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A Review of Marine Mammal Deterrents and Their Possible Applications to Limit Killer Whale (*Orcinus orca*) Predation on Steller Sea Lions (*Eumetopias jubatus*)

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A Review of Marine Mammal Deterrents and Their Possible Applications to Limit Killer Whale (*Orcinus orca*) Predation on Steller Sea Lions (*Eumetopias jubatus*)

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Abstract

The population of Steller sea lions (*Eumetopias jubatus*) in the western Aleutian Islands has declined significantly and is currently listed as an endangered species. Among the possible limiting factors for this population is predation by transient killer whales (*Orcinus orca*). The purpose of this report is to provide some analysis of the feasibility of limiting killer whale predation on Steller sea lions in the western Aleutian Islands using marine mammal deterrents. This report provides a review of various marine mammal deterrents, used primarily in fisheries, to either prevent marine mammal entanglement or predation. Deterrent methods are evaluated based upon various factors including effectiveness, particularly with killer whales, potential impacts on non-target species, including Steller sea lions, and feasibility of use in the western Aleutian Islands. Possible deterrent options are considered, however, all would require significant research before implementation. Based upon a thorough review of the literature, lack of previous long-term success and high degrees of uncertainty, it is unlikely that deterrents would be successful in this application.

Contents

Introduction

The decline of the U.S. western stock of Steller sea lions (*Eumetopias jubatus*) (defined as sea lions west of Cape Suckling, Alaska, 144º W (Ferrero and Fritz 2002)) has been the focus of much research and debate. The western stock declined by more than 15% annually throughout the 1980s leading to a threatened species listing under the Endangered Species Act in 1990 (Ferrero and Fritz 2002). The western stock was reclassified as endangered in 1997 after a decline throughout the 1990s of 5% annually (Ferrero and Fritz 2002). Adult and juvenile counts of the western stock in the Gulf of Alaska have dropped from an estimated 65,296 in the late 1970s to 7,853 in 2000, while those in the Bering Sea/Aleutian Islands declined from 44,584 in the late 1970s to 10,340 in 2000 (Angliss et al. 2001).

The causes for the decline remain elusive, although the following possible causes have been suggested and are currently being investigated:

Fisheries competition

Environmental/Climate change

Predation by killer whales and sharks

Other anthropogenic effects (e.g., incidental mortalities in fishing operations), shootings and indigenous harvest

Disease

Contaminants

A combination of the above.

Research on the Steller sea lion decline is being carried out by numerous researchers and organizations including the National Marine Fisheries Service (NMFS); the North Pacific Universities Marine Mammal Research Consortium; the Alaska SeaLife Center; the University of Alaska; Alaska Department of Fish and Game; the Laboratory for Applied Biotelemetry and Biotechnology at the Department of Marine Biology, Texas A&M University at Galveston; and the Vancouver Aquarium in British Columbia. Work focusing on the impacts of predation by killer whales (*Orcinus orca*) and Pacific sleeper sharks (*Somniosus pacificus*) includes investigations of predation in southeastern and western Alaska; studies on the distribution, abundance, and diet of killer whales; passive acoustic and video monitoring of killer whales (particularly near haul-out sites); and shark stock assessments. Additionally, modeling work is being done to evaluate and better understand the predator/prey relationships of Steller sea lions based on terrestrial models (Dahlheim and White 2002). More complete information on these and other studies can be found at the following website: www.stellersealions.noaa.gov.

Funding for this research was initiated through Federal appropriations with a significant increase combined in the Fiscal Year 2001 and Fiscal Year 2002 budgets (PL 106-554-114, detailed in H.R. 4577, Sec. 209). Further, the Fiscal Year 2001 appropriations for NMFS required development of a coordinated, comprehensive research program for the western stock of Steller sea lions and identified 12 areas of research. Of these 12 research areas, 11 are addressed by over 150 ongoing studies while the 12th, "implement on a pilot basis innovative non-lethal measures to protect Steller sea lions from marine mammal predators including killer whales" (PL 106-554-114) has received less attention. In fiscal year 2002, the Alaska Fishery Development Foundation was appropriated funds to investigate non-lethal means of preventing killer whale predation.

This report is one part of the NMFS effort to investigate the feasibility of such a program. In particular, the intent of this report is to provide a review of various types of marine mammal deterrents, drawing from the scientific literature and case histories, to evaluate the possible effectiveness of deterrents against killer whales and to finally suggest areas of future research.

Background

Killer whales are divided into three different types (i.e., transients, residents or offshores) based upon specialized feeding regimens, social structure and unique genetics (Bigg et al. 1987, Ford and Ellis 1999, Hoelzel et al. 1998). Transient killer whales feed on warm-blooded prey: seals, sea lions, porpoise, dolphins, whales, otters, birds (Barrett-Lennard et al. 1995) and occasionally deer and moose (Ford and Ellis 1999). Transient killer whales are organized in small groups, most commonly consisting of three whales and rarely more than seven whales (Ford and Ellis 1999), and generally vocalize and echolocate very little (Barrett-Lennard et al. 1996). Resident whales generally organize in much larger groups (up to 50 whales) and are more acoustically active (Barrett-Lennard et al. 1996). Stomach contents from known resident whales in British Columbia indicate that they feed exclusively on fish, including salmon, lingcod, greenling, English sole, sanddab, Dover sole, starry flounder, rex sole, rock sole, curlfin sole, staghorn sculpin, great sculpin, and sablefish (Ford et al. 1998).

Very little is known about offshore killer whales' feeding patterns and social structure, although they do appear to be more similar to fish-eating resident whales than transient whales. Offshore killer whales have been documented in Southeast Alaskan waters (Dahlheim et al. 1997). In 2001 and 2002, three separate reports of offshore killer whales occurred in the water north and west of southeast Alaska, at Aialik Bay, Kenai Fjords (C. Matkin, Pers. Comm.[1]) and south of Kodiak Island and in the southern Bering Sea (M. Dahlheim, Pers. Comm.[2]). With the exception of these three reports, nothing more is known of the occurrence of offshore killer whales in the regions occupied by the

[1] Craig Matkin, North Gulf Oceanic Society, Homer, AK
[2] Marilyn Dahlheim, NMFS, AFSC, NMML, 7600 Sand Point Way NE Seattle, WA 98115

western stock of Steller sea lions. Therefore, this report will not address offshore killer whales.

The number of transient killer whales inhabiting the waters from Washington State to Western Alaska is conservatively estimated to be 306 (compared with 995 resident type whales in the same region) (Matkin et al. 2002). An estimated 125 transient whales occupy the range of the western stock of Steller sea lions (Matkin et al. 2002).

Transient killer whales in Alaska prey on a variety of marine mammal species including the harbor seal, Dall's porpoise, harbor porpoise, various baleen whales, sea otter, and Steller sea lion (Barrett-Lennard et al. 1995). However, the impact of killer whale predation on the Steller sea lion population was considered minimal throughout the 1970s and 1980s (NMFS 1992). However, as the decline of Steller sea lions continued and more stringent regulations were put in place in the early 1990s, the role of killer whale predation on Steller sea lions received more attention.

In 1992 a male transient killer whale stranded on Montague Island, near the entrance to Prince William Sound. Analysis of stomach contents revealed 14 flipper tags from 13 Steller sea lion pups that had been tagged in 1987 and 1988 (one pup had two tags) (Barrett-Lennard et al. 1995). This animal was one of only two killer whales, of the eight stranded and necropsied in western Alaska, with Steller sea lion remains in its stomach. All eight whale stomachs contained harbor seal whiskers, three stomachs contained porpoise remains, and three stomachs contained baleen whale remains (Barrett-Lennard et al. 1995). The consumption rate of Steller sea lions by the killer whale population as a whole on the basis of these observations has been frequently debated and the actual rate of predation remains uncertain. Nonetheless, using the results of the necropsies, questionnaires to mariners, and population estimates, Barrett-Lennard et al.

