Providing Specialized, Innovative Products To A Wide Range Of Industries

PREVENTING DAMAGE TO FISH BY SEALS AND SEA LIONS

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TABLE OF CONTENTS

1.0 INTRODUCTION

The aquaculture industry is proliferating throughout the world. In some areas, the economic output of the aquaculture or aquafarming industry, where finfish (especially salmoniods), mollusk, and crustaceans are cultured, exceeds that of the commercial or wild fish industry. Pinnipeds, mainly sea lions and seals, are causing significant economic losses to this portion of the industry. Pinniped interactions with fisheries and aquaculture facilities occur throughout the world (Harwood, 1983; Northridge 1984, 1991; Woodley and Lavigne, 1991; Wursig and Gailey, 2002; Kemper *et al*., 2003). These losses include damage to the fish population itself: outright killing of the fish, reduced value caused by injured or damaged fish, increased disease susceptibility caused by descaling and other damage of the fish, and reduced fish growth rates caused by an increased stress level. In addition, the aquaculture industry suffers economic losses from pinniped damage to the fish pens themselves: by increased maintenance and repair costs, loss of fish stock through holes in the damaged pens, genetic contamination of the fish stock, and diseases transmitted between the indigenous fish stock and the fish farm stock.

In addition to the damage done by pinnipeds to the aquaculture industries, they also cause significant damage to commercial fishing operators; most specifically, commercial passenger fishing vessel operators and bait farmers. Pinnipeds damage the fishing gear, attack and ruin the catch, and drive the fish away from desirable fishing grounds.

This white paper describes a method developed by Hydroacoustics Inc (HAI) to reduce the economic losses to the fishing industry caused by pinnipeds. It will briefly describe the extent of the problem as described in the open literature. It will outline anticipated requirements for potential use of HAI Aquaculture Predator Protection System (APPS) to deter pinnipeds from depredation of fishing vessels at sea and at holding wells of aquaculture or bait facilities in United States and other areas outside the Continental U.S. waters. In addition, it will suggest ways to demonstrate the effectiveness of the HAI APPS to deter pinniped interactions with fisheries and aquaculture facilities. A preliminary and selective bibliography of scientific literature regarding fisheries interactions and deterrent devices is provided as reference for future work.

2.0 BACKGROUND

2.1 THE EXTENT OF THE PROBLEM

Damage by pinnipeds (especially seals and sea lions) to aquaculture and commercial fishing operations is having a major economic impact on those industries, contributing to frequent conflicts between humans and pinnipeds. Examples of this interaction and conflict are documented in the southern California recreational fisheries, (Beeson and Hanan, 1996), the U.S. West coast salmon fishery, (Weise and Harvey, 2005), and to aquaculture facilities worldwide (Wursig and Gailey, 2002, Kemper *et al.*, 2003). The pinnipeds may consume all of part of the hooked or netted fish or may damage the confinement pens allowing the cultured fish stock to escape or allowing indigenous fish to enter the pens (Northridge, 1984, 1991; Lunneryd, 2001).

For example, the recreational fishing industry, including the commercial passenger fishing vessel (CPFV) industry, in California together is approximately a two billion dollar a year industry. Pinniped damage to gear and fish stocks is a constant threat to the profit in this industry. Many pinniped species interact with the aquaculture industry along the California coast, California sea lions, (Hanan *et al.*, 1989; Beeson and Hanan, 1996; Weise and Harvey, 2005), harbor seals, Steller sea lions, northern fur seals, and northern elephant seals (see Barlow *et al.*, 1994, Carretta *et al.*, 2005). The population of these pinnipeds has generally increased since the passage of the Marine Mammal Protection Act in 1972. This increase has resulted in an upsurge in reports of pinniped damage (Beeson and Hanan, 1996).

The California CPFV industry has attempted to use acoustic devices to control damage to their catch and gear with limited and short-term success. Even after using the available devices, pinnipeds avoid or ignore the deterrent systems, continue taking hooked fish from lines, steal bait and chum, and prey on fish near the fishing vessel. No deterrent device or system has been offered that provides a long term, safe, and effective solution to the problem of unwanted pinniped interactions.

An aversive acoustic deterrent system should be as uncomfortable as possible for the pinniped, without injuring it (Orenstein, *et al.*, 2004 and 2006). The system should also be non-habituating and should maintain a negative stimulus over time (Jefferson and Curry, 1994). In addition, it should not cause serious injury or mortality of the target species (or to nearby non-target species). And finally, the device should be practical to operate when and where the pinnipeds interact with fishing operations and have an effective range on the order of 100 meters (Hanan *et al.*, 1989).

The use of an acoustic deterrent, if consistently effective over time, could circumvent measures such as the lethal take of pinnipeds authorized by National Marine Fisheries Service (NMFS) in 2008 as the result of ongoing interactions with the salmon fishery (Federal Register 73:57).

