Northeast Fisheries Science Center Reference Document 08-07

Northwest Atlantic Ocean Habitats Important to the Conservation of North Atlantic Right Whales (*Eubalaena glacialis*)

by Richard M. Pace III and Richard L. Merrick

April 2008

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts

April 2008

Northeast Fisheries Science Center Reference Documents

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This document's publication history is as follows: manuscript submitted for review November 28, 2007; manuscript accepted through technical review March 21, 2008; manuscript accepted through policy review April 7, 2008; and final copy submitted for publication April 7, 2008. Pursuant to section 515 of Public Law 106-554 (the Information Quality Act), this information product has undergone a pre-dissemination review by the Northeast Fisheries Science Center, completed on March 21, 2008. The signed pre-dissemination review and documentation is on file at the NEFSC Editorial Office. This document may be cited as:

Pace RM III, Merrick RL. 2008. Northwest Atlantic ocean habitats important to the conservation of North Atlantic right whales (*Eubalaena glacialis*). US Dept Commer, Northeast Fish Sci Cent Ref Doc. 08-07; 24 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026.

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ABSTRACT

We provide a spatial and temporal description of the habitats important to the conservation of North Atlantic right whales (*Eubalaena glacialis*) in US waters of the Northwest Atlantic Ocean. This analysis is based on the premise that the biological and physical feature of habitat essential to the conservation of right whales in this region (i.e., the primary constituent element [PCE] which a species needs to survive and reproduce) is the presence of dense patches of calanoid copepods (notably *Calanus finmarchicus*). Despite the general importance of copepods to the marine food web of the region, only limited data are available to map the distribution of dense copepod patches that constitute the PCE for foraging right whales. Hence, we used right whale foraging areas as a proxy for the spatial locations of these patches. Based on systematic sighting surveys for right whales conducted from 1970 through 2005, we identified concentrations of foraging right whales in US Atlantic waters north of 40° N latitude. These data were then used to define Dynamic Area Management (DAM) zones, which indicated that most of the area north of the Great South Channel on Georges Bank was used at least seasonally for foraging. This region included seasonal foraging subareas generally identified as Cape Cod Bay, Great South Channel, Northern Edge of Georges Bank, Western Gulf of Maine, Wilkinson Basin, and Jordan Basin. Wilkinson and Jordan Basins are also considered essential to the conservation of right whales because these two basins are source areas for the dense copepod concentrations upon which right whales prey in US Northwest Atlantic waters.

INTRODUCTION

Critical habitat for the North Atlantic right whale (*Eubalaena glacialis*) was designated under the U.S. Endangered Species Act in June 1994 (59 FR 28793, hereafter referred to as the Rule) and included feeding areas that extended over parts of Cape Cod Bay and the Great South Channel (Figure 1). The critical habitat definition in the Rule was based primarily on right whale sightings data (M. Payne, NOAA Fisheries, 2005, pers. comm.), and the Rule clearly noted that the timing of right whale occupancy in the feeding areas coincided with the abundance of copepods, which were concentrated by oceanographic forces (Wishner et al. 1988, Brown and Winn 1989, Kenney et al. 1986, and Mayo and Marx 1990). In the Rule, many of the features contributing to these concentrations were described, including the persistent thermal front at the northern mouth of the Great South Channel and the hydrographic density gradients that induce water flow within Cape Cod Bay. Hence, while the critical habitat designation was based largely on sightings of right whales, it was recognized that prey abundance was a primary constituent element (PCE) for right whales in northeastern U.S. waters.

The principal prey items of right whales in the Northwest Atlantic Ocean are adult copepods, most notably *Calanus finmarchicus*, at high densities. Occurrence of dense copepod patches is the most important biological component of right whale habitat in New England waters (Watkins and Schevill 1976, Wishner et al. 1988, 1995, Murison and Gaskin 1989, Mayo and Marx 1990, Beardsley et al. 1996, Woodley and Gaskin 1996, Kenney 2001, Baumgartner et al. 2003, Baumgartner and Mate 2003). Right whales frequently feed on copepod aggregations at the surface (such as in Cape Cod Bay: see Mayo and Marx 1990), but foraging at depths where copepod densities are highest is the more common feeding mode (Kenney et al. 1995, Baumgartner and Mate 2003). In fact, high concentrations of copepods trigger foraging activities in right whales. This has been deduced by measuring densities of copepods at the surface in the path of actively foraging right whales (Mayo and Marx 1990), and by detailed analyses of vertical profiles of right whale dives evaluated in conjunction with vertical plankton sampling (Baumgartner and Mate 2003). Estimates vary on the prey densities necessary to stimulate right whale foraging. For example, Mayo and Goldman (1992) reported a feeding threshold of 4,000 zooplankters/m^3 for right whales feeding in Cape Cod Bay, while Beardsley et al. (1996) observed whale feeding in a patch of 330,000 organisms/m^3. Uncertainty about the actual threshold is unimportant, but a standard analysis of metabolic needs suggests right whales require dense patches to survive (Kenney et al. 1986). Right whale feeding and habitat studies show that right whales focus their foraging activities in areas where physical oceanographic features (e.g., water depths, currents and mixing fronts) operate to concentrate copepods (Wishner et al. 1988, Mayo and Marx 1990, Murison and Gaskin 1989, Baumgartner et al. 2003, Jiang, et al 2007). For example, Baumgartner et al. (2003) found that spatial variability in right whale occurrence in the Bay of Fundy and Roseway Basin was associated with water depth and the depth of the bottom mixed layer as *C. finmarchicus* aggregated over the deepest water depths in these regions. In this study, right whales occurred in areas where the bottom mixed layer forced discrete layers of *C. finmarchicus* to be shallower in the water column, allowing more efficient foraging by the whales. Hence, the features characteristic of right whales foraging habitat are a combination of both:

