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National Oceanic and Atmospheric Administration
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Under Secretary for Oceans and Atmosphere

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Introduction

The northern right whale, the world's most endangered large cetacean, inhabits both the North Atlantic and North Pacific oceans. The right whale was prized by hunters because it occurs near shore, floats when dead, and yields large amounts of high quality whale oil. Right whales in the North Atlantic Ocean were hunted as early as the 11th century, and were the target of an extensive commercial fishery in the 18th and 19th centuries. By the end of the 19th century, northern right whale stocks were severely depleted and commercial harvest was no longer economically viable. In 1949, the International Whaling Commission banned commercial harvest of right whales. The U.S. adopted the ban and right whales have now been protected from hunters for more than half a century. Despite this protection, northern right whale populations have remained at precariously low levels; currently the population in the western North Atlantic consists of approximately 300 animals.

Recovery of the population likely is being slowed by human activities, especially fishing and shipping. Collisions between ships and whales are the single largest known cause of right whale deaths. A total of 45 right whale deaths were recorded between 1970 and 1990 (IWC 1999; Knowlton and Kraus 1998). Sixteen of these (35.6%) resulted from injuries caused by collision with a ship. Thirteen (28.9%) were neonates believed to have died from perinatal complications or other natural causes. Two known deaths (4.4%) were related to entanglement in fishing gear. Fourteen animals (31.1%) died of unknown causes. Because whale carcasses may drift undetected out to sea, it is likely that some right whale deaths are unreported and that the actual number of animals killed by ship strikes is higher.

The problem of ship strikes is an ongoing one. In recent years, several right whale deaths have resulted, or may have resulted from, ship strikes although the cause of death is uncertain in some cases. One death occurred prior to the Mandatory Ship Reporting systems (MSR) becoming operational and the others are believed to have occurred outside MSR boundaries after it was established. In April 1999, an adult female was found floating in Cape Cod Bay off Wellfleet, Massachusetts. The carcass was towed ashore where a necropsy revealed blunt trauma and a broken jaw, indicative of ship strike. A calf was found floating in waters off the Southeastern United States during the 2001 calving season, but the cause of death has not been determined. Shortly after, in March, 2001 an immature male washed ashore on Assateague Island, Virginia, and a calf was found dead off New York in June 2001. Each of these carcasses found in 2001 may have sustained pre-mortem ship strike trauma, but investigation into these has not been completed at the time of this writing. Nothing is known about where or when the strikes may have occurred.

Developing a Mandatory Ship Reporting System

Recognizing that ship strikes are a severe threat to right whales, a group of organizations began in late 1997 to develop a proposal to the International Maritime Organization (IMO) to create ship reporting systems for implementation in right whale habitats. The two proposed MSR systems (one for northeast U.S. waters and one for southeast) were collaborative efforts of the National Oceanic and Atmospheric Administration (NOAA), U.S. Coast Guard (USCG), International Fund for Animal Welfare (IFAW), and Marine Mammal Commission.

The MSR proposal was endorsed by other agencies and organizations, including private shipping interests and conservation organizations. It was presented to the IMO's Subcommittee on Safety of Navigation, which approved the proposal in its July, 1998 meeting in London. The proposal was forwarded to the subcommittee's parent body, the Marine Safety Committee, which adopted the proposal in December, 1998. In early 1999, the Office of Protected Resources of NOAA's National Marine Fisheries Service (NMFS) worked with USCG personnel and a contractor to design the satellite-linked communication systems and to develop implementing regulations. The northeast system went into operation in July, 1999, followed by the southeast system in November. The cost of operating the system is shared by NMFS and the USCG. There is no cost to the mariner.

The MSR systems require all commercial ships 300 tons or greater to report in to a shore-based station before entering pre-determined reporting areas that include federally-designated right whale critical habitats. The ships are required to report their location, speed, destination and other aspects of their operation. In return, the ships receive a message describing the status, distribution, and behavior of right whales. The return message also (a) provides information about recent right whale sighting locations; (b) advises mariners that lookouts should be alert for right whales; and (c) advises mariners to reduce speed near whales, in critical habitat, and during conditions of poor visibility.

The northeast system operates year round and encompasses right whale critical habitats in Cape Cod Bay and the Great

South Channel. The southeast system operates from 15 November to 15 April and encompasses right whale critical habitat off Georgia and Florida. The reports from ships entering the systems are automatically sorted and stored in a database for subsequent analysis. These data provide a portrait of ship traffic in areas where right whales aggregate and therefore useful in developing measures to reduce the threat of ships striking whales. This report is a summary of the incoming ship reports in both MSR systems from July, 1999 to July 2000. Required compliance with the MSR was unexpectedly low (about 50%) in the first year of operation. Therefore, not *all* ships entering the MSR boundaries are represented in our analysis. Nonetheless, using the ship reports received, we characterize ship traffic volume and patterns in right whale habitat.

Operation of the System and Data Base Maintenance

Both MSR systems were designed to use existing ship-to-shore communications systems. A computer server handles and sorts incoming reports, and sends the return message. The systems use INMARSAT C (International Maritime Satellite) communications equipment that is already required on all large commercial ships. Incoming reports are text messages that arrive via either internet e-mail or telex. When the MSR server receives a report, the server sends the ship a region-specific (i.e., (northeastern or southeastern system) return message. Area coordinators provide recent right whale sighting location information to the server for inclusion in the outgoing message.

The server sorts information from incoming ship reports and stores it in a database using ACCESS software (Microsoft Corp., Redmond, WA, USA). This database is reviewed weekly to verify all ship reports and remove duplicate messages and other errors. Anticipating the likelihood of errors in the incoming, text-based ship reports, the system was designed to recognize improperly formatted messages and store them in a separate database. Reports in this database are reviewed and improperly formatted messages are manually corrected and added to the ship report database. The systems are operated under contract by PEC Solutions, Fairfax, VA, USA.

Methods

Ships' captains are required to report both the position (latitude/longitude) of their vessel at the point of crossing the MSR boundary line (Fig 1) and their final destination. Route information is reported as either a rhumb line (a fixed compass direction) directly to a port or a series of waypoints along the intended route through the system.

ACCESS software was used to compile these positions into separate and sequential records (starting with the entry position of each ship) that includes related information (i.e., reported date, time, and port destination). The information is checked for spelling, port name consistency, and correct system name (i.e., whether the report is properly entered in the northeastern U.S. or southeastern U.S. system). Database fields for the following data are converted to formats compatible with GIS software: entry and destination coordinates, entry date, and time fields. Travel paths (or "tracks") between sequential positions along the ship's intended route (or straight line between entry and destination locations) are plotted using the ArcView (AV) Geographic Information System (ESRI, Redlands, CA, USA). Ship tracks are plotted by customized AV programs, with the track assumed to be the shortest route between sequential positions.

Two types of estimated ship tracks are generated from the programs. "Simple" tracks are plotted from a line drawn between the point of entry into the system and either the destination point or estimated destination point, that is, an estimated line between two points. "Descriptive" tracks are generated by sequentially connecting more than two points, including the entry point, the destination point or a destination estimate, and the reported waypoints along the route.

Tracks are coded with ancillary information, such as ship speed, system (north or south), and entry date, to facilitate spatial analyses (e.g., to illustrate monthly ship patterns). Each track or line segment is coded using the ancillary information associated with the starting point for that track. For instance, if a track is created between two point locations, the track information includes the ancillary data associated with the first point (entry location) rather than the second point (destination). We adopted this procedure because the entry record tends to have the most complete report information.

Some ships provided the name of a destination port (textual) without reporting destination coordinates. The custom AV programs queried for cases when the mariner did not provide destination coordinates and/or where the last route coordinate fell within the MSR zone but did not plot within a 10 km radius of the pilot station for the reported destination port. In these cases, substitution coordinates were used to complete the ship track. The coordinates were based on the textual destination description. For U.S. port destinations, substitution coordinates for pilot stations included positions of Morse Code Alpha (MoA) buoys from USCG aids to navigation databases or location estimates also provided by the USCG. For destination ports outside the U.S., port locations provided by the Bureau of Transportation Statistics, National Transportation Atlas Database (NTAD), were used to estimate the terminal point of the track when destination coordinates were not provided.

For a variety of reasons, some reports are not suitable for analysis and must be excluded. (Also, as noted above, not all ships reported into the system, as required. Therefore, we were able to analyze only those reports received and, as noted in this section, some reports were rejected as being inadequate for analysis.) Ship tracks are excluded from analysis if (a) a ship does not report a valid entry location (either no entry location is provided or the reported entry location is not near the MSR boundary); (b) the track does not intersect a MSR zone; (c) a ship reports into the southeastern U.S. system outside of the reporting season (November 15-April 15); (d) a track is outbound from a port within the MSR zone (outbound reporting is not a requirement of the system); or (e) a track has limited accuracy (for example, it crosses over land).

