

Abstract—Cape Cod Bay (Massachusetts) is the only known winter and early spring feeding area for concentrations of the endangered North Atlantic right whale (*Eubalaena glacialis*) population. During January–May, 1998–2002, 167 aerial surveys were conducted (66,466 km of total survey effort), providing a complete representation of the spatiotemporal distribution of right whales in the bay during winter and spring. A total of 1553 right whales were sighted; some of these sightings were multiple sightings of the same individuals. Right whale distribution and relative abundance patterns were quantified as sightings per unit of effort (SPUE) and partitioned into 103 23-km² cells and 12 2-week periods. Significant interannual variations in mean SPUE and timing of SPUE maxima were likely due to physically forced changes in available food resources. The area of greatest SPUE expanded and contracted during the season but its center remained in the eastern bay. Most cells with SPUE>0 were inside the federal critical habitat (CH) and this finding gave evidence of the need for management measures within CH boundaries to reduce anthropogenic mortality from vessel strikes and entanglement. There was significant within-season SPUE variability: low in December–January, increasing to a maximum in late February–early April, and declining to zero in May; and these results provide support for management measures from 1 January–15 May.

Manuscript submitted 29 July 2007.
Manuscript accepted 21 March 2008.
Fish. Bull. 108:270–280 (2008).

The views and opinions expressed or implied in this article are those of the author and do not necessarily reflect the position of the National Marine Fisheries Service, NOAA.

Spatial and temporal distribution of North Atlantic right whales (*Eubalaena glacialis*) in Cape Cod Bay, and implications for management

Owen C. Nichols (contact author)¹

Robert D. Kenney²

Moira W. Brown^{1,3}

Email address for O.C. Nichols: onichols@umassd.edu

¹ Provincetown Center for Coastal Studies
5 Holway Avenue
Provincetown, Massachusetts 02657

Present address: School for Marine Science and Technology
University of Massachusetts–Dartmouth
200 Mill Road
Fairhaven, Massachusetts 02179

² University of Rhode Island Graduate School of Oceanography
Bay Campus Box 41
South Ferry Road
Narragansett, Rhode Island 02882

³ New England Aquarium
Central Wharf
Boston, Massachusetts 02110

North Atlantic right whales (*Eubalaena glacialis*) have been commercially exploited by whalers for centuries and are listed as endangered under the U.S. Endangered Species Act (ESA). The remnant population of approximately 300 individuals, ranging along continental shelf waters from the southeastern United States to the Scotian Shelf (Winn et al., 1986; Waring et al., 2007), is considered to be a small fraction of its original size (IWC, 2001). Despite a slight increase in the minimum population estimate from 295 individuals in 1992 to 306 in 2001 (Waring et al., 2007), there has been little sign of recovery since studies began in the 1970s (IWC, 2001; Kraus et al., 2001, 2005). Although estimates of survival probability decreased in the 1990s, a relatively modest reduction in mortality rate could reverse the observed decline and reduce the potential for species extinction (Caswell et al., 1999; Fujiwara and Caswell, 2001; Kraus et al., 2005). The most frequent known anthropogenic causes of right whale mortality are collisions with ships and entanglements in fishing gear. Of 50 documented right whale

mortalities from 1986 through 2005, at least 19 (38%) were due to ship collisions, and a minimum of six (12%) were attributed directly to entanglements (Kraus et al., 2005).

Cape Cod Bay (Massachusetts), a semi-enclosed basin approximately 40 km in diameter (Fig. 1), is the only known winter and early spring feeding area for the remaining concentrations of the right whale population (Winn et al., 1986; Waring et al., 2007). Scientific observations of right whales in Cape Cod Bay began in 1955 (Watkins and Schevill, 1982; Schevill et al., 1986), and Reeves et al. (1999) reviewed whaling records indicating right whale presence from the early 1600s. During shipboard surveys and commercial whale watching trips, right whales were sighted in Cape Cod Bay and Massachusetts Bay to the north in every month except December from 1978 to 1986. Most of these sightings were sparse for most months, and peak abundance occurred from February through April (Hamilton and Mayo, 1990). With the exception of an unusual summer occupancy in 1986, most right whales had departed

the bays by mid-May (Hamilton and Mayo, 1990). Nearly one third of the population of photographically identified and catalogued individual right whales has been sighted in Cape Cod Bay in recent years (see Hamilton et al., 2007).

To reduce right whale mortality from ship strikes and entanglements, state and federal agencies have enacted a number of management measures. Cape Cod Bay was designated as federal critical habitat under the ESA in 1994 (Federal Register, 1994). The critical habitat includes all of Cape Cod Bay, except the segment of the bay west of 70°30'W, as well as a portion of the waters immediately to the north (Fig. 1), and was defined according to ESA criteria based on the knowledge of right whale distribution and patterns of habitat use available at the time (Hamilton and Mayo, 1990; Federal Register, 1994). In 1997, the state of Massachusetts instituted a Right Whale Conservation Plan that included modifications to fixed-gear fishing practices within state waters and a surveillance-based monitoring program that provided data on right whale presence to mariners and management agencies (Brown et al., 2007). Also enacted in 1997, the federal Atlantic Large Whale Take Reduction Plan (ALWTRP) included measures designed to reduce entanglements in U.S. Atlantic waters (Federal Register, 1997). Regulations under both plans have affected fixed-gear fishing activities in Cape Cod Bay, including those of the lobster trap and anchored sink-gillnet fisheries. The most stringent regulations have been implemented within the boundaries of the critical habitat from 1 January through 15 May. Regulations governing the critical habitat during this period have included a more comprehensive modification of lobster gear than that required from 16 May to 31 December and the prohibition of all gillnetting operations (Federal Register, 2002b). Additional state and federal regulations have been in effect outside the critical habitat, including the seasonal area management (SAM) component of the ALWTRP, which provides additional restrictions on fixed-gear fishing in an area immediately east of the critical habitat (SAM West) from 1 March through 30 April (Fig. 1; Federal Register, 2002a). Although the above are the most relevant spatially and temporally defined management measures, there are several additional and often overlapping regulations affecting fixed-gear fishing in the study area. Ship-strike reduction strategies currently under consideration include measures to reroute ships and to implement speed restrictions from 1 January through 30 April in Cape

