Report of a Workshop to Identify and Assess Technologies to Reduce Ship Strikes of Large Whales

Providence, Rhode Island
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Executive Summary

Vessel collisions (or "ship strikes") are a threat to a number of marine vertebrate species world wide, particularly endangered large whale species. Various modifications to vessel and water craft operations have been used in an attempt to reduce the threat of ship strikes. Seeking ways to reduce the magnitude of the threat through technological solutions has been proposed by maritime industries, resource managers, and government agencies alike. Use of remote sensing technologies may provide means to reduce ship strikes while simultaneously allowing certain maritime commerce and other activities to proceed with limited biological and economic impact. However, low whale detection rates and constraints on the effective range of some devices to provide ample warning and response times for mariners may limit their utility in this context. In addition, development, installation, maintenance, and/or operation may be cost prohibitive in some cases.

This workshop was convened to (a) identify existing or emerging technologies that might be useful in reducing ship strikes, (b) assess the feasibility of each in reducing ship strikes, and (c) identify research and development timelines needed to make a given technology useful in reducing the threat. We discussed and, in directed small groups, assessed a number of remote sensing technologies, including visual surveys; tagging and telemetry; passive acoustics; active acoustics; thermal imaging (*e.g.*, infrared); radar; and predictive modeling.

The workshop concluded that the problem of ship strikes is a complex one; there are no easy technological "fixes"; that no technology exists, or is expected to be developed in the foreseeable future that will completely ameliorate, or reduce to zero the chances of, ship strikes of large whales; and no single technology will fit all situations. Reducing the co-occurrence of whales and vessels is likely the only sure means of reducing ship strikes, but it is not possible in many locations. A variation, advanced voyage planning to avoid certain areas, is relatively more feasible. Technologies applicable to reducing ship strikes are limited almost entirely to those that enhance whale detection. Several technologies used in concert would increase the chances of detection both at a distance from, and in close proximity to, a vessel; and improve the likelihood of providing warnings to mariners. However, detection and relaying information about a whale's location represents only part of the equation: the mariner must possess capabilities (*e.g.*, adequate communication systems, adequate response time) to take evasive action to a detected whale. Responses to such information may vary among individual mariners and vessels, and substantial distances can be required for vessels underway to avoid, alter course, or even react to an object directly in their path particularly as higher speeds are considered.

All technologies assessed had certain advantages and disadvantages when considered relative to this problem. Visual surveys can be expensive, logistically complex, and are limited by low detection probabilities, poor weather, low-light conditions, and may be constrained to certain times of the year. Tagging devices are

useful for studies of whale natural history and movement; and developments in power supply capabilities and reducing data transmission costs are resulting in growth of this field. However, difficulties associated with tag attachment and attempts to attach devices to a sufficiently large portion of a population are proverbial challenges to this approach. Passive acoustic technologies are becoming a useful tool for studying whale occurrence and distribution, and the amount of data returned for cost investment makes this approach one of the most promising for detecting whale presence. However, this approach is constrained by only being able to detect whales that are vocalizing and determining specific location is not always possible. Some sonar devices appear effective in detecting whales within hundreds of meters of a vessel, although this range may be extended as technology improves. Depending on systems used, costs can be relatively high and false positives could be problematic. Radar devices can be used from ship or shore and have the advantage of operating in poor weather, but false positives are a potential problem. Thermal imaging (*e.g.*, infrared) devices have proved promising in detecting whale blows at significant ranges in experimental studies. Models using remotely-sensed oceanographic features provide means to predict where whales may occur over large areas. As models, they are prone to uncertainty (*i.e.*, predictive only), but some can be applied now. In all cases, studies are needed to confirm that any technology developed and used for this purpose are clearly capable of reducing strikes and to ensure that added environmental impacts are not introduced.

List of Definitions

Active acoustics: A means of measuring the range to an object and its size. It involves the production of a sound and analysis of the returning echo.

Infrared: Imaging that is essentially a "heat photograph". It is a diagnostic imaging procedure that is sometimes known as "thermography". The image is produced via an infrared scanner that photographs the heat being spontaneously emitted from the body's surface, giving rise to the alternative name "thermal imaging". The diagnostic analysis of the image is known as "thermography".

Passive acoustics: The action of listening for sounds. Passive acoustics methods do not produce sounds, but instead gather information about the environment by capturing sounds from it. Sensors (hydrophones) may be deployed from ships or affixed in the ocean for extended periods.

RADAR: An acronym for Radio Detection and Ranging. This is a system that uses electromagnetic waves in air to identify the range, direction, or speed of distant objects. A system consists of a transmitter that emits either microwaves or radio waves that are reflected by the target and detected by a receiver, typically in the same location as the transmitter.

SONAR: Originally an acronym for Sound Navigation and Ranging, sonar is an acoustic location technique that uses sound movement (usually underwater) to navigate, communicate, or to detect other vessels or objects in the water. Marine mammals use sonar to navigate, communicate, and locate food.

List of Acronyms

AIS	Automatic Identification System
ARU	Acoustic Recording Units
ATBA	Area To Be Avoided
CRH	Calibrated Reference Hydrophone
CTD	Conductivity (salinity), Temperature and Pressure
IMO	International Maritime Organization
GPS	Global Positioning System
LNG	Liquefied Natural Gas
NAVTEX	Navigational Telex
Nm	Nautical mile
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PTT	Pressure-Time-Temperature (tags)
R&D	Research and Development
RACON	Radar Beacon
RTB	Real Time passive acoustic Buoys
TSS	Traffic Separation Scheme
VLCC	Very Large Crude Carrier

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Introduction

The Threat of Ship Strikes

Vessel collisions are a threat to a number of marine species worldwide. Vessel collisions ("ship strikes") occur with large whale species (Best *et al*., 2001; Knowlton and Kraus, 2001; Laist *et al*., 2001; Jensen and Silber, 2003; Vanderlaan and Taggart, 2007), small cetaceans (Van Waerebeek *et al.*, 2006), marine turtles (Hazel *et al*., 2007), and sirenians (*i.e*., manatees and dugongs) (Greenland and Limpus, 2006; Calleson and Frolich, 2007). Records indicate that nearly all large whale species are vulnerable to ship strikes (Laist *et al*., 2001; Jensen and Silber, 2003; Van Waerebeek and Leaper, 2008) including, but not limited to, blue (*Balaenoptera musculus*), fin (*Balaenoptera physalus)*, humpback (*Megaptera novaeangliae*), right (*Eubalaena spp.*), sei (*Balaenoptera borealis)*, and sperm (*Physeter catodon*) whales. Van Waerebeek and Leaper (2008) reported that a number of small and mid-sized cetaceans occurring in the Southern Hemisphere are involved in vessel collisions. Strikes involving sirenians and small water craft are an ongoing problem in locations where these species occur (U.S. Fish and Wildlife Service, 2001; Greenland and Limpus, 2006).

Ship strikes of large whales are a growing problem internationally (Van Waerebeek and Leaper, 2008), particularly where endangered or depleted species are involved. A contributing factor is the increase in maritime commerce, which is expected to nearly double over the next 15 years in U.S. ports (U.S. Department of Transportation, 2008).

Laist *et al*. (2001) provided the first attempt to summarize a large collection of whale/ship strike records. Building on that collection, Jensen and Silber (2003) described nearly 300 observations of large whale ship strikes, and Van Waerebeek and Leaper (2008) compiled over 750 cetacean vessel strike records worldwide. Virtually all motorized vessel types, sizes, and classes are represented in these data bases (Laist *et al*., 2001; Jensen and Silber, 2003). Because a number, likely a substantial number, of deaths go undetected or unreported, the records provided in this literature are a minimum. In some cases, carcasses are found but because injuries are internal (*e.g*., hemorrhaging), or due to advanced decomposition, it is not always possible to determine if a ship strike was the cause of death. Additionally, when large vessels are involved, the mariner may not be aware a strike has occurred.

Vessel collisions with marine mammals can result in death by massive trauma, hemorrhaging, broken bones and propeller wounds (Knowlton and Kraus, 2001; Campbell-Malone, 2007). When large whale species and large vessels are involved, the

stricken whales can occasionally be found draped across the ship's bulbous bow when it arrives in port. Massive propeller wounds can be immediately fatal. However, if relatively superficial, some individuals can recover from seemingly serious collisions, as evidenced by photographic time series of deep lacerations healing on individual animals. In one well-documented incident, one entire fluke of a right whale was removed by the propeller of a fast-moving, 42-foot pleasure craft off Florida; the fate of this animal is not known (Marine Mammal Commission, 2006).

Numerous reports have proposed modifications to vessel and watercraft operations to avoid ship strikes (US Coast Guard, 2006; Kite-Powell, *et al.*, 2007; Elvin and Taggart, 2008; Fonnesbeck *et al.*, in prep). Steps have been taken by some countries, primarily government agencies, to reduce ship strike potential to endangered whale species through modifications to vessel operations. Those include changing shipping routes. In Canadian waters, shipping lanes have been shifted in the Bay of Fundy to reduce the proximity of ships to predictable aggregations of North Atlantic right whales. Canada also submitted a proposal to the International Maritime Organization (IMO) to establish a vessel "Area to be Avoided" (ATBA) in Roseway Basin for the same purpose. The IMO approved a U.S. proposal to establish an ATBA in waters off New England for right whales, becoming effective 1 June, 2009. In 2006 the U.S. established recommended shipping routes outside key U.S. ports and in Cape Cod Bay (www.nmfs.noaa.gov/pr/shipstrike/routes.htm) around North Atlantic right whale aggregation areas. In addition, the U.S. modified a Traffic Separation Scheme (TSS) that services Boston to reduce the co-occurrence of vessel traffic and large whales. Reducing this co-occurrence, if possible, is almost certainly the most effective means to reduce the likelihood of ship strikes. However, this is not feasible in many locations due to navigational or human safety concerns, restrictions to commerce, or other reasons.

Vessel speed has been implicated as a key factor in the frequency and severity of vessel strikes to large whales (Laist *et al.*, 2001; Pace and Silber, 2007; Vanderlaan and Taggart, 2007; Van Waerebeek and Leaper, 2008). Therefore, vessel speed restrictions or advisories are widely employed in U.S. waters to reduce the likelihood and severity of large whale ship strikes. For example, the U.S. National Park Service limits the number of cruise ships entering Glacier Bay National Park and requires that ships travel at 13 knots or less in areas and times when humpback whales are present (National Park Service, 2003). In response to blue whale ship strikes off of Southern California, the Channel Islands National Marine Sanctuary, the U.S. National Marine Fisheries Service (NMFS), and the U.S. Coast Guard advised ships to travel at 10 knots or less in shipping lanes to the ports of Los Angeles and Long Beach when blue whales are present (Bettridge and Silber, 2008). The NMFS has issued a vessel speed regulation in key port entrances and North Atlantic right whale aggregation locations along the U.S. east coast (National Marine Fisheries Service (NMFS), 2008). Furthermore, Stellwagen Bank National Marine Sanctuary and NMFS require vessels carrying Liquefied Natural Gas (LNG) to travel at 10 knots or less when right whales are detected in or near passages to offshore LNG terminals (Bettridge and Silber, 2008). Vessel speed restrictions have been suggested to reduce the likelihood of collisions with fin whales in the Mediterranean Sea (Panigada, *et al.*, 2006) and manatees in Florida (Laist and Shaw, 2006).

Use of Technological Advances to Reduce the Threat

Seeking a technological solution to ship strikes (*e.g*., sonar, radar, enhanced remote visual detection), in addition to or *in lieu* of changes to vessel operations, has been proposed by maritime industries, resource managers, and government agencies alike. Some authors, corporations, or inventors indicate a particular technology has direct application to addressing the problem, but not all claims are supported by significant or empirical test results. Further, relatively few studies have attempted to compile information on applicable technologies or assess the effectiveness of their use (Anonymous, 1999; NMFS, 2002).