2.2 EXAMPLES OF ACOUSTIC DETERRENT SYSTEMS

2.2.1 Predator Sounds

Killer whale vocalizations have been used in an attempt to keep grey seals away from salmon nets in Scotland (Anderson and Hawkins, 1978). However they were not consistently effective. Cape fur seals showed a distinctive reaction to killer whale calls, although this effect was reported to be transitory (Shaughnessy et al., 1981). The response of seals to killer whale sounds has been tested as part of the Swedish National Management Plan for grey seals in the Baltic Sea (Anon, 2002). Killer whale calls were played to a resting/slow moving common seal near Har on Norway's South West coast. The seal fled at high speed to the nearest rocky islet 200 meters away. When, in a second trial, the killer whale calls were played to a grey seal in the Sea of Bothnia, Sweden, the seal swam about 1,000 meters away, but it then resumed foraging in spite of the presence of a nearby rocky islet on which it could have hauled out. There is no detail in this study as to the type of killer whale sounds used, or the distribution or abundance of killer whales naturally occurring in the areas studied.

2.2.2 Explosive Sound Sources

Explosive sound sources and pyrotechnic devices have been used to scare pinnipeds from commercial fishing areas and fish stocks. A rocket-launched charge, which can be shot up to 300 meters (originally designed to be used to scare birds from airports) and which detonates with a flash of light and a loud bang, has been used to drive pinnipeds away from the herring fisheries in the Sea of Bothnia, Sweden (Anon, 2002). The pinnipeds dived in response to the explosion (either above or below the water) but returned a few minutes later.

Gun shots or cracker shells, small charges fired from a rifle or pistol that explode above or below the water surface (Jefferson and Curry, 1994) have been used to frighten pinnipeds from an aquaculture area. In a similar way, underwater explosive sound sources or seal bombs have been used with some success in keeping pinnipeds from foraging in aquaculture facilities. Both the cracker shells and seal bombs are effective for a relatively short period of time, and, therefore, they must be used repeatedly to be effective in reducing the damage done to the fish stock or fish farm equipment by the pinnipeds.

In order for the seal bombs or cracker shells to be effective, they must detonate near the pinnipeds (because of their relatively low energy source levels). This requirement places the operator at risk because of his close proximity of the detonating device. In addition, several studies (Shaughnessy *et al*., 1981; Mate and Miller, 1983; Pemberton and Shaughnessy, 1993; Fraker, 1994) have shown that explosives, in general, may be effective at the first use but quickly become ineffective because the pinnipeds learned to tolerate or ignore the detonation.

Since seal bombs are essentially large firecrackers, weighted to sink and explode underwater, they present a storage and handling hazard to the user, they cannot be scaled in their effect, they are not reusable, and they must be thrown from a boat or dock by the user. They may startle animals, but they have not been shown to cause animals to move substantial distances, and their use as an aversive signal to prevent damage to aquaculture facilities is limited.

2.2.3 Continuous Wave (CW) Sound Sources

Acoustic deterrent devices are marketed specifically for excluding pinnipeds from certain areas. The aquaculture industry (predominantly salmon farming) has grown rapidly over the last two or three decades, and the use of CW underwater sounds to minimize the damage caused by pinnipeds to aquaculture facilities and fish stock has also increased (Gordon and Northridge, 2002). The devices which generate these sounds are known as Acoustic Harassment Devices (AHDs) or Acoustic Deterrent Devices (ADDs). AHDs are also known as seal scrammers, seal scarers, or sealchasers. In general, these devices produce high frequency tones or band-limited noise pulses that are intended to repel pinnipeds from an area (Mate and Greenlaw, 1981, and Wright, *et al*, 2007) by causing hearing discomfort. The maximum hearing sensitivity for pinnipeds (Schusterman *et al.*, 1972) generally fall in the 10 to 20 KHz frequency range used for AHDs and ADDs.

The terms 'AHD' and 'ADD' are often used interchangeably, although a distinction has been made by some suppliers. Devices with lower sources levels (lower than 185 dB re 1 µPa @ 1m) have been called 'ADDs', while devices with source levels above this level have been identified as 'AHDs'. However, the threshold for this distinction is largely arbitrary. The distinction in terminology is not relevant to this white paper, where the purpose is to deter, not to harass. Therefore, in the context of mitigating the effect on pinnipeds, the term 'AMDs' (Acoustic Mitigation Devices) may be more meaningful.

Although the AMDs are sold specifically to reduce or eliminate pinniped damage to the fish stock and equipment in fish farms, there are no peer reviewed articles that demonstrate this effect, or that show that seals are excluded from areas other than the immediate vicinity of active devices - certainly not over the distances required distances. Pinnipeds are attracted to the aquaculture fish stock and are very likely to have identified it as a food before the devices were activated. Also pinnipeds seem to habituate to the AMD signals and seem to have developed strategies for avoiding the effects of these devices.

2.2.3.1 ADD Sound Sources

Jacobs and Turhune (2002) measured ADD source levels at sites close to aquaculture facilities in the Bay of Fundy and looked for changes in pinnipeds behavior (especially effects haul out patterns). They measured the source level at two aquaculture sites and found them to be 178 to 179 dB re 1 micro Pa @ 1 m. They observed no startle response or overt behavior and saw no measurable avoidance. In another experiment they left an ADD running continuously and found no differences in number of hauled out pinnipeds that could be correlated with the ADD operation. They noted that the pinnipeds in their experiment had been exposed to ADDs for many years (possibly all of their lives).