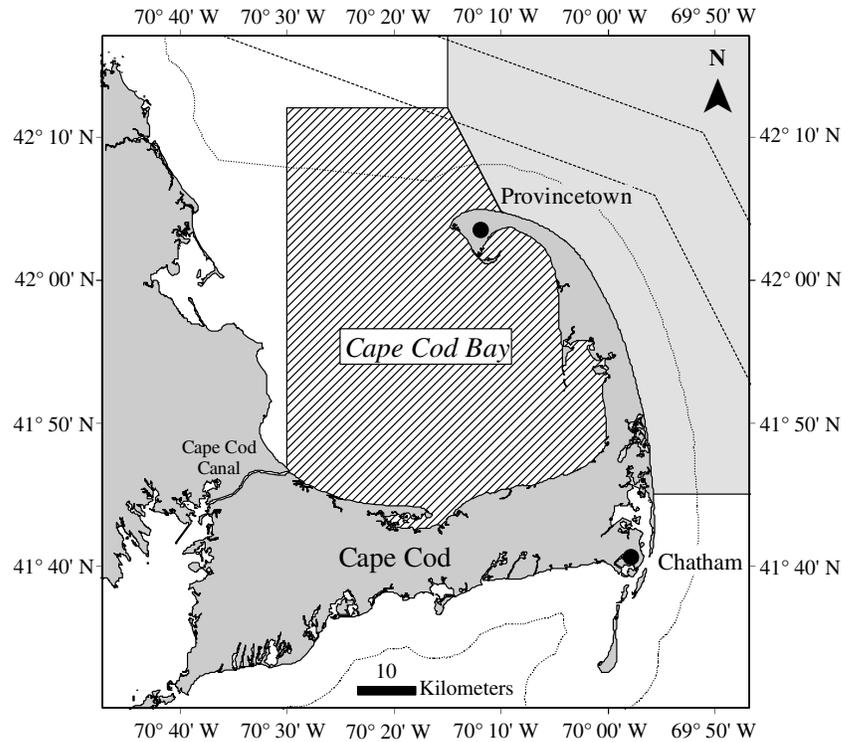


Figure 1

Cape Cod Bay, Massachusetts, including the boundaries of the right whale (*Eubalaena glacialis*) critical habitat (diagonally hatched area), Seasonal Area Management (SAM) West zone (gray shaded area), limit of state-regulated waters (dotted line), and outside boundaries for shipping lanes (dashed lines).

Cod Bay, as well as speed restrictions in the waters immediately north and east of the critical habitat, or in the proposed Off Race Point Proposed Management Area (Federal Register, 2004, 2006).

As part of the state conservation plan for right whales, a systematic aerial survey program was implemented in Cape Cod Bay during winter and spring beginning in January of 1998 (Brown et al., 2007). These surveys were designed with an emphasis on detecting right whales and notifying mariners and managers of their presence, and have resulted in a systematic data set that allows right whale occurrence and patterns of habitat use in the bay to be quantified for the first time. The objectives of this study were to use the aerial survey data to describe the spatial and temporal distribution of right whales in Cape Cod Bay, and to compare these data with the extent and timing of present and proposed management measures to evaluate their potential effectiveness. We examined the following critical management strategies: the specification of location and duration for the use of modified fishing gear; the use of critical habitat boundaries as a management unit; and the specification of critical periods when reduced ship speed would be mandated to reduce the mortality of right whales caused by ship strikes.

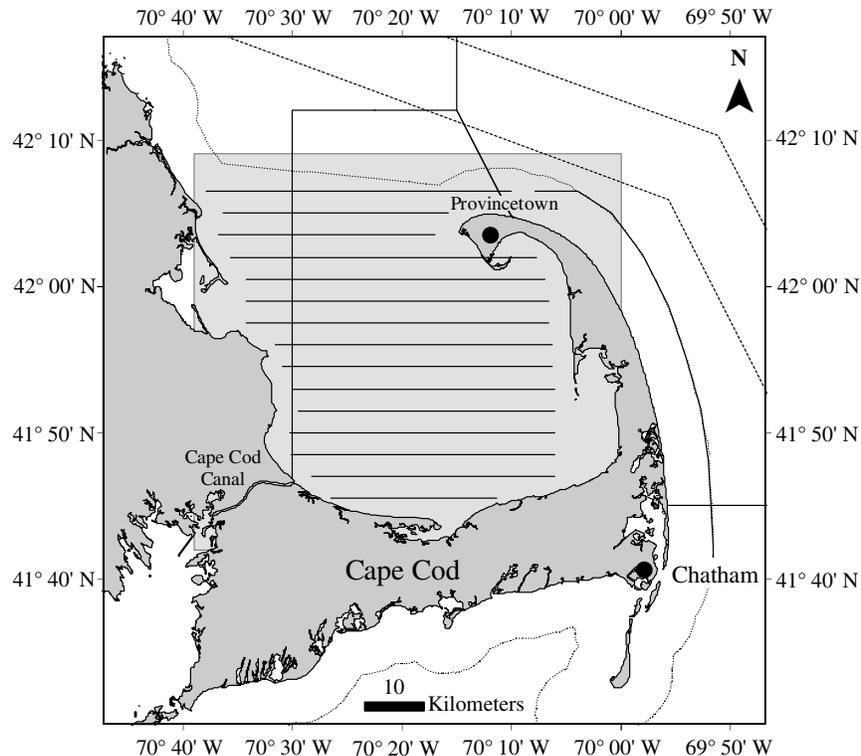


Figure 2

Aerial survey track lines for the Cape Cod Bay right whale (*Eubalaena glacialis*) monitoring program (black lines: 15 east-west lines at 1.5 nautical mile (2.7 km) intervals and a sixteenth line paralleling the eastern shore of the Cape approximately 3 nmi from shore). Also shown are the area boundaries for the sightings per unit-of-effort analysis (shaded gray).

Materials and methods

Aerial surveys

Aerial surveys were conducted from a Cessna 337-A Sky-master, a twin-engine, high wing aircraft with retractable landing gear. The aircraft was flown at a standard altitude of 229 m and a ground speed of approximately 185 km/h, and survey methods were those developed for the Cetacean and Turtle Assessment Program (Scott and Gilbert, 1982) and adapted for right whale surveys (Brown et al., 2007). The aircraft was flown in sea conditions up to and including sea state 4 on the Beaufort wind scale, but were aborted in Beaufort sea state 5 or when visibility decreased below two nautical miles (3.7 km) in fog, rain, or snow.

Surveys were conducted in winter and spring (January through mid-May) of 1998–2002. Additional surveys were conducted in December of some years (for the purpose of this paper, a given year or season includes December of the previous calendar year.) The standard survey design consisted of 16 track lines (Fig. 2). Fifteen east-west track lines were flown at 2.8-km intervals from the mainland to the eastern Cape Cod Bay

shoreline. Analysis of the right whale survey data indicated that the effective total survey swath of a Cessna 337 was 4.2 km (Kenney et al., 1995); thus the 2.8 km track line spacing of the standard survey plan was designed to provide 100% coverage of the sea surface in the study area to maximize the potential to detect right whales.

