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Characterization of Ship Traffic in Right Whale Critical Habitat

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Collisions with ships are a significant threat to the endangered North Atlantic right whale. To reduce this threat, The National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) and the U.S. Coast Guard (USCG) established the Mandatory Ship Reporting System (MSRS) in July 1999. Under this system, all commercial ships, 300 gross tons or greater, are required to report to a shore-based station when entering either of two areas surrounding designated critical habitat: one in waters off the northeastern United States and the other off the southeastern United States. Information reported to the system includes entry location, destination, intended route, and speed. Reporting ships receive an automated message indicating precautionary steps to be taken to avoid hitting whales. Ship tracks between sequential ship locations were estimated by using a geographic information system (GIS) and mapped to illustrate traffic patterns within the MSRS. In the northeast, 69% of all valid tracks transited right whale critical habitat areas. All

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but two southeastern tracks intersected critical habitat. "High-use" traffic corridors were identified within the system. The majority of ships (59%) traveled at speeds greater or equal to 14 kn, a reported speed at which large whales may be critically injured. This characterization provides a portrait of ship traffic in right whale aggregation areas that can be used to develop measures to reduce the threat of ship strikes to right whales.

Keywords geographic information system, right whales, ship traffic

Background

North Atlantic Right Whales

Centuries ago, the North Atlantic right whale (*Eubalaena glacialis*) was abundant and inhabited both the eastern and western regions of the North Atlantic Ocean. Heavy harvesting eliminated the eastern population and nearly eliminated the western population (Katona & Kraus, 1999; Reeves, 2001). Right whales were highly sought for harvest because they yielded large amounts of high-quality oil and baleen. In addition, they were easy to catch because they moved slowly, occurred primarily on the continental shelf, and often floated when dead because their thick blubber stores cause positive buoyancy. Right whale proximity to the coast was so predictable that shore-based fisheries were sustained for centuries (Reeves & Mitchell, 1986). By the beginning of the 20th century, right whale stocks were severely depleted—only tens of animals are thought to have remained along the eastern United States, making commercial harvest unsustainable (Reeves, 2001). Consequently, right whales were one of the first baleen whales to receive international protection: the commercial harvest of right whales was banned internationally, originally by way of the League of Nations in 1935 and then by the International Whaling Commission, established in 1946 (Katona & Kraus, 1999). Right whales have now been protected from commercial exploitation for more than a half century.

The typical present-day range of North Atlantic right whales includes continental shelf waters off the eastern United States and Canada (Kenney et al., 2001). In the United States, the Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973 are strong laws requiring the protection and recovery of right whales and other marine mammal populations. Additional protection includes a U.S. federal regulation requiring boats and aircraft to stay a minimum of 460 m (500 yards) away from right whales (Federal Register, 50 CFR 224.103, 2004). The National Oceanic and Atmospheric Administration's National Marine Fisheries Service is the lead U.S. federal agency responsible for the protection and recovery of North Atlantic right whales. Similarly, the Canadian Department of Fisheries and Oceans has taken protective measures to protect right whales in Canadian waters. Both agencies have designated critical habitat or conservation areas in key areas used by right whales (Figure 1). The right whale is migratory (Kenney et al., 1995). Designated areas near the northeastern U.S. and eastern Canada include typical spring and summer feeding grounds, whereas, during winter, critical habitat off the coasts of Florida and Georgia serve as the only known calving grounds (Winn et al., 1986; Kraus et al., 1986; Kenney et al., 2001). Peak abundance within the calving grounds typically occurs from December through March, although sightings have occurred outside of those months (National Marine Fisheries Service, 1991). However, the range of the species is broader than the designated critical habitats, and whale distribution can be affected by changes in food availability (Payne et al.,

Figure 1. Designated critical habitat, conservation areas, and mandatory ship reporting boundaries for North Atlantic right whale conservation.

1990; Weinrich et al., 2000; Kenney, 2001; Jacobsen et al., 2004). For instance, data from satellite-tagged right whales indicate that they travel great distances and have varied movement patterns—one whale was associated with an offshore warm-core ring (Mate et al., 1997).

Despite international and national protection measures, the North Atlantic right whale population consists of approximately 300 individuals and remains one of the most endangered mammal species. Modeling studies suggest that the North Atlantic population is declining and some models predict that extinction could occur within 191–245 years (Caswell et al., 1999; Fujiwara & Caswell, 2001). Declining survival of females is of particular concern for the species. Females historically produced more than six offspring during their lifespan, but that number has now been reduced to fewer than two (Fujiwara & Caswell, 2001). The prevention of as few as two female deaths each year would improve the chances for recovery (Fujiwara & Caswell, 2001). Demographic projections are even more dire should food resources decline (Greene & Pershing, 2004). In light of these grim predictions, active conservation efforts for the species are critical, particularly in reducing human-caused mortality.

