-bound estimate of the threshold of pain is comparable to the output of an acoustic aversion device operating at about 100-200 watts (electrical) power. Close to the transducer, then, it would seem possible to induce pain in a human.

Seals

If the threshold of pain for seals is about +120 dB above the threshold of audibility, as in humans, then pressure levels greater than about +185 dB//μPa should cause pain. These levels would be found about 2 m away from an AHD transducer operating at 100-200 watts.

Sea Lions

With the same assumptions, we can estimate the threshold of pain for sea lions at about +200 dB//μPa. These levels are not produced by most AHDs, at any range.

Part II. Generating Intense Sounds in Water

Our estimates of the sound levels required to create "pain" sensations in seals, humans, and sea lions are

seals	+185 dB//μPa
humans	+192 dB//μPa
sea lions	+200 dB//μPa

It would be interesting to estimate the sort of acoustic system that would be required to generate these levels at some useful distance.

The following equation allows calculation of the sound level, L, at a range R from the transducer driven by W watts of electrical power--

$$L = 170.7 + 10 \text{ Log } (\eta W) + DI - 20 \text{ Log } (R) \quad dB//\mu Pa$$

The transducer efficiency, η, is typically about 50%. DI is the directivity index of the transducer, the gain (in dB) of the transducer relative to an omnidirectional point source. The term -20 Log (R) expresses the loss in sound intensity due to spherical spreading of the sound wave as it travels outward from the transducer. In shallow water, this factor may depart significantly from this. Reflections from the surface can add in or out of phase with the direct-path signal, producing a doubling of intensity in some regions and total cancellation of the signal in others. This effect is largely out of the user's control.

For the sake of illustration, let us suppose we wish to inflict pain on an animal at a range of 10 m using a nondirectional transducer. The equation above can be simplified to

$$L = 150.7 + 10 \text{ Log } (\eta W)$$

Causing "pain" to a seal requires a level of about +185 dB//μPa. Solving for W, we estimate needing a power amplifier producing about 5400 watts electrical power. The corresponding estimate for causing pain in sea lions is $W \approx 170{,}000$ watts! These levels can be obtained with explosive sources but are not practical with electronic apparatus.

As an alternative to driving a transducer with very high power levels, we can use a transducer with "gain" (DI>0). For example, a long and thin cylindrical transducer could be fabricated to give a value for DI of about 7 dB. This would reduce the input power requirements to about 1000 watts for seals or about 34 Kwatts for sea lions. These values are somewhat more reasonable. Note, however, that these levels would occur only on the plane intersecting the transducer, normal to the axis of the cylinder. At angles off this plane, the levels would be substantially lower.

A piston-shaped transducer could be used to reduce the power requirements even further at the expense of creating a spotlight-like beam of intense sound. Levels away from this "spot" would be much lower.

Part III: Other Considerations

Research on human hearing has produced other results than may be of use in designing acoustic aversion techniques for pinnipeds. While not likely to be precisely applicable, the similarity of the ear between pinnipeds and humans and roughly similar results in discrimination tests suggest that data from human hearing should provide a useful guide for pinnipeds as well.

Research has found that the subjective loudness of a tone depends upon the duration of the tone as well as its intensity. The apparent loudness of a sound increases as the duration of the tone increases, up to about one second. Thus, short tones are not perceived as being as loud as longer tones of the same intensity. This effect seems to be more pronounced at higher intensities. The structure of the ear does not provide a basis for this effect, so it is assumed that this effect is due to neural processing effects in the auditory system.

In addition, the perceived loudness of a sound depends rather strongly on the frequency composition of the sound. For example, a sound made up of several tones at different frequencies can appear to be louder than one would expect from the sum of the individual tone intensities. This increase in perceived loudness can exceed 10 dB. Note that a sound made up of several tones is not the same as a sound with variable frequency content. A sound that varies in frequency still excites single regions of the basilar membrane at any given instant, and so no summation of intensities occurs. This is not to say that frequency variations might not have a psychological effect worth incorporating.

Part IV: Conclusions

The foregoing analysis suggests that acoustic aversion devices do not, in general, rely upon a pain response to avert pinnipeds. Actual sound levels in the water may approach levels of discomfort, certainly, but probably do not cause actual pain. These results also cast some doubt on any physiological basis for aversion; it seems reasonably likely that aversion results from psychological distress rather than physical distress. And though it is commonly believed that "doubling the power output" would markedly increase the effectiveness of an AAD (acoustic aversion device), this would have the effect of increasing the sound levels by only 3 dB. Since 1 dB is a just noticeable difference, 3 dB is not a marked increase in perceived loudness.

Results from human hearing research suggest that several design choices are available to increase the apparent loudness of the sounds produced by AHDs. Pulse lengths ought to be on the order of .5 second or more in order to eliminate the possibility of a duration-dependent perceived intensity effect. Some AHDs in the field use pulse lengths of .02 second. Modifying these units to produce longer pulses might improve their performance. Extrapolating from human hearing, this would be equivalent to an increase of over 20 dB in sound output in terms of perceived loudness.

It is also possible, in principle, to generate sounds consisting of several frequencies from a single transducer. A linear power amplifier would probably be required, however, substantially increasing the complexity of the design. A simpler alternative might be to drive several different transducers simultaneously at different frequencies. It should be noted that the major effect to be expected from this strategy would be the psychoacoustical increase in perceived loudness; the actual intensity would increase only as 10 Log (# of transducers) for equal-output systems. Two transducers would provide only 3 dB of actual intensity increase.

Factors That May Affect Sound Propagation from Acoustic Harassment Devices

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Pinnipeds cause considerable damage or loss to the catch in the gill net fisheries and the partyboat fishery and also take fish near traditional spawning sites, aquaculture operations, and fish hatcheries. Explosive devices, such as seal control bombs and cracker shells, have been used in attempts to deter pinnipeds from interfering with human fishing activities. Recently, a device that projects pulsed sounds at 12 kHz and 17 kHz has been used to frighten seals from fishing activities.

There are several factors governing the transmission of sound in water that a biologist should know when using acoustic harassment devices in an attempt to control the movements of pinnipeds around fishing activities. The following discussion summarizes some facts about transmission of underwater sounds and points out how this information may affect the use of acoustic harassment devices around marine mammals.

Regardless of whether a sound is transmitted in air or water, its frequency, or wavelength, affects attenuation. High-frequency sounds (or sounds with short wavelengths) are attenuated more quickly than low-frequency sounds. The source level (or amplitude at 1 m) affects attenuation. High-amplitude sounds propagate over longer distances.

Sound in water travels about 4.5 times faster than in air. The velocity of sound in water is calculated using this equation (Albers 1965):

$$c = 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 + (1.34 - 0.010T)(S-35) + 0.16z$$

where: c = speed (m/s)
T = temperature (degrees C)
S = salinity (parts per thousand)
z = depth (m)

Of the three factors affecting the velocity of sound in water (T, S, and z), temperature and depth probably have the most pronounced influence. Figures 1a and 1b (taken from Warren 1970) show the manner in which temperature changes with depth (top graph) and salinity changes with depth (lower graph) on a given day at the same locations. Researchers using underwater acoustic projectors should know the thermocline, salinity profile, and bottom profile at the site of projection. These factors may influence the propagation of the sound. In situations where any of these variables are changing, the propagation characteristics of the projected sound may vary. For example, if sounds are projected in a river where tidal fluctuations change the water depth, the projected sound field may vary with the tide. If sounds are projected at the mouth of a river flowing into the ocean, freshwater infusion may cause sound to channel in an unpredictable manner. If temperature stratification changes in a daily or seasonal manner, so may the propagation of the projected sound. Figure 2 (taken from Albers 1965) shows daily variation in the mean water temperature at varying depths at a given site. This figure illustrates that the thermocline can vary substantially throughout a 24-hour period. When acoustic harassment devices are used on a long-term basis, periodic checks of the underwater ambient environment should be made in order to interpret the results.

The ocean is a dynamic medium; several factors affect the medium and, thus, the attenuation of sound. Figure 3 (taken from Albers 1965) illustrates several factors that may affect the ambient noise level. Background noise increases with increasing sea state (figure 3a). Rain increases the ambient noise level under water (figure 3b). Various sources of man-made noise (figure 3c) increase the underwater ambient noise level. Combinations of wind, weather, and sea state produce an increased background noise level (figure 3d). In addition, biological sources of background noise, such as snapping shrimp, soniferous fish, or marine mammals, may add significant noise to the underwater environment. Scientists who use acoustic harassment devices should be aware that changes in any of these conditions may mask a projected sound and thus affect its propagation. For example, the attenuation of an acoustic harassment sound may vary greatly between a calm, clear day and a windy, rough, rainy day. If a salmon ladder is located near a spillway, there is probably a high ambient noise level in this area caused by increased water turbulance. This noise may mask any type of acoustic harassment device used at this site. Fisheries operations that are conducted from boats may project significant noise into the water from normal operation procedures onboard the boat (e.g., noise from engines, generators, refrigerators, hydraulics). Any change in operations onboard the boat will probably produce a different kind of noise field.

Because of these characteristics of sound underwater, a particular acoustic harassment device may not perform the same in different underwater environments. To adequately interpret whether an acoustic harassment device is effective in deterring a pinniped from interfering with a fishing activity, the researcher must monitor the propagation of the sound (or received level at the target animal) at any given time. Changes in the animal's response to the device may simply reflect a change in perceived level by the animal.

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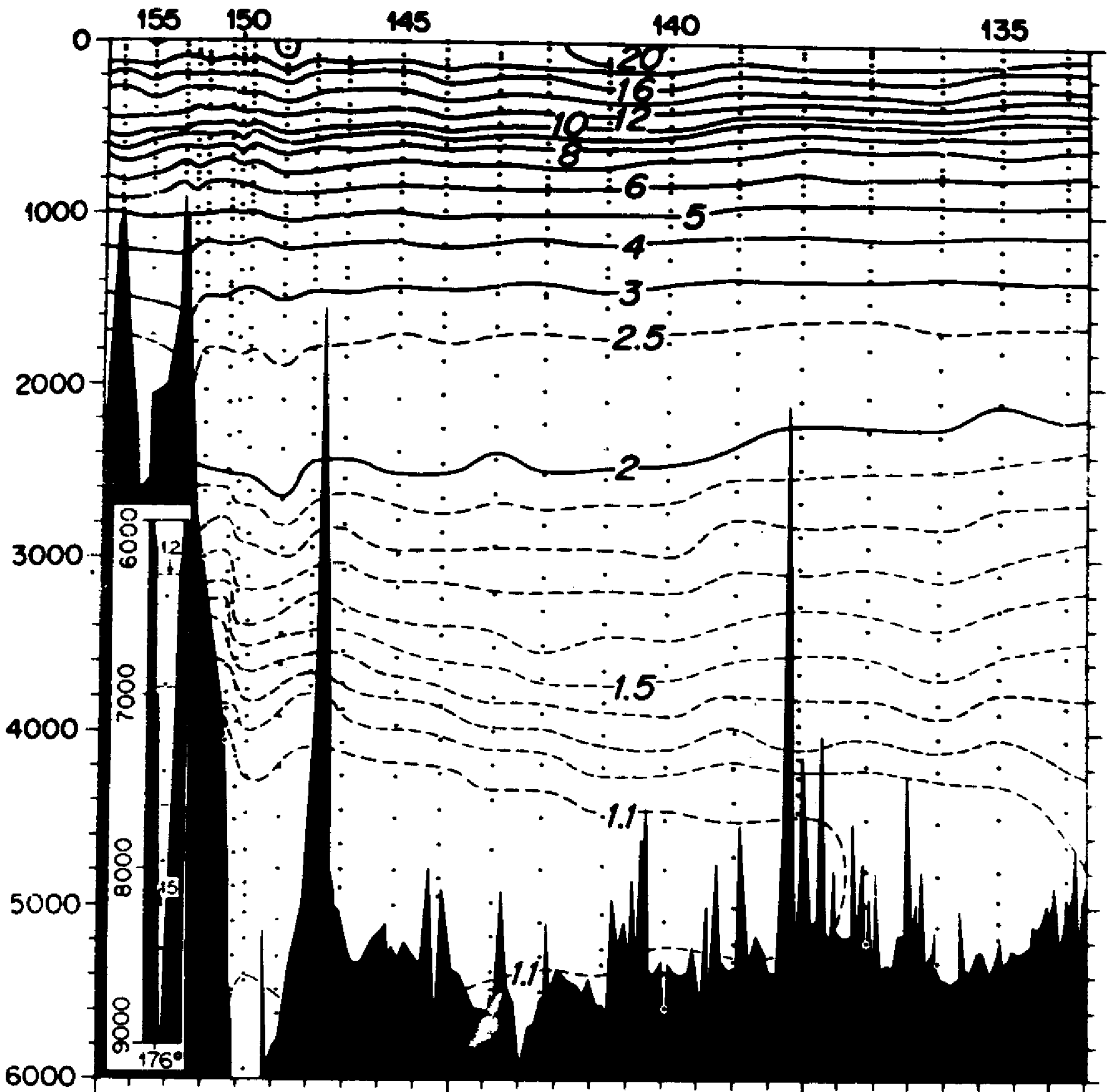


Figure 1a. Profile of temperature (°C) along 28°S near western boundary of deep South Pacific, depths in meters. July 3-18, 1967. Tonga-Kermadec Trench continued in inset. Reprinted from Warren (1970), with permission of the National Academy of Sciences, Washington, D.C.

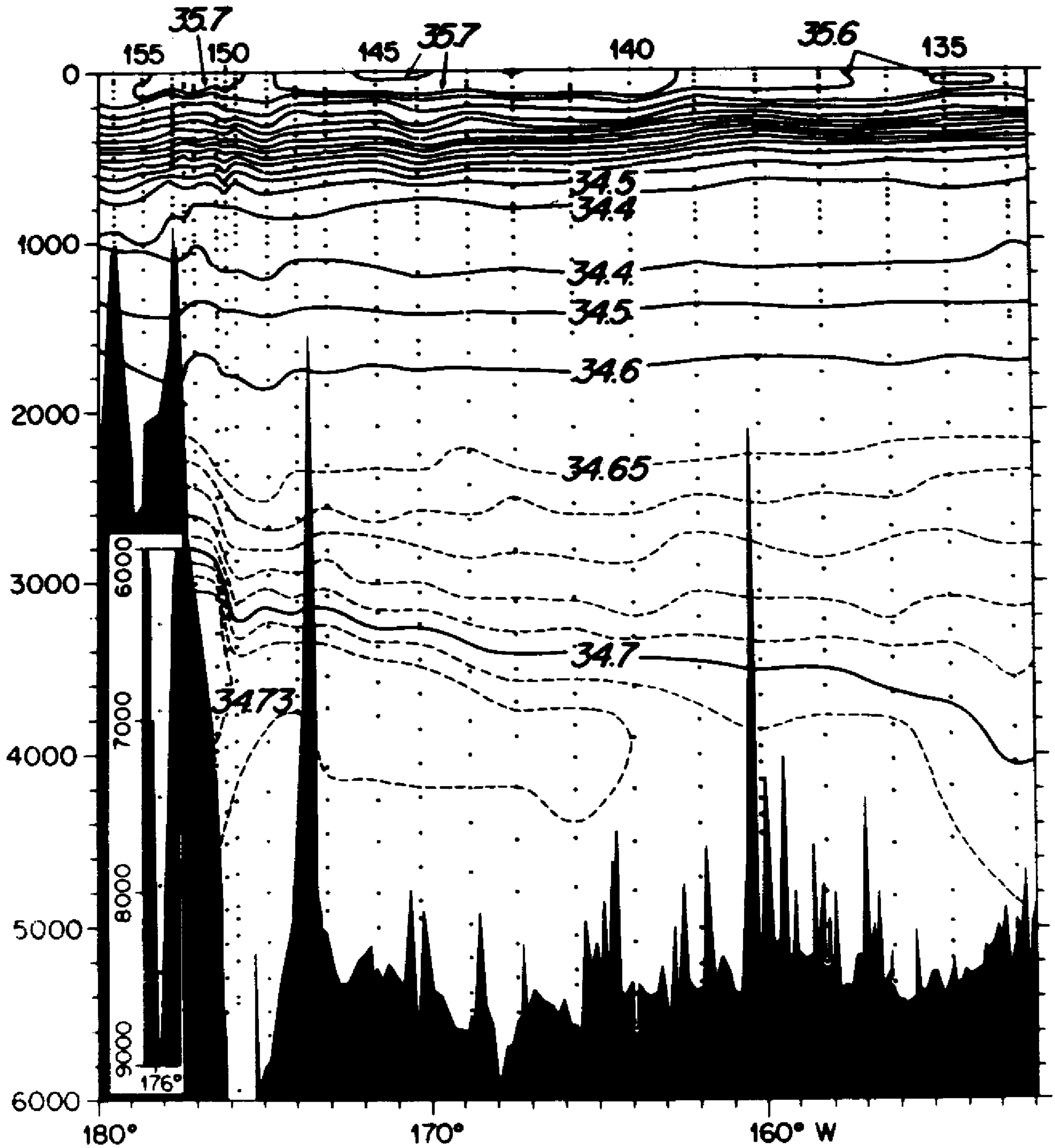


Figure 1b. Profile of salinity (‰) along 28° near western boundary of deep South Pacific, depths in meters. July 3-18, 1967. Tonga-Kermadec Trench continued in inset. Reprinted from Warren (1970), with permission of the National Academy of Sciences, Washington, D.C.

Intensity Fluctuations

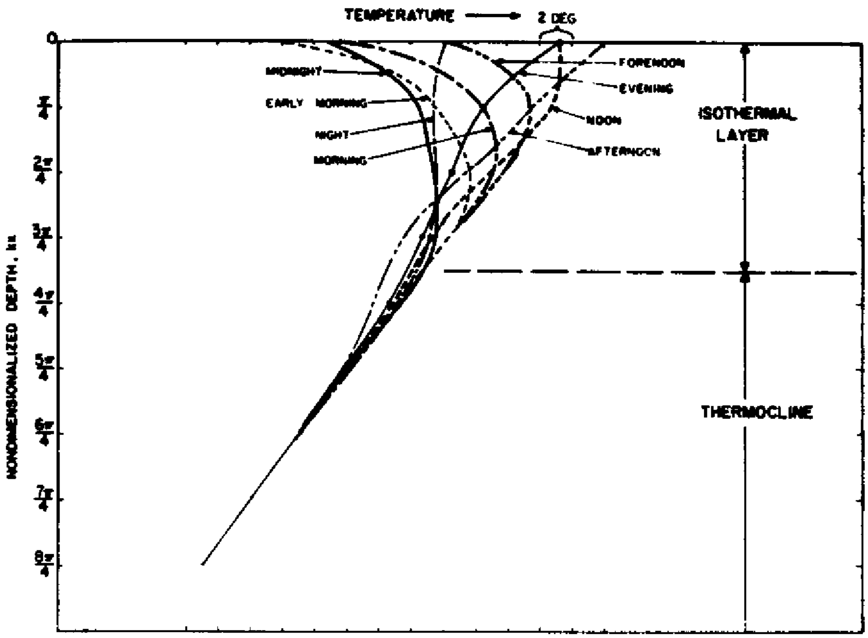


Fig. 5.1—Computed daily variations of the mean temperature of the sea.

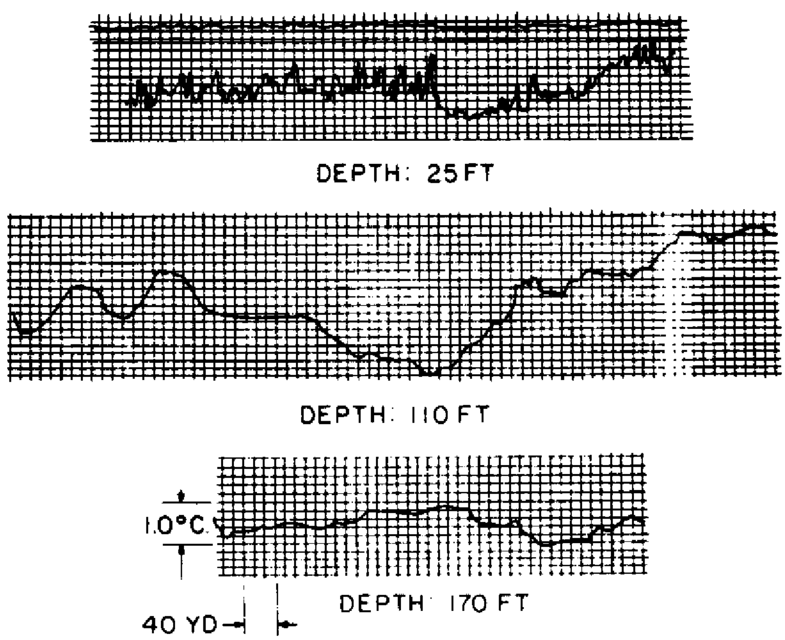
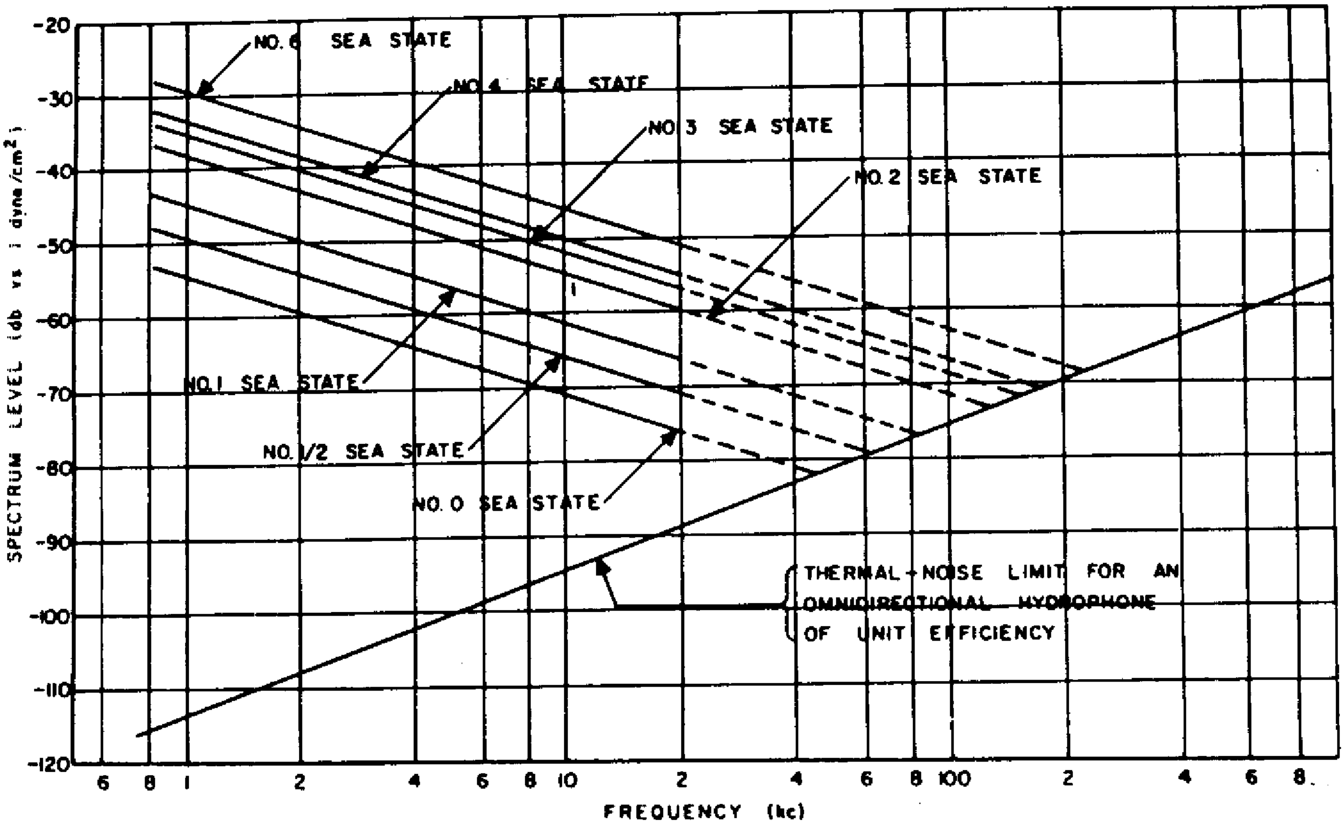


Figure 2. Example of the daily variation in mean water temperature. Reprinted from Albers (1965) with permission of The Pennsylvania State University Press, University Park, Pennsylvania.

3a



3b

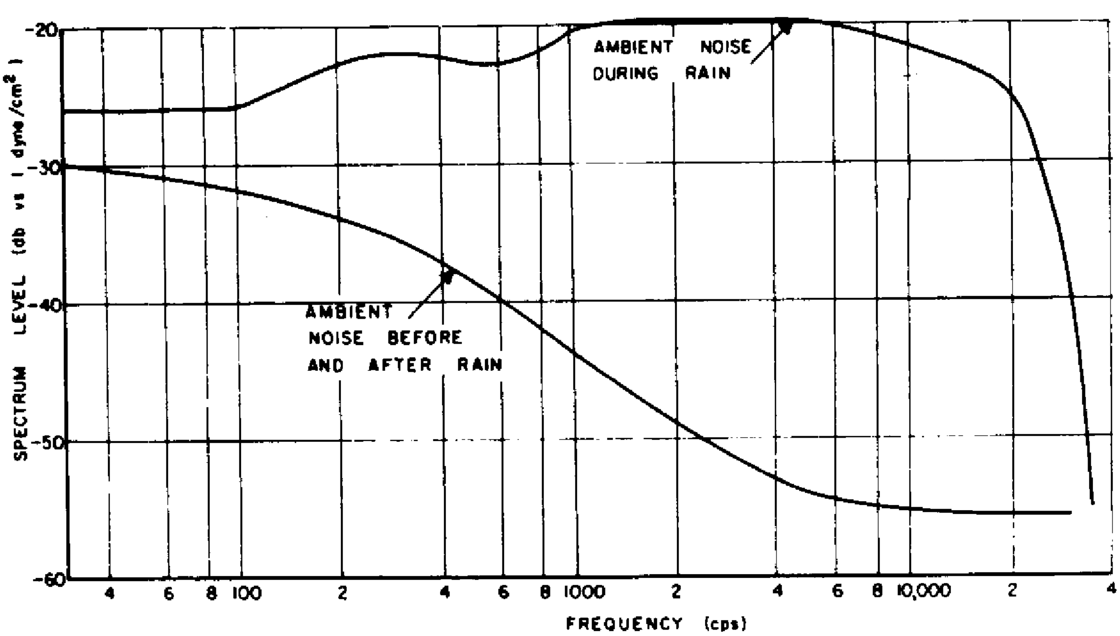
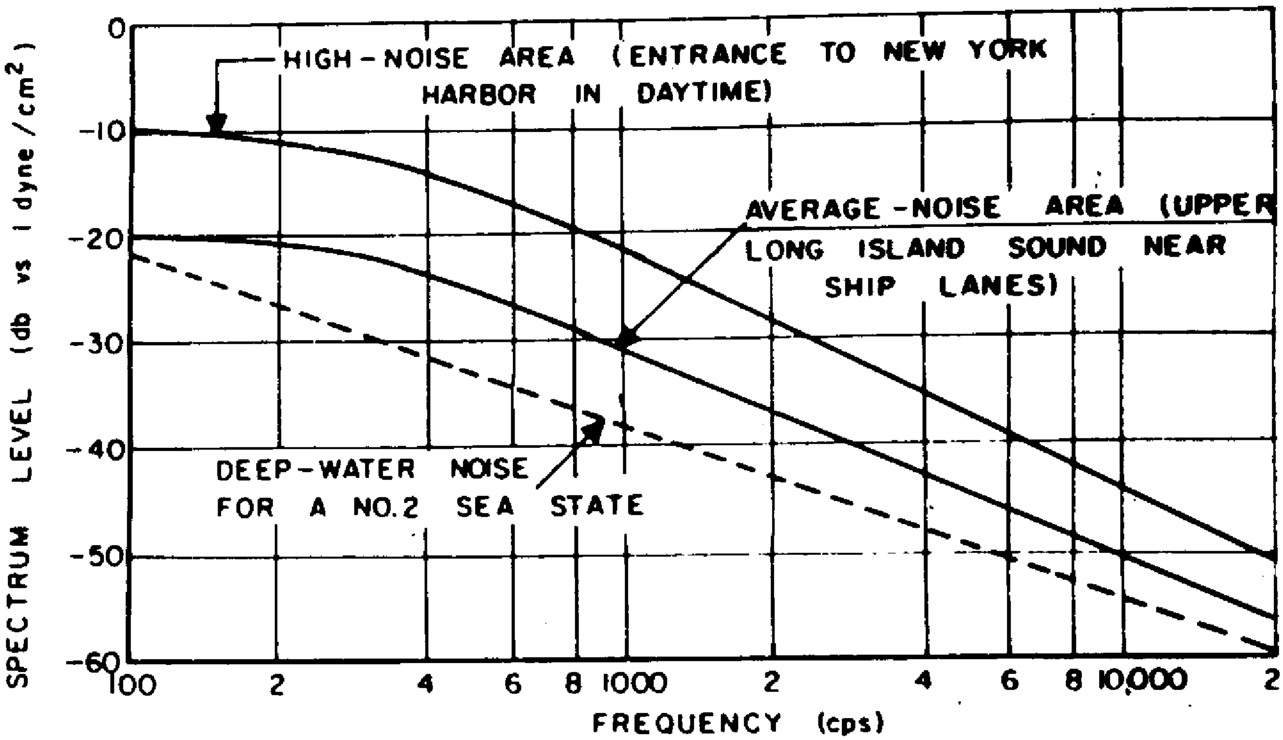


Figure 3. Examples of factors that affect ambient noise levels in the ocean. Reprinted from Albers (1965) with permission of The Pennsylvania State University Press, University Park, Pennsylvania.

3c



3d

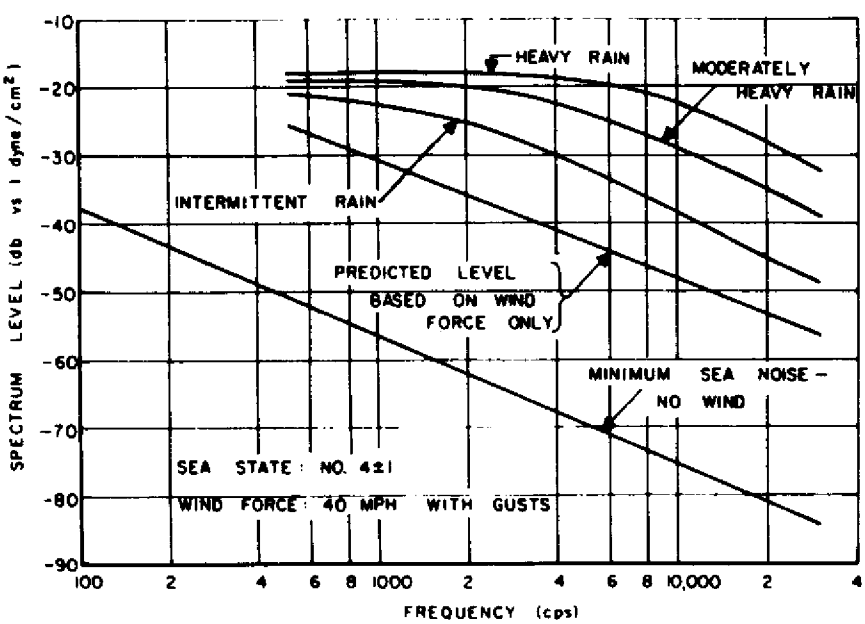


Figure 3, cont.

An Acoustic Harassment Technique to Reduce Seal Predation on Salmon

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Charles F. Greenlaw, CMI-Cascade, Philomath, Oregon
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Introduction

Harbor seals (Phoca vitulina) have always been considered competitors by salmon fishermen in the Pacific Northwest, and bounty programs were used to reduce their numbers during the first half of this century (Pearson and Verts, 1970). Besides competing for free-swimming fish, seals have caused damage to fishermen's gear and catch. Despite efforts to control seals, salmon stocks in many rivers have declined, at least in part because of over fishing, damage-related mortalities, and loss of habitat from poor logging practices. In areas where salmon have become scarce, seal damage to fishermen's gear and catch has been viewed as a major problem (Mate 1980, Contos 1982).