We prepared plots of all quality controlled tracks generated from the first year of MSR operation in the northeast (July 1999 - June

2000), and for the first season of operation (November 15 - April 15) in the southeast. We used monthly plots of simple and descriptive tracks within each system to compare ship traffic at different times of the year. Using AV, we queried for and counted those ship tracks that intersected right whale critical habitat areas (Fig 1). Port of destination information was tallied for tracks passing through critical habitat and for all quality-controlled tracks in each system. We also made comparisons of the number of reports per month within both systems and within each system separately.

We compared the number of ships entering the system in "day" (0600 – 1759h) versus "night" (1800 – 0559h) periods. We used the Levene test for homogeneity and an analysis of variance to compare number of ship passages in these two periods. Reported ship speeds were described using basic descriptive statistics. We compared reported speeds in the two systems using a Mann Whitney U test.

Results

A total of 2,890 reports were received into the two systems between July 1999 and July 2000. Initial verification eliminated 1,027 of these reports because of errors such as duplicate reports or incorrect formatting. Of the remaining reports, 885 were eliminated due to incomplete information or GIS plots indicated the position data reported were in error. Thus, 699 valid ship reports were used for analysis of the northeastern system and 279 reports were used for analysis of the southeastern system.

Of the 699 tracks from the northeastern U.S. system, 313 (45%) were "descriptive" (one or more route waypoints were provided) and the remainder were "simple" tracks (entry location and destination only provided). Of the 279 tracks from the southeastern U.S. system, 67 (24%) were "descriptive" and the remainder were "simple" tracks. Our analysis involves only quality-controlled data (total n for both systems = 978).

The greatest number of ships reporting into the systems occurred in December 1999 (n = 128, 13%) when both systems were operating; the fewest reported in July 1999 (n = 36, 4%) the first month of operation and a time when only the northern system was operational (Fig. 2). The mean was 80 reports per month, and there was relatively little variation between months in the number of ships reporting in the northern system (Fig. 3), with the exception of July, 1999. In the northern system, the greatest number reports were received in June 2000 and the fewest in July 1999. In the southern system, the most reports occurred in December (22% of the reports), and the fewest (9%) occurred in April. The variation observed in the southern system is likely attributable to the timing of the operation of this system, November 15-April 15 (Fig. 4).

Ports/Destinations

Of the 978 reports analyzed, 62 different destinations were identified (Table 1). The port most often reported was Boston, MA (n = 348), representing 36% of these reports. Combining data from both systems, the five most commonly reported destinations were Boston MA, Jacksonville FL, Portland ME, Fernandina Beach FL, and Saint John, New Brunswick, with 348, 199, 51, 48, and 40 ships reporting those ports, respectively.

Northeastern U.S. System

In the northern system, the five destinations reported most were Boston MA; Portland, ME; Saint John, New Brunswick; Hantsport, Nova Scotia; and Portsmouth, NH with 348, 51, 40, 37, and 26 ships indicating those port destinations, respectively. About half (n=339, 48%) of the ships entering the northeastern system were transiting through the zone to destinations other than in Massachusetts; the remainder were inbound to Massachusetts's port destinations.

A total of 452 ships entering the reporting system (65% of all valid reports in the northeast) also transited the Cape Cod or Great South Channel (GSC) right whale critical habitat areas. Of these reports, 57 different ports were identified as final destinations. The most frequently reported destinations were Boston MA; Portland ME; Saint John, New Brunswick; Hantsport, Nova Scotia; Portsmouth NH and Stony Point, NY.

Generally, ships in the system had used one of five basic routes (Fig. 5). These involved ships:

(a) using at least a portion of the shipping lane into Boston;
(b) approaching from the east or northeast and going directly to Boston;
(c) approaching from the south, traversing diagonally across the reporting area, headed for Portland, ME;
(d) entering the system, but only utilizing a portion of the southeastern corner of the reporting area; or
(e) traveling through the system from the south, exiting the system toward New Hampshire, or the converse route.

In comparing ship tracks plotted by month, we found that monthly patterns did not deviate substantially from that described above from the cumulative ship tracks. By way of example, a plot of ships tracks from December 1999 (Fig. 6) illustrates a similar pattern.

Southeastern U.S. System

In the southern system, destinations reported were Jacksonville FL, Fernandina Beach FL, Brunswick GA, and Mayport FL, with 193, 47, 35, and 3 ships indicating these ports, respectively. All ships entering the southern system identified one of these ports as its final destination and intersected the federal critical habitat zone for right whales (Fig. 7).

In comparing ship tracks plotted by month, we found that monthly patterns did not deviate substantially from that described above from the cumulative ship tracks. By way of example, a plot of ships tracks from December 1999 (Fig. 8) illustrates a similar pattern.

Speeds of Ships Entering the MSR Systems

The reported speeds of ships as they entered the systems ranged from 5.0 to 25.0 knots (n = 970, mean = 14.4, median =14.0) (Figs. 9 and 10). The majority (55%) traveled at speeds greater than or equal to 14 knots. In the northern system, ship speeds ranged from 5.0 – 25.0 knots, (Fig. 9, n = 694, mean = 13.9 knots), and in the southern system speeds ranged from 7.7 – 23.0,

(Fig.10, $n = 276$, mean = 15.7 knots). Reported ship speeds in the northern system were significantly lower than those in the southeastern U.S. system (Mann Whitney U: $Z = -8.31$, $p \ll 0.001$).

We found little difference in ship speed in the northern system when entering during "day" (mean = 14.1 knots) versus the speed of those entering at "night" (mean = 13.9 knots) ($n = 669$, $F = 0.9$, $p > 0.05$). Using the same periods, we did, however, find a difference in the entry speed of ships during the day (mean = 16.2 knots) versus those entering at night (mean = 14.9 knots) in the southern system (Fig. 11, $n = 272$, $F = 12.45$, $p < 0.001$).

Time of Day

Ships entered both systems at all hours of day and night, but a significantly greater number of ships entered the systems during the day than at night (Fig 12). Of all quality-controlled ship reports from the northeastern system, 54% of the reports indicated entry in hours we are calling "day" (Fig. 12, Table 2, $F = 6.6$, $p < 0.02$). Similarly, of all quality-controlled ship reports from the southern system, 59% of the reports indicated entry during the "day" (Fig 13, Table 2, $F = 8.3$, $p < 0.01$).

Discussion

The reasons why northern right whale populations have been slow to recover are not well understood, but mortalities caused by human activities (ship strikes, in particular) are likely a contributing factor. Ship strikes are also poorly understood, but steps to reduce ship strikes must include efforts to characterize shipping volume and activities in right whale habitat. It is also important to make more mariners aware that right whales are vulnerable to ship strikes. The MSR is a useful tool to meet both these needs, providing mariners with critical, real-time information on right whale distribution and sighting locations, while also providing information for the first (to our knowledge) attempt to characterize shipping patterns in right whale critical habitat.

The information provided here – especially the number of ships that traverse right whale aggregation areas – demonstrates why ships present a significant threat to the species. Although the circumstances that align to cause ship strikes are not completely understood, the risk of collision is highlighted by the sheer volume of shipping in areas where right whales occur, coupled with right whale behavioral patterns (the animals spend much of their time at the surface).

This study demonstrates that a large number of ships enter right whale critical habitat. We note, however, that the true number of ships transiting right whale habitat is certainly higher than indicated here because some ships entering the area did not report in, and others filed inaccurate reports that are not included in our analysis. The relatively low number of tracks in the Cape Cod region, for instance, may have resulted both from the elimination in this analysis of tracks that appeared to cross-land and from mariners being unaware that they are required to report in before entering the Cape Cod Canal. Nonetheless, since the monthly traffic patterns did not deviate substantially, we believe the results provide a reasonable characterization of ship traffic patterns, while acknowledging that the actual number of ships traversing these areas is likely to be substantially higher than our results indicate.

A relatively small number of port destinations accounts for the vast majority of ships entering the system. In addition, nearly half (48%) of the reporting ships passing through the northeastern U.S. system are bound for ports outside the MSR boundaries. Of these, a relatively large number were bound for ports in Canada, or likely originated in Canadian maritime province ports. Those entering the northern system from the east and northeast likely originated from European ports. Our data provide no information on probable origination ports in the southeastern system. Proposed conservation measures to protect right whales from ship strikes should consider the ship traffic features described here. For example, ships traveling northeast-southwest routes through the southern system may be able to re-route further seaward with only minor negative economic impact. However, such a measure might expose ships to navigational hazards or bring ships into areas outside critical habitat where right whales also occur.