Right whale deaths and serious injuries from human activities, particularly collisions with ships and entanglement in commercial fishing gear, are slowing the recovery of the species (IWC, 2001). The data indicate that collisions between ships and whales are the leading cause of right whale deaths. From 1970 through 1999, 35.5% of recorded deaths were attributed to ship strikes (Knowlton & Kraus, 2001). Waring et al. (2002) reported that from 1996 through 2000, "the average reported mortality and serious injury of right whales due to ship strikes was 0.8 whales per year" (p. 11). It is very possible that additional deaths have gone unreported because the carcasses were not detected before they sank. Based on the significant size of injuries incurred by struck whales, it is believed that most lethal collisions are caused by large vessels (Laist et al., 2001; Jensen & Silber, 2003). Types of documented injuries include propeller trauma such as severed tailstocks and blunt trauma such as shattered skulls and massive bruises (Knowlton & Kraus, 2001).

Shipping

Over the past half century, the United States has grown increasingly dependent on international trade; as a result, ships have increased in size, requiring that ports and coastal zones be modified to accommodate larger vessels (Hershman, 1999; Waters et al., 2000). For example, the first containerships appeared less than 50 years ago and are now the fastest-growing shipping segment; containership calls to U.S. Atlantic ports are expected to increase 4% per year through 2020 (Waters et al., 2000; Hackett, 2003). The number of active ports along the eastern North American seaboard illustrates the significant level of domestic and international commerce that is supported by these hubs (Shaw, 2002). Vessel calls to U.S. Atlantic coast ports are forecast to rise from approximately 47,200 calls in 2000 to 93,500 calls in 2020 (Hackett, 2003). Often, entrance channels to commercial ports and military bases traverse the same areas frequented by right whales. However, ships and right whales also co-occur throughout the range of right whales. Right whale deaths attributed to ship strikes have been documented in and near shipping channels as well as in coastal areas that link major aggregation areas such as the waters off the U.S. mid-Atlantic (Knowlton & Kraus, 2001).

Reducing ship strikes requires knowledge of whale occurrence and behavior, maritime traffic, and the environment in which both occur. Various strategies to reduce vessel-related risk to whales are under consideration, including the modification of traffic operations in whale habitats and enhancing educational programs advising mariners on ways to avoid collisions with right whales. For example, in 1998, the United States took the issue of right whale ship strikes to the International Maritime Organization (IMO), which was established in 1948 by the United Nations to promote international maritime safety, efficiency in navigation, and pollution control (International Maritime Organization, 2004). The IMO has the authority to adopt maritime legislation in international waters, including approval of mandatory ship reporting systems. Through the collaborative efforts of several governmental agencies and private organizations, the United States proposed creating a Mandatory Ship Reporting System (MSRS) for implementation near right whale critical habitats. This system was approved by the IMO later that same year (Silber et al., 2002).

In July 1999, NMFS and the USCG began operation of a MSRS requiring self-propelled commercial ships of 300 gross tons and larger to report to a shore-based station when entering either MSRS zone surrounding federally designated right whale critical habitat (Johnson, 2004, Figure 1). The system in the Northeast encompasses two right whale critical habitats off Massachusetts and the Gerry E. Studds Stellwagen Bank National Marine Sanctuary. The system in the Southeast surrounds most of the southeast right whale critical habitat that spans the Georgia/Florida border. The objective of the MSRS is to reduce whale and ship collisions by providing timely information to mariners entering areas used by right whales. A computer server, operated under federal contract, handles and stores the incoming ship reports, and sends an automated-return message. Incoming reports are text messages that arrive via INMARSAT-C Internet (International Maritime Satellite) or Telex (Silber et al., 2002). Through this communication process, mariners are informed of locations where right whales have recently been sighted and are given precautionary advice on how to avoid hitting a whale.

In 2002, the IMO adopted a Canadian proposal to reduce the potential for ship strikes by shifting the location of its Bay of Fundy traffic lanes to avoid an area with high sighting rates of right whales (Johnson, 2004). The NMFS has since announced an advance notice of proposed rulemaking (ANPR) for right whale ship strike reduction (Federal Register, 50 CFR Part 224, 2004). The draft strategy includes establishing new operational measures for the shipping industry such as routing changes and speed restrictions, concordance of whale conservation policy with the Government of Canada, and education and outreach programs.

Collisions with ships are a significant threat to right whales. Information, such as that presented here, will be essential in considering steps to reduce this threat. The aim of this article is to present a characterization of commercial ship traffic within designated critical habitats using MSRS data reported between July 1999–June 2002. Geographic Information System (GIS) techniques have been incorporated into our assessment as an integrative tool to aid in the development and implementation of measures needed to reduce the threat of ship strikes to right whales.