An additional 65-km track line was flown parallel to the outer coast of Cape Cod from the eastern end of the northernmost track line to a point east of Chatham, Massachusetts, at an approximate distance of 5.6 km from shore (Fig. 2). The entire survey (approximately 568 km of track line distance) was completed as often as conditions permitted (ca. 2 surveys/week), and additional track lines to the north of the standard survey design were occasionally added to address management concerns outside the bay (e.g., whale distribution in the shipping lanes).

Analysis of survey data

To quantitatively assess right whale distribution and minimize bias caused by uneven distribution of survey effort, we used the sightings per unit of effort (SPUE)

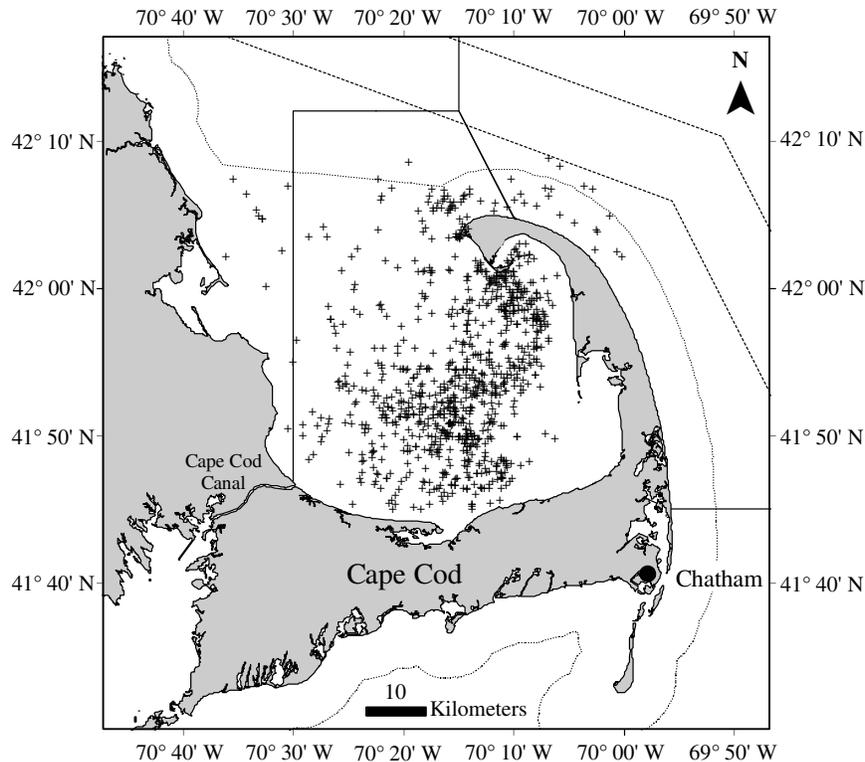


Figure 3

North Atlantic right whale (*Eubalaena glacialis*) sightings (+) recorded during valid aerial survey effort 1998–2002. A sighting is defined as one or more whales observed at the same time and location.

method (Kenney and Winn, 1986). This method first quantifies survey effort as length of track line sampled, then expresses SPUE as the number of whales sighted per standardized length of track.

The boundaries of the study area for this analysis were 42°09'N to 41°39'N and 70°00'W to 70°39'W (Fig. 2). The study area was partitioned into 117 cells measuring 3 minutes of latitude (5.6 km) by 3 minutes of longitude (4.1 km). Each cell was 23 km² in area. Fourteen cells lay completely over land and were eliminated; thus there were 103 cells available to be sampled.

Survey data comprised a chronological sequence of latitude and longitude points that described the path flown by the aircraft. Each successive pair of points described a track segment, and the length of that segment (effort) could be computed from the latitude and longitude data (Kenney and Winn, 1986). For each survey, each track segment was partitioned into smaller sections contained within the separate 3-minute cells. In order to standardize effort further, only those segments were completed where visibility was at least 3.7 km, Beaufort sea state was 3 or lower, aircraft altitude was below 325 m, and observers were on watch. Similarly, only right whales sighted under these defined, valid effort conditions were included in our study. We included only sightings identified by observers in the field as

definite or probable right whales in the analysis; sightings identified as possible right whales were eliminated. A sighting was defined as one or more whales observed at the same time and location; for simple distribution maps (e.g., Fig. 3) all sightings were treated as single points, but the number of whales sighted is factored into the SPUE analysis. The sampling season was defined as December through mid-May, and was divided for analysis into 12 two-week periods (1 December–17 May). Total effort and total number of right whales sighted within each cell were summed within periods and across years; then the number of whales sighted was divided by effort to generate the SPUE index, in units of whales sighted per 1000 km of valid effort. Cells with less than 2 km of effort (half the width of a cell) within a 2-week period were considered to have been inadequately sampled and were eliminated from further analyses.

For mapping purposes, the SPUE values were ranked into levels. All cells with SPUE > 0 were pooled, sorted from highest to lowest SPUE values, and separated by quartiles, representing the top, second highest, third, and bottom quarters of the distribution. The upper quarter was further partitioned by identifying the top 5% of all values. These values were mapped by using different shadings to show the classes. The cells were

Table 1

Total acceptable survey effort (i.e., where visibility was at least 3.7 km, Beaufort sea state was 3 or lower, aircraft altitude was below 325 m, and observers were on watch) for right whales (*Eubalaena glacialis*) in the Cape Cod Bay, Massachusetts, study area, summarized by two-week periods across the entire study, 1998–2002.

Period	Effort (km)
1–14 December	900
15–28 December	550
29 December–11 January	3203
12–25 January	5476
26 January–8 February	8242
9–22 February	7953
23 February–8 March	7535
9–22 March	4983
23 March–5 April	7965
6–19 April	9006
20 April–3 May	7863
4–17 May	2790

pooled across periods before classification; therefore the maps showing different time periods were comparable. As a test of the definition for critical habitat boundary (i.e., a definition that did not include a potential effort bias), SPUE values were compared between the 3-minute cells inside the critical habitat, outside and west of it (western Cape Cod Bay), and outside and east of it (outside of Cape Cod).