Controlled studies have shown that ADDs or pingers on fishing gear can be successful in reducing the by-catch (Kraus et al., 1997; Larsen, 1999; Trippel et al., 1999; Bordino et al., 2002). The pingers seem to reduce by-catch, at least in part, by excluding animals from the immediate vicinity of nets. Laake and co-workers (1998) found that the porpoise distribution changed when pingers were installed on the nets and that the acoustic buffer or exclusion zone had a radius of larger than 125 meters. In experiments, Culik and co-authors (2001) and Koschinski and Culik (1997) showed that their pingers created a buffer zone of a similar range.

Pingers appear to have few negative effects on pinnipeds; rather they may alert them to the presence of fish, acting as a "dinner bell'. While a study (Bordino et al., 2002) showed a reduction of dolphin by-catch using pingers, it also showed increased damage by pinnipeds over the course of the study. Based on relatively few rigorous studies, it appears most likely that pingers work with a porpoise through aversion. It is important to note that pingers are designed, fundamentally, to alert the approaching marine mammal of a physical object (net) and not necessarily to prevent foraging. However, foraging may play a role in the success of pingers since they may cause an aversion response in the prey of porpoise such as herring that have unusually high hearing sensitivity (Nestler et al. 1992). The porpoise may move in response to movements in their prey and thus avoid nets (Dawson et al. 1998).

Pingers have generally proven to be ineffective in deterring pinnipeds, rather simply alerting them to the presence of nets acts as a "dinner bell" (Jefferson and Curry 1996). Use of ADDs in the Hiram M. Chittenden Locks to prevent pinnipeds from feeding on migrating steelhead proved ineffective as the sound pressure was not sufficient to avoid habituation (NMFS 1995).

Airmar Technology Corporation makes an ADD (often referred to as a pinger or acoustic alarm) to alert the pinnipeds or other marine mammals to the presence of fishing nets, gill nets, and other fishing gear, thereby reducing the bycatch. These ADDs produce acoustic tones at a frequency between 10 KHz and 50 KHz and at a sound pressure level between 130 dB and 150 dB (re 1 micro Pa @ 1 m), which is at or above the threshold of hearing for the pinnipeds. While this type of ADD is generally effective in reducing the bycatch, they have not been shown to be effective in deterring seals or sea lions from feeding on migrating or caged fish.

2.2.3.2 AHD Sound Sources

AHDs are similar to ADDs but with significantly higher sound pressure levels. A combination of frequency and intensity are used to create a sound pressure wave that can inflict pain or discomfort for the pinniped (Reeves et al. 1996). AHDs are most often used to reduce predatory behavior, under the belief that the strong stimulus of food requires a strong aversion technique (Pryor 1986), and have most commonly been used by aquaculture operations to prevent pinniped predation in net pens. Aquaculture operations have the power and large platforms needed to support the AHD systems that can generate intense sound pressure.

Airmar Technology Corporation makes an AHD that is intended to cause discomfort or pain to the marine mammal. This AHD produces a tone with a frequency between 10 KHz and 40 KHz with a peak sound pressure level of 195 dB (re 1 micro Pa @ 1 m) at 27 KHz. Although there are some reports of these AHDs being effective in repelling pinnipeds at a distance of 3.5 Km from the source, most reports state that their effectiveness is questionable, at best. In some reports, the pinnipeds became acclimated to the AHD, swimming with their heads out of the water to avoid hearing the AHD and treating the AHD as a "dinner bell", particularly around fish farms or other similar aquaculture facilities.

Another AHD used at aquaculture sites is the Ferranti-Thompson Seal Scrammer2 which emits 25 KHz signal at 200 dB re 1 micro Pa @ 1 m.

AHDs are designed to strike critical thresholds causing discomfort or pain based on the hearing sensitivity of the pinnipeds (Jefferson and Curry 1996). Hearing impairment, pain, or discomfort levels for pinnipeds may vary. The effective range of AHDs is dependent upon the effects of spherical and cylindrical spreading, water depth, and absorption (Johnston and Woodley 1998) as well as water temperature, salinity, and the tides and waves (Reeves et al. 1996). Weather and ambient noise including anthropogenic and biological sounds also have an effect (Erbe and Farmer 2000). All of these affect the received level of the sound.

AHDs were found to be effective in adverting sea lions in the Hiram M. Chittenden Locks in Seattle, Washington. Due to their accessibility and limited size, these locks offered a rare opportunity to test various aversion methods, to modify them as necessary, and to get an immediate assessment of the effectiveness of a deterrent in both the short- and long-term. This situation would be virtually impossible in the wild. Beginning in 1985, various methods were used at the locks to prevent sea lion predation on an endangered run of steelhead. An acoustic array of AHDs effectively created a completely ensonified the area near the entrance to the locks. Several devices, some directional and some omni-directional, were placed at the entrance of the locks. The AHDs were designed to produce sounds at 195 to 205 dB RMS re 1 Pa at 1 m with primary energy ranging from 10 to 17 KHz (Norberg and Bain 1994, Bain 1997). These devices were only effective on unexposed animals; sea lions that had been previously exposed to the AHDs, but had been preying on steelhead, only modified their behaviors but did not stop preying on steelhead. The success of the strategy is likely due to the diminished run of steelhead (NMFS and WDFW 1995). Finally, the Hiram M. Chittenden Locks are in a busy urban area with very few non-target animals in the area, so potential impacts of the AHD on non-target species was considered minimal.