The 1972 Marine Mammal Protection Act (MMPA) eliminated harassment of marine mammals with only a few exceptions. One such exception allows commercial fishermen, in the act of fishing with a legal Certificate of Inclusion under the MMPA, to protect their gear and catch from pinnipeds. As a result, some fishermen still shoot seals, although it is labor intensive and may be ineffective for all but the best marksmen. In a study of dead beachcast marine mammals in Oregon, Stroud (1979) found that gunshot wounds were the leading cause of diagnosable deaths among pinnipeds.

Hatcheries, developed to enhance salmon populations, have a similar problem protecting fish from seal predation. When adult salmon return to a hatchery to spawn, they often swim slowly near its entrance in large groups before moving upstream into the hatchery. While the fish are outside the hatchery, they are vulnerable to seal predation (Brown and Mate 1983). This may not be a major problem for most government hatcheries, which need only a small return of fish for brood stock. It can, however, be a serious problem for runs of endangered fish (Gearin et al. 1986) or for private hatcheries, whose income is based entirely on the sale of fish which return to the hatchery in good condition.

The economic viability of private hatcheries depends upon a 1-2% return of released fish (Bill McNeil, personal communication, 1986). Most of the documented mortality of released fish has occurred soon after release, usually by birds, and young salmon are preyed upon by hake and other large fishes (J. Lannan, personal communication, 1987). There has been little documentation of pinniped predation on adult salmon (Fiscus 1980), and a recent comparison of methods to assess feeding habits suggests caution in interpreting the results of such studies (Roffe and Mate 1984). Brown and Mate (1983) estimated that up to 7.2% of returning adult chum salmon were consumed by seals within 150 m of a hatchery in Netarts Bay, Oregon. Twenty-three percent of returning adult salmon may be damaged at some hatcheries (Mate and Temte, unpublished data). In the Columbia River, seals damaged 15.4% of the fall coho salmon sold commercially during 1981 (Beach et al. 1985) and up to 53.3% of the spring chinook caught in the April 1980 test fishery conducted by the Oregon Department of Fish and Wildlife (Beach et al. 1981).

The purpose of this study was to develop and evaluate the effectiveness of a nonlethal method of reducing seal-caused damage to fish near hatcheries and in commercial fisheries. After examining current practices and reviewing previous attempts to control seal damage, we decided to use underwater sounds to scare seals. Seals have excellent hearing (2-60 kHz), live in an acoustically conductive medium, and are generally sensitive to any sudden or unusual environmental pertubation (Schustermann, 1981). Our work was divided into three areas: (1) physiological experiments with salmon to determine their hearing range and possible changes in fertility from exposure to high-intensity sounds, (2) fishing success during salmon gill net fishing with and without the application of underwater sounds, and (3) studies of the distribution and behaviors of seals when underwater sounds are broadcast in the vicinity of salmon hatchery opertions. Because the experiments were independent of each other and used different techniques, each is described separately in the methods and results sections.

Methods

Previous efforts to scare seals acoustically with biologically significant sounds (e.g., killer whale vocalizations) or pure tones have been unsuccessful (Anderson and Hawkins 1978). Our approach was to produce loud and highly variable noises in an effort to scare seals, perhaps even causing pain at close range. Our design incorporated factors which are known to irritate humans: aperiodic pulses, pulses varying in length, and frequency sweeps (rather than pure tones) in the middle of the hearing range, where there is good sensitivity (Mohl 1968). We used 12-kHz and 17-kHz sounds initially because relatively inexpensive transducers were commercially available, seals showed good sensitivity to these frequencies, and they were within the range of human hearing. The last reason was important during several experiments when equipment failure would not otherwise have been detected. Sounds were generated with a signal generator, a gating device, an amplifier, and a transducer. We referred to this combination of equipment as a seal acoustic harassment device (SAHD). Several combinations of off-the-shelf and custom built components components were used during this research and ultimately resulted in a compact piece of equipment specifically designed as a SAHD (manufactured by CMI-Cascade, Philomath, Oregon).

Salmon Hearing Experiments

A simple behavioral experiment was conducted to ensure that the noises from the SAHD would not scare salmon. The SAHD consisted of a highly directional transducer (ITC model 5133) driven by a 10-watt-power amplifier. Linear frequency modulated (LFM) pulses sweeping from 8 kHz to 12 kHz and approximately 200 millisecond in duration were generated every 1.3 seconds at a fixed rate. Source levels varied from 181 to 194 dB//uPa. By adjusting the position of the transducer, we established a sound pressure level (SPL) gradient within a cement holding tank (40 m x 14 m x 1.7 m deep). Twelve observers counted the number of chinook salmon in equal portions of the tank prior to any experimentation to determine the undisturbed distribution of the fish. Periodically, sounds were produced for durations up to 30 minutes, during which observers recorded the number of fish in the area under their observation every five minutes. The distribution of fish within the tank was compared between the times with and without sound production using a Wilcoxon rank test.

We further examined the hearing capability of jack coho salmon by measuring the microvolt potential within their sacculi in response to sounds of 20 Hz to 10 kHz. The experiment was designed to determine not only the hearing range of these salmon, but also whether salmon might react to the intermittent pulsing of these sounds as an independent, low-frequency modulation.

Fish were anesthetized with MS 222. Using the surgical procedures of Enger and Andersen (1967), we inserted two silver wire electrodes (0.5 mm in diameter) into the cranium to depths of 8 mm and 18 mm (determined from previous dissections) to enter the cerebellum and sacculus, respectively. The electrodes were 5 mm apart. One electrode was used as the reference, while the other was used for recording. The electrode plug was held in place by a parafin wax matrix, which was sutured into place. Following implantation, each fish was attached to a styrofoam float and allowed to recover in an 80-liter seawater tank. The electrode leads were connected to a Gould Brush EEG preamplifier/ Clevite Brush Mark 260 polygraph system or to a Tektronix RM 503 oscilloscope. The entire tank was surrounded by a fahraday cage. Sounds were produced by a waveform generator (Wavetek model 159) and amplifier (Realistic MPA-20) driving a 20-cm speaker affixed to one wall of the tank. Monotones with frequencies of 20, 30, 50, 70, 100, 200, 300, 500, and 700 Hz and 1, 2, 3, 5, 7, and 10 kHz were randomly presented to each fish three times. At each frequency the initial sound intensity was low and then was increased until some electrophysiological response was noted. Sound levels were recorded as SLPs, using a calibrated Celesco LC-10 hydrophone and an oscilloscope allowing for the calculation of threshold intensities for each frequency.

Salmon Fertility Experiment

Because hatcheries use returning fish for brood stock, it was also necessary to determine if high-intensity sounds have any effect on fertility. Fifteen male and 30 female coho salmon were exposed to sounds from a 12-kHz SAHD (193 dB//uPA) in a 1.5 x 1.5 x 1.5-m tank for 90 minutes. The transducer was suspended in the middle of the tank so that all fish were within 1 m of the sound source. An additional 15 males and 30 females were used as controls (not subjected to sounds from the SAHD). Experimental fish were fin clipped for identification. Eggs and sperm were obtained using standard hatchery procedures from the control and experimental fish as they "ripened" over the next 35 days.

A two-by-two fractional matrix design was used to test the effect of sound exposure on male sperm, female eggs, and a combination of both. Eggs from each female were divided into two groups, one to be fertilized by a control male and one to be fertilized by an experimental male. Sperm was mixed with the eggs, and a constant volume of eggs (up to 187) was placed in a 4.8-cm-high section of 5-cm-diameter PVC pipe set into a standard Heath incubation tray. Four to 16 such pipe sections were used in each tray with sufficient aquarium gravel as ballast to ensure proper water flow through the eggs. Fertilized eggs were allowed to grow for 14 to 26 days in a commercial hatchery with a continuous flow of constant-temperature water. Viable, eyed embryos were determined by placing eggs in a 5% solution of acetic acid for five minutes and then checking for clouded embryos. Ultimately, 76 crosses were made between 7 control males, 19 control females, 7 experimental males, and 19 experimental females. Thus, each male fertilized an average of 5.4 batches of eggs. A two-way analysis of variance was performed on the resulting data.

Gill Net Fishing Experiment

Experiments on the Columbia River were conducted between 2 and 24 April 1982 in conjunction with the Oregon Department of Fish and Wildlife's test gill net fishery for chinook salmon and steelhead trout (figure 1). The test fishing boat, Valisa T, was the only boat fishing during this time of the year. The test fishery had taken place during April every year since 1969 in an attempt to determine the size of salmonid runs. Fishing was conducted on alternate days at similar tide conditions with a 365-m drifting gill net that was set upstream and allowed to drift downstream for 90 minutes over a fixed portion of the river. At the end of the drift, the net was hauled in and the locations of damaged and undamaged fish in the net were recorded. The net was then immediately reset upstream to repeat coverage of the same area. With only one exception (24 April, when the order was reversed), the first drift was used as a control (i.e., no sound was produced) and the SAHD was used to produce sounds during the second (experimental) drift. We did not randomize which drifts were control and experimental because, if the SAHD were effective in scaring seals from the area during the first drift, its effects might carry over into the next drift.

The equipment for the gill net experiment consisted of a custom built, 750-watt, switching-over amplifier to drive an Edo/Western transducer (model 249-12), which was essentially omnidirectional over the frequency range of 7 to 14 kHz. The amplifier used power FET transistors and incorporated a CMOS logic random pulser and oscillator. Driven at one-fourth of its maximum power, the SAHD output had a source level of 189 dB//uPa. Fifty-millisecond pulses at 12 kHz were generated aperiodically at an average rate of 2/s. The unit was powered by a 12-V, automotive battery through a 150-watt, 12-VDC/120-VAC inverter. The equipment was housed in an insulated cooler on board a 3.2-m Zodiac inflatable boat. The transducer was suspended from the boat on a 1.5-m line. The boat replaced the normal buoy float marking the first end of the net to be set. Weather permitting, the location and time of seal surfacings within 200 m of the net were recorded during each drift.

The percentage of catch damaged was compared between control and experimental drifts using a Mann-Whitney U test. A Chi-square test was used to compare control and experimental drifts experiencing damage and to compare the proportion of total fish caught on second (experimental) drifts during 1982 with second drift catches from 1969 to 1981.

Hatchery Study

Our studies at Netarts Bay from 1978 to 1980 had indicated that most seal predation of chum salmon at the Whiskey Creek Hatchery took place during high tides within the first 25 m of the creek or in a semicircle extending 200 m out into the bay from the creek entrance (Brown and Mate 1983). During the October through November chum salmon returns of 1980, 1981, and 1982, we placed our transducers in a mud flat channel formed by the creek's current, 20 m from its entrance into Netart's Bay. In 1984 we deployed three AHDs in an attempt to keep a larger area free of seals.

Early in the 1980 season, we used the directional ITC transducer, fixed in the channel and pointing towards the bay. After only a few days, a short in the transducer cable necessitated changing to an Edo/Western omnidirectional transducer, suspended 0.2 m below the surface. A microcomputer was used to produce variable length pulses (1-32 ms long) at random intervals. An average of two pulses of continuously swept LFM (8-20 kHz) were generated). Random on/off

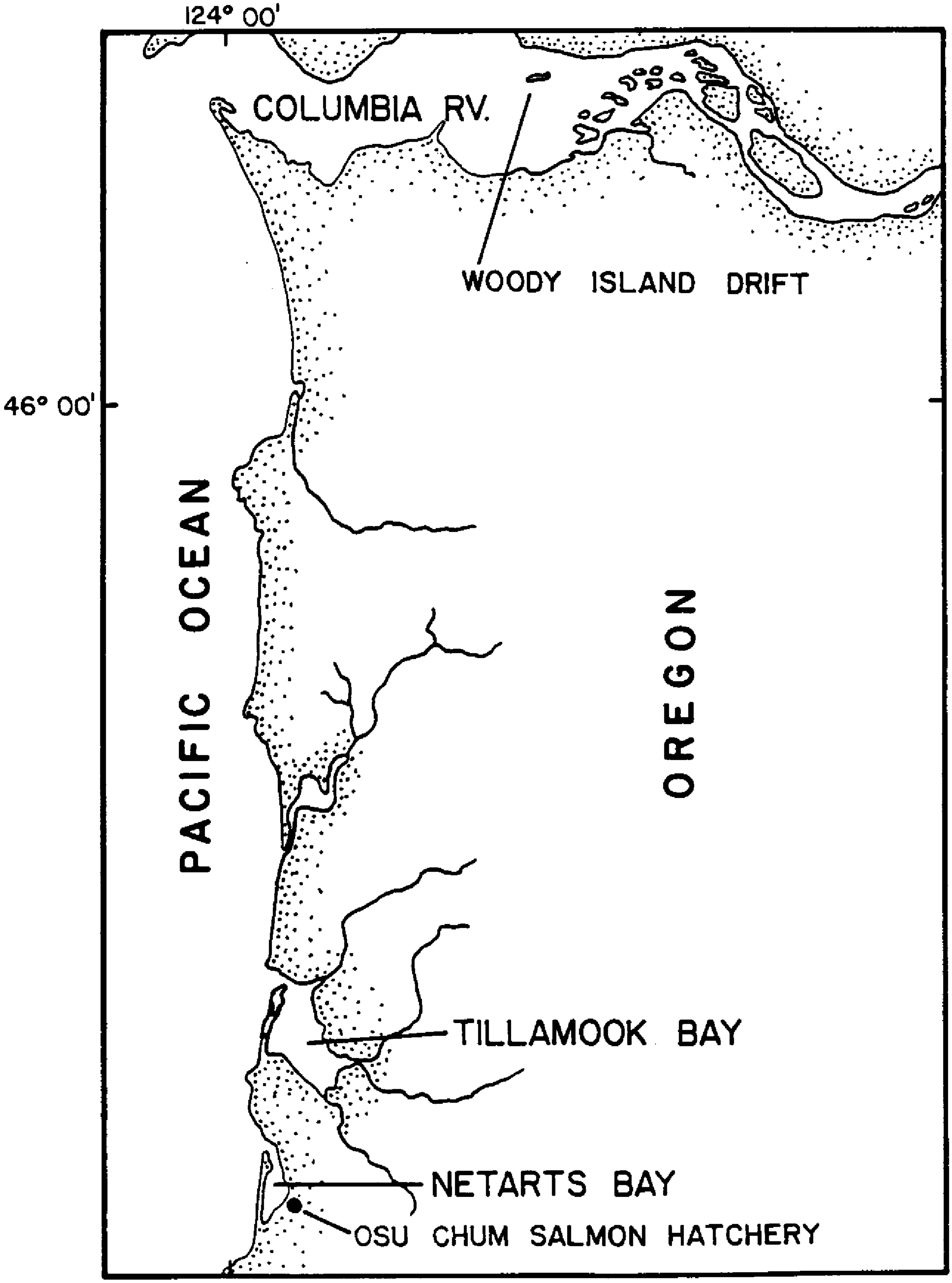

Figure 1. Locations in Oregon at which the AHD was tested.

periods were also used. A 1.4-kH-power amplifier was matched to the ITC transducer to produce source levels of 190-208 dB//uPa, but resulted in source levels of only 158-176 dB//uPa with the Edo/Western transducer because the latter was not properly matched to the amplifier.

During the 1981 and 1982 experiments, the equipment was identical to that used during the Columbia River work, with the Edo/Western transducer mounted as it had been at the end of the 1980 experiment. The mud flats on either side of the creek channel were exposed at low tides and water seldom exceeded 1.5 m over the mud flats. Measurements of the sound field showed the majority of the sound energy was trapped in the creek channel. Even at high tide, sound energy over the mud flats was 20-40 dB lower than in the channel. In 1984, we used one 17-kHz AHD powered from 110 VDC and two self-contained submersible units powered with rechargeable gel cells. The electronics and batteries were housed in a PVC cylinder 31 cm long and 11.5 cm in diameter with a potted transducer measuring 9 cm long and 9 cm in diameter mounted at one end. These units produced source levels of 187 dB//uPa.

An observer in a 4-m-high blind approximately 30 m from the entrance of the creek recorded the location and time of seal surfacings and salmon captures. Observations were limited to three hours either side of high tide during daylight hours. Seal distances from the transducer were estimated by using plastic pipes stuck in the mud as range markers. These were placed in three concentric arcs at 50, 100, and 150 m from the transducer. Observations were made from 26 October to 25 November in 1980, 26 October to 22 November in 1981, 27 October to 29 November in 1982, and 31 October to 13 November in 1984. We compared seal abundance in the vicinity of the hatchery each year between experimental periods (sound on) and control periods (sound off). The SAHD was used aperiodically from 5 November to the end of the run in 1980 to generate 29.0 hours of experimental data, which was compared with data from 61.7 hours of control observation. In 1981, between 13 November and the end of the run, 12.0 hours of experimental data were collected in contrast to 79.0 hours of control observations. Most of the latter were collected prior to the experimental period, with only 9.8 hours of the control observations occurring during the time when experimental observations were also made.

During 1982 we used the SAHD almost continuously to see if seals could be kept from the hatchery area during most of the run. We observed seal foraging without the SAHD operating at the beginning of the 1982 run from 27 to 29 October to document the presence of seals and their usual foraging activities near the hatchery. From 29 October to 23 November, we collected 49.7 hours of experimental data during 18 observation periods. Between these same dates, we also observed four short control periods (without the SAHD) caused by equipment malfunctions, for a total of 9.5 hours of sound-off observations for 1982.

In 1984, control observations were made from 31 October through 3 November and on 5 November. The externally powered SAHD was used continuously by itself on 4, 6, and 7 November and in conjunction with the two submersible units from 8 to 13 November. When three SAHDs were used, the 110-V unit was mounted in the channel (as before) with a submersible unit off to each side on the mud flats, forming an arc at the mouth of Whiskey Creek. The self-contained units were effective only during high tides when they were covered with water, but had to be pulled out each night to be recharged. Sixteen hours of control observations and 27 hours of experimental observations were made.

Seal surfacings were recorded on a map of the area. Only when actively chasing a salmon and creating a characteristic bow wake could a seal reliably be tracked between surfacings. Except for this circumstance, no attempt was made to attribute repeated surfacings to particular individuals. A conservative estimate of the number of seals using the foraging area was made every 10 minutes, usually by recording the largest number of seals seen at the surface at any one time during the period. Seal-surfacing data for experimental and control periods were compared with a Student t-test.

Results

Salmon Tests

Although the transducer of the SAHD was located in the greatest concentration of salmon, the distribution of salmon in the tank was not significantly different between control (sound off) and experimental periods ($P>0.01$). Nor was there a change in distribution when the SAHD was used at varying intensities Salmon were not observed to startle when sounds from the SAHD were initiated during experimental periods. We therefore concluded that the salmon appeared to be unaffected by the sounds produced.

The neurological studies showed that jack coho salmon hearing was most sensitive around 50 Hz with an upper limit of 800 Hz. There was no evidence that salmon detected the on and off pulsing of the SAHD as a secondary (low) frequency.

A total of 76 crosses were performed in the salmon fertility study. Nineteen crosses were made in each of four groups: control male x control female; control male x experimental female; experimental male x control female; and experimental male x experimental female. Egg viability for specific batches ranged from 0 to 100%, with most of the mortality attributable to fungal growth. The mean egg viability (as a percentage) for the four major groupings ranged from 70.79 +/- 7.31 to 77.05 +/- 4.45. A two-way analysis of variance of these results showed no significant difference between the experimental and control groups (P is greater than 0.05).

Gill Net Fishing

During 11 days on the Columbia River, 22 gill net drifts were completed and 205 coho salmon and steelhead trout were caught. Experimental drifts accounted for a significantly greater proportion (72%) of all fish caught (table 1) than

TABLE 1. A summary of seal damage to salmonid catches in the April 1982 Columbia River spring chinook test fishery.

Surfacings (x/min)	Number of Salmonids Caught (Damaged)	Mean Damage Rate (% of Total Catch Damaged)	Seal (Damaged)
SAHD off (N=11)	57 (9)	25.4	0.7
SAHD on (N=11)	148 (2)	1.5	0.06

control drifts (Chi-2 = 43.26, $P<0.05$). This was significantly different (Chi-2 = 43.36, $P<0.01$) from the average of 51% fish caught during second drifts of the test fishery for the previous 13 years (range: 45-62%). Control drifts accounted for 82% of all damaged fish and 78% of all drifts experiencing damage. One fish was damaged in each of two experimental drifts (18% of the experimental drifts), while a total of nine fish were damaged in seven of the control drifts (64% of the control drifts). The difference in occurrence of seal-damaged fish between control and experimental drifts was significant ($P<0.05$). The mean damage rate (the number of fish damaged by seals per drift over all drifts) for experimental drifts was 1.5%, only 6% of that experienced during control drifts (25.4%). Good weather conditions for seal visibility occurred during only seven pairs of control and experimental drifts. On all such control drifts, seals were observed surfacing within 200 m of the net on an average of once every one to two minutes. During the experimental drifts, seals were seen near the net only twice.

Hatchery Observations

When the SAHD was not in use at Netarts Bay, seals came to the hatchery during flood tides, foraged while deep water was available, and then retreated to the lower bay during the ebb tide. The number of seals foraging in the area during these control periods ranged from 1 to 14, with an average of 3.4 seals seen most commonly. In 1980 and 1981, a daily control (sound-off) period of 20 to 60 minutes was completed before the SAHD was turned on to assure that seals were in the area and foraging as normal. When the SAHD was turned on initially, seals in the observation area consistently reacted by immediately swimming away from the creek mouth. Often seals within 50 m of the transducer had their heads above water when the SAHD was activated. When these animals submerged enough to have their ear openings below the water, they generally reacted by leaping partially out of the water in a single porpoising dive and then retreating rapidly underwater.

The SAHD did not completely exclude seals from the hatchery area. It was not uncommon for a single seal (and two on a few occasions) to venture into the observation area and even pass close to the transducer. Typically, seals stayed inside the study area for a very short time, but they were twice successful in taking a fish.

During 1980, 1981, and 1982, the average number of seals foraging in the study area during each 10-minute period was significantly lower ($P<0.05$) while the SAHD was operating (mean = 3.3) than when it was not (mean = 0.4; see table 2). During 1984, an average of 3.7 seals used the study area during 10-minute-long experimental observations, which was not significantly different from other years. However, an average of 1.8 seals were observed during 10-minute-long experimental observations, more than twice the number observed in the three previous years and not significantly lower than 1984 control values ($t = 0.98$; $t_{.05(12)} = 2.18$). In 1984, 1,860 seal surfacings were recorded (without differentiating between individual seals), and 772 of these surfacings (41.5%) were within 50 m of the creek mouth. The proportion of seals which appeared within the 50-m area was not significantly different between on and off periods ($t = 1.12$; $t_{.05(10)} = 2.28$). It should be noted that because of the short duration of the run at Whiskey Creek, the problems we encountered with poor weather and electronics resulted in a small sample size. Perhaps equally important in the determination of no significant difference was an appreciation of the acti-

TABLE 2. The mean number and standard deviation (SD) of harbor seals observed foraging for chum salmon near the mouth of Whiskey Creek, Netarts Bay, Oregon.

	Observation hours		X seals / 10 min. (SD)	
	SAHD on	SAHD off	SAHD off	SAHD on
1980	61.7	29.0	3.3 (1.8)	0.8 (0.6)
1981	9.8	12.0	3.5 (2.9)	0.1 (0.2)
1982	9.5	49.7	3.1 (1.2)	0.4 (0.7)
1984	16.0	27.0	3.7 (1.2)	1.8 (0.9)

vities of a small number of seals. One seal, which was recognizable by markings on its head, accounted for 23 of 30 sightings of seals within the creek mouth when the devices were on. Some of the remaining seven sightings may also have been this seal, as only two other seals were known to have entered the creek. It is not known what percentage of the sightings within 50 m of the creek was attributable to this seal, which was apparently unaffected by the SAHD.

As might be expected, when the number of seals was significantly reduced by using the SAHD, so were the rates at which seals consumed salmon (table 3). During 1980 and 1981, salmon predation by seals during experimental periods was significantly lower (63% and 68%, respectively) than during control periods (table 2).

TABLE 3. The number of salmon taken by harbor seals (N), hours of observation (HRS), and predation rate (PRED RATE = salmon taken/hour observation) at the Netarts Bay chum salmon hatchery.

	1980			1981			1982			1984		
	N	HRS	PRED RATE	N	HRS	PRED RATE	N	HRS	PRED RATE	N	HRS	PRED RATE
SHAD off	18	61.7	0.29	20	79.0	0.25	1	9.5	0.11	16	27.0	0.59
				3*	9.8*	0.31*						
SHAD on	2	29.0	0.07	1	12.0	0.08	4	49.7	0.08	9	16.0	0.56

*Observations limited to the same time as the "sound on" sample.

In 1982, the SAHD was on more routinely (63% of the total observation time) than in 1980 and 1981, but the rate at which seals consumed salmon while the SAHD was in use was virtually the same as in 1980 and 1981. The 1982 control observations, however, revealed that seal consumption of salmon was 62% and 65% lower than during the control periods of 1980 and 1981, respectively. Thus, only 38% more salmon were consumed by seals during the 1982 control period (sound off) than during the application of the SAHD (compared to differences of 414% in 1980 and 388% in 1981). In 1982, one identifiable seal moved into the creek and fed on salmon without any apparent effect. In 1984, the rate of salmon consumption was almost equal for observation periods when the sound was on (0.59 salmon/hour) and off (0.56/hour). This difference was largely attributable to a single identifiable seal, which was responsible for catching 11 of 12 salmon caught within the creek (44% of the 25 fish caught within the study area).

Discussion

Salmon Tests

Some fish detect sounds up to 5 kHz, but most fish do not hear sounds above 1 kHz (Chapman 1975). The results of our experiments to evaluate the hearing range of salmon were similar to those reported for Atlantic salmon parr (Facey et al. 1977). While there is still some debate as to whether or not most pinnipeds use active echolocation to find food (Schustermann 1981), there is agreement that frequencies useful for such echolocation are beyond the demonstrated hearing range of fish. Thus, it is unlikely that fish can detect the presence of seals by passively listening for echolocation vocalizations.

We were pleased to find no effects of high-intensity sound on the viability of salmon eggs and sperm. Much higher frequency sounds than we used are employed as a laboratory method of breaking cellular membranes, which of course destroys the cell's ability to function as a unit. It is likely that any significant subcellular disturbances would have prevented fertilized eggs from developing to the eyed stage.

Gill Net Fishery

We had intentionally not randomized which drift was experimental and which was control, because fishermen and the test fishery had experienced more damage during subsequent drifts as more seals discovered their operation and then stayed with it. If there was bias in this strategy, it was that the second drift should have had more damaged fish. Therefore, our observations that there was less damage to caught fish and that greater numbers of fish were caught in the second sets strengthen our conclusion that the SAHD was effective in reducing seal damage.

The difference in the number of salmon caught between sets, we believe, is the result of both more fish being caught in the net and fewer netted fish being pulled from the nets by seals during the experimental drifts. If the SAHD were effective in reducing the number of seals in the area during experimental drifts, fewer fish would likely be removed from the nets. We have seen gill opercula in nets to attest that seals do pull salmon completely free of nets. However, it seems unlikely that this factor alone could account for the observed difference in catch, since seals were rarely seen bringing fish to the surface as they often do when consuming large prey. If the change in catch rate were the result of reduced numbers of removed fish, and if fish removed from the net had a relatively constant relationship to the number of damaged fish, then an estimated 117 fish would have been removed during the control drifts. This number is inconsistent with the scarcity of evidence (remaining opercula and certain types of web tangles) that fish were removed from the net.

It is less obvious why more fish might be caught initially. It is important to remember that we found no evidence tht salmon heard the SAHD or that their distribution was affected by it. However, we have seen fish in clear and murky water move at great speed to avoid capture when chased by seals. At close range, the lateral line system and vision may be the salmon's primary cues to avoid seals. If fish moving upstream can sense the presence of seals some other way (such as through chemorecption or hearing), the fish may behave differently (drifting downstream or seeking the bottom) and become less vulnerable to net capture. Thus, when the SAHD greatly reduced the number of seals near the net, fish may have been more vulnerable to net capture during experimental drifts.

Hatchery

The rate of fish predation by seals at Netarts Bay during the 1982 control observations was significantly lower than during 1980 or 1981. It is unlikely that this lower rate of predation, even without the SAHD in use was due to its use much of the time. Many seals experienced the effects of the SAHD at close range when it was initiated each day and may have learned that it could come on at any time. Seals that appeared to dislike the noises of the SAHD may have associated the noises with the hatchery area and avoided it, despite the apparent advantages of feeding there. The reduction in seal numbers in the study area during experimental periods was proportionately greater than the reduction in seal-consumed salmon, suggesting that the few seals which continued to use the area were much more successful catching fish than the "average" seal using the area during control periods. Just one seal immune to the SAHD could easily have accounted for the relatively constant damage which occurred during experimental periods in 1980, 1981, and 1982. The potential impact of even a single animal may be more appropriately estimated by examining the 1984 season when at least 44% of all salmon taken during the entire season could be attributed to a single seal which was totally indifferent to the SAHD. Several times this seal had a salmon taken from it by seals as it left the study area, and it immediately re-entered Whiskey Creek to get another. Thus, the number of fish taken by this seal is an overestimation of his actual intake.

Individual Variability

In both hatchery and gill net applications, the SAHD kept most seals at least 150 m away. The presence of some damaged fish in the gill nets and the observation of a few seals near the Netarts Bay hatchery when the SAHD was in use indicates it is not 100% effective. Indeed, we have seen a few seals pass within a few meters of the SAHD by choice, although usually (but not always) with considerable speed. This suggests that the SAHD causes psychological irritation for most seals, rather than physical pain. We do not know if the ability of some seals to penetrate the sound field was the result of a greater initial tolerance to the sounds (including partial or total hearing loss), habituation, or a higher motivation for food.

A few seals seemed to be totally immune to the SAHD, and it is possible that they may have had hearing loss in the 12-kHz to 17-kHz range. For a variety of reasons, partial or total losses of upper-range hearing is reasonably common in many mammal species with age. Seals that frequent nets may also be more likely to be deaf (regardless of age) from exposure to seal bombs, used by some fishermen to harass seals near their catch.

The large size of one seal, which routinely went close to the SAHD at Netarts Bay, may have been partially the result of its bolder and more successful feeding habits. If seals with healthy hearing are totally unaffected by the SAHD, they could actually learn to locate fishing activities by listening for sounds of a SAHD. If that started to occur, the identification of individual seals causing damage could be made easily and possibly dealt with by capture, shooting, or other deterrents. We have observed some seals adopt behaviors which would reduce their exposure to SAHD sounds, such as keeping their heads out of water while passing moored SAHDs, moving through shallow water, and moving behind sand bars.

This study demonstrates that certain sounds can be produced underwater which do not scare or damage fish, but which can be effective in reducing the number of seals during short-term hatchery or commercial fishery operations. It is also apparent that a single seal can cause considerable damage and that the SAHD is not totally effective. In order to reduce predation rates in some situations, fishermen may have to use more than one method to deter seals. Under such circumstances, the SAHD may still play an important role in identifying culprit individuals and aiding in their capture or elimination. It remains to be seen whether or not long-term applications of these sounds will continue to be effective for the bulk of the population. The effective range of acoustic harassment devices will always be restricted because of loss of PSLs due to spreading and attenuation. The range of one or more SAHDs may be sufficient to limit seal activities in small areas, but restricting movements in larger areas seems impractical at the present time (Harvey et al., this proceedings). We have seen no reaction to the SAHD by marine birds, such as gulls, shearwaters, ducks, and diving cormorants, even within 100 m.

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Evaluation of Seal Harassment Techniques to Protect Gill Netted Salmon

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Research conducted by the Washington Department of Game (WDG) from 1980 to 1982 documented the impact of pinniped depredation on salmon caught in commercial gill nets in the Columbia River (Beach et al. 1985). Harbor seals (Phoca vitulina) damaged 5.3% of coho salmon (Oncorhynchus kisutch) sold in the fall fishery in 1980 and 15.4% in 1981, a significant increase (Beach et al. 1985). In the winter gill net seasons of 1980, 1981, and 1982, harbor seals in combination with California sea lions (Zalophus californianus) caused damage to 8.1%, 4.6%, and 2.2% of the chinook salmon (O. tshawytscha) landed. Pinniped damage rates to spring chinook in the April test fishery conducted by the Oregon Department of Fish and Wildlife (ODFW) at Woody Island were 53.3% in 1980 (Beach et al. 1981). Steelhead (Salmo gairdneri) were also damaged in this test fishery, resulting in total salmonid damages of 44.7%. In the Youngs Bay terminal fishery off the Columbia at Astoria, Oregon, harbor seals damaged 5.2% of the chinook catch in 1980 and 9.0% in 1981, a significant increase (Beach et al. 1985). Seal damages to coho catches were 2.7% and 1.9% in these years, so a total of 3.7% (1980) and 5.5% (1981) of the Youngs Bay salmon catches were affected by seal damage.

