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LETTER

Vessel Strikes to Large Whales Before and After the 2008 Ship Strike Rule

Julie M. van der Hoop[1], Angelia S. M. Vanderlaan[2], Timothy V. N. Cole[3], Allison G. Henry[3], Lanni Hall[4], Blair Mase-Guthrie[5], Tonya Wimmer[6], & Michael J. Moore[1]

[1] Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA
[2] Large Pelagics Research Center, University of Massachusetts Amherst, Gloucester, MA 01931, USA
[3] NOAA National Marine Fisheries Service, NEFSC, Woods Hole, MA 02543, USA
[4] NOAA Fisheries Greater Atlantic Regional Fisheries Office, Gloucester, MA 01930, USA
[5] NOAA Fisheries Southeast Regional Office, Miami, FL 33701, USA
[6] Maritime Marine Animal Response Network, Marine Animal Response Society, Nova Scotia Museum, Halifax, Nova Scotia B3H 4J1, Canada

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Correspondence
Julie van der Hoop, Biology Department, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA.
E-mail: jvanderhoop@whoi.edu

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Abstract

To determine effectiveness of Seasonal Management Areas (SMAs), introduced in 2008 on the U.S. East Coast to reduce lethal vessel strikes to North Atlantic right whales, we analyzed observed large whale mortality events from 1990–2012 in the geographic region of the "Ship Strike Rule" to identify changes in frequency, spatial distribution, and spatiotemporal interaction since implementation. Though not directly coincident with SMA implementation, right whale vessel-strike mortalities significantly declined from 2.0 (2000–2006) to 0.33 per year (2007–2012). Large whale vessel-strike mortalities have decreased inside active SMAs, and increased outside inactive SMAs. We detected no significant spatiotemporal interaction in the 4-year pre- or post-Rule periods, although a longer time series is needed to detect these changes. As designed, SMAs encompass only 36% of historical right whale vessel-strike mortalities, and 32% are outside managed space but within managed timeframes. We suggest increasing spatial coverage to improve the Rule's effectiveness.

Introduction

Vessel strikes contribute significant mortality to large whale stocks in the Northwest Atlantic despite mitigation efforts (van der Hoop *et al.* 2013). In 2008, the United States regulated to reduce vessel-strike mortalities in U.S. waters to North Atlantic right (*Eubalaena glacialis*; hereafter right) whales, mandating speeds <10 knots (18.5 km/hour) for commercial vessels ≥65 ft (20 m) long in 10 spatially and temporally defined Seasonal Management Areas (SMAs; Figure 1; Table 1; NOAA 2008).

This "Ship Strike Rule" also established Dynamic Management Areas (DMAs), recognizing interannual variability in whale distribution and habitat use (Winn *et al.* 1986; Patrician *et al.* 2009). DMAs provide 15-day voluntary speed limits for right whale aggregations ($n \geq 3$) detected outside active SMAs. In addition, mariners are requested to avoid DMAs (NOAA 2008). SMA sites and seasons consider (1) right whale movement, distribution, and aggregation patterns from sightings and telemetry data; (2) vessel-strike distribution and occurrence; and (3) regions with predictable vessel traffic (Merrick 2005; NOAA 2006). Although its design was right-whale specific, it was expected that the Ship Strike Rule should benefit other large whales (NOAA 2006; NMFS 2008), as the effect of speed on the lethality of a vessel collision is not species specific (Vanderlaan & Taggart 2007).

The 2008 Ship Strike Rule included a 5-year sunset clause to relieve any affected entities, and enable the National Marine Fisheries Service (NMFS) to assess and report on its efficacy (NOAA 2008). Although this clause has been eliminated (NOAA 2013), Rule assessment remains critical to determine whether amendments are required to meet its goals.

We evaluate the Rule's effectiveness with a series of indicators against specific objectives (Hockings *et al.* 2006). Here, indicators are observed vessel-strike mortalities, and the objective is reduced likelihood of death to right whales from vessel collisions (NOAA 2008). We test the null hypothesis that SMAs introduced by the Ship Strike Rule were not effective in reducing observed vessel-strike mortalities to right whales specifically, and other large whale species generally. If effective, we expect the Rule to have yielded significant changes in the spatial distribution and a decrease in the rate of observed vessel-strike mortalities. We expect significant spatiotemporal interaction, whereby observed vessel-strike mortality rates are reduced in managed areas during managed times. By including additional large whale species other than right whales, we assess whether SMAs provide mutual benefit to other species (as expected; NMFS 2008), and calculate the degree of protection SMAs offer these populations.

