Applying a spatial model to evaluate the risk of interactions between vessels and Right Whales in the southeast United States critical habitat.

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Introduction

The nearshore continental shelf waters off of Georgia and Florida are the only know calving habitat for the endangered North Atlantic Right Whale. This region is also an area with a high amount of large vessel traffic including both military vessels associated with Mayport in northern Florida and commercial traffic associated with the ports of Jacksonville, FL, Fernandina, FL, and Brunswick, GA. Vessel strikes account for the majority of known mortalities of North Atlantic Right Whales. Given the necessity of successful calving for the survival and recovery of this species, it is important to explore strategies to reduce the risk of interactions between right whales and large vessel traffic in the calving area.

In a previous analysis (Garrison, 2002), a conceptual model was developed describing the vessel strike process, associated spatial scales, and the implications of whale and vessel behavior for strategies used to reduce the risk of interactions. In that study, a preliminary analysis was conducted examining the potential benefits of establishing vessel routes to reduce vessel-whale interactions. The approach focused on avoiding the close approach between vessels and whales at scales of approximately 1 km. Using a surface describing the spatial distribution of right whales within the area, this analysis compared potential approaches from the outer edge of the habitat to the pilot buoy for each port by calculating the cumulative likelihood of encountering a whale along the vessel track. This cumulative likelihood is estimated by summing the whale densities encountered across each vessel track. Limiting ship traffic to lanes where the cumulative density of animals is lowest will minimize the probability of interactions (Garrison, 2002).

There were several limitations noted in this earlier analysis. First, the surface of right whale densities was developed using effort corrected sightings data from aerial surveys, described as sightings per unit effort (SPUE). Both the spatial extent (i.e., offshore extent) and much of the spatial structure (i.e., patchiness) evident in the map was limited by the uneven distribution of survey data. The relative densities and the presence of "hot spots" in right whale densities may have been an artifact of limited or variable survey data. Second, a static, time averaged map of the SPUE was used for the previous analysis. Both within season and interannual variability in spatial distribution may have an important impact on the relative reduction in vessel strikes for a given vessel approach. Finally, the SPUE surface did not include an estimate of the variability in spatial distribution, therefore it was not possible to incorporate the underlying variability in both process and estimation into the analysis of strike risk.

This analysis addresses these limitations by including a surface of predicted right whale densities derived from a statistical model of spatial distribution based upon habitat characteristics. The resulting predicted surface is resolved temporally in two-week intervals between December and the end of March and includes an estimation of the variability in predicted densities. Further, the predicted surface has a coarser spatial resolution and is not limited by the spatial distribution of available survey data, thereby reducing the artificial patchiness of the empirical SPUE surface. Based upon this surface, approaches to each pilot buoy in the Southeast United States (SEUS) right whale habitat are evaluated to determine those approaches that result in a reduced probability of encountering right whales.

Methods

Modeling Right Whale Density

Aerial surveys in the SEUS right whale habitat have been conducted each winter (December – March) since 1992. The resulting right whale survey effort and sightings data were aggregated into 2-week intervals and spatially into 4x4 km square cells for each survey year between 1992/1992 – 2000/2001. The boundaries of the study area encompassed the spatial extent of flight search area (NE corner 80º28'5"W, 32º8'29"N and SE corner 80º20'4"W,29º14'4"N, Figure 1) comprising a total of 1,670 16-km^2 cells. For each spatial cell and biweekly period, average sea surface temperature was estimated using satellite imagery. Water depth for each cell was also summarized from available bathymetric grids. Additional habitat variables evaluated in this analysis included distance from shore, average monthly wind speed, bathymetric slope, year, and geographic location.

A habitat model was developed using Generalized Additive Modeling (GAM). A stepwise procedure was used to select habitat variables that are significant predictors of right whale density and spatial distribution. Annual effects were included in the model to account for interannual variability in the number of right whales arriving in the SEUS area. Water temperature and bottom depth were the only significant predictors of right whale spatial distribution in this region. Peak right whale densities are expected to occur in water temperatures between 12-15°C and depths between 10-20 m. The methods and results of the habitat model are described in detail in Garrison (2005).

Biweekly predicted right whale density surfaces were derived from average sea surface temperatures for each cell and predicted sighting rates across the period from 1992/1993 – 2000/2001 (Figures 2-3). These surfaces represent the relative likelihood of encountering right whales in each spatial cell.

Vessel Traffic Data

Information on the spatial distribution and amount of commercial shipping traffic was derived from the Mandatory Ship Reporting System (MSRS) implemented for the SEUS right whale habitat area starting in November of 1999. These data are described in detail in Ward-Geiger *et al.* (2005). Commercial vessels with gross weights greater than 300 tons are required to report their entry position, destination, and speed upon entry into the "WHALESOUTH" reporting area. Vessel tracks may be reported as "simple tracks" showing only the point of entry and the pilot buoy for the respective port or by "complex tracks" indicating one or more waypoints as they transit the area. Vessel traffic data reported between December 1999 – March 2000 and December 2000 – March 2001 were used in the current analysis.

Vessel traffic data was summarized temporally into the number of reports, representing vessels entering the system, for each biweekly interval for each port (Jacksonville, Fernandina, and Brunswick). Vessel track data was summarized spatially by summing the total reported vessel trackline in each 4x4 km spatial cell used in the habitat analysis.

Assessing the Risk of Vessel-Whale Interactions

The risk of vessel-whale interactions for each cell is represented by the product of the predicted whale density, p, and the length of vessel track, v, for the cell. The total vessel track for each spatial cell and biweekly interval was summarized for each port. The total vessel track is then multiplied by predicted whale density for that biweekly interval and the product is summed across seasons to assess the total risk. The cumulative risk of interaction is therefore given by:

$$(1) \qquad Risk = \sum_{s} \sum_{z} v_{sz} p_{sz} ,$$

where s is the number of biweekly intervals and z is the number of spatial cells where vessel traffic occurs. The "status quo" risk level for each port is calculated based upon all reported tracks and spatial distribution of vessel traffic from the MSRS data for 1999/2000 and 2000/2001.

The goal of routing measures is to concentrate vessel traffic into one or more approaches into each pilot buoy that minimize the potential encounter with whales. The "best" approaches will be those that cross regions with the lowest predicted densities. For each port, a series of 64 potential vessel approaches to the pilot buoy were drawn from the edge of the MSR box (Figure 4). The starting point for each potential route is the mid-point of a 4x4 km cell used in the analysis. The MSR box was chosen as the starting point because this is the limit of available data on vessel traffic patterns. For each spatial cell intersected by a given route, the track length was multiplied by the predicted whale density for a given biweekly interval and the total number of calls to that port reported to the MSRS system. This was summed across the biweekly intervals to provide an equivalent measure of cumulative strike risk to that of the "status quo" vessel traffic pattern. The change in the cumulative strike risk relative to the status quo for each port is used to assess the potential benefit of the route for reducing the probability of whale-vessel interactions.

Results and Discussion

Vessel Traffic Patterns

There were a total of 278 reports to the MSRS system in 1999/2000 and 327 reports during 2000/20001. The number of reports was fairly uniform across the biweekly periods and averaged 27.6 reports every two weeks during 1999/2000 and 32.5 during 2000/2001 (Figure 5). The majority of the reports in each year were from vessels bound for Jacksonville. This number of vessel reports does not represent the total amount of vessel traffic in the surveyed area. Compliance rates, particularly in the first year of the MSRS required reporting, are less than 100% and, the true level of traffic entering the system is certainly higher than the number of reports. Second, outbound traffic is not required to report and therefore is not represented here.

The spatial patterns based upon MSRS reports demonstrate an uneven distribution of vessel traffic throughout the area. The majority of vessel traffic approaching Jacksonville enters the area from the extreme southeast corner (Figure 6); however, there is a significant amount of Jacksonville traffic that traverses the habitat from the north. Both Fernandina (Figure 7) and Brunswick (Figure 8) likewise have the majority of traffic entering from southeast of the pilot buoy to due east. Fernandina does have a significant amount of traffic entering from the north However, there is significant interannual variability in the traffic patterns for these two ports. The spatial patterns in vessel traffic shown here are also demonstrated in the analysis of these data by Ward-Geiger *et al.* (2005).

Relative Risk – Jacksonville

Approaches into Jacksonville from the northeast result in considerably elevated risks to right whales relative to the status quo. This reflects both the absolute length of the transit and the relatively high densities of whales predicted offshore in the northern part of the habitat range (Figure 11). The best approaches to the Jacksonville buoy are those that enter the system from the southeast, yet have generally shorter transit distances by approaching more from the east (Figures 11-12). Approaches 40-48 (Figure 12) had largely similar reductions in the risk of vessel-whale interactions relative to the status quo. Concentrating traffic into these lanes is predicted to reduce the likelihood of interactions by 22-27%. These approaches are further north than the prevailing traffic pattern approaching Jacksonville during 2000/2001.