Gill-netters are permitted to repel depredating pinnipeds from fishing gear according to National Marine Fisheries Service (NMFS) regulations (50 CFR 216.24) for taking marine mammals incidental to commercial fishing operations. Methods in use on the Columbia River include shooting at depredating animals, exploding "seal bombs" (large sinking firecrackers) from the boat, and running the boat along the net while it drifts. Analysis of the data from 1980-82 interviews with Columbia River fishermen (Geiger, unpublished data) showed a higher rate of salmon damage for gill net trips in which marine mammals were harassed, so the efficacy of these methods could not be demonstrated using this data set.

A new technology has become available for commercial gill-netters to use in attempting to repel seals from nets. The acoustic harassment device (AHD) was conceived by Bruce Mate (Oregon State University, Newport, Oregon) and designed by Charles Greenlaw (CMI-Cascade, Philomath, Oregon). The device produces underwater pulses of high-frequency sound (12-15 kHz), inaudible to salmon but "distressing to harbor seals at close range (50-200 m)" (Mate, Brown and Greenlaw 1983). This device was shown to significantly reduce the fish damage rate from harbor seals in the 1981 ODFW spring chinook test fishery at Wood Island on the Columbia River (Mate, Brown and Greenlaw 1983).

The present study was designed to replicate this experiment and provide field evaluations of this equipment in a variety of commercial gill net fisheries. We also compared the effectiveness of this device with the traditional seal harassment methods referred to above and also with an exploding "shell cracker" fired from a shotgun which we introduced to the gill net situation. The criterion for evaluation was the effect of a particular seal harassment technique on salmon damage rates, although successful techniques for keeping seals away from fishing gear could have additional benefits such as reducing seal entanglements and incidental mortality.

Objectives

This study had the following primary objectives:

(1) to provide controlled field trials of the acoustic harassment device aboard commercial salmon gill net vessels;

(2) to evaluate the effect on salmon damage rates of using the AHD, seal bombs, and shell crackers, "running the net," and using other traditional methods of seal harassment; and

(3) to investigate the AHD's effectiveness for driving seals from an enclosed fishing area and preventing their return.

Secondary objectives included monitoring baseline rates of salmon damage from pinnipeds and investigating novel applications of the AHD on an opportunistic basis.

Methods

Equipment Tested

The acoustic harassment device tested was a "Sealchaser" dual-transducer model manufactured by CMI-Cascade, P.O. Box 510, Philomath, Oregon 97370,* for $3500. This device produces 60-millisecond bursts of pulsed sound at an average rate of 1 burst/second, with a source level of +195 dB//uPa/m. Each burst is composed of nine stepped frequencies sweeping from 11.9 to 14.7 kHz (C. Greenlaw, CMI-Cascade, personal communication). The characteristics of the sound produced underwater by this device were described by Awbrey and Thomas (1984), who concluded that these particular frequencies lie within or near the most sensitive hearing regions of many cetaceans and pinnipeds. According to OSU studies (J. Temte, unpublished report), Pacific salmon showed no behavioral, developmental, or evoked auditory responses to the AHD frequencies. Some human operators can hear in the 12 kHz band and thus be aware that the device is operating without observing the indicator light.

Both the number of "pings" in a burst and the interval between bursts can be controlled by the operator via switches. For purposes of these tests, however, the interval switch was set at zero so the pulses were continuous (within the random interval averaging 1 second).

The "Sealchaser" unit (26.5 cm X 29 cm X 15.5 cm high) was installed by the experimenters either in the cabin of the cooperating gill net vessel or in a waterproof drum on deck. The unit was connected to a 110-volt power outlet if

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*Mention of trade names or commercial firms does not imply endorsement by the Washington Department of Game.

the vessel was so equipped, or through a power inverter to a 12-volt storage battery. One waterproof cable led from the device to a coated ceramic transducer (10-cm-diameter cylinder 11 cm high, model 249-12, Edo Corporation). The transducer was suspended overboard on a 3-m rope cleated amidships so that the transducer hung below hull level. A 5-lb lead weight kept the transducer submerged. The single transducer was stowed on deck for travelling and suspended in water before the AHD was operated.

The seal bombs tested were purchased from California Sea Control Corporation, P.O. Box 949, San Pedro, California 90733, for approximately $0.30 apiece. California Seal Control Devices are classified as class C explosives and are registered as agricultural fireworks by the State of California. Each unit consists of a spiral-wound cardboard tube containing 36 grains of potassium perchlorate and pyro-aluminum flash powder with an 8-second waterproof fuse (letter from R. Robinson, California Sea Control Corporation). Weighted with sand, "when lit and dropped into water, it will sink 15-25 feet before exploding, causing a flash of light and a slight percussion in the water" (letter from R. Robinson). The auditory characteristics of the seal bomb's underwater explosion were described by Awbrey and Thomas (1984).

Shell crackers were obtained from WDG (which uses them to repel birds from fish hatcheries and game animals from agricultural areas) for testing in reducing pinniped/fisheries interactions. These were 12-gauge, 2 3/4-inch shells, distributed by O. C. Ag Supply, Anaheim, California 92805. Fired from shotguns, these shells were found in field tests to travel about 70 m when shot in a flat trajectory, exploding in air or on the surface of the water with a report like a firecracker. Sound propagation in air and water was described by Awbrey and Thomas (1984).

General Study Design and Sampling Regime

Because the long-range goal of this research is to help commercial gill net fishermen avoid pinniped interactions or lessen their impact, all tests were performed in cooperation with working gill-netters during their regular fishing operations. The gill-netters volunteering to test seal harassment devices all held Certificates of Inclusion under an NMFS-issued General Permit to take marine mammals incidental to fishing. Additional tests were conducted under Marine Mammal Protection Act (MMPA) Research Permit No. 412 (issued to Bruce Mate to test the AHD on marine mammals) with the aim of reducing salmon damage rates caused by seals in the general commercial fishery.

We made no attempt to influence gill-netters as to when, where, and how to fish. Rather, we limited our evaluations to single fishing seasons and areas so that environmental influences would be standardized and variation in pinniped and salmon abundance and behavior would be minimized. Designation of experimental and control periods was made in advance; otherwise the gill-netters had discretion over when and where the assigned harassment devices were deployed during experimental periods. For specifically testing the AHD during regular gill net seasons, successive drifts of the same net were compared for fish damage. One drift of each pair was randomly designated "experimental" (AHD operating) and the other "control" (AHD in place but not operating). On-board observers operated the AHD and recorded results but had no discretion over the regime. Analysis was performed using paired t-tests for damaged, undamaged, and total salmon caught.

A different sampling scheme was employed for the 1984 ODFW test fishery, to replicate the Oregon State University (OSU) experiment (R. Brown, OSU, personal communication). A longer random series of drift pair designations ("on/off," "off/on," "on/on," and "off/off") was established, and the results were not compared by drift in the analysis. Instead a 2 X 2 chi-square test of damaged and undamaged salmon was performed on the pooled data for all "on" and "off" drifts.

For assessing other seal harassment methods along with the AHD, continuous trials of single techniques were run simultaneously on separate boats fishing in the same area. (The assumption was that seals would choose to feed from the nets presenting the least aversive stimulus to them.) Gill-netters who fished regularly in one area were solicited as volunteers. Those agreeing to participate in the controlled evaluations were asked to provide us with catch and damage data and were supplied with either seal bombs, shell crackers, or an AHD. Other cooperating fishermen were assigned to "run their nets," to use their own guns to shoot at depradating seals, or to refrain from harassing seals at all. (For the Budd Inlet fishery, the type of harassment method used was decided initially by lot and rotated between cooperating fishermen at five-day intervals thereafter.) We requested that the gill-netters use no more than one harassment method at a time; however, the frequency and manner of use was up to each individual gill-netter.

Fishermen kept logs (figure 1) for each drift, from which the data on damaged and undamaged salmon were taken according to the harassment method used. Chi-square tests were used in comparing the effectiveness of the various harassment methods. T-tests of total salmon caught per drift using the different harassment methods were also used in evaluating the techniques.

We tested the AHD in "herding" harbor seals downstream in Youngs River, using methods previously employed by OSU and the California Department of Fish and Game when testing the device on seals in the Klamath River, California (Mate and Miller 1983). One or two "broadcast" boats towing lead-weighted transducers motored slowly downriver, zig-zagging where the river widened into Youngs Bay. These acoustic "seal drives" terminated at the old Youngs Bay Bridge, where an array of two to three AHDs powering four to five transducers was fixed (figure 2). The fixed devices were turned off by an observer on the bridge when the acoustic boats came into sight and were turned back on as the boats passed under the bridge.

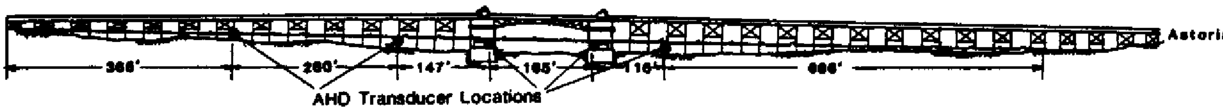
The effect of these activities on interactions between harbor seals and gill net fisheries and on salmon damage was assessed from fisherman interviews taken before, during, and after the AHD drives. Interviewing methods were identical to those used previously in Youngs Bay (Beach et al. 1985) except that fish catches were partitioned into those made upstream of the bridge (the "experimental" area) and those below the bridge (the "control" area). For each data set, damaged and undamaged salmon netted before and after the AHD screen was activited were compared by 2 X 2 chi-square tests.

More details of the various tests will be described below in sections related to each fishery. A summary of the areas selected and the tests performed in each is shown in table 1.

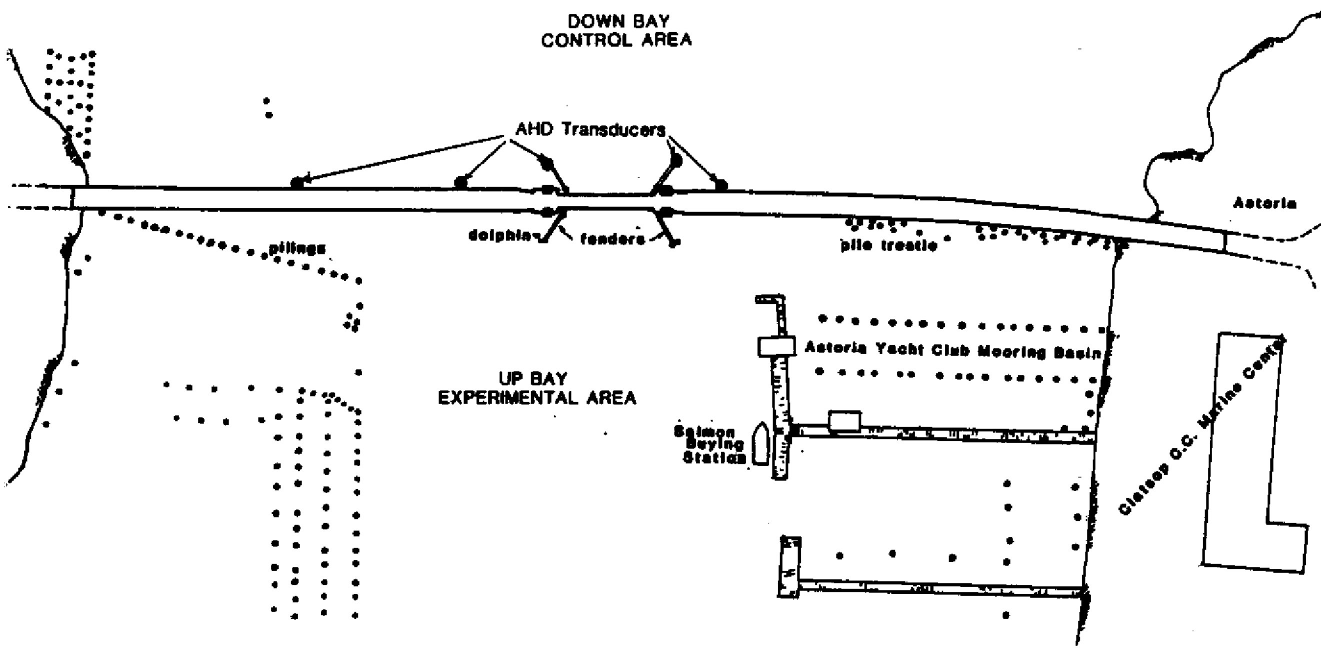
EXPERIMENTAL SEAL HARASSMENT LOG - Complete one line for each drift. RETURN TO: Washington Department of Game
Marine Mammal Investigations
EX-12
Olympia, Washington 98504
(206) 753-3703

DATE OR DRIFT #	ZONE FISHED	TIDE AND TIME DURING DRIFT	SEALS AROUND?	TYPE(S) OF HARASSMENT USED DURING DRIFT	NUMBER OF SALMON IN NET WHEN PULLED: WITH NO DAMAGE	BITTEN BUT CAN BE SOLD	REMAINS ONLY-CAN'T BE SOLD
#		FLOOD HIGH EBB LOW DAY NIGHT	SAW SEAL NOT SEEN	1. NONE 2. AHD 3. SEAL BOMBS 4. SHOT 5. CRACKER SHELLS	# UNDAMAGED	# SALABLE	# UNSALABLE
COMMENTS:							
#		FLOOD HIGH EBB LOW DAY NIGHT	SAW SEAL NOT SEEN	1. NONE 2. AHD 3. SEAL BOMBS 4. SHOT 5. CRACKER SHELLS	# UNDAMAGED	# SALABLE	# UNSALABLE
COMMENTS:							
#		FLOOD HIGH EBB LOW DAY NIGHT	SAW SEAL NOT SEEN	1. NONE 2. AHD 3. SEAL BOMBS 4. SHOT 5. CRACKER SHELLS	# UNDAMAGED	# SALABLE	# UNSALABLE
COMMENTS:							
#		FLOOD HIGH EBB LOW DAY NIGHT	SAW SEAL NOT SEEN	1. NONE 2. AHD 3. SEAL BOMBS 4. SHOT 5. CRACKER SHELLS	# UNDAMAGED	# SALABLE	# UNSALABLE
COMMENTS:							
#		FLOOD HIGH EBB LOW DAY NIGHT	SAW SEAL NOT SEEN	1. NONE 2. AHD 3. SEAL BOMBS 4. SHOT 5. CRACKER SHELLS	# UNDAMAGED	# SALABLE	# UNSALABLE
COMMENTS:							
#		FLOOD HIGH EBB LOW DAY NIGHT	SAW SEAL NOT SEEN	1. NONE 2. AHD 3. SEAL BOMBS 4. SHOT 5. CRACKER SHELLS	# UNDAMAGED	# SALABLE	# UNSALABLE
COMMENTS:							
#		FLOOD HIGH EBB LOW DAY NIGHT	SAW SEAL NOT SEEN	1. NONE 2. AHD 3. SEAL BOMBS 4. SHOT 5. CRACKER SHELLS	# UNDAMAGED	# SALABLE	# UNSALABLE
COMMENTS:							

Figure 1. Experimental Seal Harassment Log Form.



A. Location and spacing of AHD transducers, profile looking west.



B. Relationship of AHD transducers to other upbay structures, plan view.

Figure 2. Location of Acoustic Harassment Devices on the old Youngs Bay Bridge.

Table 1. Commercial and test gil net fisheries in which seal harassment (by type) was evaluated.

EVALUATION	AREA	ZONE	DATES	FISHERY	SPECIES
AHD on/off	Willapa Bay	2G,2H	9/83	WDF Test	Chinook
Sea drive & exclusion	Youngs Bay	7	9/83	Terminal	Chinook & Coho
AHD on/off	Columbia River	1	9/1/83 (12 hr)	Early Fall	Chinook
AHD on/off	Columbia River	1,2 1	9-10/83, 10-11/84	Late Fall	Coho
AHD on/off	Columbia River	2	4/84	ODFW Test	Chinook
All methods	Columbia River	2	2-3/84	Winter	Chinook
All methods	Budd Inlet/ Dana Passage (So. Puget Sound)	13D,13F	7-8/84, 7-8/85	Treaty Indian	Chinook

Results

Acoustic Harassment Device--Onboard Vessel Testing

1983 Willapa Bay and Columbia River Chinook Seasons

The Willapa Bay summer chinook season, previously studied during 1980-1981 (Beach et al. 1985), was originally scheduled for AHD tests. However, chinook catches in 1983 were insufficient to make the evaluation. Instead, we attended six days of test gillnetting conducted by WDF in September of 1983. A chartered gill net vessel fished the area between South Bend (Willapa River) and Bay Center (Rodessa Beach), where we monitored 16 drifts.

The rate of seal damage during three control drifts the first day was 13.7% of 51 salmon. The second day, no salmon were damaged of 29 caught during three AHD drifts. Paired trials (one each) were made the next four days. With the AHD on, 3 of 29 salmon (10.3%) were seal damaged, compared to 2 of 47 salmon (4.3%) damaged with the machine off. (The sample is too small for statistical treatment.) On the fifth day of AHD harassment, a harbor seal was observed 50 m from the sound source, although most sightings were 100 m away.

The AHD was next tested during the Columbia River early fall chinook season (previously described for 1980 in Beach et al. [1985]). We sampled 11 drifts on four boats during this 12-hour season on 1 September 1983. No seal-damaged salmon were landed before fishing ended, so the evaluation of the AHD could not be made. More salmon were caught during AHD drifts (118 fish) than control drifts (24 fish), but as most of the gill-netters stopped fishing after two drifts (maximum of four) when the catches declined, it was felt that too few random trials were obtained to attribute the high catches to the AHDs.

1983-84 Columbia River Coho Seasons

The fall coho season was previously described in Beach et al. (1985) for 1980-1981. The 1983 season consisted of two 48-hr openings: 4-6 and 11-13 October. Five gill net boats were used for AHD tests during the first opening: three in zone 1 (near Astoria, Oregon) and two in zone 2 (near Skamokawa, Washington). No seals were observed in the upriver sample, however, so zone 2 tests were discontinued and the data were not included in the analysis. The remainder of the sample yielded 30 paired AHD trials.

Results from 1983 showed 5.1% of 117 salmon damaged by seals when the AHD was on, versus 11.2% of 89 fish damaged with the machine off. However, neither the damage rage ($X^2 = 2.63$, $p = .11$), the number of fish damaged ($t = 1.00$, $p = .16$), nor the number of salmon caught ($t = 0.87$, $p = .20$) differed significantly between the experimental and control drifts. Therefore it was decided to repeat this test in 1984.

The same area in zone 1 of the Columbia River was sampled between 2 October and 4 November 1984, and one of the same gill net boats was used. For 17 paired trials, 19.5% of 82 salmon caught with the AHD on were seal damaged, compared to 6.0% of 83 salmon caught during control drifts with the AHD off. This difference was significant ($X^2 = 6.76$, p .01), but in the opposite direction from 1983 results. When all 47 pairs from both coho seasons were considered together, the difference in damage rates (11.1% of 199 salmon caught using the AHD, versus 8.7% of 172 salmon caught in control drifts) was not significant ($X^2 = 0.56$, $p = .45$).

On the fourth AHD trial (14-15 hours into the 1983 season), harbor seals were seen 200 ft (61 m) from one experimental boat and 30 m from another. On the following AHD trial, a seal was observed with a fish in its mouth, pulling it from the net 100 m from the first boat, while another observer saw a seal surface within 15 to 20 m from his sound source. On three occasions, one to two seals surfaced violently and dove over the corkline 10, 30, and 50 m from boats using the AHD. Seal-bitten shad and flounder (one each) were also observed in catches made while the AHD was operating.

1984 ODFW Columbia River Spring Chinook Test Fishery

The April spring chinook test fishery is conducted annually by ODFW biologists aboard a chartered gill net vessel at Woody Island. A description of the fishery for 1980 and results of ODFW seal damage monitoring from 1972-1980 appear in Everitt et al. (1981). Preliminary tests of the AHD were made by Oregon State University researchers in this fishery in 1981. OSU experiments with the AHD in the 1982 test fishery showed a significant reduction in fish damage from seals when using the device (Mate, Brown and Greenlaw 1983), along with higher catches when the sound was on (R. Brown, unpublished field report). The third year of their tests, 1983, was plagued with equipment problems, so the results were equivocal (R. Brown, personal communication). We continued this study in 1984.

Twelve drifts (two per day) were sampled. The sampling schedule was not completed as the charter was cancelled because of the sudden illness of the gill-netter, but sufficient salmon were caught to analyze the results non-parametrically. For seven AHD drifts, 32% of 72 fish (chinook and steelhead) were seal damaged. The damage rate for five control drifts was 11% of 82 salmonids caught. This difference was significant ($X^2 = 10.2$, $p < .01$), and both the greater number of damaged fish (23 vs. 9) and the higher damage rate (32% vs. 11%) occurred with the AHD on.

Acoustic Harassment Device--Seal Driving and Exclusion Experiments

1983 Youngs Bay Terminal Fishery

The AHD was operated from a WDG boat in a continuous sweep from above the upriver fishing area boundary, downstream to the old Youngs Bay Bridge. On 17 September 1983 one device was used, and personnel in the other vessel watched for seals. During ebbing tides on both 21 and 22 September 1983, two devices were used from two vessels trisecting the width of the river. Personnel in boats searched the upper bay with binoculars for seals on two other occasions (16 and 29 September). The Walluski River tributary and other navigable sloughs were checked for seals during all sweeps.

No harbor seals were seen upbay during any of these sweeps or searches. A gill-netter whose net was set across the current approximately 1.5 km below the origin of the sweep (and 5.25 km above the old bridge) reported that a seal swimming downstream ahead of the acoustic boat hit and broke through his net. A spotter on the bridge turned off the fixed AHDs there when our boat came into view approximately 1.5 km above the bridge. Observers using binoculars saw no seals within this area as the AHD-equipped boats approached the bridge. The fixed devices were turned back on as the mobile units passed under the bridge.

The baseline rate of seal damage to netted chinook and coho salmon was determined from interview data (n = 94) collected for eight days (9-16 September 1983) before AHD screening began. This was compared with results from 78 interviews collected during 12 days (17-29 September) when the fixed AHDs were operating. Gill net drifts downstream from the old Youngs Bay Bridge, where the equipment was placed on 16 September, were examined separately from those drifts made upstream, above the bridge.

Fisherman responses to interviews the day following the sweeps indicated reduced rates of seal interactions and fish damage in the experimental area above the bridge (figure 3). This effect was only temporary, however, as interaction and fish damage rates returned to maximum levels (one per interview) within two to three days.

In the control area, the AHD screen had no significant effect on salmon damage rates, as expected. Most of the damage from harbor seals occurred at the entrance to Youngs Bay (near the railroad trestle) and on the north side below the old bridge. There was some tendency for damage rates to decline (from 20% of 191 salmon to 16% of 32 salmon sampled), but this difference was not significant ($X^2 = 0.32$, $p = .57$).

Neither did the AHD screen have long-term effects on reducing salmon damage rates above the bridge where it was placed. In the sample taken before AHD harassment began (n = 43), 7% of 254 salmon netted were seal damaged. The

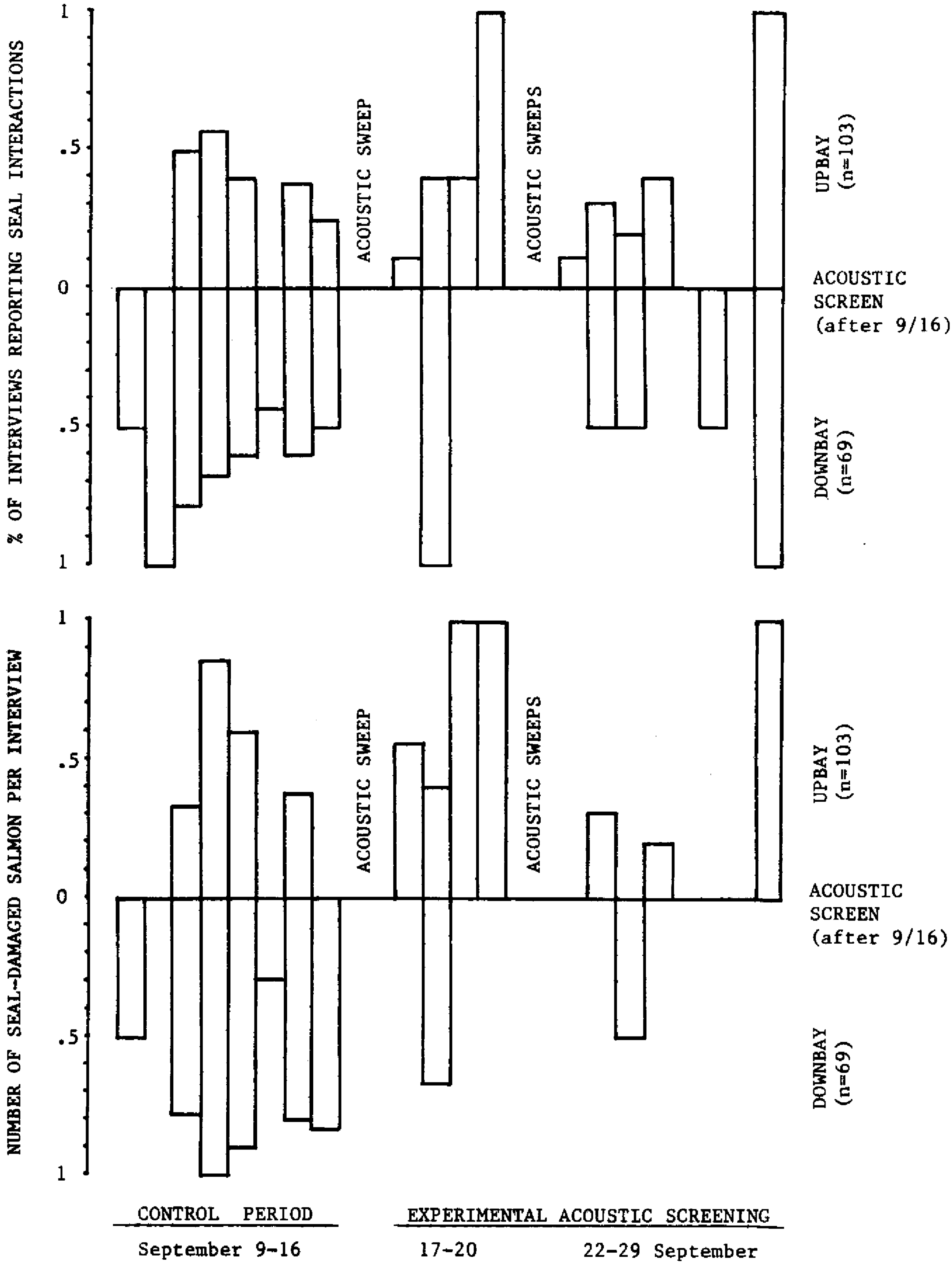


Figure 3. Daily averages on seal/gillnet interaction measures before and during acoustic screening experiment, Youngs Bay, 9-29 Sept. 1983.

damage rate when the equipment was operating was identical--7% of 288 salmon sampled; (X^2 = .002, p = .96) in the 60 trips investigated during the experimental period.

During interviews, fishermen reported seeing at least one harbor seal swimming upstream under the bridge with its head out of water while the devices were operating. This would greatly reduce the amount of sound energy reaching the seal's ears, potentially allowing the animal to pass the AHD relatively unaffected by the sound. Project observers spotted one seal swimming downstream toward the bridge in an area where the AHD signals were strong enough to be audible in air to humans. This seal dove approximately 150 m from the bridge, still headed in the direction of the AHD screen. We also witnessed an interaction in which a harbor seal ate a coho from a gill net set about 300 m above the bridge. Several fishermen reported watching from the boat basin as a seal worked a gill net which was set about 150 m above the bridge.

If we combine all Youngs Bay interview data taken in September, the damage rate from seals was 10.3% of 765 salmon sampled, with chinooks and cohos equally affected. This represents a significant increase over damage samples taken in 1981 (6.7% of 372 salmon) and 1980 (3.1% of 413 salmon) during the month of September in Youngs Bay (Beach et al. 1985).

Comparative Evaluation of Various Seal Harassment Techniques

1984 Columbia River Winter Chinook Season

Six gill-netters fishing the Woody Island drift (Columbia River, zone 2) volunteered to test the various seal harassment techniques during the winter season in late February/early March 1984. Two fishermen were each given AHDs, seal bombs, or shell crackers, plus log forms to fill out for each drift. "Control" drifts resulted when fishermen were awaiting supplies of harassment devices or chose not to employ their devices.

Since the majority of full-time gill-netters on this drift participated in the experimental harassment at the same time, we assumed that seals would choose to feed from the net presenting the least aversive stimulus to them. (Other environmental and fishing influences on seal behavior were assumed to be random with respect to the harassment technique employed.) Therefore the techniques could be ranked according to their effectiveness in preventing fish damage (table 2). Comparisons of pairs were also made using t-tests of fish per drift per day.

The AHD was the most successful method tested, although 9% damage still occurred with the device operating (table 2). Although catches made using the AHD were unaffected compared to no-harassmant conditions (t = 1.11, d.f = 13, p = .14), seal-damaged salmon were significantly reduced (t = 2.59, p <.05). One harbor seal was caught in the net during the second AHD drft made; the only other seal caught and reported was taken during a control drift. A fisherman using the AHD noted that a seal was seen 300 ft (91 m) from the device on the fifth day of testing.

Table 2. Ranking of seal harassment techniques by percent of seal-damaged chinook salmon in sampled gill net catches, Woody Island, winter season, 1984.

		# OF CHINOOKS SAMPLED		
HARASSMENT TECHNIQUE	% DAMAGED CHINOOKS	UNDAMAGED	DAMAGED	SIGNIFICANTLY DIFFERENT FROM
AHD	9.2%	108	11	SEAL BOMBS*
SEAL BOMBS	20.5%	31	8	OTHER/UNKNOWN**
NO HARASSMENT	24.3%	84	27	OTHER/UNKNOWN**
CRACKER SHELLS	36.4%	14	8	ALL OF ABOVE**
OTHER & UNKNOWN	49.1%	29	28	ALL OF ABOVE**

* Chi-square test, $p < .10$ ** Chi-square test, $p < .05$

The fish damage rate using seal bombs (20.5%) was not significantly different from that using no harassment (24.3%) over the course of this fishery (table 2). For the seven days when seal bombs were used, significantly fewer fish were damaged ($t = 1.51$, $p < .10$), but significantly fewer fish were caught ($t = 2.00$, $p < .05$) than on the no-harassment drifts. Using seal bombs, therefore, did not increase the salable component of the catch ($t = 0.11$, $p = .46$).

Drifts in which fishermen shot shell crackers ($n = 9$) or conventional ammunition ($n = 4$) had higher damage rates, 36% of 22 fish and 40% of 5 fish, respectively. The highest damage category, 50% of 52 fish, resulted from 16 drifts in which the fisherman did not log the harassment method used (if any). It is not known whether this omission systematically biases the evaluation results given here.

1984-1985 Budd Inlet Chinook Fisheries

Squaxin Island Tribal fishermen gillnet for fall chinook in the Budd Inlet/Dana Passage area of southern Puget Sound. Chinook salmon migrate during late July through September, bound for the Deschutes River at Olympia, Washington. Both drift gill nets and set nets (anchored nightly at certain locations near shore) are fished to intercept the salmon. The fishery operates from sunset to dawn.

The 1984 season was open from July 31 to September 8. Effort and catches were low the first two weeks, averaging five landings/day of six salmon each. The fishery peaked August 23-25, when a maximum of 31 fishermen caught up to 23.5 chinooks a night; then it diminished in both effort and catches during September. A total of 7619 chinook salmon were sold throughout the season, for a value of $166,222 to the fishermen. Ninety-five percent of the salmon were landed by drift-netters. Similar landing patterns were found in 1985. Peak catches occurred somewhat later (August 27-30), and fewer fish were caught overall (6980).