Table 1 Location and active time periods of Seasonal Management Areas implemented annually, since December 9, 2008

Seasonal Management Area (SMA)		Active time period
Southeast United States:	Coastal Florida and Georgia	November 15 to April 15
Mid-Atlantic United States:	Brunswick, GA to Wilmington, NC	November 1 to April 30
	Ports of Morehead City and Beaufort, NC	November 1 to April 30
	Entrance to Chesapeake Bay: Ports of Hampton Roads, VA, and Baltimore, MD	November 1 to April 30
	Delaware Bay: Ports of Philadelphia, PA, and Wilmington, DE	November 1 to April 30
	Ports of New York/New Jersey	November 1 to April 30
	Block Island Sound	November 1 to April 30
Northeast United States:	Cape Cod Bay	January 1 to May 15
	Off Race Point	March 1 to April 30
	Great South Channel	April 1 to July 31

Methods

We obtained information on 1,198 mortality events (hereafter, mortalities) from 1990 to 2012 to blue (*Balaenoptera musculus*), Bryde's (*B. edeni*), fin (*B. physalus*), humpback (*Megaptera novaeangliae*), minke (*B. acutorostrata*), right, sei (*B. borealis*), sperm (*Physeter macrocephalus*), and unidentified large whales in the Northwest Atlantic between the southern tip of Florida (25.4083° N, 80.3° W) and Cape Sable, Nova Scotia, Canada (43.5087° N, 65.69° W), from the coast to continental shelf. This geographic range encompasses numerous vessel-strike related management schemes introduced since 1997 in Canada and the United States (see e.g., Mullen *et al.* 2013 for a review) and envelops the Gulf of Maine allowing for carcass drift and coastline geography.

We obtained records (on shore and floating at sea) collected by stranding responders in the Canadian Maritime provinces from the Maritime Marine Animal Response Network, and American records from (1) National Oceanic and Atmospheric Administration (NOAA) Southeast and Northeast U.S. Marine Mammal Stranding Network Databases, and local response programs therein, and (2) NOAA's Northeast Fisheries Science Center (NEFSC).

The presumed cause of death, provided by the stranding responders or agency, was categorized as entanglement, vessel strike, other human cause (e.g., marine debris), nonhuman cause (e.g., perinatal), and undetermined (due to decomposition or where no cause of death was provided). Data were qualified through the mortality determinations of NOAA's NEFSC (e.g., Henry *et al.* 2013).

We included records of dead animals only, though previous studies include "serious injuries" that would likely

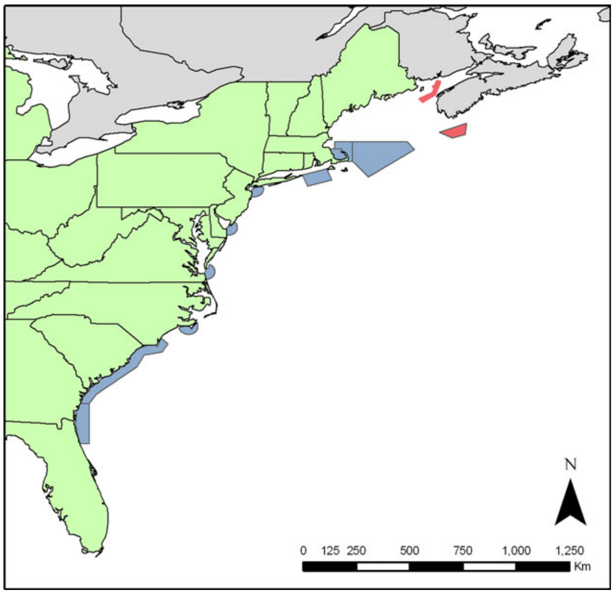

Figure 1 Map of Seasonal Management Areas (SMAs; blue) implemented on December 9, 2008 as part of the United States' vessel-strike reduction strategy (the "Ship Strike Rule") and existing vessel-strike reduction measures in Canada in the Bay of Fundy (2003) and Roseway Basin (2007) (red).

result in death (Vanderlaan & Taggart 2007; NOAA 2011; Cole & Henry 2013). Estimates herein are therefore lower than in van der Hoop *et al.* (2013) and are a greater underestimation of the true number of mortalities.