Relative Risk – Fernandina

As with Jacksonville, the best approaches to the Fernandina buoy are from the east and southeast (Figures 13-14). The approaches from the north generally have higher risk levels and concentrating traffic into these lanes would increase the probability of interactions relative to the status quo. Approaches from the east-southeast result in a reduced level of risk relative to the status quo. Approaches 32-45 result in significantly reduced levels of risk with reductions ranging between 24-32% relative to the status quo (Figure 13). The best lane corresponds to approach #41 with a risk reduction of 32.1% (Figure 14). Since the majority of the traffic into Fernandina reported for the 2000/2001 season approached from the east or northeast, the best lanes would require a significant shift in traffic patterns for this port.

Relative Risk – Brunswick

The benefits of potential routing are less pronounced for Brunswick (Figure 15). There are relatively few approaches that result in reduced risk relative to the status quo. This results primarily from the fact that Brunswick is in an area where the relative densities of right whales are predicted to be high well offshore. The best approaches into Brunswick are generally those approaching from nearly due east. These lanes result in a reduction of strike risk between 10-16% with the best lane corresponding to line #23 (Figure 16). The significant amount of traffic approaching Brunswick from the southeast traverses a large area with high densities of whales, resulting in elevated risks of vessel strikes.

Distance from Shore

This analysis of vessel-whale interaction risk conducted here assumes that potential routes will begin at the edge of the MSRS box. Conceptually, these routing measures would imply that vessels would stay outside of this box on their approach to the area and then turn in toward the pilot buoy. However, the area of highest predicted densities of right whales is generally close to shore and declines with increasing distance away from the buoys, particularly in the southeast section of the area. Therefore, the majority of interaction risk is expected to occur in areas relatively close to the pilot buoy. The cumulative proportion of risk for each of the best approaches to each port as a function of distance from shore is shown in Figure 15. Roughly 95% of risk of vessel-whale interactions for each lane occurs within approximately 45 km from shore. Depending on the location of the pilot buoy, this results in varying distances from the buoy. For example, the Fernandina buoy is located approximately 25 km from shore, and therefore the majority of the risk is relatively close to the buoy's position. Given these spatial patterns, it may be possible to consider widening the lanes or otherwise reducing traffic restrictions at the outer edges of the habitat boundary, as the large majority of risk reduction is accomplished by traffic restrictions in relatively nearshore waters.

Other Considerations

The options considered here for vessel routing are based strictly upon reductions in the likelihood of vessel-whale interactions in the SEUS during winter months. Clearly, other considerations including navigational safety are important to consider before recommending or implementing requirements for vessel routing in this region. While the entire area of these approaches up to the pilot buoys is of sufficient depth for the draft of large commercial vessels, there are numerous fish havens and underwater obstructions that may or may not pose a navigational hazard. The approaches currently used into the pilot buoys have been surveyed to ensure that there are no known hazards, and it is likely that a similar survey would be required before implementing any proposed changes.

This analysis uses information on the average spatial distribution of right whales in relationship to habitat variables as observed over the last ten years. One important aspect of right whale movement that is not included here are the daily or within season movements of right whales within the calving area. These individual movements may have important implications for exposure to shipping traffic. For example, if areas of relatively high intensity vessel traffic are established, whales may traverse these areas and thus be exposed to a "highway" effect. Conversely, the concentration of vessel traffic in a predictable area may have a beneficial effect in that the whales may alter their behavior to avoid any traffic lanes. However, these individual behavioral effects are not included in the current analysis, and they should be considered before establishing routing measures.

Conclusions and Potential Approaches

The results of the current analysis suggest that restricting vessel traffic to specific lanes may significantly reduce the probability of vessel-whale interactions in the SEUS calving area. The reduction is more significant for the ports of Jacksonville and Fernandina where generally east-southeast approaches cross areas with lower predicted densities of whales. Before implementation, any recommended routes would have to be modified for navigational safety, such as avoiding potential hazards due to fish havens or other obstructions. Therefore, I am providing an "envelope" of approaches that may be considered for each port (Table 1). Within this envelope, it is expected that one or more routes may be recommended or required for commercial shipping traffic as part of a comprehensive effort to reduce the risk of vessel strike mortalities of right whales.

Literature Cited

Garrison, L.P. 2002. An initial analysis of the risk of ship strike in the southeast US critical habitat for northern right whale: Interim recommendations for routing options. Southeast Fisheries Science Center, 75 Virginia Beach Dr., Miami, FL 33149.

Garrison, L.P. 2005. in prep. Defining the North Atlantic Right Whale Calving Habitat in the Southeastern United States: An Application of a Habitat Model. Southeast Fisheries Science Center, 75 Virginia Beach Dr., Miami, FL 33149.

Ward-Geiger, L.I, Silber G.K., Baumstark, R.D., and Pulfer T.L. 2005. Characterization of Ship Traffic in Right Whale Critical Habitat. *Coastal Management* 33: 263-278

Table 1. Potential approaches to each pilot buoy that are expected to reduce the likelihood of interactions between commercial vessels and right whales. The approaches are listed as the bearing from the edge of the MSRS box (approximately 80° 38' E longitude) to the respective buoy.

Pilot Buoy	Southern Limit	Northern Limit	Best Approach	Percent Reduction
Jacksonville	300	270	275	27%
Fernandina	322	270	312	32%
Brunswick	273	289	279	16%

Figure 1. Spatial cells (4x4 km) used to aggregate environmental and sightings data in the habitat analysis. Total right whale sightings within each spatial cell across the entire time series is shown.

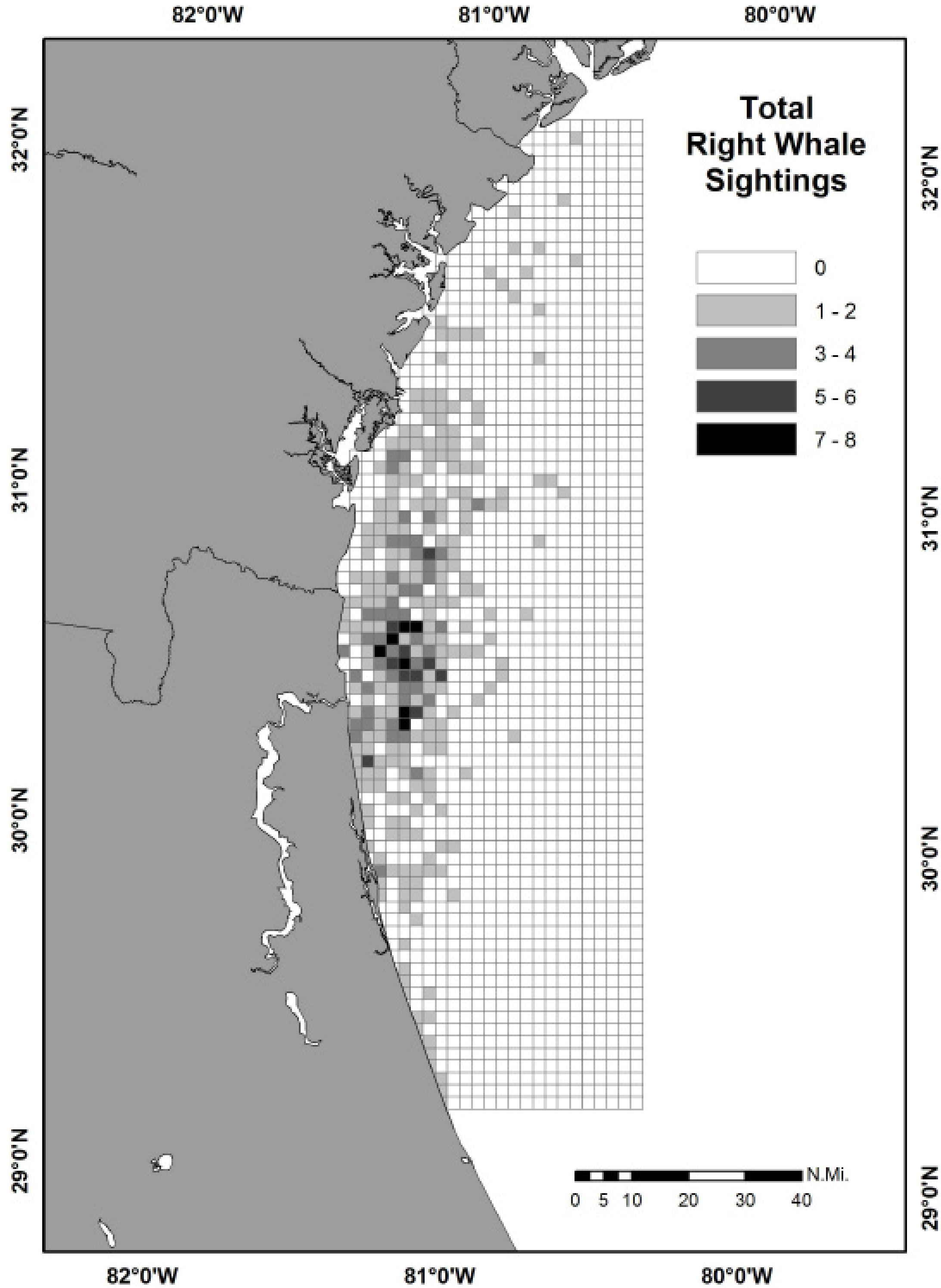


Figure 2. Predicted average right whale sighting rates for biweekly intervals in December and January between 1992/1993 and 2000/2001.