Fishermen have complained that seal interactions have been increasing in the last few years (T. Tynan, Squaxin Island Tribe, Shelton, Washington, personal communication). The Squaxin Tribal Fisheries office supplies seal bombs from the California Seal Control Corporation to member gill-netters (T. Tynan, personal communication), who also use ordinary firecrackers occasionally to repel seals.

Harbor seals which interact with this fishery could originate from one of several haulout areas in southern Puget Sound. The largest nearby haulout group, with an average of 120 seals (Calambokidis et al. 1985), uses log rafts in Henderson Inlet which are less than three miles from the Dana Passage fishing area. Another group of seals, averaging 27 animals (Calambokidis et al. 1985), hauls out on log booms in Budd Inlet. The high count of harbor seals in southern Puget Sound is about 700 animals maximum (Calambokidis et al. 1985).

Data on the baseline rate of seal interactions were collected by interviews with fishermen (Beach et al. 1985). Gill-netters using experimental seal harassment techniques were excluded from this sample, but a large percentage of other fishermen landing at Boston Harbor were interviewed daily by the Tribal salmon sampler. In 1984, from 41-93% of drift net-caught salmon landed per week (47% of the total catch) and from 28-100% of the set net catches per week (59% of the total) were sampled. Over 300 interviews were completed for marine mammal-fisheries interactions.

In 1984, seal damage rates to drift-netted chinook ranged from 61.5% unsalable the first week to 1.6% the week of peak catches (table 3). Throughout the season 213 chinooks were projected unsalable because of seal damage. This was 2.9% of the total catch and reduced fisherman income by $4670 (table 3). Damage rates to set-netters were initially zero and ranged to 54.5% the last week of the season. The 42 chinook projected unsalable were valued at $750 and represented 11.3% of the set net catch.

Interestingly, seal damage rates for the 1984 season were approximated by samples taken during the third week of the fishery (August 12-18) for both gear types (table 4). This was one week before peak run (when damage rates became minimal due to the large number of chinooks caught).

In 1985, 140 interviews with drift-netters represented 29% of the fishing trips and 30% of the catch. Chinook salmon that were unsalable because of seal damage amounted to 3.1% of fish sold, which is not significantly different from the 2.9% damage rate the previous year. This projected to 162 salmon valued at $2946 (table 3). Only four interviews were collected from set-netters, and these were taken the first and last weeks when seal damages were expected to be extreme. Thus the 26% damage rate measured is considered maximal, and no estimate could be made for the full season.

Up to eight Squaxin drift-netters and two set-netters volunteered to test seal harassment techniques in 1984. They were randomly assigned to use either AHDs or seal bombs, shoot their own guns, or use no harassment for five nights in a row, whereafter they rotated to the use of another method.

Because the volunteer gill-netters were instructed to use the assigned harassment methods in ways that suited their fishing techniques, and because fishing effort differed between gill-netters, unequal sample sizes were achieved for the various methods. The largest sample, 124 drifts, occurred under no-harassment conditions. AHD drifts amounted to a sample of 103. Both these samples were sufficient to analyze by week over a four-week period for trends in damage rates which might be related to habituation of the seals to the sound stimulus provided by the AHD. Gill-netters used seal bombs during 24 drifts, ran the net with their boats on 15 drifts, and ran their nets throwing seal bombs on 13 drifts. These samples were sufficient for analysis over the entire period. Only two shooting drifts were sampled, so these were dropped from the analysis.

The effects of the various methods were ranked according to the percent of damaged chinooks in the catches (table 4). The AHD was the most successful method, with a damage rate of 1.9% compared to 5.9% damage in the absence of seal harassment. Methods already in use in the general fishery (as evidenced by the 3% damage rate obtained from interview data during the test period) were also more successful than no harassment (table 4). Running the boat along the net ranked next, although the 3.8% damage was not significantly different from either the methods used by the fleet under baseline conditions or from no harassment. Running the net was a significant improvement over using seal bombs, however, which ranked last at 18.3% chinook damage (table 4).

Table 3. Unsalable chinook salmon remains in gill nets as a percentage of chinook sold, and projected total losses due to harbor seals, by gear type and week, Budd Inlet, July-September 1984-85.

	1984 DRIFT NET				1985 DRIFT NET			
WEEK	% UNSALABLE	PROJECTED UNSALABLE			% UNSALABLE	PROJECTED UNSALABLE		
		FISH	POUNDS	VALUE		FISH	POUNDS	VALUE
1	61.5%	9	126	$ 213	22.2%	12	193	$ 319
2	9.5%	31	480	$ 746	4.1%	26	426	$ 656
3	2.9%	34	499	$ 811	1.2%	8	125	$ 160
4	1.6%	50	642	$1133	1.8%	29	470	$ 480
5	3.1%	65	857	$1306	4.0%	88	1365	$1331
6	4.5%	25	314	$ 460				
TOTAL	2.9%	213*	2867*	$4669	3.1%	162*	2580*	$2946

*Because of rounding, the column does not total.

Table 4. Ranking of seal-harassment techniques by percent of seal-damaged chinook salmon in sampled gill net catches, Budd Inlet, 1984.

		# OF CHINOOKS SAMPLED		
HARASSMENT TECHNIQUE	% DAMAGED CHINOOKS	UNDAMAGED	DAMAGED	SIGNIFICANTLY DIFFERENT FROM
AHD	1.9%	633	12	NO HARASSMENT**
BASELINE	3.0%	2976	91	NO HARASSMENT**
RUNNING NET	3.8%	125	5	SEAL BOMBS**
NO HARASSMENT	5.9%	690	43	SEAL BOMBS**
RUN NET & BOMB	7.5%	62	5	SEAL BOMBS*
SEAL BOMBS	18.3%	85	19	ALL OF ABOVE*

*Chi-square test, p <.10
**Chi-square test, p <.05

The possibility that the harassment methods influenced chinook catches and affected the damage rates in this manner was investigated by comparing catches per drift (including damaged and undamaged fish). The mean catch using the AHD (6.3 chinooks) was not significantly different from the control (5.9 chinooks/drift). Running the net raised the average catch to 8.7 salmon, a significant increase over no harassment ($t = 1.71$, d.f. = 137, $p<.05$). Using seal bombs while running the net negated this effect (5.1 fish/drift), whereas using bombs alone significantly lowered the catch to 4.3 salmon/drift ($t = 1.32$, d.f. = 146, $p<.10$).

During the first three weeks of AHD testing, only one salmon per week was seal damaged in the sample. Nine salmon were damaged the fourth week. This damage rate (4.1% of 223 fish) was not significantly different from either the no-harassment sample ($X^2 = 0.50$, $p = .48$) or the general fishery ($X^2 = 0.07$, $p = .79$) rate for the same period.

In 1985 the experiment was repeated, comparing only the AHD versus no seal harassment. Overall, 5.1% of 475 salmon caught using the AHD were seal damaged versus 8.5% of 424 fish caught without the device. Although the chi-square for this comparison was significant ($X^2 = 4.25$, $p<.05$), sample results among the five fishermen reporting were highly variable. One had no seal damage when using the AHD, and two had damages not significantly different from the rest of the fishery (3.1% and 3.6%). Two fishermen reported higher damages when using the AHD: 15% and 18% of their respective catches.

Because of this variability, we treated "fisherman" as an independent variable and examined the gill-netters' damage rates (normalized by the arcsine transformation) using ANOVA. This analysis showed an insignificant AHD effect ($F = 1.18$, $p>.10$). A Wilcoxon rank sum test of fish per drift revealed that catches were significantly higher when using the AHD ($z = 2.28$, $p<.05$), but the number of fish damaged did not differ significantly ($z = 0.12$, $p = .45$).

In order to compare the financial benefits to this fishery of using various seal-harassment techniques, we projected the damage rates that resulted from our 1984 experiments to the total catch landed by those fishermen not involved in experimental harassment. Data were sufficient to project the costs of seal damages for only four weeks (excluding the first and last week) and on a weekly basis for only two harassment conditions: none and AHD. The other harassment methods were evaluated over the entire four-week period.

Our estimate of the baseline loss during this period was $3030 for the entire nonexperimental fishery. Using no seal harassment would have resulted in an estimated $5729 loss. The damage rate obtained using the AHD would project to a $1351 loss. Thus, if everyone in the fleet experienced the same benefit as our AHD sample, we would predict a savings to the fishery of $1679 over baseline damages. Most of the loss projected ($1013) stemmed from damage rates measured the final week, when using the AHD resulted in no significant benefit over the traditional techniques used by the fleet or using no seal harassment at all.

Running the net resulted in a greater projected seal damage loss ($4592), but this was less than if no harassment had been used. Seal bombs produced the highest estimated loss, $17,535. (This latter estimate is no doubt exaggerated, since the gill-netters would probably not have thrown seal bombs unless they had perceived seals to be a problem during these drifts.)

Discussion

Acoustic Harassment Device--Individual Net Protection

In no fishery investigated was the AHD completely successful in protecting salmon throughout a 150 fm (274 m) or 250 fm (457 m) gill net. Although seals initially seemed to maintain 100 m distance from activated AHDs, several seal observations were subsequently made between 10 and 50 m from the device. Awbrey and Thomas (1984) measured the underwater sound level of a 12 kHz swept-pulse AHD, which averaged 135-140 dB at about 100 m, and attenuated about 6 dB with each doubling of distance in water 20-30 m deep. These authors theorized that physical discomfort in pinnipeds would occur 25-50 m from the sound source. They also cautioned that exposure to higher intensities could cause hearing loss (deafening the animals to this frequency band) which would be impossible to distinguish behaviorally from "simple acclimation" (Awbrey and Thomas 1984).

In most fisheries where we tested the AHD, salmon damage was initially reduced while the machine was on. In nightly gill-netting at Budd Inlet, and during the 5-day/week winter season on the Columbia, the AHD was relatively effective for the first three weeks of testing. In the 1982 ODFW test fishery (conducted on alternate days), salmon damages were lower during AHD drifts for at least a month (Mate, Brown and Greenlaw 1983). After longer periods of use, the AHD either showed no significant effect on damage rates, or significantly more fish damage occurred while the machine was on. This latter result was found for the Columbia River coho fishery and the ODFW test fishery in 1984, as shown in figure 4.

These observations could be explained by one or more of the following hypotheses: (1) seals habituate to the sound stimulus; (2) individual seals have different tolerances to the sound, possibly because of hearing insensitivity; (3) the sound exposure is not painful to seals at these distances but merely startling, and some animals learn the limits of danger associated with the stimulus; or (4) the sound signal becomes a conditioned reinforcer for seals to find and eat fish in the net.

That the AHD influenced seal behavior suggests that its startle effect could be useful in certain situations. In order to postpone habituation/learning on the part of the seals it seems prudent to vary the stimulus by moving the sound source and by increasing the interval between pulses. (Although some fishermen in this study did this on their own initiative, these variables were not controlled for in our design.) Ideally the transmission could be made contingent upon the seal's behavior to preserve its effect as a negative reinforcer.

For the drift gill-netter wishing to purchase an acoustic harassment device, a favorable cost/benefit ratio would seem to depend on the seal-damage losses the fisherman could expect in three to four weeks of fishing in one area. In none of the fisheries we studied were individual short-term losses that valuable.

Imagining the introduction of this technology to high-volume, high-damage salmon gill net fisheries, we would expect the first fishermen to use it to have a competitive advantage over their neighbors. Continued or widespread AHD use against the same group of seals we expect would result in behavioral adaptions on their part which would negate the AHD's effectiveness as a net protector.

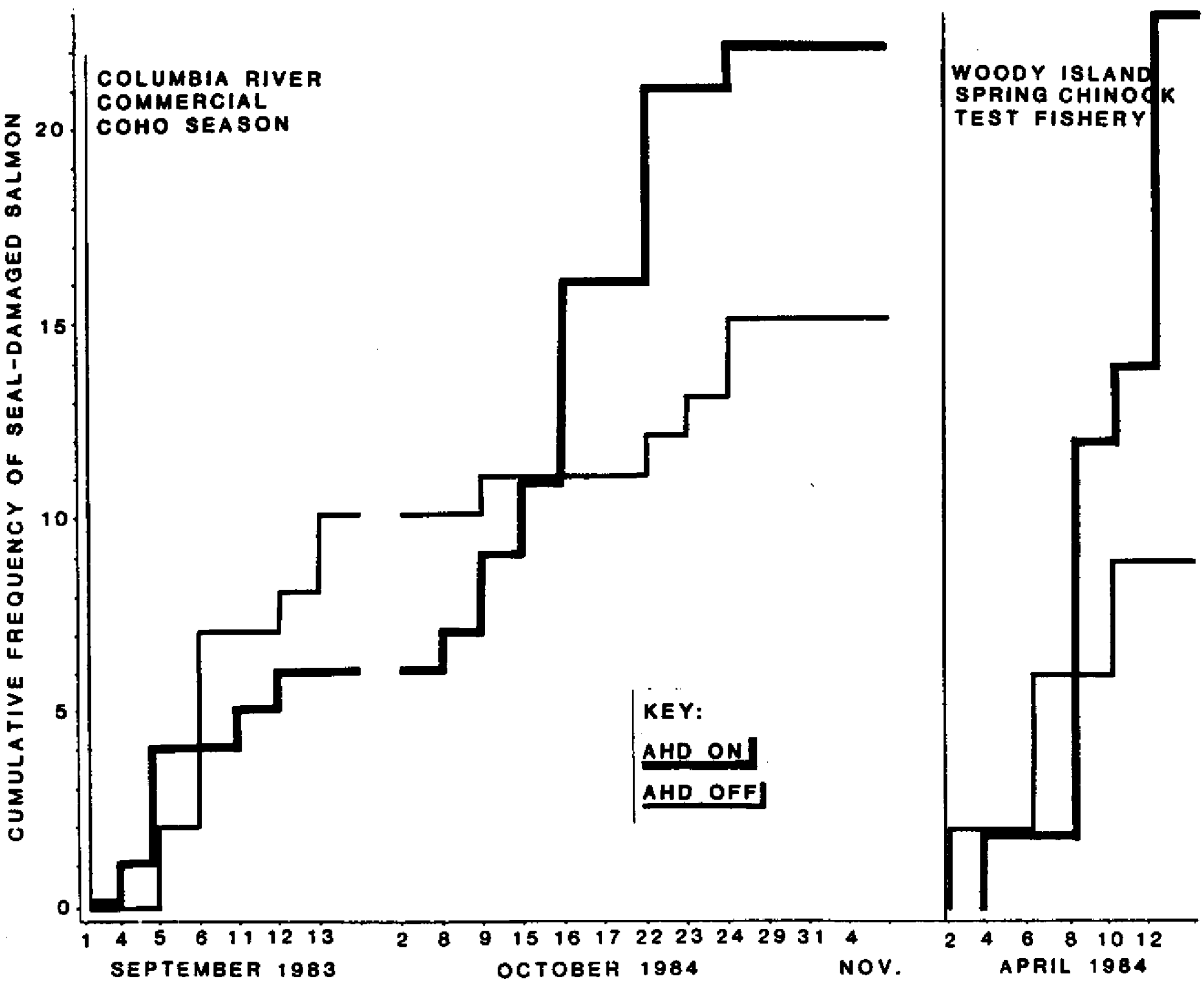


Figure 4. Daily catches of seal-damaged salmon, AHD on vs. AHD off.

Other Seal Harassment Techniques

Running the boat along the net seems to increase catches. This can be effected by manually picking individual salmon out of one section of net while the rest of the net continues to fish. WDG participated in an experiment with Tim Tynan, Squaxin Fisheries, in which chinooks known to be netted by their splashing or by dipping movements of the net were raised and their location marked with flagging, then returned to the water still gilled in the net. One marked fish was eaten by a seal prior to retrieval of the net. This suggests that "running the net" would have increased the catch and reduced the seal damage rate.

As in the Columbia River fisheries studied in 1980-82 (Beach et al. 1985), the damage rate was higher when seal bombs were used than when they were not. Two possible explanations for this finding are that (1) seals have already damaged salmon before they are seen and the seal bombs are used or (2) the sound of the explosion deters salmon from entering the net. The latter hypothesis is supported by the fact that catches were reduced in the seal bomb samples from the Woody Island and Budd Inlet fisheries. Our experimental design was not sensitive enough to test hypothesis (1), so it is not known whether seal bombs prevent further damage once some has occurred.

Acoustic Harassment Device--Driving and Exclusion of Seals from Fishing Areas

The only indication that the AHD was successful in driving seals during testing in the Youngs Bay fishery was the report from one fisherman of a seal travelling ahead of the device at great enough speed to break through a gill net. We have no evidence that any seals were driven completely out of the test area during the AHD sweeps.

The fact that seals were not seen from the boats using the AHD equipment might mean that seals (if present) avoided the stimulus. Although our boats were moving at slow speed to keep the transducers submerged, it is possible that seals could have remained underwater, hidden behind vegetation or topography, or doubled back behind the boats. Hanan and Scholl (1985), using similar equipment by the same manufacturer, reported that three AHD sweeps of the Klamath River were required to move one individual harbor seal downriver, while another avoided herding throughout several sweeps.

We presented observational evidence that some seals are able to tolerate the stationary sound stimulus up to 150 m from the source underwater and apparently at much closer distances on the surface with their ears out of water. Trial-and-error learning may have been involved with the seals which passed under the bridge when the AHD units were operating. Routes were possible around the transducers at greater distances at the ends of the bridge (figure 2) if the seals had entered shallow water and negotiated between pilings. Hanan and Scholl (1985) observed two seals attempting to pass an activated, anchored AHD transducer by swimming on the far side of a sand bar at low tide. These authors also reported that one seal succeeded in passing the AHD to move upstream on the Klamath.

Some fishermen believed that only three seals were active in the Upper Youngs Bay area during our AHD experiments. If even a few seals are not deterred by the AHD or can learn to avoid aversive stimuli, seemingly this is sufficient to cause damage to netted salmon at rates significantly higher than those measured in previous years.

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Acoustic Harassment Testing in the San Francisco Bay Pacific Herring, *Clupea Harengus*, Gill Net and Purse Seine Fisheries

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California Department of Fish and Game

The National Marine Fisheries Service and the California Department of Fish and Game are testing nonlethal methods of preventing marine mammal/fishery conflicts to reduce marine mammal mortality and the loss of caught fish. Spawning the Pacific herring, Clupea harengus pallasi, are taken by gill net and roundhaul gear in San Francisco Bay and several other large bays in northern California during the winter months. California sea lions, Zalophus californianus, and Pacific harbor seals, Phoca vitulina richardsi, have been observed to interact with these fisheries (Miller et al. 1983). In 1980, Miller estimated that pinnipeds in San Francisco Bay removed an estimated 44,000 lb of Pacific herring from gill nets and 28,000 lb of Pacific herring from pursing roundhaul nets.

Two underwater acoustic harassment devices (AHD), developed by Dr. Bruce Mate of Oregon State University (Miller 1983), were tested in the Pacific herring fisheries of San Francisco Bay. The sound emitted by these AHDs (one at 12 kilohertz [kHz] and one at 17 kHz) is within the hearing range of pinnipeds and shows some promise of driving pinnipeds away from fishing vessels. Cracker shells (CS), which are similar to firecrackers but fired from a shotgun, were also tested in the hope that they might startle and drive away the sea lions or have a synergistic effect with the AHD to drive away sea lions.

The tests were conducted on February 15-16, 1983 aboard the R/V Pandalus using the 12-kHz or 17-kHz AHDs and cracker shells in an attempt to keep pinnipeds away from commercial fishing gill nets. An AHD was used within 15 to 20 m of the gill nets, when pinnipeds were observed foraging and the fishing vessel operator was advised of the intended research. All pinnipeds observed during these tests were California sea lions foraging at the end of the net farthest from the fishing vessel. Harassment was conducted from the R/V Pandalus as close to foraging animals as possible, and the AHD was operated between 30 and 60 seconds in a random pulse mode during each harassment. Both adult male (AM) and nonadult male (NAM) sea lions reacted to the first pulse of the 12-kHz AHD with an immediate dive response. Subsequently, a few NAM were observed leaving the area swimming on the surface. Each time the device was turned off, AM were observed near the middle of the net (between the R/V Pandalus and the fishing vessel) within a few minutes.

When AM were tested with the 12 kHz and 17 kHz simultaneously, an immediate dive response was observed and was followed by recurrent sightings in the net vicinity. Surface duration, however, was obviously shortened, and dive periods seemed to be extended.

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There were only a few occasions when CS could be used safely because of the close proximity of fishing vessels. One of those tests followed by a 30-second AHD pulse produced the best results, since there were no further sea lion sightings for the remainder of the net pull (approximately 15 minutes).

Three roundhaul sets were observed on February 17 aboard a commercial herring purse seine vessel. The 17-kHz AHD was used with CS to move sea lions out of the pursed net while the herring were being concentrated for brailing. During the first two sets, CS were exploded at the center net whenever an animal surfaced, and then the AHD was turned on for 30 seconds. During each of the first two sets, at least one sea lion stayed in the net after AHD harassment. When brailing began, a special effort was required by the fishermen to get the animal out. During the third set, about ten CS were exploded at close as possible to the individual sea lions and were followed by a 30-second AHD pulse. All seven animals were cleared and kept out of the net until after the herring had been brailed. These tests show that sea lions respond, at least initially, to acoustic harassment. They show that sea lions can be driven away from fishing operations, especially when an AHD is combined with the use of CS. Because of the short duration of the tests, we do not know if these responses will be long term or lasting and would recommend additional testing in these fisheries.

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Acoustic Harassment Testing in the Klamath River Salmon Fishery

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During September 1982, two days of acoustic work were conducted on the Klamath River in conjunction with the California Department of Fish and Game's salmon seine and tag operations. Harbor seals, Phoca vitulina, are suspected of seeking out tagged salmon that are perhaps more vulnerable to seal predation after tagging. A 12-kHz acoustic harassment device (AHD) was used to herd harbor seals downstream of the seining site in an attempt to eliminate predation on tagged salmon.

Acoustic work was conducted each day after seining operations had begun and harbor seals were observed in the vicinity of the seining site. An observer on a cliff overlook stayed in radio contact with the skiff carrying the AHD and relayed sightings of seals. When a seal was sighted, the skiff swept downriver in an S-shaped pattern, starting well above the seine site and continuing to a designated anchor point below the seine site. The skiff was then anchored and the AHD was operated continuously to produce an acoustic barrier throughout the remainder of the tagging operation. Cliff observation for seals moving upriver of the acoustic barrier continued.

At least four harbor seals were observed in the vicinity of the seine site on the first day. The AHD was used in an attempt to move these animals downriver. At the end of the first sweep, one seal with dark pelage remained upriver of the area swept. Two more sweeps of the seine vicinity were required to move this animal downriver. When this was accomplished, the group of animals was kept downriver of the designated anchor site for a period of three hours as verified by the cliff observer.

The anchor site was located at midriver approximately 200 m below the seine site at midriver (figure 1). The main river channel was on the south side of the skiff, and there was a shallow sandbar between the skiff and the north shore at low tide. All observed attempts by the seals to bypass the activated AHD were made between the sandbar and the north shore. Two of the seals attempting to move past the skiff in this manner were observed frequently looking in the direction of the skiff and then turning back when reaching the end of the sandbar just upriver of the skiff. No salmon were observed eaten during the testing period. The AHD was turned off about 1430 hours, and at 1445 hours three seals were observed back in the vicinity of the seine site.

On the second day, an initial sweep of the seining vicinity moved four seals downriver to the anchor location. Within 15 minutes, a fifth seal, not previously sited, was observed in the seining vicinity. Several sweeps to move this animal downriver were attempted with no success, and so the skiff was anchored at the same anchor sight with four seals observed downriver. Sometime later, a seal with dark pelage moved upriver past the sound barrier to

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join the seal that had avoided herding, and the two seals were each observed eating a salmon near the seining site during this test period.

From this test, we might conclude that the AHD used without any other type of harassment is only moderately successful with harbor seals in a river situation. Because the test lasted only two test days and involved only nine seals, we do not feel that this was a conclusive test and recommend additional testing in this type of environment.

Effects of Cracker Shells on California Sea Lions, *Zalophus Californianus*, Interacting with the Southern California Partyboat Fishery

John Scholl and Doyle Hanan
Calilfornia Department of Fish and Game

Introduction

Two species of marine mammals interact with southern California commercial passenger fishing vessels (partyboats) (Miller et al. 1983). They are California sea lions, Zalophus californianus, and in some cases Pacific harbor seals, Phoca vitulina richardsi, which have been observed to remove bait and hooked fish from fishing lines. Partyboat skippers also complain that the presence of California sea lions causes the number of fish being caught to drop off or stop completely. Miller estimated in 1980 that sea lions removed 11,812 hooked Pacific bonito (78% of the total loss) and large numbers of several other fish species from partyboat fishing lines.

The California Department of Fish and Game (DFG) and the National Marine Fisheries Service (NMFS) are both interested in nonlethal methods of controlling marine mammals to reduce or eliminate their interaction with fisheries. This report reviews the use of a small explosive charge called a cracker shell as a potential method of keeping marine mammals away from fishing vessels.

Methodology

Two types of cracker shell (CS) were used in this research. Originally designed to scare birds away from farm crops, the first type was a small explosive shell fired from a 12-gauge shotgun. The shell explodes in the air or on the water surface and has a range of 50 to 75 m, depending on wind conditions. The objective of this explosive is to startle and scare the marine mammal away from the fishing area. The second type of CS is fired from a 6-mm pistol using a blank cartridge. The pistol is less obstrusive, allowing the skipper to carry it in a pocket; however, it is not as accurate as the shotgun type and has only a 25-m range. A propelled whistling rocket was also tested but proved to be unreliable due to its unpredictable flight path.

Since San Diego-based partyboats have the highest sea lion interaction rate in California (Miller et al. 1983), 76% of our sampling effort was concentrated off San Diego and the remainder on partyboats out of the Long Beach and Dana Point landings. Trips aboard partyboats reporting marine mammal interactions were prearranged by phone. The observer carried all necessary CS equipment aboard each fishing vessel and skippers were asked to announce to the passengers the planned use of the CS. The skippers were further instructed in the use of the CS and asked to fire the CS during all marine mammal interactions. The observer monitored total fish caught, fishing time at each location, and all sea

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lion sightings even if no interactions occurred. After fishing trips during which CS had been used in marine mammal interactions, public opinion surveys were conducted to evaluate the acceptance of CS.

Results

Twenty-nine partyboat trips were sampled during 1982-83. In general, skipper cooperation was good, but during two sampling trips, the skippers seemed to avoid using CS unless specifically asked to do so. One skipper in San Diego refused to allow CS to be used aboard his vessel although the observer had already been permitted aboard and had assumed that the skipper would cooperate. That skipper claimed he had previously tested the shells and felt that they were ineffective. A skipper from the Los Angeles area reported using CS, acquired from a source other than the DFG, and claimed that the shells were dangerous. He based his conclusion on a test he made himself when a CS exploded next to fishermen on deck.

Most of the testing was conducted in May and July although the greatest number of interactions per trip was recorded in May and August. During CS testing, San Diego boats had the highest catch rate with a mean of 1.69 fish per hook (n = 22), while all other areas combined had a mean of 1.00 fish per hook hours (n = 7). No significant correlation (R = 0.18) was found between the number of fish caught per hook hour (fishing success) and the number of sea lion sightings within 100 m of the vessel (figure 1).

The mean resighting time for a sea lion within 100 m of the partyboat following a CS explosion was 7.5 minutes (n = 56). If CSs are defined to be effective when there were no sea lion sightings within 100 m of the vessel for 15 minutes or longer following the explosion, then it was effective 27% (n = 85) of the time. However, as the effectiveness of CS increased, fishing success did not increase (figure 1). Furthermore, as the number of CS used per trip increased, the number of effective shots did not necessarily increase (figure 2), perhaps indicating a skill vector in the skipper's use of CSs or some individual tolerances to CS by sea lions. The nearness of the explosion to the animal is another variable likely to determine the effectiveness of CS or perhaps the shooting skill of the skipper, but our sample size for this variable is small (figure 2). Although effectiveness is difficult to quantify, the opinion of our staff is that adult males, especially large adult males, seemed less influenced by or even oblivious to the effect of the CS explosion.

Public acceptance of CS appears to be nearly unanimous, with 95% (n = 97) of those surveyed condoning it (table 1). A majority (75%) of the surveyed group also felt some control was needed and that the device would be acceptable on a regular basis. There were no obvious relationships between opinion survey results and either fishing success or the number of CS used per trip. Catch composition does not appear to be related to sea lion interactions except that interactions averaged 20.6 per trip when yellowtail (*Seriola dorsalis*) was a catch component and 14.4 per trip when Pacific mackerel (*Scomber japonicus*) was a catch component. The overall mean was 10.6 (n = 29) sea lion sightings per trip, and Pacific mackerel was the top fish species caught during the sampling trips.

Discussion

Although the CS is at present considered to be effective on a limited basis, the following points need consideration. (1) The CS is nonlethal, and currently the partyboat skippers have no legal recourse when harassed by seal lions but to move their vessel. (2) As skippers become more proficient with the CS, the effectiveness of the device may improve. (3) The user public would accept CS right now.

In most circumstances, the CS does not appear capable of reducing interactions with partyboats for a reasonable amount of time, and the number of shells needed to harass animals effectively does not seem to be economically feasible. CS harassment coordinated with other nonlethal devices such as underwater acoustic sound harassment may be effective. Since only limited acoustic harassment research has been conducted at this time, we recommend additional testing of CS and acoustic harassment devices.

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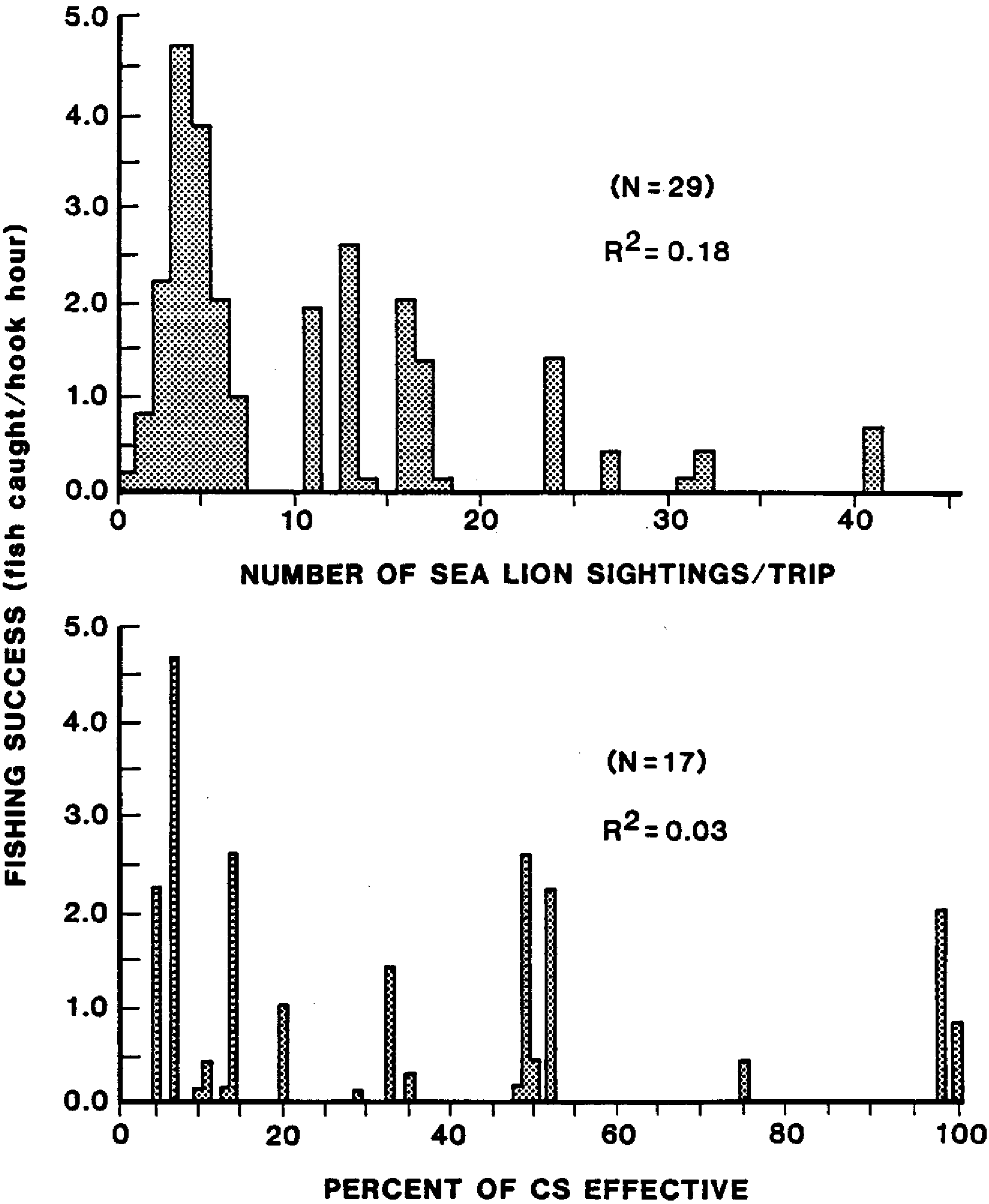

Figure 1. Fishing success (fish caught per hook hour) is plotted against the number of sea lions sighted (above) and (below) against cracker shell effectiveness (no sea lion sightings within 100 m for 15 minutes after the explosion).