Posting additional lookouts is often proposed as a measure to decrease the likelihood of ship/whale collisions, but lookouts are of little value in periods of low visibility. High speed, low ship maneuverability, and poor conditions for sighting whales can all reduce the effectiveness of lookouts. In some cases where the circumstances of a whale strike are known, the whale is not seen until immediately prior to collision, regardless of the number of lookouts. Although posting lookouts are certainly not a panacea that will eliminate ship strikes, it is encouraging to note that the majority of ships transiting critical habitat enter during the "day," when lookouts have a better chance of detecting whales.

Plots of ship tracks in the southern system suggest that ships approach their port destination from seaward approaches in an arc ranging a full 150 degrees or more. A vessel that approaches the shore from an oblique angle spends greater time and traverses a greater distance in critical habitat than one that approaches directly (i.e., a 90 degree approach to shore). It is important to note that 75% of the tracks described for this region are "simple" lines drawn from only two points. But if this feature is real – if vessels are approaching from oblique angles – a measure requiring a perpendicular-to-the-coast course might reduce the total distance and time that vessels spend in right whale habitat.

We found little seasonal or month-to-month variation in the number of ships entering the systems. The lack of seasonal variation is informative, illustrating again the overall high volume of shipping in these areas.

With regard to ship speed, it is unclear why mean and median speed were higher in the southern system than in the northern system. The difference was small and, if real, may be linked to the sizes and types of ships regularly using northeast versus southeast ports. Laist et al. (2001) examined records of 58 ship collisions with large whales, including 10 right whales. Although the data set was small and largely anecdotal, the authors concluded that ships traveling at high speeds are more likely to strike and kill a whale than ships traveling more slowly.

The authors indicated that most whale strikes occurred at 14 knots or greater and none below 10 knots. Our analysis indicates that the average speed of ships in these areas is close to the speed (14 knots) cited by Laist et al. as being critical to collisions with right whales. A majority of the vessels in our study (55%) were traveling at or above this speed when they entered the MSR areas. If slower speeds are considered as a right whale protection measure, the shipping industry may be affected economically. More importantly, the protective benefits of slower speed would have to be weighed against the fact that a slower moving vessel may spend more time in right whale habitat and may therefore pose a threat for a longer time.

From the standpoint of right whale conservation, the MSR system likely is contributing to a reduction of ship strike risk by increasing mariner awareness of right whale vulnerability to ship strikes, although the extent of the contribution is not known. While the benefits of the MSR system are difficult to quantify, increasing mariner awareness may be an important step in reducing ship strikes. Several right whale deaths possibly resulting from ship strikes have occurred since the system began operation, however the carcasses were first observed outside the reporting areas with some occurring along mid-Atlantic states. Given this, consideration should be given to expanding the MSR system into waters off the mid-Atlantic states, or otherwise taking steps to reduce the threat of ship strikes in this region. Clearly, additional steps are needed to protect right whales from ship strikes throughout its range. We hope the data from the MSR system and this analysis will be useful to those working to identify and develop those additional steps.

Acknowledgments

Creation of the MSR would not have been possible without the foresight, conviction, and expertise of Lindy Johnson. At the USCG, Admiral Ernest R. Riutta and Captain Mark Thomas provided unwavering leadership in championing development of the system. At NMFS, Rollie Schmitten, Monica Medina, Penny Dalton, Hilda Diaz-Soltero, Michael Payne, Donna Wieting, and especially Pat Montanio recognized the importance of creating the MSR and were steadfast in their commitment to it. Bruce Russell and the International Fund for Animal Welfare provided much needed technical guidance and encouragement at critical junctures. Support and endorsement from the Marine Mammal Commission's John Twiss and David Laist were vital to the creation of the systems. Tanya Pulfer of the Florida Fish and Wildlife Conservation Commission provided GIS technical support. This manuscript was improved by George Liles and Commander Lou Orsini.

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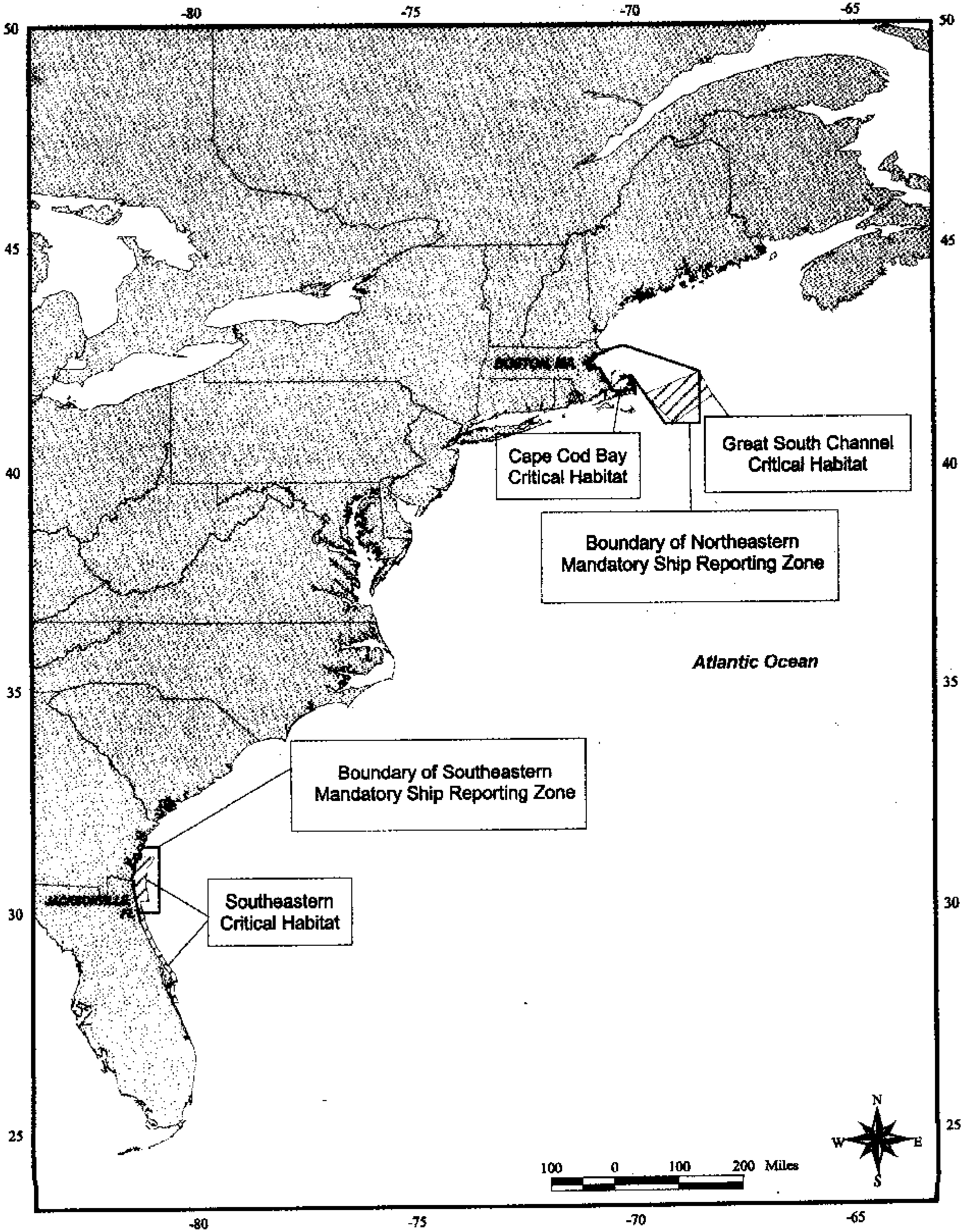

Figure 1. Boundaries of the U.S. Mandatory Ship Reporting systems and areas designated as