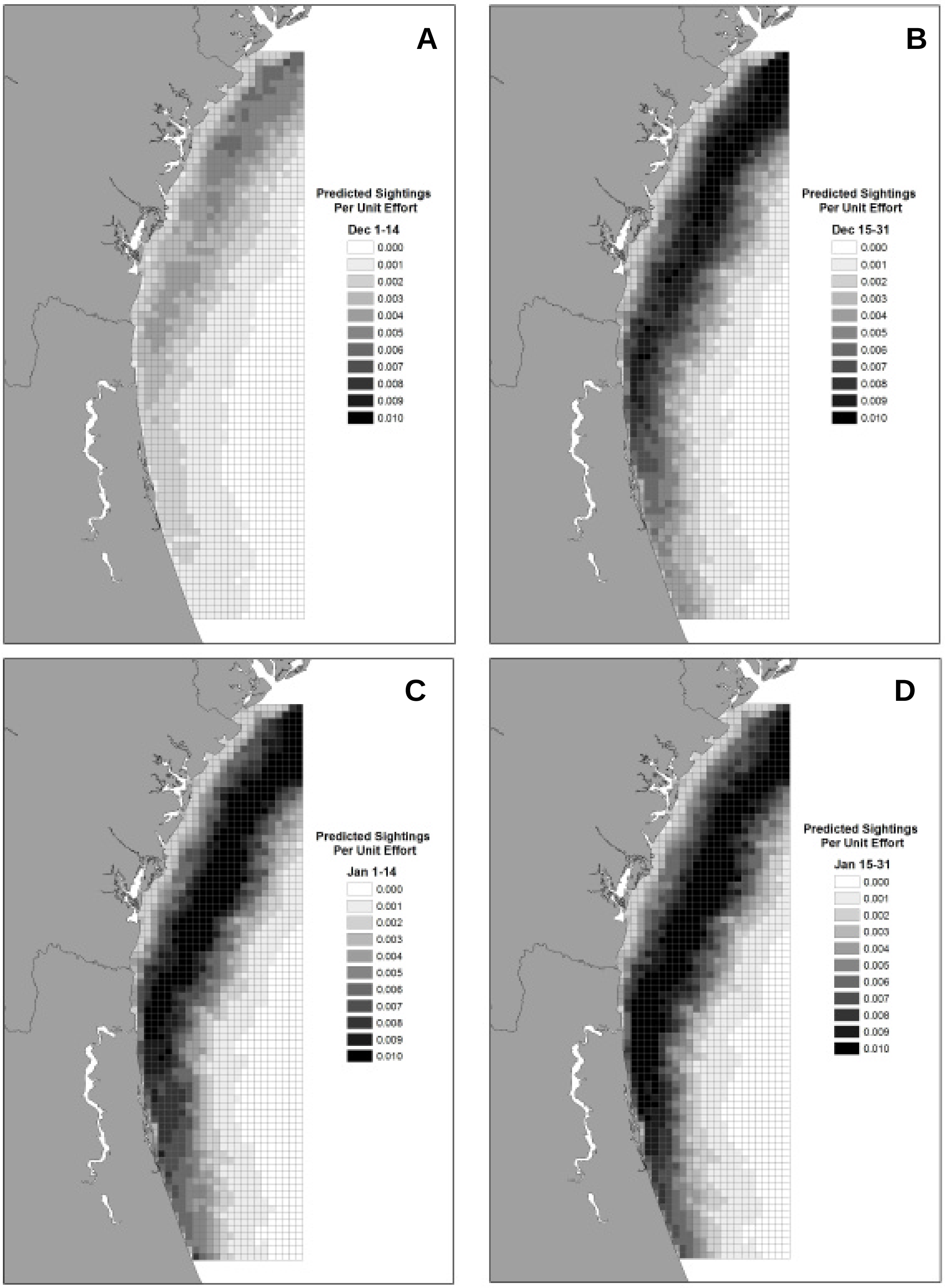


Figure 3. Predicted average right whale sighting rates for biweekly intervals in February and March between 1992/1993 and 2000/2001.

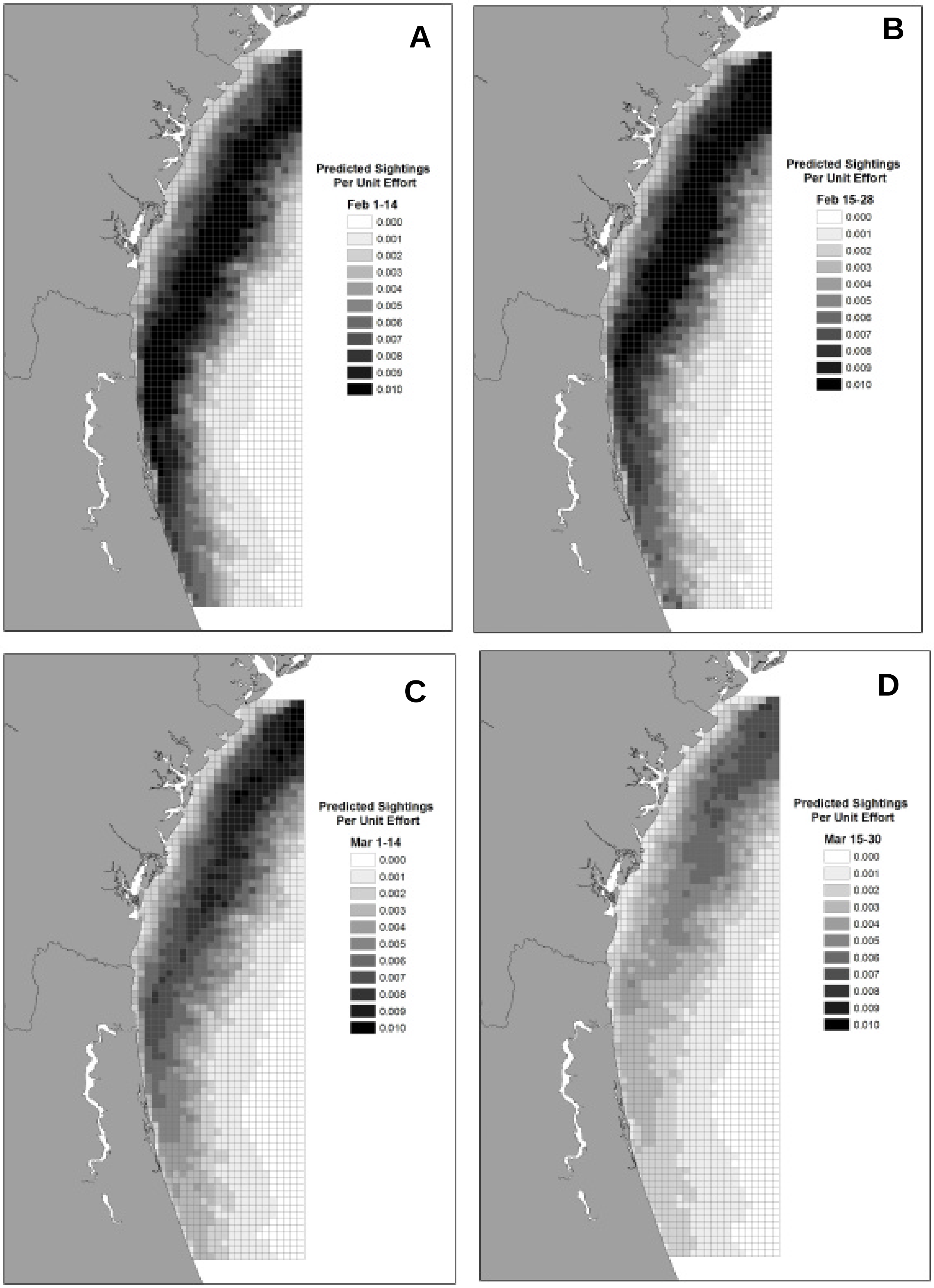


Figure 4. Potential approaches into the pilot buoys for (A) Jacksonville, (B) Fernandina, and (C) Brunswick explored as alternatives to reduce whale-vessel interactions.