- Biological Oceanography – specific areas of the Gulf of Maine (GOM) that contain significant numbers of adult copepods such as *C. finmarchicus* (e.g., the Great South Channel), and

- Physical Oceanography – the hydrographic processes that concentrate zooplankton densities above some threshold at an accessible depth that allows efficient foraging (see Kenney et al. 1986, Mayo and Goldman 1992).

In addition to foraging areas, other areas essential to the conservation of right whales are the source areas that supply the copepod prey. Within the Gulf of Maine, two sources exist for *C. finmarchicus:* (1) the advection of copepods into the Gulf of Maine via the Northeast Channel; and (2) the redistribution of overwintering copepods to shallower depths from the deep-water Gulf of Maine basins (Durbin et al. 2003, Miller et al. 1998). While copepod sources outside of the Gulf of Maine are not considered here, source habitats within US waters may be essential to the development of suitable right whale prey concentrations, even if these are located outside the primary foraging areas.

In this report, we provide a spatial and temporal description of the important right whale foraging habitats in US waters of the Northwest Atlantic. Ideally, we would prefer to rely upon fine-scale information on the spatial and temporal distribution of copepod prey in this region, but such data do not exist. Instead, we provide a description of right whale foraging habitat usage based on systematic right whale sighting surveys conducted from 1970 through 2005. We also provide in Appendix 1, a literature review of information on the distribution and abundance of calanoid copepods in the Gulf of Maine/Georges Bank area.

METHODS

As noted earlier, dense patches of calanoid copepods are essential to the conservation of right whales in the Northwest Atlantic Ocean. However, broad-scale plankton monitoring schemes have proved ineffective in detecting the high concentrations usually present in the vicinity of actively feeding whales. The alternative “whale centric” sampling approach, where sampling occurs around foraging right whales, has proven to be the only effective approach for detecting dense prey patches (M. Baumgartner, Woods Hole Oceanographic Institution, Woods Hole, MA 02543). Given that right whales only forage on dense copepod aggregations, the location of actively foraging right whales provides a proxy for the distribution of dense copepod patches.

Available sightings data on the occurrence of right whales in the western North Atlantic (Brown et al. 2007) also provide insight into the spatial and temporal variability of right whale foraging areas (and, hence, dense copepod distributions) in this region. The high seasonal variability and modest inter-annual variability observed in right whale distribution is presumed to reflect the variability in the concentrated patches of their copepod prey, typically *C. finmarchicus* (Brown et al. 2001, Kenney et al. 2001).

Hence, to describe spatial-temporal patterns of foraging right whales in the US Northwest Atlantic waters, seasonal ‘maps’ are needed from sighting surveys, in which presence-absence data have been adjusted to a common unit of survey effort. Although different sets of cetacean sightings surveys have been conducted in the Georges Bank/Gulf of Maine area using similar survey designs, none of these have adequate geographic and seasonal coverage to detect all potentially-important right whale foraging habitats in the region. The Northeast Fisheries Science Center’s (NEFSC) right whale aerial survey program is the most complete, but lacks multi-year coverage in the autumn and has only been operational since 2002. Hence, pooling of survey data sets from multiple sources would be necessary to ensure synoptic coverage. However, these data sets cannot be standardized for a number of reasons, including: (a) many of the platforms used in the surveys have considerably different effective survey strip widths per linear mile surveyed; and (b) it is impossible to evaluate the variable detection rates among observers and platforms *post hoc* (McKenzie et al. 2006).

Nonetheless, presence-only data, as distinguished from presence-absence data, can still provide insight into habitat use (Ward 2007). Although the relative likelihood of presence among adjacent areas searched with differing survey sightings effort cannot be evaluated, each occurrence observation reflects at least some use[1]. Further, all occurrence data from qualified observers are equally valid. Therefore, we used all data from qualified observers archived in the North Atlantic Right Whale Consortium's (NARWC) sightings database to infer right whale foraging habitats and, by proxy, the distribution of dense copepod patches (i.e., the PCE). Cole et al. (2007) describe the methods by which many of these data were obtained from aerial surveys. Because the database includes many sightings of one or two animals, which may not be as predictive of foraging whales as larger groupings, a subset of occurrence data was selected that was considered reflective of foraging animals. The selection protocol used was developed by Clapham and Pace (2001) in their analysis of Dynamic Area Management zones.