(1995) modeled the possible impacts of killer whale predation on the declining western stock of Steller sea lions. While citing the need for more information, the authors created a mathematical model in which they estimated that killer whale predation may account for up to 18% of the sea lion annual mortality, particularly among pups (Barrett-Lennard et al. 1995). Based upon observed harassment and predation rates in other areas and stomach contents, Matkin et al. (2002) calculated that Steller sea lions may make up 12.5% of the diet of killer whales west of Kodiak Island, or 2,103 sea lions annually (using the 1994 population estimate).

While not considered a cause of decline throughout the 1970s and 1980s, it has been suggested that killer whale predation on the western stock of Steller sea lions may be affecting the recovery of the stock (Matkin et al. 2002). Boveng et al. (1998) suggest that recovery of Antarctic fur seals (*Arctrocephalus gazella*) is limited in areas due to predation, particularly of pups, by leopard seals (*Hydrurga leptonyx*). In the Crozet Islands, killer whale predation is thought to be limiting the recovery of southern elephant seals (Guinet et al. 1992, Guinet et al. 1999). However, in both of these areas, the precise effects of top-down limitation by predation are unknown. Similarly, calculating the actual impacts of killer whale predation on the western stock of Steller sea lions is difficult given the uncertainties in the size and type of the killer whale population and the importance of Steller sea lions in their diet.

Estimating the impact of killer whale predation is further complicated by possible changes in predator/prey and trophic interactions in the Aleutian Islands and Bering Sea. Studies on climate driven ecosystem-wide changes have been ongoing since the mid-1990s (Anderson and Piatt 1999, NRC 1996, Benson and Trites 2002). Estes et al. (1998) suggested that the decline in the sea otter population in the west/central Aleutian

Islands was due to killer whale predation (the first account of predation on sea otters was recorded in 1991, with nine subsequent predation events throughout the 1990s). Estes et al. (1998) proposed that shifts in forage availability (spurred by climate change and fisheries) led to large-scale changes in trophic interactions including prey switching among transient killer whales from pinnipeds (including Steller sea lions) to sea otters throughout the 1990s. These conclusions are considered to be controversial and are being debated within the scientific community. Nonetheless, this paper points out the possible impacts of climate driven changes in predator-prey relationships.

Several key questions must be answered to better understand the killer whale-Steller sea lion predator-prey dynamics. Among them are:

What is the population size and composition of the western Alaska stock of killer whales?

What percentage of these whales prey on Steller sea lions?

How many sea lions are being consumed by the killer whales?

What portion (e.g., age group) of the Steller sea lion population is most often preyed upon?

Addressing these questions is outside the scope of this report and any discussion of the effectiveness of any possible deterrent program is constrained by the lack of answers to these questions.

Marine Mammal Deterrents

Many types of deterrents have been used worldwide for years in fisheries to prevent interaction with marine mammals (Perrin et al. 1994, Mate and Harvey 1986, Jefferson and Curry 1996, Reeves et al. 1996). Fisheries-marine mammal interactions generally fall into two categories: preventing marine mammal entanglement in nets (i.e., harbor porpoise in gill nets (Kraus et al. 1997) or predation by marine mammals (i.e., longline depredation (Visser 2000)) and predation at aquaculture sites (Iwama et al. 1997). Deterrents have been used in estuarine areas and rivers to prevent or minimize pinniped predation on migrating salmon (Scordino and Pfeifer 1993).

The most commonly used deterrents are acoustic deterrent devices (ADDs) including pingers, acoustic harassment devices (AHDs), passive acoustic devices, seal bombs, firecrackers, predator sounds, vessel chase (hazing), physical barriers (nets), taste aversion, tactile harassment (rubber bullets), scent deterrents (not applicable to cetaceans), gunshots (non-lethal and lethal), gear switching, gear modification, and fishing modifications (not applicable in this situation). Banging pipes together has been used to move marine mammals and has had limited use as a deterrent. A new pulse power acoustic deterrent has been developed but not field tested[3]. The effects of anthropogenic sounds to cause acoustic masking are being researched (Erbe 2002, Bain and Dahlheim 1994), but this has not specifically been tested as a deterrent.

Acoustic Deterrents

Marine mammals have highly developed species-specific senses of hearing, which appear to influence the effectiveness of different types of acoustic devices (Kraus 1999). A thorough review of marine mammal acoustics can be found in Ketten (1998). Acoustic devices fall into two main categories: acoustic deterrent devices (ADDs) and acoustic harassment devices (AHDs). For the purposes of this paper, the convention established by Reeves et al. (1996) will be followed. The ADDs produce or reflect sound to make marine mammals aware of, or repel them from, a structure (most often a net)

[3] Draft environmental assessment on testing a pulsed power generator to reduce California sea lion depredation of gear and catch aboard an actively fishing charter boat off southern California, Unpublished manuscript, available from Christina Fahy, Southwest Regional Office, 501 W. Ocean Blvd., Long Beach, CA 90802.

(Reeves et al. 1996) and are used worldwide in gill net fisheries (Dawson et al. 1998; Kraus 1999). The AHDs also use sound but utilize a combination of intensity, frequency or decibel levels to create a more powerful signal to avert marine mammals and inflict pain or discomfort in the approaching animal (Reeves et al. 1996). Acoustic harassment devices are generally used at fish farms where platforms and power sources are available for the large transducers needed to create the high intensity sound (Kraus 1999). (See Reeves et al. 2001, Tables 1 and 2). Other types of deterrents to be discussed in this section include passive acoustic deterrents, pipe banging, seal bombs, firecrackers, and predator sounds.

Acoustic Deterrent Devices (ADDs)

It has been estimated that over 80,000 small cetaceans die annually in coastal waters due to fishing operations (Kraus et al. 1997). Research on methods for reducing bycatch is the focus of the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCBOBANS), NMFS Office of Protected Resources, the International Whaling Commission, and some environmental organizations (see www.cetaceanbycatch.org). Many cetaceans are killed in gillnets and the most common deterrent used with gillnets is a small sound generating device generally referred to as a pinger (a type of ADD) (IWC 2000). In some fisheries the use of pingers has become mandatory in an attempt to limit cetacean bycatch (Culik et al. 2001). The standard pinger emits a signal of 10 kHz (with harmonics to at least 60 kHz) with a source level of 132 dB re 1 micro Pascal at 1 m, which is within the hearing range of most cetaceans and pinnipeds (Reeves et al. 1996). Different pingers can emit sounds differently, with regular pulse intervals, random intervals or frequency sweeps (Cox et al. 2001). Pingers are often referred to as acoustic alarms, as they are designed to alert marine mammals of the presence of nets without causing pain or damage to the animal's auditory system.

Most experiments to test the effectiveness of pingers have been done with porpoise interacting with gillnet fisheries and have shown them to be generally effective in reducing porpoise bycatch (Hatakeyama et al. 1994, Gearin et al. 2000, Kraus et al. 1997, Culik et al. 2001). Despite these successes there is still considerable uncertainty about the use of pingers. There is evidence that porpoise may habituate to pingers (Cox et al. 2001) suggesting that variable sounds and monitoring are important to maintaining effectiveness (Kastelein et al. 2000). There are also concerns that pingers alone can not effectively reduce porpoise bycatch. Tests done in the field showed that while harbor porpoise avoided nets equipped with pingers, they approached and became entangled in, unequipped nets 100 – 200 m away (Trippel et al. 1999). Incorporating time and area closures may also be important to reducing porpoise bycatch (Murray et al. 2000). Additional information on the use of pingers can be found in Special Issue 15 of the International Whaling Commission (Perrin et al. 1994).