Methods

Required ship-report information includes a system identifier (WHALESNORTH or WHALESSOUTH), vessel name and call sign, true course, speed, date, time and point of entry into the system, destination and expected time of arrival, and route information (Federal Register, 33 CFR Part 169, 2001). Required route information includes either a rhumbline (a constant compass direction) directly to port or a series of waypoints along an intended route through the system. The system in the Northeast (WHALESNORTH) operates year-round off Massachusetts, and the system in the Southeast (WHALESSOUTH) operates from November 15 through April 16 off Georgia and northeastern Florida (in 2000 and 2001 WHALESSOUTH ended April 15).

Mapping Estimated Ship Tracks

Incoming ship reports were initially reviewed by the USCG for duplicate or erroneous records and stored in a relational database. We modified the database into a format compatible for mapping locations within a GIS. We programmed the GIS to connect sequential track positions (or in some cases, a straightline between the entry and destination locations) to map estimated individual ship tracks within each system. Spatial data were processed using ARC/INFO and ArcView GIS (ESRI, Redlands, CA, USA), with the track assumed to be the shortest route between sequential positions. The resultant estimated tracks could be described as either: (1) "simple," where a line was drawn between the point of entry into the system and the reported destination; or (2) "descriptive," which included tracks that were generated by sequentially linking more than two points along the reported route. For "simple" tracks from ships that reported only the name of the destination port, substitute coordinates were assigned to complete the track. The coordinates assigned in these cases (when U.S. ports were the reported destination) were those of the Morse Code Alpha (MoA) buoys, which is traditionally where pilots meet ships to help them enter ports. The coordinates were obtained from USCG aids to navigation databases and directly from the USCG. Port location coordinates provided by the Bureau of Transportation Statistics, National Transportation Atlas Database (NTAD), were used as substitute destination coordinates for reports containing destination ports outside the United States.

To improve the value of inbound "descriptive" tracks, we mapped every route terminus coordinate within the MSRS to verify that the end of each track fell within a reasonable distance (10-km radius) from the pilot station for the reported destination port. When a "descriptive" track did not meet this criterion, we programmed the GIS to complete the track using the substitute coordinates from the appropriate pilot station (MoA buoy). Additionally, reporting requirements allowed for ships that transit a Traffic Separation Scheme (TSS) to report a location when entering the TSS and departing the TSS. Therefore, we mapped the track within the TSS for reports by ships in the northeast system that provided a valid entry location when entering the TSS headed toward Boston and reported Boston as their destination.

All tracks were coded with ancillary reported information such as entry date, system (north or south), ship speed, and destination port. The validity of each track was assessed based on criteria reported by Silber et al. (2002), and only tracks that met these criteria were used for analysis.

Tracks within each area were tallied and mapped to characterize traffic concentrations. We compared the number of tracks transiting through each system with the number of tracks traveling toward a port within the system. Tracks that crossed designated critical habitat boundaries were identified so that we could evaluate the relative amount of traffic in these areas.

To more clearly depict the relative abundance of tracks across the reporting zones, we applied a spatial filter to transform tracks (or line data) into a contoured map illustrating density. We applied the "LINEDENSITY" command using ARC/INFO's GRID software to create a raster (or cell-based) map of the density of lines in terms of km of track per km^2 within a circular neighborhood (filter) for each raster grid cell. The radius of the filter was 2 km, which was comparable to the precision of the reporting-system's requirements for location (captains are required to report location to the nearest whole minute). A kernel function option within the "LINEDENSITY" command was applied to create a smoother illustration of density.

We classified the resultant raster map of ship density by using deciles to illustrate relative ship traffic densities. "High-use corridors" were subjectively defined using the top 2 deciles from each system during three years (or seasons) of records. We estimated the distance of the high-use corridors from the area of entry into the system to their terminus. Approximate transit times along these routes were then calculated using the median speed from reported entry speed values in each system and the estimated distance of the routes.

Port Destinations and Reported Speed

We determined the most frequently reported destination ports within the system as well as those within designated critical habitat in order to identify a list of priority ports to focus the distribution of ship strike mitigation information to mariners. Ship speeds reported by mariners (for reported speeds >0 and <41 kn) were ranked (tied ranks) and compared between systems and among years using a two-way ANOVA and Tukey's honestly significant difference test for unequal sample size.

Results and Discussion

The MSRS database contained approximately 5,800 ship-report records from three years of the system's operation. Approximately 46% of the records were eliminated because of incomplete information or reporting errors, resulting in 2,146 valid ship reports from the northeast system and 1,004 reports from the southeast system that were used for analysis (Table 1). Common reporting errors included: (1) lack of valid entry location (either no entry location was provided or the reported location was not near the MSRS boundary), (2) the track was outbound from a port within a MSRS zone (outbound reporting is not a requirement of the system), (3) the track did not intersect a MSRS zone, (4) the track had limited accuracy (for example it crossed land), and (5) a ship reported into the southeastern system outside of the reporting season.