One attempt to assess ship strike reduction technologies, particularly sonar devices, was an interagency workshop convened in 1999 by the U.S. Navy, Marine Mammal Commission, and NMFS (Anonymous, 1999). Among the conclusions, workshop participants found (a) there was no reason to believe [at the time of that writing] hull-mounted sonar devices could provide a safe and economically feasible means to prevent or significantly reduce ship strikes; (b) although technically feasible, fixed [*i.e*., sea-floor mounted] sonar arrays were unlikely to provide a practical means for preventing or reducing ship strikes, even in restricted areas such as shipping channels; and (c) projecting low-level, non-averse sounds in front of ships transiting areas where whales are likely encountered could conceivably reduce the risk of ship strikes and merited further investigation. Since that workshop, some technological developments such as sonar devices (see Miller and Potter, 2001, for example) and passive acoustic detection (see, Moore *et al.*, 2006; Urazghildiiev and Clark, 2006, for example) have shown promise in the detection of large whales at navigationally useful ranges.

In 2002, the NMFS produced a summary of technologies available to reduce ship strikes, their status and feasibility, and cost-benefit analyses of each (NMFS, 2002). It, too, concluded that, while economically feasible and environmentally benign technologies to reduce the likelihood of ship strikes were desirable, and some were more promising than others, no existing or developing technology offered a high probability of eliminating or substantially reducing collisions in the near future.

There is continuing interest, however, in emerging technologies that may effectively reduce ship strikes while allowing certain maritime commerce and other activities to proceed with limited biological and economic impact. Obstacles to overcome include low detection rates and a limited effective range of some devices. In addition, development, installation, and/or operation may be cost prohibitive in some cases (Anonymous, 1999). In all cases, studies are needed to confirm that any such technologies are clearly capable of reducing strikes and to ensure that additional environmental impacts are not introduced.

The focus of this workshop was to identify and assess promising ship strike reduction technologies. The workshop also addressed limitations in the physical maneuvering of vessels and the importance of advanced voyage planning to maritime trade. Workshop participants recognized there is a human component related to the

efficacy of any new technology – both with regard to the willingness of mariners to rely on the technology, and the lead time necessary to react to whale detections. The workshop did not address mariner acquiring, utilizing, or responding to information about the detection of a whale in the vessel's path or vicinity. For example, there may be difficulties with how additional information provided by various detection technologies could be integrated into the information processing and analysis procedures already in place on the bridge of a ship relating to safe navigation. This includes the human factor issues associated with processing of this information, from receipt by the bridge team to the point at which a decision is taken to alter the track of the vessel, taking into account presence of whales as well as nearby traffic and navigational hazards. Therefore, given other constraints it is not possible to know hoe the information will be used regardless of its reliability.

Workshop Goals and Logistics

Identified goals of this workshop were to (a) identify existing or emerging technologies that might be useful in reducing ship strikes, (b) assess the feasibility of each technology in reducing ship strikes, and (c) identify research and development (R&D) and timelines needed to make a given technology useful in reducing the threat, along with estimated time needed to bring the technology into a useful form. Objectives to meet those goals included (a) updating a 2002 NMFS summary paper on technologies, (b) identifying emerging technologies by hearing from inventors or companies with candidate technologies, and (c) evaluating and ranking technologies with regard to (i) R&D needs, (ii) costs, and therefore (iii) overall feasibility (see workshop terms of reference and agenda, Appendix 1).

The workshop was attended by 30 participants (Appendices 2 and 3) from 8-10 July 2008 in Providence, RI. Of these, nine were experts in shipping or represented commercial maritime companies or interests; 10 had expertise in technologies or represented companies with available or applicable technologies; and 11 were biologists. Eight government agencies were represented including the Marine Mammal Commission, Maritime Administration, National Marine Fisheries Service, National Ocean Service, National Park Service, Office of Ocean Exploration, US Coast Guard, and US Navy. Three participants represented independent academic or research organizations.

Summary presentations and discussions of relevant technologies occurred on the first day and part of the second day. The second day included a "brainstorming session" in which participants identified additional technologies not previously identified during or prior to the workshop. In facilitated discussion groups, participants were asked to discuss and make assessments of each type of technology. Specifically, small working groups were convened to assess the advantages and disadvantages of each technology by considering immediate applicability to the problem of ship strikes, time to implementation, costs, probability of detecting whales, and further R&D needs. After reviewing available information on each technology, the workshop assessed each technology's capacity to reduce the threat of collision through facilitated discussions.

Workshop Results

Detailed presentations were provided on seven different technologies, either with direct application or having the potential to be modified for application to, reducing ship strikes of large whales. These were:
- visual surveys;
- tagging and telemetry;
- passive acoustics;
- active acoustics;
- thermal imaging (*i.e.*, infrared);
- radar; and
- predictive modeling.

Workshop Presentations and Discussions

Overviews

Challenges and Limitations; and Alarm Technologies

Shannon Bettridge, Ph.D., provided a framework for discussion of efforts to reduce large whale ship strikes and the associated challenges. Dr. Bettridge noted that the NMFS is required to recover endangered species under the Endangered Species and Marine Mammal Protection Acts and that further, reducing the threat of ship strikes is likely to enhance the probability of recovery of certain of those species, particularly of North Atlantic right whales. The goal is to do so in a manner that does not jeopardize human safety and has minimal economic and operational impact on ocean users. In addition, Dr. Bettridge identified a number of environmental, biological, technical, economic, and human safety challenges to reducing ship strikes.

Environmental challenges include inherent difficulty in locating whales due to sea state/weather, darkness, and the time whales spend underwater. Physical ocean properties affecting sound propagation and background "ocean noise" also can interfere with whales' ability to detect, locate, and avoid oncoming vessels.

Biological factors complicating effective ship strike reduction measures include:
- Whale behavior
    – Social, foraging, nursing/calving, diving and surface aggregating, etc.;
- Inconsistent and poorly known whale responses to ships; and
- Incomplete knowledge of whale life histories (particularly their distribution).

There are technical and practical challenges that we must consider, including:
- Challenges to getting tags on animals;
- Experimentation on marine mammals is not possible without research permits;
- Difficulties in sighting surfaced animals;

- Impacts of sound introduction into water (for warning signals or active acoustic sensors);
- Rates of false positives and missed detections inherent in some detection devices;
- Need for trained operators;
- Infrastructure needs (*e.g.*, research vessels, aircraft, acoustic data processing); and
- Research and logistic limitations (*e.g.*, availability of funds, availability of research vessels, challenges of a salt water environment with fouling organisms).

Economic factors must also be considered when developing ship strike reduction measures. These include: the importance of commercial and recreational ocean use and potential impacts on these activities; survey costs; cost of installing and maintaining detection or alarm devices; direct and indirect costs associated with operational measures; and research and development costs.

Human safety is a concern when conducting aerial and ship-board surveys (*e.g.*, inherent risk associated with flying and boating), and when conducting at-sea research activities (*e.g.*, tagging, carcass recovery, and buoy deployment and maintenance). There are also concerns for ship handling and mariner safety inherent in certain ship strike reduction measures.

Dr. Bettridge also discussed the use of alarm devices as a means to reduce the threat of ship strikes. She identified some of the significant disadvantages to this approach, including:
- Whale responses are unknown and likely inconsistent by species, location, and behavior;
- Whales engaged in vital behavior (*e.g.*, feeding and socializing) may not respond to strong sound stimuli (Richardson, *et al*., 1995, Southall *et al*., 2007). However, frequent or chronic disruption of vital behavior (*e.g.*, foraging, mating, communication) can have strong negative impacts to some species, particularly endangered species;
- Whales may not respond. Habituation to the signal may occur resulting in diminished overall response, especially if the sound is repeatedly encountered without any associated negative consequences, *e.g.*, sounds of predators without any actual predator presence (Reeves, *et al*., 1996);
- Right whales may surface in response to alarms, making them not only more susceptible to collision but potentially prone to physiological dangers (*e.g.*, the "bends") or excess energy expenditure issues for some species associated with a rapid ascent (Nowacek *et al*., 2003); and
- Political and biological implications of harassment to an endangered species need to be considered and may be insurmountable.

Given these significant obstacles, the workshop focused instead on technologies that did not involve alarm devices.

Vessel Maneuvering

As noted, whale avoidance requires several significant actions following detection: alerting the vessel operator, determining whether to initiate, and initiating, an evasive reaction (*e.g*., changing course or speed), and time for the vessel to respond to bridge maneuvers. Workshop participants considered vessel maneuvering capabilities, particularly vessel responsiveness to an object at the surface in advance of a ship. Intrinsic (length, mass) and extrinsic (sea state, weather, etc.) vessel maneuvering and response capabilities were considered.

Vessel characteristics that were discussed included differences in maneuverability among vessel types (hull forms), vessel speed, load characteristics (*e.g*., loaded versus ballast condition), deadweight, pivot point, type of propulsion and hydrodynamic forces exerted by moving vessels. Characteristics extrinsic to the vessel included hydrographic criteria (*e.g*., water depth and currents), weather conditions (*e.g*., wind and sea state), and situational criteria including traffic densities, presence of recommended or mandatory routing systems/traffic separation schemes and spatial and temporal proximity to critical vessel actions (*e.g*., approach to sea buoys and pick-up of pilot) (Table 1). Crew experience and local knowledge of an area can also affect vessel maneuvering. The workshop participants noted that ship handling is a combination of art and science which in sum requires the vessel Master to exercise a situational awareness specific to the characteristics in a given event, which gets more complex as extrinsic criteria increase in both number and magnitude (*e.g*., traffic density and weather/wind conditions). The ability of a vessel to implement avoidance actions in a given set of spatial and temporal circumstances, therefore, is a function of the interaction of both the intrinsic and extrinsic features.

In contrast to the 1999 workshop that produced several hypothetical vessel reaction and stop time scenarios (Anonymous, 1999), this workshop concluded that it is difficult to make generalizations about the effectiveness and feasibility of avoidance maneuvers for all vessels. The inability to generalize is based on wide variation in vessel characteristics (*e.g*., hull type, speed, draft and propulsion systems), which change for classes of vessels as well as for an individual vessel over time. Furthermore, integrating the wide variation in situational criteria (*e.g*., traffic density and weather/wind) into the maneuvering equation makes generalizations, even on a per vessel basis, nearly impossible. The workshop considered examples of these variations (Fig. 1). The examples were:
- representations of variations in rate of turn or turning radius as a function of engine rpm, and engine and helm commands;
- the relative efficiency of rudder commands as a function of vessel speed, deadweight, and pivot point; and
- impacts of current and wind as affected by vessel size, draft and sail area.

These are examples, and it is difficult to account for all vessels in all conditions.

Participants in the 2008 workshop also considered variations in avoidance actions relative to vessel position at the time the bridge team is informed of the presence of an

object in the water. A vessel traveling at normal speeds will have far fewer opportunities to take effective avoidance actions in the near field (< 1nm) than in the medium to long field. Higher speeds will provide more efficient rudder response than with lower speeds. With regard to avoidance actions, some workshop participants contended that course changing with as much advance notice as possible (the more notice provided, the less course alteration required) provides a much wider safety margin overall than an emergency action such as an emergency full astern or round turn maneuver.

Finally, the workshop participants noted that extrinsic characteristics including traffic density, obligations placed on vessels by the "Collision Regulations" or COLREGS (aka, "Rules of the Road") have impacts on vessel maneuverability in the event of an alert. In addition, requirements imposed by mandatory vessel routing and traffic separation schemes, as well as shoaling or other navigational hazards, further limit the ability of a vessel to take evasive action. In some cases, evasive maneuvers may be physically possible, but if taken, would cause the vessel to violate safety or other legal requirements and obligations.