The fundamental question of how and why pingers work, or don't work, has been studied for years. It's still unclear if the sound serves to alert the marine mammals to the presence of the net, or if the sound may simply be annoying to the animal and therefore repel it from the area, or if the sound may be aversive to the prey of marine mammals (IWC 2000, Krause et al. 1997). Experiments done with porpoise suggest it is also possible that the introduction of noise may affect an animal's echolocation, stimulating the porpoise to echolocate more and detect the net (monofilament nets are acoustically similar to the surrounding water) (Kraus 1999). It has also been suggested that the noise may mask the animal's echolocation (Kraus 1999). Experiments support both of these possibilities; there is some evidence of increased echolocation clicks by harbor porpoise in the presence of pingers (Kraus et al. 1997), yet another study indicated that click rates actually decreased around pingers (Cox et al. 2001). Carlstrom et al. (2001) presented data from a field test that indicated that harbor porpoise stayed at least 500 m from an array of active pingers and significantly reduced click trains, supporting the results of Cox et al. (2001).

Based on the relatively few rigorous studies, it appears most likely that pingers work with porpoise through aversion (IWC 2000). It is important to point out that pingers are designed, fundamentally, to alert the approaching marine mammal of a physical object (net) not to necessarily prevent foraging. However, foraging may play a role in the success of pingers. It has been suggested that pingers 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 seals and sea lions. (Jefferson and Curry 1996). Simply alerting these animals of the presence of nets has often proven to have a “dinner bell” effect for pinnipeds (Jefferson and Curry 1996). Use of ADDs in the Hiram M. Chittenden Locks to prevent California sea lions (*Zalophus californianus*) from feeding on migrating steelhead proved ineffective as the sound pressure was not sufficient to avoid habituation (NMFS 1995).

Little research has been conducted to test the effectiveness of deterring cetaceans with ADDs, although what has been done has shown mixed success. Dolphin and cetacean bycatch in the California drift net fishery was reduced with the use of pingers (Barlow and Cameron 1999). An experiment on different types of pingers showed that

Hector’s dolphins (*Cephalorhynchus hectori*) were most consistently deterred with a pinger with pulse lengths of 400 milliseconds and fundamental frequency at approximately 9.6 kHz with strong harmonics up to, and probably over, 150 kHz, although other pingers were reported to be ineffective (Stone et al. 2000). Other experiments indicated no significant deterrence of dolphins in response to pingers (Reeves et al. 2001).

Experiments to test the effectiveness of deterring baleen whales with ADDs were inconclusive (Todd et al. 1992). A “clanger”, a type of ADD, was developed in the early 1990s specifically to deter baleen whales. It is a metal acoustic device that produces sound at 145 dB centering around 4 kHz. In limited field tests, humpback whales and minke whales avoided a net equipped with a “clanger” (Todd et al. 1992).

These studies and others indicate that different species of marine mammals respond differently to ADDs. Despite years of trials, more experiments are needed to better understand the effectiveness and possible impacts of ADDs. One issue of particular concern with ADDs is the exclusion of marine mammals from areas where they typically forage (Dawson et al. 1998, IWC 2000).

Acoustic deterrent devices in their typical use are unlikely to be successful at preventing predation by killer whales, as ADDs have shown to be ineffective in deterring foraging. However, it has been suggested that ADDs may create “sonar scrambling”, particularly in dolphins thus interfering with echolocation and communication (Goodson, as cited in Reeves et al. 2001). ADDs may be useful for deterring killer whales that use echolocation or passive listening while hunting for Steller sea lions. This is a different and untested application of an ADD and highly speculative; however, it may present a potential relatively low-impact method of deterrence.

Acoustic Harassment Devices- AHDs

Acoustic harassment devices are similar to ADDs, although significantly more powerful. A combination of frequency, decibel level, and intensity are used to create a sound pressure wave that can inflict pain or discomfort (Reeves et al. 1996). AHDs are most often used to stop or 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 transducers that can generate intense sound pressure. One commonly used brand of AHD, Airmar[4], produces source sounds from 10 to 40 kHz with peak intensity at 27 kHz and 195 dB re 1 micro Pa at 1 m. Another AHD used at aquaculture sites is the Ferranti-Thompson Seal Scrammer[2] which emits of signal at 200 dB re 1 micro Pa @ 25 kHz.

Acoustic harassment devices are designed to strike critical thresholds causing discomfort or pain based on the hearing sensitivity of the target species (usually pinnipeds) and ambient noise of an area (Jefferson and Curry 1996). Hearing impairment, pain, and discomfort levels for species may vary. For humans these levels are 160 dB, 120 dB, and 90 dB above ambient noise, respectively (Olesiuk et al. 2002). 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 movement (i.e., 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.

[4] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

To mitigate the high intensity of sound and potential for causing temporary or permanent hearing loss in marine mammals, most AHDs are designed to emit a low intensity tone that increases in intensity over 60 to 70 seconds (Reeves et al. 1996). This helps create a conditioned response in the target species (i.e., leave area before sound intensifies) and also to alert non-target species (Reeves et al. 1996). However, AHDs are often run continuously, creating an ensonified zone that can displace animals from an area (Johnston and Woodley 1998). Studies done in Broughton Archipelago, Canada indicated that the sounds from Airmar AHDs were sufficient to repel marine mammals from an area at least 3.5 km from the source (Olesiuk et al. 2002, Morton and Symonds 2002).

Acoustic harassment devices have most often been used with pinnipeds although their effectiveness as a deterrent for pinnipeds is questionable (Terhune et al. 2002). Acoustic harassment devices have been used effectively to deter seals and sea lions from outmigrating juvenile salmon in a river (Yurk and Trites 2000). However, in some situations pinnipeds appeared to become acclimated to the sounds over time and may even become attracted to the sound; that is, the "dinner bell" effect, particularly at aquaculture facilities (Richardson et al. 1995). Studies have also shown that the effectiveness of AHDs appeared to decrease over time – 8 weeks in one study to 2 years in another (reviewed in Iwama et al. 1997). In one application, California sea lions were initially startled by the AHDs but soon habituated (Richardson et al. 1995). This habituation may be due to pinnipeds adapting their behavior around the AHDs - sea lions were observed swimming near AHDs with their heads out of the water (Jefferson and Curry 1996, Mate and Harvey 1986*)*. This behavior is presumably to avoid the sound pressure, as noise generated underwater does not travel well into the air (K. Stafford, Pers. Comm.[5]). It should be noted that this behavior was observed near a net pen with easily accessible prey. The effect of these types of behavioral changes on typical sea lion foraging is unknown.

The effects of AHDs on cetaceans are largely unknown. Most AHDs operate at 10 to 20 kHz, which is within the hearing range of cetaceans, including those likely to be found in Alaskan waters (e.g., harbor porpoise, Pacific white-sided dolphin, Dall's porpoise, humpback whale, killer whale, minke whale and gray whale (Iwama et al. 1997, Angliss et al. 2001)). There has been only limited research on impacts to non-target species (Johnston and Woodley 1998). In a survey of AHDs in the Bay of Fundy, it was determined that the frequency components of three different types of AHDs were in the same range of best frequencies of target species, pinnipeds, and non-target species (i.e., harbor porpoise and other cetaceans) (Johnston and Woodley 1998). Preliminary results of observations off the coast on Newfoundland, Canada, suggest that a variety of baleen whales were displaced when AHDs were in operation (Nordeen and Lien 2001).

