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Evaluation of Alternatives to Winter Closure of Black Sea Bass Pot Gear: Projected Impacts on Catch and Risk of Entanglement with North Atlantic Right Whales *Eubalaena glacialis*

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Abstract
Time–area closures have been widely used in fisheries management to prevent overfishing and reduce the bycatch of protected species. Due to quota overages and concerns about entanglement of federally protected North Atlantic right whales *Eubalaena glacialis*, the commercial harvest of Black Sea Bass *Centropristis striata* using pot gear has been prohibited in the southeastern United States in winter since 2009. Following the rebuilding of the Black Sea Bass stock and a change to the start date of the fishing year, the South Atlantic Fishery Management Council (SAFMC) increased the commercial annual catch limit (ACL) and is considering twelve alternatives to the pot gear closure that would revise the timing and/or spatial extent of the closure. Changes to this closure could affect the annual catch of Black Sea Bass and increase the risk of right whale entanglement in pot gear. Using historical fishing effort, landings, and right whale sightings data, we projected Black Sea Bass landings and the relative risk of right whale entanglement for each closure alternative, expressed in relative risk units (RRU). We predict that the ACL would be caught, resulting in an in-season closure for most of the proposed SAFMC closure alternatives. The relative risk of entanglement, estimated from the spatial and temporal overlap of Black Sea Bass pot gear fishing effort and right whale relative abundance, was lower for some alternatives than for others, and the relative differences between alternatives were consistent among uncertainty scenarios. The

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SAFMC's preferred alternative is projected to result in a relatively low increase in risk to North Atlantic right whales (3–15 RRU off North Carolina and 1–12 RRU off Florida–South Carolina). This framework demonstrates the use of temporally dynamic spatial overlays in assessing the impacts of time–area closures with multiple objectives.

Time–area closures restrict fishing in certain areas or during certain times. Closures may have multiple objectives, including protecting vulnerable life stages or habitat for a species (Hooker and Gerber 2004), extending fishing seasons by reducing catch rates (NRC 2001), and reducing bycatch (Hobday and Hartmann 2006). The design of these closures presents a challenge because the net benefits to the fishery or other resources are often unknown (Sanchirico and Wilen 2001; Sanchirico 2005). Effective closures must be of adequate extent to include the movements of the species they are intended to protect (Farmer 2009; Farmer and Ault 2011). Closures that are not appropriately sized or positioned can relocate bycatch problems spatially or temporally, be unenforceable, or cause unforeseen socioeconomic impacts (see review in O'Keefe et al. 2014). The increased use of GIS and the availability of spatial information relevant to the fishery and associated ecosystem provide the opportunity to predict the impacts of closures and assist in evaluating their design and effectiveness (Martin and Hall-Arber 2008).

The South Atlantic Fishery Management Council (SAFMC) manages the Black Sea Bass *Centropristis striata* in federal waters from the Florida Keys to Cape Hatteras, North Carolina. This stock was considered overfished during the 1990s and early 2000s (Vaughan et al. 1995; SEDAR 2002). In recent years, landings of Black Sea Bass have been tracked for a June 1–May 31 fishing year, and recreational and commercial fishing years have been subject to closure after annual catch limits (ACLs) have been met.

In 2012, the SAFMC executed Snapper–Grouper Fishery Management Plan Amendment 18A, which implemented (1) a limit of 35 Black Sea Bass pot tags each permit year to each of 32 holders of a Black Sea Bass pot gear endorsement, (2) a 1,000-lb gutted-weight (gw) trip limit, and (3) a requirement that pots be returned to shore at the end of each trip (SAFMC 2012). In 2013 an updated assessment concluded that the stock had been rebuilt and was no longer being overfished (SEDAR 2013).

Later that year the SAFMC implemented Regulatory Amendment 19 (Reg-19), which as of 2015 increased the commercial ACL for Black Sea Bass from 309,000 to 661,034 lb gw (SAFMC 2013). In 2014, the SAFMC implemented Regulatory Amendment 14 (Reg-14), which as of 2015 (1) changed the commercial fishing season for Black Sea Bass to January 1–December 31, (2) implemented a 300-lb-gw hook-and-line trip limit for January–April, and (3) established a 1,000-lb-gw hook-and-line trip limit for May 1–December 31.

The North Atlantic right whale *Eubalaena glacialis* is one of the most endangered large whales in the world, and even one death a year represents significant mortality for the population (Fujiwara and Caswell 2001; Waring et al. 2014). The species is federally protected under the Endangered Species Act (ESA) and the Marine Mammal Protection Act (MMPA). Collisions with shipping vessels and entanglement in fishing gear are the primary known sources of right whale mortality (Knowlton and Kraus 2001; Waring et al. 2014). Knowlton et al. (2012) estimated that at least 83% of right whales have been entangled at least once and 60% more than once. Documented mortality and serious injury from fishery entanglements alone exceeded the allowable MMPA potential biological removal over 2007–2011 (Waring et al. 2014).

Although entanglements incidental to commercial fishing are the primary threat to right whales, it is often difficult to identify the source of entanglements or where an entanglement occurred. In a study of 31 right whale entanglements, Johnson et al. (2005) found 14 instances of entanglement for which gear type could be identified; 10 (71%) of these were determined to be pot gear. In another study, using data from 2007–2014, 17 whales were documented as having been entangled, but none of these entanglements were attributed to a specific fishery (Waring et al. 2014). Furthermore, scarring studies suggest that the vast majority of entanglements are not observed (Knowlton et al. 2012; Waring et al. 2014). Consequently, while Black Sea Bass gear has not been definitively identified in an entanglement case, it cannot be ruled out as a gear type that poses a risk for serious injury or death in right whales.

The Black Sea Bass fishery was closed in the winter (i.e., November 1–April 30) from 2010 to 2012 because the ACL had been met. Due to the substantial increase in the commercial Black Sea Bass ACL through Reg-19, there was potential for the fishing season to remain open during winter for the first time since December 2010. North Atlantic right whales are known to occur in the mid-Atlantic and Southeast regions during that time period (NMFS 2008). The coastal waters of the southeastern United States are a calving habitat for reproductive females and wintering ground for all demographic groups (Gowan and Ortega-Ortiz 2014). Right whales travel through and possibly calve and overwinter in the mid-Atlantic during a staggered migration between the Southeast and their northern feeding grounds. In fact, right whales are present in the mid-Atlantic during all winter months (Mate et al. 1997; Schick et al. 2009; Whitt et al. 2013; Salisbury et al. 2016; W. A. McLellan and colleagues, presentation at the 15th Biennial Conference on the

Biology of Marine Mammals, 2004). To minimize the probability of entanglement of right whales and other federally protected whales in Black Sea Bass pot gear, Reg-19 implemented a prohibition on the use of Black Sea Bass pots from November 1 to April 30 in conjunction with the ACL increase.

The SAFMC initiated work on Regulatory Amendment 16 (Reg-16) in March 2013 and took final action in December 2015. Through Reg-16, the SAFMC considered shortening the Black Sea Bass pot closure season or spatially designating the closure boundaries (SAFMC 2015). The objectives for this amendment were to "minimize adverse socioeconomic impacts to Black Sea Bass pot endorsement holders … while continuing to afford protection to ESA-listed whales in the South Atlantic region" (SAFMC 2015). Under the amendment, the SAFMC considered 12 alternatives to a complete winter closure (for details, see Supplement A). Changes to the timing or spatial extent of the pot gear closure could affect both the annual catch of Black Sea Bass and the risk of whale entanglement in pot gear.

In this study, we projected potential landings by Black Sea Bass pot endorsement holders during a winter season under each of the proposed alternatives. Also taking into consideration landings with other gear types, we predicted the date that the ACL would be met under each alternative and under various scenarios of fishing effort and catch rates. We also estimated the relative risk of right whale entanglement in Black Sea Bass pot gear under each of the proposed closure alternatives by evaluating the spatial overlap of pot gear and modeled right whale occurrence.

METHODS

Data sources.—Federally permitted commercial fishermen self-report their landings by trip through the Southeast Fisheries Science Center (SEFSC) logbook program (confidential data housed by SEFSC; provided July 2014), providing species-specific data on landings (lb), primary gear type used, and primary area fished. Primary depth of capture has been reported since 2004. A single area and depth of fishing is reported in the commercial logbooks for each species per trip, although that species may be landed in many areas and at many depths during multiple sets. The SEFSC commercial ACL data set contains aggregated dealer records of monthly catch by gear type and species and includes landings through 2013 from vessels with and without federal permits. The Atlantic Coastal Cooperative Statistics Program (ACCSP) assimilates dealer trip tickets from the Atlantic states into a database of monthly catch by gear type and species, including landings from vessels with and without federal permits (ACCSP trip ticket data, accessed by SEFSC September 2014).

Black Sea Bass landings from gear other than pot gear were summarized by fishing year and fishing month from 2002 to 2013 using the SEFSC ACL data set and for 2013–2014 using the ACCSP trip ticket data set. Landings from pot gear were summarized using SEFSC logbook data by fishing year and fishing month from 1998 to 2014 for federally permitted pot gear endorsement holders. Simulations were used to correct historic data to allow for comparison between years with different regulations. To capture the impacts of the 1,000-lb-gw trip limit and the 35-pot limit implemented by Amendment 18A in 2012, the 2002–2012 time series was adjusted as follows: trips catching more than 1,000 lb gw were capped at 1,000 lb, and landings for trips using more than 35 pots were scaled down by multiplying the trip's mean catch per pot by 35 pots. Trip and pot limits were not simulated for the 2012–2013 or 2013–2014 fishing years because these regulations were already in place for that period. No additional simulations were performed to estimate additional trips that might have occurred in the past had pot and trip limit restrictions been in place.

Spatial distribution of landings and effort.—Season and water depth are important determinants of the spatial distribution of landings and effort and so must be considered when comparing the alternatives in Reg-16. Seasonal trends in catch rates per pot haul and depth of fishing were compared across fishing seasons. We used a GIS (ESRI's ArcGIS 10.1) to evaluate landings for 2013–2014 (the most recent season), 2008–2009 (the most recent November–April winter season), and 2006–2007 to 2008–2009 (the average of the last three winter seasons) to compare the spatial distribution of catch in the approximately 383,787 km^2 region where Black Sea Bass pot gear are permitted (the U.S. Exclusive Economic Zone [35°15.9′N south to 28°35.1′N]).