Table 1
Total valid reports in each system and year

MSRS	Year	Total valid reports	Mean entry speed in knots (n)	Median entry speed in knots	Homogeneous groups alpha = .01
NE	1	747	13.9 (744)	13.5	*
	2	674	14.2 (664)	13.6	*
	3	725	14.7 (716)	14.3	**
SE	1	278	15.7 (274)	16.0	***
	2	327	15.6 (324)	15.5	***
	3	399	15.9 (395)	16.0	***

Years are defined as July–June, beginning in July 1999 when the system began operation. The northeast (NE) system operates year-round and the southeast system (SE) operates on a seasonal basis (November 15–April 16). Mean and median speeds are from reported ship speeds (>0 and <41 kn) as they entered the system.

Not surprisingly, the density models indicated that ship traffic was not evenly distributed within the MSRS boundaries. Although ships travel throughout much of the waters within the MSRS boundaries, some areas were used more heavily than others. In this study "high-use" was defined as cell values within the upper two deciles (Figures 2 and 3). This approach and classification of values used to estimate high-use areas seems reasonable given that the TSS was clearly delineated by the analysis (and indicated by the letter "A" in Figure 2).

Northeast System

In the northeast system, we found little monthly variability in the number of ships reporting (Figure 4). The majority of the tracks (57%) were from inbound vessels transiting to locations in Massachusetts, and the remaining 43% of tracks were transiting through the system to a variety of other destinations, including both U.S. and international ports. The most frequently reported destinations for ships entering the northeast system were (in descending order) Boston, MA (53% of 2,146); Portland, ME (6%); Saint John, NB (5%); Hansport, NS (4%); and Stony Point/New York, NY (4%). Similarly, the most frequently reported destinations for ships that traveled through the designated critical

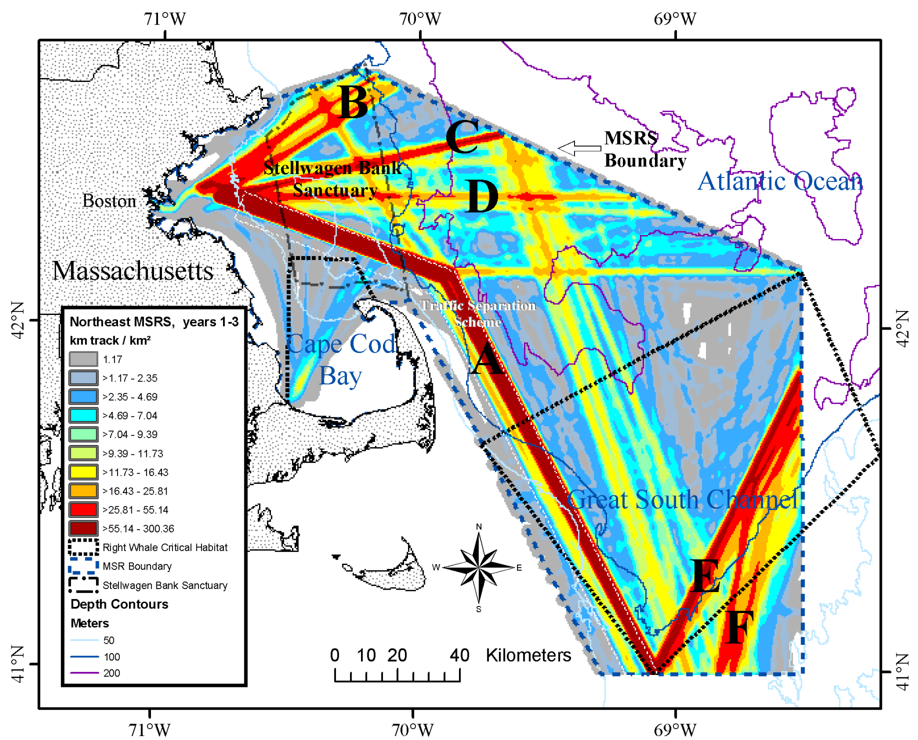

Figure 2. Relative ship traffic density (kilometers of track per square kilometer) representing data from the first three years (1999–2002) of the northeast MSRS. The letters indicate five high-use corridors that were defined as the top two decile classes. Managed areas include the federally designated Cape Cod Bay and Great South Channel right whale critical habitats, Gerry E. Studds Stellwagen Bank National Marine Sanctuary, and the northeast mandatory ship reporting boundaries are shown. The 50, 100, and 200 meter isobaths are included.

habitat portions of the northeast (69% of 2,146) were (in descending order) Boston, MA (33% of 1,479); Portland, ME (9%); Saint John, NB (8%); Hansport, NS (6%); and Stony Point/New York, NY (6%). Traffic bound for Massachusetts from the east generally used four high-use corridors (identified as A, B, C, & D in Figure 2). Of these described corridors, "A" requires the most transit time within the MSRS (using a reported median speed of 14 kn, Table 1) due to the distance of the TSS. These corridors converged near Boston, funneling about 60% of the ships that reported to the northeastern system through the Gerry E. Studds Stellwagen Bank National Marine Sanctuary (Figure 2). This sanctuary is described as the "gateway to maritime commerce of Massachusetts" in the sanctuary management plan review (Gerry E. Studds Stellwagen Bank National Marine Sanctuary, 2004) and is also an area important to several large whale species including humpback and fin whales.