We examined opportunistic and survey (aerial and vessel) sightings of all large whales, maintained within the North Atlantic Right Whale Consortium database (NARWC 2008) from 1990 to 2008 to assess their percent occurrence within SMAs.

Temporal analyses

To determine whether SMA implementation affected observed mortality rates, we used Webster's method (Webster 1973) with $y_i + y_i$ window sizes of $y = 3$ and 4 years to detect discontinuities in the time series of vessel-strike mortalities per year to right whales and, separately, to all other (including unidentified large whale) species. Discontinuities separate periods over which mortality rates are consistent, or stationary. We calculated Student's t-statistic for Webster's method with the standard deviation of the entire data series as window sizes are small (Legendre & Legendre 2012), and considered discontinuities significant at $\alpha = 0.1$.

We calculated Poisson cumulative distribution functions (CDFs) with bootstrap estimated 95% confidence intervals (CIs) based on the average number of observed vessel-strike mortalities per year (μ) as in Vanderlaan *et al.* (2009) for the stationary time periods detected with Webster's method.

Spatial analyses

Spatial coordinates reflect the location where a mortality was first detected or reported. We estimated location for 33 cases where coordinates were not provided but location information was descriptive (e.g., an address). We created a 1-D spatial coordinate system, selecting all mortalities observed within 20 nmi (37 km, i.e., the distance to which most SMAs extend) of the coastline ($n = 934$) and assigning them a coordinate for the closest location along the coastline. We then calculated the distance from the southern tip of Florida (our spatial origin), to each coastline location. We calculated smoothed (200 km bandwidth) normal kernel density distributions of these locations in two pre-Rule (19 year, January 1, 1990 to December 8, 2008; 4 year, December 8, 2004 to December 8, 2008) and one post-Rule (4 year, December 9, 2008 to December 31, 2012) period, all inclusive. To determine whether these distributions for all causes of death or attributed to vessel strike ($n = 140$) differed between each pre-Rule period and the post-Rule period, we used a two-sample Kolmogorov-Smirnov test (H_0 = no difference).

Spatiotemporal interaction

We assigned two binomial indicators (space, S; time, T) to all observed vessel-strike mortalities: $S = 1$ if the mortality was observed inside and 0 if outside SMAs, and $T = 1$ if the mortality was observed when the closest SMA was active and 0 if not active (Table 1). For example, for a vessel-strike mortality observed inside an SMA during the inactive period (e.g., Delaware Bay; September): $S = 1$, $T = 0$. For a vessel-strike mortality observed outside an SMA when nearby SMAs were active (e.g., Cape Hatteras, NC; March): $S = 0$, $T = 1$. Active times were applied to pre-Rule and post-Rule periods to test for interaction before Rule implementation. Because of SMA geometry, Great South Channel and Off Race Point SMAs were combined, yielding an active period of March 1 through July 31.

To examine whether SMAs were designated in appropriate areas, we calculated the percentage of (1) observed vessel-strike mortalities and (2) opportunistic and survey sightings for each species in the four different binomial combinations ($S = 0$, $T = 0$; $S = 1$, $T = 0$; $S = 0$, $T = 1$; and $S = 1$, $T = 1$) before implementation, 1990–2008.

To test for an interaction between space and time on the observed number of vessel-strike mortalities we performed an approximate permutation test for an analysis of variance (Anderson 2001). To remove the effects of each factor, space and time, we subtracted the appropriate mean from each observation (the number of vessel-strike mortalities within a year either pre- or postimplementation of the Ship Strike Rule) to obtain corresponding residuals that were used in the approximate permutation test (10,000 replications).