Definition of Spatial and Temporal Extent of Important Right Whale Foraging Areas in the Gulf of Maine/Georges Bank Region

We analyzed all live right whale sightings in the NARWC database observed during 1970-2005 in the area north of 40° N[2] latitude and eastward to the edge of US EEZ (i.e., the Hague Line) for which the number of whales seen was not missing (Figure 1). We observed 9,612 sighting events records involving 17,756 right whales for the entire study area (Table 1). From this set, all sighting records qualifying as part of a possible DAM event were extracted; a possible DAM event is triggered whenever there is a sighting of >2 right whales sufficiently close to each other to achieve a density of 0.04 right whales/nm^2 (Clapham and Pace 2001). This extraction encompassed 7,761 sightings events representing 15,395 whales. The DAM protocol (Clapham and Pace 2001) was then applied to calculate the circular core sightings area and, as necessary, circular zones joined. This provided 1,292 unique "pseudo-DAM" events (Table 1) that were subsequently mapped using ARCView GIS software (Figure 2).

To characterize the temporal distribution of foraging right whales, we plotted all DAM-qualified sightings by month. Although unquantified, unequal survey coverage among geographical zones and across months generated these data, we believe that these plots can still be used to define coarse seasonal patterns of right whale foraging habitats. Spatial concentrations of DAM events over repeated years (i.e., 3 or more) were considered as candidates for Seasonal Management Areas (Merrick et al. 2001).

RESULTS AND DISCUSSION

Spatial Extent of Right Whale Foraging Habitat

The DAM sighting areas (Figure 2) encompass a larger geographic area than reported by Merrick et al. (2001) and Merrick (2005). For example, the recently detected area of early

[1] The contrary, namely that no or few sightings imply little use, is not true with occurrence data.

[2] The area north of 40° N was chosen for analysis because there is no evidence of the existence of dense concentrations of copepods or foraging right whales south of this latitude. Right whale occurrence south of this latitude is generally sporadic and likely reflects animals migrating to or from the Southeastern US (SEUS) area.

winter use by right whales near the northern edge of Jordan Basin (Figure 2) is much broader than previously suspected. This basin is likely a seasonally important foraging area, as well as a prominent source of the copepods which subsequently become densely aggregated in the Great South Channel and Cape Cod Bay areas (Bucklin and Kocher 1996, Durban et al. 2003, Jiang et al. 2007).

The number of DAMs varied among years (Figures 3 and 4) and reflects both varying habitat use by the whales and variability in annual sightings effort. Nonetheless, it seems reasonable to assume that most areas in the Gulf of Maine/Georges Bank region (Figure 2) constitute right whale foraging habitat at some time during most years. As such, right whale foraging habitat in the Gulf of Maine can be broadly defined spatially as (Figure 5):

- Within the Gulf of Maine and its associated Bays (e.g., Cape Cod and Massachusetts Bays), and is
- Northward of lines drawn diagonally from the southern corner of the Great South Channel Critical Habitat Area (41.0° N latitude, 69.1° W longitude)
- Northeastward to the EEZ/Hague Line (42.2° N latitude, 67.2° W longitude) and
- Northwestward to the southern corner of Cape Cod, MA (41.7° N latitude, 70.0 ° W longitude)

Sightings (and pseudo DAM events) occur to the south and east of this area, but a pattern of repeated annual observations is not evident in these areas. Typically, whales are sighted in these areas in one year, but are not seen again for a number of years. Most likely, these are sightings of migrating whales. There are also areas within this region of the Gulf of Maine where few right whale sightings have occurred (e.g., Georges Basin); this could be the result of lack of suitable foraging habitat, but could also be the result of limited survey effort in these areas during the times when right whales are present.

The region shown in Figure 5 covers approximately 19,200 square nautical miles[3]. In this region, 17,291 individual right whales have been sighted between 1970 and 2005 (of the 17,756 right whales sighted in U.S. waters north of 40° N). This includes 7,747 sightings (15,118 individual whales) that qualified as 1,255 DAM events (Table 1).

Temporal Extent of Right Whale Foraging Habitat

The right whale foraging region depicted in Figure 5 is much more expansive than the two existing Critical Habitat Areas (Figure 1). Although the Cape Cod Bay and Great South Channel Critical Habitat Areas are primary right whale feeding areas where copepod concentrations have been documented, the enlarged area in Figure 5 encompasses additional places where right whales regularly forage during various times of the year. Clearly, there is a strong seasonal component to the utilization of this larger area as right whale foraging habitat (Figure 6, Table 2). Although interpretation of any exact seasonal patterns is affected by the disproportionate right whale survey effort among seasons and subareas within the Gulf of Maine/Georges Bank region, some broad conclusions are tenable. It is likely that the seasonal movement of right whales that occurs between winter and early summer from Cape Cod Bay to the Great South Channel and then to the Northern Edge of Georges Bank (Figure 6, monthly panels 1 through 6) reflects the seasonal occurrence of dense copepod patches in these areas (Lynch et al. 1998). Based on the seasonal movement patterns of right whales (Figure 6) and the available literature

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3 As calculated with ARCView 3.2 using a Transverse Mercator projection, UTM 1983, Zone 19, central meridian of -69°, false easting = 500000,and false northing = 0

on the distribution, abundance, and population dynamics of calanoid copepods in the Georges Bank/Gulf of Maine region (Appendix 1), six areas are seasonally important for right whale foraging (Figure 7):

- Cape Cod Bay Critical Habitat Area
- Great South Channel Critical Habitat Area
- Western Gulf of Maine
- Northern Edge Georges Bank
- Jordan Basin
- Wilkinson Basin

Each of these areas is defined by a pattern of repeated DAM events over three or more years (particularly in the past decade when more observations are available due to increased survey coverage.) Note that the spatial boundaries provided in Figures 5 and 6 are meant to be approximate.