All computations and statistical analyses were performed with Statistical Analysis System procedures (SAS for Windows, vers. 6.13, SAS Inst. Inc., Cary, NC). Calculations of effort and SPUE were performed with custom SAS programs developed at the University of Rhode Island. Whenever possible, we used statistical tests of hypotheses with nonparametric methods (in SAS PROC NPAR1WAY) to avoid the assumptions of normal distributions and homogeneous variances associated with parametric tests. The test most often used was the Kruskal-Wallis nonparametric ANOVA. When the comparison involved only two distributions, the Wilcoxon rank sum test was used (equivalent to the Mann-Whitney *U* test or a parametric *T*-test). The only parametric test that we used was a Duncan's multiple range test (in SAS PROC GLM), which allowed us to perform multiple pairwise *T*-tests while correcting the critical significance probabilities for the number of comparisons. There is no nonparametric test equivalent available in SAS.

Results

During the 1998–2002 seasons, 167 aerial surveys were conducted, yielding 66,466 km of acceptable

Table 2

Mean (\pm standard error [SE]) and maximum number of sightings of North Atlantic right whales (*Eubalaena glacialis*) per unit of effort (no. of whales/1000 km of survey effort) in Cape Cod Bay, Massachusetts, summarized by year.

Year	Mean	SE	Maximum	<i>n</i>
1998	14.58	2.45	789.4	819
1999	11.48	1.49	417.3	874
2000	18.44	2.49	625.7	728
2001	12.74	1.70	575.7	802
2002	2.11	0.61	210.7	739
All	11.91	0.84	789.4	3962

survey effort. Of the 103 3-minute cells available to be sampled in the study area, 101 (98.1%) were sampled at least once, and 88 (85.4%) were sampled in every year. Because the basic sampling unit represented aggregated data within a cell across a 2-week period, the maximum possible sample size was 6180 (103 cells \times 5 years \times 12 periods), and the actual number of samples (effort >2 km) was 3962 (64.1% of the maximum possible). Overall mean effort was 658 km of survey track per 3-minute cell (range: 2.5 to 1189.5 km). Spatial distribution of effort was fairly uniform throughout the study area; lowest effort occurred in the peripheral cells, some of which were partially over land. Temporal distribution of effort was relatively consistent during the study period, with the exception of December, when surveys were conducted on an *ad hoc* basis (Table 1). Effort was lower in May than from January through April because surveys in May were suspended after two or three consecutive surveys when right whales were not sighted. The remaining temporal variability in survey effort was primarily due to weather conditions or sea ice that prohibited or shortened surveys.

During the aerial surveys, 1553 right whales were sighted, the majority of which were sighted during February–April. Cumulative sighting totals included multiple sightings of photographically identified individual whales within and between seasons. The earliest sighting within a season occurred on 13 December 1998, and the latest sighting occurred on 2 May 1999. The highest number of right whales sighted on a single day was 47 on both 4 March 1998 and 27 March 2000. Sightings of 203 whales occurred during unacceptable survey conditions (mostly due to high sea state), and eight whales were documented for cells with acceptable conditions but during which there was less than 2 km of effort during a particular 2-week period; therefore sightings of 1342 whales were included in the SPUE analysis. Right whales were sighted during acceptable conditions in 69 of the 101 sampled cells (68.3%) over the five years of the study. Sightings were concen-

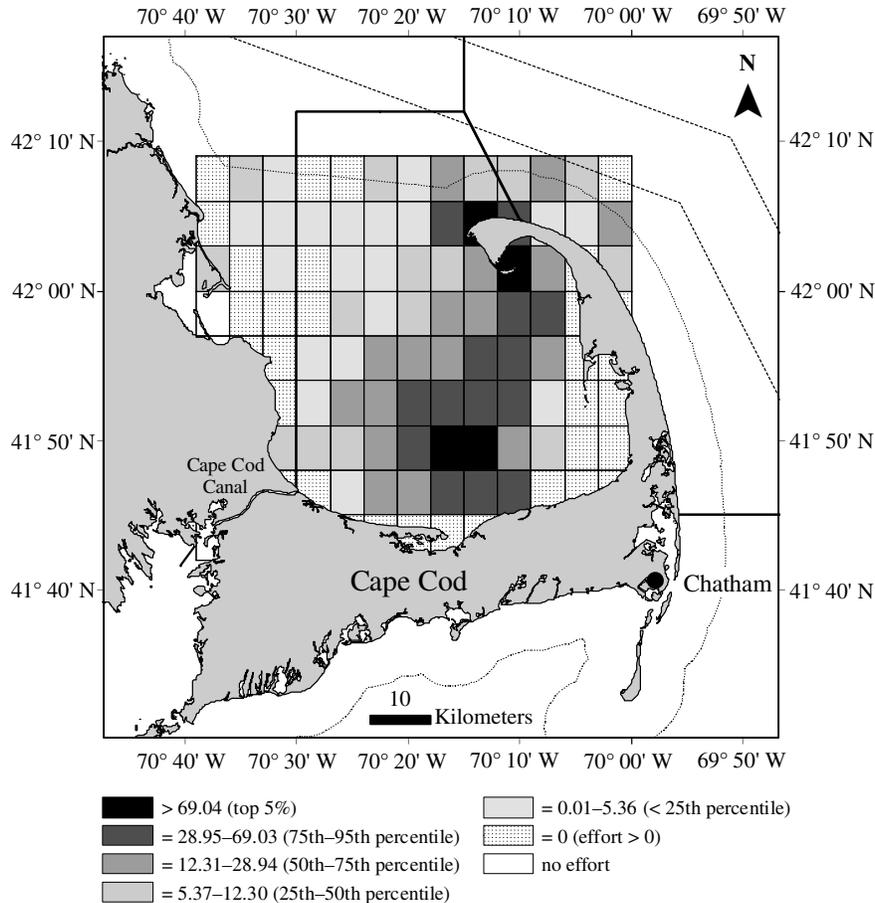


Figure 4

Overall mean North Atlantic right whale (*Eubalaena glacialis*) sightings per unit of effort (SPUE; number of whales/1000 km of survey effort) in Cape Cod Bay, 1998–2002. SPUE values are separated by quartiles, representing the top, second highest, third, and bottom quarters of the distribution. The upper quarter is further partitioned by identifying the top 5% of all values.

trated in a band extending across Cape Cod Bay from the southwest to the northeast (Fig. 3).

The overall 5-year mean SPUE value for all 101 sampled cells was 11.9 whales per 1000 km of survey effort (i.e., one right whale every 84 km of acceptable survey flown; Table 2). The maximum SPUE in a single cell during any two-week period was 789.4 right whales/1000 km (i.e., one whale every 1.3 km) during 29 December 1997–11 January 1998. An area of high-SPUE cells extended along the eastern side of the bay from the south to the tip of the Cape (Fig. 4). Distinct areas of lower SPUE values radiated out from the highest-value cells, and a gradient of decreasing SPUE values extended to the west.

