Technological Alternatives to the Problem of North Atlantic Right Whale Ship Strikes

Note: This white paper was developed within NOAA Fisheries as supporting documentation to provide explanation into the development of the operational measures in the proposed ship strike strategy. The paper should be considered a working document to be used as a tool for policy analysis and to further understand the origin of proposed measures. Comments on the document are welcomed, and may be sent to aleria.jensen@noaa.gov.

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1. EXECUTIVE SUMMARY

The North Atlantic right whale (*Eubalaena glacialis*) is a critically endangered species which has shown little recovery from the effects of commercial whaling in the 18th and 19th centuries. At present, the population is believed to number only around 300 individuals and recent modeling exercises suggest that the population could go extinct in less than 200 years if adverse effects from human activities are not reduced. These models suggest that the loss of even a single individual may contribute to the extinction of the species. Currently, mortality and serious injury due to fishing and shipping activities are a significant factor limiting right whale recovery. Ship collisions alone account for the largest number of confirmed mortalities; since 1991, 14 right whale deaths have been attributed to ship strikes. The actual number of deaths resulting from ship strikes, however, is almost certainly higher as many right whale deaths likely go undocumented.

Given the precarious status of the species, much effort has been devoted to looking for avenues to mitigate the effects of shipping activities on right whales. Members of industry, government and the public have suggested repeatedly that answers may be found in technological solutions or inventions. This document attempts to address this issue by providing a review of technologies that have been tried and those yet in their infancy. Where possible, the authors have included evaluations of the relative effectiveness of each proposed solution. This document is thus intended as an educational tool to help clarify the role that technology may play in resolving the conflict between right whales and the shipping industry.

The technologies discussed here are those that warn whales away from ships and those that detect whales so ships can avoid them. Acoustic Deterrent Devices (ADD's) and Acoustic Harassment Devices (AHD's) are audible alarm devices which warn small cetaceans and pinnipeds away from commercial fishing gear and aquaculture operations by emitting sound pulses. Their use has received mixed success and the issue of habituation is significant. No evidence exists that large whales would, in fact, respond to such a sound signal. Furthermore, such approaches have the potential to create stress in animals if they are alarmed repeatedly or periodically. In addition, exposure to alarm or alerting stimuli may result in whales abandoning a desired feeding or mating area which could result in significant adverse effects on the population.

Techniques to locate whales include ship-mounted and bottom-mounted active acoustics (e.g., SONAR), night vision optics, thermal imaging, and the use of pilot boats to precede larger vessels as "surveillance" for right whales in high risk areas (e.g., ports). Many of these techniques are impractical and expensive and have limited detection distances. Although the use of active acoustics in the form of SONAR has received much attention, significant concern exists as to its potential adverse effect on marine species by introducing additional noise into an already noisy environment.

Other techniques to locate whales and warn mariners include aerial and ship based surveys, laser detection, satellite imagery, passive acoustics, telemetry (VHF, satellite and acoustic) and

predictive modeling. Vessel and aircraft surveys are well-tested techniques to locate marine mammals and have been conducted in waters off the northeast U.S. coast since the 1960's. Surveys are currently used to locate and identify right whales along much of the East Coast of Canada and the US. They can cover large areas and provide immediate warnings to mariners. Surveys are, however, expensive and labor intensive and limited by their ability to detect whales only at the surface in daylight and desirable survey conditions. There is also little indication that ships modify their behavior to reduce the risk of collision once warned. In a few well-documented cases, ships have diverted from a whale spotted by aircraft surveys, but generally it is difficult to know or quantify how/if routine alerts are being processed by mariners (e.g., altering operations). Despite these limitations, surveys will continue to be an important management tool to locate animals.

The use of laser technology (e.g., LIDAR) in fisheries management to detect fish aggregations is still in its infancy and little has been done to apply its use to large whales. Likewise, the use of satellite imagery and remote sensing (Single Aperture Radar, SAR) has not been practical to detect large whales, although advances made in resolution may allow for the detection of individual whales in the future. A more practical use of the technology may be in locating concentrations of prey to predict whales by the presence of their food source.

Passive acoustics (e.g., moored buoys, pop-up buoys, sonobuoys, towed hydrophone arrays) have the potential to detect whale concentrations by detecting vocalizations and thus could play a role in monitoring areas for right whales. The obvious limitation is, of course, that whales must vocalize to be detected. The rate of vocalization (i.e., determining how many whales are present, rather than just presence/absence) is also an issue as is the depth at which animals vocalize (i.e., sound propagation increases with increasing water density). Passive acoustic techniques are promising tools that have been used successfully to census bowhead whales and are currently being tested in waters off the northeast U.S. to detect right whales. Initial results show that right whales indeed can be detected using passive acoustic listening devices with results uplinked from the buoy by satellite or cell-phone back to land for rapid response. The US Navy also tested the use of passive acoustic hydrophone arrays to detect right whales off Florida in 1997, but determined that it wasn't an effective tool to avoid collisions with right whales, partially because vocalization rates were low. A significant challenge in using this technique with right whales is their shallow, coastal habitat; the physical features of this topography are not conducive to sound propagation. A further limitation to the use of passive acoustics is the real time processing of the vocalization signals and the supporting technology needed to relay such information ashore.

Predictive modeling of oceanographic features and links between environmental features and whale distribution remains an elusive technique to reliably predict whale concentrations. However, it deserves further study as it may provide a tool for locating the animals if strong predictive relationships can be found. Satellite tagging of whales is a technology which faces the perennial challenge of tag attachment and longevity. Researchers have attempted since the late 1980's to develop a satellite tag that will remain attached and operational on a right whale. This has met with limited success. Additionally, health concerns have been raised as tagged right whales have shown swellings at implantation sites. Telemetry will continue to be a useful tool for monitoring the movements of individual animals, but will not be adequate for real time management of whale-vessel interactions, because it is not feasible to tag or continually tag large portions of the population inasmuch as tag life tends to be on the order of days or tens of days. Moreover, detection and localization is not a solution in itself as ships would likely be expected to divert or slow in any case.

The authors of this document share the belief that none of the technologies presented herein represent a “solution” as a right whale ship strike mitigation measure. All have limitations and many are still in the early stages of development. Although society often looks to science or technology to remedy problems of resource conservation, these “quick fixes” alone cannot be expected to solve the complex issue of right whale ship strikes. Technology warrants further study and may prove useful in tandem with other forms of management, however, reducing or eliminating the threat of ship strikes to right whales will most likely require a commitment toward other management measures.