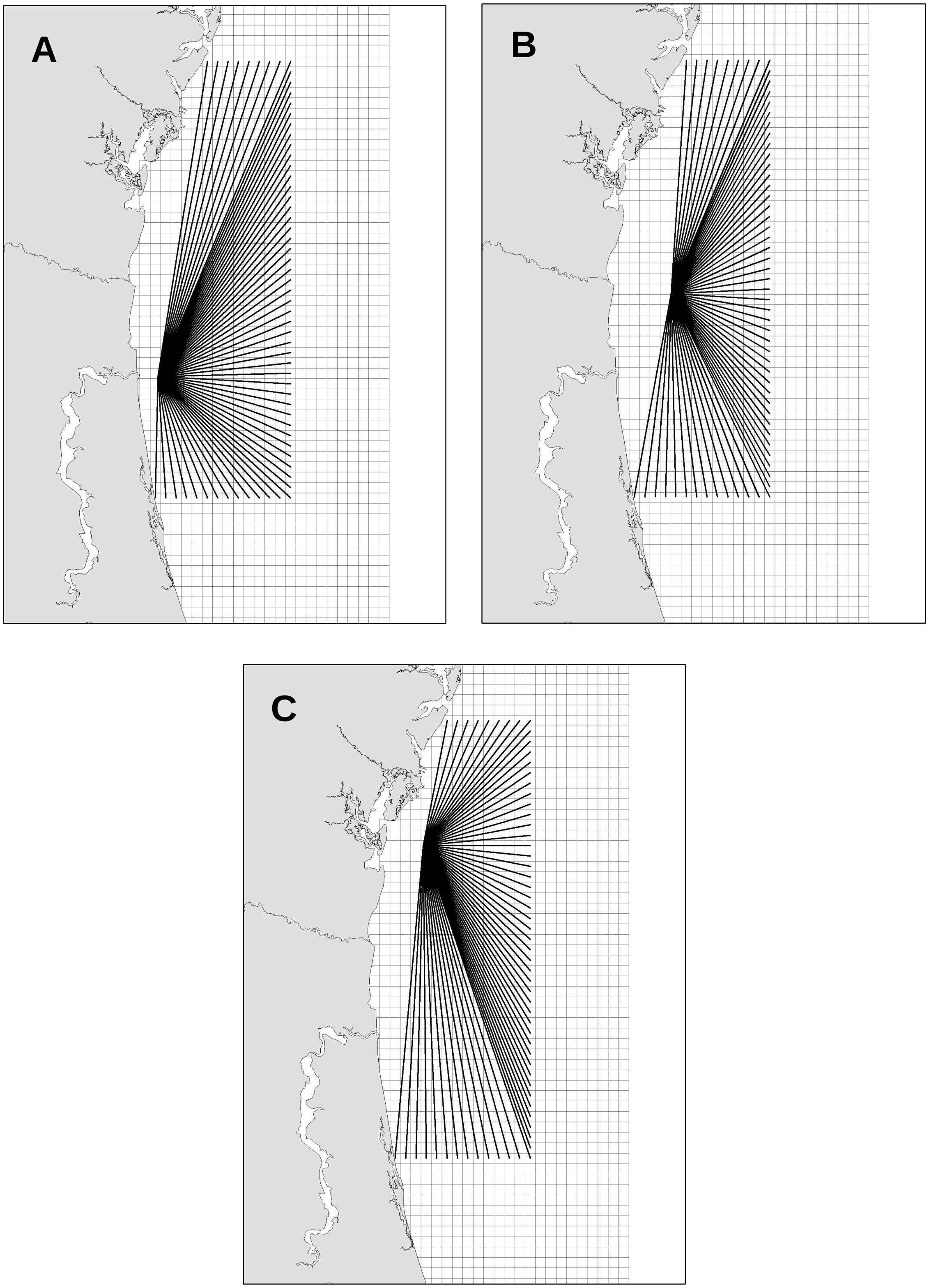
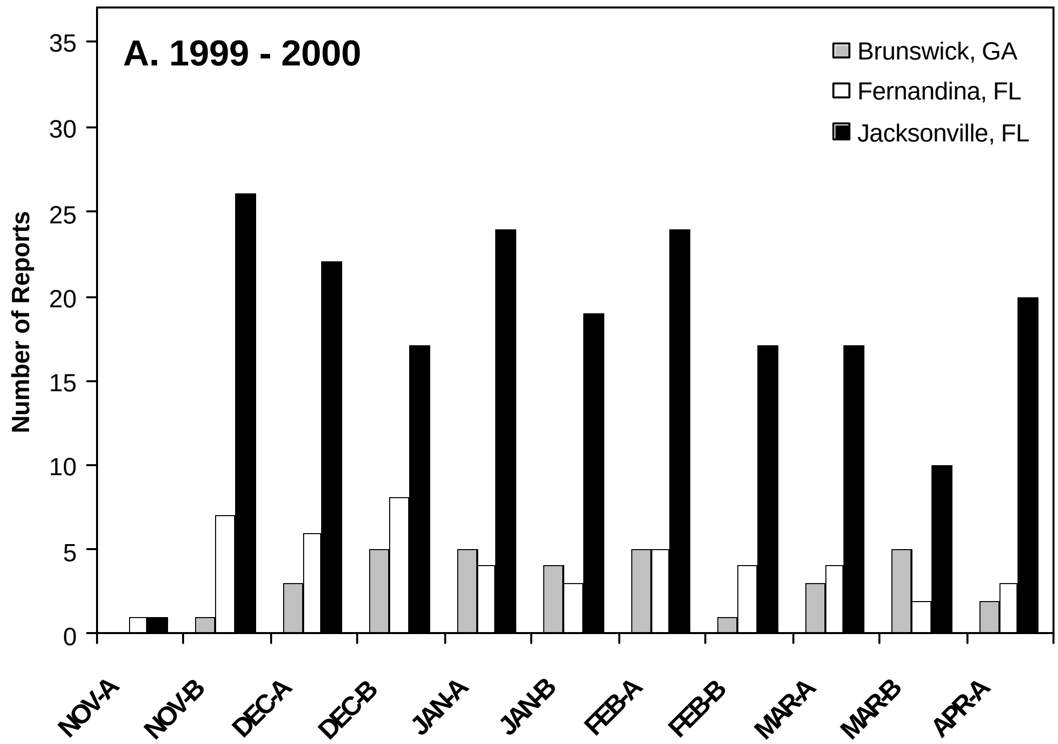


Figure 5. Total number of vessel calls reported to each pilot buoy for (A) 1999/2000 and (B) 2000/2001 per biweekly interval. The suffix "-A" indicates the first half of each month while "-B" indicates the later half.



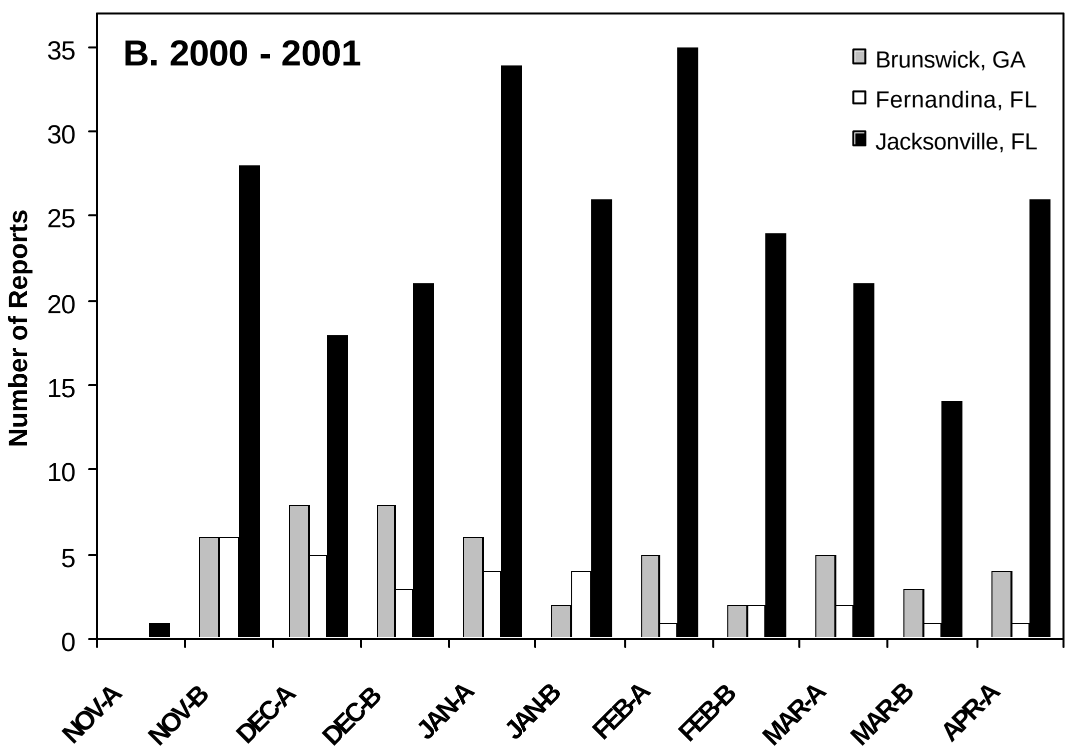


Figure 6. Total vessel track (km) per spatial cell for approaches to the Jacksonville pilot buoy reported to the MSRS in (A) 1999/2000 and (B) 2000/2001.