Results

From 1990 to 2012, 1,198 mortalities were observed. We identified 975 cases to one of eight large whale species; 223 cases involved unidentified large whales. Consistent with previous findings over the last 40 years (van der Hoop *et al.* 2013), the leading diagnosed causes of death (determined in 458 cases, 38%) were entanglement ($n = 169$), nonhuman causes ($n = 147$), and vessel strike ($n = 135$). Since Rule implementation (cause of death determined in 67/204 cases, 33%), entanglement has remained the leading diagnosed cause of death ($n = 29$) for all large whales over this geographic range, followed by vessel-strike ($n = 25$), and nonhuman-caused mortalities ($n = 10$).

Table 2 Percentage of opportunistic and survey sightings per species, 1990–2008 (pre-Rule implementation), located inside and outside (bold text) what would become 10 active Seasonal Management Areas (SMAs) following implementation of the Ship Strike Rule (NOAA 2008)

Species (*n* total sightings)	Blue (5)	Fin (6,717)	Humpback (9,503)	Minke (1,806)	Sei (3,006)	Sperm (570)	Right (21,749)
Area							
Southeast United States	–	–	0.31	0.0046	–	–	26
South Carolina Area	–	0.0046	0.083	–	–	–	2.9
Morehead City	–	–	0.023	–	–	–	0.10
Chesapeake Bay	–	–	–	–	–	–	0.092
Delaware Bay	–	–	–	–	–	–	0.014
New York, New Jersey	–	0.0092	–	–	–	–	0.0046
Block Island Sound	–	0.060	0.0046	0.028	–	–	0.11
Cape Cod Bay	–	5.3	2.5	0.65	0.0046	–	26
Off Race Point	–	1.5	1.2	0.38	–	–	3.2
Great South Channel	–	12	21	2.8	11	0.028	25
Outside	**100**	**81**	**75**	**96**	**89**	**100**	**17**

Table 3 Total number (*n*) and percentage of observed vessel-strike mortalities per species, 1990–2008, during combinations of active ($= 1$) and inactive ($= 0$) space (*S*) and time (*T*) of Seasonal Management Areas before being implemented by the Ship Strike Rule (NOAA 2008)

Species (total *n* svessel-strike mortalities)	Blue (1)	Fin (34)	Humpback (28)	Minke (11)	Sei (5)	Sperm (3)	Right (22)
$S = 0, T = 0$ (inactive space, inactive time)	–	15	21	9.1	40	100	27
$S = 0, T = 1$ (inactive space, active time)	100	8.8	32	–	–	–	32
$S = 1, T = 0$ (active space, inactive time)	–	23	21	64	20	–	4.6
$S = 1, T = 1$ (active space, active time)	–	53	25	27	40	–	36

Based on sightings data, 17% of right whale sightings, 1990–2008, were outside of what would become active SMAs following implementation (Table 2). In contrast, 27% of pre-Rule right whale mortalities occurred outside, and only 36% occurred fully inside, these spatiotemporal boundaries (Table 3). Comparable proportions of pre-Rule mortalities are observed inside future active SMA boundaries for right (36%), humpback (25%), minke (27%) and sei (40%) whales, and higher proportions for fin (53%) whales (Table 3).

Temporal

We detected three discontinuities with Webster's method, where right whale vessel-strike mortality rates were consistent from 1990 to 2000, 2001 to 2006, and 2007 to 2012 (inclusive; Figure 2). Bootstrapped 95% CIs around Poisson-aggregated CDFs indicate no difference in the right whale vessel-strike mortality rate between 1990–2001 (0.91 per year) and 2001–2006 (2.0 per year), followed by a significant decrease to 0.33 per year during 2007–2012. We detected no significant discontinuities for all other species of large whale over the entire data series. No significant discontinuities were detected for either right whales or all other large whale species between 2008 and 2009, immediately following Rule implementation.