2.2.4 Pulsed Power Devices

The Pulse Power Device (PPD) is an advanced, arc-gap transducer, which may be an effective, non-habituating pinniped deterrent device. In these devices, a large amount of electrical energy is stored at high voltage and is then released across the gap between two electrodes immersed in sea water. The resulting discharge creates an arc of ionized gas which lasts a few micro-seconds and momentarily vaporizes the sea water between the terminals. The high pressure, high temperature water vapor or plasma produces a bubble which quickly expands and collapses. This expansion and collapse produces a high frequency, broadband acoustic pulse that travels in all directions from the initiating arc. The amount of stored energy determines the magnitude of the resulting acoustic pulse. The PPD can be pulsed or cycled at a rate determined by the ability of the system to replenish the stored electrical energy.

Finneran, *et. al.* (2003) conducted experiment to assess the effects of a PPD signal on pinniped hearing (as measured by threshold sift) and behavior (as indicated by observed changes in pinniped behavior). The pinniped tested showed no signs of physical injury, and their hearing thresholds were within normal baseline ranges. In addition, there were no permanent auditory, appetite, or health effects as a result of exposure to the signals produced by the PPD. Changes in behavior were observed as the exposure level was increased. Such changes included remaining at the start station after receiving the signal to proceed to the next station, returning to the trainer before proceeding to the next station, a reluctance to return the starting station after exposure the PPD (even a reluctance to go to the starting station before exposure), looking around with the head out of the water, and hauling out. In general, the pinniped behavioral changes caused by the PPD were to avoid the location where the PPD impulse had occurred.

2.2.5 Hydroacoustics Inc. Aquaculture Predator Protection System (APPS)

The HAI Aquaculture Predator Protection System generates a low frequency, broadband, impulsive acoustic signal rather than the higher frequency, single tone signal of an ADD or AHD or the higher frequency impulsive signal from the PPD. The HAI APPS does not have the deficiencies associated with some of the explosive sound sources mentioned above.

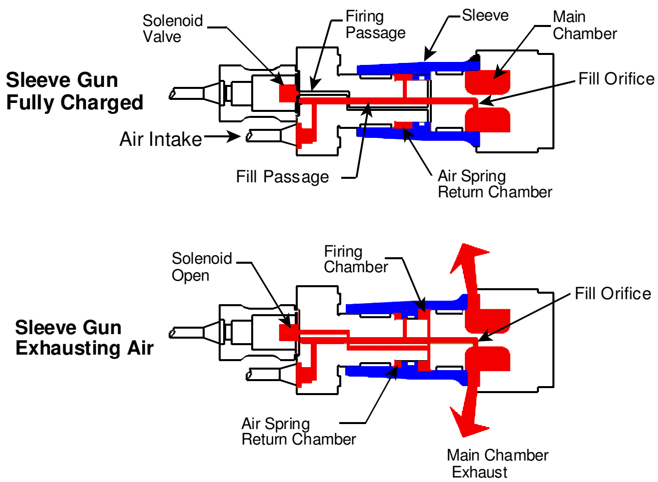
The HAI Aquaculture Predator Protection System is powered by compressed air that can be safely stored and handled. Its acoustic effect can be scaled by changing the air pressure supplied to the system or changing the chamber volume of the system. The APPS is a reusable system capable of rapid, repeatable firing (every second or so). The in-water component of the APPS can be deployed over the side of a boat or from a dock or other structure before it is armed reducing the hazardous to the operator and then can be operated from a remote site.

The basic technology supporting the HAI APD is air gun technology used by HAI for the past several decades and was developed originally by the marine seismic industry resulting in a safe, efficient, highly reliable, and highly repeatable system capable of many thousands of shots before any preventative maintenance is required.

2.2.5.1 HAI Aquaculture Predator Protection System Supporting Technology

Air guns are the most attractive choice of acoustic source to control pinnipeds. The 10 cubic inch air gun suggested for this application is shown to the left. This air gun is about 16 inches long, 5 inches in diameter, and weighs about 40 pounds. It requires simple maintenance about every 300,000 shots with a typical life well in excess of 1,000,000 shots.

The operating cycle for a typical air gun is shown in the diagram below. When the air gun is fully charged, the sleeve or poppet valve is closed, the solenoid valve is closed, and the main chamber is filled with high pressure air (between 500 and 5,000 psi). An electrical signal opens the solenoid valve which pressurizes the firing chamber, opens the sleeve or poppet valve, and releases the high pressure air into the water. The air spring return chamber and the reducing pressure in the main chamber allow the sleeve or poppet valve to close and the main chamber to recharge to the high system pressure. The high pressure air that was released into the water expands rapidly and then oscillates like a spherical bubble until all of the energy is dissipated (typically in less than 0.1 seconds). The main chamber is recharged in less than 1 second, and the air gun is ready to be fired again.



The HAI Aquaculture Predator Protection System uses a mature technology that is widely accepted in the marine seismic industry. Both safety and environmental issues have motivated the marine seismic industry to move away from the explosive sound sources and to adopt air guns as their standard acoustic source.