The impacts of the spatial closures in Reg-16 were evaluated by first assigning pot landings to area–depth grid cells that measured 1° of latitude by 5 m of bathymetry. As such, these cells were more highly resolved at the shelf edge where the bathymetric slope is greater. Bathymetry was determined from a generalization of the NOAA National Geophysical Data Center Coastal Relief Model (http://www.ngdc.noaa.gov/mgg/coastal/crm.html). Landings were assumed to be uniformly distributed within the area–depth cells. To estimate the effects of a spatial closure, historical logbook pot gear landings in each area–depth cell were reduced in proportion to the area of the area–depth cell covered by each proposed closure alternative during the closed season.

Three scenarios were used to account for the uncertainty in the spatial distribution of fishing effort: (A) the spatial distribution of pot gear endorsement holder landings under simulated Amendment 18A regulations for the November–May period of the 2008–2009 season; (B) the spatial distribution of pot gear endorsement holder landings during the June–October period of the 2013–2014 season; and (C) the spatial distribution of pot gear endorsement holder landings under simulated Amendment 18A regulations for the November–May period averaged across the 2006–2007, 2007–2008, and 2008–2009 seasons. Scenario A assumes no change in the spatial distribution of pot gear fishing pressure between the

2008–2009 and projected 2015 seasons. Scenario B assumes no change in the spatial distribution of pot gear fishing pressure between the June–October period of the 2013–2014 season and the November–May period of the projected 2015 season. Scenario C assumes no change in the spatial distribution of pot gear fishing pressure between the mean distribution of fishing pressure during the past three winter seasons (i.e., 2006–2007 to 2008–2009) and the projected 2015 season. Thus, scenarios A and C address winter–summer differences in spatial fishing pressure and scenario B addresses regional differences in fishing pressure that might have emerged over the past 5 years. Spatial distributions of pot gear before 2006 were not considered due to changes in the fishery and the lack of consistently reported depth of fishing in the logbooks.

Catch rate projections.—Projected landings were expressed as daily catch rates uniformly distributed within each fishing month. Atlantic Coastal Cooperative Statistics Program trip ticket landings using gear other than pot gear ("other gear") for June–May from the 2013–2014 fishing year were used in projections because a substantial increase in landings with such gear was observed following the implementation of Amendment 18A, which restricted the use of pot gear to federally permitted endorsement holders. For hook-and-line gear, Reg-14 implemented a 300-lb-gw trip limit for January–April and a 1,000-lb-gw trip limit for May–December. The impacts of these trip limits were simulated by examining ACCSP trip ticket records from 2013–2014 and setting any landings for hook-and-line gear that exceeded the trip limit in a given month equal to the trip limit.

Under all scenarios, catch rates for pot gear during June–October were assumed to be equivalent to those observed in 2013. Since the use of pot gear has not been allowed in winter for several years, four catch rate scenarios were developed to express the potential pot gear catch rates during November–May. Computations were performed using catch per pot rather than catch per pot haul because before the 2013–2014 season the number of hauls had occasionally been misreported (S. Turner, SEFSC, personal communication).

Four catch rate projection scenarios were simulated. Under catch rate scenario 1, catch rates for pot gear from November to May were set equivalent to those of endorsement holders for the 2008–2009 season (the last fully open winter season), under a simulated 35-pot limit and 1,000-lb-gw trip limit. Under scenario 2, winter pot gear use followed the 2008–2009 fishing season under a simulated 35-pot limit, with winter catch rates (catch per pot) being estimated as the ratio of 2008–2009 fishing season monthly catch per pot to the October 2008 catch per pot (to account for monthly differences in catch rate) multiplied by catch per pot in October 2013 (to account for the rebuilding of the stock). For example, catch per pot was 28.42 lb gw in January 2009, 15.00 lb in October 2008, and 26.94 lb in October 2013. The ratio-scaled, projected January catch rate was therefore 51.04 lb gw per pot. Under scenario 3, November–May catch rates were assumed to be equal to those observed in October 2013. Under scenario 4, November–May catch rates were assumed to be equal to mean November–May catch rates from the past three open winter seasons (i.e., 2006–2007 to 2008–2009).

Right whale spatial distribution model.—Season and habitat characteristics are important determinants of the presence of right whales and so are important in estimating the overlap of right whale presence with the use of pot gear under all Reg-16 alternatives. Gowan and Ortega-Ortiz (2014) developed a temporally dynamic habitat model to predict the distribution of wintering right whales from Florida to South Carolina using a generalized additive model (GAM) framework and aerial survey data. The model summarized whale sightings, survey effort, and environmental data in the southeastern United States semimonthly from 2003–2004 to 2012–2013.

Predictions from the model demonstrate that right whale distribution differs within and between years in accordance with the variation in environmental conditions. Gowan and Ortega-Ortiz (2014) used this model to generate 80 GIS layers (8 semimonthly periods for December–March for 10 years) of predicted relative abundances of right whales in a composite of grid cells consisting of 5.56-km × 5.56-km cells oriented east–west in the south and 7.52-km × 7.52-km cells oriented northwest–southeast in the north. These cells had higher spatial resolution than the reported landings data, as they were designed so that the survey transects bisected the grid cells, allowing all survey effort within a cell to be associated with a single transect. These predictions can also be considered an encounter rate (i.e., the expected number of whales sighted in each cell given uniform survey effort, observed environmental conditions, and the total number of sightings each year). We calculated the mean encounter rate for each month (with 95% confidence intervals) from these layers as the mean across all semimonthly periods and years for that month. Lower confidence limits were bounded at zero, consistent with the count data used to build the model (Gowan and Ortega-Ortiz 2014). To account for the variability in the spatial distribution of right whales under different environmental conditions, two model-predicted distributions were used in addition to the overall monthly means: (1) mean monthly encounter rates from 2011–2012 (representing a warmer-than-average winter scenario) and (2) mean monthly encounter rates from 2009–2010 (representing a colder-than-average winter scenario).

The model by Gowan and Ortega-Ortiz (2014) only predicts right whale distribution in coastal waters from Florida to South Carolina, yet Reg-16 alternatives also include waters off North Carolina as far north as Cape Hatteras. We therefore developed an additional right whale habitat utilization model for North Carolina waters using aerial survey data collected by the University of North Carolina–Wilmington from October 2005 to April 2006, from December 2006 to April 2007, and from February 2008 to April 2008 (OBIS–SEAMAP 2014). Using the same composite grid cells, survey effort was expressed as the cumulative number of surveys per cell across all survey months and years. The number of sightings was calculated as the cumulative number of right whales per cell across all months and years. Distance to shore, depth, sea surface temperature (SST), and slope were calculated as in Gowan and Ortega-Ortiz (2014). No temporal framework was considered in the model because of the limited number of surveys and sightings; cumulative sightings, cumulative effort, and long-term mean winter SSTs from all months and years were used to build the model.

A GAM was used to model the presence/absence of right whale sightings, with the $\log_e$ transformed number of surveys as an offset term. Because a large number of cells contained no sightings, a quasibinomial distribution with a logit link was used. Predictor variables considered were log-transformed depth, log-transformed slope, distance to the shore, and mean SST. The basis dimension parameter for each predictor variable was set to 3, and the gamma term was set to 1.4 to avoid overfitting (Wood 2006). Following Gowan and Ortega-Ortiz (2014), model selection was accomplished with a forward stepwise selection procedure using the following evaluation criteria: model generalized cross-validation scores, percentage of deviance explained, analysis of deviance tests, and average squared prediction error from a fivefold cross validation (Wood 2001; Dormann et al. 2008). We used the selected model to predict right whale encounter rates within the extent of the survey data. We used mean winter SST to predict encounter rates off North Carolina. Although sampling off North Carolina was too limited to fit a monthly model to the data, we used monthly mean SST data (winter 2003–2004 to 2012–2013) to generate separate predictions from each month with the model fit to the aggregated winter data. Thus, monthly differences in these predictions off North Carolina were based on monthly differences in SST but not on monthly differences in whale abundance or behavior.

These spatially explicit models of catch rate and whale distribution were then used to project closure dates and the relative risk of right whale entanglement, summarized by spatial scenario, catch rate scenario, and Reg-16 proposed alternative. The predicted values from the North Carolina model did not have the same scale or interpretation as the predictions from the Florida–South Carolina model (Gowan and Ortega-Ortiz 2014) and were not directly comparable due to differences in survey design, quantification of survey effort, temporal components in the model, model framework (the probability of presence versus relative abundance), and, potentially, whale behavior (e.g., a sighting availability bias in the migratory corridor off North Carolina versus the wintering grounds off Florida–South Carolina).

Relative risk of right whale entanglement in pot gear.—A lack of information regarding the fine-scale interactions between right whales and Black Sea Bass pot gear prevented us from estimating the absolute risk of entanglement. Instead, we modeled the relative risk of entanglement as the spatial and temporal overlap of right whales and pot gear using estimates of right whale relative abundance and the projected pot gear distribution. Black Sea Bass pot gear effort was expressed as monthly totals of soak time across all vessels by area–depth cell. Encounter rates between right whales and pot gear were modeled using the Florida–South Carolina and North Carolina right whale spatial distribution models. Our measure of risk therefore assumes that, given a uniform distribution of pot gear, the areas for which whale encounter rates from aerial surveys are predicted to be greatest would also have the greatest risk of entanglement (Fonnesbeck et al. 2008) and that the co-occurrence of right whales and pot gear represents a true (but unknown) entanglement risk greater than zero (Johnson et al. 2005).