Cape Cod Bay – This area exhibits high densities of copepods during winter, spring, and, possibly, fall. Of the 17,257 right whale sightings in New England during 1970 through 2005, 7,498 were in Cape Cod Bay (Table 1). A total of 543 pseudo-DAM events occurred in this area, most during January-April (Figure 6).

Great South Channel – This area has high copepod concentrations at depth, especially during March-July, owing to bathymetric features and water circulation patterns. A total of 5,753 right whales were sighted in the area during 1970-2005; this included 344 pseudo-DAMs. Most right whale sightings occurred during April-June, but also in July in some years (Figure 6). Right whale use of the Great South Channel area is not nearly as uniform as in Cape Cod Bay, but is widespread enough to indicate that the Channel is an essential foraging area in almost every year.

Western Gulf of Maine - The Western Gulf of Maine possesses a complex set of bathymetric features which markedly affect the spatial/temporal concentration of copepods among years, based on the interannual variability in right whale sightings. From 1970 through 2005, 1,749 right whale sightings (including 153 pseudo-DAMs) occurred in this area, mostly during April-May and July-October.

Northern Edge of Georges Bank – This area has high copepod densities at depth, especially during May-July, emanating from physical features (e.g., currents and upwelling) which concentrate late-stage copepods during spring and summer. Foraging right whales in this area are thought to be following an eastward progression of dense copepod patch development, which begins in late spring and early summer. A total of 408 individual right whale sightings have occurred in this area, including 32 pseudo-DAMs (Table 1). The period of greatest occupancy is during May-July.

Jordan and Wilkinson Basins – These two basins serve as over-wintering areas for copepods (see Appendix 1; Figure 10), which are then the source for most of the copepod patches on which right whales forage during the following spring and summer.

Wilkinson Basin serves as an over-wintering area for diapausing (resting/dormant stage) copepods, and also as a foraging area for right whales in spring. The limited survey sightings effort in the Basin during 1970-2005 documented 1,058 individual right whales, including 104 pseudo-DAMs (Table 1). Surveys have repeatedly found concentrations of right whales in this area during April-July (Figure 6).

Jordan Basin is also an overwintering area for diapausing copepods. As well, right whale surveys conducted in this area during the winter of 2004-2005 (perhaps the first winter surveys ever in this Basin) sighted up to 24 foraging right whales at a time (NMFS unpubl. data[4]). The limited survey efforts in the area during 1970-2005 recorded a total of 236 individual right whales, including 21 pseudo-DAMs (Table 1). The available data suggest that Jordan Basin is an important right whale foraging area, at least during August–October.

SUMMARY

Analyses of right whale sightings data in US Northwest Atlantic waters indicate that foraging habitat important to the conservation of North Atlantic right whales (Figures 5–7 and 10) is much more expansive than that within the two current critical habitat areas (Figure 1). This additional habitat includes areas where high concentrations of calanoid copepods regularly occur during the year, as well as areas where significant number of foraging right whales have been sighted. While most of the Gulf of Maine/Georges Bank region (Figure 5) can be considered as right whale foraging habitat, utilization of the region by right whales has a strong seasonal component (Figure 6). Six areas in the region are seasonally important: Cape Cod Bay (January-April), Great South Channel (April-June), western Gulf of Maine (April-May and July-October), northern edge of Georges Bank (May-July), Jordan Basin (August-October), and Wilkinson Basin (April-July). Both Jordan and Wilkinson Basins are also essential for right whales in that they serve as overwintering areas for diapausing copepods, and are the source of the copepods that right whales forage upon during the following spring and summer.

ACKNOWLEDGMENTS

We gratefully acknowledge the work of Cynthia Christman for providing data and information on DAM activities. We also thank Lisa Conger and Fred Wenzel for literature review, and Mary Colligan, David Gouveia, and Mark Minton for reviews of earlier versions of this document. The manuscript benefitted considerably from editorial comments by Fred Serchuk. Thanks to the US Coast Guard for funding support of the aerial surveys conducted by NMFS under Memorandum of Agreement NEC 2003-021. The flights were authorized under the NEFSC's MMPA/ESA permit No. 775-1600.

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Appendix I. Review of Copepod Distribution and Abundance in the Gulf of Maine/Georges Bank Region

The biological and physical processes affecting the distribution, abundance, and population dynamics of *Calanus finmarhicus* in the Gulf of Maine/Georges Bank region have received increased attention in recent years (Greene et al. 2004). Genetically, *C. finmarchicus* in Northwest Atlantic waters off Canada and the U.S. (i.e., in the Labrador Current, Gulf of St. Lawrence, and Gulf of Maine/Georges Bank regions) constitute a single, interbreeding population (Bucklin and Kocher 1996). Patterns of genetic variation in *C. finmarchicus* in the western North Atlantic are consistent with the hypothesis that copepods recruit to the Gulf of Maine/Georges Bank region from "upstream" areas. Oceanographic circulation patterns[5] (Figures 8 and 9) influence *C. finmarchicus* distribution and abundance patterns in the following ways:

- Slope waters from the Scotian Shelf (Greene and Pershing 2000) which enter the Gulf of Maine may transport considerable numbers of developing copepodites originating from both the Gulf of St. Lawrence and the Scotian Shelf (Plourde and Runge 1993, Conversi et al. 2001).
- Dense concentrations of C5-stage copepods overwinter in the deep basins within the Gulf of Maine, especially in Jordan and Wilkinson Basins[6].
- Circulation patterns within the Gulf of Maine return some progeny of copepods produced in the Gulf of Maine back to the Gulf of Maine deep basins, where these progeny overwinter and contribute to reproduction in the following spring (Hannah et al. 1997, Harms et al. 2000).
- Circulation patterns in Cape Cod Bay entrain *Calanus* produced elsewhere.
- During spring, circulation patterns within the Gulf of Maine, in conjunction with hydrographic processes and mixing fronts, concentrate copepods north of the 100 m isobath at the northern end of the Great South Channel (Wishner et al. 1995, Durbin et al. 1997, Kenney 2001).
- In early summer, continuous high-density aggregations of copepods occur along the northern edge of Georges Bank.
- By late fall and winter, dense copepod concentrations are found only in the deep-water basins.

Seasonal distributions and general patterns of abundance of *C. finmarchicus* within the Gulf of Maine and Cape Cod Bay are well documented (e.g. Meise and O'Reilly 1996). However, the geographic scales and depths at which copepods are sampled only rarely match the fine-scale at which right whales forage (Mayo and Marx 1990, Baumgartner and Mate 2003).

Much of our understanding of the dynamics of copepods within the Gulf of Maine comes from the considerable effort spent to understand the flow of *Calanus* that populates Georges Bank because of the importance of that area to valued fisheries. Relative to copepod movement, Georges Bank is considered "down steam" of the Great South Channel and, therefore, we can

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[5] Major Gulf of Maine Georges Bank features include the buoyant Maine Coastal Current, Georges Bank anti-cyclonic frontal circulation system, the basin-scale cyclonic gyres (Jordan, Georges and Wilkinson), the deep inflow through the Northeast Channel (NEC), the shallow outflow via the Great South Channel (GSC), and the shelf–slope front (SSF). (Gangopadhyay et al. 2003)

[6] Lipid content keeps these animals neutral buoyancy so that, in their resting state, they remain below the convective mixed layer (Visser and Jónasdóttir 1999).

safely assume that major sources of *Calanus* to Georges Bank are important sources to the spring bloom in the Great South Channel (Durbin et al. 2003). Briefly, 3 lines of support coalesce into support for these 2 basins in particular as important retention areas: 1) water circulation patterns, 2) *Calanus* population studies, and 3) combined biological and physical oceanographic modeling studies.

Firstly, in addition to their depth, there is reasonably strong circulation evidence that Jordan and Wilkinson have their own circulation gyres nestled inside the larger-scaled Gulf of Maine gyre (Figure 8 and 9). Several cyclonic gyres characterize near surface water flow in the Gulf of Maine, with limbs flowing toward, along and around Georges Bank from both the western side and from Jordan and Georges Basins. Generally, the intermediate and deep circulation is isolated from Georges Bank (Lynch et al. 1998). Surface flow into the Gulf of Maine is primarily Scotian Shelf water entering along the eastern side of the Northeast Channel, turning around Cape Sable and Browns Bank, then joining the cyclonic gyres over Jordan and Georges Basins. Several gyres occur in the flow regime, north of Great South Channel (the SCOPEX gyre), Wilkinson Basin and Georges Basin (Miller et al. 1998). Together, this circulation, bottom topography features, and meteorological phenomena control the water mass formation, movement and modifications (Warn-Varnas et al. 2005).

Secondly, Miller et al. (1998) provides an individual-based population model of *C. finmarchicus* for the Georges Bank region. They demonstrated the importance of Georges Basin, with Wilkinson and Jordan Basins as sources to Georges. Durbin and Casas (2006) summarize this the following way, "Local sub-populations of *C. finmarchicus* can only occur in regions suitable for diapause where it can complete its life cycle." As for specific zones within the Gulf of Maine, Miller et al. (1998) point to the MARMAP samples that support Jordan and Wilkinson, and even suggest that Georges Basin may be a contributor. This has been debated due to the considerable water movement and relative openness of Georges Basin to the shelf edge (Lynch et al. 1998).

Third, recent simulation models that combine plankton sampling results of the last 2 decades and earlier, robust circulation models of the Gulf of Maine and life history dynamics of *C. finmarchicus* have corroborated earlier conclusions about the importance of these basins as a copepod source the greater Gulf of Maine ecosystem (in addition to the exogenous sources of the Scotian shelf and its sources). As noted before, the Lynch et al.(1998) models supported all 3 deep basins (Jordan, Wilkinson and Georges) as contributors of *Calanus* to Georges Bank (and therefore GSC). The models of Li et al. (2006) suggest that conditions (copepod sources) within the Gulf of Maine are sufficient to account for the early *Calanus* population of Georges Bank, and with the importance of advected sources later in the year. The simulation models of Johnson et al. (2006) also support the prominence of Jordan and Wilkinson Basins in the *Calanus* dynamics in the Gulf of Maine. They review other lines of evidence that these are important retention areas primarily due to their depth and Gulf of Maine circulation patterns.