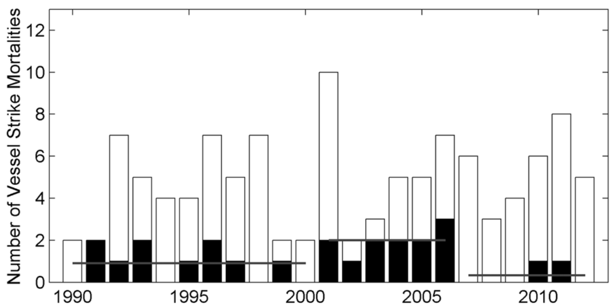

Figure 2 Total number of observed vessel-strike mortalities per year to North Atlantic right whales (black bars), and eight other, including unidentified, large whale species (white bars). Horizontal lines represent the average number of vessel-strike mortalities per year for right whales (grey) over periods separated based on discontinuities detected using Webster's method (see text).

Spatial

The smoothed kernel density distribution of vessel-strike mortalities for all species post-Rule differed significantly from the 19-year ($P = 0.013$, Kolmogorov-Smirnov Test Statistic [KS] $= 0.22$) and 4-year pre-Rule ($P = 0.0018$; KS $= 0.26$) periods. Postimplementation, increases in mortality occurred from Delaware to New York, and decreases from the Great South Channel, northward (Figure 3). In contrast, no significant differences were

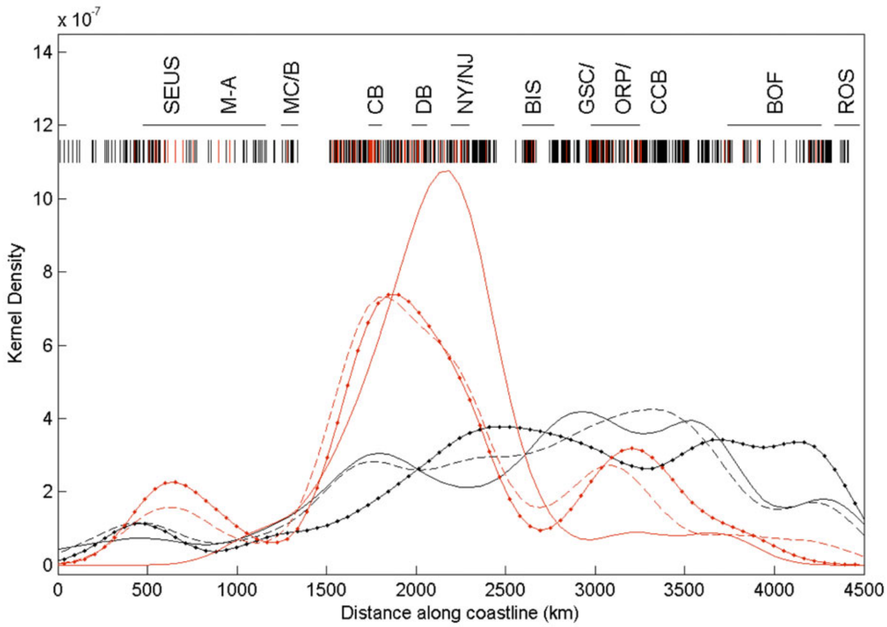

Figure 3 Smoothed kernel density estimates of all (black) and vessel-strike related (red) mortalities to large whales, including unidentified to species, before (1990 to December 8, 2008, dash; December 8, 2004–December 8, 2008, dot-dash) and after (December 9, 2008 to December 31, 2012, solid line) enactment of the "Ship Strike Rule" along the coastline from the southern tip of the Florida Peninsula, USA, to Cape Sable, Nova Scotia, Canada. Vertical lines indicate the location of all (black) and vessel strike (red) mortalities. Horizontal lines indicate the spatial extent of mandated Seasonal Management Areas (SMAs; SEUS, Southeast United States; M-A, Mid-Atlantic; MC/B, Morehead City/Beaufort, NC; CB, Chesapeake Bay; DB, Delaware Bay; NY/NJ, New York/New Jersey; BIS, Block Island Sound; GSC, Great South Channel; ORP, Off Race Point, MA; CCB, Cape Cod Bay, MA) in U.S. waters and voluntary regulations in Canadian waters (BOF, Bay of Fundy; ROS, Roseway Basin).

observed in the density distributions of mortalities for all other causes of death between either pre-Rule or the post-Rule periods (1990–2008: $P = 0.89$, KS $= 0.080$; 2004–2008: $P = 0.34$, KS $= 0.13$).

