Northeast Fisheries Science Center Reference Document 01-06

Defining Triggers for Temporary Area Closures to Protect Right Whales from Entanglements: Issues and Options

by

Phillip J. Clapham and Richard M. Pace, III

April 2001

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EXECUTIVE SUMMARY

The remaining population of the North Atlantic right whale (*Eubalaena glacialis*) is small, critically endangered, and appeared to be declining in the 1990s. Human-related mortality from ship collisions and fishing gear entanglements is known to be a major factor in this failure to recover. Among measures being considered by NOAA Fisheries to reduce or eliminate entanglement mortality are temporary area closures, in which a specified area would be closed to fishing when aggregations of right whales are observed there. A key issue concerns the number or density of right whales that must be observed to initiate or "trigger" such a closure. Here, existing data on right whale occurrence and distribution are analyzed to evaluate criteria for triggering temporary area closures. Specific criteria are then applied to existing aerial survey data sets to assess the effectiveness of the closures, as well as the frequency with which closures would have been enacted in past years had triggers been in place. Analyses are based upon the assumption that feeding right whales are at highest risk of entanglement; conversely, it is assumed that transiting whales, while certainly not at zero risk of entrapment, do not constitute sufficient grounds to close an area to fishing.

Data from Cape Cod Bay and Stellwagen Bank from April through October, 1980-1996, were used to assess whether there was any connection between the number of animals in an initial sighting and the magnitude and duration of the sighting events that followed. An *event* was defined as two or more right whale sightings separated by an interval of not more than 10 days. Conversely, a *non-event* is any right whale sighting which was not followed by another within 10 days. The data produced a total of 42 events (with durations ranging from two to 95 days) and 21 non-events. There were 50 initial sightings in which the number of right whales involved was either one or two. Of these sightings, 29 (58%) began an event, while 21 (42%) were non-events. In contrast, all initial sightings involving three or more whales ($n = 13$) began an event (i.e. they were followed by one or more subsequent sightings within ten days). Of these 13 events, 5 (38%) lasted less than a week and 8 (62%) for a week or more. The 13 events ranged in duration from two to 33 days (mean = 15 days, median = 12 days). Thus, the data suggest that an initial sighting of three or more right whales is a reasonably good indicator of an event, and the average duration of such events is about two weeks.

A trigger density of 4.16 right whales (rounded off here to 4 whales) per 100 nm^2 was calculated from the 13 events described above. Additional analysis indicated that a buffer of about 15 nautical miles placed around the sightings from the first day of an event will in most cases encompass the movements of right whales during the entire course of that event.

Data from aerial surveys in 1999 and 2000 were used to retrospectively evaluate the closure triggers. Two trigger approaches were assessed. The *Capture Radii Method* combined all sightings in a survey day to produce an overall survey density, and compared this density against the proposed trigger value of 4 whale/100 nm^2. Using this method, 19 of 54 daily aerial surveys produced capture radii with right whale densities > 4 whale/100 nm^2 (note that because of overlap among areas, this does not equal 19 closures). All but one of these 19 events involved three or more whales.

In contrast, the *Local Area Density Method* used equal-density circles centered on each whale sighting; if a contiguous set of circles encompassed at least three whales, that local set of sightings was used to construct a closure area. This method triggers closures based on density of whales in a local area and is less affected by the particular spatial coverage of an individual aerial or ship-based survey. Use of this method circumvents a major problem with the capture radii method, which is that the density of whales in a concentration may be artificially diluted by isolated distant sightings. Therefore, use of the local area density method to assess closures is recommended, notably when such assessments are based upon data from aerial surveys.

Local whale densities exceeded 4 whale/100 nm^2 in 45 of 54 surveys analyzed. The local area density approach would have triggered eight closures during both 1999 and 2000. Several of the closure areas overlapped regions already targeted for gear restrictions such as Cape Cod Bay and the Great South Channel. Based on these results, it appears that extending the Great South Channel restricted area to the northeast would reduce the need for recurring temporary area closures and offer considerable protection to right whales during April and May.

INTRODUCTION

The North Atlantic right whale (*Eubalaena glacialis*) is among the most endangered of all marine mammals (Clapham *et al.* 1999, IWC 2001). Following ten centuries of hunting, the remaining population is today believed to number only about 300 whales. Although right whales were once distributed across the North Atlantic from North America to Europe, the primary range of the population now extends only from calving grounds off the southeastern United States to feeding areas off New England and eastern Canada (Kraus *et al.* 1986).

No recovery has been evident in this population despite several decades of protection from hunting, and recent research indicates that the population declined during the 1990's (Caswell *et al.* 1999). Human-related mortalities, from ship collisions and entanglements in fishing gear, are thought to be the major causes of this decline (Knowlton & Kraus 2001). Reducing entanglement mortality has been the focus of efforts by the Atlantic Large Whale Take Reduction Team (AWLTRT), and through the team’s efforts various mitigation measures have been enacted. However, entanglements continue to occur. Hamilton *et al.* (1998) estimated that more than 60% of individually identified right whales had been entangled at some point in their lives. While many whales rid themselves of entangling gear, some sustain serious injuries and eventually die (Knowlton & Kraus 2001).

Several measures are being considered by NOAA Fisheries to reduce and eliminate entanglement mortality in right whales. One of these is temporary area closures, in which a specified area is temporarily closed to fishing following confirmed sightings of right whales in that area. A key issue in using this approach is the number or density of right whales that must be observed to initiate or “trigger” such a closure. Based upon analyses of existing data, this document evaluates various criteria to “trigger” temporary area closures. Specific criteria are then applied to existing aerial survey data sets to assess the effectiveness of the closures, as well as the frequency with which closures would have been enacted in past years had triggers been in place.

Although this document primarily presents scientific analysis relating to triggers, it is important to recognize that management measures such as temporary area closures must be considered in the broader framework of risk assessment. This is outlined below.

Levels of risk

Discussions of area closure triggers have occurred both within and outside the ALWTRT, and various “triggers” have been informally proposed. However, no reliable data exist to develop statistically sound models to predict probabilities of right whale entanglement. As such, the analyses presented in this report are based on perceived risks of entanglements. It is generally believed that whales foraging in an area are at higher risk of entanglement than those transiting through the area. Thus, the pertinent question is: what is the minimum number of whales that reliably indicates the presence of foraging whales? Alternatively, a behavioral approach might be used based upon behavior which demonstrates or implies that foraging is occurring.

Under either approach, it is assumed that feeding equates to a high risk of entanglement. Conversely, it is assumed that transiting whales, while certainly not at zero risk of entanglement (notably if they are engaging in V-shaped "prospecting" dives even while traveling in a straight line), do not constitute sufficient grounds to close an area to fishing.

No amount of analysis of existing survey data will produce a result separating whales at risk from whales that are not. For example, while one might define a trigger as (say) "four right whales observed in a 100 nm^2 area", it would be incorrect to assume that three right whales seen in the same area would be at zero risk of entanglement. Scientifically, there is no doubt that a single right whale feeding in an area with fishing gear present would be at a distinctly non-zero risk of entanglement (and thus potentially of death). Given this, the fundamental question is how much risk of entanglement is acceptable? This issue is ultimately one of policy rather than science.

Triggers: general issues

At one extreme, the question of the number of right whales to use as a closure trigger is easy. For example, it is unlikely that a reasonable argument could be mounted against using a sighting of thirty right whales in a relatively small area as a trigger, since this many whales would unequivocally indicate the existence of a significant prey resource (and thus of the feeding behavior that poses a high risk of entanglement). So would twenty whales, and so (probably all whale biologists would argue) would ten. The problem lies in selecting the smallest number that could be advanced as a reliable indicator of the same state.

In the absence of sightings of "many" whales on a single survey, residency of a smaller number over a period of two such surveys (closely spaced in time) has been suggested as an alternative trigger approach. However, residency *per se* is not the issue; rather, residency simply provides an indication that feeding is occurring.