One of the few controlled experiments of the effects of AHDs on cetaceans was done in Broughton Archipelago in British Columbia. By monitoring the abundance of harbor porpoise in the test area for 3-week intervals while the AHD was active and then 3 weeks of inactive AHD, the experiment showed that harbor porpoises avoided the area in response to AHD operation (Olesiuk et al. 2002). Another area of the Broughton Archipelago had active AHDs operating at a fish farm (although not within the Olesiuk study area). Long-term observations of killer whale distribution in the area indicated that sightings decreased significantly during the 7 years in which an AHD-equipped fish farm was in operation (Morton and Symonds 2002). Observations of Pacific white-sided

[5] Kate Stafford, NMFS, AFSC, NMML, 7600 Sand Point Way NE, Seattle WA 98115

dolphins (*Lagenorhynchus obliquidens*) were reportedly also down during the same period (Morton 2000).

Due, in large part, to these uncertainties the authors of a 1997 Environmental Assessment on marine aquaculture recommended to the Department of Fisheries and Oceans that the use of AHDs be eliminated in Canadian waters (Iwama et al. 1997).

The effects of AHDs on other marine species, fish, and birds are largely untested (Iwama et al. 1997). It is generally believed that fish have limited hearing and are only able to detect sounds up to 2 or 3 kHz. But a recent study found that American shad (*Alosa sapidissima*) can detect sounds up to 180 kHz (Mann et al. 1997). Blueback herring (*Alosa aestivalis*) have also been shown to be sensitive to high frequency sounds (Nestler et al. 1992). This may make them vulnerable to the impacts of AHDs; that is, they may move out of an area with an active AHD. This could also have an effect on Steller sea lion foraging success. Steller sea lions in Prince William Sound have been observed feeding on fall and winter on adult herring aggregations (Thomas and Thorne 2001) and in southeast Alaska they prey on spring time spawning aggregations (Womble et al. 2001). If western Steller sea lions show the same tendency to consume herring, their available forage could be affected if AHDs do cause movement of their prey.

Acoustic harassment devices were found to be the most effective in adverting sea lions in the Hiram M. Chittenden Locks in Seattle, Washington. From 1985 to the present, various methods were used at the locks to prevent sea lion predation on an endangered run of steelhead (*Oncorhynchus mykiss*). Due to their accessibility and limited size, the 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. An acoustic array of AHDs effectively created a completely ensonified 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 195-205 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. Once these animals were removed from the locks in 1996, the acoustic array has proven to be a successful deterrent (NMFS 1997, B. Norberg, Pers. Comm.[6]). The success of the strategy is likely also 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.

Use of AHDs or other acoustic devices would be difficult to permit given the potential impact on the various marine species in Alaskan waters, including Steller sea lions. Experiments designed to test the effectiveness of acoustic deterrents to limit Steller sea lion predation in fishing net were done with captive Steller sea lions in the early 1990s. Researchers found that impulsive sounds transmitted at 210 dB re 1 micro Pa at 1 m (or a pure tone with 165 dB source level) were sufficient for sea lions to leave the water and haul out (Akamatsu et al. 1996). These sounds are similar to those projected by a typical AHD.

Beyond potential biological adverse effects, the use of AHDs in the Aleutian Islands would be difficult due to the power and stable platforms needed to operate the

[6] Brent Norberg, NMFS, Northwest Regional Office, 7600 Sand Point Way NE, Seattle WA 98115

transducers. Further, the highly variable ambient noise levels (i.e., shipping noise near Unimak Pass and high energy waves and large tidal exchanges) would make achieving a sound level that would consistently avert killer whales, but not other marine mammals, very difficult. Recent work by Terhune et al. (2002) indicates perceived sound levels and ranges varied greatly dependent on level of ambient noise and hearing capabilities of the marine mammals. The same loud AHD, set to deter porpoise, varied in audible range from 3.64 km to 7.42 km, depending on level of ambient noise. The effects of such high levels of sound on target and non-target species are unknown (Terhune et al. 2002). Finally, beyond potential behavioral changes cited above, Steller sea lions rely on vocalizations, both above and underwater (Schusterman et al. 2000), thus adding high intensity sound may interfere with their communication which could adversely affect recovery.

Passive Acoustic Deterrents

Passive acoustic deterrents such as chains, rubber tubing, and thick polyester rope added to fishing nets are used in attempts to alert marine mammals to the presence of the nets. Adding objects may provide more opportunities for the animals to echolocate near the nets and thus avoid them (Jefferson and Curry 1996). Passive acoustic deterrents show mixed success (Jefferson and Curry 1996; Au and Jones 1991, Dawson 1991). Clearly, this type of aversion technique is not applicable in this situation.

Seal bombs

A seal bomb is essentially a large firecracker (e.g., M80s or cherry bombs) designed to be thrown and explode near an animal. It is weighted with sand to sink (Jefferson and Curry 1996) and explode at 2-3 m underwater producing a flash of light and an acoustic signal of less than 2 kHz and a source level of approximately 190 dB

(Mate and Harvey 1987). The light and noise are designed to scare or startle marine mammals, without causing injury.

Seal bombs were used at the Hiram M. Chittenden Locks to prevent or at least reduce sea lion predation. Although effective the first year in use, the seal bombs became ineffective deterrents in subsequent years as the sea lions learned to avoid contact by diving and swimming in unpredictable patterns (NMFS and WDFW 1995). The sound frequency emitted is within the hearing range of salmon and may inadvertently scare fish and cause them to leave an area (Mate and Harvey 1987). Even worse, dead fish were observed at the Hiram M. Chittenden Locks soon after the bombs exploded (NMFS and WDFW 1995). There is also potential injury to animals and the person throwing the explosive (B. Norberg, Pers. Comm.[6]). Experimental use in Alaska indicated that seal bombs were ineffective in deterring killer whales from long-lines (Dahlheim 1988, Matkin 1994).

Cracker shells

Cracker shells are similar to seal bombs although they are encased in shotgun shells, fired and explode in the air or at the water's surface 50 to 75 feet away from shooter (NMFS and WDFW 1995). Cracker shells are designed to scare or startle marine mammals without causing physical injury. Most of the energy falls above 200 Hz with source levels of 170 to 235 dB re 1 microPascal (Awbrey and Thomas 1986). Tests of the effectiveness of cracker shells on sea lions were done in the California party boat fishery. Experiments indicated that the sea lions showed a Median Time Away (MTA) of 4 minutes (Scholl and Hanan 1986a). Pairing acoustic harassment devices with cracker shells in the party boat fishery yielded a MTA of 6 minutes (Scholl and Hanan 1986b).

Like seal bombs, cracker shells were not shown to be an effective deterrent against killer whales in the longline fishery (Dahlheim 1988).

From a regulatory perspective, this deterrent is not favored as the guns used for firing the cracker shots could have live ammunition, making it difficult to prevent shooting of marine mammals (B. Norberg, Pers. Comm.[6]).

Firecrackers, including seal bombs and cracker shells, are unlikely to be successful in deterring killer whale predation on Steller sea lions if the attacks occur underwater as sound and light at or near the surface of the water would have little to no effect on killer whale foraging behavior. Baird (1994) reported that killer whale attacks on pinnipeds were only detected during or after the event. Unless attacks can be predicted, trying to prevent an attack with firecrackers would be impossible. Personnel needs would also need to be considered. Firecrackers must be launched or fired by someone at the time of an attack. Staffing remote rookeries continually would be logistically impossible.

Use of firecrackers has proven ineffective and potentially dangerous and experiments in other areas suggest surprisingly rapid habituation to explosives (Richardson et al. 1995). In Alaska, use of powerful explosives by longliners to prevent killer whale depredation was not effective over time (Matkin 1994). Handling explosives is obviously dangerous for people and poses a threat to the animals, both target and non-target species. In the eastern tropical Pacific tuna purse-seine fishery, the use of seal bombs to herd dolphins was banned due to potential injuries (Jefferson and Curry 1996). For all of these reasons, the use of explosives will not be considered further as a deterrent of killer whales.