The 2008–2009 fishing year was the most recent period in which pot fishing took place during November–April, but effort data for this fishing year (scenario A) and prior years (scenario C) were not considered to have been reliably reported for pot gear due to misunderstandings of the methods for reporting hauls and soak times (S. Turner, SEFSC, personal communication). To handle this concern, we used the spatial distribution of pots (i.e., the number of pots per area–depth cell) from winter fishing seasons in scenarios A and C but assigned pot soak times to area–depth cells for these scenarios using reconciled 2013–2014 soak time data. For example, under scenario A, effort in each area–depth cell was estimated by multiplying the 2013–2014 mean soak time per pot by the number of pots reported in each area–depth cell in 2008–2009. The number of pots used on a given trip in 2008–2009 was retrospectively set at 35 to reflect current regulations. Pots were assumed to be set with one line per pot based on information from endorsement holders. Mean pot soak times from the 2013–2014 season were linked to historical records following this hierarchy: vessel + area + depth, vessel, owner, area + depth, area, and region. This approach assumed that the soak times of pots deployed by a given vessel in a given area–depth cell from summer 2013–2014 would not differ substantially from that of the same vessel in the same area–depth cell in winter. If a vessel fished in a given area–depth cell in 2008–2009 but not in 2013–2014, the mean soak time across all trips for that vessel in 2013–2014 was multiplied by the number of pots reported for the given area–depth cell in 2008–2009. If that vessel did not fish in 2013–2014 but the owner of that vessel did fish, the owner's mean soak time across all trips was used. If there were no matches for the vessel or the owner between the 2013–2014 and 2008–2009 fishing years, then the mean soak time across all vessels in that area–depth cell in 2013–2014 was used as the multiplier, and so forth. The monthly spatial distribution of recomputed soak times for the 2008–2009 fishing year was summed by area–depth cell for November–April.

Fishing effort for each distribution scenario was assigned to area–depth cells. In the area where the Florida–South Carolina model predictions and the North Carolina model predictions overlapped, the North Carolina model predictions were removed in favor of the more statistically robust Florida–South Carolina model. All models were projected as Albers equal area conic projections. The area of each cell was computed. The right whale encounter rate models were clipped to the commercial area–depth cells, and right whale encounter rates were summarized as weighted means within area–depth cells, with the weights based on the areas of the right whale encounter subcells. For each area–depth cell, the weighted mean of right whale encounters was then multiplied by the total commercial pot gear effort within the area–depth cell. The products of mean encounter rates and commercial effort (e.g., "weighted risk") were summed across all area–depth cells; this sum was considered equivalent to 100 relative risk units and was used as the baseline for the analysis of the impacts of the spatial closure alternatives on potential right whale interactions with pot gear. This baseline assumes a complete opening of SAFMC waters to pot gear and estimates the daily exposure of right whales to entanglement risk until the ACL is reached and the entire fishery is closed. Thus, the comparison of closure alternatives ranged from 0 RRU (alternative 1: status quo; complete closure November–April, representing no increased risk to whales from current regulations) to 100 RRU (no closure implemented, representing maximum increase in the risk to whales). To evaluate the impacts of all spatial closure alternatives, the products of mean encounter rate and commercial effort were summed across all area–depth cells, excluding cells that overlapped with each given spatial closure alternative, and were compared with the baseline to determine the relative encounter risk remaining. Because spatial closure alternatives only partly overlapped with many area–depth cells, area-weighted mean encounter rates and effort were recomputed for each alternative.

Cumulative effects.—To evaluate the cumulative effects of spatial closure alternatives on landings and the relative risk of right whale entanglement, daily catch rates were projected for a hypothetical January–December fishing season for all twelve Reg-16 alternatives under spatial distribution scenarios A–C; catch rate scenarios 1–4; and the distribution scenarios for right whales for mean, warm, and cold winter SSTs. The cumulative relative risk of right whale entanglement was tracked under each combination of fishing scenario and closure alternative from January 1 to April 30 and from November 1 to December 31 (or through the projected quota-based closure date for each season, whichever came sooner). Total catch relative to the ACL, closure date, total days open, and cumulative relative risk of right whale entanglement were all output from the model. Total landings and season length were compared with those for alternative 1 (the status quo). Due to a lack of right whale survey data for November and April, the right whale model's December distributions were used to represent November distributions and the March model distributions were used to represent April distributions.

Under all scenarios, the daily relative right whale risk from pot gear was eliminated when a quota closure is imposed to avoid exceeding the ACL, because under a quota closure the fishery would be closed to all gear types. The cumulative relative risk of right whale entanglement might exceed 100 RRU under scenarios for which the proposed closure alternative slows catch rates sufficiently that the fishery may remain open later than it would have with no closure, but during those additional open days these closure alternatives insufficiently mitigate risk to right whales. Risk levels were categorized as follows to facilitate distinction between alternatives: low, <25 RRU; moderate, 26–50 RRU; high, 51–75 RRU; and very high, >75 RRU).

Right whale risk was estimated separately for the Florida–South Carolina and North Carolina models due to differences in model construction. Off North Carolina, the risk of right whale entanglement was estimated from predictions from separate model runs using mean winter SST and mean monthly SST. To assess the uncertainty in modeled right whale distributions, 95% confidence intervals for the mean predicted encounter rates were calculated for the Florida–South Carolina and North Carolina right whale models, with lower confidence limits being bounded at zero. Within-scenario uncertainty was evaluated using the upper and lower confidence limits for the right whale distribution model to project the closure date and relative risk of right whale entanglement.

RESULTS

Spatial Distribution of Landings and Effort

From 2004–2005 to 2008–2009, pot gear effort during months completely open to pot gear fishing amounted to 2,126 ± 1,410 pots/month (mean ± SD), with 3,038 ± 1,219 pots/month from November to April. Since the implementation of Amendment 18A, the 32 pot gear endorsement holders have averaged 2,122 ± 653 pots/month (range 1,503–3,148) during months completely open to pot gear fishing. In the 2013–2014 season, the number of pots per trip was 24.9 ± 9.7, with 52.3 ± 36.4 hauls per trip. Trip length was 1.4 ± 0.6 d. Soak time was 4.4 ± 4.0 h per trap (range, 0.33–28.0). Total soak time per trip was 245.8 ± 337.6 h (range, 5.3–5,040.0).

Black Sea Bass pot endorsement holders tended to fish in waters between 15 and 40 m deep (mean ± SD = 24.9 ± 6.7 m). A comparison of landings from by gear endorsement holders during November–May from the 2008–2009 season (scenario A) with those during June–October from the 2013–2014 season (scenario B) showed higher proportional landings off South Carolina under scenario A and higher proportional landings off North Carolina and Florida under scenario B (Figure 1). Landings and effort in the 2008–2009 winter months covered a narrower geographic range than in the 2013–2014 summer season. In the 2008–2009 winter months, fishing activity shifted from nearshore North Carolina waters

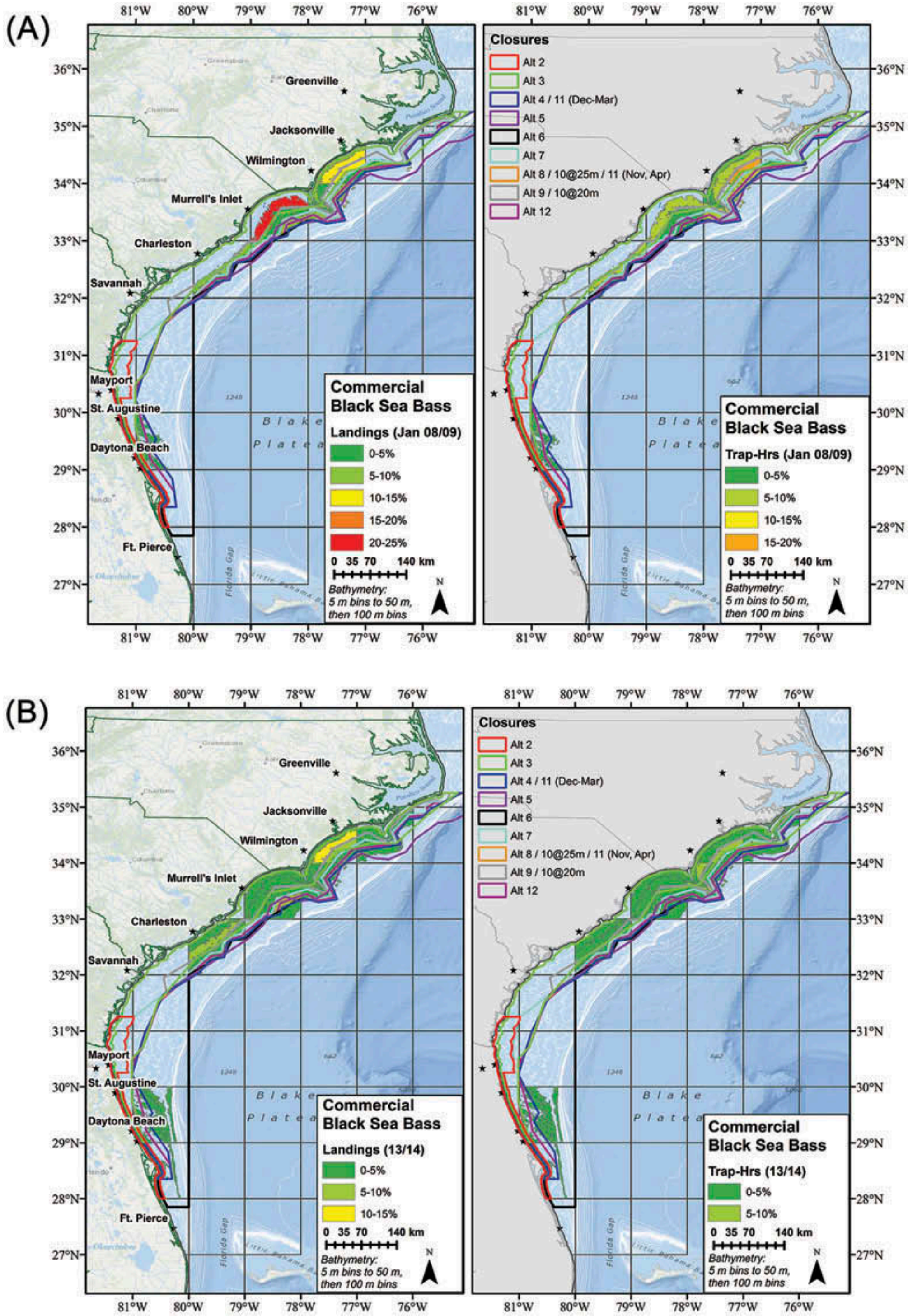

FIGURE 1. Spatial distributions of reported landings and effort by South Atlantic commercial Black Sea Bass pot gear endorsement holders under Amendment 18A regulations, by area and depth, for **(A)** January data from the most recent open winter season (2008–2009 [scenario A]), **(B)** June–October data from the most recent summer season (2013–2014 [scenario B]), and **(C)** January data using the mean of last three open winter seasons (2006–2007 to 2008–2009 [scenario C]). Landings and effort are aggregated into 1°-latitude × 5-m-bathymetry cells and expressed as percentages of the total to maintain the confidentiality of federally permitted commercial captains.

