An Acoustic Harassment Technique to Reduce Seal Predation on Salmon

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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 perturbation (Schusterman, 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 operations. 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/µPa. 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 paraffin 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 faraday 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/µPa) 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 re:1 μPa. 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 Netarts 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-kHz-power amplifier was matched to the ITC transducer to produce source levels of 190-208 dB/µPa, but resulted in source levels of only 158-176 dB/µPa 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/µPa.

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>
<thead>
<tr>
<th>Surfacings (x/min)</th>
<th>Number of Salmonids Caught (Damaged)</th>
<th>Mean Damage Rate (% of Total Catch Damaged)</th>
<th>Seal (Damaged)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAHD off (N=11)</td>
<td>57 (9)</td>
<td>25.4</td>
<td>0.7</td>
</tr>
<tr>
<td>SAHD on (N=11)</td>
<td>148 (2)</td>
<td>1.5</td>
<td>0.06</td>
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TABLE 1. A summary of seal damage to salmonid catches in the April 1982 Columbia River spring chinook test fishery.
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.

<table>
<thead>
<tr>
<th></th>
<th>Observation hours</th>
<th>X seals / 10 min. (SD)</th>
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<tbody>
<tr>
<td></td>
<td>SAHD on</td>
<td>SAHD off</td>
</tr>
<tr>
<td>1980</td>
<td>61.7</td>
<td>29.0</td>
</tr>
<tr>
<td>1981</td>
<td>9.8</td>
<td>12.0</td>
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<tr>
<td>1982</td>
<td>9.5</td>
<td>49.7</td>
</tr>
<tr>
<td>1984</td>
<td>16.0</td>
<td>27.0</td>
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... 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.

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<td></td>
<td>N</td>
<td>HRS</td>
<td>PRED</td>
<td>N</td>
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<tr>
<td>SHAD</td>
<td></td>
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<tr>
<td>off</td>
<td>18</td>
<td>61.7</td>
<td>0.29</td>
<td>20</td>
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<tr>
<td>SHAD</td>
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<tr>
<td>on</td>
<td>2</td>
<td>29.0</td>
<td>0.07</td>
<td>1</td>
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*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 that 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 chemoreception 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 holder 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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