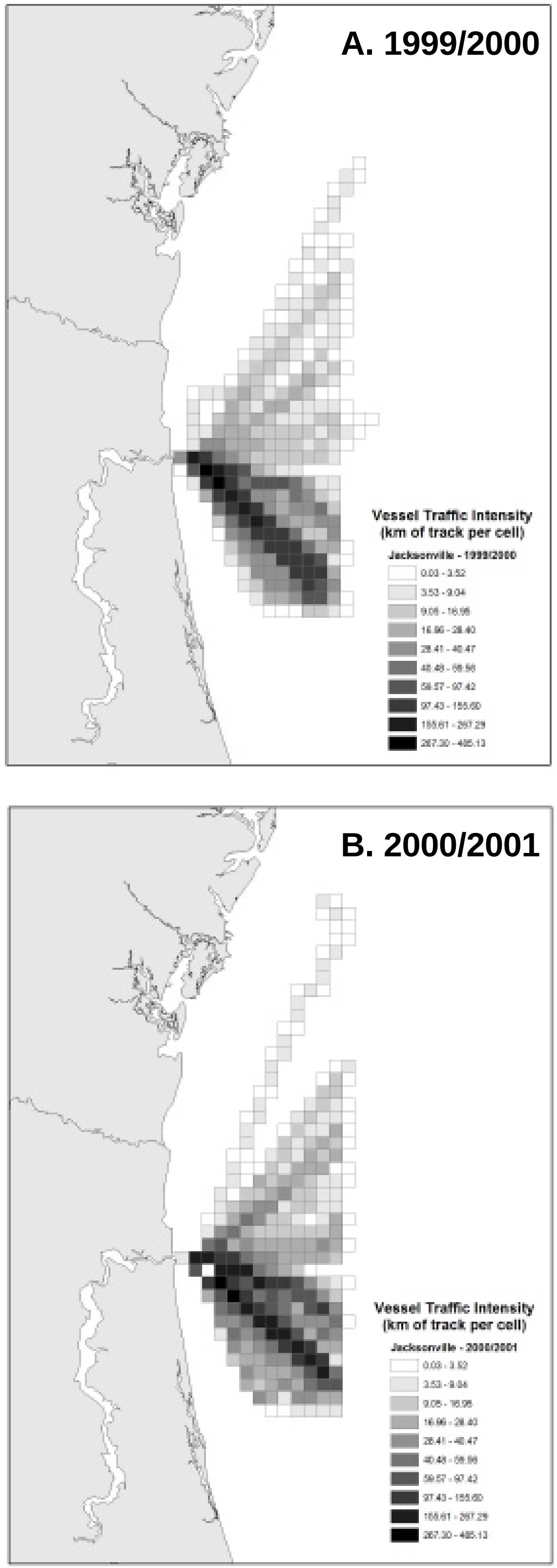


Figure 7. Total vessel track (km) per spatial cell for approaches to the Fernandina pilot buoy reported to the MSRS in (A) 1999/2000 and (B) 2000/2001.

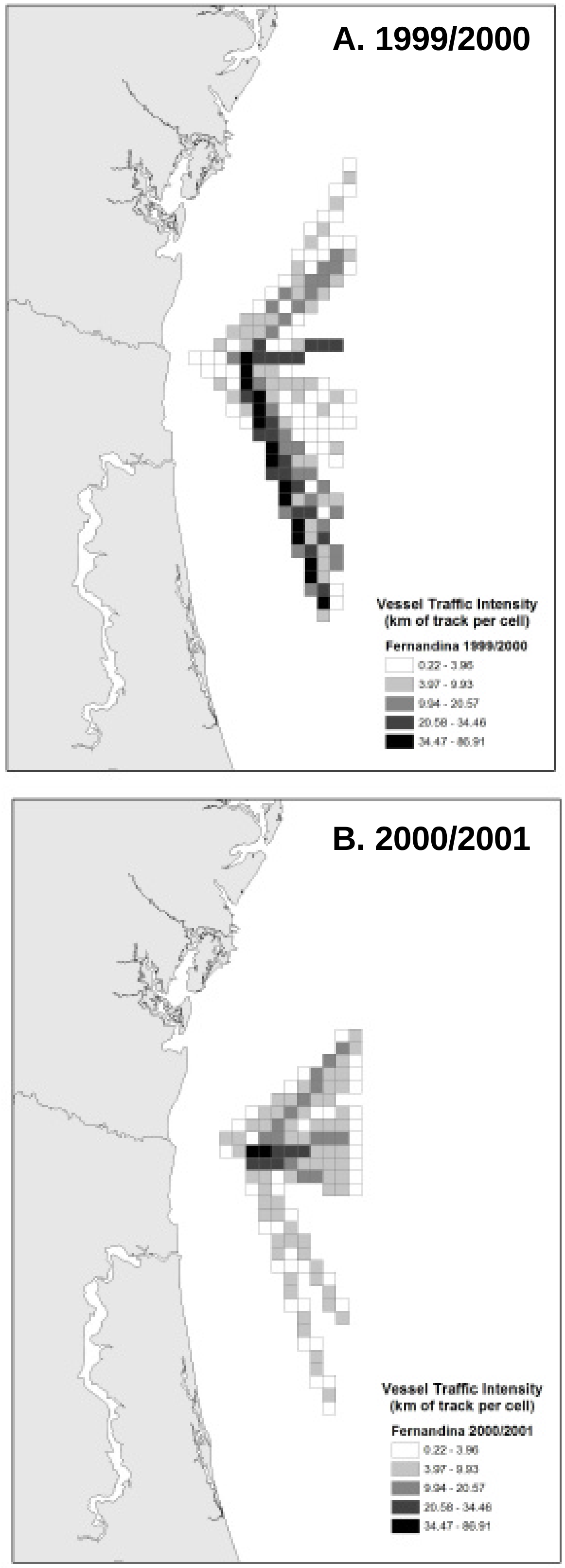


Figure 8. Total vessel track (km) per spatial cell for approaches to the Brunswick pilot buoy reported to the MSRS in (A) 1999/2000 and (B) 2000/2001.