The workshop participants also considered high speed vessels (*i.e.,* 30 to 40 knots operating speed in open water). High speed mono-hull vessels are usually so classified because of their speed relative to their length, or speed-length ratio, also referred to as hull-speed. (Additional information about high speed vessels appears in Appendix 4.) Because of their propulsion systems and other features, these hulls are regarded as highly maneuverable and can have very short stop distances, characteristics that may give them certain advantages over conventional hulls in avoiding whale strikes. However, regardless of vessel speed or maneuvering capabilities, such vessels are typically traveling at high speeds thereby providing less operator- or whale-reaction time. A number of observed ship strikes occurred when whales surfaced unexpectedly directly in front of a vessel or were unseen prior to the collision (Laist, *et al*., 2001). There are numerous reports of collisions between fast ferries and whales worldwide (Tregenza, *et al.*, 2002; Weinrich, 2004). Finally, there are reports of human injury as a result of such vessels attempting rapid at sea maneuvers high-speed to avoid water borne objects.

Role of Technologies in Voyage Planning

The 2008 workshop participants discussed the importance of advanced voyage planning in avoiding ship strikes. Specifically, they addressed timing of vessel voyages relative to whale migration and movement, and the anticipation of possible delays or small changes in course. Workshop participants concluded that, considering available and developing technologies and procedures, as well as vessel maneuvering capabilities, advance voyage planning that results in avoiding known whale aggregation areas is the most prudent way to avoid ship strikes as it diminishes the likelihood of vessels being in the vicinity of whales. In this regard, participants developed a table to illustrate relative time frames for various types of avoidance scenarios and the general technologies needed (Table 2).

Summaries and Assessments of Technologies

<u>Visual detection (*e.g.*, surveys and ship-based lookouts)</u>[1]

       Richard Merrick, Ph.D., provided a presentation on visual sighting of whales. He discussed visual (with and without binoculars) detection of marine mammals from ship, aircraft, and other platforms. He stated that, given the amount of time whales spend underwater and the small body size of some species, visual detection can never account for all individuals in a particular area. Detection rate can often be less than 20-30% even in good sighting conditions, and as low as 0% at night. The speed of the survey platform (*e.g*., ~10 knots for ships; ~100 knots in aircraft) is also an important factor, as are the number and experience of observers, and observing conditions. He pointed out that a stationary platform in an area for an extended period has near 100% chance of detecting individuals during optimum sighting conditions with expert observers. The chances of detections decreases drastically as transit speed increases, sighting conditions deteriorate, and observer experience declines (Fig. 2).

       Peter Corkeron, Ph.D., discussed the differences between visual detections from aircraft surveys and detections from passive listening devices for right whales. Specifically, comparisons were made of aerial survey sightings over Cape Cod Bay, Massachusetts with a simple pop-up array (*i.e*., acoustic detectors) between 2001 and 2005 (Clark *et al*., in prep), as well as during 2006 (Fig. 3) and 2008. Aerial surveys had almost complete coverage of the study area on days flown, whereas acoustic detectors provided more-or-less complete coverage when whales were likely to occur. On 58 days over five years there was overlapping coverage of both systems. There were nine days when whales were neither seen nor heard, 30 days during which whales were seen and heard, 19 days when whales were heard but not seen, and no days on which whales were seen but not heard. Acoustic monitoring indicates that for every five days when whales were present, aerial surveys found whales on three. The study concluded that passive acoustics methods are more reliable for monitoring than aerial surveys (Clark *et al*., in prep). However, aircraft and other visual surveys are needed to provide context to acoustic monitoring, spatiotemporal management measures, and/or photo identification information, although there are safety risks in performing surveys.

       Some participants commented that like anything else, this should be treated as cost-benefit. In this regard, visual surveys are needed to calibrate the acoustic system's performance against historical data generated by visual surveys. After that, it is a matter of how much value is added by doing both types of data collection, versus the cost of doing both, and doing one but not the other.

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[1] Although the subject of posting lookouts on transiting vessels was not specifically discussed as a feasible technology at the workshop, it warrants comment. Dedicated lookouts stationed on a vessel's bow or wheelhouse and tasked with searching for cues of whales ahead of a vessel are more likely to detect a whale than a crew engaged in shipboard operations. In addition, there are operational challenges, such as availability of crew to stand this extra watch and personnel safety issues inherent in posting a person on the bow of a vessel in rough seas. However, for the reasons described above (*e.g*., observations are limited to daylight hours and favorable weather conditions, effective detection range is limited), they may be of limited overall value in reducing ship strikes.

Tagging and telemetry

Robert Gisiner, Ph.D., discussed the state of the technology and recent advances in marine mammal archival and telemetry tagging studies (Gisiner, 2008). Tagging studies rely on subjects carrying devices capable of logging various data that are relayed back to the user, either by underwater sound (acoustic telemetry), radio (*e.g.*, FM, line of sight), or satellite (*e.g.*, ARGOS); or by archiving the data until the tag is retrieved. In addition to locating and tracking animals for collision avoidance or other applications, tags are also useful as a study tool, providing insights into the behavior and natural history of marine mammals. Tags may indicate individual identity, location, biological, and behavioral data (*e.g*., diving behavior, swim speed, and sound production), and environmental data (*e.g*., water temperature, salinity, and fluorescence). Critical elements to evaluating the application of a tag technology include:

- sensor capabilities;
- onboard data processing and storage;
- data transmission/telemetry;
- reliability, cost, and availability;
- power supply;
- delivery, attachment, and release; and
- animal and operator safety.

Relatively recent advances in miniaturization, battery life, and data storage have rendered many telemetry devices highly adaptable.

Much of Dr. Gisiner's presentation and subsequent workshop discussion focused on the difficulties associated with attaching telemetry devices to a subject. Dr. Gisiner noted that delivery, attachment, and release are the most critical remaining technical challenges for potential users. Because of the challenge of attachment and release, tags often remain on whales for only limited periods (*e.g.*, Mate *et al*., 2007), preventing long-term study, although tag life of months or even a year or more has been obtained for some large whales (Mate *et al*., 2007). Some observations of scarring at the site of the tag indicate that caution should be exercised in determining the type and number of tags one might deploy, relative to possible risk to animals.

Tagging programs can entail significant costs, in the form of ship time to locate and tag animals, for example, and the safety risks inherent to at-sea research. For these reasons, tagging a significant portion of a population for reducing ship strikes, for example, is not feasible.

Dr. Gisiner offered the following observations regarding this technology:

Data transmission. Following challenges associated with attachment, data transmission is generally considered the most limiting factor in this technology. Two types of data transmission have been used: (a) acoustic (underwater coded sound pulses) and (b) electromagnetic (FM radio, satellite radio, cell phone band). Acoustic telemetry requires more power than electromagnetic transmission, it provides less range (generally 1-2 miles, versus 10-20 or more), and has less bandwidth (although this technology is

advancing rapidly). Electromagnetic telemetry has longer range (typically line-of-sight for MHz FM signals; 10-60 miles, depending on atmospheric conditions and the height of the sender and receiver). This method has the advantage of providing greater potential bandwidth; up to real-time video and audio. However, the animal must be at the surface for data transmission, and the animals are seldom at the surface long enough for transmissions requiring minutes of uninterrupted connection. And available satellite communications capability has cost, coverage, and bandwidth limits (*e.g.,* ARGOS satellite systems).

Availability. The majority of commonly used tags, including those providing Pressure-Time-Temperature (PTT); conductivity (salinity), temperature and pressure (CTD); FastLok Global Positioning System (GPS); and acoustic dataloggers are now commercially produced.

Power Supply. Relatively recent energy savings developments in hardware and software have brought power needs largely within current battery power capabilities. Batteries account for most of the weight and volume of all but a few tag types, but drag, not weight, is usually the primary limiting factor. Some high-tech, power-dense batteries (*e.g*., lithium cells) offer problems when operated at depth, or pose hazards of fire or explosion, although this is rare. For long duration attachments, power management strategies are employed, such as limited sampling to discrete, intermittent periods or trying to establish telemetry uplink only when conditions are favorable. Next-generation energy harvesting technologies, such as biofuel cells may offer breakthroughs in the next decade or so.

Cost. Commercial tags tend to offer reduced cost, improved reliability and availability. PTT and CTD type tags cost in the range of $500-3,000/unit, while more complex tags (acoustic B-probe) cost over $10K/unit. Greater demand would likely reduce the cost. Exploration of new technical options, such as new attachment or sensor technology, typically requires a minimum of 3-5 years and $1-2 M before a reliable product can be expected, due to the costs and challenges of at-sea testing and small sample sizes. Other commercial applications must be relied on to drive technical progress, cost, and availability. New satellite technology (*e.g*., mini-satellites), new cell phone and computer technology, and new battery and power supply technology are all serving to reduce costs.

Sensors and Memory. The past decade has seen a revolution in the variety of sensor capabilities. Environmental dataloggers (*e.g*., CTD tags) offer indirect benefits by feeding dynamic ocean models to predict marine mammal habitat use and movements ("whalecasting"). Multi-gigabyte memory is now available in very small packages with low power consumption. Such systems also provide programmable sampling and various levels of on-board data analysis to reduce the amount of memory needed.

In sum, cost, availability, reliability, sensors, power, and memory are all currently capable of supporting developing telemetry applications. However, attachment remains the greatest technical challenge. Although telemetry is a highly useful tool for studying

whale behavior, natural history and movements, its utility in mitigating ship strikes is severely limited by the logistics, risks, and limited lifespan of the attachments and the cost of getting tags on the animals and keeping them tagged. Timeliness of contact is also an issue. FM line-of-sight tags and acoustically transmitting tags that communicate by satellite do so infrequently, usually one to three times per day or less, because the animals must be at the surface for sufficient time and calculation of the position of the whales is not very accurate for systems like ARGOS (ARGOS tags with FASTLOC GPS provide localizations within tens of meters, but are limited by the need to relay the GPS position via ARGOS).

Acoustic Technologies

As noted, marine mammal visual surveys are capable of detecting only a portion of the animals actually present. Detections can only occur at the surface during daylight and in relatively good weather. In addition, the coverage provided by visual surveys are non-concurrent snapshots of a very tiny area of the animals' habitats. The number of observers and platforms are usually limited to one or two at a time, and then only cover a few days or weeks of the year, and are very expensive. Survey data from winter months, for example, is much less common than data from summer. However, acoustic observation can be undertaken continuously regardless of time of day, weather, location, or other limitations to visual surveys. Acoustic observation may be "passive" (listening only) or "active" (emitting a sound and listening for echoes reflected from the animals).

Passive acoustics

Passive acoustics methods do not produce sounds, but capture sounds from the environment to gather information about it. Passive acoustic sensors (hydrophones) may be deployed from or towed behind a ship, or from a stationary receiver anchored on the ocean floor for extended periods. Use of passive acoustic methods is becoming commonplace in the study of marine mammals (see, for example, Moore *et al.*, 2006; Mellinger *et al*., 2007). However, passive acoustic detection requires acoustically active subjects; silent animals (*e.g.*, some killer whales in some situations) will not be detected. At least initially, passive acoustic methods need to be "ground truthed" to determine the corresponding number of animals for a given incidence of sounds received, *i.e.*, there may be a small number of animals calling frequently or a large number vocalizing infrequently. Gender differences in the type and rate of calling, seasonal variance in call rates as for mating calls, or differences associated with group size or other social variables may also confound the correlation between number of sounds received and number of animals actually present. Determining the distance of vocalizing whales from detectors can also be problematic.