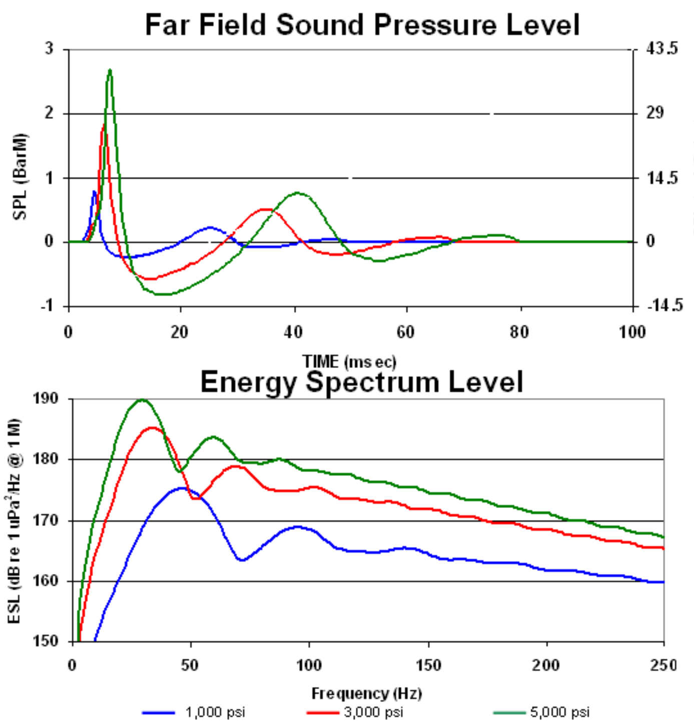
The HAI APPS does not pollute the environment since they discharge compressed air, with no chemical or plasma residue. In addition, the APPS is not consumed when used (as contrasted with explosive charges), and its performance does not change from either wear or component degradation (as can happen with some plasma discharge devices). The APPS can use an individual air gun or be assembled as a small array as needed to provide proper control of the pinnipeds. The APPS support components, such as air compressors, pneumatic controls and sensors, and air energy storage units used with air gun systems are based on mature commercial technologies. Since these components have been used for many years in offshore seismic oil exploration, they have low development cost and risk, have proven to be cost effective, exhibit high system availability and reliability, and have a long service life with established maintenance and proven safety procedures.

In an array configuration, the Aquaculture Predator Protection System air guns can be fired simultaneously, can be fired sequentially to produce a wave train of individual pulses, or can be fired in some combination to produce pulse wave trains with particular effects on the pinnipeds. The APPS utilizes the HAI air gun controller that precisely determines the firing time for each air gun to produce precisely timed wave trains as well as the ability to superimpose tones on the broadband signal.

The APPS provides a great deal of flexibility in their output, both in terms of intensity and in the specific signal characteristics. Both the level and rate at which pulses are transmitted are both adjustable. If multiple air guns are employed, tones can be superimposed on the broadband output at selectable frequencies, and the wave trains that are generated can be sustained over time. An individual air gun provides an omni-directional beam pattern and therefore can address multiple pinnipeds approaching a fish farm from different directions. The APPS does not cavitate and hence operates effectively in shallow water environments where seals or pinnipeds are likely to occur. As shown below, the acoustic output from air guns is a broadband, impulsive signal that has energy over a wide frequency spectrum, rather than an individual or swept frequency signal as produced by an electro-acoustic source.

The measured sound pressure level in BarM (a BarM is 14.7 psi relative to 1 meter from the air gun) and energy spectrum level in dB (relative to 1 uPa^2 per Hertz at a distance of 1 meter from the air gun) produced by a 10 cubic inch air gun, with system pressures of 1,000, 3,000 and 5,000 psi, is shown below. As shown; the level increases as the air pressure is increased, from 218 dB at 1,000 psi to 229 at 5,000 psi. In addition, the frequency of the peak in the energy spectrum level reduces as the air pressure is increased, but remains at effective mammal deterrent frequencies. The indicated slope of the energy spectrum level continues in frequencies beyond 1000 Hertz.