Three "high-use" corridors extend across the Great South Channel (GSC) critical habitat on both the western and eastern sides (Figure 2). The western traffic is associated

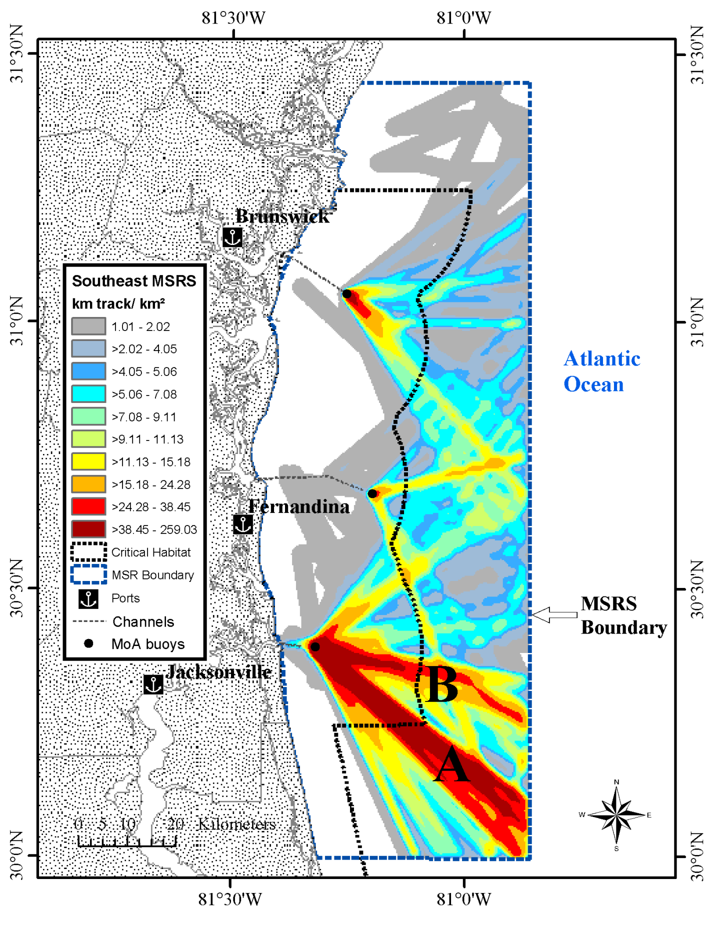

Figure 3. Relative ship traffic density (kilometers of track per square kilometer) representing data from the first three seasons (November 15, 1999–April 15, 2002) of the southeast MSRS. The letters indicate two high-use corridors that were defined as the top two-decile classes. Managed areas include the federally designated southeast right whale critical habitat and the southeast mandatory ship-reporting boundary is shown.

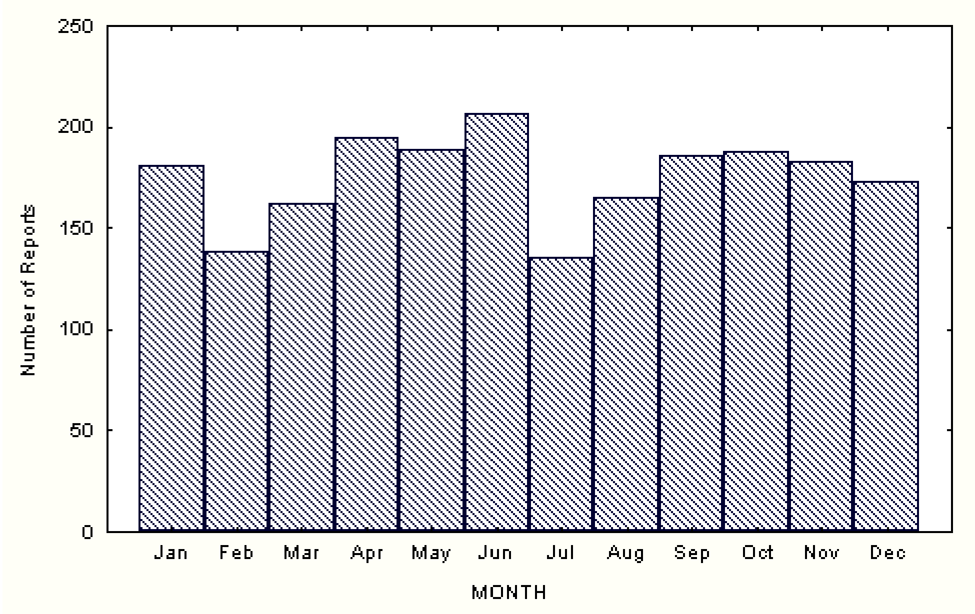

Figure 4. Number of valid reports received per month during the first 3 years (1999–2002) of the northeast MSRS (WHALESNORTH).