Jordan and Wilkinson Basins were well known as overwintering areas for copepods and, in part, sources for the spring copepod "bloom" that attracts right whales to the Great South Channel each spring. For example, Bucklin and Kocher (1996) reviewed genetic diversity among *Calanus spp.* stocks from locales and discovered continuity among the Gulf of Maine Basins, Georges Bank and Scotian Shelf source areas. This idea is reiterated often in the work of E. G. Durbin and his colleagues (see Durbin 1997 for a review and more recently Saumweber and Durbin 2006). Authors working in other areas of the North Atlantic also state as a matter of general knowledge (e.g., without corroborating references) that *Calanus* overwinter at depth including depths well below the maximum occurring in Jordan and Wilkinson Basins (see Gislason 2004 [actually sampled the Irminger Sea], Heath et al. 2004, and Speirs et al. 2005, 2006). When reference to the annual depth-to-surface cycle of *C. finmarchicus* is given, it is often to the reviews of Hirche (1996a & b). The concept is well grounded in plankton survey data that were collect in the preceding decades (e.g. Herman et al. 1991, which helps us understand some important habitat areas in Canadian waters other than Bay of Fundy). Therefore, in addition to the areas where copepods reach sufficient densities to provide forage for right whales, Jordan and Wilkinson Basins, with boundaries approximated by the 200m isopleths, represent habitats important to conserving right whales (Figure 10).

Table 1. Sighting events, individual right whales, and pseudo-DAM events, by subarea, within the Northeast foraging region (Figure 7), based on the NARWC dataset for the years 1970-2005.

Subarea	Sighting events[1]	Individual whales sighted[2]	Pseudo-DAM events
Cape Cod Bay	4,934	7,498	543
Great South Channel	2,209	5,753	344
Georges Bank Northern Edge	251	408	32
Western Gulf of Maine	1,037	1,749	153
Wilkinson Basin	523	1,058	104
Jordan Basin	111	236	21
Entire [3] Foraging Region	9,354	17,291	1,255
Outside Foraging Region	258	465	37
Entire Analysis Area	9,612	17,756	1,292

[1] Includes sighting events not occurring as parts of pseudo-DAMS.
[2] Includes whales from sighting events not occurring as parts of pseudo-DAMS.
[3] Sum of first five rows < Total for Foraging Region.

Table 2. Gulf of Maine and Georges Bank pseudo-DAM events, by month and multiple year intervals, based on NARWC data for the period 1970-2005.

MONTH	1974-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001-2005	TOTAL
JAN	0	0	1	0	0	19	16	36
FEB	0	1	2	10	6	37	26	82
MAR	0	7	14	25	33	69	49	197
APR	1	12	41	28	18	66	129	295
MAY	3	23	44	44	3	57	101	275
JUN	0	3	5	19	2	16	71	116
JUL	0	8	5	26	1	0	69	109
AUG	1	4	1	30	8	6	19	69
SEP	0	0	2	37	0	3	8	50
OCT	0	3	2	24	0	2	4	35
NOV	0	0	3	1	0	0	11	15
DEC	0	2	0	0	0	2	9	13
TOTAL	5	63	120	244	71	277	512	1292

Figure 1. Northeastern U.S. waters including the existing Cape Cod Bay and Great South Channel Critical Habitat. Small dots represent all right whale sightings in the NARWC sightings database analyzed.

