Large Whale Ship Strikes Relative to Vessel Speed

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

1. Introduction

The western North Atlantic right whale *(Eubalaena glacialis)*, currently numbering about 300-350 individuals, remains critically endangered as a result of intensive historical commercial whaling. A number of anthropogenic factors continue to limit the recovery of this population, namely mortalities from ship strikes and entanglements in fishing gear. Ship strikes to large whales were thought to be a relatively rare occurrence, given that they are often overshadowed by the more apparent, more often reported, (and often prolonged) entanglement in fishing gear. However, it is clear from recent records that ship strikes are relatively common, and an average of about 1-2 right whales ship strike deaths occur annually (Jensen and Silber, 2003). Likely more occur but go undetected.

Ship collisions are responsible for more right whale deaths than any other single human impact. Between 1991-2002, 14 right whale deaths have been attributed to ship strike (Waring *et al.*, 2001). Of 45 right whale deaths recorded between 1970 and 1999, sixteen (35.5%) resulted from injuries caused by collision with a ship. Thirteen (28.9%) were neonatal deaths attributed to perinatal complications or other natural causes, two (4.4%) were deaths related to entanglement in fishing gear, and fourteen (31.1%) died of unknown causes (Knowlton and Kraus, 1998). Thus, ship strikes are responsible for 16 of 18 right whale deaths attributed to human activity during this time period. It is important to note, however, that many ship strikes go unreported, and therefore it is highly likely that right whale mortality from ship collisions is far higher than the figure presented here.

In order to better protect this species, it is crucial to address and mitigate those human activities that result in mortality. The Final Recovery Plan for the Northern Right Whale (NMFS, 1991) lists the reduction of human-caused mortality as the number one priority for the recovery of the species, and the revised draft places similarly high priority on reducing ship strikes (in press).

Ship strikes probably occur because right whales are slow swimmers, spend considerable time at the surface, and perhaps most importantly have a coastal distribution that overlaps with heavy shipping traffic. Right whales are either unable or unlikely to detect oncoming ships or may be engaged in vital activities (e.g., feeding, mating/social activities) and are either oblivious to, or do not respond to approaching ships.

Means to reduce ship strikes in right whales have been under discussion for a number of years. It is a complex issue and the factors resulting in the high number of strikes are not well understood. In addition, management options (i.e., changes in routing) may be limited due to such things as navigational hazards, maritime safety issues, and oceanographic conditions. The most feasible and likely most effective strategies may involve educating mariners and making them aware of right whale issues, routing changes, and reductions in ship speed.

Overall, the most desirable approach is to minimize the co-occurrence of whales and passing ships. While some steps can be taken to accomplish this, it is not possible in many locations and instances. It is not a feasible alternative to move the whales from preferred habitat; and due to vital commerce, it is not practical to eliminate ship traffic from certain commercial shipping lanes and crucial ports.

As NOAA Fisheries considers measures to reduce the threat of ship strikes to right whales, it is critical to examine the role of vessel speed in whale-ship collisions in order to determine whether a speed restriction measure may have the potential to reduce the frequency and severity of ship strikes to right whales. We attempt to summarize what is known about the impacts of vessel speed on whales, and, more specifically, to address the issue of speed in the cases of ship collisions with large whales. We do this through a review of literature on known ship strikes, a database on known ship strikes and known speeds, hydrodynamic research, and selected case studies of the effect of slowing vessels and vehicles. We also attempt to summarize industry perspectives and views about the use of speed regulations based on numerous non-scientific interviews conducted as part of an initial set of management recommendations submitted to the agency. Additionally, NOAA Fisheries viewed speed as a measure of “last resort”; that is, it is considered only when other potential options are insufficient to reduce the risk.

There are few definitive data on whether slowing ships reduces the likelihood of ship strikes. But there are also few clear indications about ways to reduce ship strikes in general. There are, however, a number of indications and indirect evidence that suggest reduced ship speeds will enhance the likelihood of ships avoiding whales. This paper is an analysis of the available information on ship speed relative to collisions with large whale species.

2. Materials and Methods: Existing Data

There have been several attempts to compile all known records of ship strikes of large whales (Laist et al., 2001) and known ship strike records of right whales (Knowlton and Kraus, 2001). NOAA Fisheries also compiled a database of all known records for all large whale ship strikes world-wide from Laist et al. (2001) and Best et al. (2001), marine mammal stranding reports, ship reports, NOAA Office of Law Enforcement reports, personal communications and a review of the literature on this issue (Jensen and Silber, 2003). These sources in total reveal 292 records of known or probable ship strikes to large whales. To the best of our knowledge, reports from these sources represent the majority of known cases of ship collisions with large whales from 1975-2002. Since publication, NOAA Fisheries has received several dozen additional reports consisting of historical incidents not originally included in the database, as well as strikes to whales subsequent to 2002 (Jensen, pers. comm.).

Records of ship strikes come from several sources. Direct reports from ships, crew and captains are the most reliable source of information on an actual ship strike incident. In these cases, in which the ship's crew was aware of the strike, it is possible to obtain information on ship speed, damage to a ship, and relative degree of severity of the strike to the animal.

Ship strike information can also be determined from stranded or floating dead whales in which definitive evidence of a massive internal or external trauma or lacerations from propellers are documented. In these cases, however, there is virtually no information on how, when, or where the strike occurred. In addition, in some cases of stranded or floating dead whales, it is difficult (when decomposition is advanced or forensics do not have sufficient resolution) to determine whether the injury indicative of ship strike occurred pre- or post-mortem.