with the TSS leading to destinations in Massachusetts. Of ships using the eastern GSC high-use corridors (identified as E & F in Figure 2), approximately 39% (of 343) were destined for the Bay of Fundy ports (Hansport, NS; Saint John, NB; Little Narrows, NS; Bayside, NB). Other destinations that were reported from ship captains using this high-use area included ports in New York (20%), Maryland/Virginia (19%), and Florida (18%). This suggests that a certain amount of commercial vessel traffic may routinely transit three right whale protection areas, including the Bay of Fundy Conservation Area and two U.S. critical habitats (GSC and southeastern critical habitat), while traveling between U.S. and Canadian ports. This idea is supported by a report from the Port of Jacksonville indicating that Canada is a leading import country based on tonnage of all cargo types (Jacksonville Port Authority, 2004). Therefore, as a possible protection measure, consideration should be given to rerouting ships that are transiting through critical habitat bound for ports outside an MSRS boundary and minimizing the area and time in which whales would be exposed to ship traffic. Logically, navigational safety must be kept in mind in the development of proposed measures.

The GSC is intensively used by cetaceans and is a primary feeding ground for North Atlantic right whales (Kenney et al., 1995). Identified ship corridors on both sides of the GSC (A, E, & F) are in close proximity to the 100-m isobath. This finding has management implications because right whales are typically observed in the GSC during the late spring/early summer and are also roughly coincident with the 100-m isobath (Winn et al., 1986, Brown & Winn, 1989; Kenney, 2001). In the GSC, whale aggregations associated with the 100-m isobath may be related to physical oceanographic features that support dense patches of zooplankton upon which right whales feed (Brown & Winn, 1986; Beardsley et al., 1996). Feeding whales may be distracted and thus be less capable of detecting—and, therefore, avoiding—approaching vessels (Watkins, 1986; Laist et al., 2001).

Southeast System

In the southeast system, the frequency of reports per month showed little variation (Figure 5). All but two ships were inbound after entering the system and traversed through critical habitat (Figure 3). Jacksonville, Florida, was the most frequently reported destination (74% of 1,004 reports), followed by Brunswick, Georgia (15%); Fernandina Beach, Florida (9%); and Mayport, Florida (0.8%). Our density model showed that ship traffic was not evenly dispersed throughout the system. Two "high-use" corridors were associated with the approach into Jacksonville (Figure 3). Of the two, corridor "A" required the greatest estimated transit time within the MSRS (Table 1), based on distance traveled and a median speed of 15.7 kn.

The southeast area presents unique management challenges because pregnant right whale cows and cows with newly born calves frequent this area (Kraus et al., 1986), the only known calving grounds of the species. There have been three documented ship strike deaths in the southeast. A vessel operator who struck a calf reported traveling at 15 kn when the calf, unseen before impact, was struck from behind (Knowlton & Kraus, 2001). Of all confirmed right whale deaths attributed to ship strikes in the western North Atlantic between 1970 to 1999, 50% of the carcasses were juveniles or calves (Knowlton & Kraus, 2001).

The postnatal period in mammals is a vulnerable time. With calves, behavioral responses (if any) to vessels may be limited because of a lack of experience and physical capabilities that may prevent them from diving sufficiently deep or from maneuvering away from an oncoming vessel. As in other mammalian species, right whale cows maintain close contact with their newly born calves. Southern right whale (*Eubalaena australis*)