2. INTRODUCTION

The problem

The North Atlantic right whale (*Eubalaena glacialis*) is one of the world's most critically endangered whale populations. The North Atlantic population was severely depleted by extensive commercial whaling in the 1700 and 1800s, but recovery has been slow or non-existent despite a ban on commercial harvest. Only about 300 right whales occur in the North Atlantic today, and recent modeling exercises suggest that the population could go extinct in less than 200 years (Caswell *et al.*, 1999). Recovery is almost certainly retarded by death and serious injury resulting from human activities, notably from fishing and shipping activities. At present, the loss of even a single individual may significantly retard recovery and indeed contribute to the extinction of the species.

The impact of ship strikes on right whales has been well demonstrated. Massive wounds (e.g., fractured skulls, severed tails, and large propeller slashes) found on right whale carcasses document that collisions between the whales and large ships have been responsible for a number of deaths. Since 1991, 14 right whale deaths have been attributed to ship strikes; however, the actual number of deaths resulting from ship strikes is almost certainly higher. That is, most right whale deaths likely go undocumented and some carcasses evidenced by photographs could not be further examined for injuries.

Right whales occur mostly in coastal areas and on the continental shelf and its areas of aggregation and migration are in or near shipping routes into major ports along the eastern sea board. Most carcasses of whales struck by ships were recovered in or near major shipping lanes, which cross the five high use right whale habitats and the whales' coastal migratory corridor between the southeastern U.S. and northeastern United States and southeastern Canada. Finding and employing measures to reduce the threat of ship strikes is imperative.

Finding Technological Solutions

There are no easy solutions to reducing or eliminating the threat of ship strikes. Many bright, capable people in academia, industry, the environmental community and the government have been working on these issues for some time. In seeking a strategy to reduce or eliminate the threat of ship strikes to right whales, it is necessary to consider a wide range of potential measures. Representatives of the shipping industry, government, and science have suggested that a solution to right whale ship strikes may be found in applications of advanced technology.

Our intent here is to provide a review of the technologies that have been identified, those that have been tried, and the current status of research on such technologies. In preparing this analysis, we draw upon the available scientific literature, results of research underway, and the considerable expertise within the agency on the biology of marine mammals.

Techniques discussed in this document are those that can be used to 1) locate, or enhance location of, whales; 2) to alert, alarm, or warn whales away from ships; and 3) to alert ships to whales in their vicinity. Technologies include passive and active sonar devices, optics, alarms, remote sensing, telemetry, and modeling. For each of these devices or methods, a general theoretical description is provided, followed by actual and practical application. Some technologies are well-documented and currently in use, such as vessel and aerial surveys to detect locations and numbers of whales. Others, such as predictive modeling and satellite imagery, are still in development.

We, the authors, wish to express the strong view that the problem of ship strikes and right whales is not likely to be fixed through technological solutions or inventions. Society often looks to science or technology to remedy problems of resource conservation or protection. At these times, "magic fixes" are sought. However, more often than not, such solutions do not exist, or a great deal of money can be devoted to seeking solutions perhaps with even greater deleterious effects. In addition, critical time may be lost without addressing the problem head on, and the resource suffers.

The search for technological solutions fall into two basic categories: detecting whales so ships can avoid them, or alerting whales and moving the whales from the ship's path. We wish to point out, in the case of the latter, assuming such a device existed, had been tested, and was indeed effective, there are substantial biological and legal problems with the prospect of periodically moving a highly endangered species from a preferred habitat or migratory corridor. With regard to the (remote) detection of whales, we wish to note that, even if reliable methods existed to detect whales, ships would still be expected to respond to the whale's location – probably by slowing down and/or changing course.

Over the years, quite a number of "solutions" have been suggested; some have been tried. We have attempted here to provide a review of what has been tried and to evaluate the relative effectiveness of each proposed solution.

3. TECHNIQUES TO LOCATE WHALES

It may be possible, in certain circumstances, to remotely detect whales and relay the sighting location to ships in the area. However, most technological systems will not have 100% accuracy, and if ships are alerted and re-routed, there is always the possibility that we may move a ship away from one group of whales into another, undetected group. In addition, large ships need substantial time and distances (e.g., several kilometers) to make course changes and to slow down. Therefore, for ship-mounted technologies, detection ranges need to be on the order of kilometers and the amount of warning time probably needs to be on the order of tens of minutes. These ranges of several kilometers and reaction time of tens of minutes, as well as some standard of detection rate (while also ensuring other, undetected whales are not nearby) become the criteria by which technology solutions are pursued. Moreover, with detection technologies, ships will still need to find ways to maneuver around whales or slow down – two principal components of regulatory measures being considered. One additional note is that whales can surface unexpectedly, so last minute surface detection (i.e., no opportunity for a ship to react) may offer little relief.

3.1 Ship-based Active Acoustics

3.1.1 Sonar

Description: The goal of this technique is to detect shapes (e.g., whales) underwater using high-energy SONAR devices (i.e., sending out a high-energy sound source and gathering information about objects in the water column from the returning sound signals), much the way submarines are detected by surface or sub-surface vessels. Of course, Naval operations have a long history of developing and refining such devices starting not long after underwater warfare began.

Some marine mammal species use echolocation (i.e., emitting a sound source and learning something of the surroundings and prey based on the returning echo) quite effectively. In dolphins and other toothed whales (e.g., sperm and beaked whales) these are generally described as “clicks”. Sperm whales are probably the champions as their clicks can be recorded by human listening systems at many kilometers. Dolphins are probably detecting (prey) items in the relative near-field, inasmuch as many signals are very high frequency (e.g., 50-139 kHz) and likely do not travel great distances.

In general, the use of active sonar to detect animals is contingent upon a variety of factors: source level, frequency, transmitted waveform, target strength, ambient noise and two-way transmission loss (Gisiner 1998). In biological systems as well as human-made systems, the physics of sound traveling underwater applies a number of constraints, namely, low-frequency sounds travel far, high-frequency sounds do not. Therefore, to increase range of detection, relatively lower frequency devices need to be employed. The lower the frequency used, the greater number of species are likely to be affected as it enters the hearing range of these species. If relatively higher frequencies are used, potential adverse effects to marine species are avoided, but detection range is sacrificed. In addition, the strength (amount of noise energy) of the signal needs to be increased to increase transmission range with the potential to adversely affect marine organisms.

What has been tried: A High Frequency Marine Mammal Mitigation (HF/M3) sonar system has been designed to meet the mitigation requirements proposed for the operation of the Navy’s SURTASS LFA submarine detecting technology. Due to concern over the acoustic effects of LFA, the Draft Environmental Impact Statement proposed developing an active detection system to thereby avoid exposing marine mammals to high sound pressure levels generated by LFA. The system is suspended beneath a vessel’s hull and utilizes four independent transponders mounted on a rotating carousel on top of a vertical transmit array. The HF/M3 is comprised of commercial off-the-shelf components, operates in the 30-40 kHz range and uses PC based processing and control. The ability of this system to detect marine mammals of various sizes has been qualitatively verified and has been used for marine mammal protection during Littoral Warfare Advanced Development (LWAD) exercises in Europe. The system is most effective at detecting large, slow-swimming animals above the main thermocline, i.e. roughly within 200 m of the surface (Ellison and Stein 1999). However, in its current form, this system is not applicable as a mitigation for right whale ship strikes. It is specifically designed for an LFA carrier vessel and not for vessels underway. Additionally, the system is adapted for detection in open ocean conditions and not the shallow, coastal waters most frequented by right whales.