Single 10 Cubic Inch COTS Air Gun At A Depth Of 52 Feet

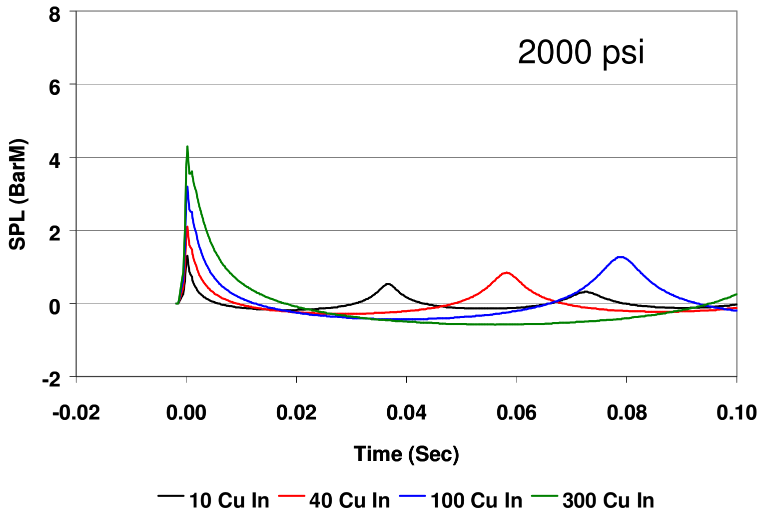


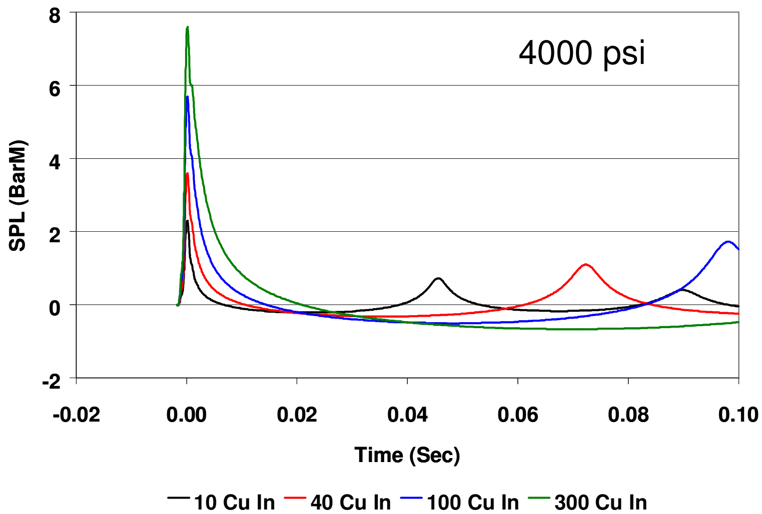
Supply (psi)	Peak (psi)	Impulse (psi*msec)
1,000	12	18
3,000	27	59
5,000	39	100

These Peak Pressures Convert To 218, 226, And 229 dB re 1 uPa At 1 Meter.

The Frequency Of The Peak In The Energy Spectrum Level Reduces As The Supply Pressure Is Increased.

Another way to vary the sound pressure level from an air gun is to change the volume of high pressure air stored within the air gun. Air gun volumes can range from as small as 10 cubic inches to as large as 300 cubic inches.





These plots show the acoustic signal generated by air guns with different chamber volumes for supply pressures of 2,000 and 4,000 psi. The peak pressure generated by an air gun increases as the volume of compressed gas is increased – going from near three BarM with the 10 cubic inch chamber suggested for pinniped control, to nearly eight BarM for the 300 cubic inch chamber.

Still another way to vary the sound pressure is to combine multiple air guns into an array and then fire them simultaneously. If each of the air guns is properly controlled, the peak of the pressure signals will add thereby increasing the total peak pressure experienced by the pinniped. By varying the number of air guns in the array being fired, the operator can vary the acoustic output to achieve the desired effect on the pinniped.

Since marine mammals such as pinnipeds are known to acclimate to repetitive acoustic signals, the APPS control system is capable of randomly varying the sequence of air gun shots so that the acoustic environment is continually changing. A sequence is one or more air gun shots with variable time intervals between the shots. Several sequences are defined and are repeated in a continuously variable order. In addition, the time between the repeating sequences is variable. All of these variations are controlled by a computer as part of the air gun control system. Since the possible number of sequences and variations is very large, a major result from the test is to determine which sequences, and variations within those sequences, are most effective in keeping the pinnipeds away from the fish cages. Another important result from the test is to determine how often the air gun system needs to be fired, which relates directly to the amount of high pressure air consumed, and how much exposure the fish in the cages have to the acoustic signals.

3.0 TESTING THE HAI APPS

3.1 TESTING IN CONTENENTAL UNITED STATES WATERS

As mentioned in Section 2.1, the feasibility and profitability of many aquaculture operators in continental United States (CONUS) waters are threatened by damage the their facilities or fish stocks. In addition to these established fisheries along the CONUS, the development of new, large-scale aquaculture facilities, as pending off southern California coast, would be threatened by pinniped damage. Such operations provide ideal sites to demonstrate the effectiveness of the HAI APPS using at-sea fishing vessels, recreational fishing, floating docks, and/or bait receivers.

3.1.1 Requirements for Demonstration Tests

It is anticipated that the initial demonstrations of the HAI APPS in CONUS waters would require a Marine Mammal Permit or Authorization and would require involvement of NMFS personnel. Outlined below are examples of this process. Jefferson and Curry (1996) conducted a review of the effectiveness of acoustic methods in reducing the marine mammal – fisheries interactions. As part of the planning for any demonstration tests, this review would be updated to include more recent information and technologies.

3.1.1.1 Marine Mammal Safety Issues

A primary concern for any deterrent method is the safety of the targeted marine mammals, specifically pinnipeds. Many of the deterrents described in Section 2.2 rely on producing a sound that is heard by the pinniped thus causing an aversion. Ketten (2004) reports that most pinniped species have peak sensitivities that fall into the range between 1 KHz and 20 KHz. The primary effect from the HAI APPS is a “full body” impulsive force or pressure wave with only a secondary aversion caused by hearing.

Of the four zones of man made noise described in Richardson *et al.* (2005): the zone of audibility; the zone of behavioral and/or physiological responsiveness; the zone of masking which interferes with echolocation, communication, prey or environmental sounds; and he zone of discomfort, hearing loss, or injury, the Marine Mammal Protection Act considers the last three zones of influence as harassment. Therefore, an understanding of the total effect of the HAI APPS on the pinnipeds would be needed for demonstration tests within U.S. waters.

3.1.1.2 NMFS Approval for HAI APPS Demonstration Tests

It is possible that NMFS will require the preparation of an Environmental Assessment (EA) prior to any demonstration tests in CONUS waters. NMFS (1999) produced a draft Environmental Assessment for using a pulsed power acoustic source to reduce damage caused by California sea lion to the gear and catch on fishing vessels. Since this EA described the effects on hearing shockwaves on marine mammals, sea turtles, fish, and sea birds, it can serve as the basis for an EA for the HAI

APPS. This draft EA would be updated to include the works published since its preparation in 1999.