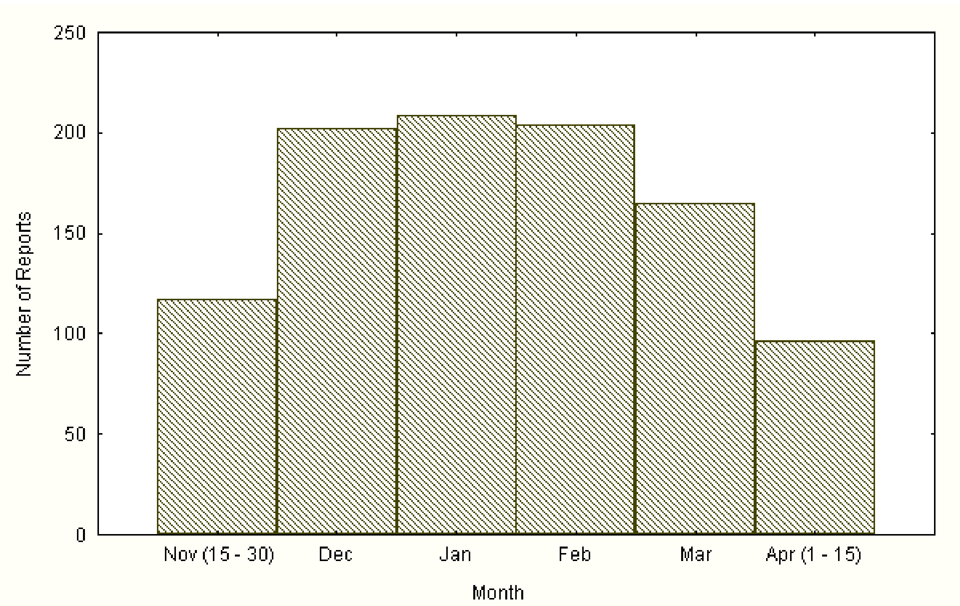

Figure 5. Number of valid reports received per month during the first 3 seasons (1999–2002) of the southeast MSRS (WHALESSOUTH). Seasonal reports from WHALESSOUTH were from November 15–April 15. For consistency, reports made on April 16 were excluded from the southeast system because the interim federal rule required reporting through April 15, so the first two seasons did not require reporting on April 16.

cows spend about 90% of their time within a distance of one-quarter of their body length from their calves (Taber & Thomas, 1982; Van Waerebeek et al., 1998). This maternal behavior may increase the cow's vulnerability to ship strikes in that her attention is focused on maintaining contact with her calf and on nursing. Potential effects of traffic such as separation of a cow from her calf and harassment, are unmeasured in the southeast. Based on studies of the effect of human disturbance on wildlife, consideration should be given to the potential effects on the energetic and time budgets of cows and calves during a reproductive stage when conserving energy may be critical for lactation and calf growth (Gabrielsen & Smith, 1995).

Measures taken in the southeast to protect whales in the calving area include intensive and systematic aerial surveys flown throughout designated critical habitat during peak calving season (December–March). Sighting information from these surveys and other observations are broadcast to mariners through coordinated efforts by the U.S. Navy, the USCG, and other cooperating agencies. The northeast region also has a seasonal (January–early July) advisory system in place that alerts the shipping industry to right whale sightings. This information is collected from aerial and ship surveys and is distributed to mariners through multiple media, including the MSRS (NOAA Fisheries, 2004). The surveying and communication network provides mariners with near real-time information on locations of some right whales. However, even this system is limited. Only about 33% of whales are seen because of detection constraints such as whales not being at the surface, observer's ability to see the whales (Hain et al., 1999), and limitations of aerial coverage of the area such as not flying during poor weather or at night (Colborn et al., 1998). Additional measures need to be developed and implemented to provide an effective reduction of risk in these important areas.

Reported Ship Speed

In the northeast system, reported speed at entry into the system ranged between 5 and 40 kn (n = 2,124, mean = 14.27, median = 14.00, SD = 2.8). In the southeast system, reported entry speed ranged from 5 to 25 kn (n = 993, mean = 15.72, median = 15.70, SD = 3.1). The majority (59%) of ships reported travel speeds greater than or equal to 14 kn (Figure 6), a speed at which Laist et al. (2001) reported that large whales may be critically injured. Ranked speed values were different between systems and years (ANOVA $p < 0.002$). Ships from the southeast system reported faster entry speeds than those from the northeast system. Entry speeds reported into the northeast system increased each year whereas reported speed changed little between seasons in the southeast (Table 2).

Summary

The MSRS generated information that was incorporated into a GIS, reviewed, and transformed to a density surface, providing a portrait of the relative concentrations of ship traffic in areas where right whales tend to aggregate. Although the traffic density estimates presented here are relative concentrations, we believe that the results of our analyses provide an accurate characterization of ship traffic because monthly counts and spatial patterns have been generally consistent over time. Year-one MSRS data were presented by Silber et al. (2002). There are some limitations to our characterization of vessel traffic, including (1) the absolute number of ships transiting critical habitats is certainly higher than we have indicated here because overall compliance rate estimates were not 100%, and some mariners have filed incorrectly formatted reports that disqualified them