Another type of record is the occurrence of a ship entering port with a whale carcass draped across its bow. Generally, in these instances the ship's crew was unaware of the strike. Most often this occurs with large container, tanker and cruise ships, and a collision is only determined when the whale is noticed wrapped around the bow by a pilot boarding the vessel or lookouts posted for harbor entry. In 42 of 292 known or probable cases of ship strike, evidence of a collision was only noticed when a whale was brought into harbor on the bow of a large vessel. Time and location of impact were determined by back-calculating to correlate with a previously unexplained decrease in vessel speed (Jensen and Silber, 2003).

Given the fact that large vessel operators often do not detect the impact of striking a whale, animals may be hit and passed over without observation. Likewise, operators may be aware of a strike, but choose not to report it. Again, it is highly likely that far more collisions are occurring than are actually reported.

Shipping Industry Input

Any attempt to require ships to reduce speeds in certain areas may be met with skepticism or opposition by the shipping industry. For most segments of the industry, delays in travel time translate into economic loss. Like many industries, the delivery of goods is time sensitive and critical. And, like most industries, there is much competition.

Shipping industry representatives have participated in various fora in which the impact of ship strikes and protective measures for whales have been discussed. Segments of the industry, at minimum, understand the endangered status of North Atlantic right whales and the problem of ship strikes. All commercial ships 300 gross tons or greater entering the Mandatory Ship Reporting system are required to report their locations and, in return, receive reports as to recent right whale sighting locations. In addition, NOAA Fisheries has engaged in an aggressive outreach program to distribute right whale materials and placards to port authorities, pilots, and maritime training facilities. Further, right whale information is included in Coast Pilot publications and nautical charts. Industry representatives also participate in the Northeast and

Southeast Right Whale Recovery Implementation Teams. Most industry representatives engaged in this dialog acknowledge that some measures may be necessary to address the adverse effects of shipping operations on endangered whale species. The views toward speed restrictions are mixed, but many industry personnel understand the limited tools and technology presently available to effect right whale avoidance.

3. Results

Speed Data

Vessel speed at the time of strike was reported for 58 (19.8%) of the 292 cases in the 2003 NOAA Fisheries database. Operating speeds of vessels that struck various species of large whales ranged from 2–51 knots with an average speed of 18.1 knots. The average vessel speed that resulted in injury or mortality to the whale was 18.6 knots. Evidence of serious injury or mortality is characterized by blood noted in water; animal observed with cuts; propeller gashes or severed tailstock; animal observed sinking after strike indicating death; fractured skull, jaw, vertebrae; hemorrhaging, massive bruising or other injuries noted during necropsy of animal. Of the 58 cases, 19 (32.8%) resulted in injury to the whale and 20 (34.5%) resulted in mortality. Thus, a total of 39 (67.2%) ship strikes are known to have resulted in injury or mortality to the animal. When these 58 reports are grouped by speed, most vessels were traveling in the ranges of 13–15 knots, followed by speed ranges of 16–18 knots and 22-24 knots. These speed groupings may be consistent with normal operational speeds for different commercial vessel types.

There are only two definitive strikes to right whales in particular where associated vessel speed is known with absolute certainty. One incident occurred on July 6, 1991 when a right whale calf was killed east of the Delaware Bay by a ship traveling at 22 knots. A second right whale, a juvenile, was killed on January 5, 1993 between Mayport and Fort Pierce, Florida by an 82 ft. vessel operating at 15 knots. A third collision that may have involved a right whale occurred in the winter of 1972/73 east of Boston, Massachusetts. A bulbous bow container ship traveling at 21-23 knots collided with an unidentified whale, killing it. The animal is listed in the record as a possible right whale (Laist et al., 2001).

Distribution of Strikes

Ship strikes to large whales occur world-wide. From the 2003 database of compiled ship strikes, collision incidents in the U.S. are recorded from almost every coastal state: Alaska, California, Delaware, Florida, Georgia, Hawaii, Maine, Maryland, Massachusetts, New Jersey, New York, North Carolina, Oregon, Rhode Island, South Carolina, Texas, Virginia, and Washington. Also, collisions occurred in three National Marine Sanctuaries (NMS): Stellwagen Bank NMS (humpback, fin and right whales), Channel Islands NMS (gray and several unidentified whales) and the Hawaiian Islands Humpback Whale NMS (humpback whales). Internationally, large whale ship strikes are recorded from waters off Canada, Puerto Rico, Brazil, Peru, Panama, South Africa, Japan, Antarctica, Mexico, France, Australia, New Zealand, the Canary Islands, the Caribbean Sea, the South Pacific, the Indian Ocean and the Yellow Sea.

Of 53 ship strikes to right whales world-wide, 28 (53%) occurred in the waters off the United States. Ten right whale ship collisions occurred in the northeast (including the Gulf of Maine and the Great South Channel), eight in the mid-Atlantic (from New York to North Carolina) and eight in the southeast (including waters off Florida, Georgia and Texas). Two right whale ship strikes were reported along the U.S. Gulf Coast. Ten right whale ship strike victims were reported in Canada (in the Bay of Fundy, Browns Bank and off Halifax, Nova Scotia), ten in South Africa, four in Brazil, and one in Argentina. Thus, it is clear that most recorded right whale strikes have occurred in Canada, the northeast U.S. and South Africa.