Given that foraging whales are assumed to be at risk of entanglement, it may be irrelevant whether or not whales are resident in a particular area for a protracted period. If whales are feeding, they are at risk, irrespective of whether or not they quickly consume the resource and move elsewhere. In other words, the potential for entanglement does not depend upon the prey resource remaining in place for an extended time. This is important, since it means that any trigger (numerical or behavioral) based upon observed or implied feeding behavior would require data from only a single survey.

Indeed, given the many logistical and regulatory problems involved in identifying a right whale aggregation "event", and expeditiously removing gear from an area, it is of paramount importance that triggers be based upon single rather than repeated surveys. This principle underlies all of the analyses presented below; i.e. triggers have been defined that reliably indicate the presence of non-transient whales using data from a single survey. For those cases where right whales are observed in densities below the trigger threshold, additional (prioritized) survey coverage would be needed to determine whether the animals sighted were in residence or merely transiting through.

DATA ANALYSIS AND DEFINITION OF CLOSURE TRIGGERS

The following sections of this document provide analyses of right whale sighting data for use in defining triggers and areas for spot closures. The first set of analyses looks at events in which right whales were observed repeatedly over periods of time in an area, and evaluates whether there is any connection between the number of animals in the initial sighting and the magnitude and duration of the sighting events that followed. The results of these analyses are subsequently translated into a density of whales (whales per X square miles) which would trigger a temporary area closure; a modification of this approach is also proposed to avoid a problem which became apparent during the analysis. The trigger criterion is then applied retrospectively to aerial survey sighting data from 1999 and 2000 to investigate how frequently closures would have been effected, and how large the areas concerned would have been, had the trigger been in place in these years.

ANALYSIS 1: TRIGGERS - MINIMUM NUMBER OF WHALES

Because of large gaps in temporal and spatial coverage, NOAA Fisheries aerial survey data from 1999 and 2000 were not sufficient to address the question of how many whales need to be seen to reliably predict that other sightings will occur. What was needed was daily effort over long periods in a single area; data from the Center for Coastal Studies' (CCS) vessel cruises (both directed trips and whalewatching cruises) provide exactly this type of consistent coverage and were therefore used. CCS whalewatching cruises made up the bulk of the effort; these provided daily coverage of Cape Cod Bay and southern Stellwagen Bank from mid-April to the end of October each year. Although daily effort varied from one to as many as nine cruises, and while a few days a year were typically missed due to bad weather, daily coverage was effectively continuous during this 6.5-month annual time period.

The issue of spatial stability - how much a concentration of right whales moves over the period that it remains together - is addressed in a separate analysis in the second section of this report.

Methods

CCS sighting data from 1980 to 1996 were analyzed. The months of January, February, March, November and December were excluded to restrict the data to months of continuous daily coverage from whalewatching vessels. Directed cruise data from the April-October period were also used. We used data from only the first trip each day, to avoid counting the same animals two or more times in a day.

Data were sorted by area according to the following three categories: Cape Cod Bay (CCB), Stellwagen Bank, and Other. "Other" was excluded from all analyses. Cape Cod Bay was defined as anything within the Bay south of the 44120 Loran line. Stellwagen Bank was defined as a box north of this to the 44280 line and bounded by Loran lines 13675 to the east and 14000 to the west.

Sightings were then grouped by date such that an "event" was defined as any two or more sightings of right whales, separated by an interval of no more than X days. We ran this program separately for intervals of 4 days, 7 days, 10 days and 14 days, and ran each of these for CCB/Stellwagen together, and Stellwagen alone.

The choice of interval is important in defining the event. Short intervals (e.g. 4 days) can result in the breakup of events which are actually longer. Long intervals (e.g. 14 days or more) risk grouping as a single event sightings which do not belong together (e.g. a single whale seen on day 1 and a single whale seen on day 14, with nothing in between). Results using different intervals are given in Appendix A (Tables 1, 2a and 2b). Comparisons of results indicated that the best interval is 10 days, and this was used in all analyses.

For each event, we calculated: (a) the number of whales in the initial sighting (the total number observed on the first day); (b) the number of separate days on which sightings were made; (c) the total duration of the event (first day to last day); and (d) the mean number of whales sighted overall.

We also looked at cases where an initial sighting of a right whale was *not* followed by another within the specified interval (termed "non-events" here). In this analysis, we excluded any sighting that was the last record in the series for an event, since by definition the last such sighting could not be followed by another within 10 days (or the event would not have ended).

Thus, in what follows:

> ***an "event" is two or more right whale sightings separated by an interval of not more than 10 days***

and:

> *a "non-event" is any right whale sighting which was not followed by another within ten days (unless the sighting concerned represented the end of an event).*

Results

Events

Limiting the data to Stellwagen Bank, analysis of the CCS daily sightings data produced 17 events under the 10-day definition. Adding in the Cape Cod Bay data increased this to 42 events, many of which involved sightings from both areas. Differences between the two treatments highlighted the potential problem of relying on data from a smaller marginal area that may involve spillover from a nearby, higher-use habitat. A list of events from the combined data sets is given in Tables 1a and 1b (sorted chronologically, and by the number of whales in the initial sighting). Events from just the Stellwagen Bank area are presented in Tables 2a and 2b.

Non-events

Right whale non-events (i.e. sightings not followed by subsequent sightings within ten days) totalled 21 for the combined Cape Cod Bay/Stellwagen data set (Table 3), and 16 for the Stellwagen-only data set (Table 4).

Initial sighting size as a predictor

Table 5 summarizes the frequency of events and non-events, by number of right whales recorded in the initial sighting in the combined Cape Cod Bay and Stellwagen Bank data set. There were 50 initial sightings in which the number of right whales involved was either one or two. Of these sightings, 29 (58%) began an event, while 21 (42%) were not followed by a subsequent sighting within ten days (i.e. they were non-events). In contrast, all initial sightings involving three or more whales (n = 13) began an event (i.e. they were followed by one or more subsequent sightings within ten days).

Of the 16 non-events noted in the Stellwagen-only data set (Table 4), all but one involved initial sightings of either one or two right whales. The exception, a sighting of four whales on 30 May 1992, was a non-event only because Cape Cod Bay data were excluded; this sighting was actually part of an event lasting two days which included sightings from both Stellwagen Bank and Cape Cod Bay.

Event duration

The duration of the 42 events in the combined Cape Cod Bay/Stellwagen data set (Tables 1a and 1b) ranged from 2 to 95 days (the latter being the unusual summer residency recorded in 1986). Of these events, 19 (45%) lasted for less than a week, and 23 (55%) for a week or more. Of 29 events beginning with initial sightings of one or two right whales, 14 (48%) lasted less than a week and 15 (52%) for a week or more. Of 13 events beginning with initial sightings of three or more right whales, 5 (38%) lasted less than a week and 8 (62%) for a week or more. The 13 events ranged in duration from two to 33 days (mean = 15 days, median = 12 days).

Conclusions

The analysis above indicates that an initial sighting of three or more right whales in an area appears to be a reasonably good indicator of an event. The average duration of an event is about two weeks.

ANALYSIS 2: CLOSURES - TRIGGER DENSITY, BUFFERS AND AREA DEFINITION

In the following section, the "three or more whales" trigger initiating an event is converted into a density of whales which can be uniformly applied in any area. A method is then developed for establishing a closure area that is robust to movements of whales over the course of an event. Finally, the trigger criterion is applied to existing aerial survey data to examine how frequently closures would have occurred in the past.

In other words, the questions being addressed are:

- What density of whales (taken from analysis of past events) would trigger a closure?
- How much of an areal buffer would there have to be around the sightings from the first day of an event to make sure that all whales present over the course of that event were protected by the closure area?
- Applying these methods to data from 1999 and 2000, how many closures would have been triggered?

Definitions

The following definitions are used in this analysis:

Event - An event is two or more right whale sightings separated by an interval of not more than 10 days. We focus on events triggered by an initial sighting of three or more right whales because initial sightings of one or two whales were more frequently associated with non-events (see Analysis 1).

Event epicenter - The geographic center of all sightings on the first day of an event.

Capture radius - The distance between an event epicenter and the most distant sighting from that center. This is the radius of the smallest circle, centered at the epicenter, which captures a particular set of sightings (e.g. day one of an event or all sightings in an event).