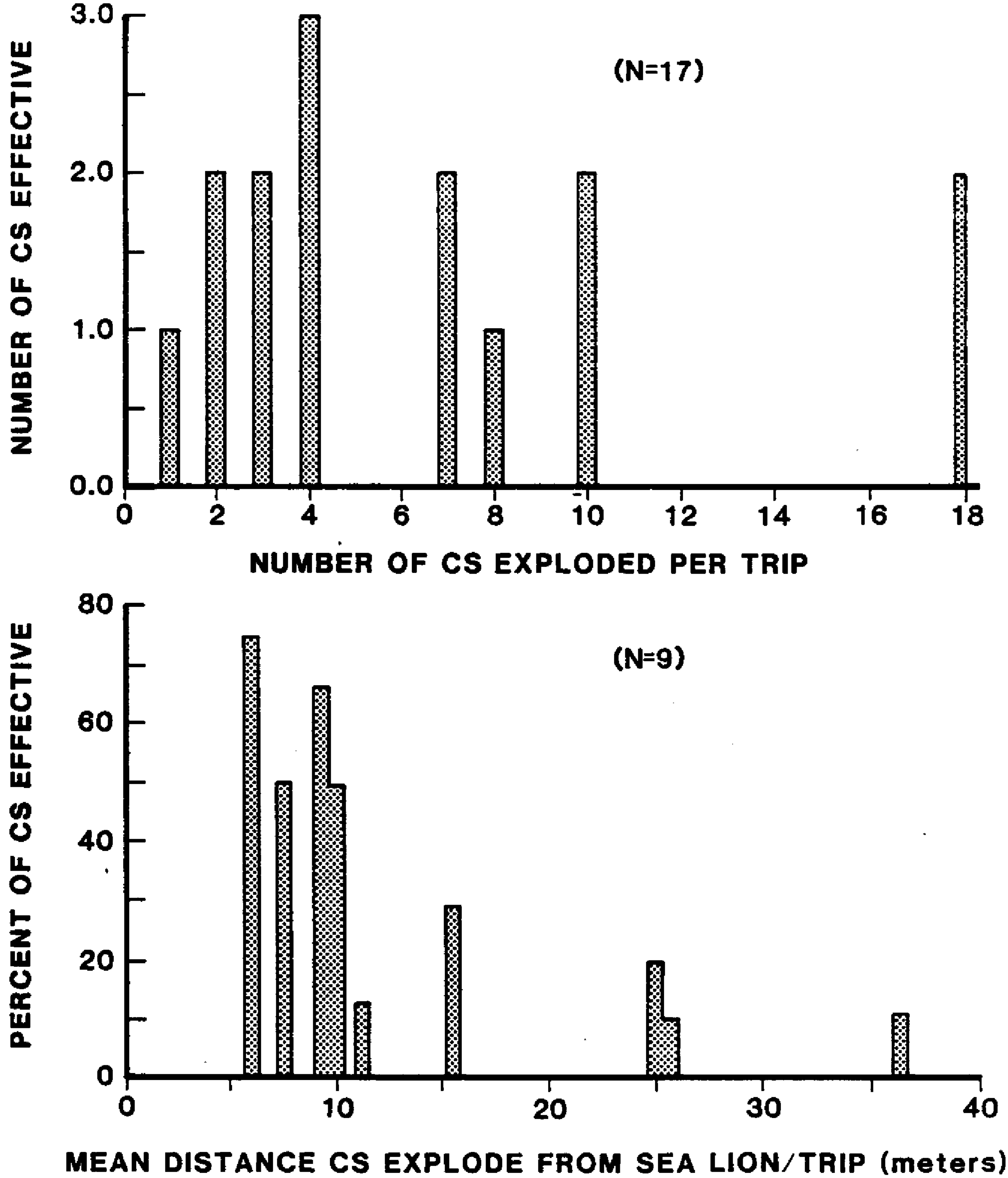

Figure 2. Total number of effective (no sea lions within 100 m for 15 minutes) cracker shells plotted against total number of cracker shells plotted against the mean explosion distance from the sea lions.

Table 1. Public Opinion Survey of Cracker Shell Use on Partyboats

Date	Location	No. C.S. used	Total Fish caught/ hook hour	No. people surveyed	Device bothersome		Control needed		Acceptable regularly	
					Yes	No	Yes	No	Yes	No
5-28-82	San Diego	22	0.44	5	0	5	5	0	1	4
6-12-82	Long Beach	2	0.83	12	N/A	N/A	9	3	9	3
6-25-82	San Diego	3	4.71	10	0	10	8	2	10	0
6-29-82	San Diego	10	1.01	10	0	10	5	5	10	0
6-30-82	San Diego	5	2.26	10	0	10	6	4	6	4
7-13-82	San Diego	4	2.22	10	1	9	5	5	5	4
7-22-82	San Diego	2	0.38	5	0	5	3	0	4	0
8-5-82	San Diego	0	2.01	4	N/A	N/A	1	3	1	3
1-20-83	San Diego	5	0.70	3	2	1	1	2	1	2
7-19-83	San Diego	4	0.26	8	0	8	7	1	6	2
7-21-83	San Diego	7	0.15	9	0	9	9	0	9	0
8-11-83	San Diego	10	0.13	15	2	13	14	1	14	1
8-12-83	San Diego	5	0.15	12	0	12	11	1	11	1
TOTALS 13 days		79		113	5	92	84	27	74	24
% Yes					5%		76%		76%	
% No					95%		24%		24%	

Acoustic Harassment and Cracker Shell Tests in the Southern California Partyboat Fishery

John Scholl
California Department of Fish and Game

In January and April of 1983, a 12-kHz acoustic harassment device (AHD) was tested in the partyboat fishery near San Diego. The first test, January 5, took place approximately three miles west of Point Loma shortly after the partyboat drifted over a surface school of Pacific bonito, Sarda chiliensis. One adult male (AM) and one nonadult male (NAM) were observed consuming Pacific bonito within 25 m of the partyboat and removing hooked fish from fishing lines. The AHD was turned on for 30 seconds with no noticeable response from either of the animals, which continued to eat fish at the surface. A cracker shell (CS) was exploded within 3 m of the sea lions, causing an immediate dive response. The AHD was then turned on for 30 seconds. One minute later, the sea lions were observed surfacing 80 m from the vessel and moving away. When fishing slowed, the vessel moved and no further interactions occurred on that trip.

During the second test trip on January 20, one and a half miles offshore of Pacific Beach, a NAM was observed within 25 m of the partyboat. Because fishing was poor and there had been no interactions with the animal, the devices were not used until it was determined that the NAM had some desire to stay in the vicinity. At 0940 hours, a CS was exploded near the animal immediately followed by a 30-second AHD harassment. The animal dove and at 0943 hours was observed 90 m from the vessel. At 0949 hours another CS was exploded near the animal, followed by AHD harassment. At 0951, the sea lion was observed at 75 m, but moving toward the vessel. The behavior of the animal had changed to extremely short surface periods which did not allow for effective CS harassment. Fishing continued to be poor and the vessel departed shortly thereafter.

There were too few interactions on the other trips to warrant use of harassment, but these two tests suggest that CS and AHD used in combination may effectively move sea lions away from fishing vessels, at least for short periods of time. More extensive research is recommended.

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Acoustic Harassment Devices Tested in Combination with Cracker Shells on Pinnipeds Interacting with the Southern California Partyboat Fishery

John Scholl and Doyle Hanan
California Department of Fish and Game

Introduction

Miller et al. (1983) documented that California sea lions, *Zalophus californianus*, and Pacific harbor seals, *Phoca vitulina richardsi*, interact with southern California commercial passenger fishing vessels (partyboats) by removing fish from fishing lines. Because of increasing complaints about fish losses and pinniped injuries, a study was initiated to seek solutions to the conflict. The study was conducted by the California Department of Fish and Game (CDFG) and the National Marine Fisheries Service (NMFS). The emphasis of the program was to produce an effective nonlethal means of keeping marine mammals from interacting with fishing operations.

Cracker shells (CS), which are exploding projectiles fired from shotguns, were initially tested during 1982-1983 and found to be marginally successful at driving sea lions away from boats which were fishing (Scholl and Hannan, "Effects of cracker shells on California sea lions," and Scholl, "Acoustic harassment and cracker shell tests in the southern California partyboat fishery," both in this volume). Acoustic harassment devices (AHD), which transmit noise under water to drive marine mammals away from fishing operations, were also tested in California fisheries with moderate success (Mate and Miller 1983, Scholl, in this volume). To test the effectiveness of combining CS with AHD to drive pinnipeds away from fishing vessels in the partyboat fishery, a study was conducted from March through September of 1984. The results of that study are presented in this paper.

Materials and Methods

AHDs used for this study were originally developed by Dr. Bruce Mate of Oregon State University and Mr. Charles Greenlaw of CMI-Cascade, Inc., to keep harbor seals away from salmon spawning areas. Each AHD is composed of an underwater transducer which transmits sound generated by a signal production box using 110 AC power. Following is a list of AHDs used in this study; they were interchanged frequently during the tests, since each unit broke down at least once.

AHD Device Name	Sound Level Emitted
12k	12 Kilohertz (kHz)
17k	17 kHz
12wb	12-17 kHz
212r	12 kHz

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The tests were conducted aboard partyboats as they went about their daily fishing operations. Trips were prearranged by the observers to focus on fishing areas reported to have high sea lion depredation rates. Test equipment, including an AHD, a shotgun, CS, and a tape recorder, was taken aboard by the observer. Skippers were asked to announce to the passengers at the beginning of the trip that DFG personnel were aboard and going to be testing AHD and CS. The skippers were also asked to fire the CS with the shotgun during sea lion interactions.

The AHD signal production box was placed in an easily accessible location on the boat. At each fishing site the transducer, with lead weights attached for stability, was lowered into the water to a level well below the vessel's draft (5-7 m), thus allowing the sound waves to emit in all directions. Catch rates by fish species and incidents of catch depredation by sea lions were recorded on the tape recorder.

When a sea lion was sighted within 100 m of the vessel, the observer recorded the time, species, age class, and distance from the fishing vessel. When the target animal was within range of the shotgun (<50 m), the skipper was asked to shoot the shotgun with the intention of landing the CS as close as possible to the animal without hitting it. The AHD was turned on immediately following the CS explosion, and the animal's reaction and movements, especially inside the 100 m perimeter, were recorded.

The observer recorded the time from firing the CS (or activating the AHD when it was used alone) until return of the same pinniped species (of the same age class) within the 100-m perimeter of observation. Animals observed beyond 100 m of the vessel were not considered interactive and were not recorded. Each firing of the CS followed by use of an AHD was considered a paired test. Since the vessel changed location depending on the skipper's view of fishing success, not all tests lasted the same amount of time, and on 33 occasions during the 418 tests, the skipper changed fishing location before 20 minutes had elapsed during a test. Because sea lions were kept away from the boat at least until the boat departed, those data were included in the analysis.

At the end of each test trip, the observer conducted a survey of the passengers' observations and their opinions on the use of AHDs and CS.

Results

Data were gathered primarily to explore the effectiveness of CS paired with AHDs, but occasionally only AHDs or only CS were used to drive the sea lions away from the partyboat. There were 418 total interactions during which either an CS or an AHD was used. Of those interactions, 209 involved an AHD and CS used in combination; 66 involved CS used alone; and 143 involved an AHD used alone.

Observers conducted tests on 105 of the 121 partyboat trips taken. Trips originated from Long Beach, Dana Point, Oceanside, and San Diego during the period March through September of 1984. The percentage of trips with tests (87.5%) is an indication of sea lion interaction rates, since tests were made only when sea lions were within 50 m of the fishing vessel. The highest number of tests per trip (5.1) was in April. During May, the number of tests declined to 2.8 per trip and stayed at low levels until August.

For all tests using AHDs, the mean time until pinniped return was 13.74 minutes (SD = 23.08, n = 352) and the median time was 4.0 minutes (table 1). Because the data were not normally distributed (g1 = 3.3; g2 = 16.5), the median time away (MTA) was considered a less biased measurement of central tendency than the mean and was used to compare effectiveness in these tests.

CS were tested alone when an AHD malfunctioned or an AHD was not available for testing. The MTA for those tests was 5.0 minutes (n = 66, table 1).

Combining the results of all four AHDs used with no CS gives an MTA of only 2.0 minutes (n = 143); however, when the AHDs were paired with CS, an MTA of 6.0 minutes (n = 209) was achieved with an MTA range of 3.0 minutes to 9.0 minutes for each of the four AHDs (table 1).

Paired CS-AHD Tests

Two variables in the pairing of CS and AHD are the nearness of the CS explosion to the target animal and the nearness of the target animal to the AHD transducer (table 2). When the MTA ratings were evaluated by the nearness of the CS explosion to the target animal, the data show that the closer the explosion was to the animal the more effective the test. CS exploding within 1 m of the animal gave an MTA of 12.0 minutes (n = 59). The most frequent CS exploding distance was 2 m to 5 m from the target animal with an MTA of 7.0 minutes (n = 83). Tests were most often initiated with target animals between 31 m and 40 m from the vessel with an MTA of 12.0 minutes (n = 74), and if the animal was nearer than 31 m, the MTA was much shorter (6.0 minutes or less, table 2).

During months when adult male sea lions interacted more frequently than other age classes, depredation of catch was also at the highest level. The paired AHD-CS tests on adult males showed this age class to be the least affected (MTA = 4.0 minutes, n = 45, table 3). When females or subadult males were tested with AHD-CS, and MTA of 6.0 minutes (n = 150) was obtained. Juvenile sea lions were the most responsive to acoustic harassment with an MTA of 15 minutes, although sample size was small (n = 14).

Fishing block 860 (see figure 1), in the vicinity of the Point Loma kelp beds, was the area with highest interaction rates and the ony block having interactions each month during this study. The MTA for all tests in this block was 7.0 minutes (n = 101, table 4). Of the blocks with 16 or more tests, the shortest MTA was in block 720 (MTA = 2.0 minutes, n = 16) and the longest MTA was in block 877 (MTA = 15.0 minutes, n = 22). Other areas, such as block 761, had seasonally high interaction rates with some problems lasting a week or less. For example, an interaction occurred June 1 about 5 miles south of San Mateo point (block 802) in 5 fm of water. A male adult sea lion appeared to follow a fishing vessel to four different locations during a trip. This trip had the highest fishing success (3.28 fish per angler hour) and the shortest MTA (3.0 minutes, n = 35). On June 12 the same area was fished again with a similar catch of fish but no pinniped sightings.

During the month of July, the lowest number of paired tests per trip and the longest MTA for any one month (28.0 minutes, n = 15) were recorded (table 5). The shortest MTA (3.0 minutes, n = 35) during this study was obtained during the month of March.

There was little difference in the MTAs, depending on the fish species being caught (table 6) although there was more success at keeping the sea lions away when barracuda was the most abundant component of the catch (MTA = 10, n = 16).

Two hundred and one opinion surveys were taken by the observers following acoustic harassment testing. The results (table 7) indicate acceptance of the harassment methods used although there probably would have been acceptance of most nonlethal methods as long as something was tried. These results are similar to those of the opinion survey taken during the 1982-83 tests of CS.

Discussion

The MTA for the 1982-83 CS tests was four minutes (n = 72) (Scholl and Hanan, "Effects of cracker shells," in this volume), which is quite close to the results obtained during this study for CS used alone (MTA = 5 min, n = 66). The use of CS paired with AHD improved the MTA to only six minutes (n = 209). Four to six minutes of sea lion-free fishing is not a very long time for fishing, especially when one considers the amount of time it may take to chum or lure the desired fish to the fishing boat. Although some of the observers felt that they could effectively keep sea lions away from the fishing operations, the data do not show that to be true. Another factor needing consideration is the extinction rate of the AHD-CS effectiveness with time. It is possible that the sea lions would learn not to fear or be driven away by the AHD-CS. We did not address that factor in this study but expect it to be of considerable importance for evaluation of these devices.

Our paired tests were effective with harbor seals (MTA = 14, n = 6) although sample size was small. Other studies (Hanan and Scoll, "Effects of crackershells," in this volume) suggest that harbor seals are responsive to AHD harassment. Since the AHDs used in this study were originally developed for use with harbor seals (Charles Greenlaw, personal communication) and since these AHDs were effective with harbor seals, it is possible that modification of the AHDs to improve their effectiveness with sea lions would be a worthwhile extension of this study.

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Table 1. Summary of harassment test results in the southern California partyboat fishery. Tests employed electronic acoustic harassment devices (AHD) and explosive cracker shell harassment (CS). Results are presented as time (in minutes) from beginning of sea lion harassment to return of a similar sea lion.

DEVICE	NUMBER TESTS	MEAN TIME AWAY	STANDARD DEVIATION	COEFFICIENT VARIATION	MEDIAN TIME AWAY
CS 1983	72	8.8	8.8	100%	4.0
CS 1984	66	7.6	12.0	158%	5.0
AHD no CS					
12k	2	29.0	38.2	132%	NA
17k	32	7.7	14.8	192%	2.0
12wb	9	2.6	0.7	27%	2.0
212r	100	8.3	15.4	186%	2.0
AHD with CS					
12k	50	17.1	22.7	133%	9.0
17k	91	19.4	29.1	150%	7.0
12wb	39	15.0	13.4	89%	5.0
212r	29	16.7	33.6	201%	3.0
ALL AHDs COMBINED					
No CS	143	8.1	15.2	188%	2.0
With CS	209	17.6	26.5	151%	6.0
Total	352	13.7	23.1	168%	4.0

Table 2. Results of paired AHD-CS tests on California sea lions based on (1) nearness of CS explosion distance to the sea lion and (2) the distance of the sea lion to the AHD transducer.

DISTANCE	NUMBER TESTS	MEAN TIME AWAY	STANDARD DEVIATION	COEFFICIENT VARIATION	MEDIAN TIME AWAY
1) CS DISTANCE					
0-1 m	57	16.3	17.4	107%	12.0
2-5 m	83	20.8	30.4	147%	7.0
6-10 m	38	13.7	24.3	177%	4.0
11+ m	31	16.5	31.8	193%	4.0
2) SEA LION DISTANCE					
0-10 m	9	11.7	12.3	106%	3.0
11-20 m	46	11.2	13.8	123%	6.0
21-30 m	60	19.2	31.3	164%	5.0
31-40 m	74	19.6	23.1	118%	12.0
41-50 m	14	28.0	51.9	185%	6.0
51+ m	6	NA	NA	NA	NA

Table 3. Results of paired AHD-CS tests on California sea lions based on age class (AM = adult male, NAM = female or subadult male, Juv = juvenile).

AGE CLASS	NUMBER TESTS	MEAN TIME AWAY	STANDARD DEVIATION	COEFFICIENT VARIATION	MEDIAN TIME AWAY
AM	45	15.9	30.3	191%	4.0
NAM	150	17.1	22.4	131%	6.0
JUV	14	29.2	47.3	162%	15.0

Table 4. Results of paired AHD-CS tests on California sea lions based on Caifornia Fish and Game fishing blocks (see Appendix IV).

BLOCK #	NUMBER TESTS	MEAN TIME AWAY	STANDARD DEVIATION	COEFFICIENT VARIATION	MEDIAN TIME AWAY
701	1	170.0	-	-	-
720	16	4.8	7.7	160%	2.0
740	1	21.0	-	-	-
756	5	18.4	-	-	-
760	4	1.5	-	-	-
761	7	18.4	-	-	-
801	8	21.6	-	-	-
802	8	5.1	-	-	-
821	10	17.8	-	-	-
842	20	30.6	47.3	155%	7.0
860	101	16.0	18.4	115%	7.0
877	22	22.5	24.3	111%	15.0
878	6	13.0	-	-	-

Table 5. Results of paired AHD-CS tests on California sea lions based on month.

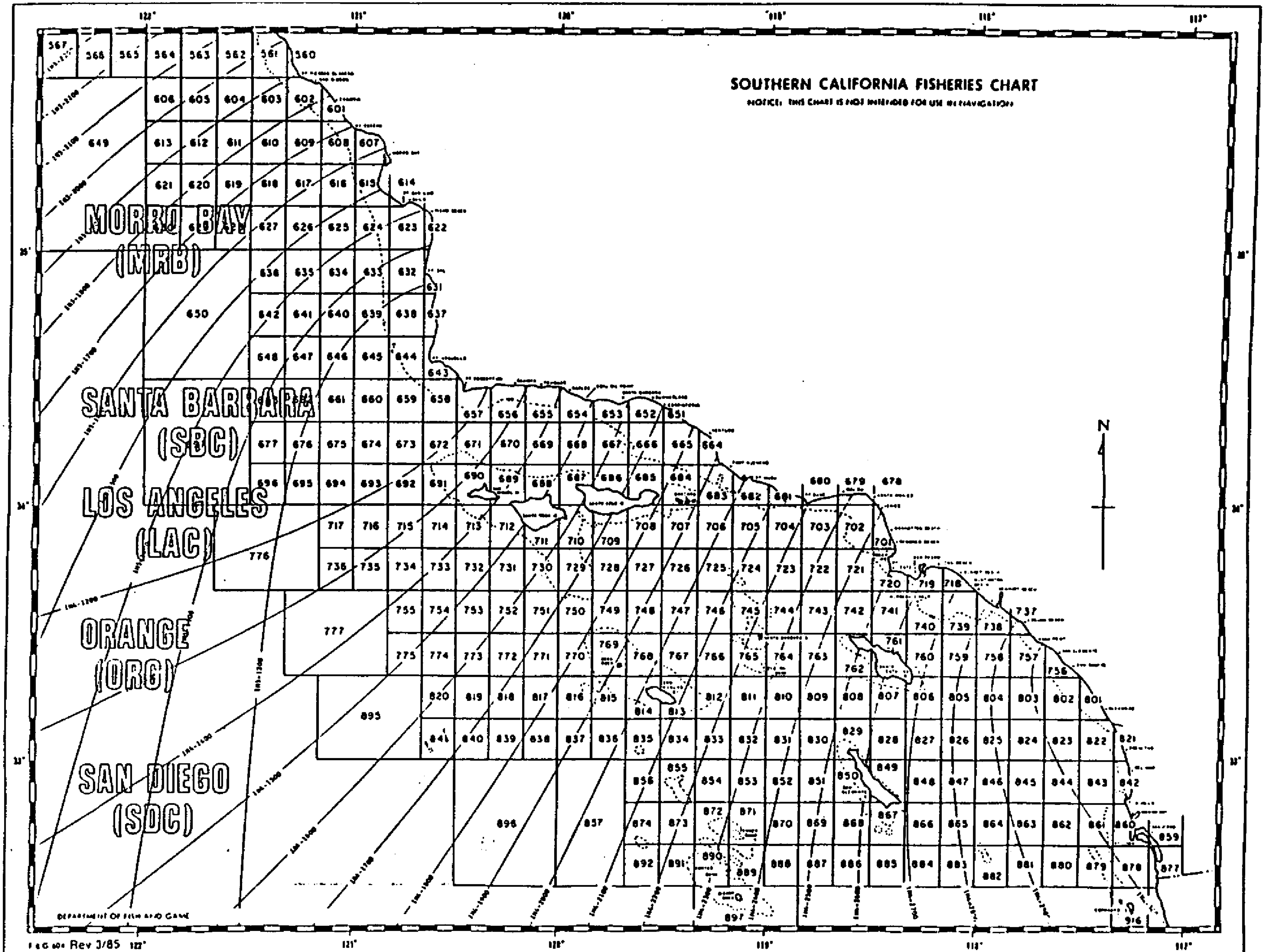
MONTH	NUMBER TESTS	MEAN TIME AWAY	STANDARD DEVIATION	COEFFICIENT VARIATION	MEDIAN TIME AWAY
March	35	11.3	16.8	149%	3.0
April	26	20.1	30.0	149%	6.0
May	50	17.3	28.2	163%	7.0
June	18	11.8	18.5	157%	6.0
July	15	44.0	52.3	118%	28.0
August	29	19.2	19.6	102%	11.0
September	36	13.0	14.2	109%	6.0

Table 6. Results of paired AHD-CS tests on California sea lions with a sample of size 16 or more based on (1) the fish most abundant in the catch during a test and (2) a fish being one of the three most abundant in the catch during a test.

FISH	NUMBER TESTS	MEAN TIME AWAY	STANDARD DEVIATION	COEFFICIENT VARIATION	MEDIAN TIME AWAY
1) Barracuda	16	46.0	62.6	136%	10.0
Bonito	48	16.9	17.3	102%	7.0
Kelp bass	70	14.6	21.2	145%	6.0
P. mackerel	51	15.7	21.4	137%	6.0
2) Barracuda	33	22.5	37.7	154%	7.0
Bonito	93	21.6	33.2	113%	6.0
Kelp bass	134	17.7	27.0	152%	6.0
P. mackerel	79	18.0	25.6	142%	6.0
Yellowtail	33	22.5	37.7	168%	7.0

Table 7. Public opinion survey (1982-83 and 1983-84 results) results from acoustic (AHD) and cracker shell (CS) harassment in the southern California partyboat fishery.

	CS 1982-83	CS and AHD 1983-84	Combined 1982-84
Tests Bothersome?			
YES	5%	3%	4%
NO	95%	97%	96%
Controls Needed?			
YES	76%	89%	84%
NO	24%	11%	16%
Controls Regularly?			
YES	76%	94%	88%
NO	24%	6%	12%
Total Surveyed	113	201	314



Figur) 1. Souther) California)isheries Ch( )t

The Feasibility and Effectiveness of Using an Acoustic Barrier to Restrict the Movements of Seals into Netarts Bay, Oregon

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Introduction

In 1980 Oregon State University developed an acoustic harassment technique as a nonlethal means of mitigating the effects of harbor seal (*Phoca vitulina*) feeding activities on hatchery and gill net fishing operations. Since then an acoustic harrassment device (AHD) has been developed and used by different agencies on a number of marine mammal species. The results of these tests have been variable. In some cases, the AHD appeared to work well, while in others it proved ineffectual. Work has continued on the project in an effort to ascertain the conditions under which it is effective and discover possible modifications which would improve its performance.

Since its inception, the AHD has been used to repel harbor seals from the vicinity of an experimental chum hatchery at Whiskey Creek in Netarts Bay, Oregon. During late October through November, numerous seals in front of the creek mouth prey upon returning salmon. The AHD has kept the majority of the seals outside a 50-m radius of the creek mouth. Unfortunately, the AHD does not influence all individuals; in 1984 one to three seals were seen repeatedly in the creek preying upon salmon.

In 1985 we placed a number of AHDs at a mouth of Netarts Bay to determine how many seals could be excluded from the bay for a period of one week. We had hoped this would allow us to determine the proportion of the population affected by this device and investigate the possibilities of using AHDs to create a barrier to their movement.

Methods

Netarts Bay was chosen for this experiment because it is a relatively small embayment, has a narrow mouth, and has been the location of numerous seal studies over the last five years (Brown 1981).

Seals were driven from the bay by using two operating AHDs, cracker shells fired over animals on haulout grounds, and seal bombs. Three boats were used to drive animals from the bay during the afternoon low tide of 8 October 1985. Using the main channel and starting from Whiskey Creek, the boats moved slowly downbay with two AHDs operating continuously. Cracker shells and seal bombs were used intermittently. There was no way of assessing what proportion of the seals in the bay at the time of the sweep remained; however, all seals observed were rapidly headed downbay, and none were observed surfacing upbay of the boats as they advanced.

After the boats with the harrassment devices had reached the mouth of the bay, the AHDs were transferred to two of five boats which were moored at equal intervals of 50 m across the mouth of the bay. The other three boats already contained AHDs, so that each moored boat had a single AHD at the start of the experiment. Transducers were suspended 2 m below the water's surface. Each AHD was powered by a 12-volt, deep-cycle battery.

Each morning and evening the AHDs and moorings were checked and inoperative batteries were replaced. The number of harbor seals at each haulout site was recorded for each low tide, starting the day of the experiment and continuing until seven days after the sound was turned off.

Results

All five systems did not remain operative the entire experimental period. One AHD had electrical problems from the second day and did not function for the remainder of the test. On various occasions, one or two batteries failed and the devices became inoperative. On three mornings only two of the five AHDs were operating. The interpretation of the results must therefore be tempered by knowledge of the inconsistent functioning of the AHDs.

There were 288 seals hauled out within Netarts Bay three hours prior to the beginning of the experiment. The number of seals observed hauled out within the bay slowly increased the following week to approximately 100 (table 1). The day after the acoustic barrier was turned off (all moored boats were still in place), the number of seals within the bay was 295.

Discussion

A very simple interpretation of these results would imply that approximately two-thirds of the seals in the area were restricted outside the acoustic barrier during the test. We do not know how effective the devices would have been over a longer period of time. The gradual increase in the number of seals using the bay during the experiment may have been due to the inconsistent operation of the AHDs or the animals becoming conditioned to the sounds produced. The sound production near the mouth haulout site certainly influenced the haulout behaviors of these seals. Seals completely abandoned this spot until the sound was eliminated.

Alternatively, the gradual increase in numbers within Netarts Bay may have been a natural response to the harassment administered during the driving of animals out of the bay. A control experiment is planned soon, where we will harass animals out of the bay in a way similar to that of the experimental period, but not place an acoustic barrier across the mouth. The number of seals using the bay will be monitored for two weeks prior to the harassment. If the number of seals using the bay returns to preharassment numbers soon after disturbance, we will conclude that the AHDs were responsible, in great part, for the low numbers of seals during the AHD experiment. If the number of seals using the bay increases gradually after harassment, similar to that of the experimental period, we will conclude the AHDs had relatively little effect on the distribution of seals in the bay.

Hanan and Scholl (1985) used an AHD to move harbor seals down the Klamath River in California in an attempt to protect recently tagged salmon. The device was somewhat successful in herding animals down the river and obstructing their movements back up river. This procedure was used only two days and involved

Table 1. Numbers of seals counted on various haulout grounds in and outside Netarts Bay prior, during, and after the acoustic barrier was in operation. Seals were counted at haulout sites designated as flembil (F), mouth (M), and ocean (O).

DATE	TIME	NUMBER OF SEALS F	M	O	COMMENTS
8 Nov	1435	107	181	0	Count prior to drive
9 Nov	0830				5 AHDs operating
	1630	2	0	0	5 AHDs operating
10 Nov	0730				5 AHDs operating
	1700	0	1	0	1 AHD off 1000-1600
11 Nov	0730	22	0	0	4 AHDs operating
	1700	53	0	0	2 AHDs operating
12 Nov	0800	44	0	0	2 AHDs operating
	1700	40	3	0	2 AHDs operating
13 Nov	0730	83	0	0	4 AHDs operating
	1630	54	0	0	4 AHDs operating
14 Nov	0730	103	0	125	3 AHDs operating
	1600				3 AHDs operating
15 Nov	0730	68	0	100	2 AHDs operating turned system off
16 Nov	0843	72	223	0	
17 Nov	1500	98			
19 Nov	1200	254			
20 Nov	1330	175			
21 Nov	1430	250			
22 Nov	1530	0			

nine seals; however, a few seals did not appear to be affected by the device. Geiger (1985) reported the use of an array of three AHDs and six transducers in Youngs Bay, Oregon, in an attempt to exclude seals from this estuary after the seals were swept from the area. Damage rates were not significantly reduced after seals had been swept from the upper bay and the devices were in operation. There was a slight reduction in damage rate immediately following the sweep of the river, but damage rates returned to normal within two days. In all attempts to exclude seals from an area, the effectiveness of the initial removal of animals has been uncertain and not adequately documented.