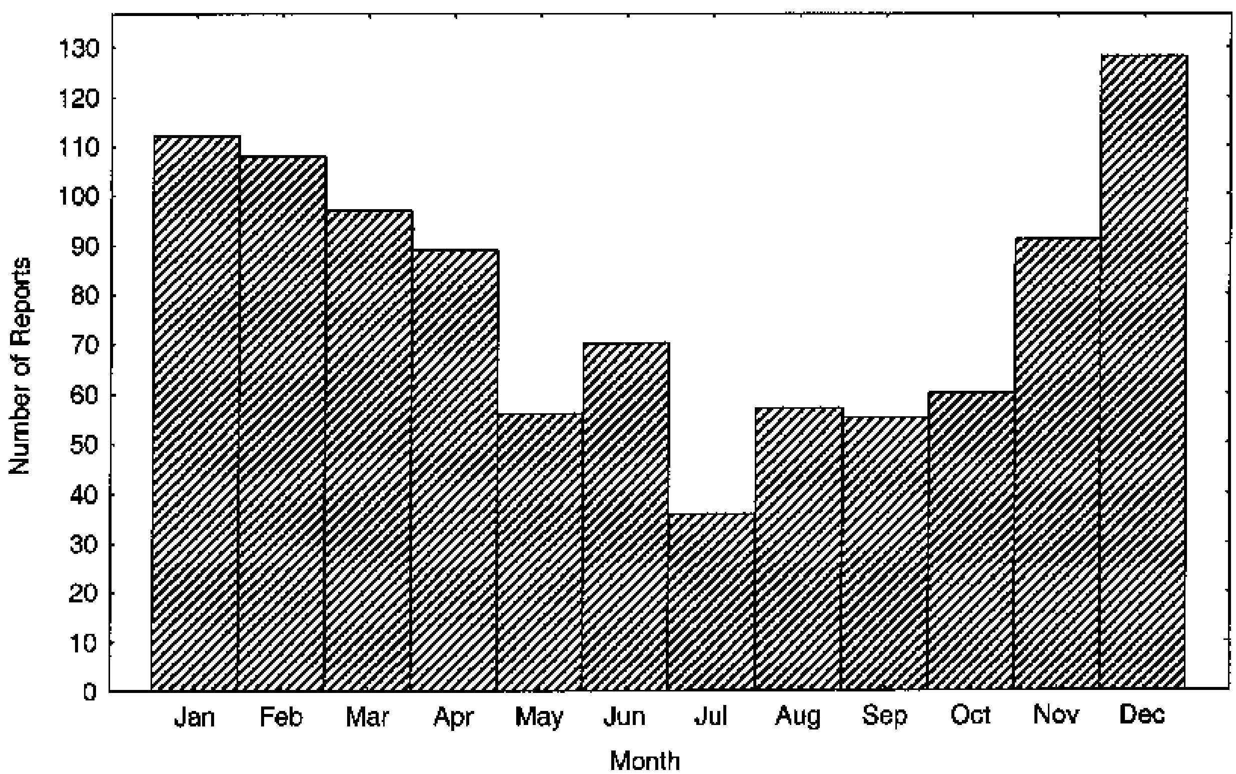

Figure 2. Number of reports received by the system, by month, between 1 July 1999 and 30 June 2000. Southeastern U.S. system reports are included and represent data from 15 November 1999 to 15 April 2000.

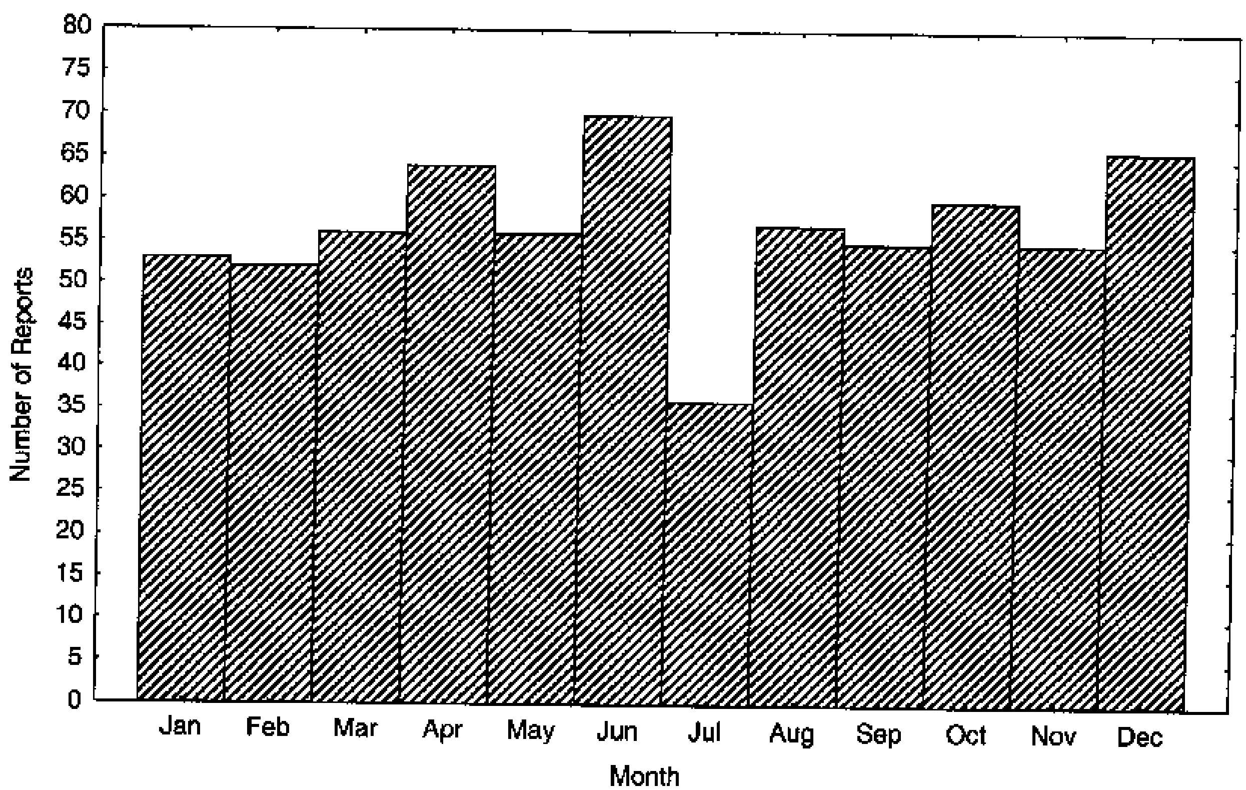

Figure 3. Number of reports received by the northeastern U.S. system, by month, between 1 July 1999 and 30 June 2000.

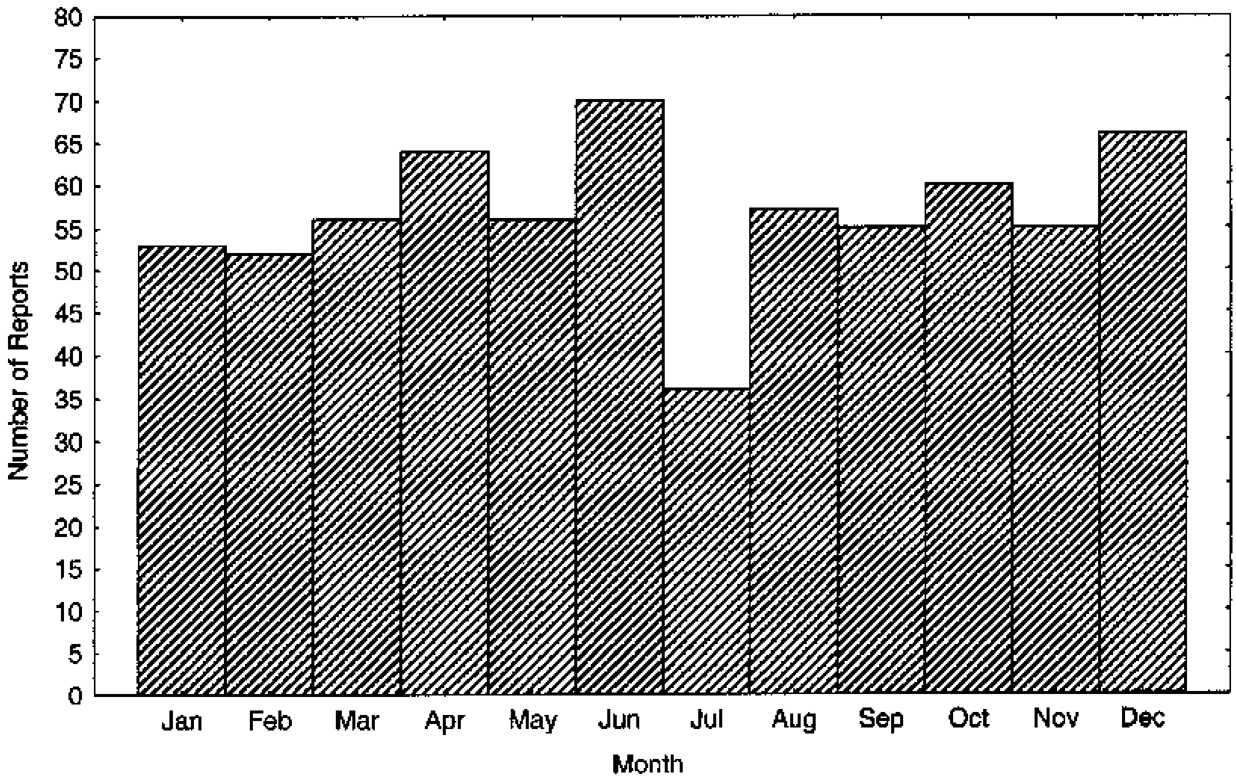

Figure 3. Number of reports received by the northeastern U.S. system, by month, between 1 July 1999 and 30 June 2000.