Annual mean SPUE was highest in 2000 and lowest in 2002 (Table 2), and the difference was almost an order of magnitude. The interannual variability was statistically significant (Kruskal-Wallis nonparametric ANOVA, $P < 0.001$). When 2002 data was eliminated, the interannual variability remained statistically sig-

nificant (Kruskal-Wallis, $P = 0.033$). When we tested for differences among the annual means with a parametric Duncan's multiple range test, using either unweighted or effort-weighted means, 2002 was found to be significantly different from all other years. Using the unweighted means, we found that 1998 and 2000 were not different from one another, and neither were 1998, 1999, and 2001. Using the effort-weighted means, we found that 1998, 1999, and 2001 did not differ, but that 2000 was significantly different from all other years.

When separated into two-week periods pooled across all years, mean SPUE values varied considerably. SPUE values were low in December and January, increased during February, exhibited two peaks in late February–early March and late March–early April, and declined to low values by the end of April and to zero in May (Table 3). The within-season temporal variability was statistically significant (Kruskal-Wallis, $P < 0.001$). The area occupied by right whales expanded and then contracted over the course of the season in

the same fashion (Fig. 5). The center of right whale occurrence tended to remain relatively consistent across the season, and there was no statistically significant variability in mean latitude or longitude (for the 2-week intervals, weighted by SPUE) across the periods (Kruskal-Wallis, $P=0.270$ for latitude, $P=0.580$ for longitude). Similarly, there was no significant interannual variability in mean latitude ($P=0.063$) or mean longitude ($P=0.797$).

The timing of the SPUE maximum varied markedly between years: late February–early March in 1998, early to mid-April in 1999, late March–early April in 2000, early March to mid-April in 2001, and late February–early March in 2002. This interannual variation was responsible for the apparent bimodal pattern seen over the season when data were pooled across all five years (Table 3). The within-season temporal variation was statistically significant in each of the five years ($P<0.001$ for each). The duration of right whale occurrence also varied substantially between years: January–April in 1998 (no December 1997 surveys), December–April in 1999, mid-January–mid-April in 2000, and at least late December–mid-April in 2001 (no surveys were undertaken during the first two weeks of December 2000), and only late January–late March (and a second brief period in early April) in 2002. The numbers of consecutive two-week periods when right whales were observed were 9 in 1998, 9 in 1999, 7 in 2000, 9 in 2001, and 5 in 2002.

Approximately 97% of the right whales sighted within the study area by aerial survey were within the critical habitat boundaries (Fig. 3). The critical habitat included approximately 75% of the total ocean area within our defined study area. The majority of cells within which right whales were sighted were inside the critical habitat, but 17 cells with SPUE >0 fell partially or entirely outside the critical habitat (Fig. 4). SPUE did vary significantly among the three areas (Kruskal-Wallis, $P=0.009$). However, the mean values for the cells east of the critical habitat (11.1 unweighted, 10.9 weighted by effort and by the proportion of cell area for the five cells straddling the eastern boundary) fell between the area inside the critical habitat (18.5 unweighted, 23.1 weighted) and the area outside to the west (2.3 unweighted, 2.0 weighted). Pairwise nonparametric comparisons (Wilcoxon rank sum tests, weighting was not possible) showed statistically significant differences between the areas east and west of the critical habitat ($P=0.023$) and between the areas inside and to the west ($P=0.003$), but not between the areas inside and to the east ($P=0.669$).

Discussion

The spatial pattern of right whale distribution observed during this study was largely similar to that described by Hamilton and Mayo (1990); most sightings were concentrated toward the eastern side of the bay (Fig. 3). The majority of the data collected by Hamilton and Mayo

Table 3

Mean (\pm standard error [SE]) and maximum number of sightings of North Atlantic right whales (*Eubalaena glacialis*) per unit of effort (no. of whales/1000 km of survey effort) in Cape Cod Bay, Massachusetts, summarized by two-week periods across the entire study, 1998–2002.

Period	Mean	SE	Maximum	<i>n</i>
1–14 Dec	4.21	3.53	417.3	121
15–28 Dec	4.47	4.47	339.9	76
29 Dec–11 Jan	7.70	2.87	789.4	328
12–25 Jan	4.53	1.34	288.3	378
26 Jan–8 Feb	10.98	2.67	554.4	417
9–22 Feb	14.08	2.40	510.8	407
23 Feb–8 Mar	23.15	4.60	729.8	333
9–22 Mar	14.79	3.14	625.7	395
23 Mar–5 Apr	23.54	3.47	575.7	410
6–19 Apr	14.70	2.51	552.1	412
20 Apr–3 May	6.63	1.67	293.1	380
4–17 May	0.00	0.00	0.0	305

(1990) was derived from opportunistic sightings recorded by researchers working aboard commercial whale watching vessels departing from Provincetown multiple times per day, bound for Stellwagen Bank to the north of Cape Cod, from mid-spring through early fall. Aerial survey effort in our study was systematic, consistent across years, and spatially uniform throughout the study area and thus provided the first complete representation of the spatial and temporal distribution of right whales in Cape Cod Bay during winter and spring. The SPUE analysis provided a more refined interpretation of raw sighting data than have earlier analyses by reducing bias caused by uneven allocation of effort.

During the seasonal expansion of right whale distribution in the bay (Fig. 5), right whales may be particularly at risk from collisions with ships traveling between the mouth of the Cape Cod Canal at the southwest and ports to the northeast of the bay (Fig. 1; Ward-Geiger et al., 2005). The above risk should be considered when implementing routing measures for shipping traffic. The boundaries of the Cape Cod Bay critical habitat encompassed the areas of highest SPUE values when pooled across all years and periods, and therefore the existing boundaries appear to service as a good management unit. Despite the low number of sightings east of Cape Cod, the area- and effort-weighted statistics indicated that the waters east of the critical habitat may be important habitat for right whales, providing some support for existing fishery management measures in place east of the critical habitat (SAM West; Fig. 1) and the proposed Off Race Point Seasonal Management Area for shipping activity, which includes the portion of SAM West within the boundaries of this analysis (Federal Register, 2006).