Spatiotemporal

We detected no significant interaction between space and time on the observed number of vessel-strike mortalities for all species in the 4-year pre- ($P = 0.82$) and post-Rule implementation periods ($P = 0.48$; Figure 4). There was a significant interaction in the 19-year pre-Rule period ($P = 0.040$), indicating that sample size or short time series may preclude the determination of significant interactions in 4-year periods. Observations suggest that following Rule implementation, fewer vessel-strike mortalities have occurred inside active SMAs, whereas their prevalence has increased outside inactive SMAs (Figures 4 and 5).

Discussion

Given the continued interest in implementing speed restrictions around the world (Silber *et al.* 2012b), it is essential that existing measures be assessed for their ability to achieve their objectives, and to determine what factors may contribute to their success or failure (Hockings *et al.* 2006). The significant reduction in right whale vessel-strike mortality between 2001–2006 and 2007–2012 observed here is not directly coincident with the implementation of the Ship Strike Rule alone (which would be 2008–2012), but likely reflects the combined effect of numerous measures introduced since 2006 (see e.g., Mullen *et al.* 2013 for a review). Voluntary and mandatory routing changes in the Bay of Fundy (since 2003), and in the Southeast United States and Cape Cod Bay (since 2006); and an Area to be Avoided (ATBA) in Roseway Basin (since 2008) have provided significant decreases in relative (Fonnesbeck *et al.* 2008; Vanderlaan *et al.* 2008; Vanderlaan & Taggart 2009) and absolute (van der Hoop *et al.* 2012) vessel-strike risk to right whales.

Though spatial and temporal trends are often analyzed separately, their interaction must be considered when testing the effectiveness of a regulation with specific extents in space and time. The lack of significant interaction following Rule implementation suggests that SMAs have been ineffective in reducing vessel-strike mortality in managed areas during managed times. We attribute

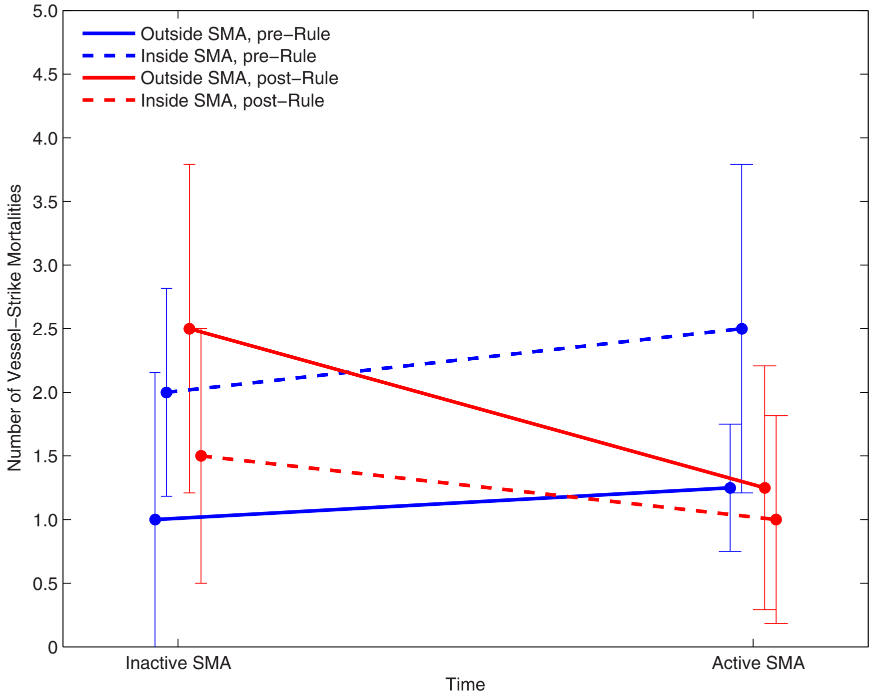

Figure 4 The number of vessel-strike mortalities per year to large whales (including unidentified to species) observed inside (dashed lines) and outside (solid lines) inactive and active Seasonal Management Areas (SMAs) before (blue) and after (red) their implementation on December 9, 2008.

our inability to detect many of the intended effects of the Ship Strike Rule to three issues of rule design and implementation: (1) low vessel compliance with the SMAs; (2) insufficient time and/or monitoring to examine effectiveness; and (3) SMAs may be inappropriately located, or may be too short in duration and/or too small (Schick *et al.* 2009).