Strikes by Species

From our database, eleven different species were confirmed victims of ship strikes: humpback, finback, North Atlantic right, southern right, sperm, blue, gray, sei, minke, killer and Bryde's whales. Of the ship strike records available, finback whales are the most often reported species hit (75 records of strike), followed by humpback (44 records), North Atlantic right (38 records), gray (24 records), minke (19 records), southern right (15 records), and sperm whales (17 records). Far fewer reports exist of strikes to blue (8 records), Bryde's (3 records), sei (3 records) and killer whales (1 record). Several collision incidents were identified as a general baleen whale (3 records of strike), while a large proportion of reported strikes were not identified to species (42 unknown records). Coastal species (e.g., right and humpback whales) may be over represented in the database, due to a greater likelihood of near-shore detection of a ship struck carcass than individuals that may have died at great distances from shore.

These records indicate that North Atlantic right whales are one of the most frequently hit species of large whale. World-wide, 53 right whales have been victim to vessel strikes (38 from the North Atlantic population, 15 from the southern hemisphere). Five of these were calves and six were juveniles.

Severity of Strike

Of the total 292 large whale ship strike reports, 48 (16.4%) resulted in injury to the animal and 198 (68.0%) were fatal. Thus, in a total of 246 (84.3%) records, animals that were hit or bear evidence of ship strike were in fact injured or killed by the interaction. This high injury and mortality figure for all whales in the database includes numerous records of stranded or floating animals found dead, fatalities presumed and confirmed due to ship strike. In contrast, the injury and mortality figure for definitive ship strikes with known speeds is lower, 65%, likely due to the exclusion of the records of stranded and floating whales.

Type of Vessel

Collisions between ships and whales are associated with a wide variety of vessel types. From our database, 134 (46%) of 292 cases of ship strike include vessel type in the report, while in 158 (54%) cases the type of ship was unknown. Of the 134 known cases of vessel type, there are 23 reported incidents (17.1%) of Navy vessels hitting whales, 20 reports (14.9%) of ship strike for container/cargo ships/freighters, 19 (14.2%) reports involving whale-watching vessels, and 17 reports (12.7%) for cruise ships and liners. Sixteen (11.9%) reports are attributed to ferries, and nine cases (6.7%) are reported for Coast Guard vessels. Eight (6.0%) cases are reported for tankers, while recreational vessels and steamships account for seven collisions each (5.2%). Fishing vessels were responsible for four collisions in the database (3.0%), and one collision (0.75%) was reported from each of the following: dredge, research vessel, pilot boat and whaling catcher boat. It should be noted that the high incidence of Navy and Coast Guard collision reports may be largely a factor of standardized military and government reporting practice rather than an actual higher frequency of collisions relative to other ship types. Although these data give valuable information regarding the wide range of vessels involved in collisions, care should be taken in extrapolating from these numbers. As noted earlier, many large ships, such as containers, tankers, and cruise ships, may not be aware that a collision with a whale has occurred and thus do not report the incident. It is also likely that ships of all sizes under no authority to report, in fact, do not, out of apathy or fear of enforcement consequences.

Vessel Damage and Mariner Safety

The regulation of speed is a relevant issue not only for the safety of whales, but the safety and economic interests of mariners as well. Thirteen records indicate damage to the vessel (as reported by the vessel), ranging from minor to extreme, as a result of impact with a vessel operating at or greater than 10 knots. Three cases were at speeds between 10-15 knots, while the remaining reports of damage occurred at speeds over 20 knots.

Many of these ships report damaged propellers, propeller shafts and rudders. In one case, an Alaskan whale-watching vessel traveling at 22 knots lost a port stabilizer in a collision. In another case, a high-speed ferry traveling around 30 knots in the French Mediterranean broke a T-foil and arrived in port two hours late as a result of a collision with a whale. On August 11, 1998, an 8 m recreational Bayliner hit a humpback whale outside Juneau, Alaska at 12 knots, resulting in a cracked hull. A 126 m Navy frigate sustained significant damage when it struck an undetermined whale species off southern California. “Divers sent down to survey the hull reported...a 1.6 m tear in the leading edge of a propeller blade. The propeller had to be replaced at a cost of $125,000.” By far the most extreme example was that of a 24 m Navy hydrofoil which hit an undetermined whale species at a speed over 40 knots on April 16, 1991 off Key West, Florida, resulting in $1 million in damage. “Port and starboard aft strut actuators were severely damaged, port and starboard steering arms broke, ruptured seawater piping caused flooding of the gas turbine, the hull was warped in numerous places, and starboard diesel engine shifted forward off its mounts.” (Laist et al. 2001).

In addition to vessel damage, collisions can pose a hazard to human safety. In several cases of collisions, particularly with small vessels and fast-moving vessels (e.g., ferries), passengers have been knocked off their feet or even thrown from the boat upon impact with a whale. Hazards to human safety can be even more severe; thus, ship/whale collisions are not necessarily only fatal for the whale. Laist et al. (2001) list a case in February 1992 in the Canary Islands in which a high-speed ferry collided with a sperm whale at 45 knots, killing it and reportedly killing one passenger as well. Thus, the issues of vessel damage and mariner safety should be given serious consideration in the development of a ship strike strategy. From the data available, it appears that most damage and injury occur from vessels striking whales at higher speeds; therefore this factor should be noted in considered when developing speed restrictions to minimize the severity of collisions for both whales and humans.