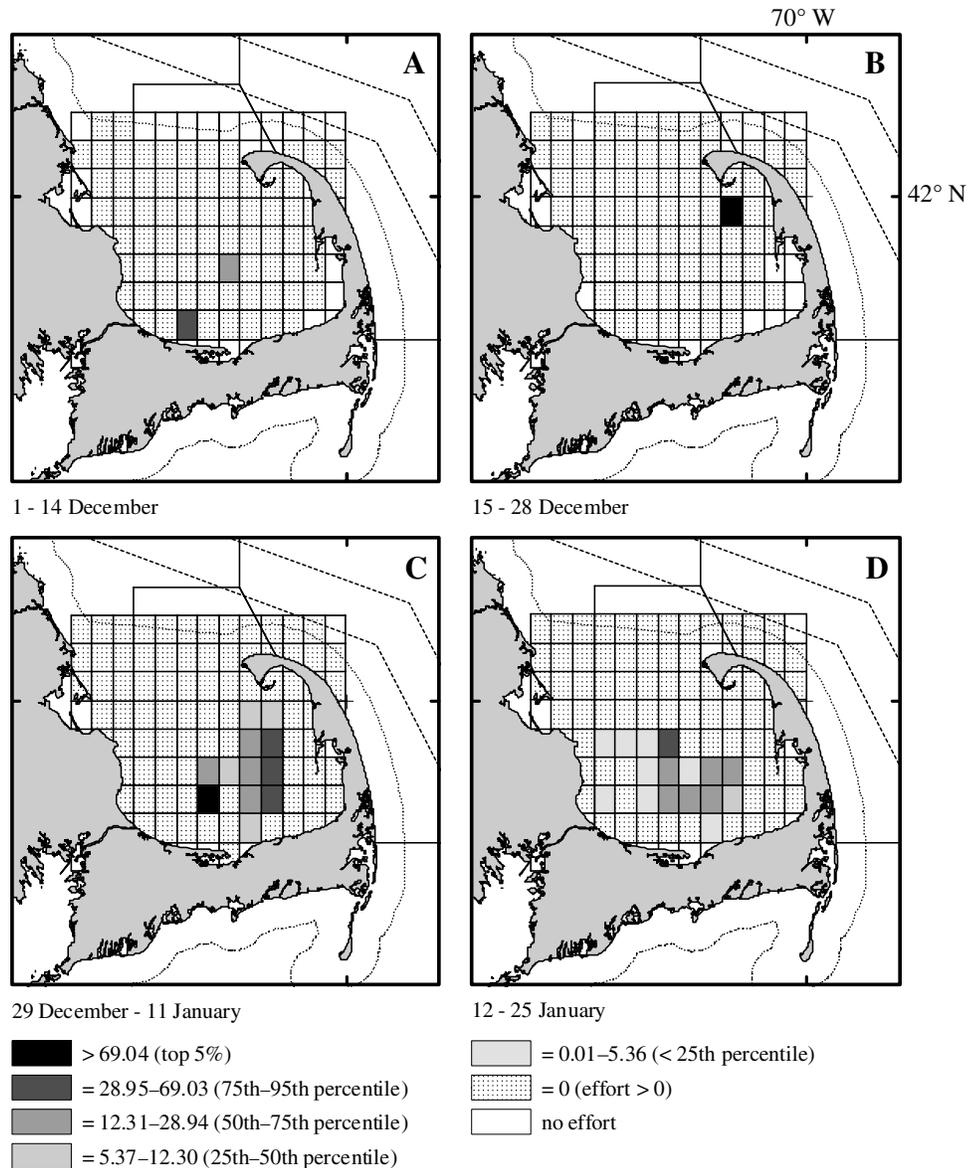


Figure 5

North Atlantic right whale (*Eubalaena glacialis*) sightings per unit effort (SPUE; whales/1000 km of survey effort) in Cape Cod Bay, by two-week period (A–L), 1998–2002. SPUE values are separated by quartiles, representing the top, second highest, third, and bottom quarters of the distribution. The upper quarter is further partitioned by identifying the top 5% of all values.

The significant interannual variations in mean SPUE and timing of annual SPUE maxima were likely due to physically forced changes in available food resources. An atypical physical environment and zooplankton assemblage were observed in 2002, compared to 2000 and 2001 (DeLorenzo Costa et al., 2006; Jiang et al., 2007), which corresponded to the order-of-magnitude difference in 2002 right whale SPUE compared to that in 2000. Further comparisons of right whale distributional data and environmental variables should be conducted to assess the causes of the patterns observed.

Despite the interannual SPUE variability, the significant within-season and interannual spatial stability of right whale occurrence lends support to the use of these data to define the spatial extent of management measures.

The results of the aerial surveys and SPUE analysis confirmed earlier findings of Hamilton and Mayo (1990) in that peak occurrence of right whales in the study area occurred from February through April. The patterns observed in both studies are largely consistent with earlier, more qualitative descriptions of right whale