The rule's perceived ineffectiveness could be due to compliance, which has been low (20.7%–32.8%, 2009–2011; Silber & Bettridge 2012) and is in many areas unknown. Although automatic identification system data have been used to determine changes in relative vessel-strike probabilities since Rule implementation (Wiley *et al.* 2011; Conn & Silber 2013), these studies do not report on compliance or vessel traffic distributions. Rule awareness by mariners likely increased following implementation, as outreach (e.g., through compliance guides, Mandatory Ship Reporting Systems) and enforcement programs (e.g., through violation notices, at-sea hailings) developed and particularly strengthened in 2010 (Silber & Bettridge 2012). How these efforts have influenced operator compliance, and how the Rule has influenced vessel distribution remains unknown.

The detection of a significant spatiotemporal interaction in the 19-year pre-Rule period, but not the 4-year pre-Rule period suggests the second issue, that the Rule likely imposed an insufficient time frame for monitoring to detect an effect. Indicators available to assess the Ship Strike Rule (i.e., observed mortalities) occur with relatively low frequency, and require long periods to accumulate adequate sample sizes (Pace 2011). If the rule does not include sufficient monitoring provisions or support to test its own efficacy, then that is a failure in its design and implementation.

Finally, SMAs may not be appropriately located or timed. The SMAs only protect 23% of our study area and the active boundaries of SMAs encompass only 36% of historical right whale vessel-strike mortalities (Table 3). Although they overlap critical habitat and calving areas, SMAs do not provide protection in the mid-Atlantic migratory corridor where mortality density and incidence is greatest (Figures 3 and 5). Further, SMAs may be too short in duration and/or too small (Schick *et al.* 2009). A large proportion (32%) of pre-Rule right whale vessel-strike mortalities occurred outside SMAs during their active times, suggesting that the spatial extent is insufficient in certain seasons.

From Delaware to New York, SMAs are small and protect only port entrances (Figures 1 and 5). Here, visual survey data are sparse (Russell *et al.* 2001), and acoustic survey data are available but have not been used to design regulations. Increasing the size of SMAs