Passive acoustic devices are typically deployed in one of two forms: cabled hydrophones and autonomous recorders. Large-scale, cabled hydrophone systems can be very expensive to install and maintain. Historically most, if not all, such large arrays have been built for national security and military training purposes. Some of these systems

have at times been made available for research and other non-military uses. Autonomous recorders consist of hydrophones and battery-powered data-recording systems, sometimes with onboard pre-processing capability to minimize memory usage. These instruments are moored on the seafloor, sometimes with flotation that stations the sensor up in the water column. Unmanned autonomous vehicles, or "gliders", are increasingly being used as platforms for transporting acoustic recording devices. Three or more hydrophones are typically deployed in arrays both to ensure coverage of a particular area and to provide information on the location of sound sources through triangulation from more than two sensors, although accurate distance information is not always available.[2] Sampling can be continuous or through another more limited sampling regime. Data transmission (via radio or satellite links) must occur when the device is brought to the surface either on a pre-determined surfacing schedule or can be down-loaded by acoustic telemetry without being retrieved. Most often, data are retrieved during scheduled battery changes. Algorithms have been developed to discriminate marine mammal calls from other ambient underwater sound sources (fish, ships, industrial activities, etc.), and, in many cases, can be used to automatically detect species specific calls. As noted earlier for calibration of acoustic surveys with visual surveys, automated signal detection and classification programs first need to be calibrated against the current "best available" acoustic signal processor, the human brain. In some cases, automated processors may perform better in noise or for faint signals than a human, but that can only be established through testing with artificial data sets of by knowing the location and source characteristics of test sources in the detection field.

Two presentations were made on passive acoustics. Sofie Van Parijs, Ph.D., led a discussion of a study that used a passive array system to monitor fin, humpback, and right whale presence in Stellwagen Bank National Marine Sanctuary and involving vessel Automatic Identification System (AIS) data to track ship traffic. Here, two passive acoustic detection technologies, marine acoustic recording units (ARUs) and real-time passive acoustic buoys (RTB), are being used to understand the vocalization patterns and distribution of North Atlantic right whales. RTBs are also used to alert mariners to right whale presence. ARUs are bottom-mounted archival buoys that enable long-term (months to years) collection of large whale vocalization data. The acoustic data from these recorders are processed for right whale up calls using a custom made automated detector (Urazghildiiev and Clark, 2006). Studies have demonstrated seasonal and diurnal variation in calling behavior. To estimate detection distances for right whale up calls, propagation loss has been modeled using a source level of 150dB, with the whale and ARU at water depths of 5 and 30 m, respectively. The model incorporated average ambient noise of 80 to 90dB, using a measured winter average for Stellwagen Bank National Marine Sanctuary waters. The calculated range from the buoy was 2.0 to 5.5nm (S. Van Parijs, pers. comm.). Varying ambient noise levels will affect this detection range and a more comprehensive set of measurements over multiple seasons is underway for both Stellwagen and Cape Cod Bay, as is analysis of a large sample of whale up call source level measurements. An acoustic clip of up calls is collected and transmitted to

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[2] Comprehensive and detailed descriptions of specific instruments and their use and capabilities in various geometric configurations are beyond the scope of this report. More complete discussions appear in Richardson *et al*. (1995), Moore *et al*. (2005), and elsewhere.

Cornell University where it is checked by a trained person for accuracy. Once confirmed by visual inspection of call audiograms, the presence of a whale is posted on a map on a web site (www.listenforwhales.org) and reports are sent twice daily to NOAA's sightings advisory system. Some ARUs and RTBs record/monitor continuously, are robust and capable of data collection in all weather conditions and at night. However, ARUs have been lost to trawling in heavily fished areas. Currently, RTB detections are an effective means for reporting right whale presence. Improvements need to be made in certain aspects of the acoustic detector. An increased understanding of how RTBs perform in different habitats and a better understanding of right whale calling behavior is still needed to improve the efficacy of both technologies.

Gary Donoher, of Analysis, Design, & Diagnostics, described a system involving a ship-based passive acoustic detection and classification system. The system has been subjected to limited testing by the U.S. Navy to detect marine mammals during active sonar operations that could potentially affect marine mammals. The intent is to provide a system that can operate continuously and is capable of providing automated detection with minimal involvement by a watch stander. Mr. Donoher reported that detection probabilities were high. This system uses the calibrated reference hydrophone (CRH), which is onboard all Arleigh Burke Class Destroyers and Ticonderoga Class Guided Missile Cruisers. These sensors have an effective bandwidth of 100 kHz.

Mr. Donoher reported that his company is developing a multi-channel automated detection and classification system that will support the processing of a wide variety of sensors including the CRH onboard ships, fixed sensors used at Navy Undersea Warfare Ranges, towed array sensors, sonobuoys deployed by aircraft as well as other specialized sensors. He also indicated that this same technology can be readily modified to support commercial shipping and port operations. However, some workshop participants commented that much work is needed to make such a system functionally able to determine range or bearing to a vocalizing marine mammal – data essential to reducing collision risk – although detections are certainly possible. At present, the Navy's Marine Mammal Monitoring on Ranges (M3R) is developing an automated classifier for two species of beaked whales. There are significant issues to be faced before this capability can be applied to the vast majority of marine mammal species, and making such a system fully functional (*e.g.*, species recognition, bearing, and range data) may take years of research.

Active acoustics (e.g., SONAR)

Active acoustic techniques (*e.g*., active sonar) involve the production of a sound and analysis of the returning echo. Active sonar is widely used in a number of marine research fields, such as fisheries sciences.

The workshop included two presentations on active acoustics. Ms. Cheryl M. Zimmerman, of FarSounder Corporation, presented information on a 3D navigation and obstacle avoidance sonar for whales that provided an overview of the technology and compares 3D processing with traditional 1D and 2D sonar devices. FarSounder is

currently using these systems for detection of submerged hazards, shallow water navigation, port disaster operations, and marine mammal ship strike avoidance. The systems have been deployed in a number of locations and have previously been used in proof of concept studies with regard to fin whales in waters off Virginia (2001), right whales in Cape Cod Bay (1999), and humpback whales on Stellwagen Bank (1998). Ms. Zimmerman said the systems have been used by a number of vessels including cruise ships, yachts, and ferries for the purpose of avoiding whales. Incentives for ships to avoid whales with these systems could help justify the cost.

Ms. Zimmerman indicated that her company's product produces a signal at 60kHz with a source level of <204dB, has a one-quarter mile (0.463 km) range, and is capable of operating from a ship moving at 10 to 20 knots. The two msec signal is transmitted at a pulse rate of one per second at maximum power of 0.56kW rms. She stated that it emits less energy than commonly accepted commercial echosounders and provides a full volume field of view of 90 degree/60 degree wide and to water depths of 50 m with a single ping. She said her company expects to launch a device in the coming year that has a detection range to ½ mile and discussed planned next generation systems with expected ranges of 1-2 nm. Her company expects devices under development to enable localization of the whales as well as advanced classification of various species. She expects the systems to have automated detection and low false detection rate capabilities.

Mr. Jeff Condiotty, of Kongsberg Underwater Technology, Inc., discussed a fisheries sonar device potentially adaptable to detecting marine mammals. Mr. Condiotty described various underwater scanning devices that his company manufactures, including scanning sonar, single- and split-beam echo sounders, multi-beam sonar, and omni-directional sonar devices capable of detecting objects ahead of and below a ship. Mr. Condiotty reported that these acoustic systems are used on government research and commercial fishing vessels. He noted that sonar signals can vary in frequency, from <30 - >120 kHz. Wide-swath, multi-beam echosounder devices, in frequencies from 70kHz - 120kHz, are designed to acoustically sample a fish school with one ping. Mr. Condiotty also described several applications used in certain locations including: sonar coverage at port entrances for national security purposes, and bottom-mounted moored systems (using a signal at 38 kHz) to sample biological entities in the water column.

Mr. Condiotty described pilot trials in waters off Norway involving whale detections during seismic surveys. Omni-directional sonar devices detected humpback, minke, and killer whales with pulsed frequency modulated signals at 26 kHz up to 64 ms, and source levels of <180dB. Detection ranges, confirmed by visual observation, were around 2000 m under good conditions. Fast swimming (9-12 knots) whales were detected at ranges of 1500 - 2000 m. Groups of about 10 killer whales, as well as mackerel schools on which they were feeding, produced return echoes from distances of several hundred meters. Mr. Condiotty reported that during trials, whales showed no observable behavioral change indicative of avoidance from sonar exposure. He indicated such devices are used on commercial fishing vessels.

Remote Sensing

Radar

Charles Forsyth, Ph.D., of Areté Associates, Inc., discussed application of radar systems to detect marine mammals. Commercial ship-borne radars can be used to detect marine mammals if the signal is processed differently than customarily processed for navigational purposes. These devices share characteristics with visual and infrared methods in using electromagnetic waves that travel well in air (but not water). It has the advantages of potentially greater range than either visual or infrared sensors and can be subjected to automated signal detection and tracking rather than relying on constant visual monitoring. Radar works equally well at day or night and is less affected by fog and light rain than visual or infrared sensors. Although radar can only detect animals at the surface, it can continually operate during reduced visibility conditions and at night. Systems can be either land-based or aircraft- or ship-mounted. The basic hardware is available commercially and generally is easy to install. Processing software requires modification and is being developed. Data are processed in real-time.

Both commercial grade and custom radar setups have been considered, but custom or military grade radars provide significant advantages over commercial radars. However, they have greater cost and limited availability. Therefore, greater potential lies with larger commercial navigation radars (such as Furuno) that are widely installed. While these have been at the upper end of available power, utilize large antenna, and require speed upgrades, all of these are standard options. Data processing uses customized software. Additional processing hardware required can be as small as one or two workstations with appropriate displays.

Radar detects marine mammals at the surface by the reflection of the radar pulse off the exposed back of the animal, or in the case of schools of small dolphins, by the unusual amount of splashing. The radar signature of a marine mammal differs from a surface ship in several ways. First, its radar cross section is much smaller than a typical surface ship. Also, marine mammal signals usually occupy a smaller piece of the ocean than ships and they are intermittent as the animal dives and resurfaces. Standard radar processors, designed to detect surface ships, are ill-suited for finding the animals, because marine mammals present only a temporary reflective surface. However, custom data processing software can extract their signatures from cluttered data. In addition to whales, detections of similar objects such as seabirds, logs, and whitecaps hamper interpretation, but the expert operator can discriminate them because birds, logs, and whitecaps do not move like whales and dolphins. Similar to visual methods, radars are limited by high sea conditions (especially severe white capping).

In the course of three separate experiments, the Areté radar processor successfully detected and tracked marine mammals including humpback whales in waters off Hawaii (land-based), fin whales in the Mediterranean (ship-mounted), and gray whales off the southern California coast (ship-mounted). Visual observation confirmed detection to six km in moderate sea conditions. The next steps are to establish real false alarm rates to go

along with the detections, characterize performance in various sea conditions, and make the capability real-time.

Infrared

Olaf Boebel, Ph.D., discussed the development and use of several infrared cameras for cetacean detection in Antarctic waters. Infrared devices are used to detect "thermal signatures" of animals against backgrounds of different ambient temperatures. Devices can be land- or ship-based. Dr. Boebel used several devices to determine if whale blows were detectable. (The whale itself may not be detectable due to thick insulating blubber layers.) He also evaluated methods to overcome technical challenges, such as ship vibration, the effects of ambient and light and reflections, various kinds of thermal noise, and damage to the instrument by direct sunlight.

In a pilot study in 2003, Dr. Boebel's team used a hand-held infrared camera, successfully detecting blows from humpback whales at distances of 300-400m. In a subsequent study in 2004, two fixed infrared cameras were mounted on the ship's flying bridge with 24° field of view and each capturing about a dozen encounters of various species. In 2006, a system mounted and passively gimbaled in the crow's nest involved a visual camera (24° field) and two infrared cameras (7° and 12° fields). With these, minke whale blows were detected in the infrared images for 0.56 sec, and at distances of $1,164\pm$ m.