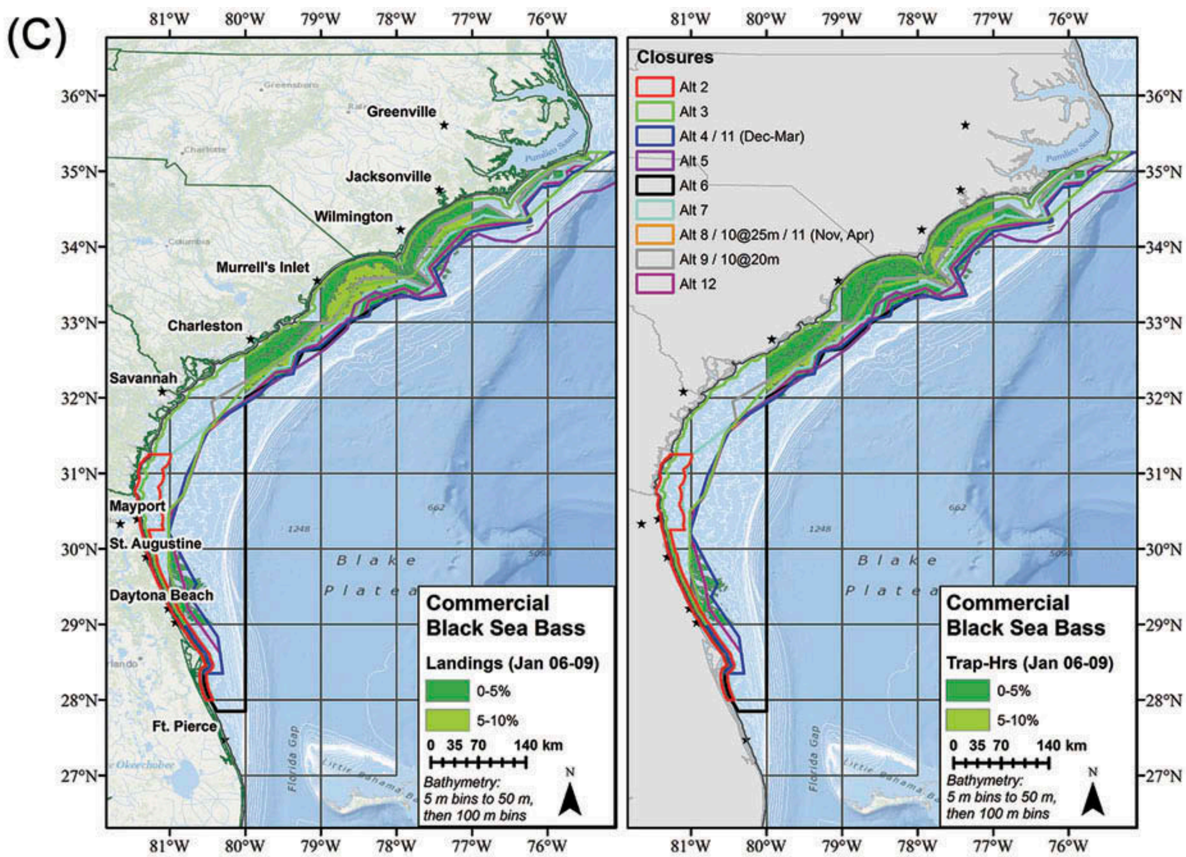

FIGURE 1. Continued.

(November–December) to South Carolina waters (December–February; Figure 1A) and then farther offshore of both North Carolina and South Carolina (February–April). This spatial shifting was not observed in scenario B due to the static treatment of the summer 2013–2014 landings and effort data (Figure 1B). The spatial extent of landings and effort under scenario C (Figure 1C) was similar to that under scenario A, but landings and effort were more diffuse under scenario C when averaged across the three winters.

Catch Rate Projections

Between 2006–2007 and 2013–2014, an average of 24% of trips were within 50 lb of the 1,000-lb-gw trip limit, with a maximum of 56% of trips in 2011–2012 and a minimum of 10% in 2013–2014. Catch per pot haul in the Black Sea Bass fishery has historically been higher during the winter months, but this shifted toward the summer months as early quota closures created a derby fishery in 2009–2010. Daily catch rates for projection scenarios 1–4 are presented in Figure 2. Winter catch rates were highest under scenario 2 and lowest under scenario 3. Scenarios 1, 2, and 4 showed maximum catch rates during December–February. The estimated abundance of Black Sea Bass vulnerable to pot gear has increased in recent years, from 3.3 million fish in 2007 to 6.5 million fish in 2015 (SEDAR 2013).

Right Whale Spatial Distribution Model

The Florida–South Carolina right whale distribution model predicted that encounter rates would be lower and that right whales would be distributed farther north in December and March than in January and February (Figure 3). Under the cold-winter-SST scenario, right whale distribution shifted farther south and farther offshore than in the mean- and warm-winter-SST scenarios (see Figure 5 in Gowan and Ortega-Ortiz 2014). The North Carolina right whale distribution model (Tables S.B.1 and S.B.2 in Supplement B) predicted the highest encounter rates close to shore and in relatively shallow water (Figure 3).

Relative Risk of Right Whale Entanglement in Pot Gear

Figure 4 shows the relative risk of right whale encounters with pot gear under fishing effort scenarios A and B. Pot gear distribution (and consequently the risk of entanglement with right whales) under scenario C was similar to that under scenario A and is not depicted in Figure 4. Because the North Carolina right whale distribution model and pot

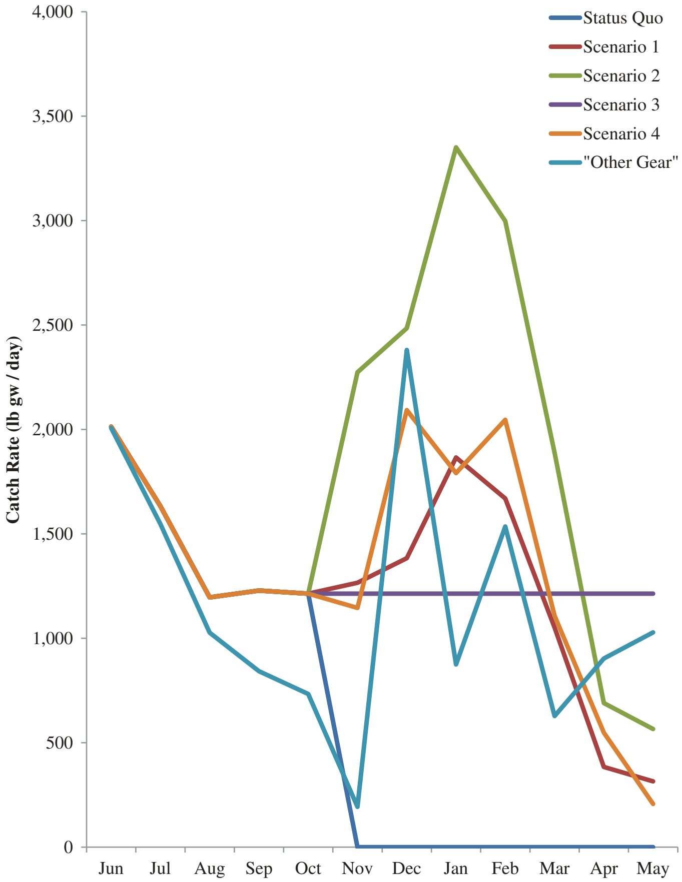

FIGURE 2. Predicted commercial Black Sea Bass daily catch rates, by month, in pounds of gutted weight. Note that historically the Black Sea Bass fishing season was June 1–May 31.

distribution in scenario B are not time-dynamic, the modeled risk off North Carolina for scenario B did not vary by month.

Risk of entanglement was predicted to increase relative to the present closure only in area–depth cells with projected pot gear effort. Although the relative risk of entanglement varied between months and pot distribution scenarios, it was generally highest in waters 5–30 m deep. For the North Carolina area overall, relatively higher risk was predicted from Jacksonville, North Carolina, to the South Carolina border. For the Florida–South Carolina area overall, higher risk was predicted off Murrell's Inlet, South Carolina; Charleston, South Carolina; St. Augustine, Florida; and Daytona Beach, Florida (Figure 4). In general, pot fishing effort and the associated right whale entanglement risk were more broadly distributed off Florida–South Carolina under scenario B and off North Carolina under scenario A.

Cumulative Effects

Different catch rate scenarios and closure alternatives resulted in different projected closure dates for the commercial Black Sea Bass fishery to avoid an ACL overage (Table 1). Most alternatives were projected to catch 100% of the ACL, with a quota closure being put into effect before the end of the fishing year; the remaining alternatives (alternative 1 and a few scenarios for alternatives 7b, 8b, 9b, and 10) were projected to catch at least 97% of the ACL (Table 1). Under warmer than average conditions, when right whales were predicted to be closer to shore, most depth-based spatial closure alternatives more effectively reduced the relative risk of entanglement (Table S.B.3). Some permutations suggested that alternative 7b would impose more risk than no closure at all because it would allow two additional months of fishing during winter. Under colder than average conditions, when the predicted right whale distribution was more southern and more broadly dispersed offshore, most depth-based closure alternatives were less effective than under average conditions (Table S.B.4).