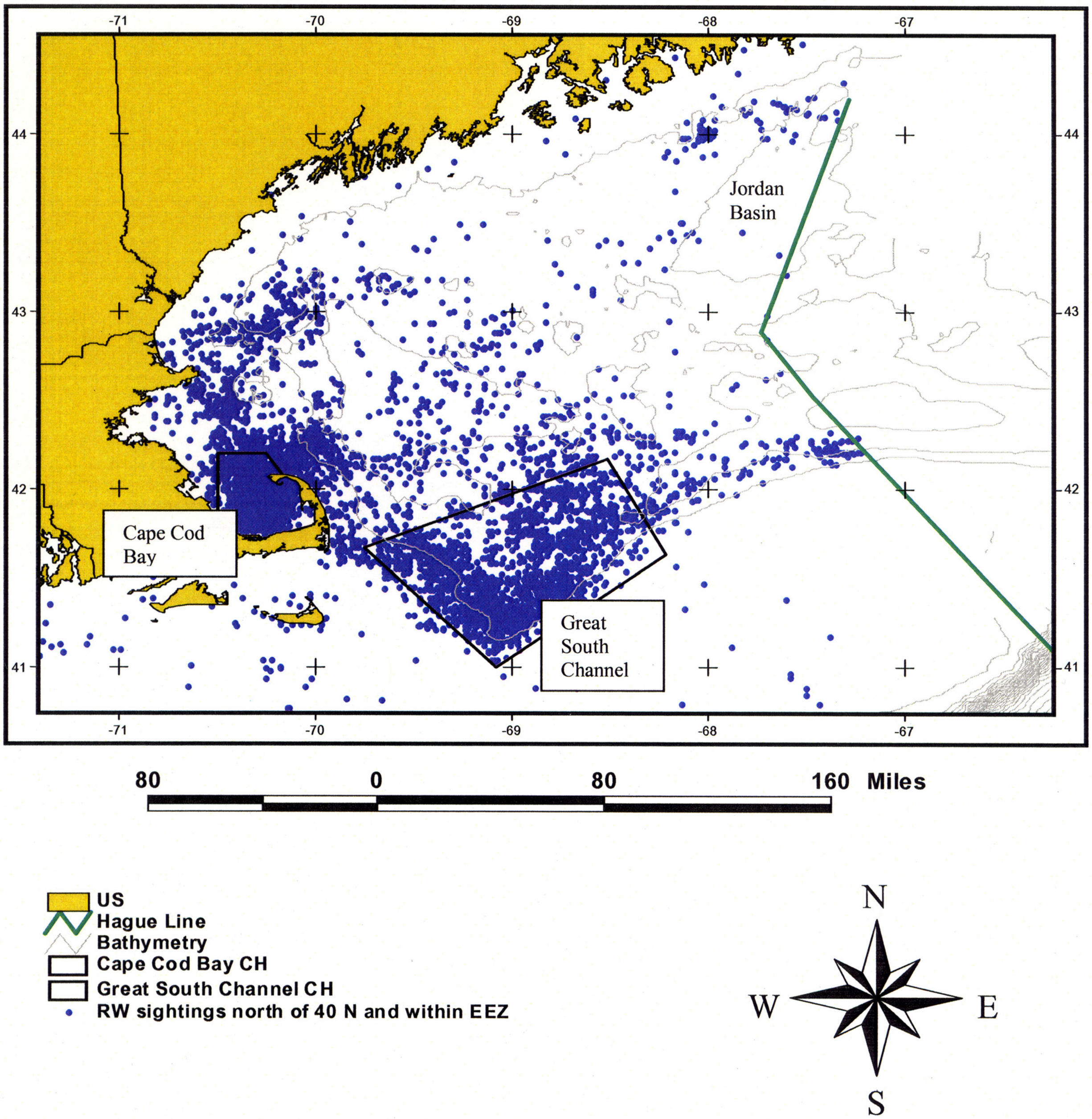


Figure 2. Location of right whale sightings found in the NARWC sighting data base for sightings meeting the DAM criteria during 1970-2005. Qualifying sightings are small dots and "stippling" is the area defined by the joined density specific radii.