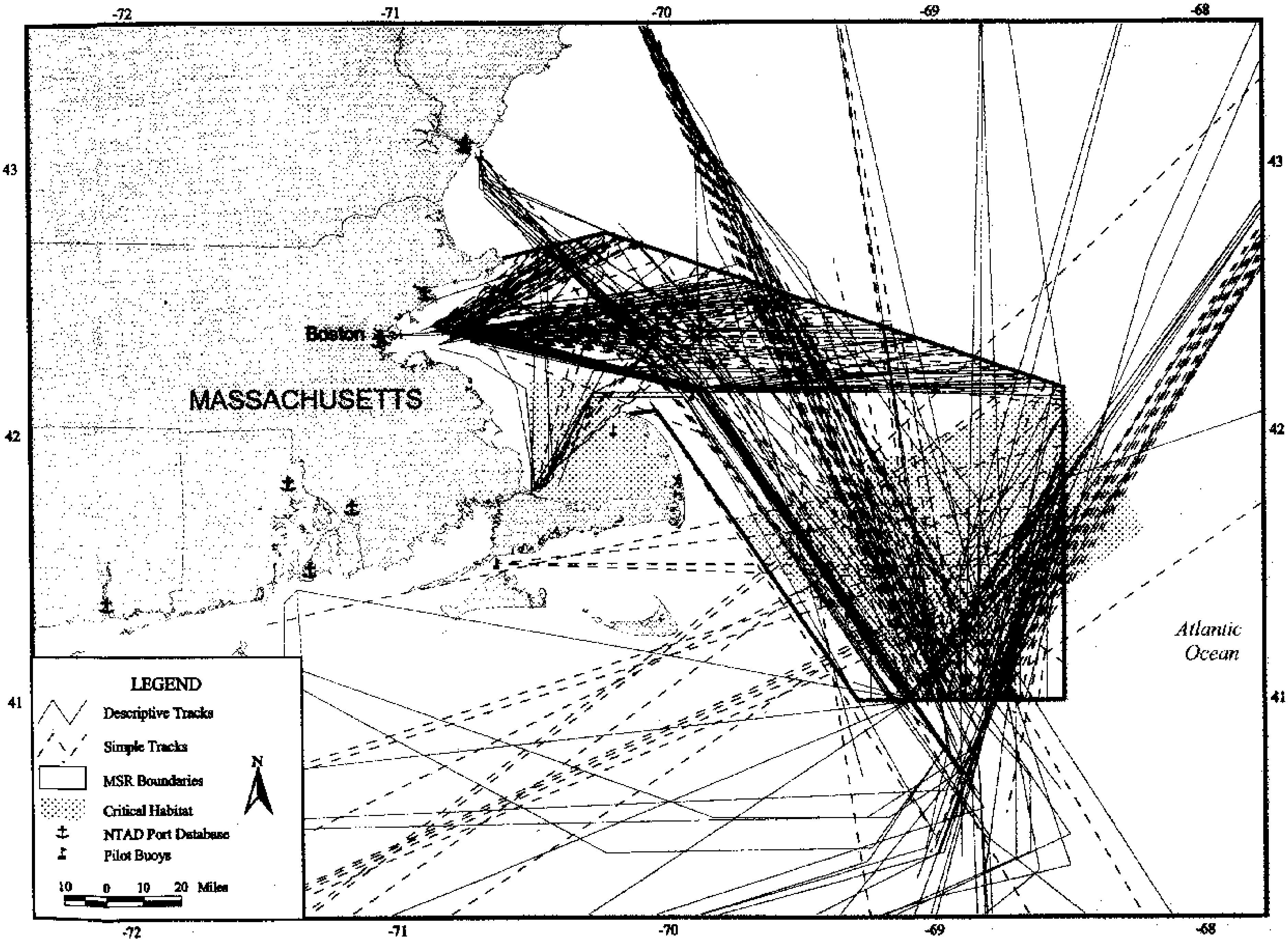

Figure 5. All simple and descriptive ship tracks (see text) in the northeastern U.S. system between 1 July 1999 and 30 June 2000.

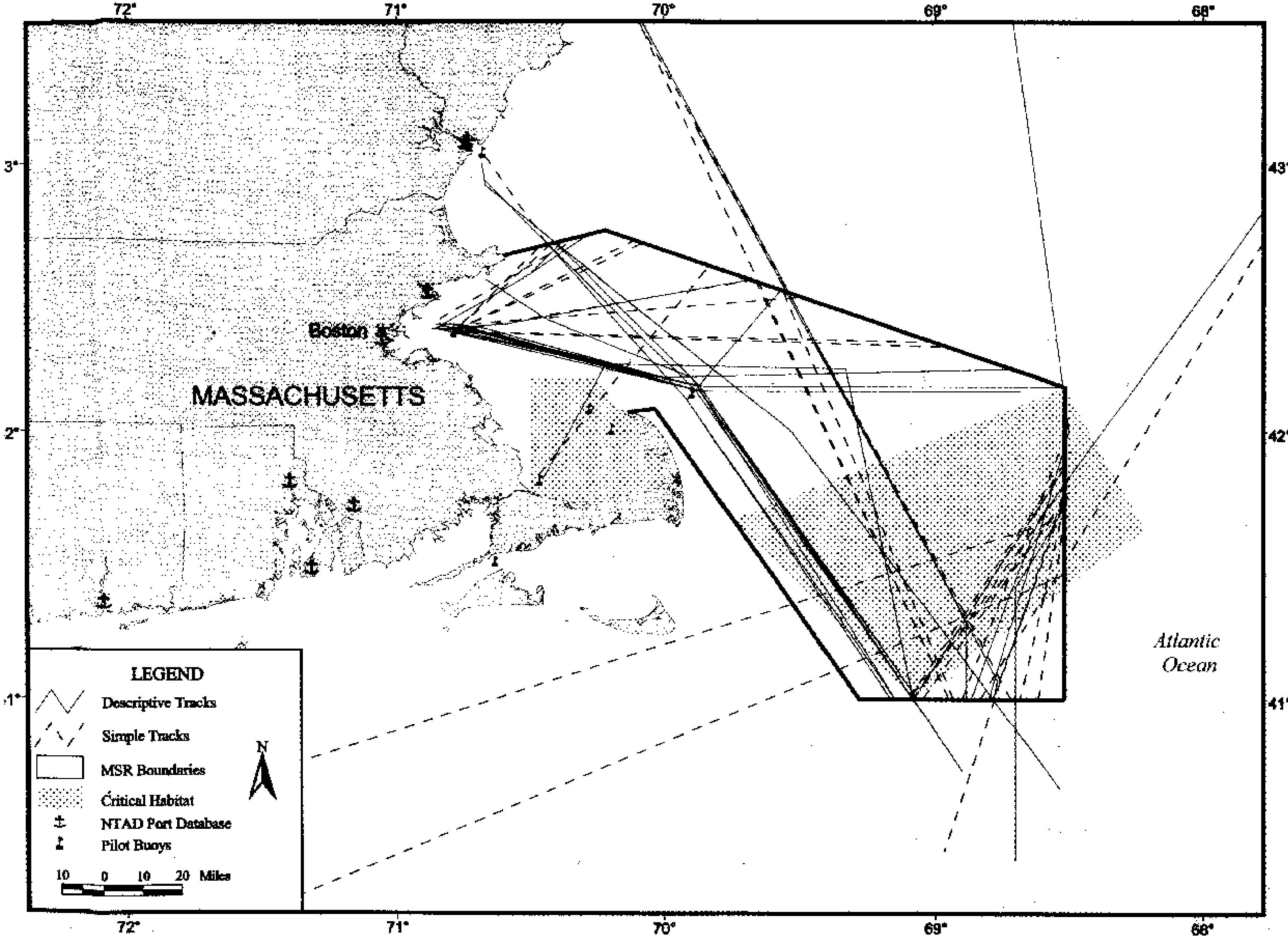

Figure 6. All simple and descriptive ship tracks (see text) in the northeastern U.S. system in December 1999.