Pulse Power Deterrents - PPDs

A new acoustic deterrent that has not been tested in the field is the pulse power deterrent (PPD) developed to prevent predation in the party boat fishery in southern California. The PPD is based on observation of Cape fur seals (*Arctocephalus pusillus*) leaving an area when bullets are fired in the water (NMFS 1999) and the assumption that underwater compressions caused aversion. The PPD is an arc-gap transducer that generates a shock wave that simulates a bullet hitting the water by producing both underwater compression and noise. The PPD has a stored energy of 1 – 3 kJs and peak sound pressure of 132 dB re 1 Pa at 1 m[3].

In the late 1990s, experiments were planned in California to test the effectiveness of PPDs. An important aspect of the test was the use of buffer zones. If animals moved closer than 26 m to the PPD it was to be shut off due to potential hearing damage from operations at 1.8 kJs. The experiment was prevented by the State of California and no further tests have been suggested (C. Fahy, Pers. Comm.[7]).

PPDs should not be considered for application with killer whales and Steller sea lions as bullets shot into the water have been shown to be an ineffective deterrent of killer whales (Dahlheim 1988, Matkin 1994) and there is great potential for hearing damage in a variety of marine species. Given the uncertainty of impacts and lack of testing, it would be unlikely that a permit would be issued to experiment with PPDs around endangered Steller sea lions.

Banging pipes

Banging pipes has been used for years in the Japanese drive fishery to herd dolphins into shallow bays where they are then killed (Jefferson and Curry 1996).

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Banging pipes has also been used in rescue operations of cetaceans (e.g., a humpback calf in the Sacramento River, California, and killer whales in Barnes Lake, Alaska (D. Bain, Pers. Comm.[8])). In 1982, pipe banging was used by protesters at the entrance to a bay to keep killer whales out and away from capture boats stationed in Pedder Bay, Washington (R. Osborne, Pers. Comm.[9]). However, attempts to use bang pipes to scare dolphins from fishing grounds in Japan were ineffective, probably due to habituation (Jefferson and Curry 1996).

It has been suggested that the sound from banging pipes may cause a middle ear reflex in cetaceans (D. Bain, Pers. Comm.[8]) thus averting them from an area. Key to the success of banging pipes appears to be the concentration of sound in a relatively small or enclosed area and lack of previous exposure to the sounds (Jefferson and Curry 1996). These conditions do not exist in the range of the western Steller sea lion. Further, it would be difficult to create a completely ensonified area around rookeries. Finally, certain individual whales may be responsible for predation (Maniscalco et al. 2002) and therefore are likely to habituate after repeated exposure.

Predator sounds

The effectiveness of transmitting recording of predator sounds, typically killer whale calls, to deter marine mammals is mixed. Killer whale sounds were used in the Kvichak River, Bristol Bay, Alaska to prevent beluga whales from entering the river and eating salmon. The salmon run only lasted 2 weeks and the belugas did not appear to become habituated to the sound, which was turned off at the end of 2 weeks (Fish and Vania 1971). Clear avoidance behavior on the part of belugas to killer whales had been

[8] David Bain, University of Washington, Department of Psychology, Seattle, WA.
[9] Richard Osborne, The Whale Museum Friday Harbor, WA.

observed (Frost et al. 1992) which may have contributed to their response to the perceived threat. Dall's porpoises twice left an area when exposed to killer whale sounds (Jefferson and Curry 1996). Gray whales immediately left an area when killer whales sounds were broadcast in the water off the coast of California (Cummings and Thompson 1971).

However, in most situations, playing killer whale sounds has proven ineffective in changing the behavior of potential prey (Jefferson and Curry 1996). Killer whale sounds were played in an attempt to deter California sea lion predation at the Hiram M. Chittenden Locks. In this case, the sea lions showed no reaction (Scordino and Pfeifer, 1993). The lack of response to calls may be due to lack of reinforcement (i.e., calls were not followed by an attack).

The type of call and the nature of interactions between killer whales and the species targeted may also be of critical importance when using predator sounds. It has been suggested that in unsuccessful attempts to use predator calls, resident whale calls have been used. Resident whales are not likely to harass or kill other marine mammals (Jefferson and Curry 1996). Recent work by Deecke et al. (2002) suggests that harbor seals selectively habituate to known killer whale calls. Unfamiliar resident killer whale calls elicited avoidance responses similar to those observed when familiar transient killer whale calls were played. Familiar resident whale calls caused very little change in the behavior of harbor seals. Other observations of reactions by potential prey and killer whales suggest that the predator-prey relationship is a complex one which relies on more than just sound cues to trigger a response (Baird and Stacey 1989).

There are published and anecdotal reports of resident and transient killer whales indicating that they don't interact with one another and may deliberately avoid one another (Baird 1994, Matkin 1994). It is possible that this could be utilized as a deterrent of transient killer whales. Although experiments on the use of recorded killer whale calls suggest that the effectiveness wanes with time, if the transient killer whales demonstrate a seasonal exploitation of certain areas, a deterrent may only be necessary in the short-term. It is also possible that transients may stop emitting echo-location clicks in the presence of residents thus interrupting their ability to hunt. Barrett-Lennard et al. (1996) reported that resident killer whales on two occasions stopped vocalizing when approached by transient killer whales and left the areas without emitting echolocation clicks. Transient killer whales may respond similarly to the presence of resident killer whales. This option will be considered further below.

Vessel harassment or hazing

Boats have been used to herd, harass, and attempt to deter marine mammals in a variety of contexts. Boats have been used for decades in the eastern tropical Pacific to herd dolphins used by yellowfin tuna seiner boats (Joseph 1994). Chasing pinnipeds with boats was tried in the Hiram M. Chittenden Locks but was unsuccessful due to adaptations of the sea lions (avoiding or swimming under the boats) and the limitations of space in the locks (inhibited boat maneuverability) (NMFS and WDFW 1995).

Killer whales in the Pacific Northwest are among the most well-studied whale populations in the world (Ford et al. 1994) and are regularly exposed to boat noise (Erbe 2002). Preliminary studies on the effects of boats around the whales are being carried out in Canada and the United States (www.whale-museum.org). While the type of boat interactions being studied are not designed to deter killer whales, the findings are useful for understanding the nature of killer whale/boat interactions. The use of boat hazing as a deterrent is a complex issue which may involve habituation, sound masking, passive listening, and stress. Studies in different areas with both types of killer whales suggest that responses to boats can be quite varied.

A study carried out around northern Vancouver Island in British Columbia detected changes in resident killer whale swimming patterns in the presence of boats. As a boat approached, whales changed their swimming paths, speeds and dive times (Williams et al. 2002). The number of boats and proximity caused different effects on the behavior of the whales, with males and females responding somewhat differently (Williams et al. 2002).

Around southern Vancouver Island, boat traffic is considered one of the potential causes for the decline in that population (Baird 1999). Erbe (2002) modeled the potential of boat noise to mask vocalizations and affect the hearing of southern resident killer whales. Her model indicated that boat noise could mask calls and cause a temporary threshold shift in hearing (Erbe 2002). However, killer whales in British Columbia and Washington annually return to areas with heavy boat traffic (both commercial and recreational) (Ford et al. 1994) which may suggest a high capacity for habituation to boats.