Density - A measure of distribution expressed as the number of whales per 100 nm^2.
Proximity - A function of density; if the minimum density to trigger an event is D, then proximity is the radial distance that circumscribes a point location of sighted whales equal to D.

Methods

For the 42 events identified in the combined Cape Cod Bay and Stellwagen Bank data set (Tables 1a and 1b), distance relationships among whales sighted during the *first day* of the event were calculated (using the statistical software package SAS), as well as relationships among all whale sightings for the *entire duration* of that event. For each event, distance epicenters were determined and plotted (together with geographic reference features) using the software package ARCVIEW. Then, distances were calculated between the epicenter and the most distant whale seen during the first day (r_1), and the most distant sighting during the entire event (r_2). The difference between these two radial distances was considered to be the buffer (Figure 1).

A density for the first day of an event was also calculated as $D = n[1]/[\pi r_1)^2$, where n[1] was the number of whales seen on the first day of an event. Essentially, this density represents the number of whales divided by the area of a circle, centered at the epicenter, that enclosed all whale sightings on the first day of an event.

Results

The 42 analyzed events ranged in duration from 2 to 95 days and included between two and 449 total sightings (Table 1a). Buffers and trigger densities were calculated only for the 13 events which were initiated by an initial sighting of three or more animals; the other 29 events were ignored.

Buffer size

For the 13 events triggered by an initial sighting of three or more right whales, first-day capture radii ranged from 0 (i.e. all whales seen on the first day were together in the same place) to 10.4 nautical miles (nm). Total capture radii (i.e. for all sightings over the duration of an event) ranged from 1.6 to 25.2 nm. The largest buffers were slightly larger than 15 nm; thus, a buffer of 15 miles around the first day's sightings will usually enclose all of the right whales in an event, irrespective of their movements during the course of the event (Table 6).

Whale density

The minimum first-day density for the 13 events was 4.16 whales/100 nm^2, rounded off here to 4 whales in a 100-square mile area (roughly equivalent to 3 whales in a 75 nm^2 area). This density is therefore considered a reasonable trigger for a closure. However, when a large area is surveyed on one day (i.e. with an aircraft), a situation can occur where a concentrated cluster of sightings (one that would normally trigger a closure) falls below the trigger density through inclusion of another right whale sighting a long way away, creating an artificially large circle for that days' sightings (and consequent low overall whale density). To address this problem, an alternative trigger approach called the Local Area Density Method was developed (see Retrospective Analysis section below).

The inverse of the 4 whales/100 nm^2 density is 24 nm^2/whale, which is equivalent to a radial distance of 2.77 nm for a single whale sighted (3.91 nm for 2 whales, 4.79 nm for 3 whales, etc). When whale locations are plotted together with their proximity circles, local whale densities above or below closure triggers are identifiable (Figure 2).

ANALYSIS 3: RETROSPECTIVE ANALYSIS

Methods

Right whale sightings from four data sets were used in a retrospective evaluation of the closure triggers: the 1999 and 2000 NOAA Fisheries Northeast Fisheries Science Center (NEFSC) aerial surveys, and the 1999 and 2000 NOAA Fisheries Northeast Regional Office/Sighting Advisory System (NERO/SAS) surveys (Figure 3). These data were analyzed to examine the frequencies and sizes of area closures that would have resulted from using the density trigger proposed above. The four data sets included all documented right whale sightings observed during aerial surveys conducted by one or two aircraft on 30 different days during the period 10 March to 27 June 1999, and on 24 different days during the period 25 March to 6 July 2000. The aerial surveys sighted 461 right whale groups involving 652 whales. The surveys covered several areas, including the Great South Channel, Georges Bank, Jeffreys Ledge, Cashes Ledge and adjacent areas, Platts Bank and Wilkinson Basin.

Two trigger approaches were used:

The *Capture Radii Method* combines all sightings in a survey day to produce an overall survey density and compares this density against the proposed trigger value of 4 whale/100 nm^2.

The *Local Area Density Method* uses equal-density circles centered on each whale sighting. If a contiguous set of circles encompasses at least three whales, that local set of sightings is used to construct a closure area. This method triggers closures based on density of whales in a local area and is thus less affected by the particular spatial coverage of an individual aerial or ship-based survey. Use of this method circumvents the problem noted above regarding dilution of density caused by isolated sightings that are distant from a concentration of whales.

Results

Capture Radii method

Of the 54 daily aerial surveys, 19 produced capture radii with right whale densities > 4 whale/100 nm^2 (Figure 4). All but one of these 19 events involved three or more whales. Note that the 19 events would not translate into 19 closures, because many of the events would be part of the same closure. The recognized high concentration of whales observed near Cashes Ledge during June 2000 would not have triggered a closure under this approach because one or two whales observed on the western edge of that day's survey would have diluted the density of the other 20+ whales to <4 whale/100 nm^2 (Figure 5). Because of this shortcoming, use of the capture radii method is not recommended; instead, the local area density method should be employed in all assessments of potential closures.

Local Area Density Method

Local whale densities exceeded 4 whale/100 nm^2 in 45 of 54 surveys analyzed. The local area density approach would have triggered 8 closures during both 1999 and 2000 (Figures 6-7, Table 7). Several of the closure areas overlap areas already targeted for gear restrictions such as Cape Cod Bay and the Great South Channel (GSC). Based on these results, it appears that extending the GSC restricted area to the northeast would reduce the need for recurring temporary area closures and offer considerable protection to right whales during April and May.

SUMMARY

1) An initial sighting of three or more right whales, with a minimum density of about 4 whales per 100 nm^2, is a reliable indicator that additional sightings will occur in an area (i.e. that an event will take place).

2) Establishing a buffer of 15 nm will in most cases demarcate an area that will include all right whales sighting throughout the duration of an event.

3) Where aerial survey data are used to assess closures, the Local Area Density Method should be applied to avoid the problem of density dilution that occurs when sightings distant from a concentration of whales are included.

ACKNOWLEDGMENTS

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Table 1a. Events involving sightings of right whales at intervals of 10 days or less, ordered chronologically. Data from Cape Cod Bay and Stellwagen Bank combined.

First date	Initial sighting	Total days	Duration (days)	Mean RW#
80.04.16	2	2	2	2.0
82.04.18	4	3	6	2.3
82.05.20	2	2	3	2.0
82.09.18	2	2	3	2.0
83.04.17	2	20	42	5.1
84.04.01	6	15	29	4.7
85.04.12	15	10	23	4.0
85.10.09	2	2	6	1.5
85.10.25	2	2	3	2.0
86.04.01	1	10	21	3.6
86.06.30	2	5	6	2.0
86.07.24	2	76	95	5.9
87.04.03	3	7	20	6.6
87.07.07	1	2	6	1.0
87.08.21	2	8	27	1.1
88.04.01	2	2	3	5.5
88.04.14	23	7	14	4.9
89.04.17	1	2	3	1.0
89.07.14	1	27	71	2.0
90.04.01	6	2	2	8.0
90.04.13	4	3	6	3.0
90.06.27	1	7	9	1.0
90.10.13	3	4	12	1.5
91.04.02	8	2	6	5.0
91.10.08	1	3	11	1.0
92.04.04	7	5	10	16.2
92.05.30	4	2	2	3.0
92.07.31	2	19	32	2.8
92.09.16	2	2	2	2.0
92.10.04	2	10	20	1.8
93.04.18	1	7	13	1.3
93.07.02	2	2	8	1.5
93.07.28	1	7	21	1.0
94.04.01	27	13	24	5.6
94.07.24	1	9	15	1.4
94.08.26	1	5	6	1.0
95.04.16	2	5	8	1.6
95.06.17	1	2	2	1.0
95.07.23	1	2	2	1.0
95.08.14	2	3	4	2.0
96.04.01	138	11	33	25.8
96.09.24	1	4	18	1.3

Table 1b. Events involving sightings of right whales at intervals of 10 days or less, ordered by number of whales in the initial sighting. Data from Cape Cod Bay and Stellwagen Bank combined.