However, the fields of view for single cameras are limited. While this is less a concern for the application discussed in this workshop (*i.e.*, collision avoidance), the detection of marine mammals for mitigation measures when using air guns (*i.e.*, the goal of the study) requires a continuous monitoring of the ship's entire perimeter. To this end, in early 2009 an infrared device with 360° scanning capabilities will be tested. This system will also be actively stabilized and use a cooled detector, which is expected to greatly improve image quality and facilitate automatic pattern recognition. Automated recognition algorithms are needed to minimize watch stander requirements. While basic versions of these have been developed and successfully tested, significant improvements are needed to filter out false positives (*e.g.*, reflections off breaking waves), which is part of an ongoing research project. Based on this work, Dr. Boebel concluded that whale blows are detectable, at least in Antarctic waters, up to ranges of at least 1,000 m. Gyro-stabilized systems are expected to reduce ship vibration while thermal noise can be reduced using cooled units (although these are expensive), resulting in higher image quality. Direct sunlight did not damage the devices, addressing one concern, but ambient light and reflections can result in false positives, which need to be addressed using advanced automated pattern recognition systems. He estimated commercially available systems could be available within three to four years.

Predictive modeling

Andrew Pershing, Ph.D., assessed methods he and colleagues are developing to predict right whale distribution using oceanographic information from satellites. In particular, satellites provide data on sea surface temperature, sea surface height and reflectance at certain wavelengths of light indicative of the concentration of chlorophyll, and thus primary productivity. These data can be used to project likely copepod (*Calanus spp.*) (*i.e.*, primary right whale prey) location, abundance, and growth, based upon what is known about the ecological dynamics between copepods and primary production. The goal is to provide mariners those locations where right whales are likely to aggregate, based on model predictions, to minimize whale-vessel interaction. In addition, the models can contribute to aerial survey planning, shipping lane evaluation, and characterization of zooplankton resources in various habitats. Dr. Pershing indicated that the first generation forecasting system provides information on (a) copepods and whales, (b) conditions in late-winter that determine copepod abundance in summer, and (c) how this is linked to when and how many right whales arrive in the Great South Channel (Pershing *et al.*, 2009). His group is working on the next generation of models that will have finer spatial and temporal scales and assimilate zooplankton observations in Cape Cod Bay. The output from the copepod models will be used to drive right whale distribution models, and they are currently developing techniques to assimilate whale localizations from passive acoustics or surveys into the distribution models. Participants discussed possible limitations to the technique, including that the system is predictive, is limited by the availability of satellite data (which can be reduced by weather), does not provide definitive, real-time information on right whale aggregation locations, and the fact that development of models is still underway. Nonetheless, it is a very cost-effective means to provide information on ocean conditions relevant to whales.

Workshop Discussions

Discussions of various technologies were expanded to include specific features of each in break-out groups, which resulted in an overall summary of the following general points and tables of "pros" and "cons" (Appendix 5).

General Points to Consider Applicable To Multiple Technologies

- If the United States were to require use of any of the ship-board technologies discussed at this meeting as a condition of port entry for foreign or domestic vessels, the United States would likely face impediments and challenges based on international maritime law.
    - The United States would have to develop operational standards for any of the technologies.
    - The United States would likely have to phase in any such requirements for ship-based technologies.

- The United States would have to develop key metrics for determining the standards of any technologies and the way they would be used, including feedback loops of the information gathered and communication systems to assure that information collected was widely disseminated.
- All passive acoustic listening systems only detect whales when they are vocalizing. Vocalization rates vary by species, gender, and season.
- Any tagging of large whales would require MMPA and possibly ESA permits.
- Active acoustics research would require MMPA and ESA permits.
- Some of the technologies discussed at this meeting require considerable training for the operators and could involve significant costs (including maintenance).
- Technologies that can be incorporated with existing systems are more likely to be accepted by maritime industry than those that require autonomous equipment and dedicated staff to use them effectively.
- Ensonifying large areas of ocean would require significant power. Power requirements of some moored systems present technological challenges. Power requirement are not a limiting factor for ship-mounted forward-looking sonars.
- The issue of underwater noise is an international concern (ship noise, sonar noise, etc.). Active acoustic technologies would involve increasing noise levels in the ocean.
- Any technology employed should introduce no, or minimal, co-occurring negative effects to marine organisms or habitat.
- Ideally, applicable technologies can be situation or context specific, *e.g.*, can be fine-tuned to area or vessel type.
- Ideally, can be dovetailed with multiple detection systems.
- Ideally, a viable technology operates in real-time, but with sufficient time to react.
- Involves minimal impact to normal bridge operations, *i.e.*, least amount time involvement from the mariner while underway.
- Important to be able to communicate information to the mariner, through existing and standard vehicles such as AIS, NAVTEX,[3] RACON,[4] etc.
- The United States may be able to implement some measures through conditions of port entry.
- Finding technological solutions is a multi-part process; there is no one measure to fit all situations.
- Other communities are thinking about similar problems (*e.g.*, detection of submarines), and we should tap into their work.
- Large vessels pay about $700/ton of fuel. Any hull changes or other devices added will increase fuel consumption. Environmental footprint will increase with physical solutions. It is highly undesirable to transfer one biological problem for another environmental problem.

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[3] NAVTEX is an international automated medium frequency direct-printing service for delivery of urgent marine safety information and navigational and meteorological warnings and forecasts to ships. NAVTEX is an acronym for Navigational Telex.

[4] RACON is a type of radar transponder that is used to mark maritime navigational hazards. RACON is an acronym for RAdar beaCON.

- Smaller craft, not much considered in the workshop, may have different operating characteristics than the vessels primarily considered, however they also hit whales.
- Of all the technologies considered during the workshop, the one that seems to be most cost-effective is passive acoustics. Active acoustics, for example, have relatively more technical drawbacks and potential negative impacts.

In the course of discussions and during a "brainstorming" session, the workshop participants also identified several other potentially applicable technologies to address ship strikes. These were briefly discussed, but were not assessed in facilitated working groups. Technologies identified were:

- tactile alarm in front of ships, *e.g.*, water cannons;
- satellite- or unmanned aircraft-based hyperspectral imaging (*i.e.*, detection of electromagnetic spectra, such as ultraviolet);
- tomographic profiling of the water column;
- physical technologies such as prop guards and hull designs; and
- wake detection and other indicators of whale presence as detected from the air.

Some participants advocated integrating multiple systems and technologies to best mitigate ship strikes. They envisioned, for example, predictive modeling of regional whale occurrence, refined use of passive acoustics to determine local (10s to 100s of km out) occurrence, with yet further detail on whales in the vessel's immediate vicinity provided by active acoustics. This hypothetically provides better basis for voyage planning and relatively near-field evasive actions, leaving mariners with the freedom to determine the best means of avoiding whales. However, such systems might be costly to maintain and would still rely on potentially hurried last minute evasive action by a large vessel.

Summary and Conclusions

The workshop participants weighed the advantages and limitations of a number of technologies applicable to reducing ship strikes. The participants concluded that the problem of ship strikes is complex one, with no obvious, simple technological "fixes" immediately available for wide scale use. Thus, no single technology now exists, or will be developed in the foreseeable future that will eliminate, or reduce to zero the chances of, ships striking large whales. Reducing the spatial overlap of both whales and vessels is likely to remain the best means of reducing ship strikes, although not feasible in many locations.

Technologies applicable for reducing ship strikes are largely focused on enhancing whale detection. Enhanced detection capabilities can and should be pursued; however, reaction times of both whales and mariners remain important and challenging components of the problem. Several technologies used together would increase the

chances of detection at ranges both near and far from a vessel, improving the likelihood of providing early warnings to mariners. However, this only partly addresses the problem: the mariner must have the capabilities (*e.g.*, adequate communication systems and adequate response times) to take evasive action to avoid a detected whale. Responses to such information may vary amongst mariners and vessel types. Substantial distances may be necessary for vessels underway to avoid, alter course, slow down, or even react to an object directly in their path, particularly at higher speeds.

Of the technologies considered, alarm devices that scare or deter an animal from a particular location were rejected early in the workshop because it would be highly undesirable to repeatedly or chronically inhibit an endangered species from a preferred habitat, feeding site, or migration route. In addition, Nowacek *et al*. (2003) showed that at least a couple of typical alarm sounds either elicited little response, no response, or resulted in right whales exposed to the sound to rise to the surface where collision risks were greater. Even if the whales initially responded in a desirable way, workshop participants noted that whales may become habituated to such alarm signals.

Because most large, traditional hull vessels have very long reaction times and distances, workshop participants concluded that thousands of meters are needed to significantly alter the course of a large vessel in most conditions. While executing such a maneuver, the vessel has limited options for evasive actions, is vulnerable to reduced maneuverability throughout the action, and may inadvertently veer toward unseen whales in avoiding an observed one.

High-speed vessels (*e.g.*, some passenger ferries) represent exceptions to general maneuverability rules. Many possess unique hull configurations, propulsion systems, better maneuvering capabilities, and shorter stopping distances. However, even with greater maneuverability than conventional hulls, such vessels may not be able to react to an observed whale in less time due to their faster speeds.

Workshop participants concluded that carefully considered voyage planning that anticipates the potential for whale interaction is more desirable than attempting to react to the presence of whales in the near field. Several technologies (*e.g.*, predictive modeling, passive acoustics, and active acoustics) employed together could provide far- and near-field detection capabilities to aid voyage planning, as well as immediate avoidance response.

Small directed group discussions resulted in specific information on the "pros" and "cons" of each technological approach. Some conclusions can be made from these discussions. Visual surveys can be expensive, logistically complex, and are limited by poor weather, low-light conditions that vary by time of the year. Even in the best of conditions, only a fraction of the whales actually present may be detected. (Most of these points can generally be applied to the posting of dedicated lookouts, as well.) Telemetry is highly useful for studies of whale natural history and movement, and the field is advancing rapidly, particularly in regard to increasing power supplies and decreasing costs to transmit data. However, this approach faces challenges in attaching devices to

whales and in the logistics of deploying devices to a sufficient number of individuals to make it a viable means to reduce ship strikes.

Passive acoustic technologies are becoming commonplace in many locations for studying whale occurrence and distribution. Due to the amount of data returned for cost investment, this approach may be one of the most promising for addressing ship strikes. However, these devices will only detect vocalizing whales and determining specific location is not always possible unless multi-unit arrays are used. Active sonar devices can be effective in detecting whales within hundreds of meters (perhaps up to one thousand in certain cases and circumstances) of a vessel, although this range may be extended as technology improves. Wavelengths of sound that work best for detecting whales are also audible to other marine mammals and fish, and may produce undesirable effects on other organisms and parts of the ecosystem while reducing risks for large whales. Depending on the eventual system designs used, costs can be relatively high and false positives could be problematic. Radar devices can be used from ship or shore and have the advantage of operating in poor weather. False positives are a potential problem, though, and more performance data will be needed before commercialization can be contemplated. Ranges are also limited to line-of-sight, which for a small vessel might be 5-8 km (about the same or slightly better than ideal visual detection ranges). The higher the antenna above the water's surface, the farther a radar can detect objects, with shore-based systems providing detections at ranges exceeding 10 km. Thermal imaging devices have proved promising in detecting whale blows in Antarctic waters, at ranges greater than one km but are less effective in warmer climates where blows and ambient temperature differences are less. Predictive models using oceanographic data from satellites or other sources are a relatively low-cost means to predict where whales may occur. Like all models, including weather forecasts, there is an inherent amount of uncertainty in the predicted outcome, but fairly reliable models can be applied now to provide information on large scales. Coverage potentially can be regional in scale, but resolution (and therefore utility) is greatest at scales on the order of 100s of meters.