It appears to be feasible, at least in Netarts Bay, to moor AHD systems across a mouth of an embayment. The logistics of maintaining numerous systems for prolonged periods of time remains a problem. In this case, converters, which were required to run some of the AHDs, were responsible for draining the batteries much more rapidly than recently built AHDs. The ultimate success of this type of operation is, in great part, due to the availability of reliable equipment. To effectively create an acoustic barrier across the mouth of many Oregon bays would require many more devices or a more effective transmission of sound. Two AHDs at either side of the channel with directional transducers might be more effective. In areas of substantial boat use, mooring AHDs in the channel may not be practical.

The ultimate application of this type of acoustic arrangement would most likely be during a local short-term run of fish up a river system. If the acoustic barrier proved mostly effective (e.g., obstructing at least 75% of the seals), the expenditure of time and money may be cost-effective. The amount of seal predation which would have occurred had the acoustic barrier not been in place needs to be assessed as a factor in deciding whether such use of AHDs is worthwhile. This type of experiment may be valuable to try again once equipment failures are alleviated.

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Oregon Aquafood's Experience with a Seal Avoidance System

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Oregon Aquafood

Oregon Aquafoods is a salmon-ranching company with a release-recapture facility located on Yaquina Bay, Oregon. We at OreAqua knew in the very beginning of our efforts that as our salmon runs developed and marine mammal populations continued to strengthen, marine mammals would be an issue we would be forced to deal with. In Yaquina Bay, the two animals that posed a potential problem were harbor seals and California sea lions. Early examinations of returning adult salmon in 1978 and 1979 showed an incidence rate of seal damage of nearly 25%.

In 1980 OreAqua installed two seal-avoidance systems, one each at sites on Yaquina Bay, and Coos Bay. The systems were based on a design produced by Dr. Bruce Mate of the Oregon State University Marine Science Center in Newport, Oregon. Each system consisted of an amplifier designed to deliver a specific frequency impulse at random intervals through a cable to a noise-emiting transducer submerged in the bay.

The systems were placed by attaching the transducers to stainless mounts and driving the mounts into the sand on the bottom of the bay. The units were mounted in such a way that the transducers remained submerged even during the lowest tides. In Coos Bay, the fish ladder extended 580 ft from the bank, across the tide flats to the edge of the shipping channel. The transducer was placed approximately 50 ft off the end of the fish ladder. In Yaquina Bay, the ladder parallels and sits directly against the bank. In this case, the transducer was placed approximately 150 ft offshore and slightly downstream of the entrance to the fish ladder.

When the systems were operating, it was clear from the behavior of the harbor seals present that they were effective. Seals that moved into the mouths of the ladders when the units were off, quickly moved out 200 to 300 ft from the end of the ladder, and would not come any closer when the units were operating.

Two problems were observed in 1980. First, we used surplus amplifiers from the Weyerhaeuser Technical Center to provide the impulse signals. The signals required so much energy, generated at such close intervals, that the amplifiers would overheat and shut down on overload after 45 min to 1 h of continuous operation. The units had to be given time to cool down and be reset manually. Because of heavy production activities, the units remained off more than they operated during this season. The second problem was observed in Yaquina Bay, and this was the presence of "dead spaces" around the ladder that the impulse noise did not seem to reach. These areas provided seals with a safe haven free of the signal within the operating range of the avoidance system. It was determined that a combination of the bottom contour and the presence of eel grass beds were blocking and reflecting the signal, creating these "dead spaces."

In 1981 the surplus amplifiers were replaced with impulse amplifiers, and the systems have worked without technical difficulties ever since. We also added a second transducer to the Yaquina Bay facility. The original transducer was placed in its original location, and the second transducer was suspended from a float approximately 120 ft from the mouth of the ladder to provide a signal that would fill in the dead spaces.

In 1981 and 1982, the avoidance systems at both Coos and Yaquina bays seemed to be quite effective. Seals were kept good distances away from the fish ladders throughout the season. The last year we operated the Coos Bay facility was 1982, so more recent performance of that system cannot be addressed in this report.

In the fall of 1983 we began to notice some seal activity in the immediate area of the seal-avoidance systems in place at Yaquina Bay. One or two animals seemed unaffected by the signals. These animals worked the ladder area throughout the season, even venturing into the ladder itself towards the end of the season.

Throughout 1984 and 1985, we saw the same thing happen: two to four animals worked the ladder in spite of the seal-avoidance systems. Any number of possible reasons have been proposed, ranging from partial or complete deafness of these animals due to injury or disease to the suggestion that over time the animals have just gotten used to what had been an objectionable noise. The transducer frequency is generated by vibrations set up in a crystal within the transducer. If the crystal has degenerated in any way, it could be that the frequency is slightly different and not one that is objectionable. Clearly, these animals are not concerned, as they routinely rest within 1 or 2 ft of the transducer float and do not react in any way to the impulse that can be heard by human observers on land 120 ft away.

Throughout our experience, California sea lions have not been an issue, as their return to Yaquina Bay overlapped only the very end of our fish return. In 1985, however, four sea lions showed up in mid-October and worked the ladder continuously until the water was turned off in mid-December. Our seal-avoidance systems were intended to be harbor seal specific and were never expected to work against sea lions, so their presence is not surprising. As fish returns to OreAqua continue to improve and sea lions learn of the potential food resource, it is quite likely that they will begin to show up in Yaquina Bay in greater numbers to take advantage of this resource. They will undoubtedly develop into a force that OreAqua will have to deal with in the not too distant future.

The Use of Acoustic Harassment Devices in Coos Bay at the Anadromous, Inc., Saltwater Recapture Facilities

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Introduction

In a census of harbor seals (*Phoca vitulina*) taken within Coos Bay in 1981 by Greybill (1981), it was determined that the mean monthly maximum count from December to May was 78.5. Greybill also found that the highest monthly maximums were 180 and 190 in July and October, respectively, and that this pattern reflects the peak timing of the runs of salmon to hatchery facilities within the bay. Indeed, seal and sea lion populations within Coos Bay do increase when there are large numbers of salmon in the estuary, and their presence has created innumerable problems at the two Anadromous release-recapture facilities located at Jordan Point and North Spit in Coos Bay. The decreased value of damaged fish, as well as of those actually killed, represents a significant loss in revenue each year, and efforts to minimize that damage have resulted in considerable expense. Historical efforts have included the use of bottle rockets and shell crackers, maintaining nearly constant surveillance of the recapture ladder, and the purchase, operation, and maintenance of several acoustic harassment devices.

Discussion

In 1982 a sampling program was initiated to determine the extent of pinniped damage on returning adult spring chinook and coho. The fish were examined for seal and sea lion rakings and bites throughout a significant part of the recapture season.[1] Incidences of bites and rakings on spring chinook were recorded separately; i.e., if a returning adult had a bite and was raked it was recorded as a positive occurrence under both categories. Of 811 spring chinook adults taken in the period July 16 through September 9, 1982, 20% exhibited some form of injury from pinnipeds--11% with bites, and 15% with rakings. During the period August 25 through October 6, 1982, the overall incidence of injury to the returning coho adults was 19%: 4% with bites and 15% with rakings.

On October 21, 1982 an acoustic harassment device was installed adjacent to the Jordan Point facility in an effort to provide some protection to the returning adults (North Spit was without a device). The transducer was placed at the end of the wing wall toward open water approximately 50 m from the foot of the ladder. From that time forward the incidence of injury to coho was

[1]We obviously could not estimate the number that they actually killed although we believed it to be considerable.

20%--4% with bites and 16% with rakings. Seals and sea lions were still observed in the area, usually beyond 30 m from the mouth of the ladder, but some actually entered the ladder. Generally, it would appear that the acoustic harassment device was ineffective in this test, although the results tend to be paradoxical. Geiger and Jeffries (1986, see their paper in this volume) discuss some possible explanations for a similar experience: "(1) individual seals have differential tolerances to the sound signal; (2) seals habituate to the sound; (3) the intensity is not sufficient to cause unconditioned aural pain in seals over the length of the net [weir], and some seals learn the limits of danger associated with this (initially startling) sound stimulus; and (4) the sound signal becomes a conditioned reinforcer for seals to find and eat fish in the net [weir]." In addition, placement of the transducer 50 m from the foot of the ladder may have been inappropriate for this particular model[2], but tidal fluctuations precluded a closer placement. Seaweed and debris clogging the transducer was periodically a problem, and on a couple of occasions the unit needed servicing.

In 1983 we obtained several improved models[3] of the device and installed two approximately 10 m off the North Spit ladder, 15 m apart. At that time we began recording the incidence of pinniped-related injuries (combined bites and rakings) on all marked fish as part of our standard data collection. The following table depicts the results of these observations through 1985[4].

YEAR	SPECIES	NUMBER RETURNING	NUMBER IN SAMPLE	% WITH INJURY
1983	Coho	1,318	407	7
1983	Chinook	2,988	724	7
1984	Coho	5,923	1412	11
1984	Chinook	2,177	429	14
1985	Coho	88,900	3278	13
1985	Chinook	9,500	1137	5

During the 1983-1985 seasons the incidence of injury was less than in 1982. This might indicate that the harassment systems reduced overall injury rates or that the pinniped population residing in the bay may have been less during and after the El Nino years (83-84).

No significant intraspecific difference was detected in the injury rates between the two recapture facilities in 1984 and 1985 as they were within 3% of each other in those years. There was, however, a dramatic interspecific dif-

[2]Acoustic harassment device. 12 Khz or 17 Khz with power output 75-100 watts.

[3]Acoustic harassment device. 13.9 Khz with momentary output rated for 350 watts.

[4]The data taken in these years include adults taken from brood stock that were not recorded for seal damage. As it is our policy not to take damaged fish for brood stock, it is assumed that the overwhelming majority were not damaged and these numbers should be approximately correct.

ference in injury rates between the coho and chinook in 1985. Differences in the timing of return may have played a part. The overall abundance of coho in that year may also have somehow contributed to the reduced predation, perhaps as a result of different migrational patterns of the species within the bay. Pinnipeds may have cued the timing of their foraging behavior more toward the run of coho.

Although the above data is somewhat confusing, we have substantiated over the years (by subjective observation) that the number and frequency of pinniped sightings definitely increases relative to return numbers, and pinnipeds have been observed much more frequently in mornings and evenings and at flood tides. The latter observation appears to be consistent with that made at the Netarts Bay Hatchery (Mate et al. 1986). Numbers of pinnipeds spotted at this time have been as high as seven, with three being about average, and the majority of the sightings have occurred in the shallows near the foot of the ladder. They have also been observed frequently at night, apparently preying on the juveniles, after large releases of smolts. Generally, this activity is limited to one or two seals, but the observation may be biased by the fact that it is also much more difficult to spot seal activity at night.

We have used and still use bottle rockets (with report) and shell crackers to drive pinnipeds from our facility. This technique is reasonably effective in the short term but can be costly. Two or more shots are usually required, as some pinnipeds seem to be a bit more stubborn than others, or they may have been submerged during the first report(s). Generally, they will move out to about 200 m and stay at that range for up to an hour before making any repeated attempts at approaching the ladder. Pistols were originally used for the shell crackers but after a few incidents of explosion at less than a half meter away, volunteers to fire it were hard to come by. A shotgun with greater range was then used exclusively.

The placement of the transducer from the acoustic harassment device is extremely important as solid barriers can create sound shadows that the marine mammals will learn to use. We have noted that in open water without barriers the range of effectiveness is limited to less than 100 m, although 1000 f is claimed in the operating manual (CMI-Cascade). It has also been our experience that some harbor seals appear to become accustomed to the device and will tolerate the signals at any distance. This observation is consistent with that of others who have used or researched the acoustic harassment devices (Hanan and Scholl 1985; Mate and Miller 1985; and, in this proceedings, Geiger and Jeffries; Harvey, Mate, and Brown; and Mate, Brown, Greenlaw, Harvey, and Tempte). In addition, we have observed that sea lions do not appear to be repelled by the acoustic harassment devices.

Conclusion

These mixed results suggest that the verdict is still out on acoustic harassment devices. Despite the uncertain effectiveness, however, Anadromous will continue to use the devices, and any other means at our disposal, in an effort to reduce pinniped damage. Further data collection may provide a clearer picture of their performance and efficacy.

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Mate, B., and D. Miller. 1983. Acoustic harassment experiments on harbor seals in the Klamath River, 1981. Coastal Marine Mammal Study, Annual Report for the period of July 1, 1981-June 30, 1982. Administrative Report No. LS-83-21C. Southwest Fisheries Center, NMFS

Measurements of Sound Propagation from Several Acoustic Harassment Devices

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Introduction

A variety of sounds have been used in attempts to deter pinnipeds from fishing activities. On 11 April 1984 personnel from Hubbs Marine Research Institute and the California Department of Fish and Game measured the underwater propagation and acoustic properties of three sounds produced by an Acoustic Harassment Device (AHD) manufactured by CMI-Cascade of Philomath, Oregon, and of three explosive devices currently used by fishermen to deter pinnipeds. Our objectives were to describe these sounds and measure their propagation to help researchers using the devices interpret responses of pinnipeds.

Methods

The CMI-Cascade AHD has three sound generators listed on its control panel: (1) a 12-kHz "pulser," (2) a 17-kHz "pulser" with selectable durations of 20, 50, and 100 ms, and (3) a 12-kHz "sweeper." This device could be powered by either a generator (we used a 400-W Honda generator) or a 12-V battery with an inverter. The explosive devices we examined were (1) seal control bombs (distributed by California Seal Control Corporation, San Pedro, California), (2) cracker shells (distributed by O. C. Ag. Supply Company, Anaheim, California) fired from a 12-gauge shotun, and (3) cracker shells fired from a Record-Weinberg flare pistol.

Propagation of these six sounds was measured in two areas: a deep-water area (over 300 m deep) over La Jolla Canyon off San Diego and a shallower area (20 to 30 m deep) near the NOSC tower off Point Loma. Sounds were transmitted from one boat and received at another. Distances between the boats, measured with a radar and a Lietz 8026-19 optical rangefinder on the transmitting boat, were 926 m (1/2 nmi), 463 m (1/4 nmi), 232 m (1/8 nmi), and 116 m (1/16 nmi). These distances were selected empirically. Beyond 1 km the signal-noise ratio was too low for reliable measurements of the projected sounds. At distances closer than 100 m, the high peak levels from the explosive devices overloaded our receiving equipment. Measuring sound pressure levels at several distances allowed us to use regression analysis to estimate source sound pressure levels.

Receiving equipment was an International Transducer Corporation (ITC) 6050C hydrophone ($\pm$ 3 dB, 5 Hz to 40 kHz, sensitivity 11.75 mv/Pa) and a Nagra IV-SJS tape recorder ($\pm$ 2 dB, 20 Hz to 20 kHz at 19 cm/s tape speed). A 5-kHz insertion voltage equivalent to a known sound pressure level (SPL) was recorded periodically for a calibration reference. All SPLs are reported in decibels referenced to 1 microPascal.

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In the laboratory, flat-weighted, root mean square sound pressure levels of the recorded sounds were examined with a Spectral Dynamics model 345 spectrum analyzer and a Bruel and Kjaer 2230 integrating sound level meter. Because agreement between these instruments was excellent, we report only those levels obtained with the Bruel and Kjaer instrument. This instrument makes parallel measurements of average SPL (L_{eq}), maximum fast SPL, and sound exposure level (SEL), all of which we report. For a time-varying sound pressure level, the average SPL is equivalent to the sound pressure level that would be produced in the same time by a steady sound. Maximum fast SPL is the highest level measured during a period, using fast (125 ms) time weighting. Maximum fast SPL usually is much more variable than average SPL. Sound exposure level is the time integral of the squared instantaneous sound pressure. Integration time is not critical, but must include all significant sounds of an event and exclude extraneous sounds. SEL allows direct comparison of the energy in transient sounds because it estimates the sound energy of an event.

Results

AHD

Maximum fast sound pressure levels and average sound pressure levels produced by the AHDs in each location are shown in table 1. Levels produced when the device was powered by the battery/inverter were lower than those produced when it was powered by the generator, and so tests were completed using only the generator. At each water depth, the AHD produced average sound pressure levels of 135 to 140 dB at about 100-m distances. Maximum fast levels were 6 to 10 dB higher because of the pulsed nature of the sound and the variable underwater environment.

The 12-kHz "pulser" was actually an 11.15-kHz tone presented at regular or random intervals. The spectrum and maximum fast SPL of this sound recorded 232 m away in deep water is shown in figure 1. Figures 2 through 4 show spectra of the 17-kHz "pulser" at 20, 50, and 100 ms durations, also recorded 232 m away over deep water. The 12-kHz "sweeper" (figures 5 and 6) was a 12.55-kHz tone that was amplitude-modulated at about 540 Hz. The signal was on and off at irregular intervals and its level varied with time.

AHD levels attenuate more rapidly in deep water than in shallow water. In general, at 1 km, sound pressure levels from the AHD were 5 to 10 dB lower in deep water than in shallow water. Attenuation rates (dB/2x, in table 1) calculated from the regression of level on the log of distance were about 6 dB per doubling of distance in shallow water and about 9 dB in deep water. Consequently, source levels estimated for deep water were much higher than those estimated for the same devices in shallow water. Although the regression for shallow water is probably a better estimate of source levels, we emphasize that this is a theoretical construct and should be used with caution.

Explosives

Sound pressure levels of the three types of explosive devices are reported in table 2. Sound exposure levels and maximum fast SPL for seal bombs were much less variable than for cracker shells. Seal bombs explode rather uniformly at 2- to 3-m depths, whereas cracker shells explode either on or near the surface. The cracker shells fired from a shotgun tended to ricochet when aimed at the surface, often exploding several meters in the air. Cracker shells fired from a flare pistol were less prone to ricochet, but rarely sank more than 1 to 2 cm before exploding. Those that exploded in the air were not detected by the hydrophone at any distance, although pinnipeds at closer distances probably could have heard them under the water. A seal nearby with its head out of water would have heard the airborne sound, but airborne measurements were not a part of our study.

Figure 7 shows the recorded waveform of a seal bomb exploded in deep water 116 m from the hydrophone. The original pressure wave was modified by interference, which severely attenuates low-frequency energy when an explosive sound propagates from the surface to a shallow receiver (Young 1947), and by the limted low-frequency response of our receiving system. Blast duration was 30 ms, followed about 55 ms later by a prolonged echo. Most of the sound energy falls below 2 kHz, as shown in figure 8. Sound exposure level was 153.8 dB.

In contrast, the blast duration of cracker shells fired from a shotgun was less than 10 ms, with substantial high-frequency energy (figure 9). The spectrum (figure 10) shows that most of the energy falls above 200 Hz, with substantial energy at 10 kHz. SEL was 124.3 dB.

Both types of cracker shell sounded alike, although cracker shells fired from a shotgun were slightly higher in amplitude than those fired from a flare gun. Instead of having a "bang" sound like a seal bomb, they were heard as a crackling noise at the hydrophone. The waveform (figure 11) of the cracker shell fired from a flare pistol over deep water 463 m from the hydrophone shows why. Low frequencies from the very shallow explosion has been so severely attentuated that no characteristic blast waveform is evident. Only high-frequency energy was captured, with maximum energy at 2950 Hz. SEL was 126.8 dB.

Discussion

Acoustic harassment devices intended to keep pinnipeds away from fishing activities usually are activated near the surface and received by animals that also are near the surface. In this situation, sound pressure levels, especially at low frequencies, in this situation are affected by water surface reflections, bottom reflections, ambient noise fluctuations, and the relative locations of the animal and the sound source. These factors can cause animals in the same general area to hear a sound with very different amplitudes, thereby reducing the predictability of a deterrent's effectiveness.

Discomfort or pain levels associated with high-level noise have been measured only for humans. In humans, the threshold of discomfort depends on the frequency, ranging from 120 dB above the threshold at the most sensitive frequencies to 68 dB above the threshold at the least sensitive frequencies (Kinsler et al. 1982). The threshold of pain for humans is about 20 dB higher. Because we have no data on whether a seal's ear responds to loud transients in the same way a terrestrial mammal's ear does, we oppose using data on humans to predict the effects of noise on pinnipeds.

AHD

The CMI-Cascade AHD has the advantage of avoiding the uncertainties and potential hazards associated with explosive devices. The frequencies of this AHD, 12 kHz and 17 kHz, lie within the most sensitive hearing regions of pinnipeds (figure 13). The types of signals selected for this AHD maximize the "unpleasant" qualities of a sound by producing sounds that are high in amplitude, pulsed, and presented irregularly.

Explosives

The traditional seal deterrent is the seal bomb, which produces an N-wave impulse with a source SEL of nearly 190 dB. Whether this would endanger a seal depends on the correspondence between the animal's hearing sensitivity curve and the spectral distribution of the explosion energy. Most of the sound energy in seal bombs lies below 1 kHz. As shown in figure 13, hearing sensitivity of *Zalophus* at 1 kHz is 85 dB (Schusterman et al. 1972) and is about the same for *Phoca vitulina* (Mohl 1968). Whether physical harm to the inner ear of a pinniped would result from a seal bomb explosion can not be evaluated without experimentation.

Cracker shells radiate less energy into the water than seal bombs because they explode nearer the water surface. Source levels of cracker shells vary more than those of seal bombs and are strongly affected by how deep the cracker shell has sunk when it explodes. Only when cracker shells explode quite close to an animal swimming under water are levels likely to be high enough to drive the animal away, especially if the animal is experienced. Consequently, users are more likely to aim the explosive close to the animal, increasing the probability of causing physical harm with a direct hit.

Whether the AHD or explosives we examined could cause hearing damage in marine mammals can be determined only by measuring hearing sensitivities before and after exposure or by inspecting cochleas from animals that have been exposed at known depths and distances.

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Table 1. Acoustic Harassment Device sound levels in dB re 1 pa. Leq is the average flat sound level (SL) in t seconds. A is the slope of the regression of SL on log distance. B is the intercept, an estimate of source level (See text for caution). dB/2X is the change in level with each doubling of distance and r is the product moment correlation coefficient.

Dist. (m)	12 kHz Pulse Max Fast	12 kHz Pulse Leq	t	17 kHz 20 ms Max Fast	17 kHz 20 ms Leq	t	17 kHz 50 ms Max Fast	17 kHz 50 ms Leq	t	17 kHz 100 ms Max Fast	17 kHz 100 ms Leq	t	12 kHz AM Max Fast	12 kHz AM Leq	t
SHALLOW															
926	129.1	116.5	10	125.7	117.4	10	126.0	118.8	10	131.3	117.2	5	134.6	125.3	10
463	130.8	122.4	10	132.4	125.6	6	136.2	125.7	5	136.5	125.7	8	144.2	131.9	10
232	139.3	130.6	10	141.8	134.2	5	143.3	132.3	10	150.1	134.6	10	151.3	140.2	10
116	142.0	134.8	15	142.2	134.7	5	145.1	136.0	10	146.9	136.6	7	153.4	142.3	15
A	-15.7	-21.0		-19.6	-20.1		-21.4	-19.3		-20.1	-22.3		-21.1	-19.7	
B	174.8	178.9		184.7	178.5		191.5	176.8		191.7	184.6		198.9	184.5	
dB/2X	-4.7	-6.3		-5.9	-6.0		-6.4	-5.8		-6.0	-6.7		-6.4	-5.9	
r	-0.96	-0.99		-0.95	-0.95		-0.96	-0.99		-0.87	-0.97		-0.97	-0.98	
DEEP (Generator)															
926	119.2	110.9	25	119.7	113.3	10	118.9	112.7	10	119.6	110.5	10	125.2	115.4	30
463	119.8	113.1	15	120.7	114.7	10	123.7	116.1	10	118.4	112.2	8	131.6	123.3	15
232	132.1	123.2	7	132.8	125.7	10	136.0	128.6	11	128.2	119.6	30	143.6	133.1	18
116	145.1	135.6	12	143.1	136.6	5	145.7	137.3	10	148.5	137.2	10	144.9	136.8	10
A	-29.9	-28.0		-27.3	-26.9		-30.8	-28.7		-32.0	-29.1		-23.6	-24.2	
B	204.2	191.0		197.8	190.1		208.5	195.8		209.3	193.0		195.7	189.0	
dB/2X	-9.0	-8.4		-8.2	-8.1		-9.3	-8.6		-9.6	-8.7		-7.1	-7.4	
r	-0.95	-0.96		-0.96	-0.96		-0.99	-0.98		-0.89	-0.93		-0.96	-0.99	
DEEP (INVERTER)															
926	115.2	109.7	5	115.1	110.4	10	117.6	110.9	10	116.2	108.3	10	126.6	115.1	15
463	117.8	110.9	20												

Table 2. Maximum fast sound levels and mean, maximum and minimum sound exposure levels (dB re 1 pa) for explosive seal control devices. A is the slope of the regression of SL on log distance. B is the intercept, a theoretical estimate of source level (See text for caution). dB/2X is the change in level with each doubling of distance and r is the product moment correlation coefficient.

	Seal Bombs					12 Ga. Cracker Shells					Flare-gun Cracker Shells				
Distance (m)	n	Mean SEL	Max SEL	Min SEL	Max Fast	n	Mean SEL	Max SEL	Min SEL	Max Fast	n	Mean SEL	Max SEL	Min SEL	Max Fast
SHALLOW WATER															
926	3	148.0	148.6	147.6	156.5	2	119.3	120.7	117.9	126.8	2	113.0	114.9	111.0	119.1
463	4	152.4	153.8	151.6	161.5	2	130.7	131.7	129.7	139.1	2	124.7	127.0	122.4	131.3
232	3	157.8	158.2	157.4	166.0	2	141.8	144.5	139.1	144.5	3	134.3	139.6	127.8	139.6
116	4	160.2	160.8	158.9	168.5	1	139.0	--	--	147.1	2	132.8	133.8	131.7	141.8
A		-14.0					-23.3					-22.9			
B		189.7					191.4					183.9			
dB/2X		-4.2					-8.1					-6.9			
r		-0.99					-0.73					-0.91			
DEEP WATER															
926	5	139.7	141.0	136.2	144.2	2	121.2			130.9	--	--	--	--	--
463	4	143.2	145.1	140.9	151.1	1	127.3	--	--	130.6	2	122.8	126.8	118.7	132.6
232	4	144.4	145.5	142.8	150.7	1	123.0	--	--	127.1	1	129.0	--	--	134.5
116	5	156.4	158.7	153.2	165.6	2	139.8	146.7	132.9	153.9	3	148.6	151.7	144.7	158.7
A		-17.1					-17.0					-42.9			
B		188.9					170.7					235.0			
dB/2X		-5.1					-5.1					-12.9			
r		-0.91					-0.79					-0.96			