First date	Initial sighting	Total days	Duration (days)	Mean RW#
86.04.01	1	10	21	3.6
87.07.07	1	2	6	1.0
89.04.17	1	2	3	1.0
89.07.14	1	27	71	2.0
90.06.27	1	7	9	1.0
91.10.08	1	3	11	1.0
93.04.18	1	7	13	1.3
93.07.28	1	7	21	1.0
94.07.24	1	9	15	1.4
94.08.26	1	5	6	1.0
95.06.17	1	2	2	1.0
95.07.23	1	2	2	1.0
96.09.24	1	4	18	1.3
80.04.16	2	2	2	2.0
82.05.20	2	2	3	2.0
82.09.18	2	2	3	2.0
83.04.17	2	20	42	5.1
85.10.09	2	2	6	1.5
85.10.25	2	2	3	2.0
86.06.30	2	5	6	2.0
86.07.24	2	76	95	5.9
87.08.21	2	8	27	1.1
88.04.01	2	2	3	5.5
92.07.31	2	19	32	2.8
92.09.16	2	2	2	2.0
92.10.04	2	10	20	1.8
93.07.02	2	2	8	1.5
95.04.16	2	5	8	1.6
95.08.14	2	3	4	2.0
87.04.03	3	7	20	6.6
90.10.13	3	4	12	1.5
82.04.18	4	3	6	2.3
90.04.13	4	3	6	3.0
92.05.30	4	2	2	3.0
84.04.01	6	15	29	4.7
90.04.01	6	2	2	8.0
92.04.04	7	5	10	16.2
91.04.02	8	2	6	5.0
85.04.12	15	10	23	4.0
88.04.14	23	7	14	4.9
94.04.01	27	13	24	5.6
96.04.01	138	11	33	25.8

Table 2a. Events involving sightings of right whales at intervals of 10 days or less, ordered chronologically. Data from Stellwagen Bank only.

First date	Initial sighting	Total days	Duration (days)	Mean RW#
83.05.24	1	2	5	1.0
85.04.12	15	3	13	8.0
86.06.30	2	4	6	2.0
86.07.24	2	47	64	4.0
86.10.20	7	4	7	12.3
87.07.07	1	2	6	1.0
89.07.14	1	6	31	1.8
90.06.27	1	7	9	1.0
90.10.13	3	3	12	1.7
92.08.22	2	5	9	2.4
92.10.12	2	3	12	1.3
93.08.06	1	2	10	1.0
94.07.24	1	5	11	1.4
95.04.20	3	2	3	2.0
95.07.23	1	2	2	1.0
96.04.29	1	2	5	1.0
96.10.01	1	3	12	1.3

Table 2b. Events involving sightings of right whales at intervals of 10 days or less, ordered by number of whales in the initial sighting. Data from Stellwagen Bank only.

First date	Initial sighting	Total days	Duration (days)	Mean RW#
83.05.24	1	2	5	1.0
87.07.07	1	2	6	1.0
89.07.14	1	6	31	1.8
90.06.27	1	7	9	1.0
93.08.06	1	2	10	1.0
94.07.24	1	5	11	1.4
95.07.23	1	2	2	1.0
96.04.29	1	2	5	1.0
96.10.01	1	3	12	1.3
86.06.30	2	4	6	2.0
86.07.24	2	47	64	4.0
92.08.22	2	5	9	2.4
92.10.12	2	3	12	1.3
90.10.13	3	3	12	1.7
95.04.20	3	2	3	2.0
86.10.20	7	4	7	12.3
85.04.12	15	3	13	8.0

Table 3. Non-events: sightings of right whales which were not followed by other sightings within ten days. Data from Cape Cod Bay and Stellwagen Bank combined.

Date	Initial sighting
85.07.13	1
86.05.14	2
86.05.25	2
86.06.19	2
87.05.03	1
87.06.09	1
87.06.20	2
88.07.10	1
89.05.18	2
89.06.22	1
89.07.03	1
90.05.06	2
90.08.26	1
90.09.10	2
91.05.25	2
91.06.20	1
92.06.22	2
93.06.05	2
93.09.04	1
93.09.25	2
94.07.02	2

Table 4. Non-events: sightings of right whales which were not followed by other sightings within ten days. Data from Stellwagen Bank only.

Date	Initial sighting
80.04.16	2
85.07.13	1
86.05.25	2
86.06.19	2
87.06.20	2
89.05.18	2
89.07.03	1
90.08.26	1
90.09.10	2
91.05.25	2
92.05.30	4
92.06.22	2
92.07.31	2
92.09.16	2
93.07.02	2
94.07.02	2

Table 5. Frequency of events and non-events, and characteristics of events, by number of whales in the initial sighting. Data from Cape Cod Bay and Stellwagen Bank combined. Mean dur = mean duration (days). Mean RW = mean number of right whales recorded per day during the event.

Initial sgt	*n*	Events	Non-events	Events			
				Mean dur	sd	Mean RW	sd
1	22	13	9	15.2	17.3	1.4	0.7
2	28	16	12	16.5	23.5	2.6	1.5
3	2	2	0	16.0	4.0	4.1	2.6
4	3	3	0	4.7	1.9	2.8	0.3
5	0	0	0	-	-	-	-
6	2	2	0	15.5	13.5	6.4	1.7
>6	6	6	0	18.3	9.2	10.3	8.1
TOTAL	63	42	21				

Table 6. Whale density characteristics of 13 events characterized from historic Cape Cod Bay and Stellwagen Bank whale watch data during April-October 1980-96. Note that no density estimate exists if all whale sightings recorded during the first day were assigned the same coordinates.

Event No.	First-day Radius (nm)	First-day Density (whales/100 nm^2)[1]	No. First-day Whales	Buffer	Total No. Whale Sightings
1	0		4	10.1	7
2	1.20	132.0	6	16.0	70
3	3.67	35.4	15	11.7	66
4	4.79	4.16	3	10.1	46
5	10.4	6.75	23	5.9	34
6	0.76	329.0	6	0.90	16
7	0.78	207.0	4	15.5	9
8	0		3	9.2	6
9	3.22	21.4	7	5.2	9
10	0		7	15.1	81
11	0.71	251.0	4	9.3	6
12	8.39	12.2	27	7.9	73
13	2.71	598.0	138	15.8	284

[1]Note that because localized density is expressed in animals per 100 nm^2, values in excess of the estimated total population size (300 animals) are obtained. These high values are not intended to imply that more than 300 whales exist in the population.