Beyond this LFA mitigation system, very little empirical work has been tried in detecting whales in the open ocean using SONAR. One of the most promising applications for active acoustic detection may be in determining the locations of whales at close range that are not vocalizing.

Successful detection of submerged animals has been reported using fish-finding and mine-hunting sonars (Gisiner 1998). NMFS is currently funding and working collaboratively on testing the feasibility of several modified commercially available fish-finding devices to detect large whales. Thus far, the systems have been able to detect humpback whales at relatively close ranges (e.g., <200m). This work is ongoing.

In addition, to outfit all or a large portion of commercial ships or even selected "pilot" vessels, as has been suggested, with specifically designed (e.g., not off the shelf technology) active acoustic detection devices may be prohibitively expensive. To bottom mount and/or retrofit such devices and all the electronics required would be highly cost intensive. Further, such a device may require near-constant monitoring by a human operator to make assessments of the validity of potential "detections', as opposed to false detections of fish schools, flotsam and jetsam, zooplankton swarms, or even water masses. Certain criteria of detection target strength would need to be established and, even then, human judgement would almost certainly need to be called into play prior to the actual diverting of a ship.

Sonar

PROS	CONS
+ has been used to successfully detect marine mammals	- extremely expensive
	- impractical to outfit ships (large size)
	- trained operator necessary for use
	- low detection range
	- introducing (potentially) high-energy sound sources into the water with possible adverse biological effects
	- likelihood of false positives, e.g., detection of fish schools and other submerged biological or physical features

3.2 Bottom-mounted or moored active acoustics devices

Description: It may be possible to equip a relatively small area, a shipping lane for example, with bottom mounted, upward scanning active acoustic devices to search for objects in the water column. This possibility was assessed in a workshop held on 28 July 1999 (Marine Mammal Commission 1999). The workshop concluded that deployment of an array of such devices would be prohibitively expensive and difficult to maintain. Moreover, it would have high energy input requirements (both powering the device and the sound source) and a limited detection range.

What has been tried: To our knowledge, moored active acoustic devices to detect whales have not been tried.

Bottom-mounted or moored active acoustics devices

PROS	CONS
+ if effective, relatively small areas could be ensonified, and whale locations relayed to ships in the area	- the disadvantages of using such as system are the same as those identified for ship-mounted devices noted above (i.e., potential biological effects of ensonifying right whale habitat with loud sound sources)
	- potentially prohibitively expensive
	- difficulties with logistics; power sources, electronics, laying of cable, etc.

3.3 Light Enhanced Optics

3.3.1 Night scope

Description: Certain devices improve vision at low-light levels by gathering and enhancing available light. Using infrared illumination, night-vision optics are also capable of providing images where no ambient light is available. Such devices were developed some years ago and have wide application in various terrestrial military operations and commercial purposes (e.g., law enforcement, night surveillance, deer hunting). They are generally marketed as hand-held monoculars/scopes or goggles and sold for $200 - $2,000.

What has been tried: Some years ago, NMFS used night vision scopes and thermal imaging sensors to attempt to count migrating gray whales along the west coast of North America to "ground truth" daytime visual counts (Perryman et al. 1999). Exhalations (blows) of gray whales were detected as gray whales passed the California coast during their southbound migration in January 1994, 1995 and 1996. Results showed that over the entire migration period, pod sizes were larger and located farther offshore during the day while overall migration rate (number of whales passing per hour) was higher at night. To our knowledge little has been tried since those experiments to detect whales at sea using these technologies.

Night scope

PROS	CONS
+ relatively inexpensive means to detect whales at sea	- detection range is limited to well within line of sight
	- detection is limited to whales at the surface
	- a large ship moving > 15 knots needs ample distance to slow or maneuver

3.3.2 Image intensifying optics

Description: Certain devices, such as infrared, are used to detect differential thermal signatures, either from body temperature or from exhalations.

What has been tried: In 2001, NMFS provided a contract to researchers at the University of North Carolina, Wilmington (Pabst et al.) to study the feasibility of using an infrared video camera to detect right whales at sea. This "off the shelf" technology has primary application in detecting very fine-scale temperature differences in veterinary and animal health fields (e.g., inflamed tissue in domestic animals). The camera was adapted to assess whether it could detect differences in large whale exhalations or body temperature relative to ambient waters. In preliminary trials the camera was able to detect right whale thermal signatures at relatively close ranges (e.g., tens of meters.) More work is needed to explore the capabilities and limitations of this technology, but it may have limited utility in this context since relatively great distances are needed for ships to respond to a whale at the surface.

Advantages of this technique are that the devices are relatively inexpensive and readily obtained. One disadvantage of this technique is the need for trained personnel to interpret the visual output from a sensing device. That is, the device would likely relay an image to a computer screen (perhaps a ghostly image) that must be interpreted by someone familiar with what it means. Therefore, most ships, even if outfitted with such devices, would need to devote personnel to watching a screen for possible detections.

Image intensifying optics

PROS	CONS
+ relatively low cost	- not well studied
+ relatively easy to obtain	- low detection distance
	- high level of investment needed in trained personnel to interpret visual image in real-time

3.4 Pilot Boat Preceding Larger Vessels in High Danger Areas

Description: Large ships entering most harbors are accompanied by a pilot vessel. Pilot vessels assist ships in maneuvering in harbor channels and in docking or mooring large ships. It may be possible to equip pilot vessels with some type of whale detection technology (e.g., SONAR) that would then facilitate both vessels maneuvering around the location. Such an approach could be prohibitively costly, but it has the advantage of focusing "surveillance" to a relatively limited area, i.e., harbor entrances and approaches.

What has been tried: Very little has been studied in this regard, however, many vessels on regular, local transits (e.g., dredge vessels) often employ trained observers to scan for marine mammal and turtle species. Since no effective whale detection technology exists or is likely to exist in the near future, the observer option is limited by daylight and good visibility (as are aerial ship surveys).