4. Discussion

Distribution of whales and ships

One of the greatest factors contributing to ship/whale collisions may be the overlap of right whale distribution and vessel traffic densities. As a highly coastal species, right whales spend much of their time in areas where vessels concentrate because of entry into ports and other factors. The population migrates along the continental shelf of the eastern seaboard between foraging areas in the northeastern U.S. and Canada and breeding/calving areas in the southeastern U.S. Their primary concentrations are found in Cape Cod Bay, the Great South Channel, the Bay of Fundy and the coastal waters of Georgia and Florida.

In the United States, annual use of these habitats precipitated the designation of critical habitat for right whales in Cape Cod Bay, the Great South Channel and the waters off the eastern coasts of Georgia and Florida. Although some protection is afforded by the federally designated critical habitat, these are also areas of high ship traffic. No regulation currently exists for shipping in these designated zones, although a Mandatory Ship Reporting (MSR) system was implemented in 1999 that requires mariners to report such things as their location, course, speed, and destination when entering the reporting areas. In return, mariners receive information on right whale distribution, vulnerability to ship strikes, steps to avoid collisions, as well as real-time information about status and locations of right whales in the area. Although the MSR is a valuable tool for raising mariner awareness and examining ship traffic patterns, it is not a stand alone solution for whale-ship collisions.

Furthermore, ship strikes of right whales do not necessarily occur within the boundaries of the MSR or critical habitat. The entire Atlantic seaboard is highly trafficked by both whales and ships. Right whales migrate along the east coast of the U.S. and Canada in near-shore waters, and vessels of all sizes and types (tankers, container ships, cruise ships, fishing vessels, whale-watch vessels, private yachts, Navy vessels and Coast Guard cutters) transit these same waters. Particular areas of high overlap include the ports of Halifax, Boston, New York, Baltimore/Washington and Jacksonville and numerous other harbor entrances.

Whale Behavior

It is difficult to determine whether and at what distance whales may be able to detect and avoid ships. Some studies indicate that large whales do change behavior and exhibit avoidance in response to vessels, while evidence from other studies shows little or no apparent behavioral change. In 1981 and 1982, Baker and Herman (1989) studied vessel impacts on humpback whales in Southeast (SE) Alaska and concluded that changes in whale behavior were significantly correlated with vessel number, speed, size and proximity. In a more recent study of humpback behavioral responses to vessels in SE Alaska, focal animals were rarely found to respond to vessels with avoidance behavior (Peterson, MS Thesis 2001).

In the case of right whales, when animals are engaged in mating or feeding activities they appear oblivious to passing vessels, particularly if there is not an abrupt change in engine speed or course (Richardson et al. 1995). Likewise, blue and Bryde's whales have been observed to be unresponsive to passing ships, and fin whales off Cape Cod were found to ignore slowly approaching boats, of varying sizes, that maintained a steady speed. Reactions have been observed when boats changed speed or direction, or made fast, erratic approaches. Generally, it appears that baleen whales often ignore low-level sounds from distant vessels; more often, they exhibit avoidance behavior when vessel noise or speed changes, particularly when the vessel is heading directly toward them (Richardson et al. 1995). Avoidance reactions may include interrupting normal behavior, diving, or swimming rapidly away from approaching vessel. Some whales attempt to avoid an approaching vessel by outrunning it, which is often ineffective for slow-swimming species like right whales that can only swim at speeds of up 8 knots in short bursts (15km/h) (Cummings et al. 1972). Right whales are not, however, able to maintain these speeds for sustained periods, and any ship traveling at a speed of 14-20 knots (25-40 km/h) would easily overtake a right whale (if the animal is swimming directly in the same path as the ship). Clearly, not all avoidance reactions are successful in preventing collisions, injury and mortality. That is, a decision to flee directly away from an oncoming ship may not necessarily be the most desirable avoidance behavior.

Not only are right whales unlikely to horizontally outswim a ship, they may not be able to vertically avoid an approaching vessel. Recent research using new technology, a digital acoustic recording tag (DTAG), indicates that right whales may be limited in their ability to react to vessels by their positive buoyancy and reduced maneuverability during an ascent from a dive (Nowacek et al., 2001). The DTAG is attached to the whale and records swim stroke and pitch angle of the animal's swimming and diving activities. Data from recovered tags from right whales indicated that the animals were using muscular effort (fluke thrusts) to dive, but glided when ascending. This glide when surfacing is largely powered by the high amount of positively buoyant tissue (blubber) in right whales. Even if a ship were detected, this type of passive ascent might hinder the whale's ability to respond, react and effectively avoid a collision. Furthermore, results show that right whales may not only be limited by their maneuverability in *ascent,* but also in their ability to *descend*. Near the surface, right whales are positively buoyant and as a result may have difficulty counteracting this to dive quickly to avoid an oncoming vessel. These characteristics may explain, in part, why this species is so highly vulnerable to ship strikes (Nowacek et al., 2001). In addition, the positive buoyancy of the species itself suggest that these whales are prone to spending extended periods at the surface, when at rest, for example.