In all cases, efficient and reliable means to provide information to mariners, which they can use to effectively respond is the best course to avoid whale strikes. Therefore, some technologies hold promise and may have application to this problem in the relatively near term, perhaps when used in combination. Others will require continued research and development before wide scale application is feasible. Whereas mariners are expected to avoid whales when forewarned, most technologies have limitations in providing detection ranges adequate to allow mariners sufficient time to respond. Given the severity of the problem for a number of endangered species and the relative paucity of foolproof solutions, technological approaches are worthy of, and should be the subject of, ongoing pursuit.

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Table 1. List of variables involved in vessel handling. Includes variables intrinsic to the vessel itself and external situational characteristics.

1. Vessel Type (Hull Forms)
   - Tanker (VLCC and product)
   - Bulk carrier
   - Containership
   - Passenger vessels
   - Tugs/barges (towing, pushing)
   - Smaller commercial vessels (fishing, ferries)
2. Vessel Speed
   - Sea speed
   - Full maneuvering speed
   - Lower speeds below optimum steerage
3. Vessel Load
   - Fully laden
   - Partial load
   - Light
4. Vessel Propulsion
   - Single screw
   - Twin screw
   - Other (bow thrusters, Kort nozzles, etc.)
5. Hydrographic Criteria
   - Depth of water
   - Current
6. Weather
   - Sea state
   - Wind (esp. re: sail area above water line)
7. Situational Criteria (including Rules of the road impacts on maneuvering)
   - Open sea (no or minimal traffic)
   - Coastal (minimal to moderate traffic)
   - Limited maneuvering scenarios (approach to sea buoys, entrances to port)
   - Traffic separation schemes (moderate to heavy traffic)

Table 2. The role of various technologies in advance voyage planning and options
presented in avoiding detected whales.

	TIME SCALE	DISTANCE	ACTIONS NEEDED	POTENTIAL TECHNOLOGY
Voyage planning	1 week +	1,000 miles	* General course planning * Increase awareness and crew training	* Historical records * Forecasts * Predictive models
Voyage adjustments	1 day – 1 week	200 – 1,000 miles	* Adjust route or speeds * Post observers * Obtain whale alerts	* Notices of whales in area of travel
Precautionary and evasive actions	During transit to and from high-density whale areas	0 to 20-30 miles	* Slow down * Post observers * Obtain whale alerts * Establish anticipatory communications on ship * Contact nearby mariners * Change course	* NAVTEX * Buoy or other whale alerts * Visual observation aids * Electronic observation aids (sonar, radar, passive acoustics)

Figure 1. Comparison of calculated "crash astern" maneuvers with full-scale trial results (Exxon 191,000 dwt tankers, loaded condition). Please note, these comparisons are hypothetical and are intended for illustrative purposes only given the variables for any given situation such as wind and current forces, vessel size, weight and windage play significant roles in the curves presented here. It may not be possible to generalize them to other situations, hull types, etc. Graphic courtesy of Maritime Institute of Technology and Graduate Studies (MITAGS), provided by Robert Becker.
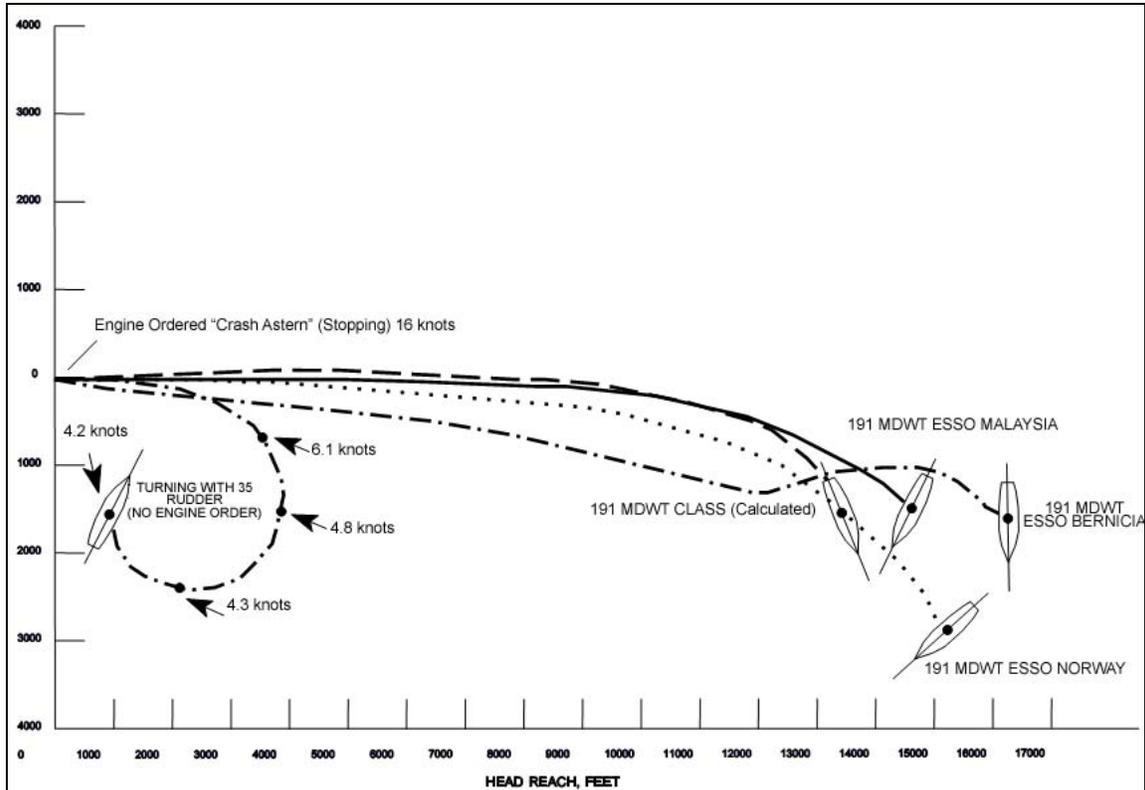
VESSEL	CALCULATED 191 MDWT	ESSO MALAYSIA	ESSO NORWAY	ESSO BERNICIA
TRIAL DRAFT	60' 5.5"	60' 5.5"	60' 5.5"	55' 3.25"
DISP.L TONS	221,400	221,400	221,400	201,000
V. APPROACH	16.0 knots	16.0 knots	16.6 knots	16.6 knots
RPM ASTERN	55	54	56	55
RPM TIME-LAG	92 SECONDS	44 SECONDS	102 SECONDS	65 SECONDS
TIME TO STOP	20.0 MINUTES	17.6 MINUTES	18.0 MINUTES	21.3 MINUTES
HEAD REACH, FEET	13,550	14,400	19,050	16,600
SIDE REACH, FEET	1,650	1,650	2,900	1,750

Figure 2. Hypothetical depiction of whales seen as a function of observational quality, going from zero sightability at night or in fog through sightability approaching 100% from a stationary platform using expert observers. Graphic provided by Richard Merrick, Ph.D.
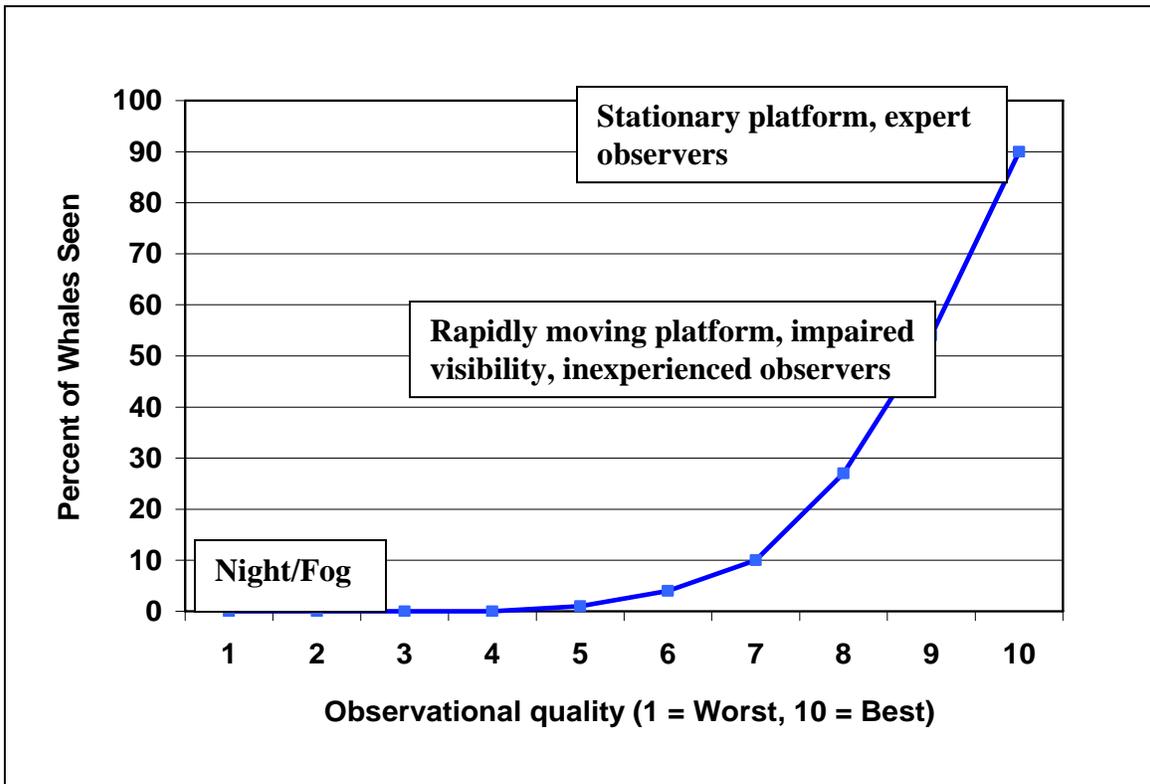
Figure 3. Comparison of days in which aircraft surveys detected right whales versus those days in which they were detected acoustically in 2006. Graphic provided by Peter Corkeron, Ph.D. (RWSAS = Right Whale Sightings Advisory System.)
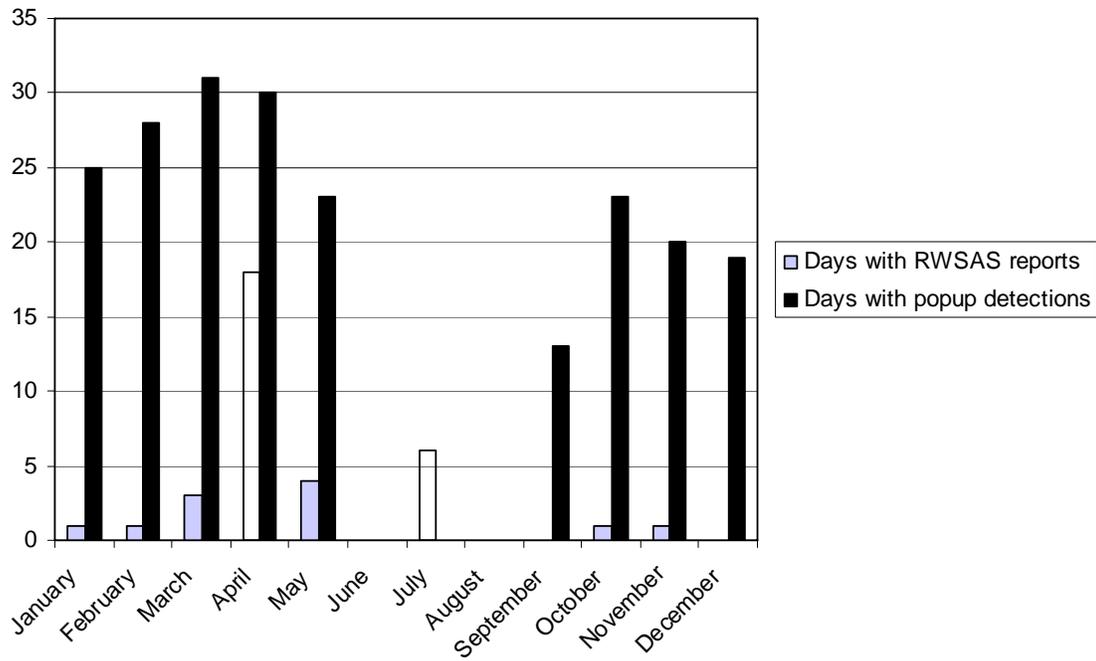
Terms of Reference and Agenda for

Workshop to Identify and Assess Technologies to
Reduce Ship Strikes of Large Whales

Providence, Rhode Island
8-10 July 2008

Background

      A major threat to endangered large whales species, the North Atlantic right whale in particular, is collisions with ships. NOAA is addressing this threat through, for example, modifications of vessel operations, providing whale sightings advisories, and proposed vessel speed regulations. However, there may also be current or emerging technologies not currently in wide use that may also be used to reduce the threat. NOAA is committed to identifying and developing technologies that will reduce ship strikes.