Pilot Boat Preceding Larger Vessels in High Danger Areas

PROS	CONS
+ limited to relatively small geographic areas, e.g., harbor entrances and approaches	- because this approach would be limited in area, not all areas where right whales occur would be covered
+ does not require all ships entering right whale habitat to purchase, carry, and maintain high-tech devices	- hugely expensive; would require dedicated vessels and paid, trained observers
	- subject to any technological constraints of any of the active acoustic devices discussed previously

4. TECHNIQUES TO WARN WHALES

4.1. Alarms

4.1.1 Audible

Description: There are at least two principal applications of marine mammal warning devices. One is the use of Acoustic Deterrent Devices (ADD), or "pingers," which are attached to (primarily gillnet) fishing gear to limit marine mammal entanglement in the gear. Pingers used in the gillnet fishery emit a 10kHz sound at 132 dB re 1 FPascal@ 1 meter. A single "ping" is emitted every 4 seconds lasting 300 milliseconds. During the course of preliminary tests, a particularly well-designed study in 1994 showed a 92% reduction in bycatch of harbor porpoises in sink gillnets equipped with acoustic pinger. These results, however, have never been replicated and statistical models indicate that such studies are feasible only in areas of high levels of bycatch (Dawson et al., 1998).

Although concern remains over the effectiveness of pingers and their effects on marine mammals, their use became widespread in the late 1990's on both coasts of the United States. In the US Pacific, pinging devices have been used since late 1997 on fixed and drifting gillnet gear, and in the Gulf of Maine since 1999 (by late 1997, pingers had been used in 16 fisheries). The average annual harbor porpoise mortality decreased during this time. Between 1994 and 1998, harbor porpoise bycatch in the northeast gillnet fishery numbered 1,163 individuals; in 1999, this dropped to 270 individuals (Stock Assessment Report 2001). It is unclear, however, whether this reduction can be attributed to pingers or changes in management practices that occurred during these years.

The mechanism by which pingers reduce entanglement is not understood. Presumably, the pingers "warn" the animals that the net is present and that it should be avoided. However, for this to be a factor, the animal must not only detect the sound but recognize the net to which it is attached as a source of danger. There is no evidence that such recognition occurs. It is possible that the pingers merely increase the "alertness" of some animals to the presence of something unfamiliar in its environment. Little is known about the possible effects of habituation to the sound sources such that their effectiveness decreases with exposure. Pingers are not known to deter species other than odontocetes (i.e., toothed whales, including dolphins and porpoises).

A second application is the use of loud scaring devices used primarily to deter pinnipeds from aquaculture operations. Acoustic Harassment Devices (AHD) emit high intensity, mid-frequency, intermittent sound pulses that are designed to drive marine mammals away from a pen area or enclosure by frightening or even hurting the animal - a mechanism very different from merely alerting the animal. Source levels for AHD are usually greater than 190 dB. Such devices have had some success, but it is well-documented that seals and sea lions often habituate quickly to these sound sources or develop strategies to avoid them, simply lifting their heads out of the water, for example. The use of pingers and AHD were the topic of a workshop on the subject (Reeves et. al., 1996).

There are a number of problems with considering acoustic warning or alarm devices to scare or alert whales. First, they are predicated on that an animal would be "warned" or frightened away from an area that is of particular importance to the animal. There is no indication or evidence that whales would actually respond to such a sound signal. Behaviorally, this may require the animal to associate the sound signal with a source of danger, that is, it may require repeated exposures to the signal and some type of experience with a non-fatal or near-miss vessel collision. Second, such an approach has the potential to create stress in the animal if it is alarmed repeatedly or periodically. It may require the animal to abandon a desired feeding or mating area (usually animals are in a particular location because they need or want to be there, e.g., some vital function). Individual whales being repeatedly dislodged from a desired habitat may have significant adverse effects on the population. In addition, there is good evidence that whale response to sound is highly dependent on the behavior in which it is engaged. That is, whales engaged in vital behavior such as feeding or mating (or even migrating) are unlikely to respond to certain sounds. Finally, in an already noisy ocean that is rapidly getting noisier (with undetermined impacts to biological systems), this approach would add new sound sources.

A recent study to assess risk factors associated with ship strikes (Nowacek *et al.*, 2004) indicated that whales may actually respond to alarms meant to deter them with approach behavior rather than avoidance. Multi-sensor acoustic recording tags measured the responses of whales to passing ships to experimentally test the whales' responsiveness to controlled sound exposures. These exposures included recordings of ship noise, social sounds of their species, and signals designed to alert the whales. The whales showed little response to the sounds of passing vessels, reacted mildly to other whales' social sounds, and reacted strongly to the alert signal. Whales responded to the alert by swimming strongly to the surface, a response likely to increase rather than decrease the risk of collision. Such results indicate that introduced sound, such as might be associated with vessel alarm devices, may not be an appropriate tool to deter whales from ships' paths to reduce the threat of ship strikes.

There are other instances in which deterrents have been used. For example, firecrackers and "cherry bombs" are used to scare pinnipeds away from some fishing operations. Apparently, these have had some success in deterring marine mammals (e.g., sea lions can be scared away from sport fishing lines using cherry bombs). In other instances, various sound sources were used without success in deterring California sea lions from taking salmon in the Ballard Locks (Washington). Various kinds of clangers and bells were used in the mid-1980s to warn humpback whales from fishing weirs with equivocal results.

What has been tried: As noted above, certain types of alarm or harassment devices have been used with adequate success on some marine mammal species. There are also quite a number of examples in which noise is used to deter terrestrial animals, including "deer whistles" and various types of sounds to deter birds from airport runways and preferred roosting trees. With the exception of the Nowacek study described above, there have been no systematic studies of the response of effects of alarm devices on large whales. There is no information on whether habituation would occur.

Audible Alarms

PROS	CONS
+ relatively low-tech and inexpensive	- dislodging whales from preferred habitat
	- introducing more sound into an already noisy ocean, with possible harmful side-effects
	- possible habituation

4.1.2 Visual

Techniques have been proposed to visually deter marine mammals from fishing nets to reduce the occurrence of entanglement. One such method proposed in the cetacean research community consists of using light deterrents on fishing nets. As proposed, lines would be illuminated in a wavelength visible to marine mammal species to illicit an avoidance reaction and steer animals away from fishing gear. At present, this technique has not been tested and it is unclear whether illumination would in fact deter marine mammals. It is also unclear whether marine mammals would habituate over time to lighted lines, rendering such an approach less effective or ineffective.

4.1.2.1 Lights on ships

There have been no studies of lights being used to warn marine mammal species away from ship traffic. One obvious limitation is that generally light does not travel great distances underwater due to defraction and absorption. Tens of meters might be the greatest distance that could be expected in the best of conditions.