The Status of Vessel Traffic: Increasing Numbers and Speed

Generally, shipping speeds are on the rise world-wide. As human population continues to grow and commerce becomes increasingly globalized, so too does the demand for more ships which can travel faster and transport cargo more economically. Already it is expected that oceangoing freighters may soon double their speeds with new designs. Recently developed 'FastShips' can sail twice as fast as traditional freighters due to innovative hull design and high-powered propulsion system (Giles 1997). As a result, cargo between the U.S. and Europe may cross the Atlantic in days rather than weeks. Another concept currently under development is a hybrid catamaran and surface effect ship (SES), which, if successful, will lead to larger fast ferries and other high-speed vessels. This design, subject to extensive sea trials after receiving a 1996 patent, boasts high speed at low power, a low resistance hull, low wash and smooth travel (Anon. 1998). In the San Francisco Bay, the number of fast ferry traffic and vessel speed are both on the rise, with estimates of daily fast ferry trips increasing from 100+ trips at present to 665 trips daily in the next 10 years (Walther and Aspland 2001). High speed ferries (e.g., the "Cat") now make routine trips in areas and during periods when right whales aggregate in Northeast U.S. and Canadian waters. On the U.S. east coast, Blount-Barker Shipbuilding has begun development of a new high-speed catamaran to operate out of Bar Harbor, Maine (pers comm.). The vessel will conduct both seasonal whale-watch tours and high-speed commuter service at loaded operating speed of 40 knots.

Thus, as the capability to design and build fast ships rises to meet the demand for increased commerce and tourism, increased vigilance is necessary to safeguard marine wildlife, especially right whales, which are vulnerable ship strikes and in particular high speed craft.

Existing Speed Regulations

Terrestrial

Vehicle speed limits have traditionally been used to protect humans and terrestrial wildlife. In one study in Yellowstone National Park, 939 large mammals were killed on roadways in eight years, and there were numerous threatened and endangered species among them (Gunther et al. 1998). Overall, more than 14 species of wildlife were killed by vehicles on park roads, while park visitors also were injured and killed by collisions with wildlife. During the study, researchers analyzed the frequency of roadkills in relation to speed limits and actual average speed of vehicles. They found that vehicle speed was the primary factor contributing to vehicle-wildlife collisions.

Concern by resource agencies over the relationship between increased vehicle speeds and wildlife mortalities has led to mitigation attempts in the construction of new roads. In the case of Yellowstone, a study is being conducted to learn more about the mitigation effectiveness of the Wyoming Department of Transportation's plans for new road construction. The Agency's theory is that wider shoulders and lanes will provide the driver more sight distance and width to react to wildlife in the road, thereby reducing collisions (Bonds 1996). Vehicle-wildlife collision mitigation is also being attempted in the Canadian Rocky Mountains in Alberta where transportation infrastructure threatens seven native large carnivore species. Overpasses and buried, culvert-style underpasses have been built along sections of road as wildlife crossings (Gibeau and Heuer 1996).

Marine
Attempts to reduce impacts from vessels, such as speed restrictions, have been used to protect marine species. Currently, speed regulations exist for two endangered marine mammal species in U.S. waters: manatees and humpback whales. Vessel collision is the principle threat to the recovery of the West Indian manatee (*Trichechus manatus*), which congregates in coastal waters along the east coast of Florida and Georgia. Most deaths are caused by vessel impact, followed by propeller cuts, while many living manatees bear scars or wounds from vessel strikes. Over the last 25 years, a clear increase in mortality has been noted in the manatee population in the southeastern U.S., largely attributable to watercraft collisions (USFWS 2001). Between 1976 and 2000, deaths caused by watercraft collisions increased by 7.2% per year; as a result, boat speed regulations have been implemented in areas with high manatee concentrations along the east coast of Florida. The Florida Manatee Recovery Plan (2001) states, *"Because watercraft operators cannot reliably detect and avoid hitting manatees, federal and state managers have sought to limit watercraft speed in areas where manatees are most likely to occur to afford both manatees and boaters time to avoid collisions."* In 1989, in an effort to improve manatee protection in 13 counties, the governor and Cabinet of Florida approved conservation recommendations from the Florida Department of Natural Resources. Currently, state and local governments have plans to cooperate in building and implementing four county Manatee Protection Plans and 12 county-wide manatee protection speed zones rules (USFWS 2001).

The Florida Fish and Wildlife Conservation Commission has the responsibility to develop and maintain state waterway speed and access regulations to protect manatees under the State of Florida Manatee Sanctuary Act. These rules aim to protect manatees by taking into account manatee habitat use patterns and the needs of watercraft users. Under the authority of the ESA and MMPA at 50 CFR 17, the U.S. Fish and Wildlife Service may restrict vessel speed and access in conjunction with efforts to designate manatee protection areas (USFWS 2001). For example, in Brevard Country, historically one of the Florida counties highest in boat-related manatee deaths, slow speed zones and manatee sanctuaries have been adopted in an effort to reduce injury and mortality. Boater compliance with speed regulations has been examined through water-based surveys and aerial surveys with respect to boat type, activity, time and location (Morris et al. 1995).

In Alaska, a vessel speed limit is enforced in Glacier Bay National Park for protection of the endangered North Pacific humpback whale (*Megaptera novaeangliae*). Humpback whales feed in several areas throughout southeast Alaska during summer, but the waters of Glacier Bay are the only area in which a speed limit in enforced. Vessel operating restrictions are intended to minimize disturbance to the whales and lower the risk of vessel/whale collisions. In the past, a 20 knot speed limit was mandatory in the lower Bay from May 15 to August 31, and could be dropped to a 10 knot speed restriction by the park superintendent during times of high whale densities throughout summer months (Glacier Bay Boating Regulations 2002).