Using mean monthly SST data to generate monthly predictions of the right whale distribution off North Carolina resulted in similar estimates of the relative risk of entanglement as using mean winter SST data (differences = 0–6 RRU). The relative differences between closure alternatives were consistent across scenarios (Table 1; Figure 5). The differences between alternatives with regard to projected closure dates and the relative risk of entanglement were consistent after accounting for the 95% confidence limits around whale encounter rates. Uncertainty was greatest for alternatives 3, 5, and 7–9b, but these alternatives remained significantly different from alternatives 4 and 6, which resulted in the lowest relative risk of right whale entanglement among all alternatives that allowed the use of pot gear during winter (Figure 5).

The relative risk of right whale entanglement was lowest for alternative 1 (status quo) and greatest for alternative 2 (Figure 6). Alternatives 4 and 6 resulted in the lowest risk of any pot gear opening under consideration, also allowing long fishing seasons and 100% of the ACL to be caught (Table 1). Alternatives 2, 7a, and 7b resulted in high relative risk and generally shorter seasons than other alternatives (Table 1; Figure 6).

DISCUSSION

This analysis used historic catch data to predict future commercial Black Sea Bass catches and historic right whale survey data to predict relative right whale abundance, which were combined to predict the relative entanglement risk to right whales under 12 proposed time–area closure alternatives for pot gear off the coastal southeastern United States. During the 2013–2014 season, the Southeast Fisheries Science Center's in-season quota monitoring estimated that 99.6% of the ACL was caught with no pot gear fishing during November–April due to a substantial increase in hook-and-line landings. Analyses of Reg-16 closure alternatives indicate that nearly all scenarios would result in the ACL being caught. Associated economic analyses indicate substantial gains by pot gear fishermen coupled with nearly equal losses to fishermen using other gears (SAFMC 2015). Because

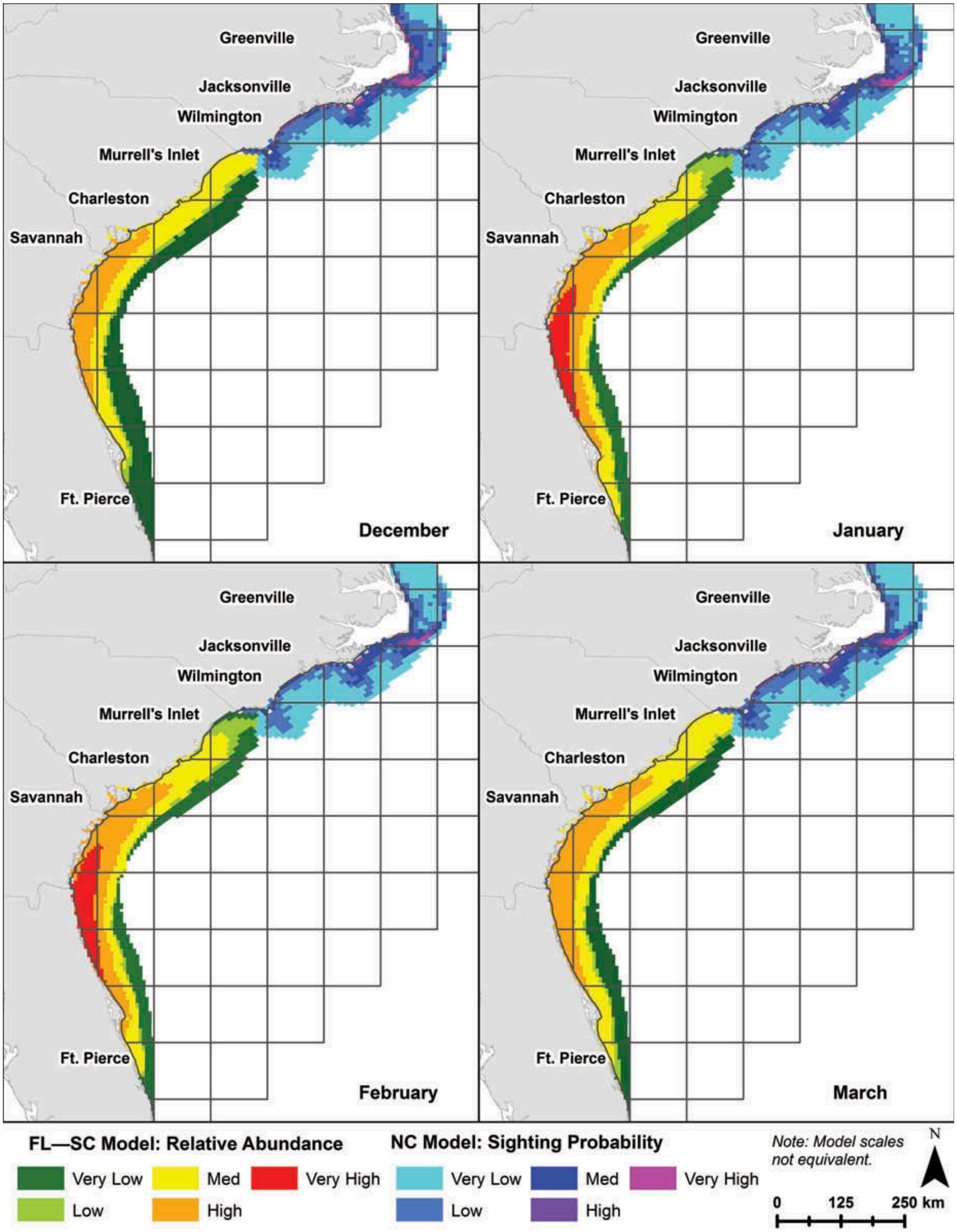

FIGURE 3. Predicted distributions of right whales based on modeled habitat from right whale sightings for Florida–South Carolina and North Carolina. The grid cells are those used by the National Marine Fisheries Service commercial logbook program.

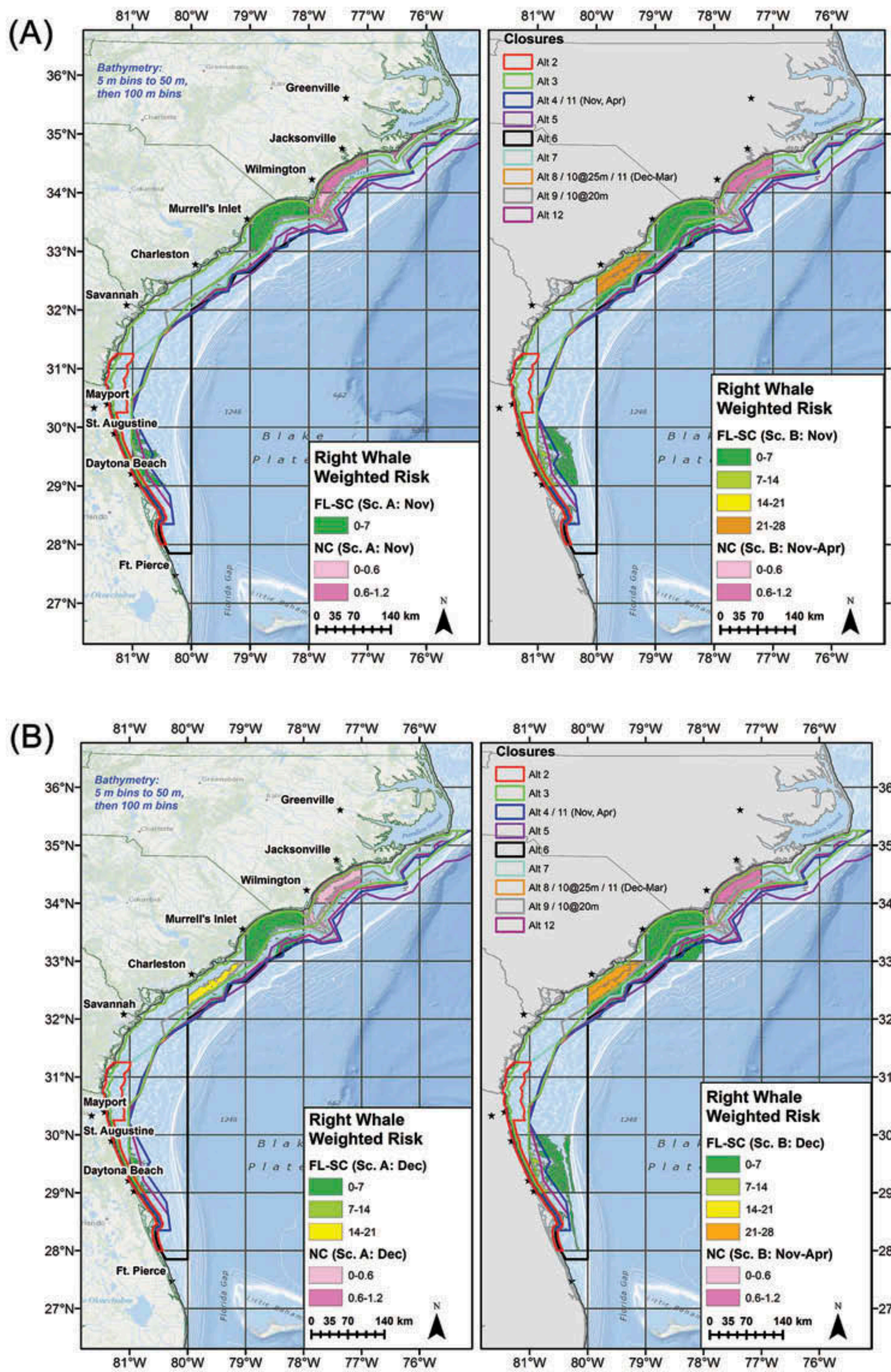

FIGURE 4. Relative risk (0–100) of entanglement of right whales in pot gear based on right whale habitat models and projected commercial pot gear effort by area–depth cell and month; the risk units off North Carolina and Florida–South Carolina are not directly comparable. In scenario A (left panels), the spatial distribution of pot effort is based on observations from the 2008–2009 winter fishing season. In scenario B (right panels), the distribution is based on observations from the 2013–2014 summer season. The relative risk in scenario C was similar to that in scenario A and therefore is not shown.