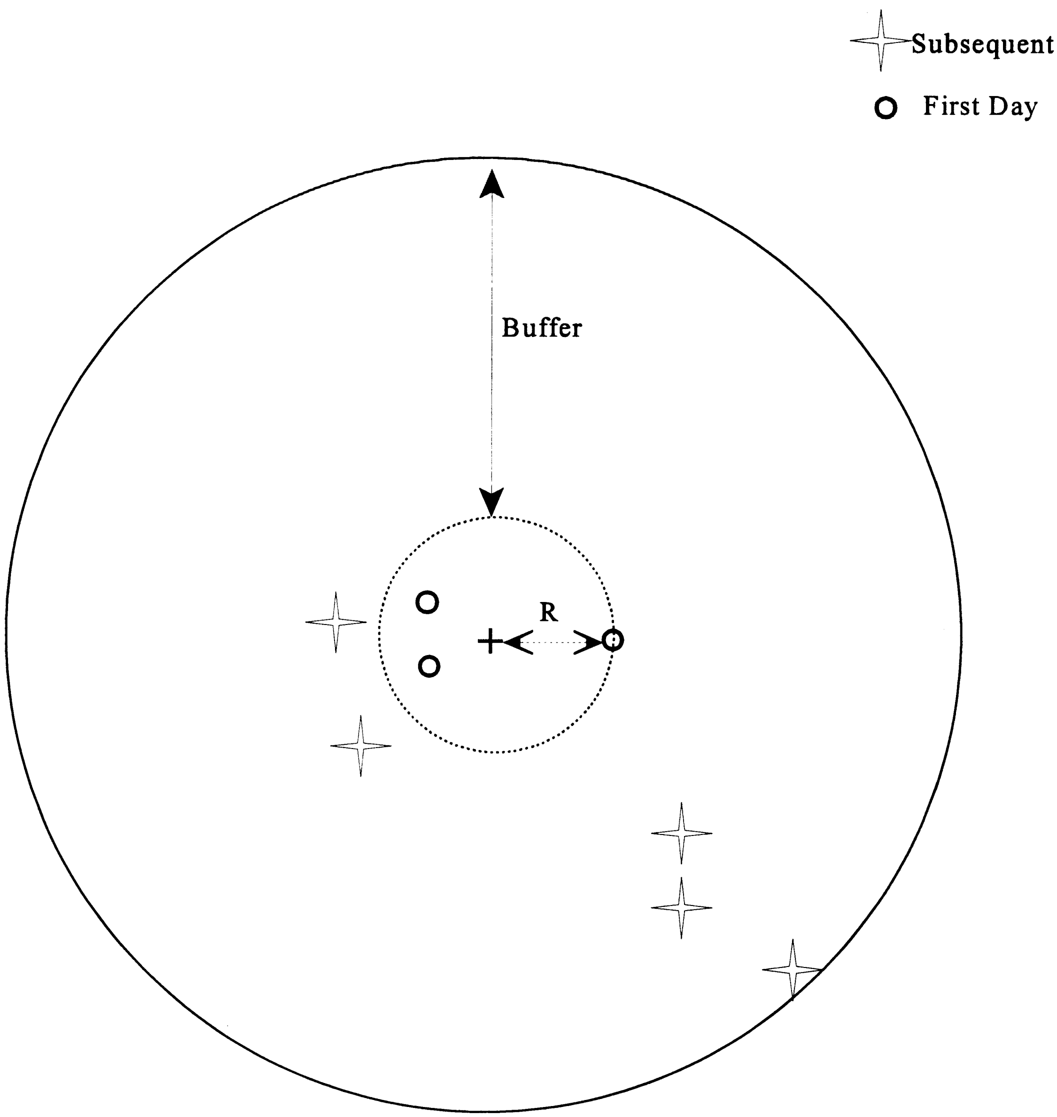
Table 7. Start date, duration, and subsequent sightings for 16 closure areas triggered and constructed based on a retrospective analysis of 1999 and 2000 NEFSC and NERO aerial survey using the local area density method.

RETROSPECTIVE ANALYSIS
LOCAL-DENSITY BASED CLOSURES (see Figs)

YEAR	id	START	Other	Other	Other	Other	LAST
1999	1-2	01-Apr	15-Apr	16-Apr	29-Apr		29-Apr
	3	11-Apr	01-May	12-May	28-May	02-Jun	02-Jun
	4	15-Apr	16-Apr	25-Apr	01-May	11-May	11-May
	5	01-May	10-May	12-May	13-May	15-May	30-May
	6	12-May	22-May	6-Jun			6-Jun
	7	14-May	15-May	17-May	30-May	19-Jun	19-Jun
	8	27-May	5-Jun				5-Jun
2000	1	31-Mar	25-Apr	28-Apr	4-May		4-May
	2	28-Apr	6-May	26-May			26-May
	3	25-Apr	28-Apr	28-May	4-Jun		4-Jun
	4	14-Apr	16-May	26-May	27-May	1-Jun	8-Jun
	5	17-May	8-Jun	14-Jun			14-Jun
	6	15-May	16-May	17-May	26-May	31-May	31-May
	7	08-Jun	14-Jun	20-Jun			20-Jun
	8	20-Jun	21-Jun	28-Jun	29-Jun	6-Jul	6-Jul

Notes
4 MAY 2000 subsequent sighting in 2 also covered by 1
Many sightings not listed above were covered by multiple closure areas
A 5 MAY 2000 sighting of 5 whales near the edge of closure area 4 could meet the criteria for a new closure to be triggered but was not used
Other refers to other survey dates that verified whale presence in the initial closure area

Figure 1. Drawing depicting some of the calculations based upon analysis of first day sightings and all other sightings during an event.



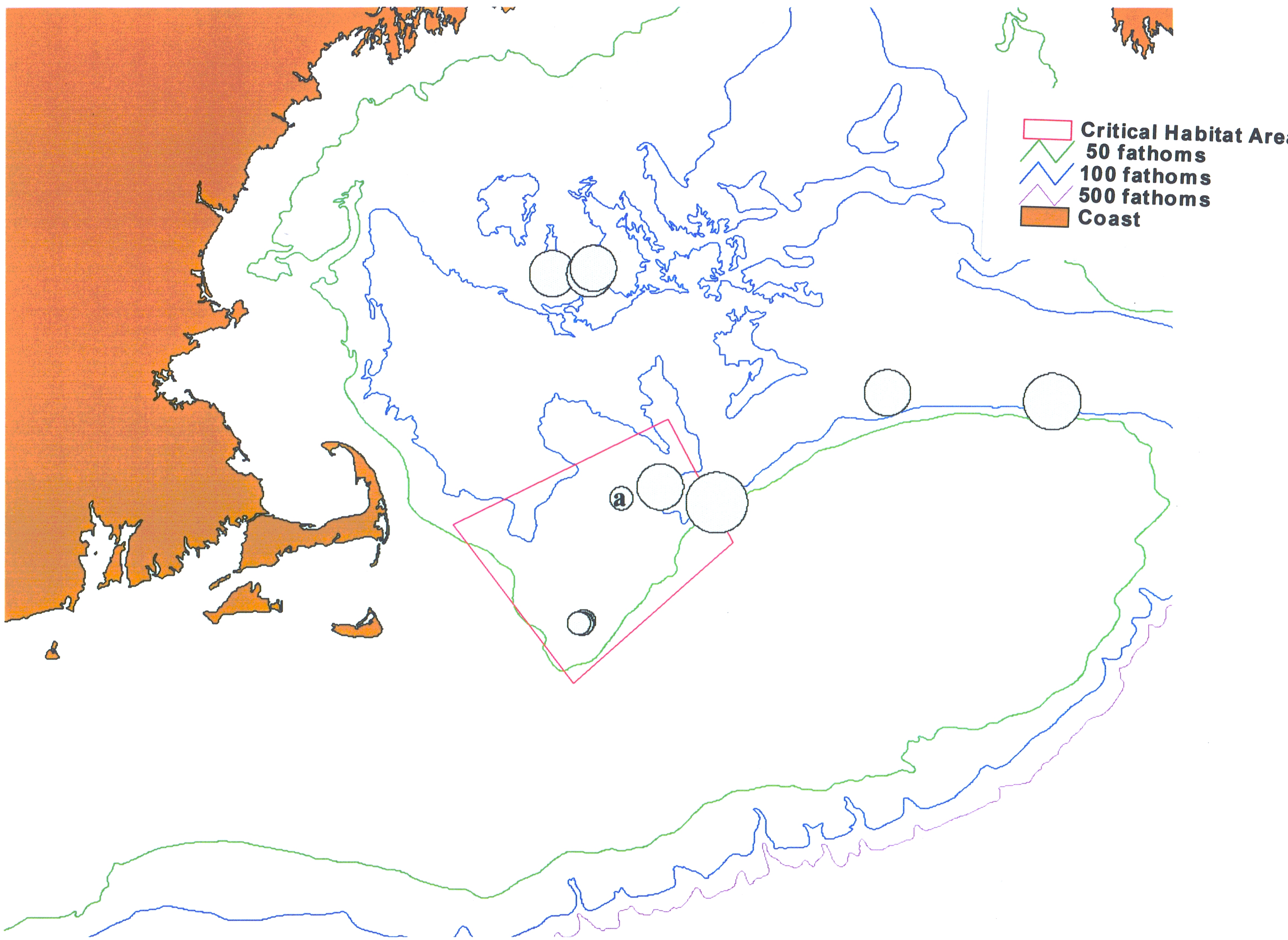


Figure 2. Example plots of proximity circles used to gauge local Right whale densities. Circles are scaled to represent a density of 4.16 whales /nm2 with the smallest circles representing a single whale. Only the lone circle **a** does not trigger a closure.