More recently, the Park Service analyzed its vessel operating requirements through a 2003 Environmental Impact Statement (EIS). The Park Service EIS Record of Decision (ROD) revised previous vessel requirements to mandate that a 13 knot speed limit for vessels greater than or equal to 262 ft (80 m) be in effect as needed in Glacier Bay on a year-round basis. The ROD states “The Superintendent may impose a 13-knot speed limit, as necessary, for motor vessels greater than or equal to 262 feet (80 meters) in length throughout Glacier Bay due to the presence of humpback whales. Park Service staff will monitor whale abundance, movements, and distribution, and provide this information to the park superintendent, who will then determine whether to set a 13-knot speed limit for vessels of this length or greater.” (Glacier Bay Vessel Quotas and Operating Requirements EIS 2004). In the appendix of supporting materials, the EIS includes a Biological Opinion prepared by NOAA Fisheries that cites Laist et al. 2001 as a basis for this speed restriction: “Generally, there is a direct relationship between the occurrence of a whale strike and the speed of the vessel involved in the collision. Most mortalities that have been documented occur when a vessel is traveling in excess of 13 knots (Laist et al. 2001).” (NMFS 2003)

In 2000, NOAA Fisheries in Alaska proposed a regional 200 yard approach rule for humpback whales. The number of responsive comments on the proposed rule was extremely high, with many commenters emphasizing, in particular, the need for vessel speed limits in areas where whales are predictably found. They recommended that NOAA implement speed limits through guidelines or regulations. Likewise, the recommendations from a recent study of humpback whale behavior and vessel activity in SE Alaska also urged NOAA Fisheries to consider speed limits in areas of high whale concentration. This study recommended that the Glacier Bay National Park restriction of 10 knots in “whale waters” be replicated in other seasonal humpback whale “hotspots” throughout Alaska to reduce the risk of vessel strike or harassment (Peterson, MS Thesis 2001).

Internationally, vessel speed limits have also been recommended for the protection of marine species. In Australia in 1999, the Great Barrier Reef Ministerial Council, committed to not only halting the decline in dugong numbers but actually restoring populations by endorsement of the recommendations of a dugong conservation review that included implementing boater speed limits (Anon. 1999).

Hydrodynamics

Vessels in transit exert hydrodynamic forces which can draw in whales and result in injury or mortality. To better understand the physical forces around a moving ship, Knowlton et al. (1995) conducted a computer simulation study to examine the effects on the body of a whale from the forces created by pressure fields as water moves around a ship’s hull. In addition to the hydrodynamic forces computed for the ship, the simulation was extended to calculate the movement of the whale in relation to the passing ship.

The simulations used three forces which may act on a whale from a passing ship: sway, surge and yaw. Sway is the lateral force, surge is the longitudinal force and yaw is the horizontal movement. These forces generally increase with the square of the ship speed and a decrease in water depth. In the simulation with whales at various distances from the side of the vessel, the initial positive force induced by the passing bow pushed the whale away from the ship. The subsequent negative sway force then drew the whales back in toward the ship's path. The timing of when a whale actually arrived in the path of the ship varied with the initial distance between ship and whale. If within a certain distance threshold, the whale is nearly always struck by the ship. If the whale's initial position is at an even closer threshold, it is likely a collision would result. An additional simulation indicated that if a whale surfaced in proximity to a passing ship and was not subjected to the initial positive force, the animal would be drawn in to the ship and collision would result. The maximum distance at which a whale could be drawn in toward the ship has not been determined, but most likely depends on water depth and ship speed.

Although different vessel types exert unique levels of force on whales, in general, an increase in speed increases the forces acting on the whale. Thus if the speed of a vessel increases, the whale will be drawn in more quickly (Knowlton et al.1995).

To accurately model and predict ship speed impacts on whales, a discussion of whale behavior must be included. For instance, if a whale attempts to avoid a passing ship, it can escape by swimming left, right, or straight up or down. The viability of these options will depend, for instance, on whether the incident is occurring in shallow or deep water. If right whales are indeed cognizant of the danger of approaching vessels and exhibit avoidance behavior, then speed reduction may be beneficial by reducing the hydrodynamic forces imposed on the whale and providing a longer reaction time to escape the danger zone (Knowlton et al.1995)

Ship Strike Simulations

Very few studies have been conducted which relate directly to speed in incidents of ship strikes to whales. In addition to the previously described hydrodynamic study, an additional computer simulation by Clyne (1999) was conducted to investigate right whale interactions with ships. By analyzing the size, movement and speed of both ships and whales in simulation, results showed the change in relative proportion of whale collisions with different parts of the ship against changes in ship speed. Based on this modeling, the study showed that the proportion of whale collisions with the side of a vessel decreased as speed increased, collisions with the bottom of a vessel stayed relatively even with change in speed, and the proportion of collisions with the bow of a vessel increased as speed increased. Thus it is evident that hydrodynamic and spatial factors play an important role in collision dynamics; ship strike incidents are more complex than the simple fact of a vessel hitting a whale. It is important to note from the results that the proportion of collisions with the bow of the ship increased at higher speeds; thus, it is possible that vessel speed reductions could mitigate incidents of head-on ship strikes to whales.