      The goals of this workshop are to (a) identify existing or emerging technologies that might be useful in reducing ship strikes, (b) assess the feasibility of each in reducing ship strikes, and (c) identify R&D and timelines needed to make a given technology useful in reducing the threat. Specifically, we will (a) update a 2002 NMFS summary paper on technologies, (b) identify emerging technologies by hearing from inventors or companies with candidate technologies, and (c) evaluate and rank technologies considering (i) R&D needs, (ii) costs, and therefore (iii) overall feasibility.

      The workshop will be a 2 ½ day meeting, 8-10 July 2008 at the Biltmore Providence Hotel in Providence, RI. Summary presentations and discussions of relevant technologies will be provided on the first day. We will generate a report of the workshop that, ultimately, lists potential technologies with an assessment, and ranking, of each with regard to advantages and disadvantages of developing each and an overall "feasibility ranking".

      Prepare a final report describing workshop findings.

**Workshop to Identify and Assess Technologies to
Reduce Ship Strikes of Large Whales**

**Providence, Rhode Island
8-10 July 2008**

Agenda

<u>**Tuesday, July 8**</u>

<u>Morning (8:30 AM-10:30 AM)</u>

Call to order (Hunt)

Welcome and purpose (Cottingham)

Introductions, presentation of agenda, and housekeeping (Hunt)

Workshop objectives, context, charge, and outcome(s) (Silber)

Ship and shipping characteristics (*e.g*., dimensions/drafts, speeds, slowing and maneuvering capabilities, vessel & wheelhouse operations) (Becker)

Limitations on use of technologies; brief summary of alarm research (Bettridge)

<u>Break (10:30 AM-10:45 AM)</u>

<u>Morning (10:45 AM-12:00 PM)</u>

Presentation and discussion of technology evaluation criteria and tools; and the goals of the technology (*e.g*., detection capabilities) (Hunt)

Technical Presentations on:

  a.   Visual detection (Merrick, Corkeron) (15 min)

  b.   Telemetry and Tagging (Gisiner) (20 min)

  c.   Passive Acoustics (Van Parijs, Hatch) (30 min)

  d.   Passive Acoustics (Donoher) (15 min)

Q&A and discussion of morning presentations

Lunch (12:00 PM-1:00 PM)

Afternoon (1:00 PM – 3:30 PM)

Continuation of Technical Presentations on:

  e. Active Acoustics (Zimmerman) (15 min)

  f. Active Acoustics (Condiotty) (15 min)

  g. Infrared (Boebel) (30 min)

  h. Radar (Forsyth) (15 min)

  i. Predictive modeling (Pershing) (15 min)

Q&A and discussion of afternoon presentations

Break (3:30 PM – 3:45 PM)

Afternoon (3:45 PM – 5:00 PM)

Brainstorm session: identify new technologies not already discussed (Hunt)

Evening - Optional

Drafting group(s). Work on descriptions and evaluations of technologies. Consider forming breakout groups.

Consider holding open session to hear additional technology presentations (*e.g*., poster displays, demonstrations).

Wednesday, July 9 (8:30 AM-5:00 PM; lunch, two breaks)

Complete any presentations not completed in Day 1. Additional brainstorming of heretofore not discussed technologies.

Begin to assess each technology and populate the criteria template. Breakout groups.

Begin to rank technologies by most feasible and easily developed.

Continue drafting group assignments

<u>Thursday, July 10</u> (8:30-12:30; one break)

Continue working on technology evaluations

Discuss proposed workshop conclusions and recommendations; work on drafting assignments; assemble drafting completed to date; to the extent possible, assemble draft final report

Synthesis and Conclusions

Next steps

Adjourn

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Appendix 4. High speed vessels

High speed mono-hull vessels are usually so classified because of their speed relative to their length, or speed-length ratio (speed in knots/square root of the waterline length in feet, or V/√L), also referred to as hull-speed. In general, at a speed-length ratio of 1.0 to 1.3, the wave, or induced drag, of the hull becomes dominant over frictional drag and rises at a greater rate. The displacement relative to length is also much less than a conventional low (*e.g.*, Very Large Crude Carrier, VLCC) or medium speed (*e.g.*, container ship) hull, to lessen induced drag. Conversely, any increase by a conventional hull above its hull-speed excites an exponential and, therefore, prohibitive drag-rise.

Although constant rather than exponential, the drag-rise above V/√L=1.0-1.3 in a high-speed mono-hull is much greater than its frictional drag-rise. High speed is therefore sustained by much greater relative power. Displacement, or mass, and thereby forward momentum is also less than in a conventional vessel. Thus when power is suddenly reduced, the drag is such that the vessel slows down very quickly - as shown in an exaggerated way by a speedboat coming off the plane. Furthermore, because of its greater power relative to its mass, it also has greater astern power, which can be applied almost immediately. This means that it can stop in a relatively short distance.

Because of the greater relative power of a high-speed mono-hull, maneuvering is usually superior to conventional hulls -- although this may not apply generally as in the case of stopping. This can depend upon the number and design of rudders, propellers, or water jet nozzles equipped with steering or reversing "buckets". Various performance features, based on maneuvering tank measurements for a particular high-speed semi-planing mono-hull vessel, the "FastShip", operating at typical approach speeds used near the Delaware Bay, were compared to those of VLCCs (see table below).

Comparison of various features of a Very Large Crude Carrier (VLCC) and the "FastShip" high speed vessel[5].

Vessel	Length Overall (ft)	Displacement (tons)	Available Astern (hp)	Speed (knots)	Stop Time (min)	Stop Distance (ft)	Stop Dist. x Ship Length	Tactical Diameter (ft)
VLCC	1,500	200,000	100,000	16	19.2	15,000	10	4.000
FastShip	870	36,500	118,000	25	3.2	2,750	3.1	2,158

Note: In the case of FastShip, the speed for traversing the Outer Delaware Bay would not exceed 20 knots.

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[5] Tank measurements were conducted on a 770-foot/32,000-ton FastShip vessel under Dr. Hans Liljenber at the Chalmers University SSPA maneuvering basin in Gothenburg, Sweden.

Appendix 5. Technological assessments

Active Acoustics: General		
	PROS	**CONS**
Summary	Generally, relatively high levels of detection and precision in localization capabilities.	Some concern about overall cost effectiveness, depending on ship type and overall context and operational effectiveness. Possible impact to behavior of whales.
Probability of detection	Nearly all objects in the water column of sufficient target strength; whales should theoretically be detectable in the water column.	Target strength varies based on some conditions (i.e., at depth). Concerns about how source level may affect behavior of whales, (i.e., acoustic footprint). Therefore care should be taken in considering use.
Probability of detecting behavior	Likely good during variety of behaviors. Expected to be able to detect whether whales are traveling, milling, etc.	None identified.
Operational status	May have application to specific areas, e.g., bottom-mounted; perhaps a key component to a multi-tiered approach. Numerous sonar devices commercially available. May have application to smaller-vessel types in some situations, e.g., while entering port, or after a "general" (e.g., passive) detection is made. Accurate position characterization (range-bearing, position, depth, tracking). Range envelope out to several thousand meters. Real-time detections. Works effectively in fog. Whales do not need to vocalize. Can collect ancillary biological data.	Some questions about overall (cost) effectiveness. Ranges may be limited to within several thousand meters. Detections may be limited at the surface, and at great death. Sonar is for near field. May effect behavior and distribution of other organisms as well; may need permits.
Availability	Side-scan, multi-beam, and bow-mounted devices commercially available	Bow-mounted device capable of detecting target at 2.0 miles under development, 2.5 years hence
Communication rate	Very rapid, e.g., ethernet protocol.	None identified.
Detection to notification to response time	Immediate.	None identified.
Cost	$100,000s/unit.	May have some extensive operation, training, and maintenance costs. Installation may be complicated by different hull designs, quieting issues, specific requirements, etc. R&D: improve classification systems.

ACTIVE ACOUSTICS: VESSEL MOUNTED		
	PROS	**CONS**
Summary	Relatively high level of detection and precision in localization capabilities (within meters) using high frequency signals (>40 kHz); can detect non-vocalizing animals; 3D forward-looking sonars can provide avoidance cues for other obstacles including rocks, sailboats, shipping containers, etc.	May affect marine mammal communication and behavior as sound source is within frequency range for toothed whales and other organism hearing and vocalizing. Returning signal may be ambiguous (*e.g.,* difficulties differentiating a whale from other objects) and requires interpretation of signal by trained personnel.
Probability of detection	(See "Active Acoustics, General") Possible on a coarse level (e.g., group size, swimming direction) and requires repeated detections. Expected high probability of detection inside ca. 500m of vessel (less probability at 500+m). Some detections are expected at depth. Other large submerged navigation hazards are also detectable.	See "Active Acoustics, General". Many large vessels may not be able to take evasive action for detections within 1000 m given time needed for communication with master, deciding on and implementing maneuver, and vessel response to command. To make an informed decision regarding avoiding action, a track of the animal is needed, which takes time to build during which the vessel has traveled 100s of yards. Once an animal's track is established, it may change course.
Probability of detecting behavior	Possible on a coarse level (e.g., group size, swimming direction) and requires repeated detections.	Ranges limited to <1000 m presently. Probability of detection decreases beyond 500 m and decreases to 50% at 1000m.
Operational Status	Various devices being developed and deployed with ranges of 100s of meters. Ongoing R&D anticipates extending the range.	Requires watchstander and training, (*i.e.*, trained personnel to interpret returning signal and classifying a whale image from other objects.) Requires retrofitting vessels.
Availability	Various devices being develop and marketed.	None identified.
Communication rate	Whale positions updated frequently.	None identified.
Detection to notification response time	Immediate.	None identified.
Cost	3D Forward looking sonar units available for less then $100k. Maintenance for 3D forward looking sonar straightforward with underwater connectors.	Retrofitting can be complex issue; may require dry docking.

ACTIVE ACOUSTICS: FIXED		
	PROS	**CONS**
Summary	Relatively high levels of detection and precision in localization capabilities (within meters).	Some concern about overall cost effectiveness. Possible impact to behavior of whales and power supply and communication distribution issues.
Probability of detection	Whales should theoretically be detectable in the water column.	Target strength varies based on some conditions (i.e., at depth). Source level may affect behavior of whales, (i.e., acoustic footprint).
Probability of detecting behavior	Likely to be quite good. During multiple behaviors.	None identified.
Operational status	(See Active Acoustics General)	Ranges may be limited to within several thousand meters. This range increases dramatically if used in a series or network. Detections may be limited at the surface, and at great death. May affect behavior and distribution of other organisms (e.g., harbor porpoises); may need permits.
Availability	Multi-beam and 3-D.	Some power supply and signal distribution issues need to be resolved.
Communication rate	Very rapid.	None identified.
Detection to notification to response time	Immediate.	None identified.
Cost	Total number of units is less than vessel mounted approach. On the order of hundreds of $100,000s/unit. Possible cost-sharing opportunities with public and private stakeholders. Can piggyback with multi-sensor ladened buoys; multi-sensors (e.g., active and passive acoustics are paired) can feed into a tiered whale detection system.	Installation and maintenance may be costly. Integration expenses. What is the incentive? Needs improved classification systems. Power supply requirement issues may need to be resolved. Getting signal to a central communication and distribution system.