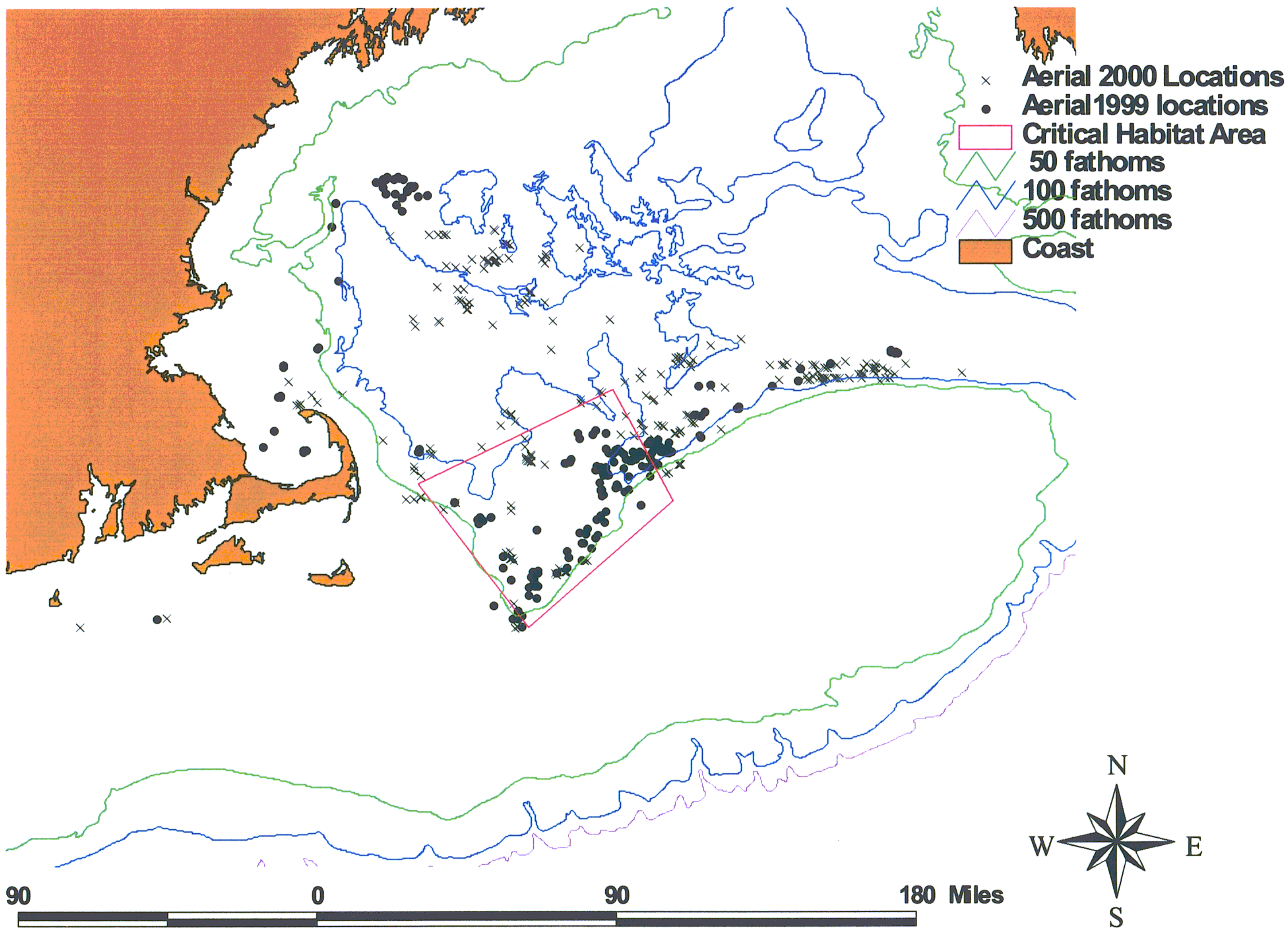


Figure 3. Geographic distribution of Right whale sightings used in the retrospective analysis.

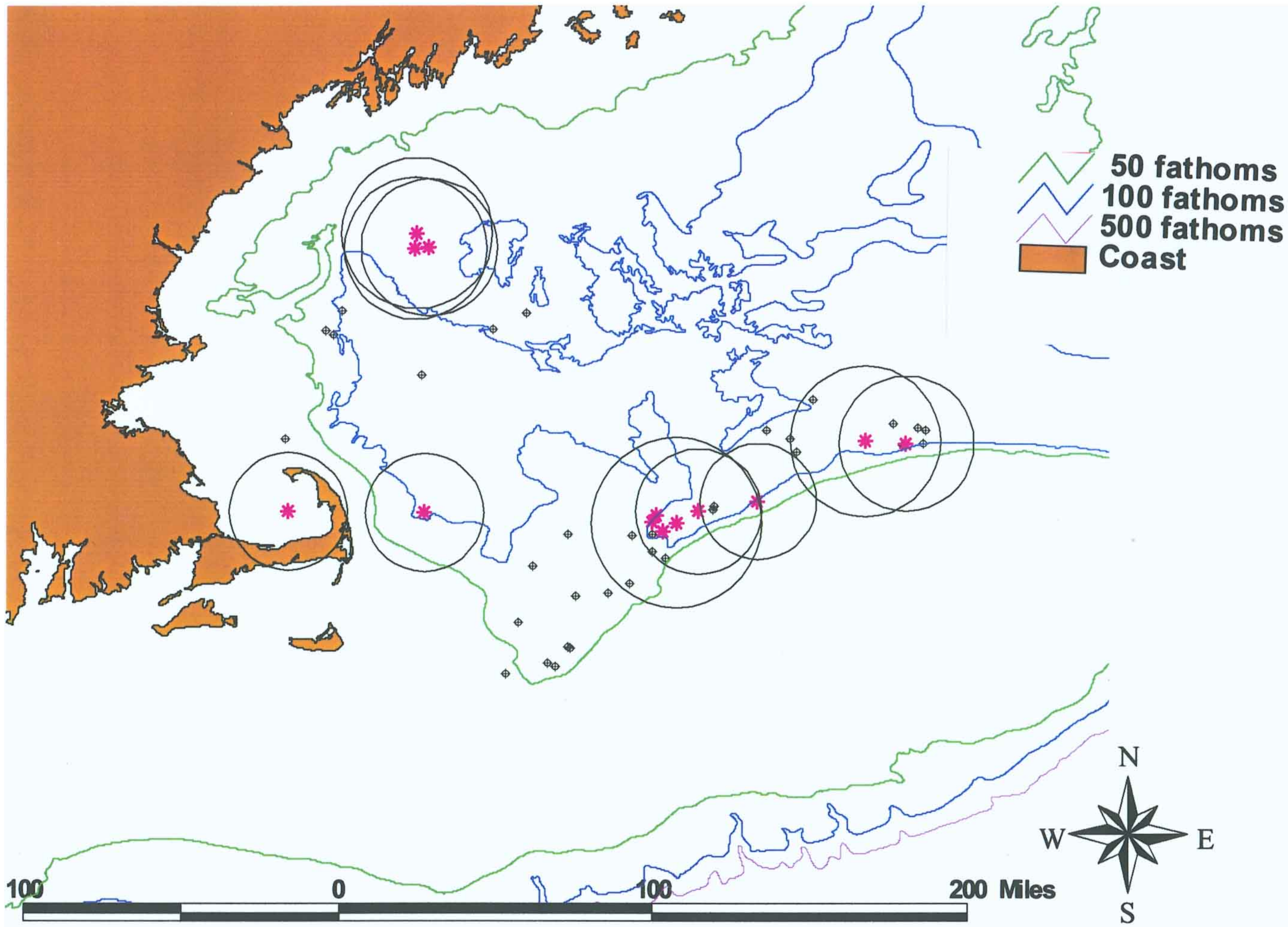


Figure 4. Map depicting 13 of 19 events that would trigger area closures based on capture radii method applied to 1999 and 2000 survey data. Asterisks (*) mark centroids of trriggered closures.