In 2008, NMFS prepared a letter that outlined guidelines for using a pulse power acoustic source in which they conclude that such a device "can safely be used at sea as a nonlethal deterrent on California sea lions". Modifying this letter to apply to the HAI APPS could be more expedient than preparing a full EA as described above.

3.1.1.3 Laboratory Testing to Support HAI APPS

Laboratory or controlled testing of the effects of HAI Aquaculture Predator Protection System acoustic signals on marine mammals, especially pinnipeds, should be conducted to validate the concepts behind the deterrent system design. An example of such testing has been done by SPAWAR Systems Center, San Diego, CA where they studied the auditory and behavioral responses of pinnipeds to various types of acoustical signals (see Finneran *et al.,* 2003 for a study to the effects of a pulsed power source). Controlled tests of the effects of the HAI APPS on seals and sea lions can be conducted either under laboratory conditions (as at SPAWAR) or at sea near aquaculture facilities or around charter fishing boats.

Controlled testing should also be done on the fish species typically grown in aquaculture facilities to determine the effect of the HAI APPS signal on their behavior. Much of the research to date show that the proposed sound pressure levels from the proposed HAI APPS can be controlled to be below the level that causes damage to the fish hearing organs. Of primary concern are the changes, if any, in the feeding habits and stress levels caused by the HAI APPS signals.

3.2 TESTING OUTSIDE CONTENENTAL UNITED STATES WATERS

Many regions outside of the CONUS waters have significant problems with damage to aquaculture facilities by pinnipeds. Among these regions are Australia, Chile, Scotland, and Mexico. These countries issue permits that allow killing or physical removal of rogue pinnipeds. Tests, similar to those described above, should be conducted in cooperation with the local science, industry, and governmental organizations in the countries selected.

4.0 HAI APPS PERFORMANCE DEMONSTRATIONS

The effectiveness of the APPS in reducing the damage to fish farms caused by pinnipeds would be shown in the two demonstrations described below. The initial demonstration will be relatively short and will show the effect of the HAI APPS on pinnipeds. The second will be somewhat longer and would study the effects of the APPS on salmonids.

4.1 THE EFFECT OF THE APPS ON PINNIPEDS

One or more typical fish farm cages would be selected to demonstrate the effectiveness of the APPS in reducing the damaging impact of pinnipeds on both the cages and the fish in the cages. These demonstration sites would be selected where numerous pinnipeds are known to be present and where the fish in these cages would be near maturity. Mature fish are desirable for this demonstration in order to reduce any potential damage by the air gun system to the fish growth prior to their harvest.

The APPS would be deployed to form an acoustic barrier around all or a portion of the fish cage system. The number, specific location, and depths of air guns in the APPS would be dependent on the specific geometry of the fish cage system. The deployment depth of the air guns would depend on the depth of the water and the configuration of the bottom of the fish cage. It may be necessary to use more than one air gun at each location in order to extend the acoustic barrier from the surface to the bottom of the water volume. The air guns would be deployed either from existing structures near the fish cages or from floats and anchors at the air gun locations.

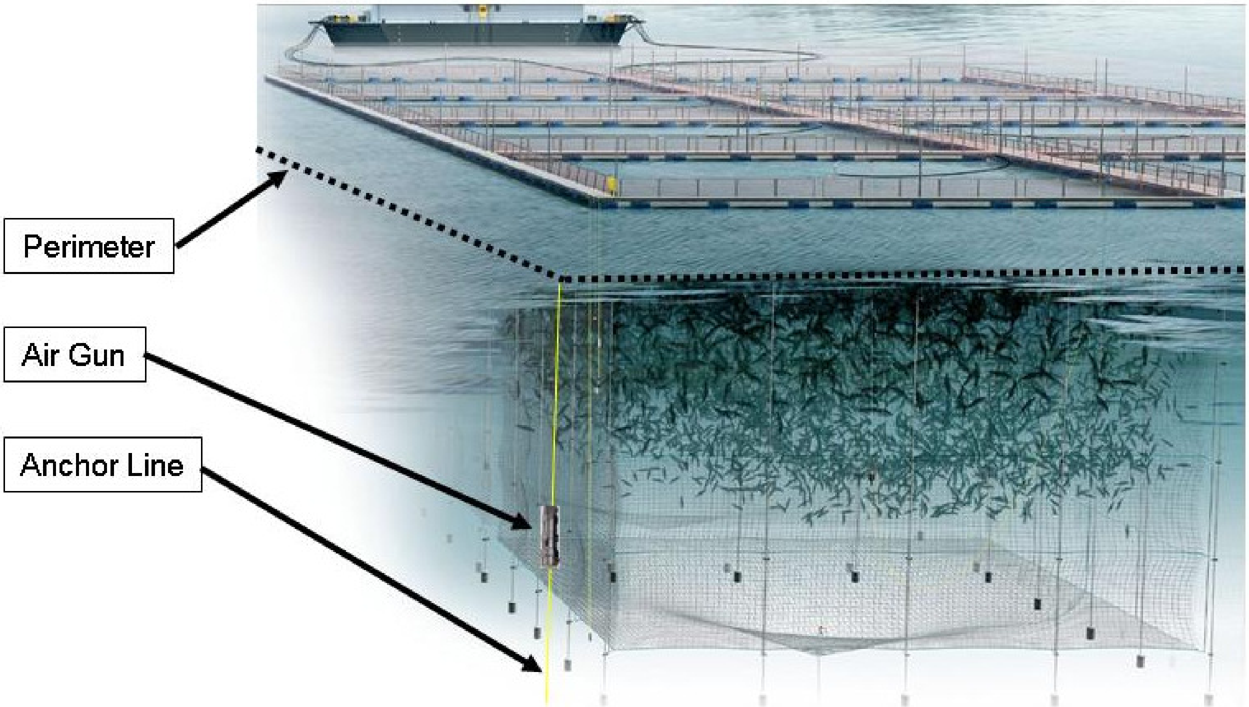
The control system for the APPS would be in a central office near the demonstration site. This control system would provide the firing signal for each air gun either via hard wire or through a wireless connection and allow either manual or computer controlled, automatic firing.