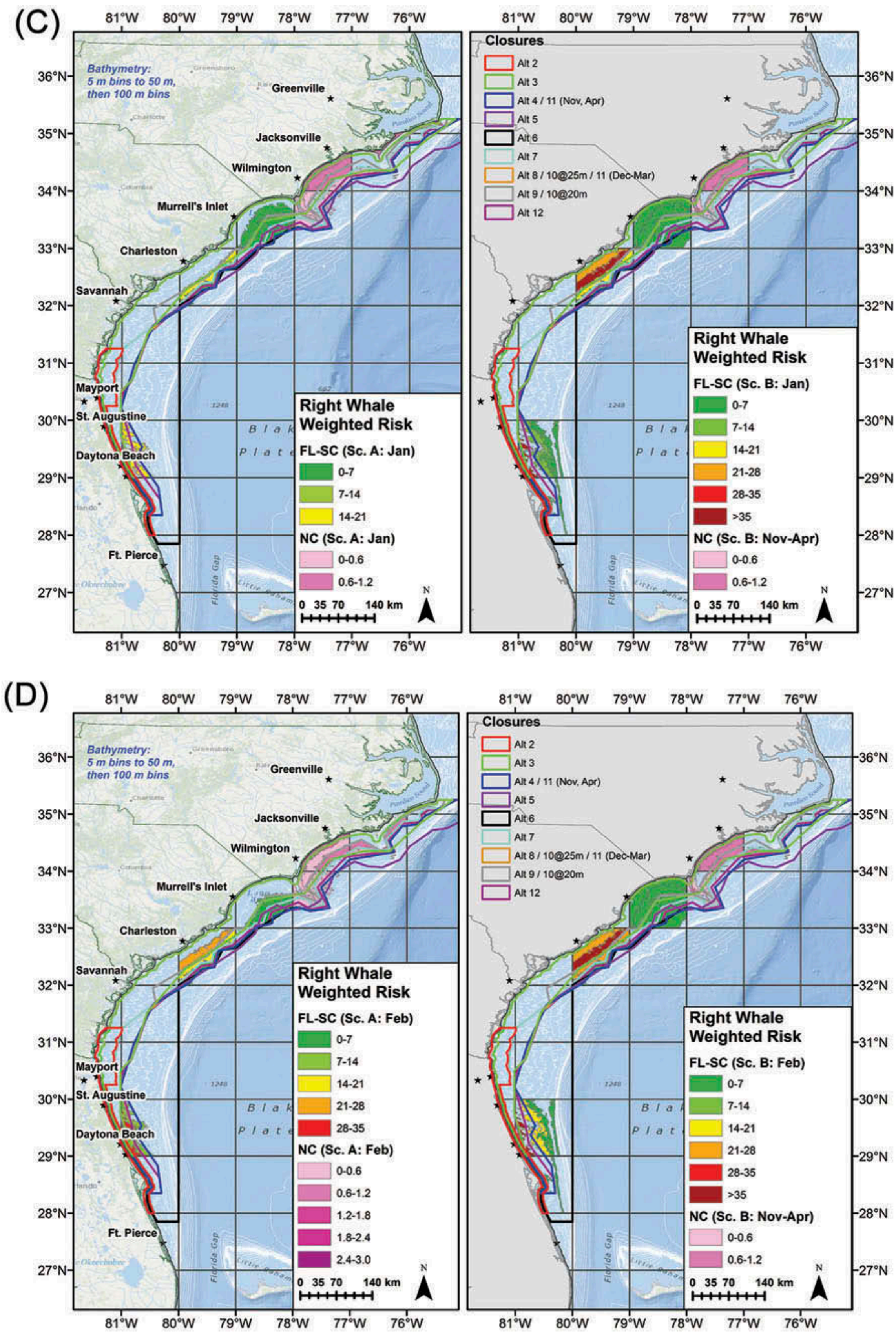

FIGURE 4. Continued.

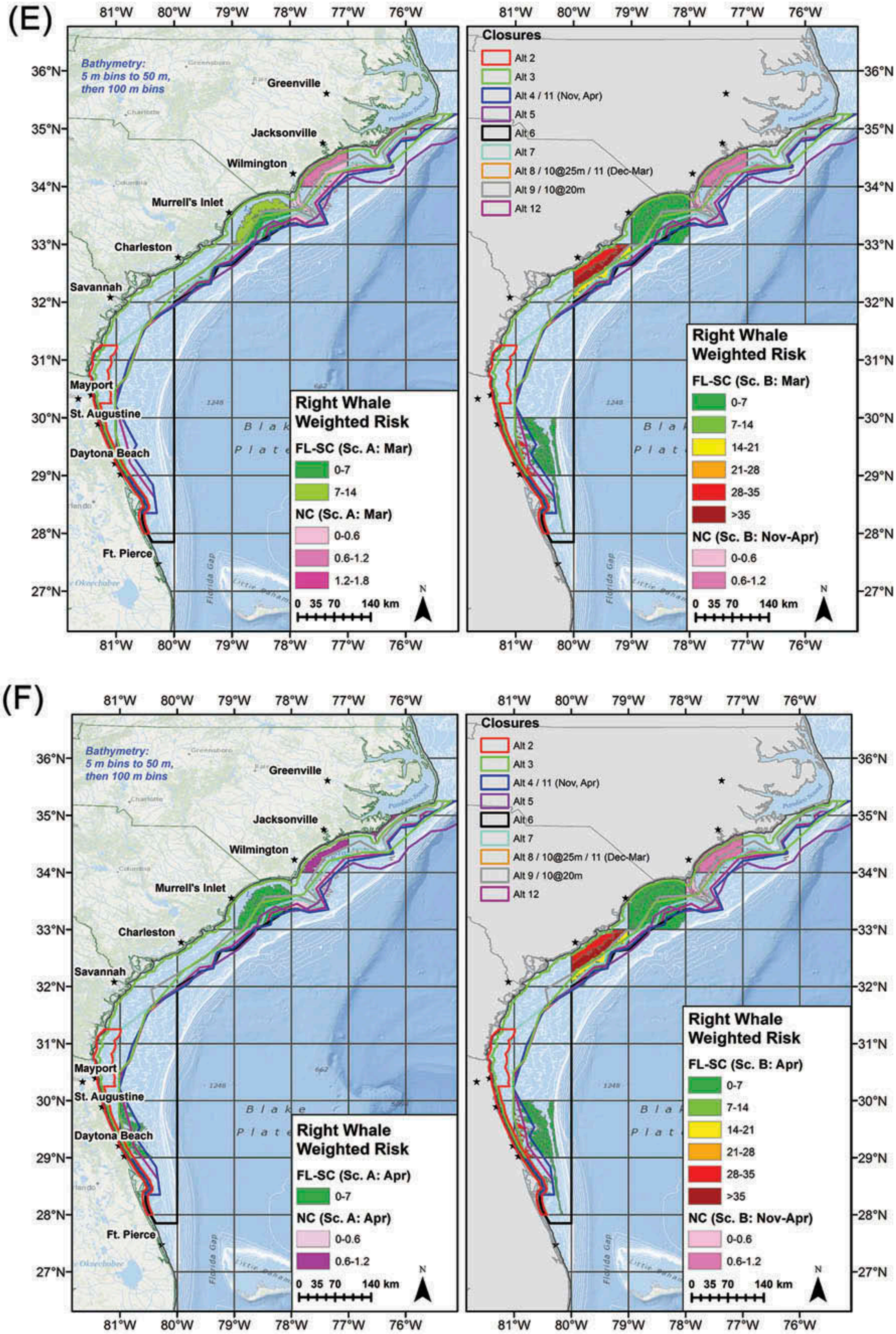

FIGURE 4. Continued.

TABLE 1. Projected commercial Black Sea Bass closure dates, percent of annual catch limit (ACL) reached, and risk (in relative risk units) of right whale entanglement in pot gear off North Carolina and Florida–South Carolina under various proposed closure alternatives (Alt1–Alt12). The spatial distribution of fishing effort scenarios (A–C) and the catch rate scenarios (S1–S4) are described in text; Alt1 = the status quo.

			Alt2				Alt3				Alt4				Alt5			
Scenario and condition		Alt1	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
A	Closure date		10/2	8/4	9/20	9/27	12/5	10/12	10/28	12/3	12/30	12/22	12/18	12/30	12/24	12/11	12/11	12/23
	%ACL	97	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Risk (North Carolina)	0	100	100	100	100	14	10	10	14	2	2	2	2	2	2	2	2
	Risk (Florida–South Carolina)	0	100	100	100	100	48	47	47	48	0	0	0	0	37	37	37	37
B	Closure date		10/2	8/4	9/20	9/27	12/3	10/17	11/4	12/2	12/28	12/19	12/18	12/29	12/18	12/2	12/8	12/17
	%ACL	97	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Risk (North Carolina)	0	100	100	100	100	26	21	21	26	8	8	8	8	2	1	1	2
	Risk (Florida–South Carolina)	0	100	100	100	100	30	29	29	30	2	2	2	2	43	42	42	43
C	Closure date		10/2	8/4	9/20	9/27	11/26	10/4	10/26	11/19	12/20	12/7	12/11	12/19	12/16	12/1	12/6	12/15
	%ACL	97	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Risk (North Carolina)	0	100	100	100	100	17	13	13	16	4	3	3	3	2	2	2	2
	Risk (Florida–South Carolina)	0	100	100	100	100	44	43	43	44	1	1	1	1	34	33	33	34

			Alt6				Alt7a				Alt7b				Alt7c			
Scenario and condition		Alt1	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
A	Closure date		12/29	12/21	12/18	12/29	10/11	8/18	10/6	10/7	10/11	8/18	10/6	10/7	10/23	9/6	10/16	10/20
	%ACL	97	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Risk (North Carolina)	0	2	2	2	2	74	74	74	74	74	74	74	74	48	48	48	48
	Risk (Florida–South Carolina)	0	0	0	0	0	94	94	94	94	87	87	87	87	70	70	70	70
B	Closure date			12/25	12/20	n/a	10/12	8/20	10/9	10/9	10/13	8/22	10/10	10/9	10/26	9/11	10/21	10/24
	%ACL	97	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Risk (North Carolina)	0	8	8	8	8	69	69	69	69	69	69	69	69	50	50	50	50
	Risk (Florida–South Carolina)	0	0	0	0	0	77	77	77	77	67	67	67	67	55	55	55	55
C	Closure date		12/20	12/7	12/10	12/19	10/11	8/18	10/6	10/7	10/11	8/18	10/6	10/7	10/23	9/6	10/16	10/20
	%ACL	97	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Risk (North Carolina)	0	4	3	3	3	71	71	71	71	71	71	71	71	46	46	46	46
	Risk (Florida–South Carolina)	0	0	0	0	0	84	84	84	84	80	80	80	80	65	65	65	65

TABLE 1. Continued.