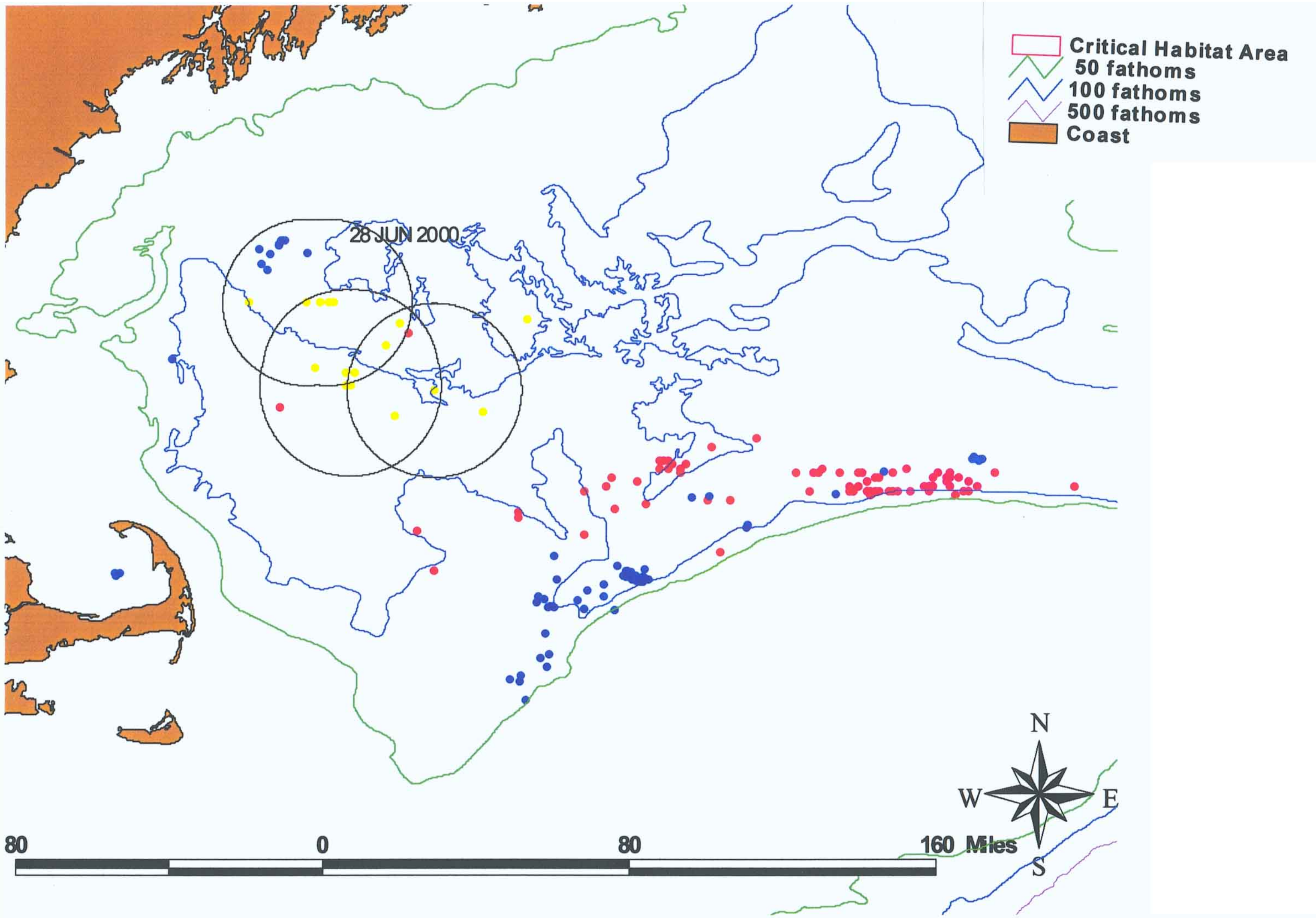


Figure 5. Geographic distribution of a high concentration of Right whale sightings observed 28 June 2000 (light gray) that would not have triggered a closure based on the capture radii methods plotted with three closures triggered using local density method. Other sightings shown as well.

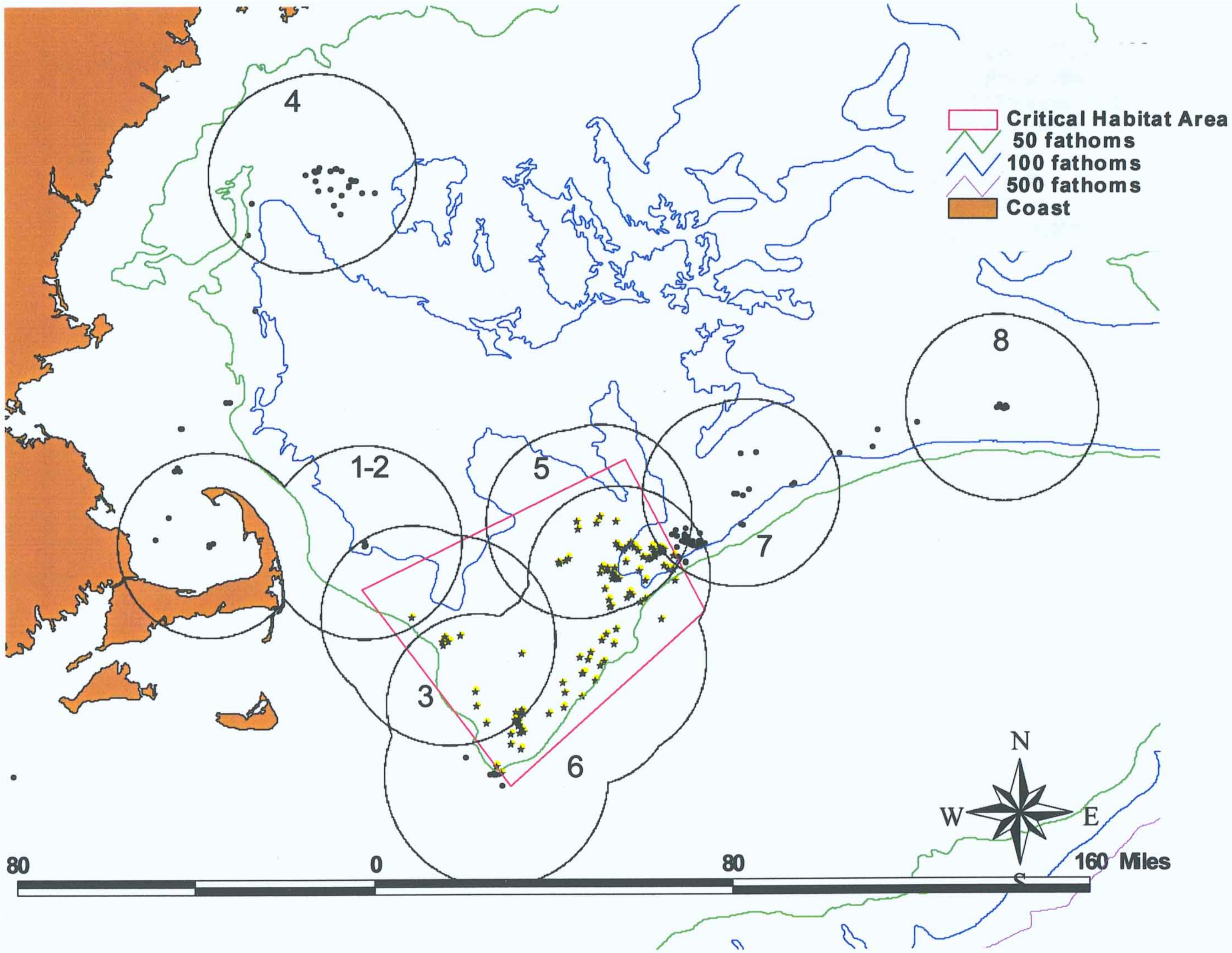


Figure 6. Geographic distribution of 8 area closures that would have been triggered during 1999. Stars (★) mark right whales sightings that occurred inside the Great South Channel critical habitat area. Numbered areas reference Table 7.