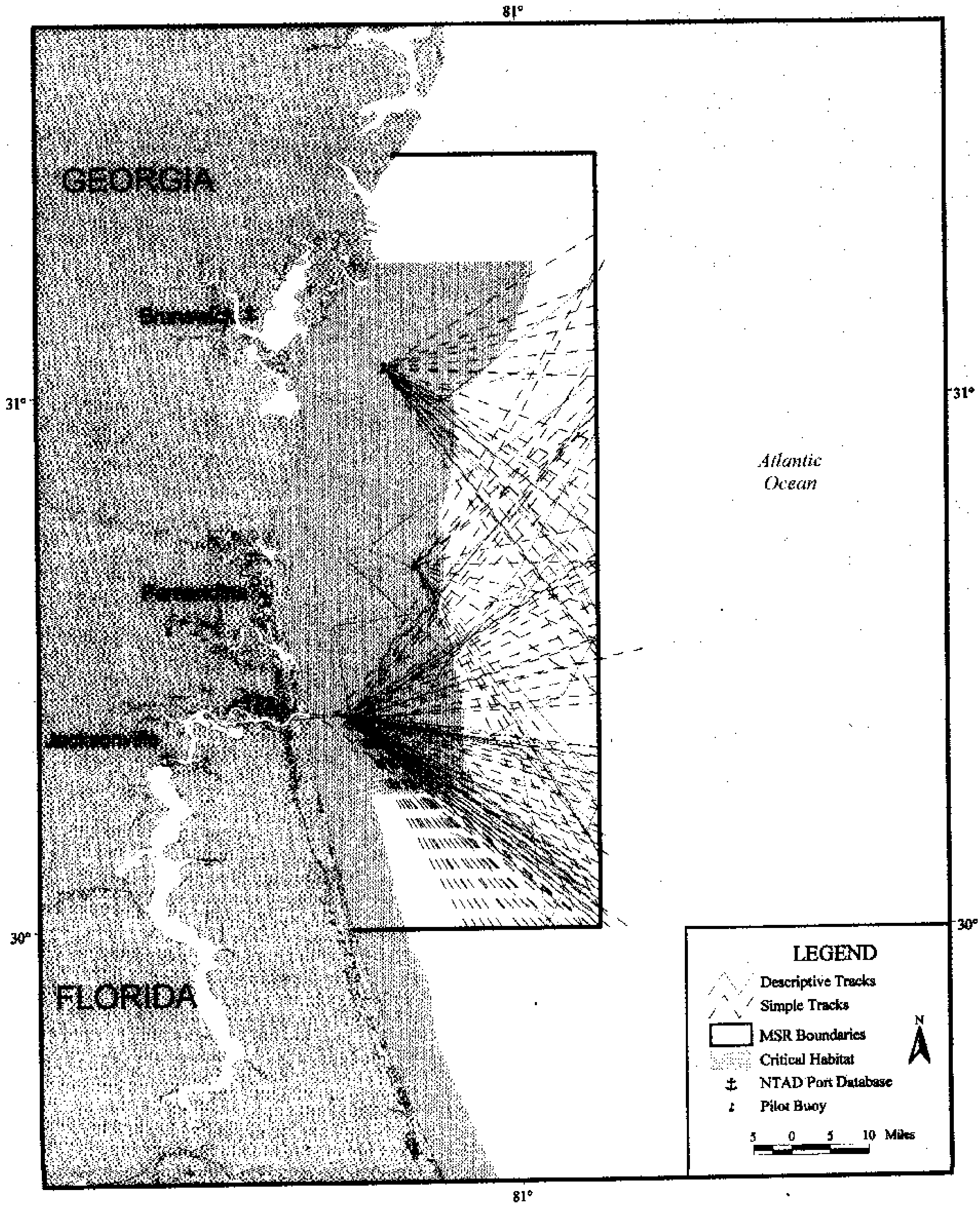

Figure 7. All simple and descriptive ship tracks (see text) in the southeastern U.S. system between 15 November 1999 and 15 April 2000.

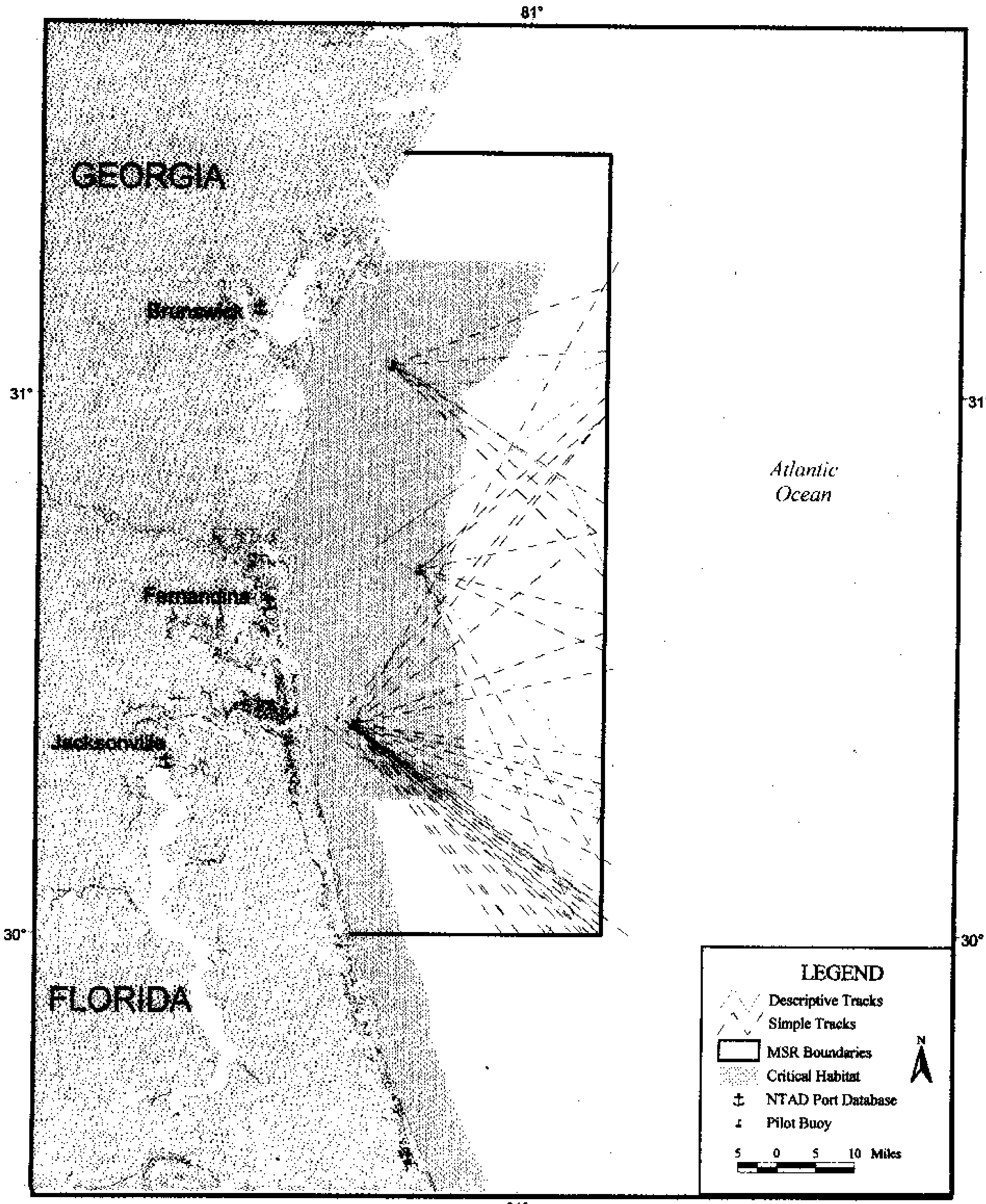

Figure 8. All simple and descriptive ship tracks (see text) in the southeastern U.S. system in December 1999.