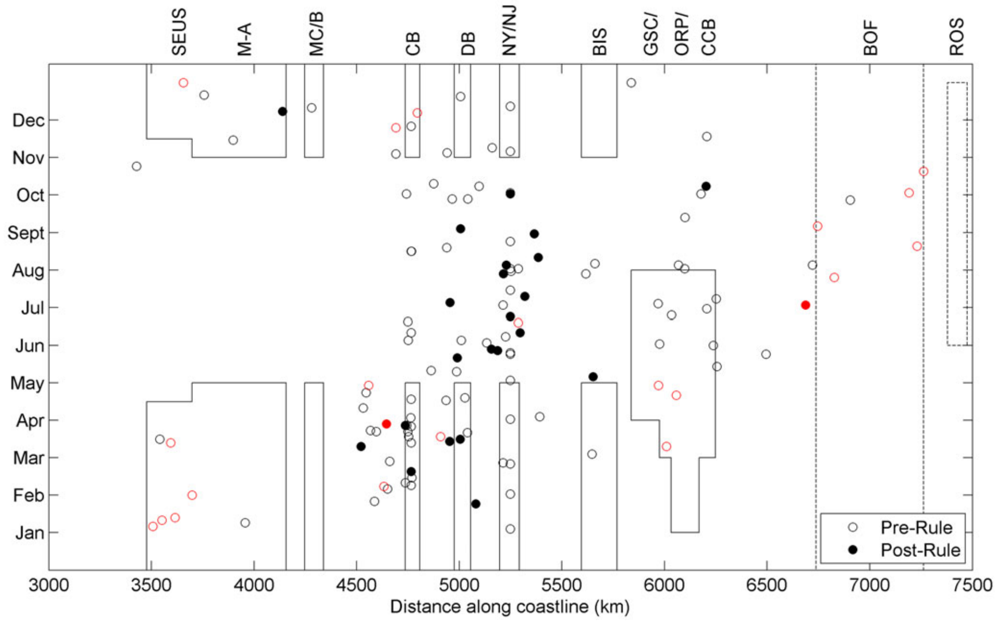

Figure 5 Spatial and temporal distribution of vessel-strike mortalities to North Atlantic right (red) and other (including unidentified) species of large whale (black) before (open circle) and after (closed circle) the enactment of the "Ship Strike Rule" on December 9, 2008. Boxes illustrate the spatial and temporal extents of mandated Seasonal Management Areas (SMAs; solid line; SEUS, Southeast United States; M-A, Mid-Atlantic; MC/B, Morehead City/Beaufort, NC; CB, Chesapeake Bay; DB, Delaware Bay; NY/NJ, New York/New Jersey; BIS, Block Island Sound; GSC, Great South Channel; ORP, Off Race Point, MA; CCB, Cape Cod Bay, MA) and concurrent regulations in Canadian waters (dashed lines) active since 2003 (BOF, Bay of Fundy) and 2007 (ROS, Roseway Basin).

could mitigate this high-risk area (overlapping high vessel and whale densities), maximizing conservation gain, while minimizing industry cost. Similar strategies (e.g., the shipping lanes in the Bay of Fundy or ATBA in Roseway Basin) have been extremely successful in reducing vessel-strike risk and incidence to right whales (Vanderlaan *et al.* 2008; Vanderlaan & Taggart 2009; van der Hoop *et al.* 2012), though effectiveness still relies on compliance.

Laist *et al.* (2014) conclude SMAs are properly located, as 87% of right whale vessel-strike mortalities in U.S. waters were found in or near SMAs during what would become effective dates. This large difference (87% vs. 36% reported here) is likely due to a 45 nmi (74 km) buffer zone around SMAs in their analysis. This increases SMA size by a relatively arbitrary amount, especially given that the authors recommend a 10-nmi extension of SMAs, which would fall within the managed area, under their definition.

Although low sample size and limited power precluded the determination of some significant effects of the Rule (see also Pace 2011; Silber & Bettridge 2012), it appears that vessel-strike mortality to large whales has decreased inside active SMAs (Figure 4). Otherwise, vessel-strike mortalities have increased outside of active SMA (Figures 4 and 5), contrary to expectation. If effective, DMAs should have contributed to decreased vessel-strikes outside of SMA time periods and regions, which does not appear to be the case. Unfortunately, DMAs have not been found to result in any changes in vessel speeds or routing (Silber *et al.* 2012a), which would explain these observations.

It was expected that SMAs should benefit other whales (NMFS 2008). Pre-Rule sightings and mortalities (Tables 2 and 3) suggest SMAs provide little-to-no benefit to blue and sperm whales, but offer similar (though low) protection to humpback, minke, sei, and fin whales as they do for right whales.

The number of observed vessel-strike mortalities is affected by many variables that change through time (van der Hoop *et al.* 2013). The exact detection location is not necessarily where death, or the vessel strike, occurred; however, there is a limited amount of drift data available for vessel-struck animals, drift will differ with location, and thus designating a limit of potential drift would remain subjective. Whale distribution may have changed throughout the study period, though we believe that it has remained fairly constant because the distribution of whale mortalities for other causes of death has not changed. The factors that then likely affected vessel-strike mortality distributions are related to vessels (abundance, distribution, and speed).

Conclusions

Lethal vessel-strikes to right whales appear to be less common than before SMAs and other mitigation strategies were implemented, and the spatial density of vessel-strike mortality to all large whales has changed. However, measures of spatiotemporal interaction are required to directly assess whether SMAs have been effective in reducing mortality inside managed areas during managed times. It would be optimistic to expect that changes in rare events could be detected in the short time period imposed by a sunset clause; rules should include adequate time periods to evaluate their own efficacy with sufficient statistical power. The Ship Strike Rule has been extended indefinitely (NOAA 2013). These and other methods should be applied as part of NMFS's agreement to periodically review the Rule as implementation continues. Suggested improvements to the Rule, specifically, increasing the spatial and temporal extent of SMAs in the mid-Atlantic, should be considered.

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