Transient killer whales in the Pacific Northwest appear to be more sensitive to boat traffic, often avoiding boats, although not necessarily leaving an area (Ford and Ellis 1999). This response to boats may be due to hunting techniques. There is anecdotal evidence of transient killer whales stopping their vocalizations when boat engines are running (Barrett-Lennard et al. 1996). Foraging transient killer whales rely on passive listening to detect prey (Hoelzel 1991), as vocalizations and echolocation may be detected by marine mammals (Barrett-Lennard et al. 1996). It is possible that the sounds of the engines may interfere with the hunting whale’s ability to passively listen for prey

(Matkin 1994). Although, Baird and Dill (1996) observed 138 attacks from two small boats during a 7-year study. It's possible that the number, size, type, and proximity of boat engines may cause different responses in foraging killer whales.

Interrupting passive listening and possibly masking calls or echolocation may be options for deterring killer whales and will be discussed further below. Accomplishing this with boat hazing could be difficult as providing crews and boats to remotes sites would likely be expensive and potentially dangerous. This approach may be attempted at more accessible Steller sea lion rookery sites. Use of boats around rookeries must be done with caution as Steller sea lion pups are vulnerable to disturbance (www.marinemammal.org/research, viewed September 2002) and may be flushed into the water if boats approach too closely (Maniscalco et al. 2002) making them more susceptible to predation.

Non-acoustic Deterrents

Physical barriers, nets

Physical barriers have been used at aquaculture sites to prevent predation by pinnipeds. The use of small mesh, inflexible, heavily weighted semi-permanent nets with a sufficient buffer zone around primary nets has been shown to be an effective deterrent of seals and sea lions in British Columbia (Iwama et al. 1997). In the 1987-88 field season, barrier nets were placed at the major predation site at the Hiram M. Chittenden Locks but were unsuccessful at decreasing California sea lion predation on steelhead. The sea lions moved to other areas, including Lake Washington, above the locks, and continued to feed on steelhead (Scordino and Pfeifer 1993).

Physical barriers are not a viable option for deterring killer whale predation at Steller sea lions rookeries as the predator nets are semi-permanent structures and may disrupt the activities of the sea lions and other animals if placed near haul-out sites. Entanglement is also a concern; a barrier net at a aquaculture site in Rich Passage, in Puget Sound, Washington, caused the entanglement and death of two California sea lions (Norberg 2000). Humpback whales (*Megaptera novaeangliae*) have died in shark nets in Hawaii (Mazzuca et al. 1998).

The physical characteristics of the areas occupied by Steller sea lions would make the effective use of physical barriers difficult. The steep drop in bottom contours could make anchoring the nets difficult and high wave action could potentially foul the anchor lines. Thus this option should be disregarded.

Taste aversion

This technique has been used successfully with coyotes, wolves, and other terrestrial mammals to prevent predation (Kuljis 1986). The most common type of taste aversion involves putting an emetic, usually lithium chloride (LiCl), in a potential prey item (e.g., cow or sheep carcass) that is then consumed by the predator. After repeated treatments, the predator is supposed to be conditioned to avoid that prey (NMFS 1995). Lithium chloride is generally preferred over apomorphine as it has a more lasting effect (Ralphs 1998) and attempts to trigger emesis with apomorphine and other typical emetics were unsuccessful in captive Weddell seals (*Leptonychotes weddellii*) (Bornemann et al. 1997).

Kuljis (1986) experimented with taste aversion using captive California sea lions. Using paired sets of sea lions, three exposures to the LiCl in mackerel (one of two types of fish typically fed to the sea lions) were sufficient to cause one sea lion to refuse to eat mackerel for 18 days. Though not reported in the Kuljis paper, LiCl was used to create an aversion response in dolphins although the cetaceans were much more sensitive to the drug and possible poisoning (cited in Matkin 1986). No published record of testing taste aversion on wild cetaceans could be found.

Taste aversion was tried with wild pinnipeds at the Hiram M. Chittenden Locks without success (Gearin et al. 1988). To test the effectiveness of taste aversion, California sea lions were habituated to take tethered, recently killed steelhead. Once this was accomplished, LiCl tablets were placed in steelhead carcasses that were tethered and made available to the sea lions. Two known animals each consumed one steelhead carcass treated with LiCl. Within an hour they moved from their usual forage site and indications were that they became ill. However, within 2 hours they were foraging again although neither animal would take another tethered fish. Although foraging declined immediately following the treatment, within 5 days normal levels of foraging returned (Gearin et al. 1988). It's unclear whether the experiment worked as the tethered fish was avoided by the sea lion (conditioned response) but predation on free swimming steelhead was not affected (Gearin et al. 1988).

Attempting to use taste aversion with wild killer whales around Steller sea lions would most likely involve placing LiCl in a pup carcass that could be tethered and presumably consumed by a whale to create a conditioned response associating Steller sea lion pups consumption with illness. There are a number of difficulties in using taste aversion to deter killer whale predation on Steller sea lions. LiCl has not been tested as an emetic on cetaceans in the wild, so the dosage and effectiveness can not be certain. The correct dosage to elicit a specific response is critical to conditioning an animal using taste aversion (Kuljis 1986). Also of concern is that LiCl stays in the system of lab animals and livestock for up to 96 hours and can be passed along to offspring via milk (Ralphs 1998). The potential impact on nursing killer whale calves ingesting LiCl laced milk is unknown. The success in the Kuljis experiment was likely due in part to putting LiCl in a normal food item for the captive sea lions, which may account for their willingness to eat it (Kuljis 1986). Pup carcasses (i.e., dead pups) do not appear to be a normal food item for killer whales in Alaska. Only one account could be found in the literature of killer whale scavenging; a seal hunter in Alaska reported that a killer whale took a speared harbor seal (George and Suydam 1998). Researchers in Alaska reported no accounts of killer whales eating pup carcasses after many years of observations (C. Matkin, Pers. Comm.[1]; L. Barrett-Lennard, Pers. Comm.[10]). It is likely that other animals may scavenge on the pup carcass producing unknown reactions in non-target animals. Interestingly, a recent article reported on the first observed occurrence of cannibalism in an otariid, the New Zealand sea lion, *Phocarctos hookeri*, by males at a rookery site (Wilkinson et al. 2000). While cannibalism has not been recorded for the Steller sea lion, they, like the New Zealand sea lions, will prey on other pinnipeds species (Wilkinson et al. 2000).

Tactile harassment

Few accounts of using non-lethal bullets to deter marine mammals could be found. Shooting rubber bullets or blunt tipped arrows at California sea lions was attempted at the Hiram M. Chittenden Locks with no significant change in predation rates (NMFS and WDFW 1995). The sea lions responded to being hit by subsequently avoiding the "target area" and/or spending less time at the surface (NMFS and WDFW 1995).

The success of tactile harassment is dependent on a person being in the immediate vicinity of an attack and ability to fire rubber bullets or arrows at very close range (B.

[10] Lance Barrett-Lennard, Vancouver Aquarium Marine Science Centre, Vancouver, B.C.

Norberg, Pers. Comm.[6]). Therefore this option is not a viable option for killer whale deterrence.

Scent deterrents

The use of scent deterrents has been reported for some applications for marine mammals, (B. Norberg, Pers. Comm.[6]) but is not applicable to killer whale predation as cetaceans have no sense of smell.

Gunshots

Gunshots have been used to attempt to deter seals and sea lions from aquaculture operations in British Columbia with limited success (Iwana et al. 1997). Dahlheim (1988) reported that gunshots were ineffective in deterring killer whales from longlines in Alaska. Shooting with buckshot was also ineffective, as the whales appeared to quickly become tolerant of the harassment (Matkin 1986, Matkin 1994).

It should be noted that discharging a firearm within 100 yards of the western stock of Steller sea lion is prohibited under the Endangered Species Act and Marine Mammal Protection Act. Therefore, this option is not legal or feasible.