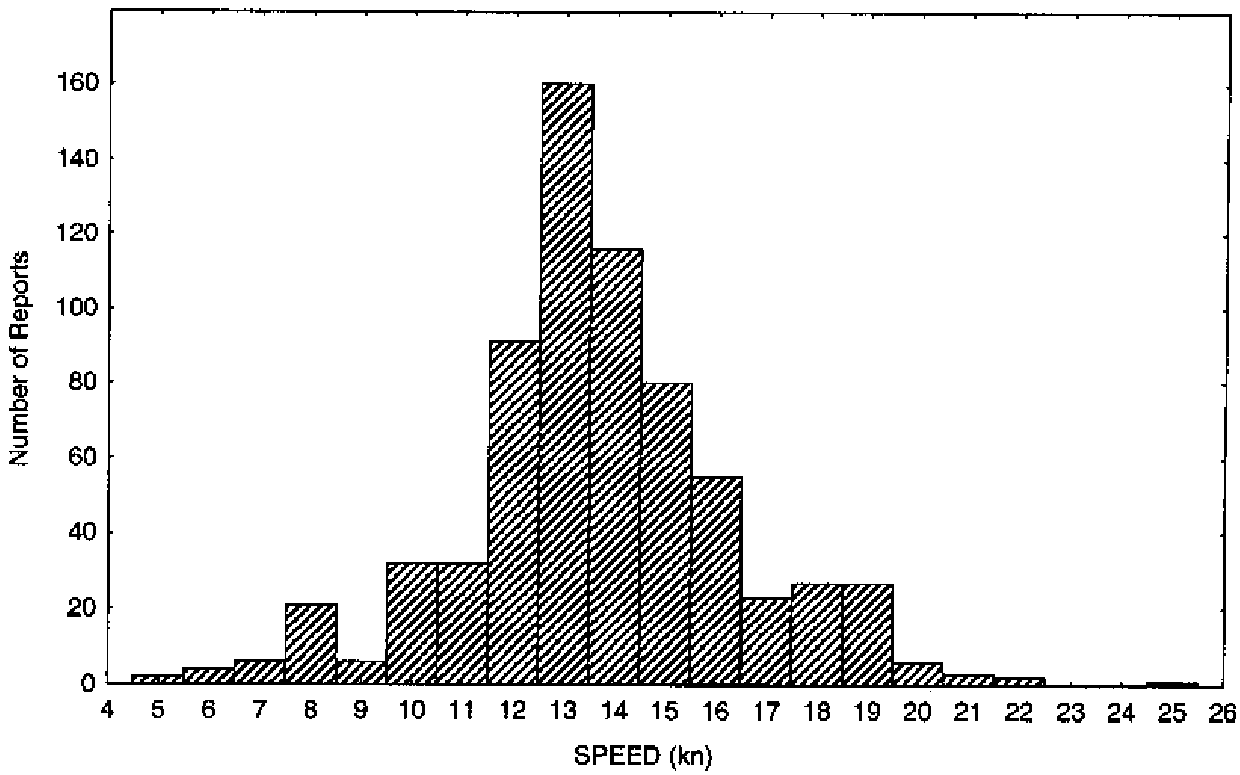

Figure 9. Histogram of entry speed of ships reporting into the northeastern U.S. system between 1 July 1999 and 30 June 2000.

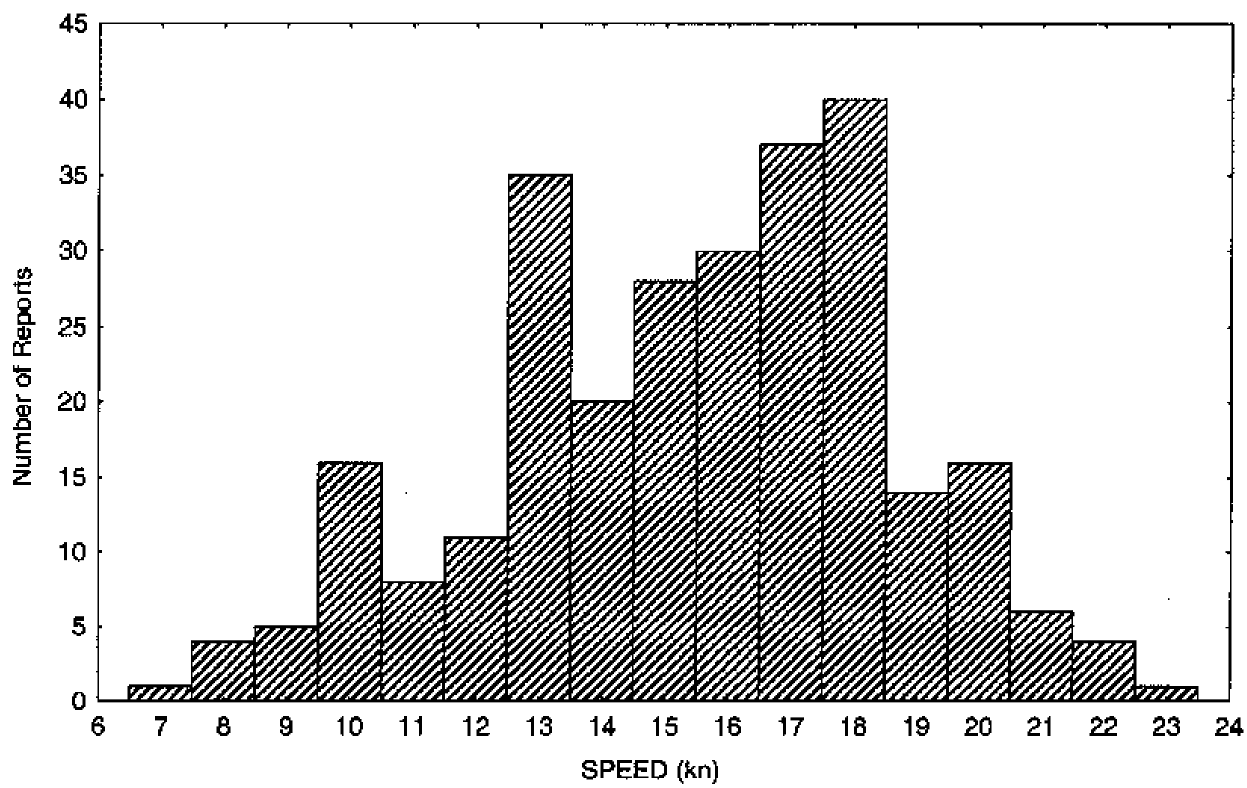

Figure 10. Histogram of entry speed of ships reporting into the southeastern U.S. system between 15 November 1999 and 15 April 2000.

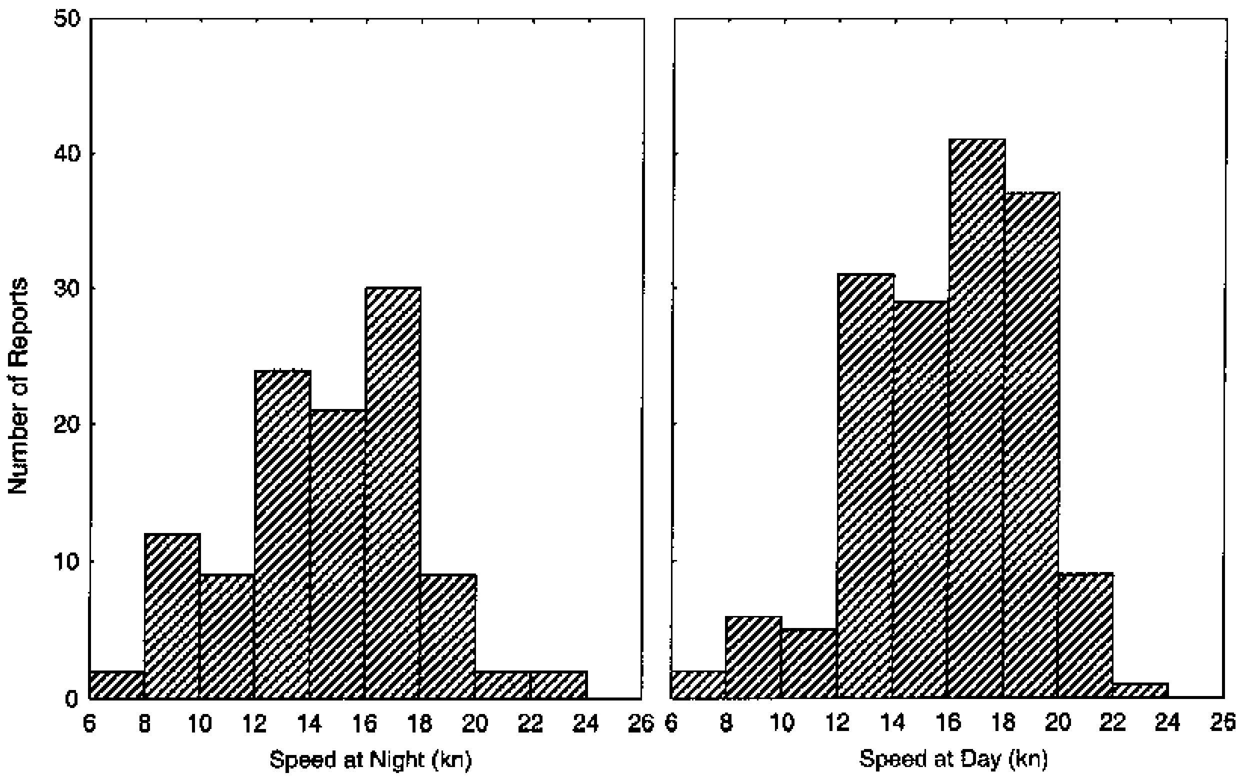

Figure 11. Histogram of entry speed of ships as reported for night versus day for the southeastern U.S. system.