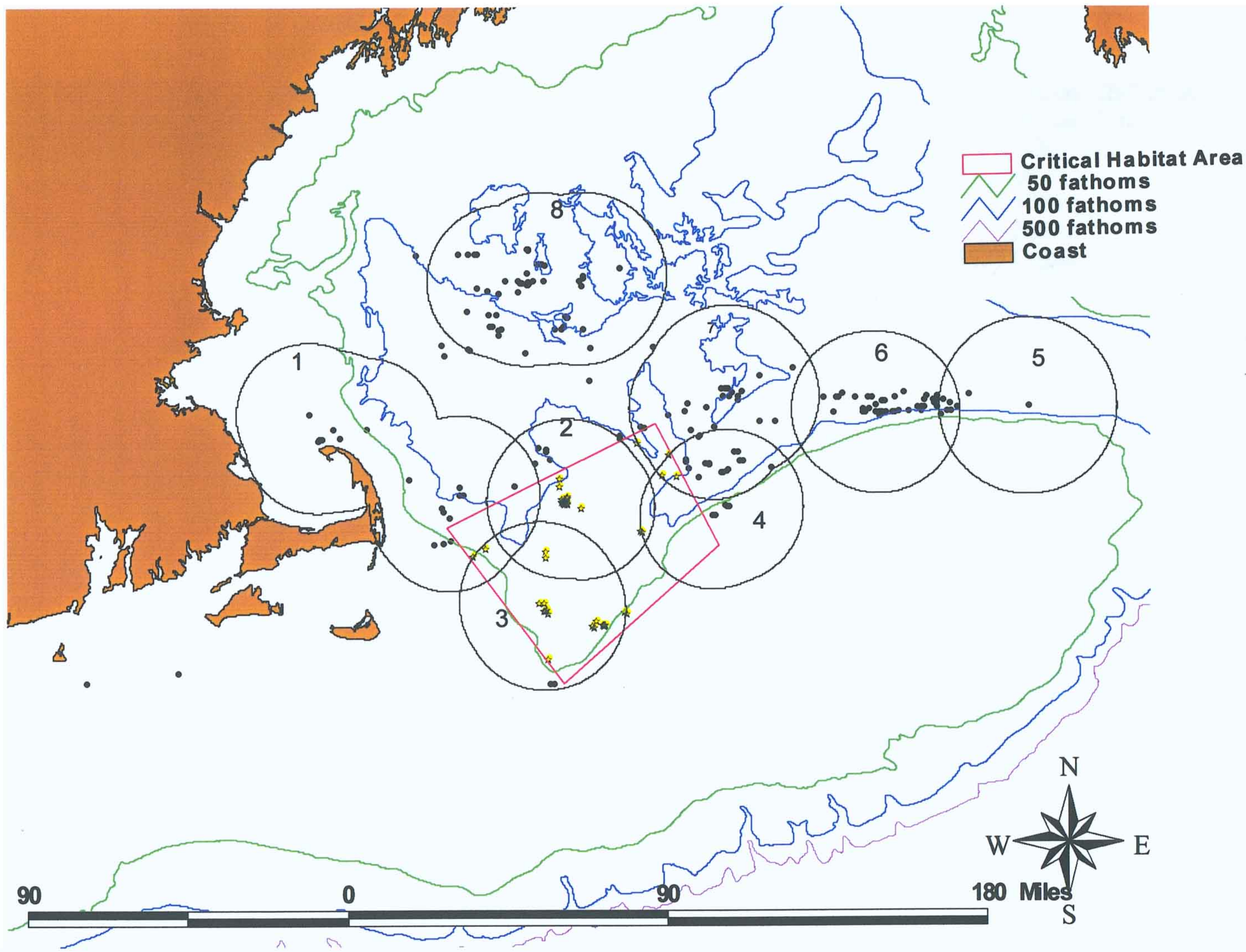


Figure 7. Geographic distribution of 8 area closures that would have been triggered during 2000. Stars (★) mark right whales sightings that occurred inside the Great South Channel critical habitat area. Numbered areas reference Table 7.

APPENDIX A
CHOICE OF INTERVAL FOR ANALYSIS

As noted above, the choice of interval is important in defining the sighting events that underlie the definition of closure triggers. Accordingly, an analysis is given here of how results differed using the four different intervals examined (4, 7, 10 and 14 days). A comparison of these differences is given in Appendix Table 1. Details of the comparisons between the chosen 10-day interval and the other three options are given below.

10 days vs 7 days

The largest difference (in terms of number of events identified) was between analyses using 7- and 10-day intervals. A listing of events identified using a 7-day defining interval that differ from those identified using a 10-day defining interval, and *vice versa*, is given in Appendix Tables 2a and 2b together with a description of nature of the difference. In all cases (11 in total), the 10-day interval captured additional sightings that were close together in time but more than 7 days apart, thus lengthening the duration of the event concerned. However, it should be noted that all of the 11 cases began with an initial sighting of only one or two right whales; thus they would not fall within the trigger criteria proposed here.

10 days vs 4 days

Using an interval of 4 days gave 11 events that were different (in start date) from those captured by the 10-day interval. In all cases, these were part of longer events which began earlier and usually ended later under the 10-day criterion. In other words, the shorter interval broke up more protracted events and thus did not adequately reflect residency by right whales in the area.

10 days vs 14 days

Using the 14-day interval provided only four differences with the 10-day criterion results. These were as follows:

> 1. An event beginning 86.05.14 was one of only two sightings of two whales separated by 12 days. It is likely that this represented two isolated sightings of transient whales, since it was not followed by a longer event picked up by the 10-day criterion.
>
> 2. A single sighting of two whales on 86.06.19 preceded by 11 days and then merged with an event beginning (under the 10-day criterion) on 86.06.30.

3. An event beginning with one whale on 87.06.09 and consisting of two sightings (the other of a pair on 87.06.20) preceded and merged with an event beginning (under the 10-day criterion) on 87.07.07.

4. An event beginning on 89.06.22 and consisting of two sightings of single whales (the other on 89.07.03) preceded and merged with a prolonged event beginning (under the 10-day criterion) on 89.07.14 and lasting 71 days.

In summary, use of the 14-day interval either artificially connects sightings that are probably unrelated, or extends the front end of events that were already established under the 10-day criterion. Although the latter instance would marginally extend protection to the one or two animals concerned, this is not a significant benefit given the infrequency with which these cases occur and the additional costs of increasing closure times.

Appendix Table 1. Comparison of different intervals used in defining events. Data from Cape Cod Bay and Stellwagen Bank combined.

Interval	Events	Days			Duration (days)			$\bar{X}$ Whales
		Min	Max	Mean	Min	Max	Mean	
4 days	51	2	58	6.1	2	67	8.6	3.4
7 days	47	2	76	6.9	2	95	11.6	3.3
10 days	42	2	76	8.0	2	95	15.4	3.6
14 days	41	2	76	8.3	2	95	18.5	3.4

Appendix Table 2a. List of events identified using a 7-day defining interval that differ from those identified using a 10-day defining interval. Comparisons in Comments are made relative to events reported in Appendix Table 2b or to other data.

Ref	Start date	Initial sighting	Days	Duration	Mean RW#	Comments
A	83.05.24	1	2	5	1.0	Using the 10-day interval, this event began on 83.04.17 and lasted 42 days
B	87.08.30	1	2	3	1.0	Part of event 1 below
C	87.09.10	1	5	7	1.0	Part of event 1 below
D	89.08.02	2	8	12	2.1	Part of event 2 below
E	89.08.22	2	16	24	2.0	Part of event 2 below
F	92.08.10	2	18	22	2.8	Part of event 3 below
G	92.10.20	1	2	4	1.0	Using the 10-day interval, this event began on 92.10.04 and lasted 20 days
H	93.08.15	1	2	3	1.0	Using the 10-day interval, this event began on 93.07.28 and lasted 21 days

Appendix Table 2b. List of events identified using a 10-day defining interval that differ from those identified using a 7-day defining interval. Comparisons in Comments are made relative to events reported in Appendix Table 2a.

Ref	Start date	Initial sighting	Days	Duration	Mean RW#	Comments
1	87.08.21	2	8	27	1.1	Began earlier and merged into events B and C above
2	89.07.14	1	27	71	2.0	Began earlier and merged into events D and E above
3	92.07.31	2	19	32	2.8	Began earlier and merged into event F above

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