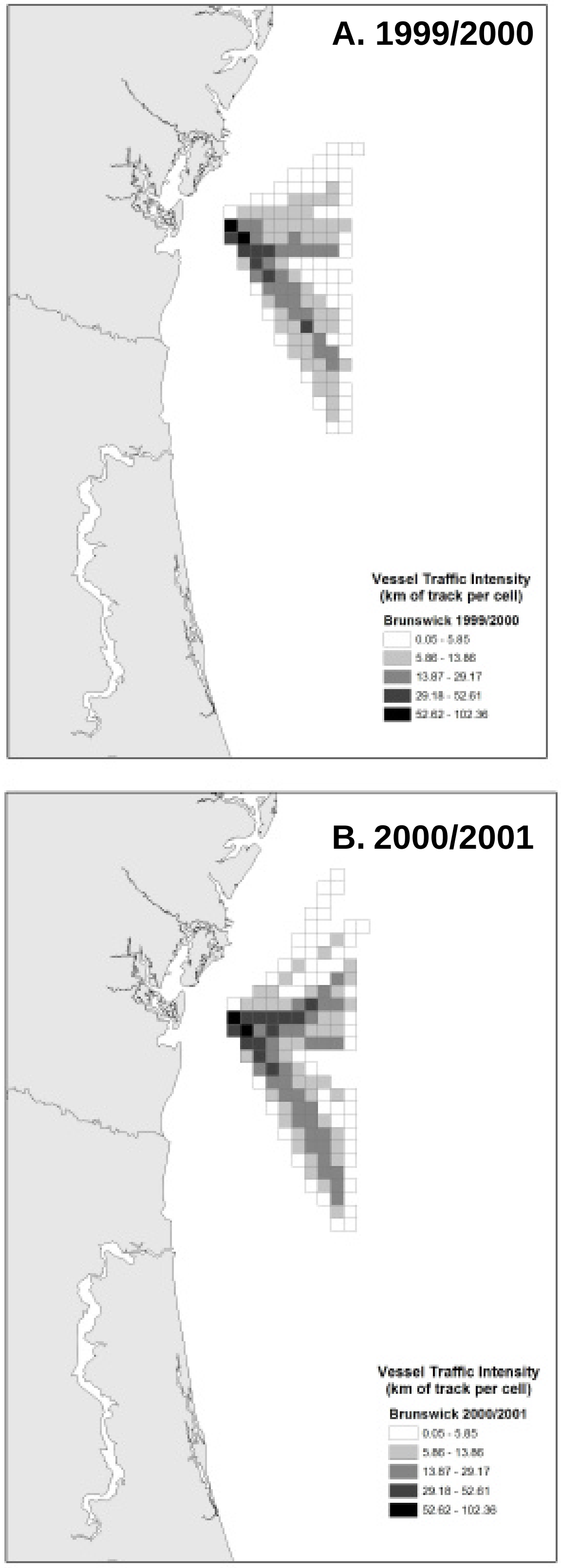


Figure 9. Risk value for each potential approach into the Jacksonville pilot buoy. Error bars indicate the 95% confidence interval of the risk value. The status quo risk level for approaches into Jacksonville is 86.7 (35.5 – 156.2 95% CI) indicated by the dashed line.

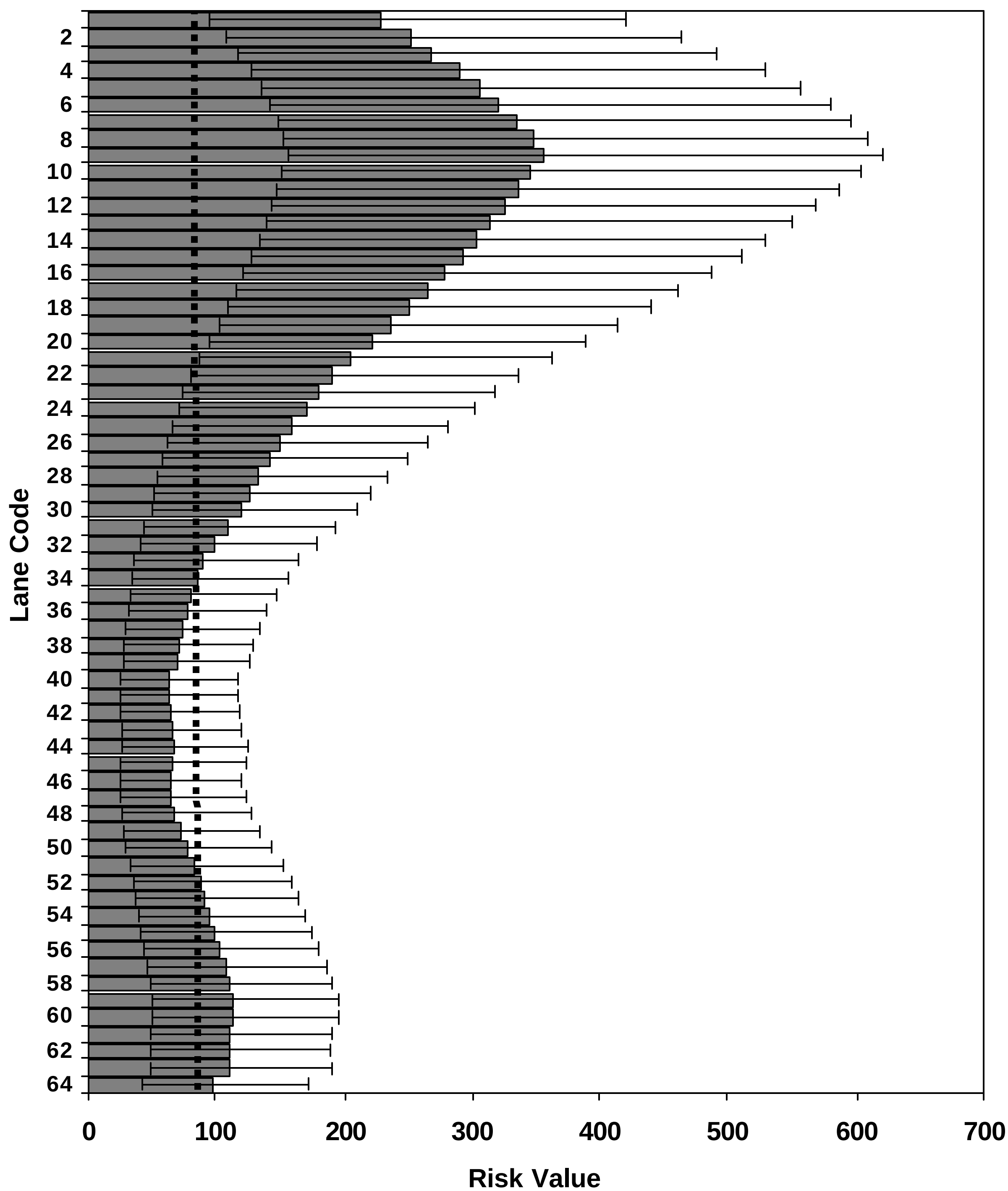


Figure 10. Reduction in risk relative to the status quo for each potential approach into the Jacksonville pilot buoy. The reported vessel traffic pattern from the MSRS for 2000/2001 is shown.

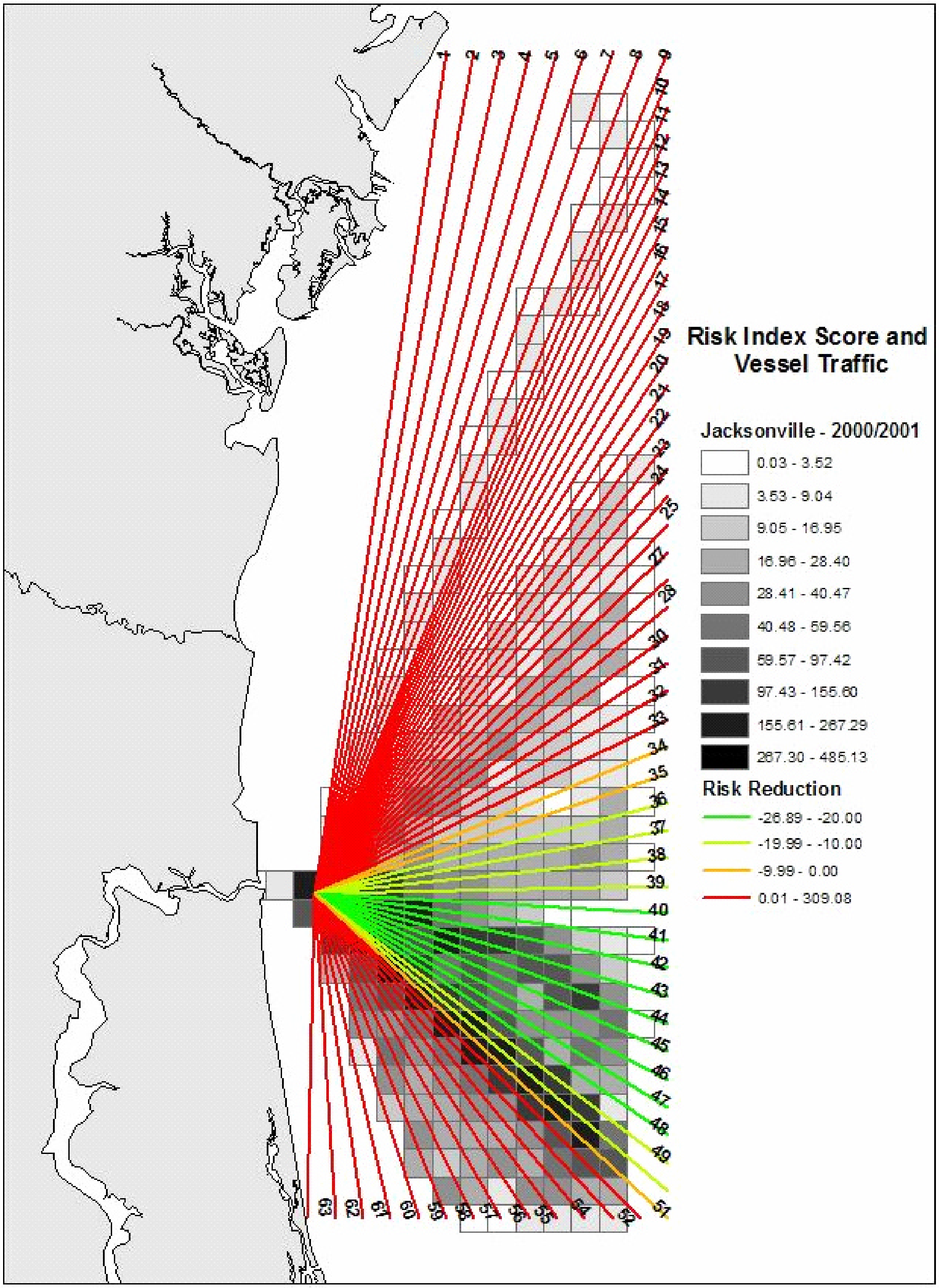


Figure 11. Risk value for each potential approach into the Fernandina pilot buoy. Error bars indicate the 95% confidence interval of the risk value. The status quo risk level for approaches into Fernandina is 13.9 (5.6 – 25.1 95% CI) indicated by the dashed line.