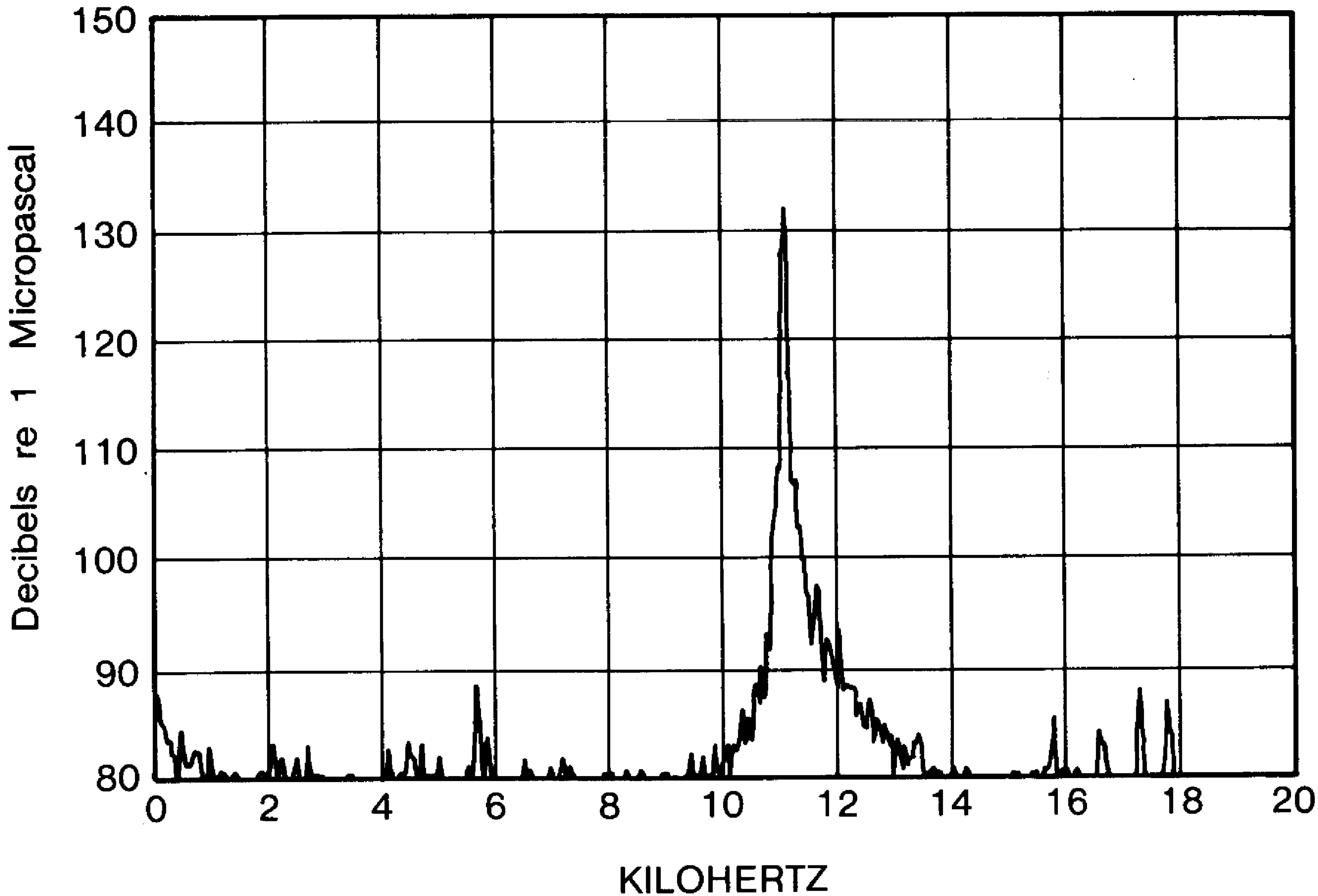
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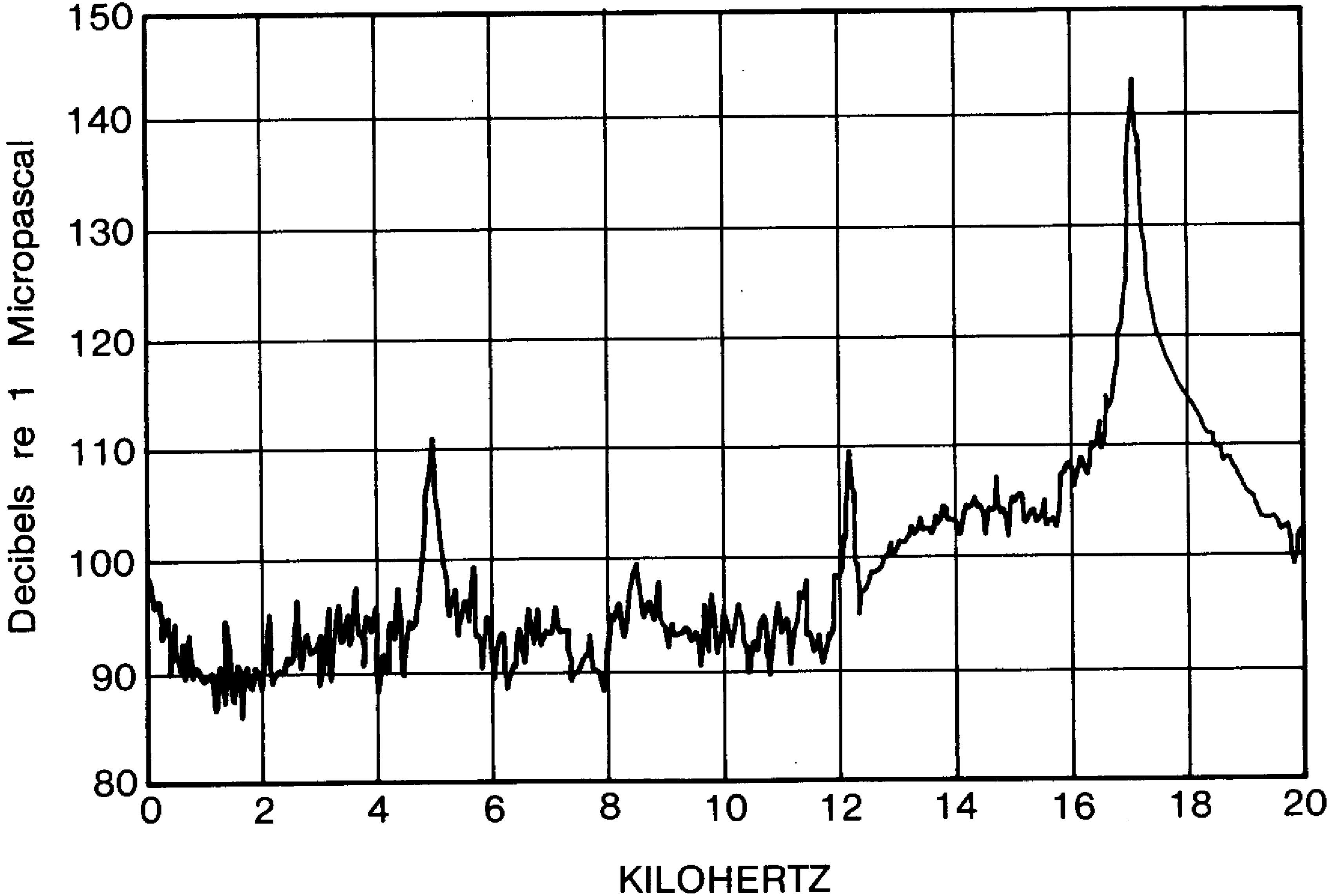
Figure 1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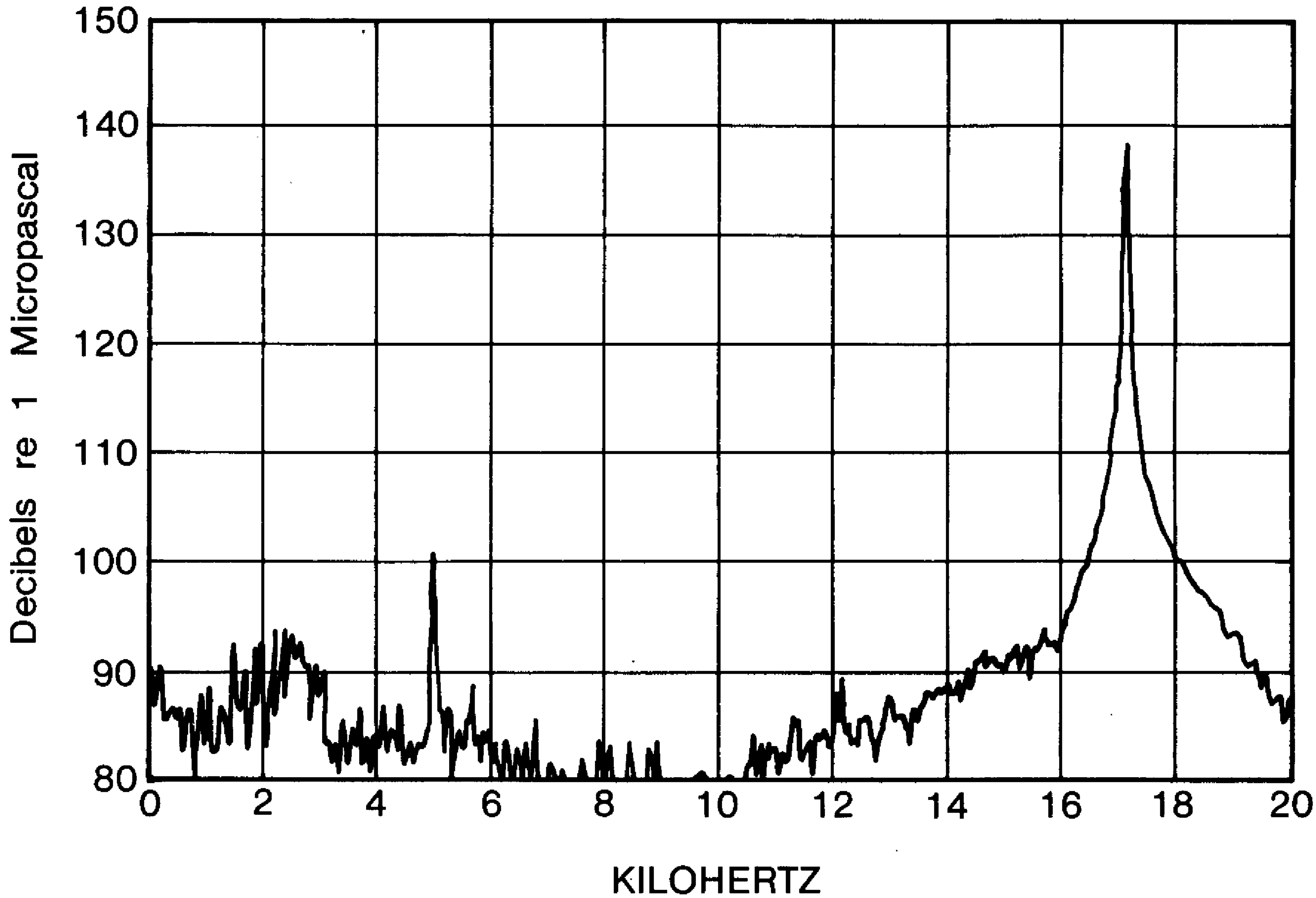
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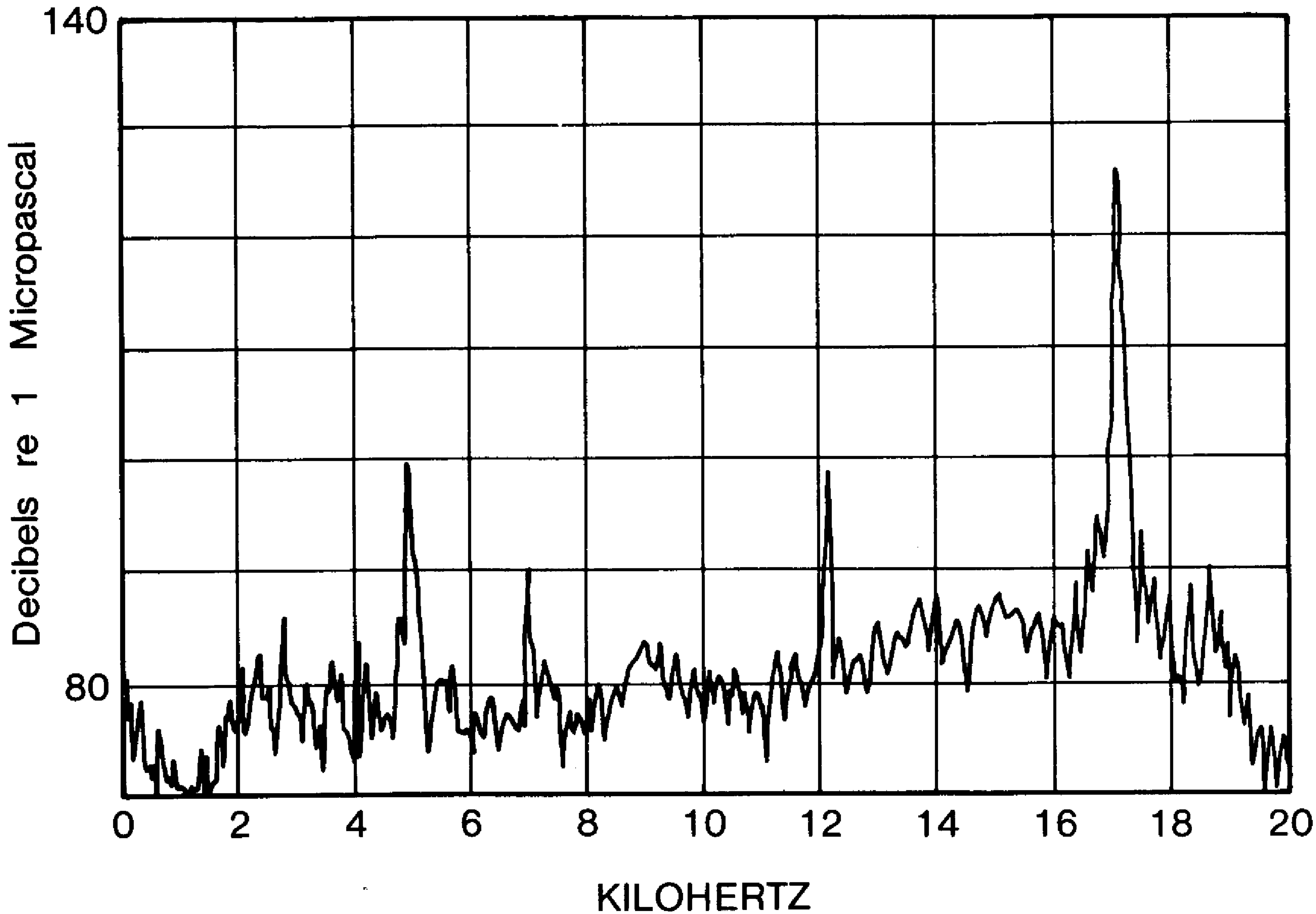
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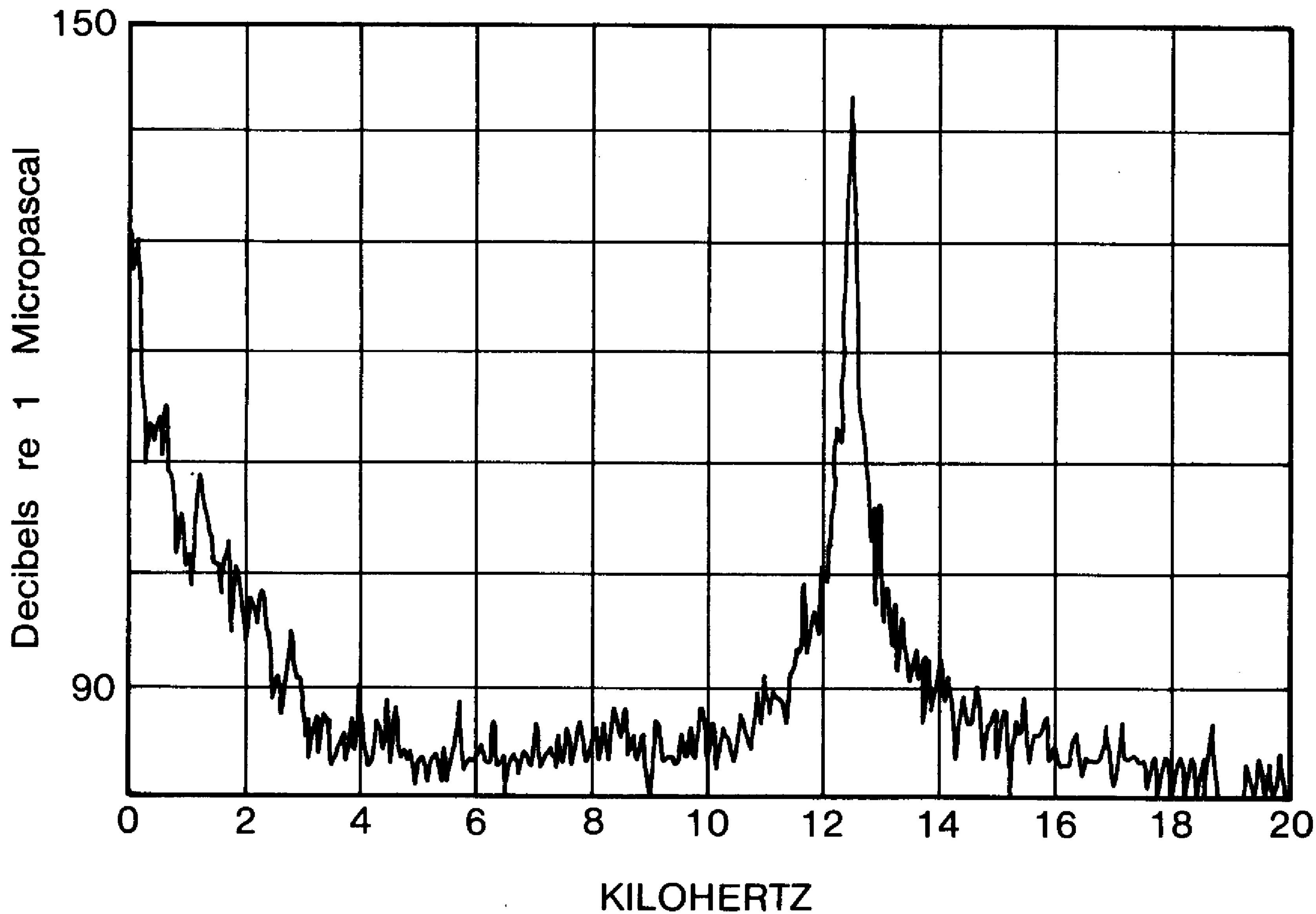
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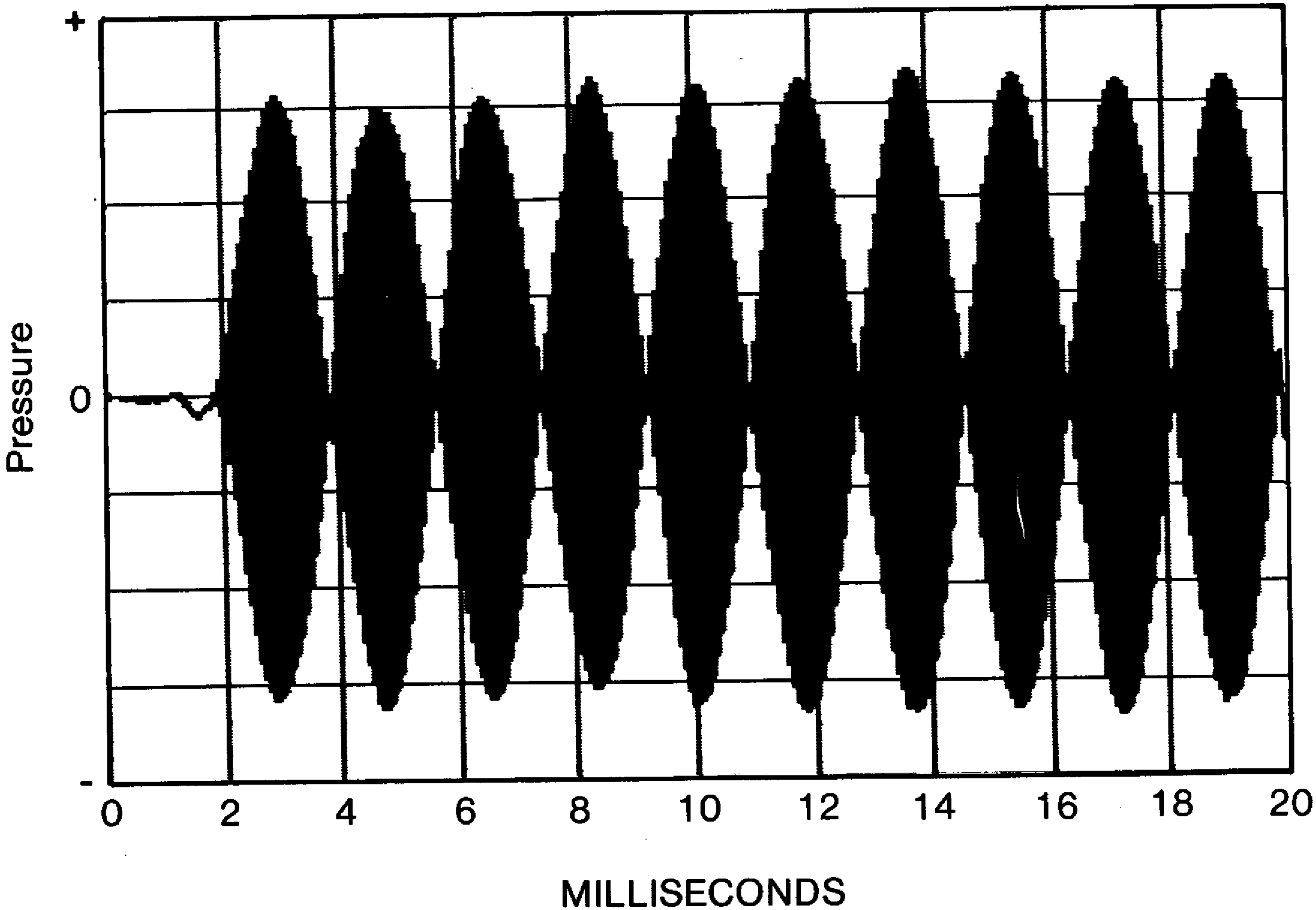
Figure 5



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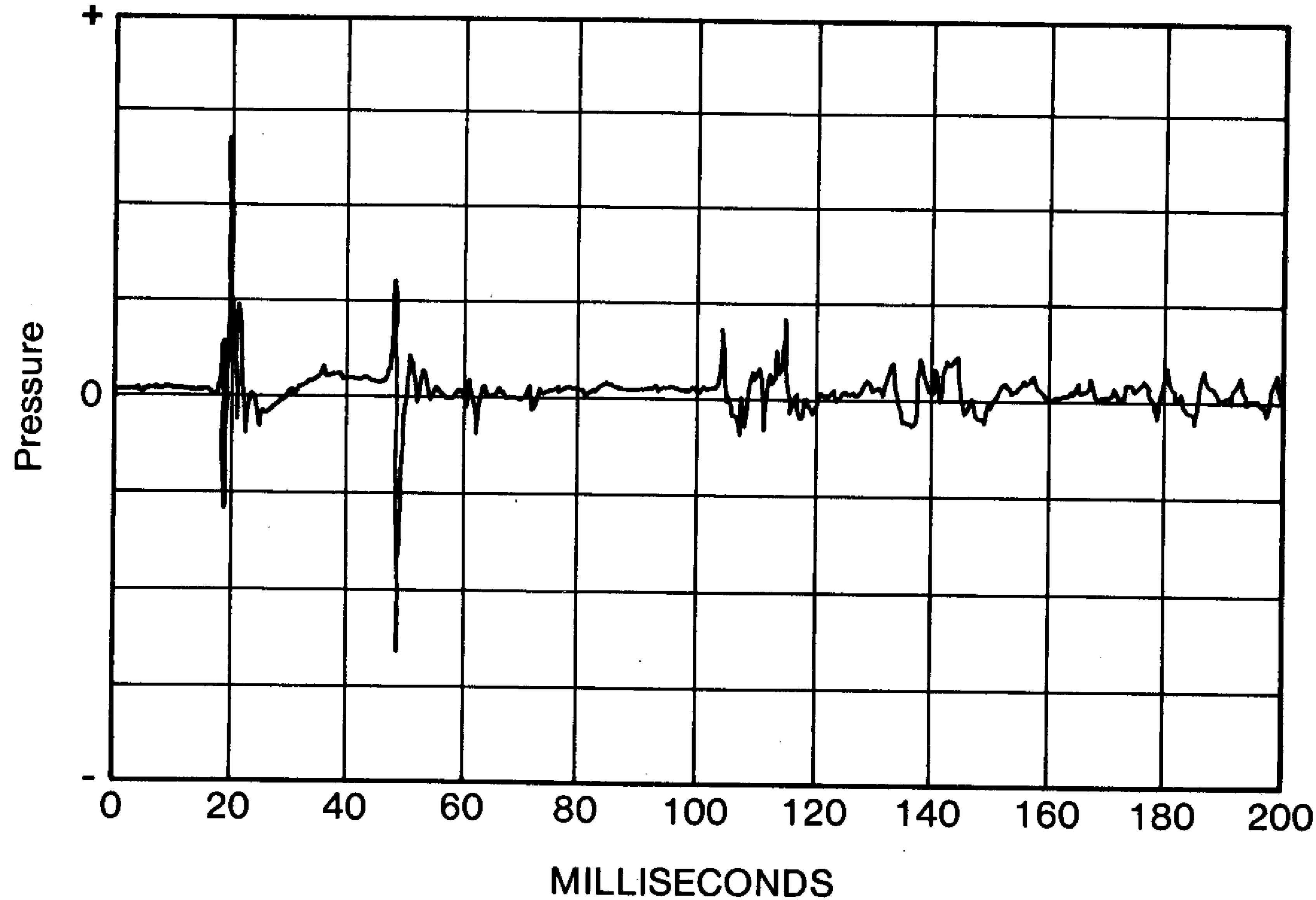

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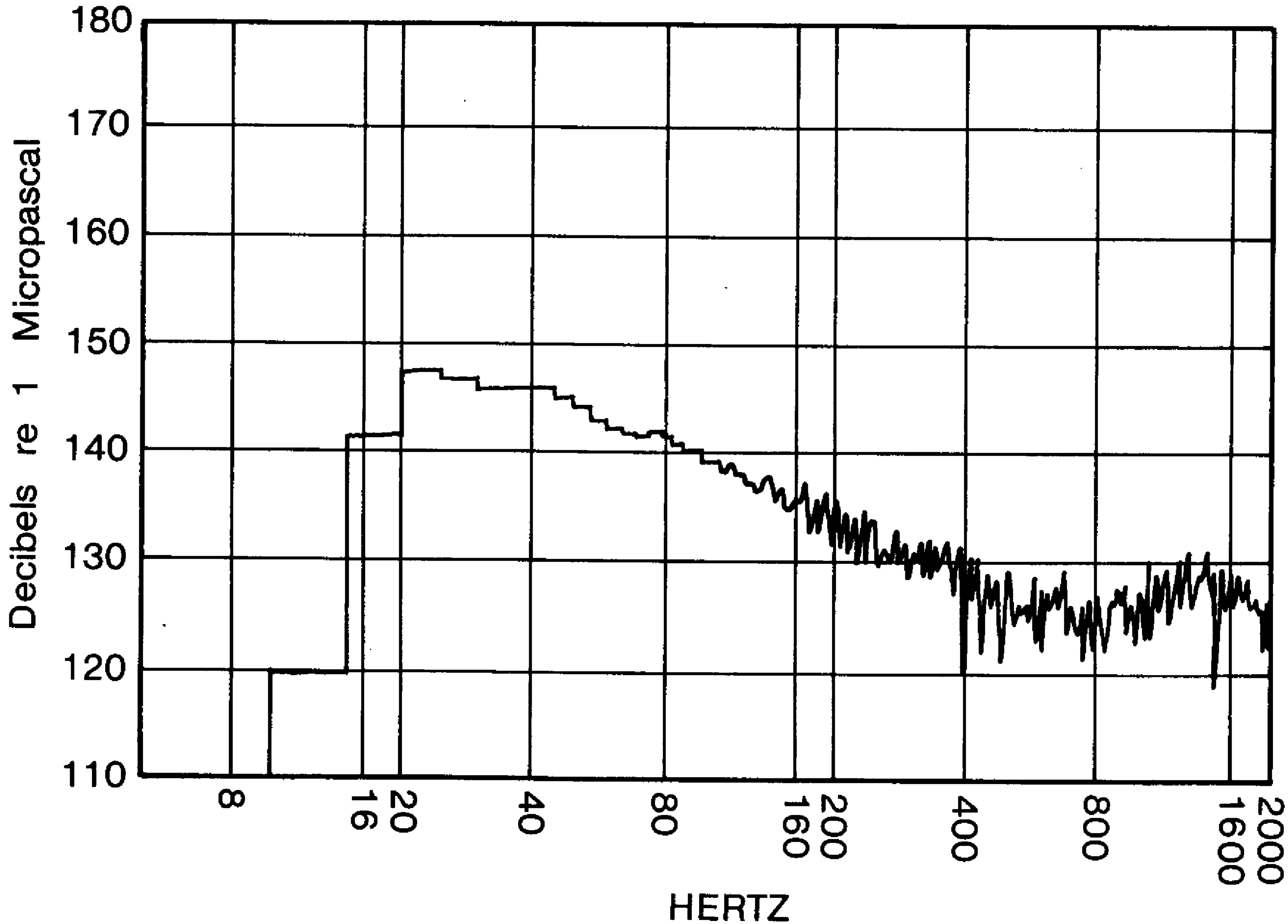
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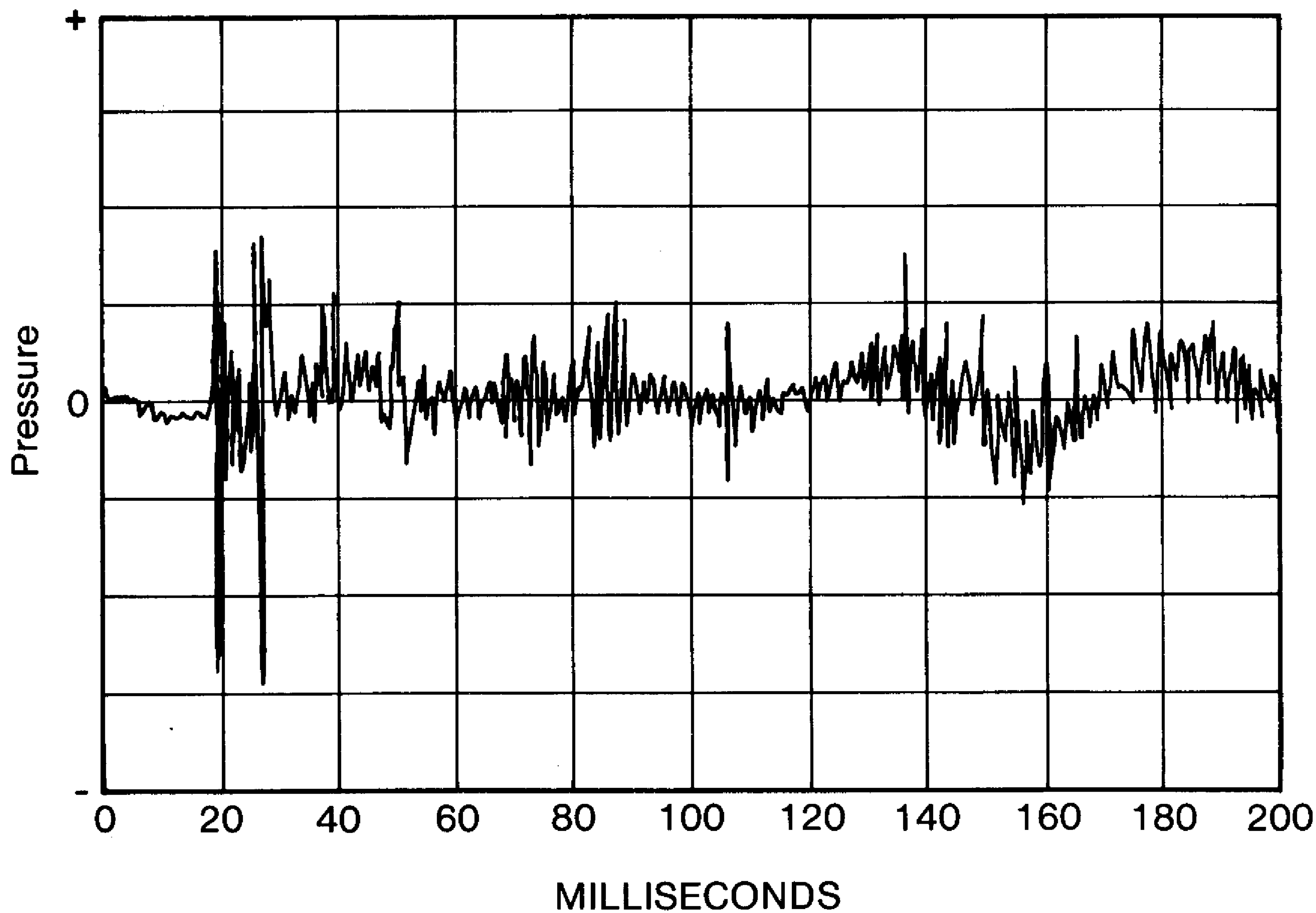
Figure 8



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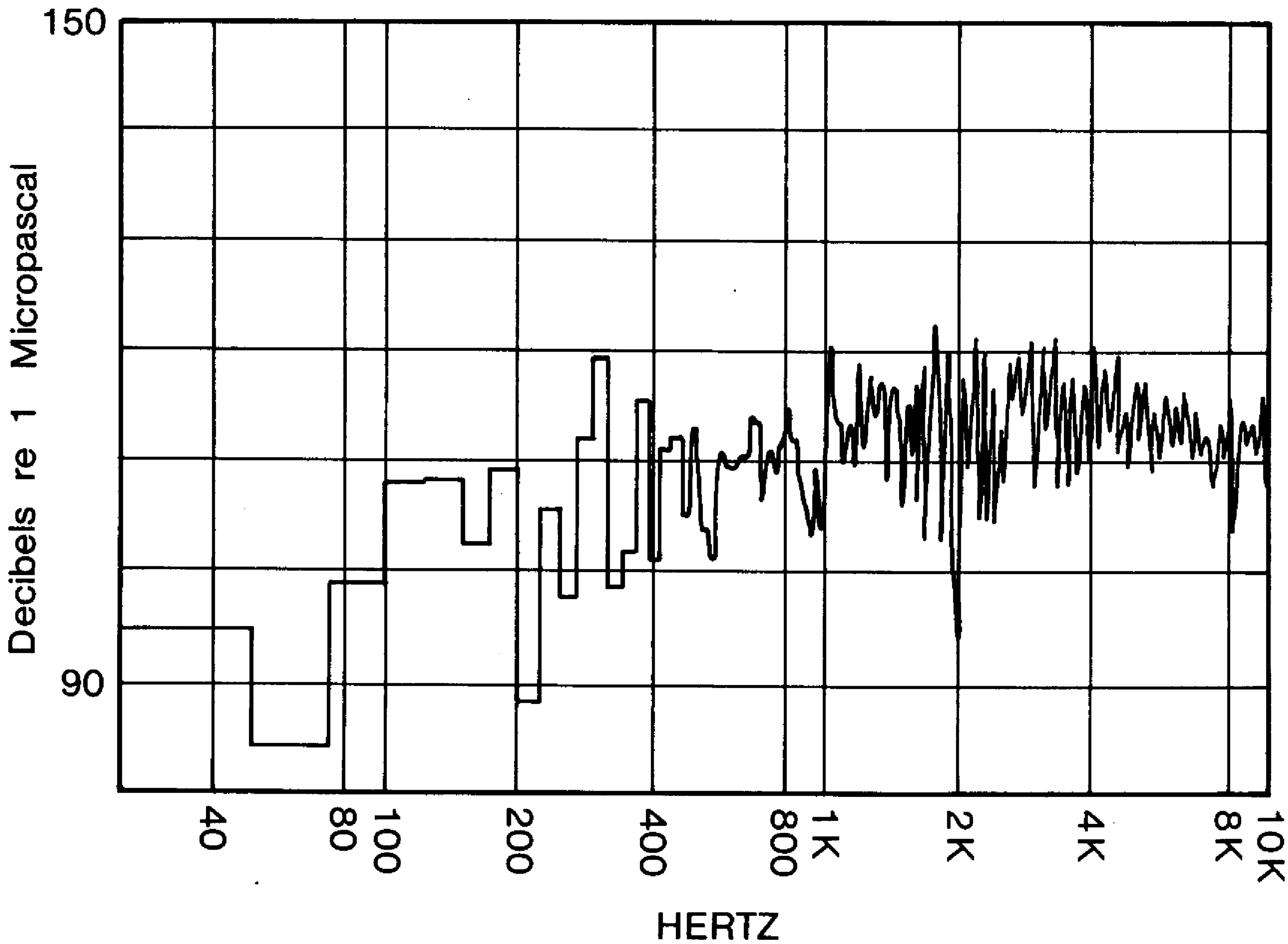
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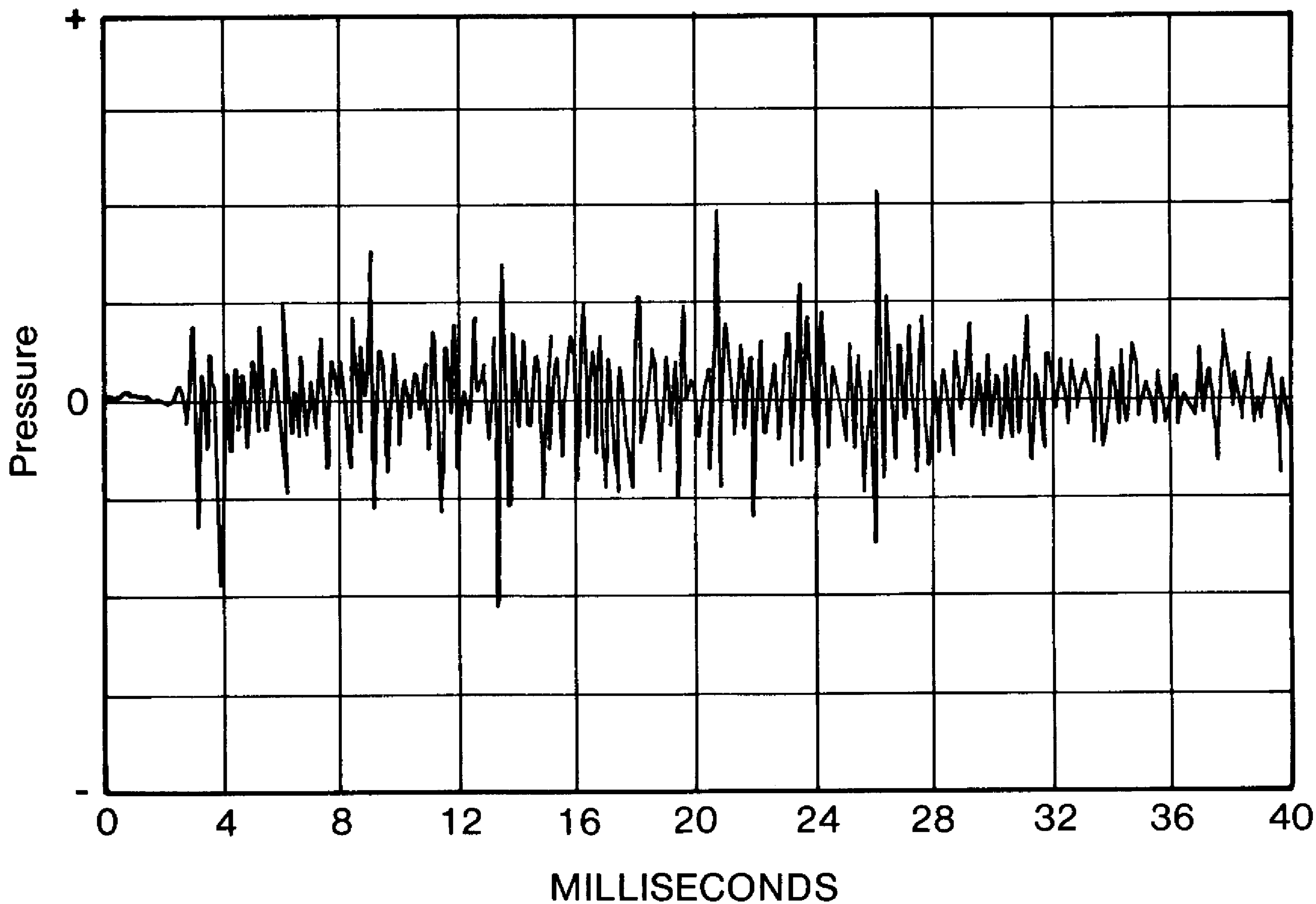
Figure 10