Scenario	Condition	Alt1	Alt8a S1	Alt8a S2	Alt8a S3	Alt8a S4	Alt8b S1	Alt8b S2	Alt8b S3	Alt8b S4	Alt9a S1	Alt9a S2	Alt9a S3	Alt9a S4	Alt9b S1	Alt9b S2	Alt9b S3	Alt9b S4
A	Closure date		12/12	10/27	12/1	12/11	10/23	9/6	10/16	10/20	10/31	9/20	10/15	10/27	10/14	8/23	10/7	10/11
	%ACL	97	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Risk (North Carolina)	0	7	6	7	7	48	48	48	48	26	26	26	26	54	54	54	54
	Risk (Florida–South Carolina)	0	39	38	39	39	70	70	70	70	62	62	62	62	79	79	79	79
B	Closure date		12/9	10/28	11/25	12/8	10/26	9/11	10/21	10/24	11/9	9/27	10/19	11/3	10/19	8/30	10/11	10/15
	%ACL	97	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Risk (North Carolina)	0	26	20	24	26	50	50	50	50	51	48	48	49	63	63	63	63
	Risk (Florida–South Carolina)	0	43	41	42	43	58	58	58	58	57	56	56	56	64	64	64	64
C	Closure date		12/7	10/20	11/9	12/6	10/23	9/6	10/16	10/20	10/28	9/15	10/13	10/24	10/15	8/24	10/6	10/11
	%ACL	97	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	Risk (North Carolina)	0	11	9	9	11	46	46	46	46	35	35	35	35	57	57	57	57
	Risk (Florida–South Carolina)	0	35	34	34	35	64	64	64	64	56	56	56	56	71	71	71	71

Scenario	Condition	Alt1	Alt10 S1	Alt10 S2	Alt10 S3	Alt10 S4	Alt11 S1	Alt11 S2	Alt11 S3	Alt11 S4	Alt12 S1	Alt12 S2	Alt12 S3	Alt12 S4
A	Closure date		10/23	9/6	10/16	10/19	12/28	12/18	12/13	12/27	12/23	12/10	12/11	12/22
	%ACL	97	100	100	100	100	100	100	100	100	100	100	100	100
	Risk (North Carolina)	0	6	6	6	6	3	3	3	3	3	3	3	3
	Risk (Florida–South Carolina)	0	38	38	38	38	3	3	3	3	6	6	6	6
B	Closure date		10/26	9/11	10/21	10/24	12/23	12/11	12/10	12/24	12/19	12/4	12/9	12/18
	%ACL	97	100	100	100	100	100	100	100	100	100	100	100	100
	Risk (North Carolina)	0	20	20	20	20	15	15	15	15	14	13	13	14
	Risk (Florida–South Carolina)	0	42	42	42	42	7	7	7	7	5	5	5	5
C	Closure date		10/23	9/6	10/16	10/20	12/18	12/3	12/6	12/17	12/15	11/21	12/5	12/14
	%ACL	97	100	100	100	100	100	100	100	100	100	100	100	100
	Risk (North Carolina)	0	9	9	9	9	8	7	7	8	6	4	5	6
	Risk (Florida–South Carolina)	0	34	34	34	34	5	5	5	5	6	6	6	6

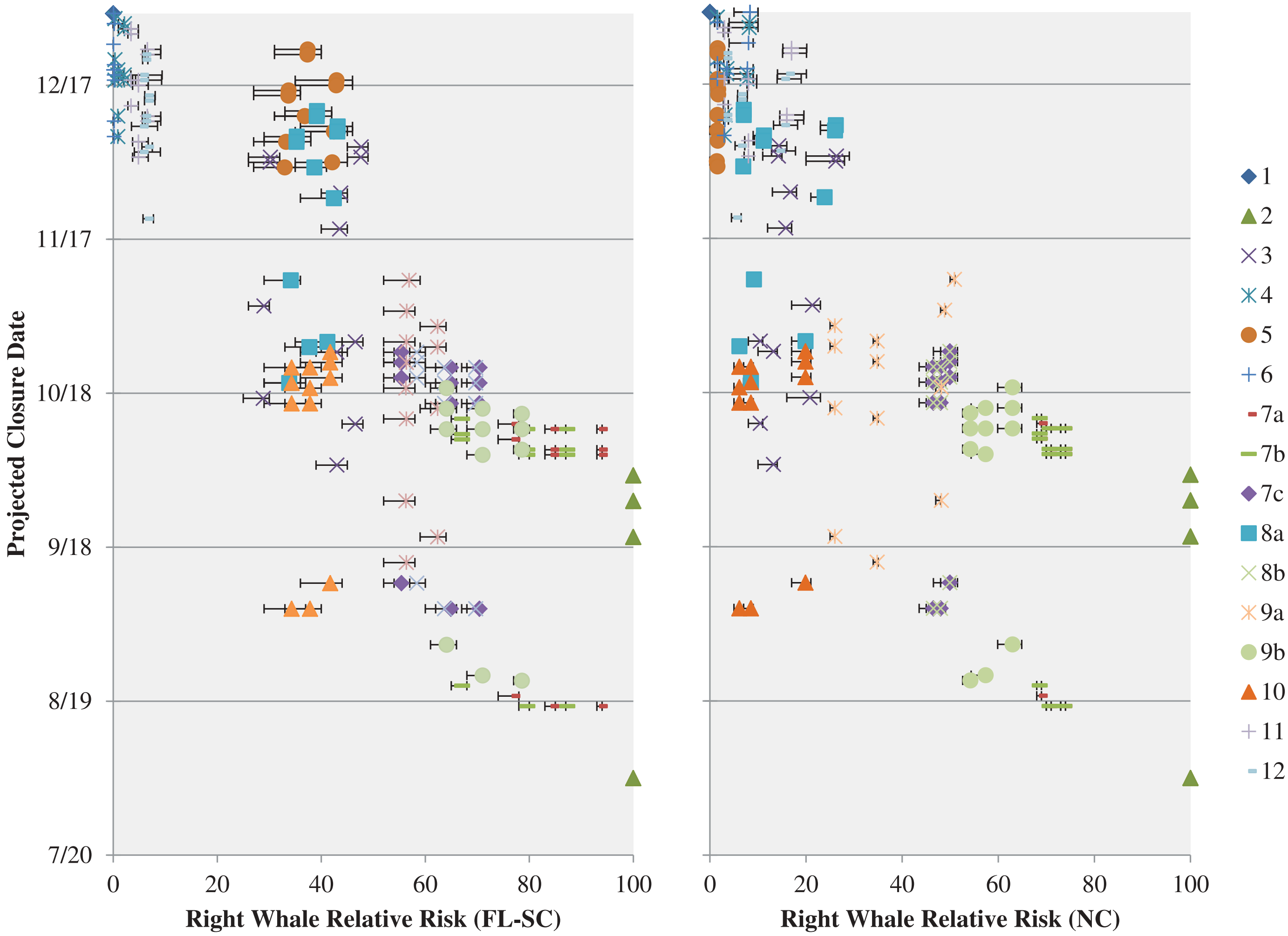

FIGURE 5. Projected closure dates versus the relative risk of right whale entanglement, by alternative (colored numbers), across catch rate scenarios 1–4 and spatial pot gear distribution scenarios A–C for right whale distributions under mean conditions. Number–letter combinations correspond to the closure alternatives in Reg-16 (Supplement A). The error bars denote the 95% confidence limits around the mean right whale encounter rates.

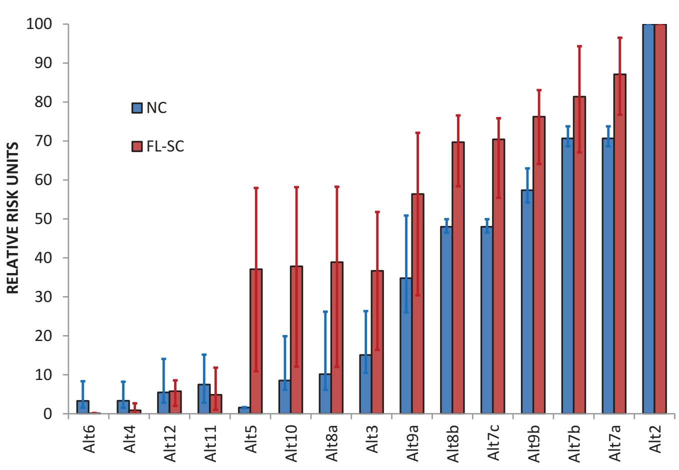

FIGURE 6. Median relative risk to North Atlantic right whales by Reg-16 alternative for the North Carolina and Florida–South Carolina models across environmental conditions; the error bars denote the minimum and maximum modeled risks.

the ACL is reached under most alternatives, the overall net gains to the fishery are minimal (<US$60,000).

The analyses of the economic effects presented in Reg-16 and the biological effects presented in this study are based heavily on data from the 2013–2014 fishing season to account for recent increases in the stock size. Catch per pot haul indicated that there was a full-season fishery with peak catches in winter during the early 2000s which in the most recent 5 years has shifted to a derby fishery characterized by high summer catch rates and early quota closures. The 2008–2009 season was the last season with no quota closure during right whale season (November 1–April 30). Despite effort restrictions implemented under Amendment 18A and the substantial increase in ACL implemented by Reg-19, the commercial fishery caught more than 99% of its ACL in the 2013–2014 season. Even with the hook-and-line trip limits imposed by Reg-14, the fishery was projected to catch 97% of its ACL under alternative 1 (the status quo) for the 2014–2015 season. The implementation of Reg-14 shifted the season's start date from June 1 to January 1 and, exclusive of Reg-16 alternative 1, will guarantee at least some pot gear fishing during the period November 1–April 30, when right whales are present.