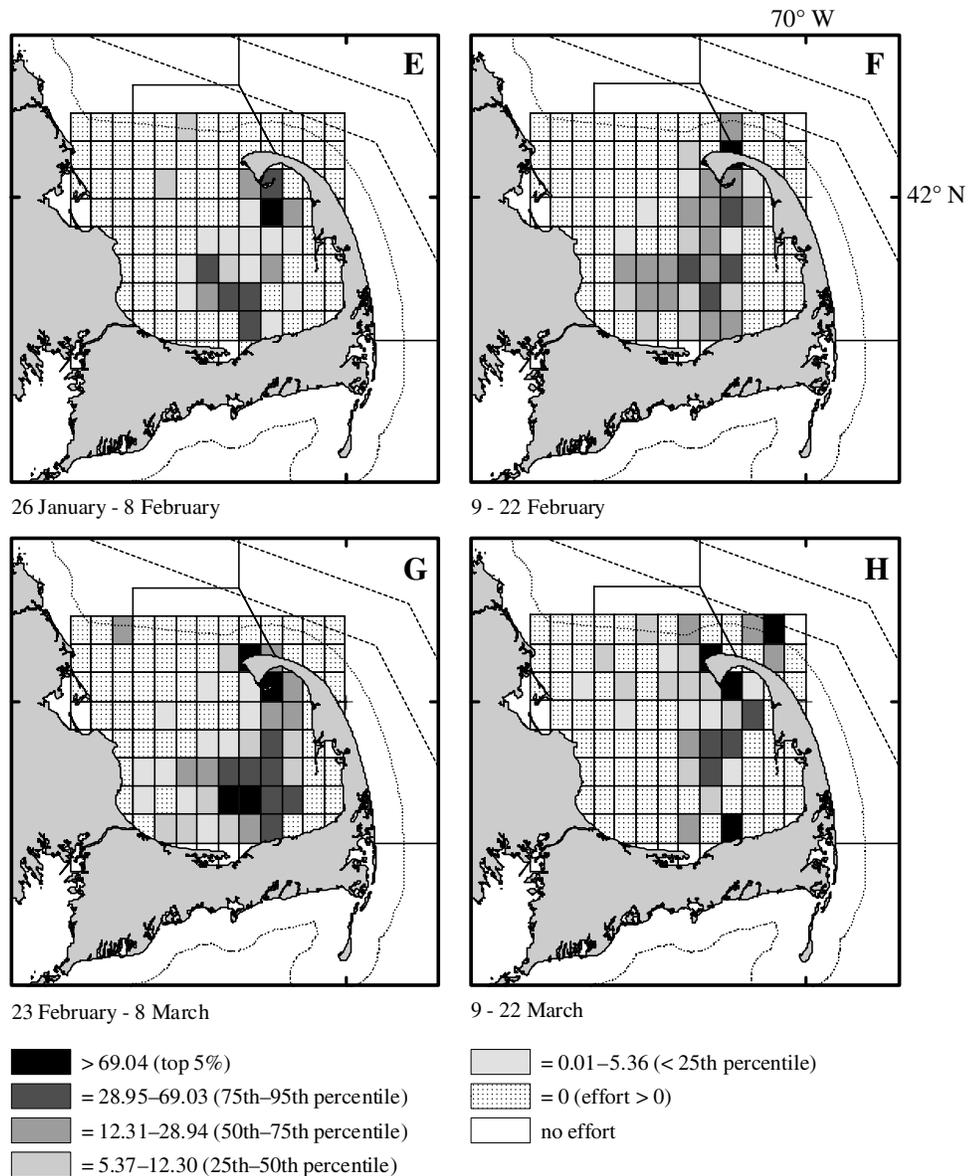


Figure 5 (continued)

occurrence in Cape Cod Bay (Allen, 1916; Watkins and Schevill, 1982; Schevill et al., 1986). More right whales were sighted in December and January of our study than by Hamilton and Mayo (1990); likely a result of the spatial and temporal expansion of survey effort through the surveillance-based monitoring program. The shipboard survey effort of Hamilton and Mayo (1990) was not consistent throughout all the months that were examined in the present study. In the first five years of their eight-year study, there were no surveys in January or February.

Right whales were present inside the critical habitat in December, before the comprehensive gear restrictions were implemented within its boundaries on 1 January, although low December effort makes it difficult to interpret the significance of the sightings.

Although gear restrictions were in place through 15 May, no right whales were sighted after 2 May, and SPUE dropped to zero throughout the study area during the period 4–17 May. Moreover, although there were no sightings of right whales after 2 May during our study, there were a few sporadic sightings in the study area throughout May in other years (Hamilton and Mayo, 1990). Given that the period of peak SPUE occurs from February through April, the duration of existing fixed gear fishing regulations (1 Jan–15 May) appears adequate because it provides a buffer of a few weeks on either side of the peak period of right whale abundance—a buffer that allows for the interannual variation observed. The ship-strike reduction measures currently proposed for the period 1 January–30 April (Federal Register, 2004, 2006) should be extended to

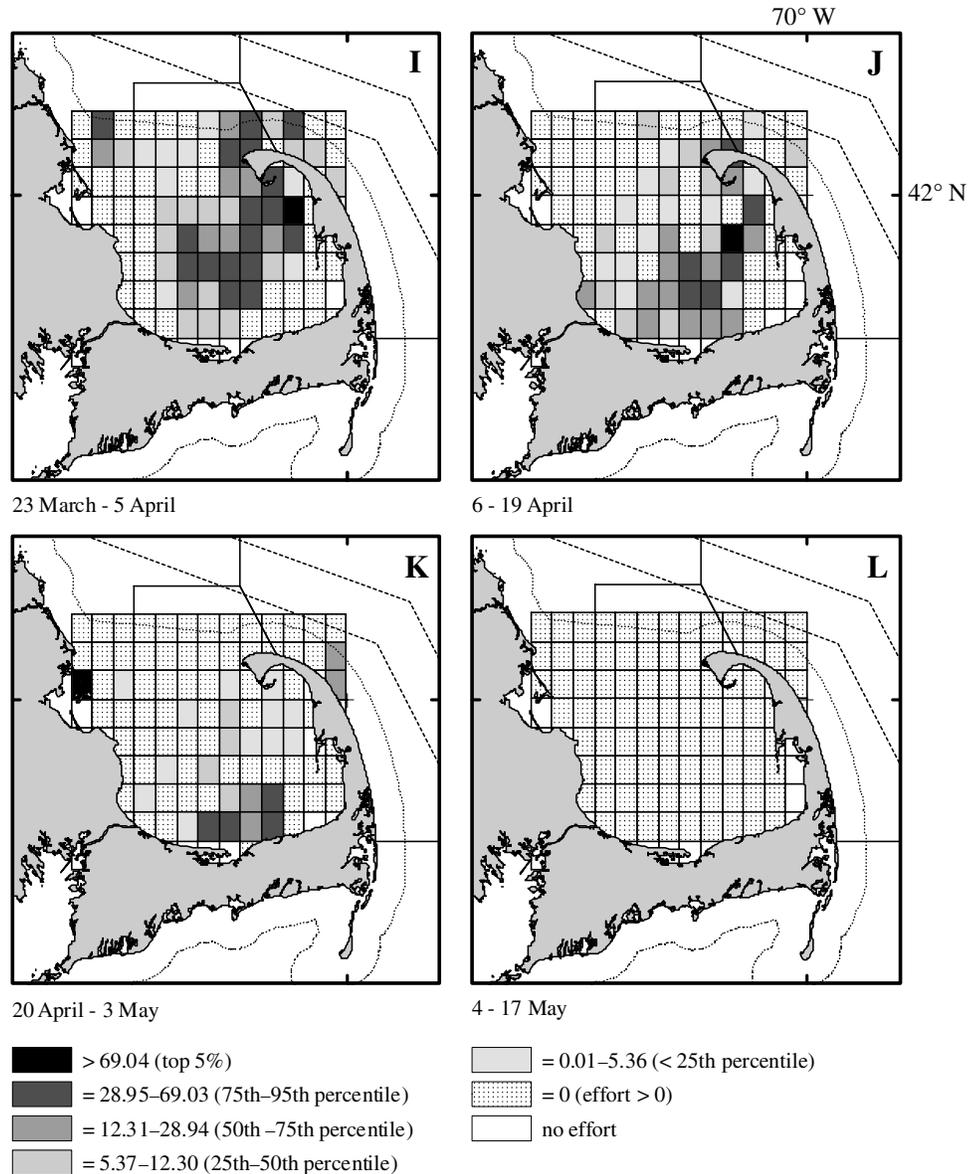


Figure 5 (continued)

15 May to match the duration of fixed-gear fishery restrictions. The efficacy of management measures in Cape Cod Bay has range-wide importance for the right whale because a large portion of the remnant population frequents the bay and because the possibility of even a slight reduction in mortality may prevent species extinction.