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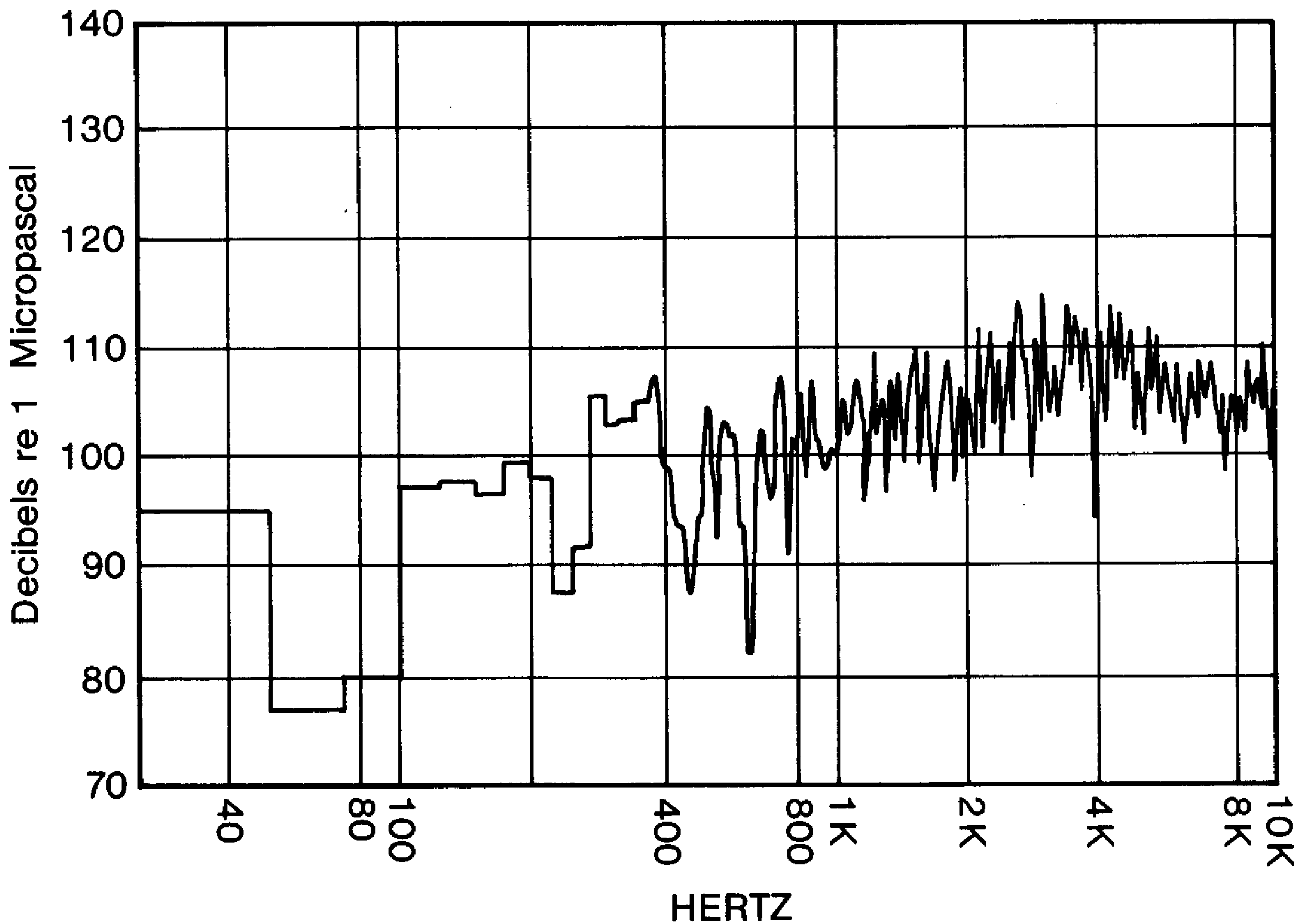

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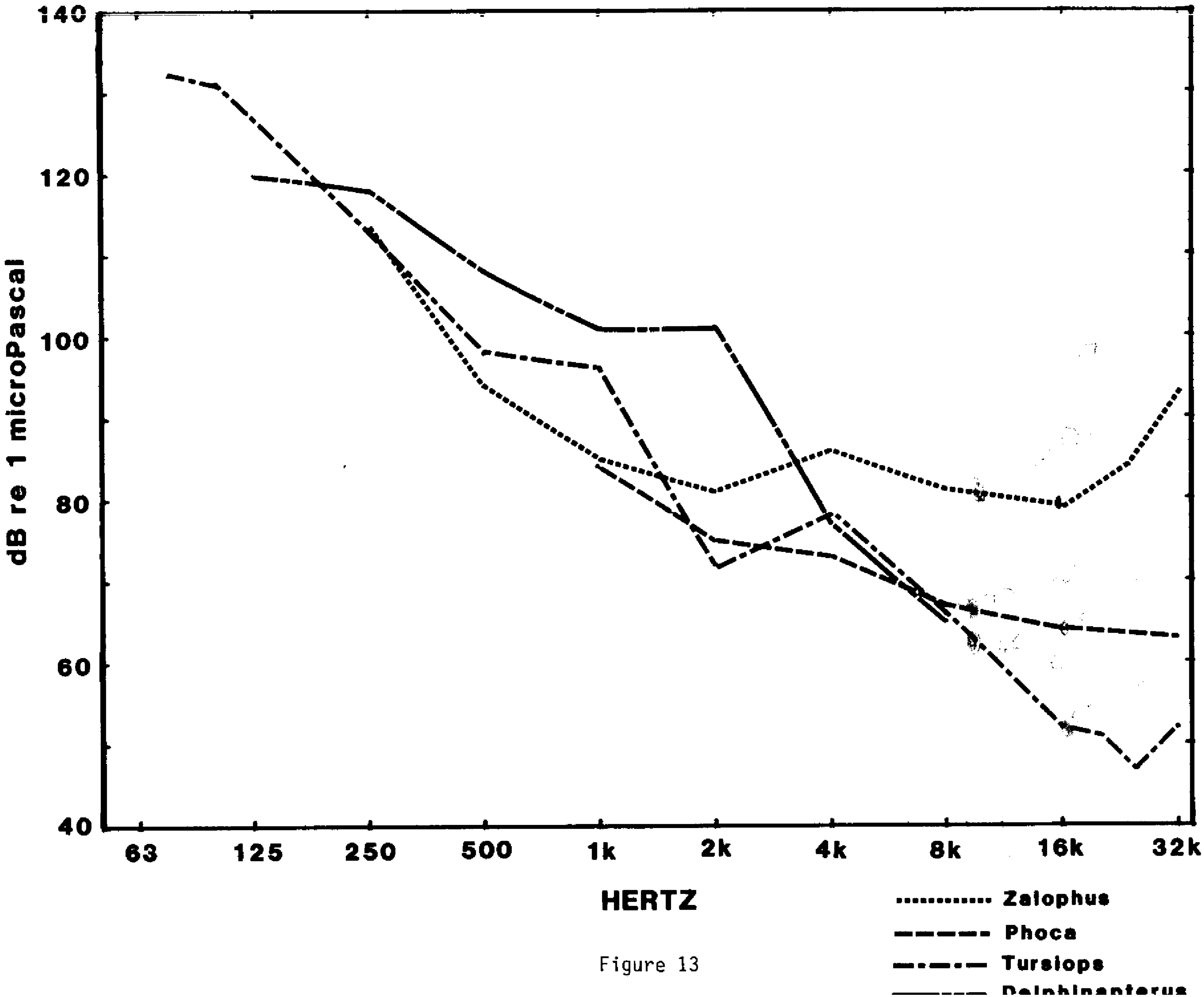
Figure 12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HERTZ
Zalophus
Phoca
Tursiops
Delphinapterus

Figure 13

Behavioral Conditioning

Karen Pryor, Private Consultant

I'm a behavioral biologist who was one of the founders of Sea Life Park in Hawaii back in the 60s. I got my education at Cornell and the University of Hawaii in marine zoology, but basically I'm a sort of Konrad Lorenz of bird-watching. However, in 1963, I took over the porpoise training at Sea Life under duress. That was my introduction to Skinnerian psychology, operant conditioning, and reinforcement theory, which was very new then, at least in the general field. We had a nice animal to work with that we could not punish. So we had to learn how to use reinforcement correctly. What are you going to do if he swims away? You can't hit him. Obviously, porpoise shows are not run by punishment; they're run by reinforcement.

Most of my published work has been either in biology or in the social behavior of dolphins. That's popular writing as well as technical writing. It's an area that fascinates me very much, and this particular problem, which has been around for awhile, is one of great personal interest. This is a puzzler; this is a very complex training situation.

What I might do is just touch on some of the basics of reinforcement contingencies so that whether you're in this game or not you can see how the game works and then apply some of these principles to things we've been talking about today. Psychologists have been so occupied with developing the theory of reinforcement that they have paid very little attention to the art of applying it. People who develop applications for it are the porpoise trainers, the Hollywood animal trainers. They call it affection training. You've seen stuff on TV commercials that could not have been done 30 years ago through reinforcement contingencies. Working in situations--such as with retarded patients--where you cannot explain to the person what to do and you can't make him do it is where reinforcement theory comes in very handy, and that, of course, is the kind of situation we've got here.

This is basically the reinforcement circle.

Positive Reinforcement

Behavior	Signal	R+
jump	Yes!	
	conditioned reinforcer	unconditioned reinforcer

Negative Reinforcement (Things we'll work to avoid)

Behavior	Signal	R-
come near	No!	(sound)
	conditioned reinforcer	unconditioned reinforcer

You have a positive reinforcement, something the animal wants. I'll use a dolphin. This is what dolphin trainers do. Dolphins eat fish. If you give the animal fish, it enjoys the fish; it's hungry. Positive reinforcement is something the animal will work to get. That's the simplest definition. If you want an animal to jump in the air, you can get it jumping in the air by giving it a fish every time it jumps in the air. But it doesn't give you much control over that jump.

Let's say you want a high jump. Well, the animal doesn't know. It got the fish after the jump was over. So the animal doesn't know what part of the jump you liked. You'll have to have millions of jumps to sort out the ones that are worth the fish and the ones that aren't. So trainers introduce a conditioned reinforcer. Usually this is the sound of a whistle, just because a whistle reaches the animal underwater and is easy to handle. A conditioned reinforcer means nothing to the animal at first, compared with the unconditioned reinforcer, the real reinforcer. But pretty soon this signal means to the animal, "That's what we want. Yes." Then you can tell the animal by when you blow the whistle whether you like high jumps, or jumps left to right, or jumps in which it falls in the water. You can, in other words, direct the behavior any way you want. That's called shaping. That's how dolphins are trained.

We also have negative reinforcers--things we will work to avoid. You sit down at a table in a restaurant and the air conditioner is blowing right on you. It's not painful, but it's unpleasant, so you get up and leave. That's a negative reinforcer. You move to another table. Life is full of negative reinforcers. They work exactly the same way for animals. In this case the seal comes near your fish or fish ladder or whatever it is; that's the behavior you don't want. You apply a negative reinforcer, a sound. The animal can avoid the sound by leaving. That's what we're doing: we're using an unconditioned reinforcer to keep the animal away.

You could also introduce a conditioned reinforcer, a signal that means I'm going to throw a seal bomb at you or I'm going to turn the loud sound on now. And you wouldn't be able to control this behavior with a conditioned reinforcer, theoretically.

These little equations are like laws of physics. In real life, though, there are other contingencies inside the contingency--the animal is so looney that it doesn't care about the sound or the animal doesn't hear the sound. Those big male sea lions are so dominant they're not going to let President Reagan tell them what to do much less some machine making noise. This really is probably a factor in the fact that you can't get big males away from fish ladders just by making noises at them. You've got animals that have had many years in which to learn to recognize your techniques.

Using reinforcement and all of the things that come out of these two simple equations, you can get rid of almost any kind of behavior one way or another. From a logical standpoint there are only seven ways to get rid of behavior.

1. Shoot the animal
2. Punish the animal
3. Apply negative reinforcement
4. Extinguish the behavior
5. Incompatible behavior
6. Shape the absence
7. Change the cause of the behavior

And these apply not only to seals eating, coming to fish tanks, or entering fish farms, but to the cat on the kitchen table and your boss being mean to you and your bad golf swing and your whining kid in the supermarket. All of these are behaviors we try to get rid of. And whatever we do one way or the other, we're going to use one of these enhancements. Applying reinforcers does not have rights and wrongs to it. After all, this is a kind of logical game which has many variants. So when you're thinking about changing behavior by using reinforcement, it's not a physics problem. If one thing doesn't work you can try another. Perhaps things worked on one dock but won't work on another dock. It's all right if it works only for two weeks and then you have to figure out something else. That's the nature of behavior. However, this bunch of tools will give you a flexible way of thinking about your problems.

Punishment is everbody's favorite method. That's the first thing we think of--it did a bad thing, we'll do a bad thing back. We've discussed at this workshop using a chemical inside fish--the so-called taste aversion. I've used lithium chloride. There are others; Ivory soap will do it cheaply. The effect is that the animal eats a piece of food and it makes him throw up. Now, there's a lag, of course, between the time that it eats the food and the time it gets nauseated. So from a porpoise trainer's standpoint (from a reinforcement standpoint), you wonder whether that animal has any way of mentally connecting its behavior with the ultimate results. This has always been the worry about taste aversion--that the animal won't know until two hours later that it shouldn't have eaten that fish, so it won't really remember that it got that fish from your party boat. In fact, nausea is very effective in negative reinforcement because the food comes right back up and you do remember what it was you ate. And you may remain somewhat averted to that particular food for a long time. I think that because the punishment (even though it's delayed and it's a punishment rather than negative reinforcement) involves simply nausea, it has a chance of being effective in repeated situations where an animal has learned to go to a particular boat and eat its particular fish and then for two or three particular times has an unpleasant experience.

Negative reinforcement is what we're talking about with the seal bombs and harassment devices. Punishment is unavoidable--when you eat the fish and you're throwing up it's too late to change your mind. On the other hand, you can get away from negative reinforcement. This makes it a very powerful teaching tool. The animal comes in, it suddenly hears this loud noise, it goes away, and you turn the noise off. When it starts to come back you turn it on again. I think acoustic harassment has legitimate value in terms of teaching the animal that the way to get away from this noise is to go with the others.

Extinguishing behavior is just letting the problem go away by itself. This is what we usually do with the problem of sea lions hauling out at places where we wish they wouldn't. We want them to go away. Eventually they do.

These are the methods that I ordinarily recommend to schoolteachers for getting rid of undesirable behavior. But they all involve a positive reinforcement. Basically, the behavior we're concerned about in this workshop doesn't tend to extinguish by itself because you've got a lot of positive reinforcement going on. The animals come in and they get fish, so the animals are training themselves to come in.

Offhand I can't see any way you can keep animals away from the fisheries with a positive reinforcement system because you don't have anything for them they want more than they want those fish. On the other hand, there are as many different ways to train behavior as there are trainers to apply methods. Somewhere in one of these methods there might be something useful. I wouldn't want to throw it out the window. Reinforcing behavior means to reinforce the animals for doing something they can't do while they're also on your fish ladder. What that might be I don't know--going through hoops out in the ocean; putting the behavior on cue; calling seals to the fish ladder at a specific time of day, giving them one fish, and sending them away. Putting behavior on cue is a great way to get rid of behavior because what happens, oddly enough, is that once animals understand the signal and they come in response to the signal and get reinforcement, they stop coming in the absence of the signal.

Some of the more complex things that happen under reinforcement contingency circumstances really do pertain to what is going on because of the kinds of problems I've been hearing about at this workshop. One of the rules of reinforcement theory that is not intuitive, that doesn't seem to be obvious when you think about it, is that variable schedules of reinforcement are more powerful than fixed schedules of reinforcement in maintaining behavior. What this means in English, instead of Skinner, is that once you have learned the behavior--once you have learned that if you jump, you get a fish--you now understand the behavior and you're simply doing the behavior in return for reinforcement. If you get reinforced every time you do it, you will emit the minimum amount of energy necessary to get that reinforcement. In other words, the jump will fizzle down to a little plop in terms of the porpoise in the show tank. If you get a reinforcement every fifth time you jump, you will make four little jumps and one big one. It's amazing how it works; it always works. However, if you don't know if you're going to get a fish the first time, or the second time, or the eighth time, you'll jump like crazy, especially if you like those log-sized fishes now available. So, in order to keep an animal really working once it has learned the behavior, we porpoise trainers put it on a variable schedule and it never knows whether it's going to get a fish this time or not.

Hence, Las Vegas. All gambling is simply the variable schedule of reinforcement on which somebody got hooked. And interestingly enough, compulsive gamblers usually got a great big jackpot the first two or three times they played a slot machine or whatever. They got hooked right away with a big reinforcement, and it's that variable schedule that keeps them coming back. If you went to Las Vegas and put a nickel in the slot machine and every time you did it you got a dime back, how long would you do it? Half an hour. That is a really dumb way to make money.

Variable schedules also work with negative reinforcement. And this is why I think one of the most effective acoustic harassment devices is the one that works intermittently so that sometimes the thing goes off, then it doesn't go off for 30 seconds, then it goes off again for two minutes, then it doesn't go off for 30 minutes, and then in 15. It's impossible for the animal to predict when the device is going to go off in his hemisphere. This variation at least postpones the time when you get to the treat. The animal has really no good chance to get used to it.

There's a practical limit to how much down time you can have and how much quiet time because you don't want to have so much quiet time that the animal can come in, do all his dirty work, raid your whole net, leave, and never get hit just because the variable schedule was too stretchy. So probably your overall mix of different lengths would be different for animals that are raiding driftnets, animals that are trying to come in to fish ladders, animals that are in your net pens, and animals that are not. I think this is the kind of tinkering that is perfectly legitimate to do.

We've heard a lot about habituation. You can hardly build a stimulus so severe that people can't get used to it, can't learn to tolerate it and to regulate it so that you don't have to keep readjusting to changes in it. In New York City I lived in a fourth-floor apartment, on the corner of 10th Street and University Place, with big buildings up to 15 stories on all sides of the corner; it was a real little sound canyon in there.

Everything that happened on the street ricocheted all the way up. It was a very noisy corner because there was a lot of traffic and three or four late night jazz places that didn't shut down until four in the morning so there were drunks and screaming and yelling and music in the streets all night long. I got so I could sleep through anything except automobile crashes and gunshots. Everything else, I just didn't even hear. The noise level was very high, but unless it spiked way up above that uniform high level, it didn't disturb me.

So your animals are habituating to the continuous sound and also to the intermittent sounds. I've been wondering what is going on in the animal's head. Can you change what is going on? Sometimes I hear something that suggests to me that the animals are really frightened by the sound, perhaps just because it's new--that they have some kind of fear which gradually wears off. You wonder, too, if sometimes it may actually be a painful stimulus, in which case it would be more difficult to habituate to it. Putting the sounds on variable schedules is one way of attacking the problem when you apparently have a habituation. Another way is to keep the sound off unless the animal starts to do what you don't want him to do.

What crossed my mind first was to use the acoustic device as a conditioned signal or stimulus for the seal bomb. But you could also use the acoustic device to have another sound which is simply a buzzer or warning that we're going to do this bad thing; then if you could make that warning contingent on the animal's behavior so that the animal itself sets off the gun, you would have successfully used negative reinforcement. The animal has learned when it hears this, that something is coming. Now it discovers that it hears this sound every time it does this behavior or even sometimes.

The first thing that will happen is that you will train the animal. The animal will train itself not to do this behavior. It won't come as close. And another thing that will happen is that you can use this warning without following it up with an unconditioned reinforcer. It's for the trainer on the spot to figure out how this works in some practical situations. I'm sure it's different in every situation.

It takes a positive reinforcement to teach a porpoise to jump. The porpoise learns that it is going to get a fish only sometimes so it jumps vigorously. We also teach it by giving it a cue when it can jump and other learner reinforcement. But very often we don't have to give it the fish. The whistle is enough. The whistle becomes a signal; it becomes the porpoise's information. And information itself is very reinforcing to living organisms. It is as reinforcing as food. This is information, too. This information becomes so powerful that some avant garde trainers don't even use food rewards. They use the fish at the end of the day or they may give the animal all its fish in one shove and then they can run four or five more shows without any fish at all. The animal is satiated with the fish that the trainer has hooked it on; it's a variable schedule of information.

This means using several different kinds of reinforcement. The more reinforcements you can attach to your conditioned reinforcer, the more popular conditioning becomes. The nice thing about conditioned reinforcers is that it doesn't matter how big they are as long as the animal can perceive them. For example, you will stop when you see a red light. A red light means stop. We know this is a conditioned stimulus or a conditioned reinforcement. But when we see a light we stop. It doesn't matter if it's up here or over there or big or little. None of the details about it are important anymore. It doesn't even have to be big, just big enough for us to perceive it. So you can control the behavior somewhat without going to the expense of escalating your signal. That way you don't have to use a big one or you may use it only occasionally. The animal is conditioned to learn that this warning signal means something worse is following. Somehow that's even more painful. You go to the dentist and you smell the stuff and you feel worse about going to the dentist than if you hadn't smelled the disinfectant that makes you remember the unpleasant past.

The Design and Operation of Acoustic Aversion Devices: Some Notes

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The use of acoustical pingers to repel seals, sea lions, and other marine mammals from fishing gear, hatchery ladders, and fish pens has been tested by several fisheries researchers, aquaculture firms, and scientists. Most of the devices tested have been designed and built by Cascade Applied Sciences (a division of CMI-Cascade) over the past five years. The February 1986 workshop that was the occasion for this volume drew together researchers who have used the pingers. The notes that follow constitute my understanding of the information and suggestions presented at this workshop and in subsequent conversations with participants at that workshop.

One main conclusion obtained from users of AADs (acoustic aversion devices) was that effectiveness was less than 100% in almost all experiments. Greater success in repelling seals than sea lions was typical. One report noted that river otters were successfully kept completely away from a pen farm for three-month periods over two years. Other reports described animals swimming within a meter of the transducer.

Success, of course, needs no explanation. Failures deserve careful attention, for it is here that we may learn something. In cases where it was possible to identify individual animals, it was found that only one or two seals out of populations of 50-250 were responsible for most of the damage (Whiskey Creek Hatchery, Klamath River). The "success" rate, in terms of seals kept away, might appear rather high, 98% or more. Relatively few seals were known to frequent the areas of damage when acoustic aversion was not used, however, so the success rates might be closer to 60-70%. There is some possibility that the seals involved had impaired hearing, but this cannot be proven and cannot be seriously considered without substantive evidence.

Other examples of failure included attempts to "fence" a river system to exclude seals. Again, relatively few animals passed the acoustic screen, but they were enough to give the appearance of failure to affected fishermen. One obvious deficiency of this application of acoustic aversion comes out in the comment that seals were seen passing the line of AADs with their heads out of the water. I suggest that this is adequate demonstration that acoustic aversion is best suited to the defense of point targets--a hatchery ladder or a fish pen. Such seal behavior also points out the fallacy of thinking of the acoustic energy as a force field that absolutely repels intruders.

A third area of failure, not explicitly addressed in the workshop but worthy of notice, is that of dealing with abused animals. I use this term to describe animals that have been harassed for considerable periods in the past and are desensitized to almost any further harrassment. Rather like abused children, they may come to expect harassment in feeding situations and do not react as a naive animal might.

In the paper I presented, I argued that it was exceedingly difficult to produce sounds at the threshold of pain underwater. The observations of animals passing very close to the transducer would tend to bear out this analysis. It is possible that the sounds are uncomfortably loud, but obviously they could usefully be louder. Part of my analysis, drawn from psychoacoustical research on humans, was aimed at the question of "loudness." I showed that perceived loudness in humans tended to increase as the duration of tone increased, up to about one second. After about ten seconds, the loudness appeared to decline. This effect is more pronounced at high sound intensities. If seal/sea lion ears and auditory systems are reasonably similar to the human system's, then an effective aversion tone would have to be at least .5 seconds in duration to attain maximum perceived loudness. For the sake of reference, the AADs now in the field produce tones (or frequency sweeps) with durations of 0.02 seconds to about 0.12 seconds. Extrapolating from human data, it would seem possible to increase the perceived loudness of these signals by up to 20 dB (two orders of magnitude in perceived intensity) by increasing the pulse durations.

Karen Pryor presented some basic tutorial information on behavioral conditioning at this workshop. From her analysis, several strategies of operation appear to offer promise in increasing the effectiveness of AADs. First, it would seem to be advantageous to produce the sounds in bursts, with quiet intervals of random length between the bursts of pulses. Her estimate of a reasonable average time for these off periods was a few minutes, perhaps 3-5. (Some of the units in the field have this capability. I am aware of no experiments where this feature was used. If the sounds produced are thought of as a sonic "fence," then the idea of frequently tearing down this "fence" is not appealing. Experience, such as that recounted above, has shown that the sounds are not an impenetrable barrier, however. It seems clear that some new thinking is required here.) This strategy is an approximation to a conditioned response--where the sounds would be produced only when the animal engages in some specific activity, such as approaching within a certain distance of a protected installation.

An ideal system would detect the presence of an intruder and trigger the acoustic signals when the intruder crossed some fixed boundary. This is certainly a feasible technical task--an acoustic detection system modelled on swimmer detection systems could be developed--but the economics are not favorable. The random-length quiet period is a crude approximation to the trigger-on-detection approach.

The second operational strategy is truer to the conditioned response case. This mode of operation involves producing a "signal" followed, usually, by a series of loud acoustic tones. The signal may be acoustical as well, but should be nonaversive. The relationship between duration and "loudness" noted above suggests that an appropriate signal might be a short (ca. .005 second) tone. The loud (e.g., long duration) tones should follow this signal by a few seconds, enough time to permit a seal/sea lion/otter/etc., to begin withdrawing from the region.

The concept of a "variable schedule" of negative reinforcement suggests that the signal not always be followed by the loud tones. On a random basis, the reinforcer tones would not be generated, leading to considerable uncertainty (anxiety?) on the part of the animal when the signal was heard. This would help to reduce the possibility of habituation--which is probably the explanation for most of the cases where acoustic aversion appears not to help.

Operation of several units, all with the burst-mode of operation, might increase the effectiveness of acoustic aversion. In addition to being unable to predict the time when sounds will occur again, the animal would also be uncertain where the sound would come from.

Another suggestion, not necessarily part of the strategies above, is to vary the form of the negative reinforcement. This might best be done in the form of a training process. An operator would watch for intruding animals. Upon sighting an animal within a pre-defined region, the operator would trigger an AAD modified to produce only 'signal' tones. A few seconds later, he would throw a seal control bomb near the intruder. This 'training' would have several positive results. First, it would target those animals that are potential problem animals, experienced or naive. Second, it would help to directly link the three elements of conditioning: the behavior (coming too close to the area), the 'signal', and the reinforcement. Third, it would amplify the effectiveness of the 'signal' at times when the observer was not present because a variable schedule of reinforcement would be applied, both in frequency of presentation and type of reinforcement.

Appendix: Behavioral Conditioning

Very briefly, the following description summarizes what I understand to be the basics of behavioral conditioning theory.

Conditioning requires three elements: a specific behavior by the animal that the trainer intends to reward (positively or negatively), a signal to the animal that the behavior has been observed, and a reinforcement. In most cases of animal training, the behavior sought is some trick. A whistle is often used by the trainer to signal that the behavior has occurred. The reinforcement in this case would be positive--bits of fish, perhaps--to positively reinforce the desired bahavior. When conditioning is completed, the use of the signal should produce the desired behavior; the behavior and signal become linked together in the animal's mind as indications of potential reward. One then says the animal is trained.

Negative conditioning works in precisely the same way. The main differences lie in the fact that the behavior is undesirable, and the reinforcement is negative. Electric shock, chemical doses, physical abuse, and--we hope--acoustic stimulation are potential negative reinforcements. Again, the key to "training" an animal to avoid a certain behavior is the linking of a signal with the prospect of punishment and the linking of the signal with the behavior.

The reinforcement need not--some would say should not--inevitably follow the signal. A random presentation of the reinforcement following the signal has been found to reduce the hazards of habituation to the signal in animal training The animal begins to work for the prospect of reward (or the prospect of avoiding punishment) when the signal is presented but cannot be certain that it will actually appear this time. This uncertainty, I suppose, causes the animal to have a stake in paying stricter attention to the signal since it cannot predict, absolutely, the consequences. This probabalistic reinforcement strategy is called variable reinforcement. The probability of receiving the reinforcement should be high when training starts and lower when training is completed and the "act" is routine.

Application of these concepts to protection of fishery areas with acoustic aversion is complex and, at this date, not well understood. Some of the possibilities are described in the text above. Others will occur to astute observers as experimentation proceeds.

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