Given the substantial changes in the fishery in the past two fishing seasons and the lack of fishing in November–April (the period of greatest concern for federally protected large-whale species), it is challenging to predict the impacts of the various alternatives under consideration by Reg-16. To encompass the range of realistic possibilities, four scenarios were evaluated for catch rate, three scenarios were evaluated for the spatial distribution of fishing, and three SST scenarios were evaluated for the spatial distribution of whales. The projected quota closure dates for the spatial closure alternatives varied by as much as 59 d across scenarios, but the differences between alternatives were consistent across scenarios. The differences between alternatives were also mostly consistent across the Florida–South Carolina and North Carolina models despite differences in approach and the modeled whale distributions. Catch rate projection scenario 1, which is based on catch rates from 2008–2009, does not account for the rebuilding of the Black Sea Bass stock, but it does feature winter catch rates on a par with those observed in summer months during the 2013–2014 season. Scenario 2 does not account for high fishing pressure during the summer months, which would likely result in local depletions and possibly a decline in catch rates during winter months. The catch rates predicted by scenario 2 have been observed in a single month but never in multiple consecutive months, as predicted. Scenario 2 exceeds the highest observed catches for each month by 5%; however, the abundance of Black Sea Bass available to the pot gear fishery is projected to be substantially higher as a result of the rebuilding of the stock (SEDAR 2013), and the reconfiguration of the commercial season to January–December by Reg-14 increases the likelihood of high January–April catch rates and reduces concerns about the impacts of localized depletion on projected catch rates in the first few months of the season. In summary, scenario 2 may capture this increasing abundance trend or it may overestimate the catch rates that could be achieved in future seasons. Scenario 3 assumes that catch rates in November–May will be constant and equal to those observed in October 2013; thus, it does not account for any temporal dynamics of the catch rate that might be caused by fish movements or a reduction in the number of trips because of adverse weather. Scenario 4 moderates variability across years by averaging catch rates across the past three open winter seasons (2006–2007 to 2008–2009).

Of the scenarios for the spatial distribution of pot gear, scenarios A and C do not account for recent shifts in the distribution of fishing pressure. The stock may have shifted in regional abundance due to localized recruitment pulses (Caley et al. 1996) or serial depletion (Cardinale et al. 2011), and some pot gear endorsement holders may have moved or dropped out of the fishery. Conversely, scenario B does not account for inshore–offshore dynamics in winter months because it is based on data from June–October. Accurate prediction of the impacts of spatial closures is further challenged because the locations and depth of fishing are reported by trip. Multiple sets may be made during a trip, so the depths and areas fished might not be accurately represented in the logbook. This is less of a concern with the Black Sea Bass pot gear fishery than for many other fisheries due to the relatively low limit on the number of sets per trip. The model assumes that landings during May–October will be equivalent to 2013–2014 observations. Reduced catch rates before November would result in longer winter seasons for all scenario–alternative combinations with projected quota closures, leading to increased cumulative risk of right whale entanglement.

Removing the pot gear closure would provide the fastest path toward achieving the ACL, as it removes all spatiotemporal restrictions on the use of pot gear to harvest Black Sea Bass. The relative risk of entanglement for large whales in pot gear among the alternatives considered ranged from no increased risk (alternative 1) to maximum exposure to pot gear (complete removal of the closure).

Alternative 2, with a spatial closure boundary represented by the North Atlantic right whale critical habitat designated in 1994 (USOFR 1994), did not reduce entanglement risk relative to complete removal of the closure because no fishing effort was projected to occur inside this boundary, yet right whales were predicted to occur outside this boundary. Alternatives 7b, 7c, 8b, and 9b resulted in very high relative risk of right whale entanglement for temporal reasons (right whales were predicted to be present off North Carolina and South Carolina during all winter months and were observed there during surveys from December to May) and spatial reasons (right whales were predicted to occur and were observed outside of these spatial boundaries).

Of the alternatives that would permit pot fishing during the winter, alternatives 4, 5, and 6 resulted in the lowest increases in relative risk. The spatial overlap of Black Sea Bass fishing effort with the proposed closed areas under alternatives 4 and 6 was consistent among fishing effort scenarios. Alternative 4 was based on sightings of right whales from all demographic groups from aerial surveys off Florida–South Carolina and University of North Carolina–Wilmington aerial surveys off North Carolina (SAFMC 2015), and the spatial extent of this alternative encompasses 96% and 97%, respectively, of these sightings in the Florida–Georgia and North Carolina–South Carolina regions. The spatial overlap of Black Sea Bass fishing effort with the proposed closed areas under alternatives 3, 5, 7a, 8a, and 9a depended on assumptions about the spatial distribution of fishing pressure. Alternatives 3 and 5 would not close pot gear effort from St. Augustine to Cape Canaveral, where whales were predicted to occur (see Figure 3), and these resulted in slightly greater risk of entanglement than did alternative 4. Alternatives 3 and 5 were based on relative thresholds from habitat models developed for calving right whales (i.e., not all demographic groups; Good 2008; Keller et al. 2012). Juvenile right whales appear to be most prone to entanglement (Knowlton et al. 2012) and so must be taken into account specifically. The spatial closure for alternative 6 had the largest extent and therefore resulted in the lowest relative risk of right whale entanglement of all the alternatives except alternative 1 (the status quo). Alternative 11 (the SAFMC's selected alternative that will be implemented in 2016) represents a compromise between alternative 4 (which provides a high level of protection during the core calving months [December–March]) and alternative 8a (which allows for some pot fishing during November and April).

There is uncertainty in the predicted distribution of right whales, especially off North Carolina, where survey effort was limited. Both the Florida–South Carolina and North Carolina models implicitly assume that the detectability of right whales (and its effect on predicted encounter rates) is equivalent across the study area; detectability, however, can vary in space if survey conditions or whale behavior vary. For example, right whales likely use the mid-Atlantic as a migratory corridor (Schick et al. 2009), and migrating whales that spend a small percentage of time at the surface can go undetected, resulting in an underestimate of right whale occurrence from visual surveys (Richardson et al. 1995). Nevertheless, the aerial survey data used in this study confirm that right whales are present off North Carolina and South Carolina during the entire winter, from at least December to May.

In this study, the relative risk of entanglement was estimated from the co-occurrence of right whales and Black Sea Bass pot gear in space and time. Although some studies have made absolute estimates of risk (e.g., van der Hoop et al. 2012), relative risk is frequently used when assessing the risk to protected species because the level of detail required to estimate absolute risk is often lacking (Fonnesbeck et al. 2008; Vanderlaan et al. 2011; Murray and Orphanides 2013; Redfern et al. 2013; Whitt et al. 2013; Brown et al. 2015). For example, we used survey encounter rates averaged across years as a proxy for true whale densities, which are unknown and likely to vary across years. Additionally, actual entanglement rates for right whales with Black Sea Bass pot gear are unknown and may vary with whale behavior and size and the characteristics of the fishing gear (Knowlton et al. 2012). If predicting environmental conditions is not possible, using historical means may be the most practical way to forecast risk. However, our results demonstrate that the impacts of a given management boundary may vary depending on SST and possibly other oceanographic conditions. After considering several scenarios, we determined that the relative differences in landings and the relative risk of right whale entanglement among closure alternatives were consistent despite these uncertainties. Furthermore, comparing alternatives on a relative risk scale mitigated the uncertainty in true entanglement rates, pot gear soak times, and catch rates.

This analysis implicity assumes that recent fishing pressure is predictive of future behavior. Fishermen can change their fishing effort in response to management actions, which might compromise the effectiveness of closures (Abbott and Haynie 2012). Our analysis did not consider that effort might shift into open areas during November–April. Few of the areas that would remain open have been fished for Black Sea Bass, and most of them have not been fished in November–April for 5 years or more. Thus, it is difficult to determine how much effort might shift to open areas and which areas would receive the new effort. If effort shifts into open areas, our projections may underestimate catch rates, although the fuel costs associated with reaching open areas farther offshore and the requirement to bring pot gear back to shore under a 1,000-lb-gw trip limit might provide some financial disincentive to shift effort. The relative entanglement risk for right whales in open areas would increase if effort shifted into those areas, although for some closure alternatives the areas of highest risk would be closed and effort would shift into low-risk areas. Additionally, we assumed endorsement holders' pot gear soak times would be consistent with their observed, spatially explicit soak times from summer 2013–2014. If winter soak times are shorter, the impacts may be overestimated, and conversely if soak times are longer. However, because soak time is a scalar applied to the distribution of pot gear effort, the relative ranking of alternatives would not be impacted by this assumption. Finally, closures to pot gear may also lead to shifting effort to other gears (primarily hook and line). Shifting from pot gears with buoy lines to hook and line gears would likely reduce serious injury and mortalities because buoy lines and groundlines are the gear types most often identified as entangling right and humpback whales *Megaptera novaeangliae* (Johnson et al. 2005; Knowlton et al. 2012).

The maintenance of management areas, including the imposition of time–area closures, can result in impacts to a fishery and other resources affected by that fishery. If there are sufficient data, the design of these areas can be evaluated by comparing the predicted impacts among different closure alternatives within the context of management objectives. Integrating spatial data relevant to the fishery and other natural resources can facilitate decision making about the most effective closure boundary. For example, Vanderlaan et al. (2011) evaluated the threat of fishing gear to right whales in Canadian waters and recommended area-specific seasonal closures of some fisheries during the times of greatest risk. Methods of addressing the uncertainty in the projected impacts of a closure are also necessary to reliably compare alternatives. To more fully elucidate the impacts of a closure, future work evaluating closure alternatives should consider the economic impacts on the fishery, the effects of potential changes in the behavior of fishermen, and the fine-scale interactions between fishing activities and protected resources.

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