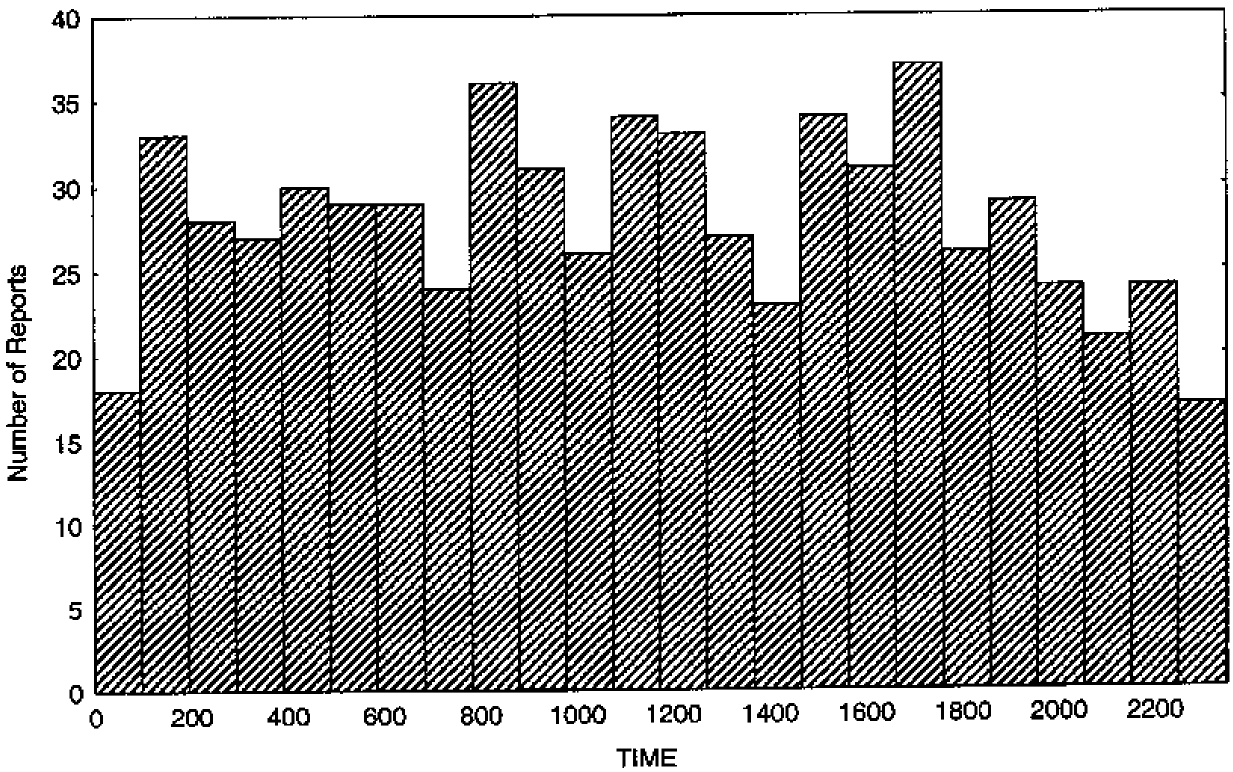

Figure 12. Histogram of time of entry for ships in the northeastern U.S. system between 1 July 1999 and 30 June 2000.

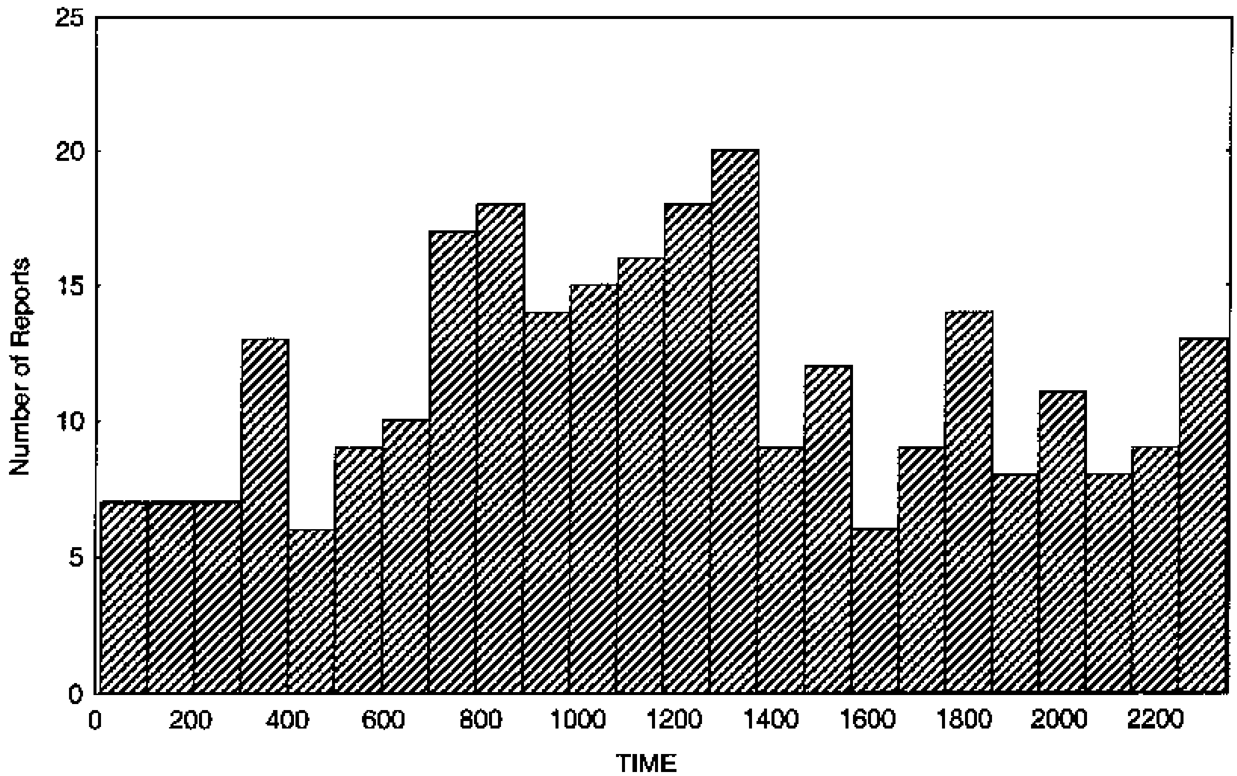

Figure 13. Histogram of time of entry for ships in the southeastern U.S. system between 15 November 1999 and 15 April 2000.

Table 1. Port destinations (those reported more than once) for ships entering the Mandatory Ship Reporting systems and the number of times each destination was indicated.

Port or Destination	Number of Reports
Boston,MA	348
Jacksonville, FL	199
Portland, ME	51
Fernandina Beach, FL	48
Saint John, New Brunswick	40
Hantsport, Nova Scotia	37
Brunswick GA	35
Portsmouth NH	26
Stony PT, NY	25
Baltimore, MD	20
Norfolk, VA	17
Puerto Miranda	8
Delaware Pilot	8
Savannah, GA	7
Little Narrows, Nova Scotia	6
Philadelphia, PA	6
Bayside, New Brunswick	6
Newington, NH	5
New York, NY	5
Eastport, ME	4
Cape Henlopen	4
Cape Cod Canal	4
Woods Hole, MA	4
Amuay Bay, VZ	4
Searsport, ME	4
Mayport, FL	3
Salem, MA	3
Houston, TX	2
Punta Palmas	2
Providence, RI	2
Halifax	2
Bar Harbor, ME	2
Ambrose Pilot	2
Wilmington, NC	2

Table 2. Number of ships entering the northeastern and southeastern U.S. systems in day versus night. "Day" = 0600h-1759h; and "night" = 1800h – 0559h.

	Day	Night
Northeast US system	365 (54.5%)	305 (45.5%)
Southeast US system	164 (59.4%)	112 (40.6%)