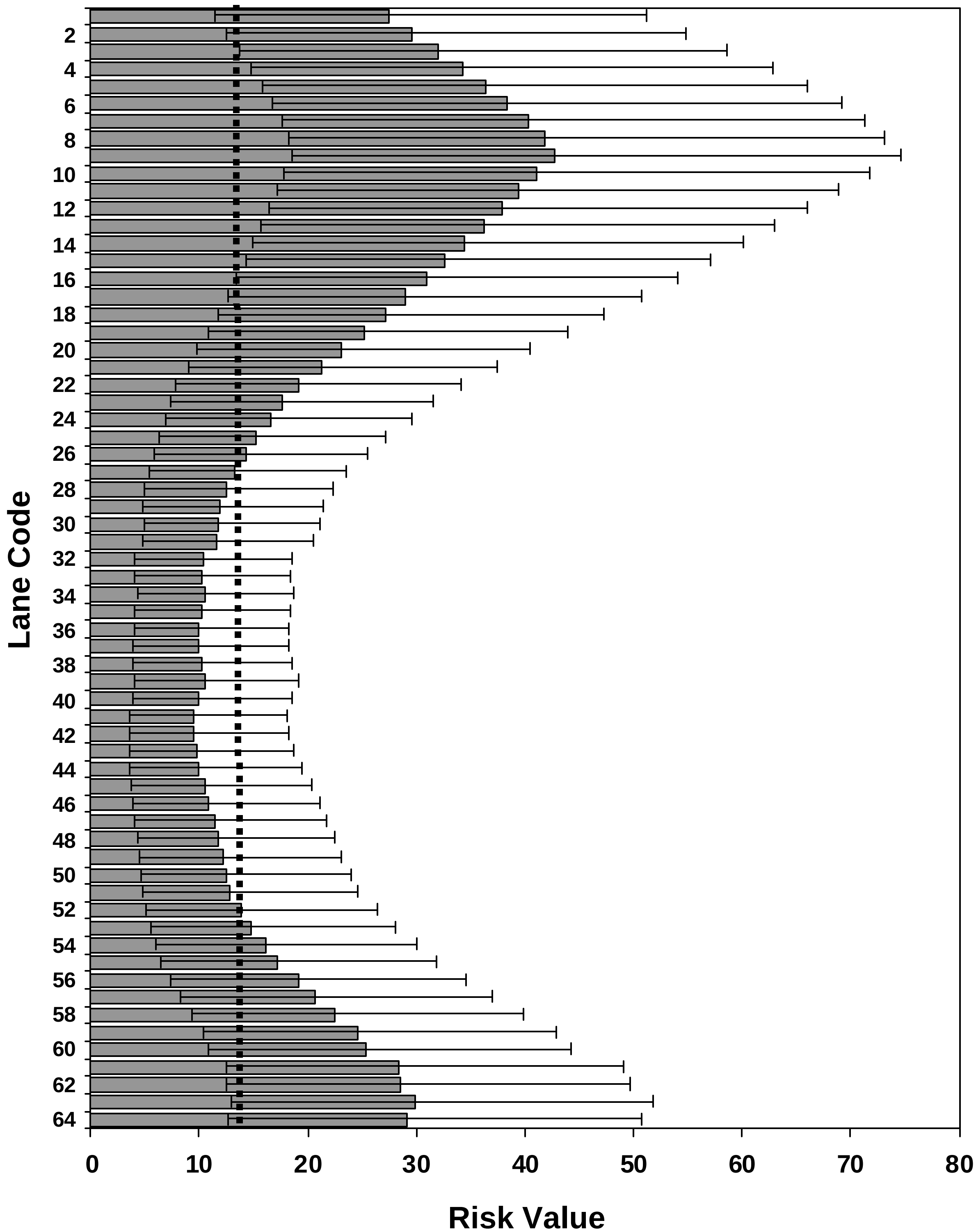


Figure 12. Reduction in risk relative to the status quo for each potential approach into the Fernandina pilot buoy. The reported vessel traffic pattern from the MSRS for 2000/2001 is shown.

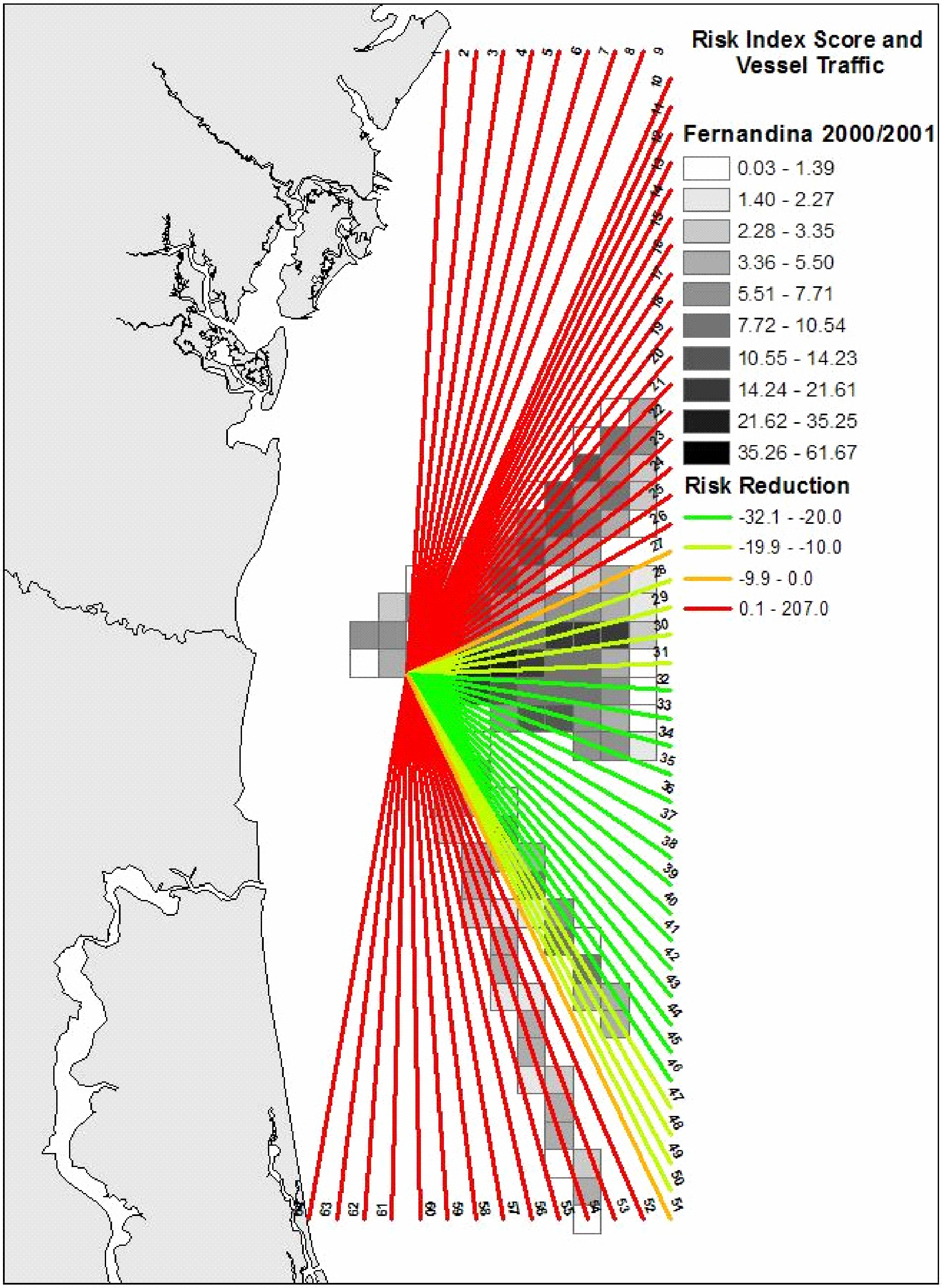


Figure 13. Risk value for each potential approach into the Brunswick pilot buoy. Error bars indicate the 95% confidence interval of the risk value. The status quo risk level for approaches into Brunswick is 20.7 (8.8 – 37.3 95% CI) indicated by the dashed line.