Visual Alarms

PROS	CONS
+ relatively inexpensive	- not well studied
	- effectiveness limited by distance that light can travel underwater
	- unclear whether light would result in avoidance behavior by whales
	- habituation

5. TECHNIQUES TO FIND WHALES TO WARN MARINERS

5.1 Remote Sensing

5.1.1 Aerial or ship based surveys

5.1.1.1 Visual techniques

Description: In this, the most traditional of marine mammal survey techniques, a team or teams visually locate animals at the surface using either the naked eye or various forms of binoculars. Relatively extensive surveys are flown off the U.S. east coast to assess right whale distribution, collect photo-identification data, and to provide sighting information to mariners. Surveys can be opportunistic (e.g., surveying areas of known concentrations) or systematic (e.g., flying predefined transect lines by line or strip transect protocols). For right whales, a typical aerial survey is conducted at a flying altitude of 300 m with an aircraft velocity of .027 knots/sec (50 m/sec), giving an instantaneous field of view of 150 m and covering 27 km^2/hr (Abileah 2001). Survey conditions vary and the capacity to detect right whales at the surface is closely linked to conditions – whales become more difficult to detect as sea state increases. Survey duration is dependent upon optimal weather conditions, sun illumination, and sea state.

What has been tried: Vessel and aircraft surveys have been conducted in the NE since the late 1960s. Surveys are now conducted to locate and identify right whales along much of the east coast of the U.S. and Canada. Systematic aerial surveys are flown over waters off the southeast U.S. coast during December through March, and over northeast U.S. waters during January through July. Canadian researchers also survey during late summer and early fall in the Bay of Fundy and Scotian Shelf areas. Recently, fall aerial surveys conducted by NMFS have also been initiated in New England waters. These surveys are usually flown with a twin-engine, high wing aircraft with 3+ observers on board. Flights are flown at ca. 400 m and 100 kts from shore out to 200 nm offshore. Surveys are up to 6 hrs in length. A systematic aerial survey gap remains in the mid-Atlantic

Vessel based surveys are conducted in waters off New England January through April (Cape Cod Bay and its environs), in the Mid-Atlantic during March, on the Georges Bank in May, and in the Gulf of Maine, Bay of Fundy and the Scotian Shelf during July-September. Surveys usually use medium to large research vessels with multiple observer teams (e.g., 2 teams of 3) with surveys conducted continuously during day light hours. Information from the surveys on right whale sighting locations is transmitted usually within several hours to mariners via Broadcast Notice to Mariners, NAVTEX, fax, the Mandatory Ship Reporting systems, and other means.

Aerial or ship based surveys

PROS	CONS
+ visual surveys are simple to conduct	- moderately expensive and labor intensive (particularly for vessel based surveys)
+ well tested and understood techniques	- dangerous

+ can provide photographs for identification of individual right whales	-only useful in day light hours, when weather conditions are excellent
+ can provide a variety of supporting data on environmental conditions, vessel locations, gear concentrations, etc.	- only observe whales along track line (a few miles on either side)
+ vessel surveys provide platforms for a variety of other right whale research (e.g., biopsy darting, satellite tagging, prey studies)	- animals below the water are not observed
+ aerial surveys can cover large areas in a single survey	
+ can provide immediate warnings to mariners near observed right whales	
Source of information on entangled and dead animals	

5.1.1.2 Light detection and ranging systems

Description: LIDAR (Light Detecting And Ranging) operates from aircraft or satellite by producing short pulses of laser light which can pass through the water surface and reflect off objects in the water (e.g., whales, fish, particles). The returning reflected pulse is measured by a receiver and the target is distinguished by the strength of the pulse returned. The depth of the target is determined by the elapsed time between pulse emission and return.

What has been tried: The use of LIDAR technology in fisheries is still in its infancy, although fish schools have been detected using LIDAR equipment (Lo et al 1999). Existing technology has not yet been adapted for fishery (or marine mammal) survey needs, but the potential exists for airborne LIDAR surveys to detect marine life. Currently, a system is being developed jointly by two of NOAA's laboratories (Environmental Technical Laboratory, Boulder, CO and Southwest Fisheries Science Center, La Jolla, CA) to evaluate prototype instruments and model survey performance. No work has been done with right whales, but NOAA staff indicate that gray whales have been located with the technology.

LIDAR

PROS	CONS
+ can detect animals underwater	- dependent on visual-based surveys (e.g., weather condition and sea state)
	- difficult to identify target without visual confirmation
	- moderately expensive
	- few aircraft with these capabilities

5.1.2 Satellite imagery

5.1.2.1 Visual (including UV and IR wave lengths)

Description: The use of satellite-based imaging devices represents a potential technique to locate whales. This technology is limited, however, by the need for animals to be at the surface for detection. Also, there are questions of resolution, i.e., while fine-scale resolution is possible, it is often broad, oceanic swaths that are the area of interest coupled with the difficulty of meeting the simultaneous need to detect something on the order of meters in length. In addition to providing visual images of individual animals, satellites can observe concentrations of prey (e.g., krill and other zooplankton) allowing for the inference of whale location by the presence of their food source. The use of this technology potentially could be combined with modeling of ocean temperatures, migratory pathways and historical sighting records to indicate where whales are likely to occur.

What has been tried: Little seems to have been done with large whales. Exploratory analyses with pinnipeds (i.e., seals and sea lions) suggest aggregations can be located, but problems may remain with regard to having sufficient resolution to locate or count individuals. To date, there has been no practical application for finding any marine mammal at sea, though satellite imagery has the potential for locating potential whale habitat. Research funded by NMFS for University of Massachusetts to assess the utility of Sea Surface Temperature (from satellite imagery) as a proxy for right whale habitat has not found the relationship to be particularly strong.

Recently, commercial high-resolution satellites have improved to the point where individual marine mammals can be detected, opening up the possibility for their use in monitoring marine mammal abundance and distribution. Cost is reportedly comparable with that of aerial surveys. Although resolution is far from competitive with human vision from low-altitude aircraft, new satellite imagery has resolutions of 1 m and 4 m. In contrast, the previous best available technology provided imagery insufficient for the detection of marine mammals at resolutions from 10 m - 30 m. In addition to the limitations presented by resolution, the “noise” of sea surface conditions presents a formidable obstacle to clarity in imagery. Also, as noted above, the question of resolution is a thorny one, given resolution can be fine-scale but large swaths for searching may be a more desirable scale. Satellite imagery has been traditionally designed for terrestrial applications to cover radiance from landforms. In general, radiance from the ocean and marine subjects is far less than those from land features and thus presents difficulties for satellite use in the marine environment with current technology (Abileah 2001).

Visual satellite imagery

PROS	CONS
+ provides data for predictive modeling	- potentially costly
+ covers wide areas	- need trained professionals for interpretation of data
+ relatively inexpensive if “piggy-backed” with other data acquisition	- resolution may be insufficient to reliably identify whales, let alone identify whales to

missions	species
	- requires good sea conditions with limited cloud cover
	- there is always the possibility of "piggy-backing" whale data collection onto other satellite platform tasks, but there may be logistical and queuing complexities, along with funding constraints to accomplish this

5.1.2.2 Synthetic aperture radar

Description: Synthetic aperture radar (SAR) is a remote sensing technology that uses propagation of long-range radar signals to provide high-resolution images of the earth's surface (Read 1998). The technology has traditionally been used to map terrestrial ecosystems, primarily assessing vegetation cover, land use practices and forestry. SAR also has a variety of marine applications. The imagery provides a two-dimensional spatial view of ocean surface and has been widely used in oil spill detection, ice cover analyses, studies of sea floor topography and wave circulation patterns. SAR application for sea ice and climate studies is well-documented in the literature; currently it is also used for marine navigation in arctic regions. SAR is capable of high spatial resolution and can operate independently of weather or light conditions.