INFRARED		
	PROS	**CONS**
Summary	Training can occur in a day. Can use in ice areas for ice detection.	
Probability of detection	Blow dependent and species specific. Capable of detecting multiple species. Detection range within 1 mile. Works well at night. Low false positive rates. Observer alerted by sound and can watch replay to verify blow. Images can be processed.	Dependent upon weather, sea state. Temperature dependent. Doesn't work in fog. Behavior of the whale shouldn't influence the probability of detection.
Probability of detecting behavior	Possible.	Low for behavior under water.
Operational status	Immediately available but must be configured to ship.	Auto detection software not yet available.
Availability	Now.	Software for autodetection (algorithms) may be available in next several years.
Communication rate	Real time.	After alert human validation for decision making.
Detection to notification to response time	Immediate.	None identified.
Cost	50,000-100,000 Euro	None identified.
Research and Development	Feasible to track bearing. System online continuously. Shipping industry could move into infrared technology in future; high potential especially with application to other regions. Infrared would detect small craft which would be 360 degree system.	Specific developments to specific systems.

PASSIVE ACOUSTICS: ANCHORED SURFACE BUOYS		
	PROS	**CONS**
Summary	Semi Permanent. Installation costs less than installing sea bed cables. Real time detection, classification and localization capability. Detection of multiple species possible. Mobile – adaptable in deployment configuration Regional to local scales. Dual use – single buoys can support multiple tasks, *e.g.* oceanographic sensors Continuous. Non-ship based. Able to be integrated into existing vessel systems. Low false positive rates.	Maintenance once installed (power limited). Susceptible to trawling, vessel and whale interactions. Localization requires multiple surface buoys. Moderate permitting to install (NEPA and other). Onboard buoy processing may be required. Multiple species detection restricted by transmission capabilities and bandwidth. Ship based - jurisdictional issues. Integration of acoustic information into ship based systems for all maritime traffic needs.
Probability of detection	Less sensitive to environmental conditions than other technologies (wind, night etc.).	Animals need to vocalize to be detected .Localization of callers is a function of sensor spacing. Ambient noise (high vessel noise) can limit detection range.
Probability of detecting behavior	Can support animal tracking.	Requires relatively high surface buoy densities.
Operational status	Real time detection and localization capability exists. Shown to work for several species.	Needs more field testing for some species and some conditions.
Availability	Commercial availability: 12 - 24 month lead time.	Research and development to reduce vulnerability to fishing needed. Wide scale commercial production development required 4 - 5 years.
Communication rate	Real time. Possibility of wide bandwidth : 10Hz - 60kHz i.e. multi species capability.	Requires research and development to be applicable for multiple species.
Detection to notification to response time	See software matrix.	See software matrix.
Cost	Non-localization capabilities costs less. Single system with multiple users and advantage.	Localization capabilities require more sensors. Some species require more or fewer sensors than others Increased accuracy requires more sensors.

PASSIVE ACOUSTICS: SEA BED MOUNTED ARRAY		
	PROS	**CONS**
Summary	Permanent. Low maintenance once installed. When buried partially protected from trawling. Caller localization capability. Real time. Capable of detecting multiple species. Continuous data stream. Can work at all scales (*e.g.*, regional to local). Continuous. Non-ship based. Able to be integrated into existing vessel systems.	Initial installation costs very high (dependant on length of cable). Permitting to install needed (NEPA and other). Susceptible to bottom trawling if not buried. Fixed – not flexible in design. Ship based - jurisdictional issues. Integration of acoustic information into ship based systems for all maritime traffic needs.
Probability of detection	Less sensitive to environmental conditions than other technologies (wind, night, etc.).	Animals need to vocalize to be detected. Localization a function of sensor spacing. Ambient noise (*e.g.,* high vessel noise) can limit detection range.
Probability of detecting behavior	Potentially can support tracking of animals.	High cost driven by need for high sensor density needed for tracking.
Operational status	Currently used by the Navy.	Not used/available by commercial entities.
Availability	Gold standard.	Sensors not commercially available. Most of this technology is available to the Navy. Would take 4 – 5 years for research and development for commercial purposes. Research and development to reduce vulnerability to fishing needed.
Communication rate	Real time. Possibility of wide bandwidth: 10Hz - 60kHz, therefore multi-species capability.	Lower frequencies more costly. Increased bandwidth increases cost.
Detection to notification to response time	See software matrix.	See software matrix.
Cost	Non localization capabilities costs less. $1 million/sensor. Single system with multiple users.	Localization capabilities require more sensors. Some species require more or fewer sensors than others. Increased accuracy requires more sensors.

PASSIVE ACOUSTICS: VESSEL BASED SENSORS		
	PROS	**CONS**
Summary	Provides local vessel situational awareness. Good detection capability. Localization possible with multiple sensors onboard vessel. Real time. Multiple species may be detected. Able to be integrated into existing vessel systems. Continuous. Non-ship based. Able to be integrated into existing vessel systems. Less sensitive to environmental conditions (wind, night etc.).	Extremely difficult to require installation aboard foreign flag vessels (other than as a condition of port entry). Maintenance once installed. Onboard vessel processing required. Multiple species detection restricted by bandwidth. Requires informed expert to screen data and make informed decision – on board acoustic processing required. Ship based - jurisdictional issues. Integration of acoustic information into ship based systems for all maritime traffic needs.
Probability of detection	Less sensitive to environmental conditions than other technologies (wind, night etc.).	Flow noise a problem (especially at high speeds). Near field technology – high speed applications limited. Function of sensor spacing. Animals need to vocalize to be detected.
Probability of detecting behavior	Potential to support animal localization.	Additional capability and research and development needed to localize. Near field – high speed applications limited.
Operational status	Real time detection possible.	Additional capability and research and development needed to develop localization capability. Near field – high speed applications limited.
Availability	Single sensor commercially available. Omni-directional sensor available.	Vessel level arrays not commercially available at the moment. Directional sensor not available (research and development needed).
Communication rate	Real time. Possibility of wide bandwidth: 10Hz-60kHz, therefore multi-species capability.	Requires research and development to be applicable for multiple species.
Detection to notification to response time	See software matrix.	See software matrix.
Cost	Widely variable in cost.	Widely variable in cost. Single system with single user.

PASSIVE ACOUSTIC SOFTWARE		
	PROS	**CONS**
Summary	Detection, classification and localization capabilities available for some species.	Expertise needs to be further developed. Techniques need to be validated for all species. Certification and standardization not yet established. Density applications not available (enumeration).
Probability of detection	Not identified.	Not identified.
Probability of detecting behavior	Not identified.	Not identified.
Operational status	Little training needed to determine marine mammal call (dependant on software used). Potential for automation in some management contexts (highly possible for right whales, longer research and development needed for other species).	Acoustic experts needed to validate data (either few on land for entire system or onboard every single vessel).
Availability	Many products available and evolving.	Require experts to use in an informed manner. Detection priorities for non right whales need to be examined.
Communication rate	Possibility of wide bandwidth: 10Hz - 60kHz multi-species capability.	Requires research and development to be applicable for multiple species. Research and development needed for validation, certification and standardization.
Detection to notification to response time	Can be rapid.	None identified.
Cost	Widely variable in cost. Open source (no cost) applications available.	Widely variable in cost.

RADAR		
	PROS	**CONS**
Summary	Familiar to shipboard personnel.	Many false positives due to white caps and big waves.
Probability of detection	Will vary depending upon conditions; probability of detection is high within 4 km range. Can use at night and in fog. Potential to increase capability to see 6-8 km out, can see other objects in addition to whales so co-benefits.	Many false positives; closer to the ship you get much sea clutter (from wave action). Orientation of animal may affect detection probability.
Probability of detecting behavior	Low. Could be good at tracking bearing under good conditions.	Subject to detection and availability bias issues. Cannot get behavior underwater.
Operational status	Immediate.	Some work needed to increase RPM.
Availability	Immediate.	None identified.
Communication rate	Immediate.	Humans watching radar assume that something that is seen then disappears written off as false positive. Need training or automated message. Need dedicated watch officer watching only radar while possibly sacrificing other duties.
Detection to notification to response time	Immediate.	None identified.
Cost	Low hardware costs; 1-2 workstations for filtering.	None identified.
Research and development	Could reduce need for constant watch by filtering and classification; extend range, real reduce operational clutter.	None identified.

TAGGING/TELEMETRY		
	PROS	**CONS**
Summary	Tags have low per-unit cost. Potential for a variety of data. Value in ground-truthing other research methods. Indirect value in providing data for other research (ancillary data collection).	Need to find the whales to tag. Attachment wounds on some whales. Attachment difficulties (drag). Altering behavior of whales. Battery power issues in some cases. Safety of humans involved in attaching. Permitting issues.
Probability of detection	High probability of detection (90-100%). Acoustics – do not need to surface to transmit. In-air telemetry/electronic tags have a longer range.	Electronic tags – need to transmit through air (whale must surface). Acoustics – limited range; can only be heard underwater. Pit tags limited range; only underwater.
Probability of detecting behavior	DTAG and critter cam capable of following whale movements (large tags can get a variety of data types).	DTAG: Cost. Archival, not real time. Don't stay on long (tag life = 1 day).
Operational status	Has been developed and used in the field; proofs of concept have been done. Some have been tested on right whales already. Some infrastructure in place already for retrieving data (satellites).	Attachment problems: don't stay on/drag, wounds on some whales. Power source for long-term tags. Not yet providing real-time data. Generally must be custom built. No tag for addressing vessel operator needs is presently available. For pit or acoustic tags, receive networks would need to be built and deployed and maintained.
Availability	Many tag types are commercially available. Can be off-the-shelf or easily prepared. Some arrays are already in place that could be modified and used (piggy-back).	Perfect tag is not developed. Likely best design would need to be custom built (time and cost for development and testing).
Communication rate	Daily (satellite) to real-time, depending on type.	Attachment. Power source.
Detection to notification to response time	(Function of communication rate.)	Attachment. Power source.
Cost	Fairly low cost per unit. Infrastructure costs low compared to some other technologies.	Costly to attach to all whales. Costly to build and maintain an array (a few $ million to build, a few $ million a year to maintain). Costs to process the data. Potential impact of acoustic tags on whales or non-target species? Biological costs.

VISUAL: POSTED LOOKOUTS		
	PROS	**CONS**
Summary	Seasonal information about habitat known in advance; can then allocate people to bridge in known areas.	Would need warnings prior from other technologies to allocate extra observers on the bridge assuming personnel available and increased awareness that whales are in area.
Probability of detection	Will vary depending upon conditions of ship, whale, and environmental conditions.	Sea conditions. Limited by distance of binoculars. Observer fatigue also an issue. For large whales depending upon blow rate. Depends upon speed of ship, day versus night, and orientation of animal.
Probability of detecting behavior	High if whale is detected.	Low if behavior occurs under water.
Operational status	Can be implemented immediately.	If personnel are available. May not be available on the ship. Would need training/experience of personnel to spot whales. Cannot always detect from bridge. Recommended to put lookout as far forward as possible, but bow post would depend upon weather.
Availability	Immediate.	If personnel are available. May not be available on the ship.
Communication rate	Immediate. Can get direct communications with the bridge.	None identified.
Detection to notification to response time	Immediate.	None identified.
Cost	Inexpensive if personnel available to monitor but expensive if person dedicated although person would be cheaper than installing technology (ships often have image stabilizing binoculars).	Mariner training required.
Research and development		Improved automation. Possibly put camera on the bow would have co-benefits of knowing where other things are.