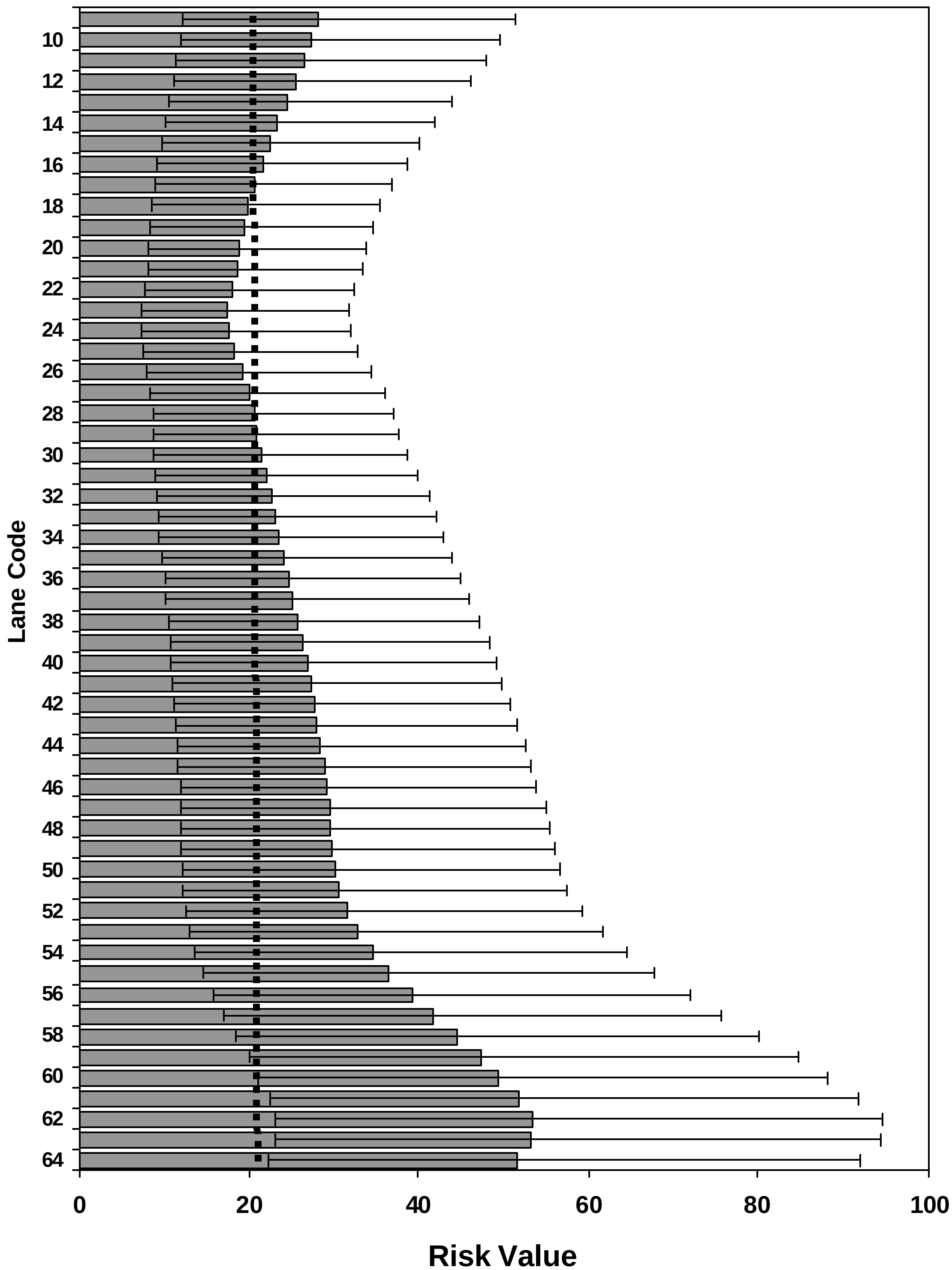


Figure 14. Reduction in risk relative to the status quo for each potential approach into the Brunswick pilot buoy. The reported vessel traffic pattern from the MSRS for 2000/2001 is shown.

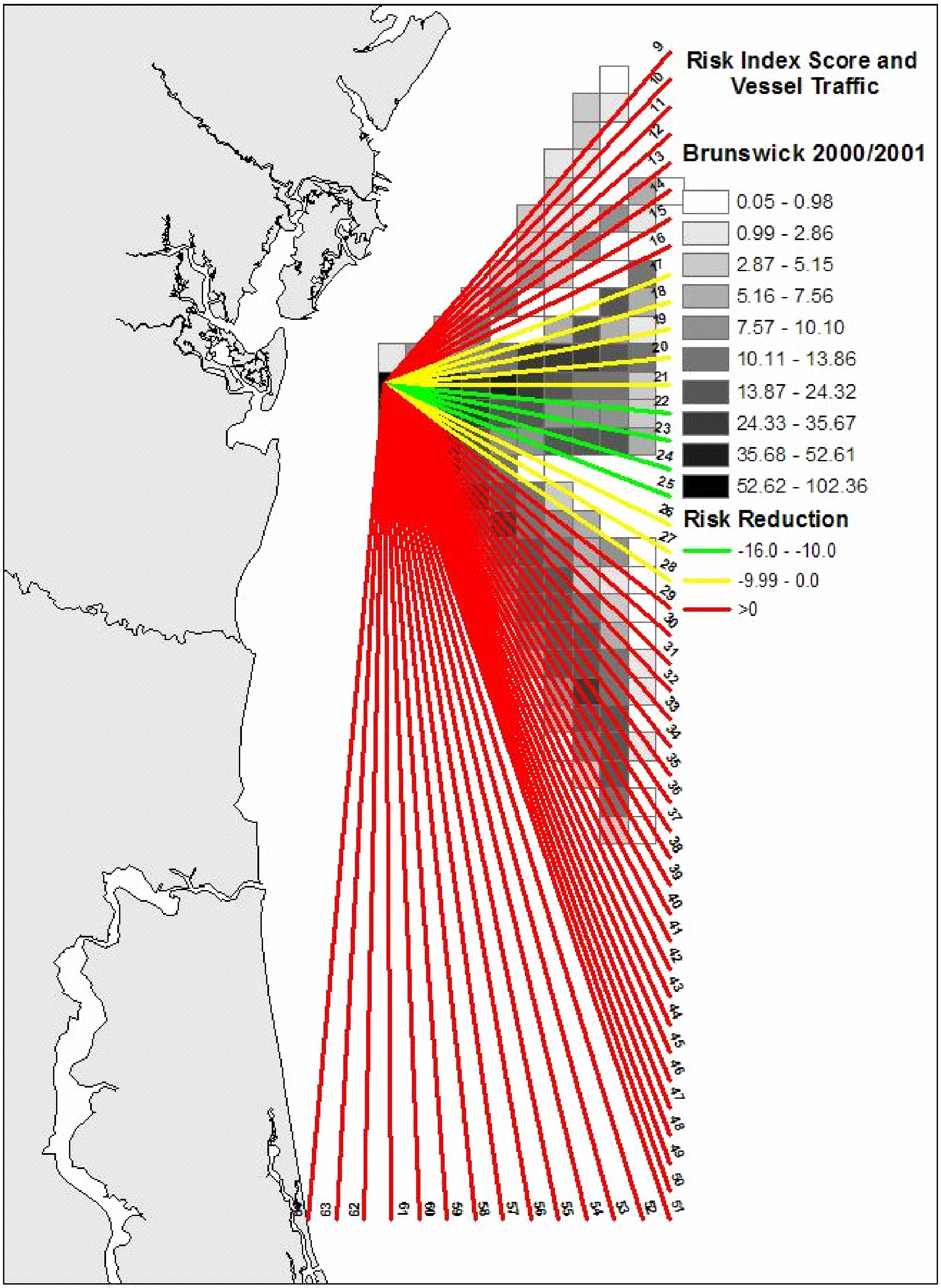


Figure 15. Cumulative risk as a function of distance from shore for the best approaches to each pilot buoy.