The use of SAR has expanded continuously since the development of SEASAT in 1978 (Espedal et al. 2000). At present, three spaceborne SAR systems are operational with an additional system approved. Three further SAR systems have been proposed. In addition to the United States, SAR systems have also been deployed by Russia, Canada, Japan and the European Space Agency (ESA).

What has been tried: Current SAR satellite technology detects large spatial targets and thus does not lend itself readily to the detection of whales. Field experiments in 1996 and 1997 used SAR successfully to detect large ships with an average length of 120 m (Vachon et al. 2000). Most smaller ships were not detected, nor would much smaller objects such as whales. Applications may become relevant in the future, however, as this technology is refined.

SAR can also be used from aircraft to detect oceanographic features. In a limited marine mammal application in 1989, wakes of migrating gray whales were detected by the U.S. Navy's P-3 XLC SAR. The wakes generated by the migrating whales' fluke thrusts were detected under calm sea conditions, similar to detection of the wakes of commercial ship traffic (Radford et al. 1994). Although limited to use in optimal weather conditions, this indirect application to locate whales may prove useful in the future.

SAR

PROS	CONS
+ covers wide areas	- unproven for marine mammal application
+ equipment already in place on satellites	- cost unknown; may be expensive for widespread use
+ relatively inexpensive if "piggy-	- resolution may be insufficient to reliably

backed" with other data acquisition missions	identify whales, let alone identify whales to species
	- only useful for whales at surface
	- likely requires good sea conditions

5.1.3 Passive acoustics

5.1.3.1. Buoy platforms (moored buoys, pop-up buoys, sonobuoys)

Description: Passive acoustics, or the use of underwater listening devices, involves determining whale locations by detecting and locating whale vocalizations. The obvious limitation, of course, is that whales must vocalize to be detected, and the rate at which they vocalize can be inconsistent. Nonetheless, passive acoustics have been used quite successfully to count bowhead whales off Alaska, and determine presence or absence of a variety of cetacean species while at sea using towed hydrophone arrays. Passive acoustics used to detect right whales have certain challenges, related primarily to right whale distribution. Right whales are primarily a coastal species, occurring mostly on the continental shelf. Physical features there are not conducive to effective sound transmission. Deep water sounds enter the "SOFAR" channel and can be propagated great distances, but the physical features that lead to formation of the SOFAR channel do not exist in shallow water. In addition, much sound energy is dissipated in shallow water by refraction off the sea surface and sea floor. Detection distances for sounds on the continental shelf are limited to probably under 20 kilometers in most cases. Therefore, North Atlantic right whale habitat is generally not conducive to sound propagation. Nonetheless, it may be worth further exploring this technology, perhaps in conjunction with visual surveys, as a means to detect whales and warn mariners of their locations.

What has been tried: From December 1996–February 1997, the US Navy deployed a hydrophone array in a right whale calving/nursery area in waters off Jacksonville, Florida to investigate whether right whale presence could be determined. The Chief of Naval Operations sponsored the Northern Right Whale Monitoring Project to evaluate existing technologies to locate right whales and thus preclude injury or mortality to the animals. Few right whales were heard, and more whales were seen in the area than heard. Additionally, northern right whales were found to vocalize primarily at night in this region. These results demonstrated that acoustic systems indeed can detect right whale vocalizations in shallow water but would not provide significant advantage to the U.S. Navy efforts to avoid collisions with right whales in critical habitat shallow waters (ONR 1997).

In contrast, researchers as Cornell University, in conjunction with biologists at the North Slope Borough, have been very successful at acoustically counting bowhead whales that swim by an ice camp off the north slope of Alaska, in the Beaufort Sea. The counting method revolutionized the prior visual counts by pointing out that many more whales were heard than seen. Those acoustic censuses, however, are done from a stationary, ice-based camp as the animals migrate within several kilometers of the camp.

DIFAR (Direction Finding Acoustic Receiver) buoys, developed for the military and used by the U.S. Navy for several decades, also have recently been applied to marine mammal studies. A single system of buoy, receiver and software can be generally purchased for under $5,000, while an individual buoy costs about $700. DIFAR technology has been demonstrated on blue, fin and humpback whales and has successfully been used by researchers to determine North Pacific right whale locations (Gillespie and Leaper 2001). Whales were detected at ranges up to 30 km and the range to each right whale call was estimated with an accuracy of approximately 1 km. Whether this method of range detection could be applied in Cape Cod Bay or the Great South Channel (i.e., North Atlantic right whale habitat) remains unknown (Gillespie and Leaper 2001).

Subsequently, Cornell University working with support from the International Fund for Animal Welfare, the Center for Coastal Studies, the Gulf of Maine Ocean Observing System (GoMOOS), NMFS, and National Ocean Service (NOS) have deployed acoustic listening buoys in the NE along the Great South Channel (2000), Cape Cod Bay (2001-2002), and along the coast of Maine (2001-2002). One set of instruments is presently suspended from a GoMOOS buoy off the coast of Maine. Another eight pop-up buoys were deployed in winter 2001 in areas off Cape Cod and within Cape Cod Bay. Initial results suggest that right whales can indeed be located with passive acoustic listening devices. Using this system, the maximum range at which a right whale was detected was 10 nm. Data indicated, however, that 5 nm was a more realistic range of detection (Gillespie and Leaper 2001). Thus, with limited range, many hydrophones would be needed to sufficiently cover the area potentially occupied by right whales. An important technical development included in the GoMOOS deployment is processing on board the buoy to summarize the data, which is then uplinked by satellite or cell phone back to land for a quick response.

One potential problem with this technology is that of providing the whale sighting locations to mariners in "real-time." At the time of this writing, it is not possible to do so, but researchers at Cornell University are attempting to address this problem and may have a solution in the relatively near future (months/years).

Temporal scale must be addressed when considering the use of passive acoustics for ship strike mitigation. Passive acoustic monitoring systems can be either long-term, autonomous systems which need to be retrieved to access information collected over weeks or years, or short-term, real-time systems providing a consistent stream of data. Surveillance data must remain valid over the time required to receive vocalizations from whales, process the information, make management decisions and relay those determinations to industry. At present, analysis of acoustic data can be costly and time-consuming, requiring trained personnel listened to headphones and scanning spectrograms by eye; but this may be changing as software analysis systems are improving. Thus, considerable advances in technology may be required to make acoustic data viable in real-time (Gillespie and Leaper 2001).