Perspectives from the Shipping Industry

Generally, various sectors of the maritime industry have argued simply that if mariners know where whales are located, they will avoid them. Most are looking for real-time information, and many advocate management measures that are entirely dynamic (i.e., nothing permanent). Speed reduction is not a measure that is readily envisioned or accepted, but neither is it universally opposed. The following discussion attempts to synthesize perspectives gathered by industry liaisons in response to this issue.

Support

Not all sectors of the shipping industry are opposed to speed restrictions. Many support geographically and temporally targeted speed restrictions based on real-time observations. Several shipping companies that operate along the U.S. east coast and Canada have indicated that they would willingly adjust their schedules for a port entry speed restriction. Some members of the shipping industry have communicated that a 10 knot speed during a seasonal 20 nm port entry/exit restriction is agreeable, while many others advocate a 13 knot seasonal restriction for port entry/exit . One northeast industry representative indicated support for speed restrictions based on the frequency of occurrence, duration and expected small areas where restrictions would likely be imposed. Another northeast representative indicated that speed restrictions will not affect commerce, as few ships are on such a tight schedule that a reasonable limit on a speed would disrupt their activities, especially since a speed limit will be known and can be taken into account in voyage planning. A marine pilot from the northeast advocated speed reduction as the sole management tool since it is the approach that allows the master an alternative and the scheduler a constant. A manager for a southeast port indicated that slowing vessels is the only viable solution to the problem of right whale ship strikes. Predictable areas of speed reduction can ultimately be factored into vessel scheduling and would not then be considered ‘delays’.

Speed restrictions around port entrances may be easier to implement and encounter less opposition than, for instance, a designated route that may cause a ship to deviate off its course and cost the ship more time than a speed restriction. In their current operations, vessels are already typically slowing to 6-10 knots to approach pilot buoys outside harbor entrances. In some ports, vessels slow to 5-8 knots to pick up marine pilots. In addition, vessels often slow to switch to lighter fuel during port approach to allow for increased maneuverability.

Opposition

Industry representatives have argued that there is little or no evidence that speed restrictions will actually provide protective measures for right whales. Indeed, there is only limited information on the speeds of vessels when ship strikes occurred. Experiments to injury and mortality at varying speeds are not possible. However, several hydrodynamic studies indicate that speed is a causal factor in ship strikes. It is known that four forces may act on a whale from a passing ship. First, the whale is initially pushed out of a ship’s path by the bow wake, and secondly, it is pulled back in.   The third force is that of the propeller, which at higher speeds has a higher negative pressure forward of the propeller. A whale can get sucked into the propeller. The fourth force is below the vessel; the faster a vessel moves through the water, the greater the negative pressure below the keel. Several hydrodynamic studies (Knowlton et al, 1995; Clyne, 1999) that model the bow wave/right whale interaction indicate that speed is likely a causal factor in ship strikes. As a result of these hydrodynamic forces, it is likely that at higher speeds a right whale will be pushed out of the way of a vessel and then drawn back in, whereas at slower speeds a whale is less likely to be drawn in.

Industry also argues for "slow, safe speed," a COLREGS definition that leaves discretion to the mariner, rather than regulating vessels at specific speeds. This term has been mis-used in the past by NOAA Fisheries, the U.S. Coast Guard and the U.S. Navy in their whale watch regulations, environmental impact statements and field guidance, respectively. Slow, safe speed is not defined in the COLREGS; safe speed, however, is defined, but is used in vessel to vessel collision guidance. In utilizing safe speed, a mariner considers weather, sea conditions, visibility, the vessel's ability to maneuver and other factors. Presumably other mariners are considering the same variables. In leaving the definition of safe speed up to individual interpretation, it is likely to be the normal operating speed, because no mariner will want to be put at a competitive disadvantage vis–a-vis other ships that might determine safe speed to be normal operating speed. A prescribed speed will provide consistent, definitive guidance to mariners in an effort to mitigate ship collisions with right whales.

In general, opposition from shipping associations and ports is based on potential economic impacts, coupled with the lack of definitive evidence showing that slowing ships will result in greater protection for right whales. Economic impacts are of great concern in the highly competitive shipping industry. Competition among ports is based not only on ship costs, but also on rail and highway access, connecting inter-modal costs, federal and state taxes, labor costs and supply, port capacity, and state and local incentives. In addition, many ports struggle to maintain their existing client base. The issue of port dislocation resulting from speed restrictions is a significant concern for port authorities and shipping interests. In developing markets to attract shipping companies, some port authorities argue that imposed delays, i.e, additional time to call at a port, will put them at a competitive disadvantage. Ports raising the greatest level of concern have significant RO-Ro and container ship traffic. Other vessel types that are on time sensitive schedules include cruise and LNG vessels. Other concerns voiced relate to companies that have signed contracts at fixed prices and to the additional transit times that may not have been factored into existing contracts.

Technological solutions, rather than speed restrictions, are advocated by industry to address ship strikes. Industry representatives ask why an answer cannot be found in tagging whales or in acoustic detection, both ship-board or along designated shipping lanes. Interest is so great that industry in the northeast has even offered to provide platforms for testing acoustic detection prototypes. However, it is widely accepted throughout scientific and management sectors that these methods currently do not represent viable means to address right whale ship strikes. Furthermore, if these techniques were to be used, the actions to follow would most probably result in speed or routing changes. Consider that a tagged whale is detected and the information relayed to a mariner. Likewise, consider right whale vocalizations heard using passive acoustics technology and conveyed to a ship in the vicinity. How will these masters respond? The only alternatives available to them if they are to change their operations in the presence of right whales are the same alternatives available to the agency: slow down, route around the animal or re-route and slow down. Thus, whether technology is used or not, the impact to the mariner may be largely the same when a right whale (s) is encountered. Speed is one of the few factors in vessel transit that can be controlled. Moreover, it is the only measure, in some instances, that is available to reduce the risk. Thus, it is necessary to consider it as a management measure to reduce right whale ship strikes.