Aversion Techniques and Killer Whales

Killer whales have been known to adversely affect fisheries operations, particularly longline fisheries, around the world. A comprehensive list of locations with killer whale - longline interactions can be found in Visser (2000) along with methods used to prevent depredations – none of which proved to be effective over a long time period (Visser 2000).

In Alaska, depredation on longlines, particularly sablefish, has been an issue for decades (Dahlheim 1988) and accounts of attempts to deter killer whales are numerous (Matkin 1994, Matkin 1986, Yano and Dahlheim 1995). A review of aversion techniques and effectiveness in sablefish longline fisheries in Alaskan waters is provided in Dahlheim (1988). The following were not effective in deterring the killer whales: seal bombs, decoy boats, blank sets, combined hauling, night fishing, short movements, shooting, electric currents, tangle imitator, and pipe banging. The following showed some positive effect: dummy buoys, stopping operations, and long movements of the vessels away from the whales. The following were considered very effective: change of target species (sablefish were the preferred prey species in Alaska) and changes from longline gear to trap gear. Explosives and acoustic harassment devices were not adequately tested to assess their effectiveness. Subsequent work with explosives and acoustic devices indicate that they too were ineffective (Matkin 1994, Visser 2000)

It is important to note that these depredation events involved resident, or fish-eating killer whales. Whales that prey on Steller sea lions are transient, or marine mammal-eating killer whales and no record of attempts to deter transient killer whales could be found. Therefore the use of any type of deterrent is highly speculative and would require significant research.

Further, the only options available have either not been tested or are deterrent options that have failed in other applications. Given the high level of uncertainty, the options that seem to deserve consideration should have minimal potential for causing harm to non-target species, particularly the Steller sea lion. Proposed use of any deterrent should be coupled with research and significant experimentation before implementation and monitoring during operation to ensure no adverse effects. Additionally, any options considered should be based upon a review of existing deterrents, behavioral information on transient killer whales and Steller sea lions, and should utilize the expertise of, and be reviewed by, researchers in the field.

Using this criteria, one option for deterring transient killer whales would be to play the sounds of resident killer whales. This possibility is based on evidence that transients will avoid an area if resident whales are present (Baird and Dill 1995, Barrett-Lennard et al 1996) and one report of an attack on transients by resident killer whales in British Columbia (Ford and Ellis 1999). In the other parts of Alaska, known residents and transients are rarely seen together and have never been seen interacting (C. Matkin, Pers. Comm.[1]). Baird (1994) reported an observation in British Columbia of transient killer whales changing course and moving away from approaching resident whales. The sounds of resident killer whales, and their perceived presence, may have caused the transient killer whales to leave an area.

The nature of resident and transient killer whale interactions is not understood well enough to say with a high level of certainty how transients will respond to resident calls. While transient whales generally appear to avoid residents by remaining silent or leaving an area, there are accounts of transients occasionally being quite vocal while in the waters of resident whales, particularly during or after a kill (Ford and Ellis 1999). More research is needed to better understand the relationship between resident and transient killer whales, to determine if playing calls could be effective at causing transient killer whales to leave an area.

There are some technical problems involved in killer whale playback that should be considered. Continuous broadcast of resident killer whale vocalizations is likely to lead to rapid habituation (Jefferson and Curry 1996). Therefore, some sort of triggering device would be required. This would likely involve either visual or acoustic monitoring of sites. Further, the development of remote acoustically triggered devices is still underway (J. Olson, Pers. Comm. [11]). Transmitting the resident killer whale calls with the correct sound characteristics to replicate actual calls would require expensive equipment and a power source that may not be available in remote areas. This inability to replicate the sound qualities of calls may be part of the reason this deterrence has failed in the past (J. Olson, Pers. Comm.[11]).

Another potential method of deterrence would be interfering with transient killer whales' passive listening while hunting near Steller sea lions. Killer whales are believed to be reliant on passive listening while hunting (Ford and Ellis 1999, Hoelzel 1991). There is anecdotal evidence that transients will stop hunting when boat engines are on (Matkin 1996) presumably due to an inability to hear prey. It may be possible to use a sound generating device (perhaps similar to an ADD) or boat hazing to interfere with passive listening.

To avoid habituation and minimize impacts on other marine species, there would need to be some sort of triggering device when transient killer whales are in the area to engage a sound device or boat hazing. Whether or not such a triggering device could be reliably used in western Alaskan waters is speculative and beyond the scope of this paper.

The feasibility of this option is further constrained by the lack of information about the role of passive listening for transient killer whales in western Alaska. Ford and Ellis (1999) express concern that anthropogenic noise may be interfering with transient killer whale hunting. On the other hand, Baird (1994) noted that observed capture rates of harbor seals by transients was unaffected by a research boat operating in the area of the whales. Although there is a high amount of uncertainty about the effectiveness, this

[11] Joseph Olson, President, Cetacean Research Technology, Seattle, WA

option could be explored, as the sounds required would be relatively quiet and therefore less likely to adversely affect non-target species.

The final option considered in this paper is the most speculative: masking of killer whale echolocation and vocalizations using anthropogenic sound. Research is being carried out to determine the impacts of anthropogenic sound on marine mammals and masking of vocalizations and echolocation (Richardson et al. 1995). The use of anthropogenic sounds to deliberately mask marine mammal vocalizations or echolocation could not be found, although it is likely that boats may cause sound masking (Bain and Dahlheim 1994, Erbe 2002) or interfere with vocalizations (Rezende and Monteiro-Filho 2001). Attempting to mask or interfere with transient calls and/or echolocation may be one option for limiting predation on Steller sea lions.

Transient killer whales are usually silent while hunting, emitting only low frequency sounds during active foraging (Barrett-Lennard et al. 1996). These sounds are quiet and very difficult to hear against the ambient underwater noise (Barrett-Lennard et al. 1996, Saulitis 1993). Analysis of echolocation clicks from Johnstone Strait killer whales indicate they are of low frequency with wide bandwidths (Au et al. 2001) which are characteristics consistent with sounds that can be masked by boat noise (Erbe and Farmer 2000, Bain and Dahlheim 1994). It is beyond the scope of this report to speculate on the type of sound (frequency, decibel, intensity) that could effectively mask the sounds of killer whales, or to even suggest that this could be done. However, this option may deserve further consideration by researchers trained in acoustics. More information on masking whale vocalizations and echolocation can be found in Richardson et al. (1995), Bain and Dahlheim (1994), Erbe and Farmer (2000), Erbe (2002).

It is important to point out that marine mammals are very adaptable to sound, as has been discussed in earlier sections about acoustic deterrents. Interestingly, marine mammals respond to non-anthropogenic acoustic interference as well. It was discovered that killer whales, in the southern ocean, changed the sounds they used for hunting when leopard seals (*Hydrurga leptonyx*), a fellow predator, were present (Mossbridge and Thomas 1999). Both species were hunting for crabeater seals (*Lobodon carcinophaga*) and Weddell seals. The calls of the leopard seals may have masked the sounds of the killer whales, causing the whales to change their sounds to above and below the frequency of the leopard seals (Mossbridge and Thomas 1999). Similarly, seals have been found to change their calls in response to interfering and possibly masking sounds (Serrano and Terhune 2001). Therefore, any use of sound as a deterrent may have only short-term success as the animals learn to adapt.

The use of any type of additional sound in the water could have adverse effects on Steller sea lions. As noted earlier, both in air and underwater vocalizations are used by Steller sea lion mothers and pups to find one another and for other social interactions (Schusterman et al. 2000). The underwater vocalizations of sea lions are of low frequency, less than 4 kHz (Schusterman et al. 2000), and may therefore be vulnerable to masking caused by adding anthropogenic sounds to their environment. Research on masking in other pinniped species should be reviewed (Southall et al. 2000) and experiments should be carried out to ensure that Steller sea lion communication would not be adversely affected by use of acoustic killer whale deterrents.