Further research is necessary for passive acoustic systems to accurately determine right whale vocal behavior and location and thus inform management decisions. Advances need to be made to better assess the relationship between right whale acoustic signals detected and actual number of whales present, i.e., ground-truthing vocalization rates. Investigations should proceed to validate acoustic data (i.e., detection rates) with aerial surveys or some other means of verification. Further examination of transmission loss, source levels and detection of false positives are needed to increase accuracy (Gillespie and Leaper 2001).

Passive Acoustics -- Buoy platforms

PROS	CONS
+ capable of detecting and locating vocalizing whales at close ranges	- detects only vocalizing whales
+ works at night and in all weather conditions	- limited detection distance (e.g., 5-10 kilometers), so a vast array would be needed to cover even a portion of right whale habitat.
	- could be very expensive for broad scale application
	- only successful in oceanographic conditions conducive to sound propagation
	- vulnerable to damage by shipping/fishing activities
	- need trained personnel to analyze acoustic data (but this may be changing)

5.1.3.2 Towed passive arrays

Description: This is an extension of technologies developed by the US Navy for submarine detection (e.g., Surveillance Towed Array Sensor System or SURTASS). The technology is conceptually the same as with buoy based devices, except that the listening devices are towed behind a quiet ship.

What has been tried: Presently, four of the NMFS Science Centers are experimenting with the use of towed arrays for cetacean assessments. The arrays have a variety of configurations, but typically consist of multiple hydrophones strung out on a cable towed behind the ship. These are linked to computers and recording devices on board the ship for processing of the signals. Although towed arrays are becoming less expensive and the computer technology necessary for data processing is now widely available, significant time is required to train personnel to use the array and implement the software (Gisiner 1998).

Passive acoustic monitoring may be most effective when used in combination with other techniques. Acoustic methods used in complement with non-acoustic methods (i.e., aerial surveys, tagging, photo-identification) can serve to enhance the effectiveness of either technology used alone.

Towed passive arrays

PROS	CONS
+ mobile system	- requires quiet ship
+ relatively inexpensive supplement to vessel based visual survey	- detects only vocalizing whales
+ allows surveying to continue at night or	- useful only in relatively small areas

in poor visibility conditions precise, at least for those species readily detected	
	- surface noise (sea state) may be a concern

5.1.3.3 US Navy Sound Surveillance System

Description: Beginning in the early 1950s, the US Navy established an elaborate system of multiple hydrophone arrays to detect surface and sub-surface ships, called the Sound Surveillance System (SOSUSS). (The next generation, now currently used, is called the Integrated Undersea Surveillance System (IUSS)). The arrays were installed in key locations on the sea floor in both the North Pacific and the North Atlantic oceans. They have remarkable capabilities to detect, localize, and track ships at great distances. At present the systems are on standby status. But in the mid-1990s, the systems were opened, on a limited basis, to other users, and the whale community was invited to participate in demonstration projects.

What has been tried: SOSUSS is effective for acoustical monitoring of species whose calls contain significant energy at low frequencies in deep water (Gisiner 1998). The arrays are efficient at detecting and even tracking individual blue, fin, humpback and minke whales. These species generally, at least in the cases of blue and fin whales, are "blue water" species with ocean-wide distributions. Blue and fin whales produce low frequency calls highly adapted to long-distance communication. Also, because the systems involve multiple arrays, it is possible to determine the location (perhaps within a several square mile polygon) of the caller. Blue whales have been located routinely at distances of more than 1,500 km. using this system (Clark 1995). Seasonal distribution patterns and vocal activity have been documented in various deep-water regions using SOSUSS arrays over an extended period (Moore et al., 1998). However, to our knowledge right whale calls have not been detected by the arrays in either ocean basin, due primarily to the fact that the arrays are placed in deep, offshore waters, away from main right whale distribution. Nonetheless, it may be worth considering further analysis to determine if the SOSUSS arrays are capable of detecting right whales, although the chances are very slim that anything useful would come of this exercise.

At present, it is not possible to conduct whale tracking on a systematic basis because research is dependent on Navy personnel to conduct the analysis. If an individual, however, were available full-time for this task, the possibility exists to track individual vocalizing whales throughout an entire ocean basin (Read 1998).

U.S. Navy Sound Surveillance System

PROS	CONS
+ SOSUSS is a system already in place, though inactive	- system is located in waters (deep, off the shelf oceanic waters) which are not major right whale habitat, so likelihood of a right whale being located is very low
+ analysis (but not maintenance) is relatively inexpensive	- North Atlantic system may be deactivated

+ precision of localization is relatively precise, at least for those species readily detected	- security requirements may limit quick availability of the data
+ can process large areas	- costly to operate and maintain

5.2 Telemetry

5.2.1 General comments

Description: Telemetry devices involve attaching a transmitting device to an animal and tracking its movement either remotely using satellite uplinks (e.g., Service-Argos) or directly by following/relocating using a vessel or aircraft with receiving equipment on board. Satellite tags provide information on ocean basin scales; locations from VHF radio or acoustic transmitters are limited to the range of the signal, roughly equivalent to line of sight, generally tens of kilometers or less. Satellite fixes are obtained intermittently when a satellite pass occurs, and fixes are obtained on the order of perhaps one per day. VHF/acoustic telemetry is useful in studies of local movements and behavior and tracking locations are obtained by obtaining fixes from an aircraft or nearby vessel.

All three approaches are widely used with terrestrial, avian, and marine wildlife. The perennial challenge facing whale tracking has been tag attachment. For two decades or more, researchers have attempted to perfect attachment delivery systems. Challenges regarding the packages themselves and the telemetry have been fairly well worked out. Quite a number of methods have been used including suction cups and various tags implanted in the blubber. (For seal and sea lions this has been less of an issue as tag packages are simply glued to the fur or pelage.) In general, most whale tagging has met limited success due to attachment problems, and attachments have not lasted for long periods. In recent years, this technology has improved and, in some cases, implantable tags have remained attached and operating for as long as months.

5.2.2. Satellite based telemetry

What has been tried: Researchers have attempted since the late 1980's to develop a satellite tag which will remain attached to and operate on right whales (Mate et al. 1997, Slay and Kraus 1998). Between 1997 and 1998, 41 satellite tags were attached to right whales. All tags were implantable. A reliable tag did not result, as most instruments failed within a few weeks of the initial deployment. In 2000, NMFS provided funds for Oregon State University researcher Dr. Bruce Mate and colleagues to conduct satellite tagging studies of right whales in the Bay of Fundy. In summer 2000, Dr. Mate successfully tagged 16 whales. Transmitters sent signals for up to 130 days with this transmitter broadcasting during a migration from the Bay of Fundy to the coast of South Carolina. It was believed that the antennae on the other tags were rubbed off during whale-to-whale contact. As a result of the partial success here, Dr. Mate was funded in 2001 to continue his studies using southern right whales off of South Africa. Deployments there appeared to be more successful, and NMFS expects to further fund Dr. Mate's work in the future. As a cautionary note, there has been much concern expressed over the physiological and medical impacts of implantable tags; swellings have been noted at the site of tag implantation. Whales tagged by Dr. Mate in 2000 were observed during 2001 with photostudies to track the progress of the wounds. Swellings were noted, but there was no evidence of long-term effects.