Acknowledgments

We thank the aerial observers, the pilots of Ambroult Aviation, and the staff of the New England Aquarium. N. Jaquet (Provincetown Center for Coastal Studies), D. McKiernan and E. Lyman of the Massachusetts Division of Marine Fisheries (MADMF) reviewed ear-

lier versions of this manuscript. Surveys were funded by MADMF with support from the National Oceanic and Atmospheric Administration (NOAA) and the Northeast Consortium and conducted under NOAA Fisheries permits 1014 and 633-1483. R. Kenney was supported by the NOAA Cooperative Marine Education and Research Program. This article is dedicated to those lost in a right whale survey aircraft crash on 26 January 2003.

Literature cited

Allen, G. M.
1916. The whalebone whales of New England. Mem. Boston Soc. Nat. Hist. 8:107-322.

- Brown, M. W., S. D. Kraus, C. K. Slay, and L. P. Garrison.
2007. Surveying for discovery, science, and management. *In* The urban whale: North Atlantic right whales at the crossroads (S. D. Kraus, and R. M. Rolland, eds.), p. 105–137. Harvard Univ. Press, Cambridge, MA.
- Caswell, H., M. Fujiwara, and S. Brault.
1999. Declining survival probability threatens the North Atlantic right whale. *Proc. Natl. Acad. Sci.* 96:3308–3313.
- DeLorenzo Costa, A., E. G. Durbin, C. A. Mayo, and E. G. Lyman.
2006. Environmental factors affecting zooplankton in Cape Cod Bay: implications for right whale dynamics. *Mar. Ecol. Prog. Ser.* 323:281–298.
- Federal Register.
1994. Designated critical habitat; northern right whale (final rule). *Federal Register* 59:28793–28808. Office of the Federal Register, National Archives and Records Administration (NARA), College Park, MD.
1997. Taking of marine mammals incidental to commercial fishing operations; Atlantic Large Whale Take Reduction Plan regulations. *Federal Register* 62:16519–16538. Office of the Federal Register, NARA, College Park, MD.
2002a. Taking of marine mammals incidental to commercial fishing operations; Atlantic Large Whale Take Reduction Plan regulations. *Federal Register* 67:1142–1160. Office of the Federal Register, NARA, College Park, MD.
2002b. Taking of marine mammals incidental to commercial fishing operations; Atlantic Large Whale Take Reduction Plan regulations. *Federal Register* 67:1300–1314. Office of the Federal Register, NARA, College Park, MD.
2004. Advance notice of proposed rulemaking (ANPR) for right whale ship strike reduction. *Federal Register* 69:30857–30864. Office of the Federal Register, NARA, College Park, MD.
2006. Proposed rule to implement speed restrictions to reduce the threat of ship collisions with North Atlantic right whales. *Federal Register* 71:32699–36313. Office of the Federal Register, NARA, College Park, MD.
- Fujiwara, M., and H. Caswell.
2001. Demography of the endangered North Atlantic right whale. *Nature* 414:537–541.
- Hamilton, P. K., A. R. Knowlton, and M. K. Marx.
2007. Right whales tell their own stories: the photo-identification catalog. *In* The urban whale: North Atlantic right whales at the crossroads (S. D. Kraus, and R. M. Rolland, eds.), p. 75–104. Harvard Univ. Press, Cambridge, MA.
- Hamilton, P. K., and C. A. Mayo.
1990. Population characteristics of right whales (*Eubalaena glacialis*) observed in Cape Cod and Massachusetts Bays, 1978–1986. *Rep. Int. Whal. Comm. Spec. Issue* 12:203–208.
- IWC (International Whaling Commission).
2001. Report of the workshop on status and trends of western North Atlantic right whales. *J. Cetacean Res. Manag. Spec. Issue* 2:61–87.
- Jiang, M., M. W. Brown, J. T. Turner, R. D. Kenney, C. A. Mayo, Z. Zhang, and M. Zhou.
2007. Springtime transport and retention of *Calanus finmarchicus* in Massachusetts and Cape Cod Bays, USA, and implications for right whale foraging. *Mar. Ecol. Prog. Ser.* 349:183–197.
- Kenney, R. D., and H. E. Winn.
1986. Cetacean high-use habitats of the northeast United States continental shelf. *Fish. Bull.* 84:345–357.
- Kenney, R. D., H. E. Winn, and M. C. Macaulay.
1995. Cetaceans in the Great South Channel, 1979–1989: right whale (*Eubalaena glacialis*). *Continental Shelf Res.* 15:385–414.
- Kraus, S. D., M. W. Brown, H. Caswell, C. W. Clark, M. Fujiwara, P. K. Hamilton, R. D. Kenney, A. R. Knowlton, S. Landry, C. A. Mayo, W. A. McLellan, M. J. Moore, D. P. Nowacek, D. A. Pabst, A. J. Read, and R. M. Rolland.
2005. North Atlantic right whales in crisis. *Science* 309:561–562.
- Kraus, S. D., P. K. Hamilton, R. D. Kenney, A. R. Knowlton, and C. K. Slay.
2001. Reproductive parameters of the North Atlantic right whale. *J. Cetacean Res. Manag. Spec. Issue* 2:231–236.
- Reeves, R. R., J. M. Breiwick, and E. D. Mitchell.
1999. History of whaling and estimated kill of right whales, *Balaena glacialis*, in the northeastern United States, 1620–1924. *Mar. Fish. Rev.* 61:1–36.
- Schevill, W. E., W. A. Watkins, and K. E. Moore.
1986. Status of *Eubalaena glacialis* off Cape Cod. *Rep. Int. Whal. Comm. Spec. Issue* 10:79–82.
- Scott, G. P., and J. R. Gilbert.
1982. Problems and progress in the US BLM-sponsored CETAP surveys. *Rep. Int. Whal. Comm.* 32:587–600.
- Ward-Geiger, L. I., G. K. Silber, R. D. Baumstark, and T. L. Pulfer.
2005. Characterization of ship traffic in right whale critical habitat. *Coast. Manag.* 33:263–278.
- Waring, G. T., E. Josephson, C. P. Fairfield, and K. Maze-Foley, eds.
2007. U. S. Atlantic and Gulf of Mexico marine mammal stock assessments—2006. NOAA Tech. Memo. NMFS NE 201, 378 p.
- Watkins, W. A., and W. E. Schevill.
1982. Observations of right whales, *Eubalaena glacialis*, in Cape Cod waters. *Fish. Bull.* 80:875–880.
- Winn, H. E., C. A. Price, and P. A. Sorenson.
1986. The distributional biology of the right whale *Eubalaena glacialis* in the western North Atlantic. *Rep. Int. Whal. Comm. Spec. Issue* 10:129–138.