An air compressor or other suitable source of compressed air storage would be available near the demonstration site. To insure that the demonstration continues without interruption, a back up supply of compressed air would also be available.

Two options are available for providing compressed air to the APPS. One option would be to have air storage bottles at each air gun in the APPS and to manually recharge these bottles as the air is consumed – perhaps on a daily basis. The other option would be to provide the compressed air to the APPS through a system of hoses or pipes that connect the air guns to a central air compressor system. The permanent APPS configuration would utilize this last option for the air supply system.

The performance of the APPS would be demonstrated by monitoring the percentage of pinnipeds that leave the area near the APPS and the length of time that they are gone. This would be measured using above water and perhaps underwater cameras, which would be distributed around the demonstration site and that would communicate back to the central office. The effect on the pinnipeds would be correlated to the acoustic signals by measuring the sound pressure levels at selected locations around the fish cages using hydrophones whose outputs are communicated to the central office. During this demonstration, the effects of the APPS on the fish would be noted using the underwater cameras that are typically installed in the fish cages to monitor the condition and eating habits of the fish.

Below is an image (shown using Wavemaster Steel Cages) illustrating how an air gun could be integrated into a fish farm cage system.



4.2 THE EFFECT OF THE APPS ON SALMONIDS

A second, longer demonstration would logically follow the initial demonstration described above. This demonstration would show the long term effect, if any, of the HAI APPS on the fish stock. This demonstration would also provide data on the long term cost of operating the APPS. As this demonstration progresses, the fish farm operator would be able to determine the service and preventative maintenance required to operate the APPS in the particular conditions of the fish farm.

Two groups of fish would be collected: one to be a control group and the other to be the test group. If the fish farm operator has suitable records of typical fish growth, the control group may not be necessary. Each group would have several sub-groups – each perhaps a year different in age. Both groups would be fed and managed using the standard procedures of the fish farm operator. The control group would not be subjected to any acoustic signals from the HAI APPS while the test group would be separated from the control group and would be subjected to repeated acoustic signals – typical of those expected to deter pinnipeds.

The growth rate and behavior patterns of each group would be monitored over a period of several months to determine if the HAI APPS has any effect on the development of the fish stock. This demonstration would continue until sufficient data are collected to demonstrate the effect of the APPS on the fish stock.

5.0 SELECTED LITERATURE

Since the middle of the 1940's, both the scientific community and the general public have been concerned with the effects of man-made, under water sound on marine animals. This concern grew in the 1970's when under water seismic exploration and near-shore construction activities increased. The concern very rapidly increased in the early 1980's, through the current time, when both military and commercial activities were associated with injury to, and stranding of, endangered marine mammals, and various fish-kills. As a result of this concern over the past 60 years, many hundreds of scientific papers and articles have been published describing the effects of sound on marine animals, especially on marine mammals (mostly whales, seals, sea lions, and dolphins) and finfish. Many of these published papers study the physiological effects of sound ranging from temporary shifts in hearing threshold, to permanent shift in threshold, to damage to body tissues, through lethal effect on the animal. Many other papers concentrate on effects of sound on behavior such as foraging, communication, social interactions, reproduction, parental care, and avoidance of predators.

A limited number of papers discuss the effects on seals or sea lions in shallow water from the impulsive sound signals generated by an air gun. These papers and articles generally suggest that pinnipeds showed evidence of an immediate fright response when exposed to the air gun signal. This was followed by a rapid change in their heart rate. They typically exhibited a strong avoidance behavior, by swimming rapidly away from the air gun, and changing from foraging dives to transiting dives. The typical avoidance response for pinnipeds was to move away from the source, while some pinnipeds hauled out. Within about two hours after air gun usage stopped, most pinnipeds returned to the behavior they exhibited before the use of the air guns. It is expected that sustained operation, using varying shot sequences, or a more powerful air gun system would have produced a longer lasting response.

It is understood that the behavioral response within a species will vary considerably from one animal to the next. It is thought that this is caused by the previous associations the animal may have had with the air gun output signal, its hearing sensitivity, its age and social status, or its general behavioral state. Animals have been seen to habituate because no aversive events have been associated with the signal, or it is no longer new (i.e. predictable and unvarying).

5.1 SUPPORTING REFERENCES

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