We have heard the suggestion that all or nearly all right whales in the North Atlantic population should be tagged so their locations could be relayed to mariners. However, due to (a) logistical complexities (e.g., ship time and expense to locate and tag whales), (b) possible health issues, and (c) existing technology constraints (e.g., given existing tag duration of days to tens of days), it is highly impractical, perhaps impossible, to reliably tag and repeatedly tag a significant portion of the population.

Satellite based telemetry

PROS	CONS
+ operates at basin scales	- expensive (several thousand dollars per tag, plus ship time to deploy)
+ independent of weather	- attachment and longevity may still be a problem
+ can obtain other information (e.g., dive duration) with same package	- most invasive technique (likely only one attachment per animal)
+ do not need an observation platform	- only animals that can be accessed can be instrumented
+ life of the telemetry device could be up to a year	- individual animal focused
	- possible health issues resulting from implantation of foreign object in tissue

5.2.3. VHF telemetry

What has been tried: VHF tags have been successfully attached to right whale on several occasions either as implantable tags (14 animals; Goodyear 1993) or as suction cup tags (sometimes associated with other instruments). The most recent application of an implantable tag was with right whale cow on January 20, 1999, approximately 30 nm east of Fernandina Beach, Florida. The whale and her calf were tracked continuously for 44 hours, when tracking was abandoned due to bad weather. The pair was relocated on January 25, 1999 and tracked continuously for an additional 96 hours.

Joint studies conducted between NMFS, Oregon State University (OSU), and the Woods Hole Oceanographic Institute (WHOI) involving time-depth recorders now regularly incorporate VHF tags both for tracking the animals and for relocating the instrument packages (which are attached by suction cups). These deployments typically last a few days (as would be expected from this attachment).

VHF telemetry

PROS	CONS
+ Low cost	- short term attachment, unless implanted
+ small and relatively noninvasive in a single attachment	- have to have platform nearby to track

+ good as part of larger package for relocating whales or instruments	- only animals that can be accessed can be instrumented
+ moderate range and battery life	- limited detection range (usually roughly line of sight)
+ can be tracked from a variety of platforms with the proper antenna and receivers	
+ not weather dependent (unless tracking platform is effected)	- possible health issues resulting from implantation of foreign object in tissue

5.2.4 Acoustic telemetry

What has been tried: Acoustic tags operate by providing a low frequency (but audible) signal, which is then received with a hydrophone suspended from the tracking platform (e.g. a ship). This has been one of the least used telemetry techniques for whales, but is widely used for fish. Goodyear (1993) was likely the first to use the method for right whales. More recently, researchers from OSU and NMFS have incorporated sonic tags with instrument packages on right whale in the Bay of Fundy (n =25 in 2001), and have found these to be more reliable for short term, close tracking than VHF tags. The underwater detection range (i.e., tracking distance) is on the order of hundreds of meters.

One suggested approach which has not been tried is to implant sonic tags, and then listen for them with a passive hydrophone array.

Acoustic telemetry

PROS	CONS
+ low cost	- short range
+ small and relatively noninvasive in a single attachment	- short term attachment, unless implanted
+ good as part of larger package for relocating whales or instruments	- have to have boat nearby (i.e., within 100s of meters) or a listening array to track
+ not weather dependent (unless tracking vessel is affected)	- generally short battery life
	- only animals that can be accessed can be instrumented (i.e., need to locate and tag whales which is not always easy)

5.3 Predictive Modeling

Description: If one knew the oceanic features of its habitat that were linked to right whale occurrence (e.g., sea surface temperature or plankton distribution), then it would be possible to predict right whale locations using satellite imagery. Such a capability could be developed by comparing historical sighting locations with oceanographic features that correlate with right whale distribution. As a result, this tool may make it possible for ships to avoid, or increase their alertness, in areas where whales are likely or predictably to occur.

What has been tried: NMFS and others have supported research over the past decade comparing the distributions of right whale and oceanic conditions. Some of this work has suggested that there is a clear relationship, particularly with prey abundance (Finzi et al. 1999). Other work comparing right whale sighting locations with sea surface temperature has been less successful. Oceanographers funded through NMFS and the NE Consortium (Pershing and Greene 2001) continue to explore the relationships between right whale locations and oceanographic features. Researchers at the New England Aquarium have similar modeling work underway.

Almost certainly, there are oceanic features which correlate with right whale distribution, however, the key research problem is to identify relationships which can <u>reliably</u> predict right whale presence. Once models are developed, the overall goal will be to provide the shipping industry with locations were whales are likely to occur.

Predictive Modeling

PROS	CONS
+ low cost once research is complete	- relationships still not well understood
+ results can be provided in close to real time	- predictive power may be low and imprecise
+ basin scale	- data collection is dependent on availability of satellite imagery (e.g., may not be available on cloudy days or at night)

6. CONCLUSION

Many technologies considered in this document are not applicable for ship strike mitigation at this time based on expense, lack of demonstrated success, and concerns associated with their use. Methods that warn whales away from ships, such as alarm devices, have only been somewhat effective, and the possibility of adverse effects on the population from introduced noise is significant. Other techniques such as the use of pilot “surveillance” vessels, night vision optics, and thermal imaging may be impractical and appear to have limited detection distance. Satellite, laser, and remote sensing technology (i.e., LIDAR and SAR) are still being developed to be applicable to marine mammal management; further advances in resolution may mean that whales can be accurately detected in the future.

Of the methods reviewed here to warn mariners with whale-finding technology, it appears that continued visual surveys (mostly aerial) will be the key tool for the near term. However, passive acoustic techniques (notably moored buoys with satellite or cell phone links) likely provides the most promising new technique for locating animals. Predictive modeling may also provide a tool for providing the general locations of animals, if strong predictive relationships can be found. Telemetry will continue to be a useful tool for monitoring the movements of individual animals, but will not be adequate for real time management of whale-vessel interactions.

At present, there is no single technology that represents a “solution” to mitigate vessel collisions with right whales. Although numerous research efforts are underway to determine the feasibility of using various technological methods to reduce ship strikes of right whales, the issue of vessel collisions remains a complex one that requires other management measures. Used in tandem with other forms of management, technology may play an increasing role in resolving the conflict between right whales and the shipping industry in the future.

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