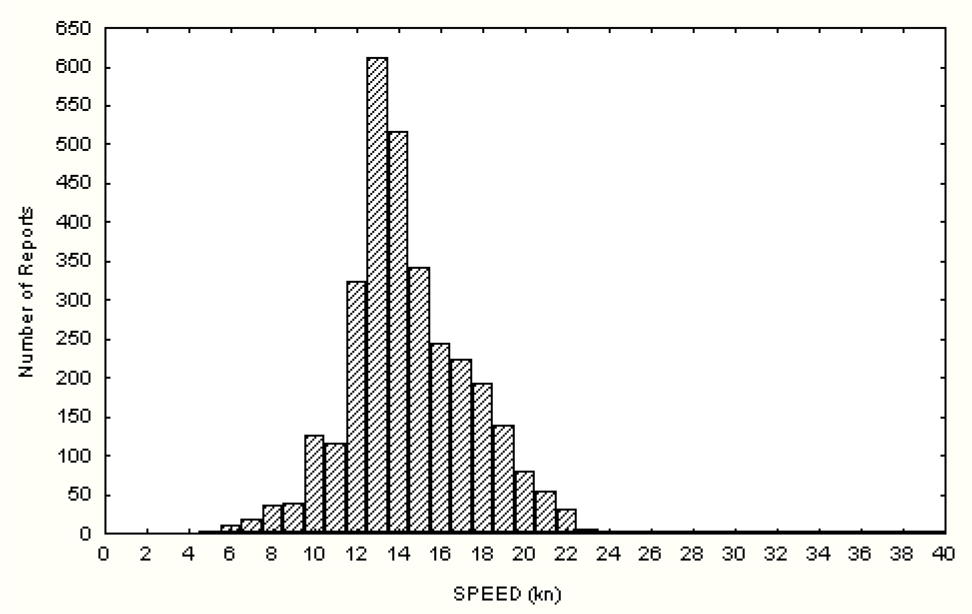

Figure 6. Histogram of speeds (kn) reported from ships as they entered the MSRS between July 1999 and June 2002 (n = 3,117).

Table 2
High-use corridors were defined as the top two deciles using values from a raster density surface of ship tracks representing 3 years (or seasons) of valid reports from each system

MSRS	High-use route	Approximate distance (km)	Estimated transit time (hours)
SE (WHALESSOUTH)	A	58	2.0
	B	49	1.7
NE (WHALESNORTH)	A	223	8.6
	B	70	2.7
	C	94	3.6
	D	136	5.3
	E	109	4.2
	F	94	3.6

The approximate distance values represent central length estimates of high-use regions from the area of entry near the MSRS boundary to or near the approach for Boston or Jacksonville (Morse code alpha buoy). In the case of high-use corridors in the northeast region used by ships that were traversing the system to ports outside of Massachusetts (E and F), distances were measured from the points of entry and exit at the MSRS boundary. Ship transit times across high-use routes were estimated from the approximate distances of the route and median entry speeds for each system (15.7 kn for the southeast and 14 kn for northeast).

from our analyses; (2) the MSRS generates information from inbound traffic only (ships that are leaving ports within the MSRS are not required to report); and (3) many tracks terminate at the location of a pilot station or MoA buoy, but this should not be interpreted as the ships' travel terminus, because ships continue to travel toward ports (see channels toward ports depicted in Figure 3). To maximize information gained through MSRS and reduce potential bias from excluding a large number of reports, it is essential to contact mariners who submit erroneous reports and instruct them on how to submit properly formatted information.

This study provides managers with information that shows where commercial traffic is concentrated within U.S. right whale critical habitats. Traffic patterns in the northeast system are more complex than in the southeast because they include a large number of ships that traversed critical habitat but were bound for destinations outside the MSRS boundary. Overall, reports from the northeast MSRS indicated that mariners in this region were traveling to nearly 100 different destinations, including ports outside U.S. waters. This finding has implications for the implementation of mariner education and outreach programs, as well as considerations regarding possible routing measures, key elements of the draft NMFS ship strike strategy described in its ANPR (2004). Although, the number of destinations creates a challenge for those determining where to distribute whale protection materials to ships traversing the region, a majority (72%) of the northeast system reports specified one of five destinations. Such information will help focus efforts to distribute information to mariners and help guide additional right whale protection measures. In contrast, traffic in the southeast system consists almost exclusively of inbound vessels traveling to four destinations within the MSRS boundary. Of those four destinations, the most frequently reported (74%) was Jacksonville. Thus, the limited number of destinations reported in the southeastern MSRS may simplify ship strike reduction measures (including, but not limited to, educational outreach efforts) in comparison to the northeast system.

Improving mariner awareness may be key in ship strike mitigation. This is based on the fact that several right whale deaths have occurred since the MSRS began operation, but the carcasses were discovered outside the two reporting areas. In particular, captains who routinely navigate through multiple areas that are known to be used by right whales should be provided with updated educational materials and encouraged to comply with MSRS requirements.

The NMFS draft strategy (2004) for right whale ship strike reduction proposed various regulatory measures including designated routes, speed restrictions, and "Areas to be Avoided" (ATBA). In considering these and other measures, the NMFS will need to take into account several factors such as navigational safety, enforceability, and economic impacts. The MSRS GIS database can assist the NMFS in several investigative analyses. For example, it will be useful in estimating potential vessel transit impacts such as distance traveled if an ATBA were implemented, the potential economic impact of speed restrictions, and identifying possible routing measures that reduce the confluence of ships and whales. The system will also lend value in monitoring mariner compliance with restrictions, if imposed. Moreover, if regulations are enacted, the system will be an important avenue for providing information about regulations to inbound ships.

Future directions in evaluating where whales may be at greater risk include investigating the concordance of vessel traffic with effort-corrected whale distributions and habitat-use models (Best et al., 2001). The development of predictive models that incorporate key environmental variables may be useful to managers by providing them with a means to dynamically and proactively focus surveillance and management strategies in an effort to reduce the threat of ship strikes to right whales.

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