Enforcement

NOAA Fisheries is considering the issue of enforcement while formulating a strategy to address right whale ship strikes. Many question the enforceability of vessel speed restrictions, and thus, the effectiveness of such a management measure. This is indeed a valid concern and clearly a challenge for the agency. Depending upon where possible speed restrictions are implemented, means to support these regulations may involve using USCG or NOAA Office of Law Enforcement vessels to monitor harbor approaches, critical habitat and other select areas with high right whale concentrations. Additionally, vessel speed limit enforcement could be achieved using aircraft, GPS, and via the USCG Port State Control inspection dockside. Vessel logs and MSR reports can be reviewed dockside. The Automated Identification System (AIS) (Title 33 CFR 164.46) will be in effect by the end of 2004 and another possible enforcement tool.

In Florida, an effort to reduce manatee injury and death and increase boater compliance within speed zones, both federal and state agencies have used targeted enforcement practices. The U.S. Fish and Wildlife Service strategy has been to allocate enforcement personnel to specific areas with significant histories of manatee deaths due to vessel collision. Emphasizing these sites, enforcement teams travel around the state of Florida. Likewise, the Florida Fish and Wildlife Conservation Commission has increased its emphasis on enforcement of manatee speed zones by adding additional officers, increasing overtime and increasing the proportion of law enforcement time directed toward manatee conservation efforts (USFWS 2001).

Furthermore, improved data collection and processing associated with high resolution spatial technologies will soon make it possible to determine ship speed by satellite. With further development of remote sensing technology, synthetic aperture radar (SAR) will be able to determine ship speed from the images of ships' wakes. In addition, SAR will be able to remotely calculate hull characteristics such as length and volume, hypothetically presenting a method to "enforce" vessel speed and determine identity (Griffin et al. 1996). These types of strategies, or similar strategies, will be explored for right whales.

5. Conclusion

The number of options available to effectively reduce ship strikes are few. As noted earlier, ideal measures would minimize the overlap of whales and ships. In many instances, this is impractical or impossible for both economic and biological reasons. That is, marine safety, detection capabilities, and economic factors may prohibit routing ships away from areas of whale occurrence. Thus, the manager and decision-maker must resort to the limited options available. Reducing speed is among the few viable options.

Although there are uncertainties, it is possible to assume certain things. Slowing ships may give more time for a whale to detect and possibly avoid the low-frequency sounds of an approaching vessel. As discussed, ships operating at reduced speed may be less likely to impose strong hydrodynamic forces on whales which otherwise might pull whales into the path of a ship. Additionally, slower vessel speeds may give a whale more time to detect, react and avoid a vessel. Finally, collision at a slower speed results in less actual impact (physical force) to the whale and to the vessel. This may spell the difference between mortality and less serious injury for the animal, and likewise, the difference between damage to the vessel or not.

Information in the Jensen and Silber (2003) database and Laist et al. (2001) indicates that the majority of vessel collisions with whales occurred at speeds between 13-15 knots. Overall, most ship strikes of large whale species occurred when ships were traveling at speeds of 10 knots or greater. Only 12.3% of the ship strikes in the Jensen and Silber database occurred when vessels were traveling at speeds of 10 knots or less. While vessel speed may not be the only factor in ship/whale collisions, or even the primary factor, data indicate that collisions are more likely to occur when ships are traveling at speeds of 14 knots or greater. This strongly suggests that ships going slower than 14 knots are less likely to collide with large whales. Therefore, NOAA Fisheries recommends that speed restrictions in the range of 10-13 knots be used, where appropriate, feasible, and effective, in areas where reduced speed is likely to reduce the risk of ship strikes and facilitate whale avoidance.

Some opponents to speed and routing management measures argue that a solution to the issue of right whale vessel strikes lies in educating mariners and/or outfitting ships with alarms and other technologies to warn whales. Although raising mariner awareness is an important facet of the ship strike strategy and something NOAA Fisheries has been actively engaged in for years, it is clear that ship strike and whale avoidance management must be addressed and not simply left to the vessel operator. In the Laist et al (2001) review of ship collisions, accounts indicate that most whales hit by ships were not seen beforehand or only seen at the last moment. Thus, collision avoidance strategies which rely on “mariner discretion” may be ineffective for large ships with limited maneuverability.

Likewise, just as NOAA Fisheries cannot rely on the mariner to react to potential collision situations, we cannot rely on the whale to avoid an approaching ship successfully. Since right whales engaged in feeding, mating or other social behaviors often appear oblivious to nearby vessel traffic, it cannot be assumed that they will avoid an approaching vessel, even if it were outfitted with alarms. In addition, in certain cases right whales may be *unable* to avoid the path of a ship due to hydrodynamic forces exerted upon them, their positive buoyancy and their lack of maneuverability during ascent. Because of these reasons, NOAA Fisheries believes measures to implement speed restrictions and/or re-route ships in specified areas are likely to be the most successful mechanisms to reduce the threat of ship strikes of right whales.

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