It is necessary to be cautious when considering adding sound to the marine environment and to consider all possible effects on killer whales and other species. For example, one possible impact of displacing killer whales from Steller sea lions sites and predation is that it may force them to forage in other areas and on other species. The consequences on other species are difficult to calculate (L. Barrett-Lennard, Pers Comm.[10]) although Estes et al. (1998) predict one possible outcome (declining sea otter populations) as a result on killer whale prey switching.

Another unknown effect of adding sound to the marine environment is the possibility of causing a temporary threshold shift (TTS) or permanent threshold shift (PTS) in the hearing ability of the target and non-target species. A TTS is defined as a temporary loss of hearing due to exposure to loud sound. The loss is regained over a fairly short period of time, such as 24 hours (Kastak et al. 1999). A permanent threshold shift is a loss of hearing that is not regained. Few experiments have been conducted to measure noise exposure required to cause TTS (see Kastak et al. 1999, Au et al. 1999, Nachtigall et al. 2001), and no studies could be found on PTS (Erbe 2002) or TTS in Steller sea lions. For further information on TTS and killer whales, see Erbe 2002, Erbe and Farmer 2000, Bain and Dahlheim 1994. TTS in marine mammals may result in short-term inability to communicate, navigate, hunt and hear predators (Kastak et al. 1999), which could have serious consequences.

Given the high level of uncertainty over potential impacts, any attempt at killer whale deterrence must be well-tested and based on good science. To meet this goal, more research is critical.

Research Needs

The need for research on the basic life history, ecology, abundance, and distribution of transient killer whales is important for determining the possible impacts of predation on endangered Steller sea lions and determining if options for possibly minimizing these impacts through some sort of deterrent are appropriate.

Research is needed to determine population size and foraging behaviors of killer whales in western Alaska. Whale surveys and annual counts are currently being carried out and tissue samples are being taken from animals to determine the proportion of residents and transients. In addition, a photo-identification record of all known killer whales is being created by staff at NMFS, with cooperation from two other research groups, which will help in estimating population abundance. Use of photo-identification of individuals and residents and transients will aid in learning more about the relationships between these two populations of killer whales. This may be key to designing a low impact deterrent such as playing resident killer whale calls.

As has been shown in the Pacific Northwest (Ford et al. 1994) many years of observation and study are necessary to understand killer whale communities, their feeding behaviors and distribution. In Southeast Alaska and Prince William Sound long-term studies have provided information on the distribution and feeding habits of transient killer whales in those areas. Saulitis et al. (2000) estimated that Prince William Sound transient killer whales spent 22.2% of their time foraging near shore for harbor seals and 27.8% of their time offshore in pursuit of Dall's porpoises. Behavior budgets of this type would need to be established for western Alaska transient killer whales to aid in determining where and when predation may be occurring. Saulitis et al. (2000) also noted that there were two distinct populations of transient killer whales in the Prince William Sound area, Gulf of Alaska transients and the "AT" transients, and only Gulf of Alaska transient were observed attacking and eating Steller sea lions. Interestingly, eleven incidents of killer whales swimming among Steller sea lions were observed, with no kills noted, although the sea lions were observed nipping and charging at the whales

(Saulitis et al. 2000). This suggests that caution be used when evaluating potential predation events on Steller sea lions based on proximity to haul-out sites.

Based on the finding of Saulitis et al. (2000) and others, tracking the number of attacks and rates of predation near rookeries may best be accomplished by deploying hydrophones at a number of sea lion rookeries (i.e., sampling sites with relatively low, medium, and high pup production). Transient killer whales have specific calls associated with an attack and shortly after a kill (Saulitis 1993, Morton 1990). Recording these sounds could aid in determining impact and trends of killer whale predation. However, this method is not without flaws as the killer whale's prey may not necessarily be Steller sea lions. Harbor seals, humpback whales and minke whales have been observed near sea lion haul-out sites and could be the targeted prey items (J. Sterling, Pers Comm.[12]). Observing rookeries for evidence of killer whale predation is further complicated by the movements of mothers and pups. Pups may be moved to different haul-out sites as early as 4 months old (Loughlin and York 2000) and 5-month-old pups have been observed 400 km from their natal rookery (Raum-Suryan et al. 2002). This may complicate attempts at drawing cause and effect relationships between low pups success and the presence of killer whales; a decline in pup population may mean the pups have left with their mothers, not necessarily become prey for killer whales.

A hydrophone array may also detect seasonal utilization of various sea lion rookeries by killer whales. Resident, or fish eating, killer whales appear to move seasonally in response to prey availability (Ford et al. 1994). There is some evidence of transients moving in response to seasonal abundance of pinniped prey (Guinet et al. 1999, Iniquez 2001, Baird 1994). Matkin et al. (1999) have observed some evidence of

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seasonal movements of transient killer whales in Alaska in response to Steller sea lion pup abundance. Determining patterns of presence of transient killer whales in the range of western Steller sea lions during certain times of year would be helpful in determining how best to deter predation. Methods that may not have been shown to be successful in the long term may be effective if only utilized for a short period of time (such as when Steller sea lion pups first enter the water).

Currently, video monitoring of Steller sea lion rookeries is being carried out at four sites, while audio monitoring is being done at two additional sites (Maniscalco et al. 2002). Additional monitoring, either audio or visual, at various rookeries (with high, medium and low pup production) would assist in direction of effort to those sites proven to be most vulnerable. Pairing audio and video monitoring may also help to establish if certain pods, or individuals, are responsible for the majority of the predation.

This report has focused on the feasibility of using deterrent devices near Steller sea lion rookeries, working under the assumption that the highest rate of predation occurs in these areas. This assumption cannot, at this point, be tested due to lack of data. It is generally believed that pups are most often taken by transient killer whales (Barrett-Lennard 1995). This is consistent with report for other killer whale populations that prey on pinnipeds (Lopez and Lopez 1985, Guinet et al. 1992, Baird 1994). However, it is also possible that given the large size of adults (male Steller sea lions may weigh up to 1,120 kg, females up to 350 kg (NMFS 1992) that juveniles and adults may be targeted. This is consistent with evidence of prey sharing among transient killer whales (Hoelzel 1991). Resolving the issue of which age group is most often preyed upon by killer whales would be critical if any type of deterrent were to be used. This report has focused on deterrents to be used near rookeries from a purely practical standpoint, as the effective use of deterrents in open water would be virtually impossible.

A more thorough understanding of possible impacts of deterrents on non-target species is critical, particularly if any type of acoustic deterrent is considered. Experiments on the impacts of anthropogenic noise are being carried out and published, however, much more needs to be known, including behavioral and physical impacts of sound. Research on the hearing capabilities and sensitivities of Steller sea lions could not be found and this type of information would be critical for making a decision on use of acoustic deterrents.

Conclusion

Whether or not a deterrent to killer whales predation on Steller sea lions could be created is speculative as killer whales are highly intelligent and adaptable and attempts at deterrence have failed in the past. For example, one attempt to prevent long-line depredation was to attempt to "trick" the whales using two longline boats. As the group of killer whales approached one boat pulling in its gear, the operation stopped and the other boat, a few miles away, began to pull in their lines. After swimming back and forth a few times the whales gathered between the two boats and after a bit of milling separated into two groups, each approaching a different boat (Matkin 1994).

Beyond the inherent difficulties of trying to affect the behavior of killer whales, this report has tried to point out the cautions that must be considered if using deterrents, including potential impacts on non-target species, particularly Steller sea lions.

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