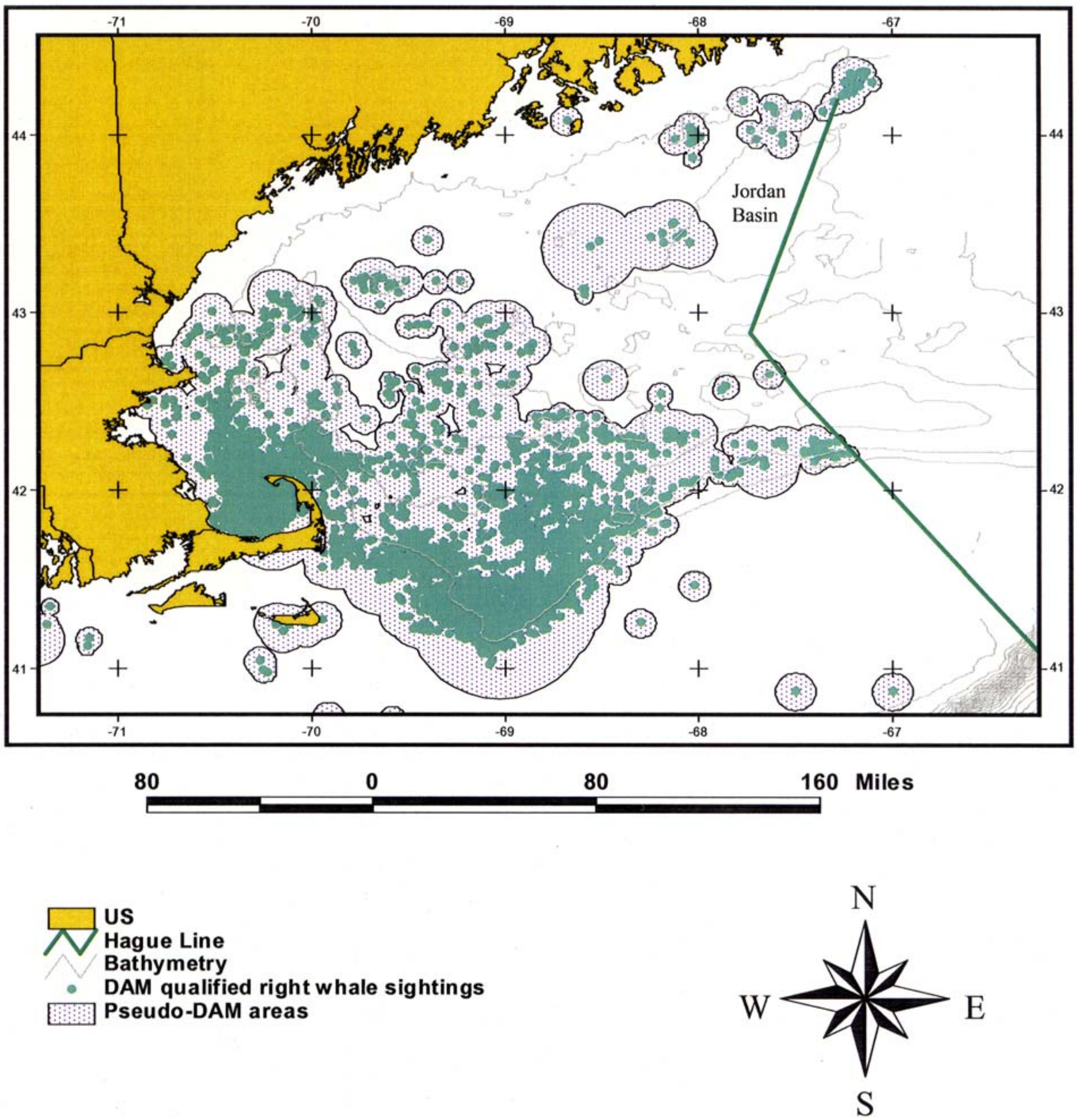


Figure 3. Annual distributions of DAM-qualified right whale locations extracted from the NARWC sightings database for 1975-1990, north of 40° and not more than 30 nm outside the US EEZ. Data were not adjusted for varying spatial and temporal effort or differential platform efficiency.

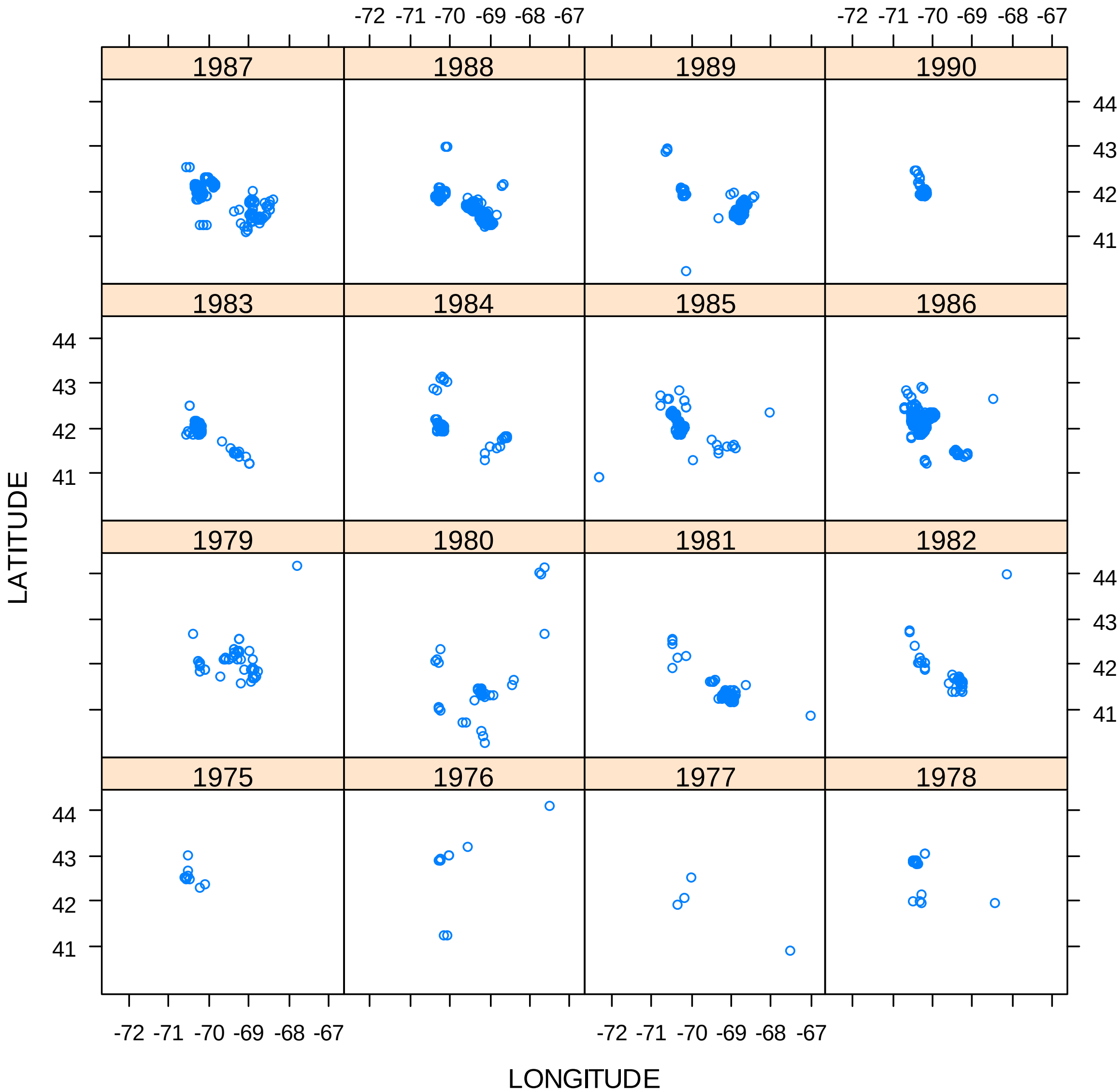


Figure 4. Annual distributions of DAM-qualified right whale locations extracted from the NARWC sightings database for 1991-2005, north of 40° and not more than 30 nm outside the US EEZ. Data were not adjusted for varying spatial and temporal effort or differential platform efficiency.

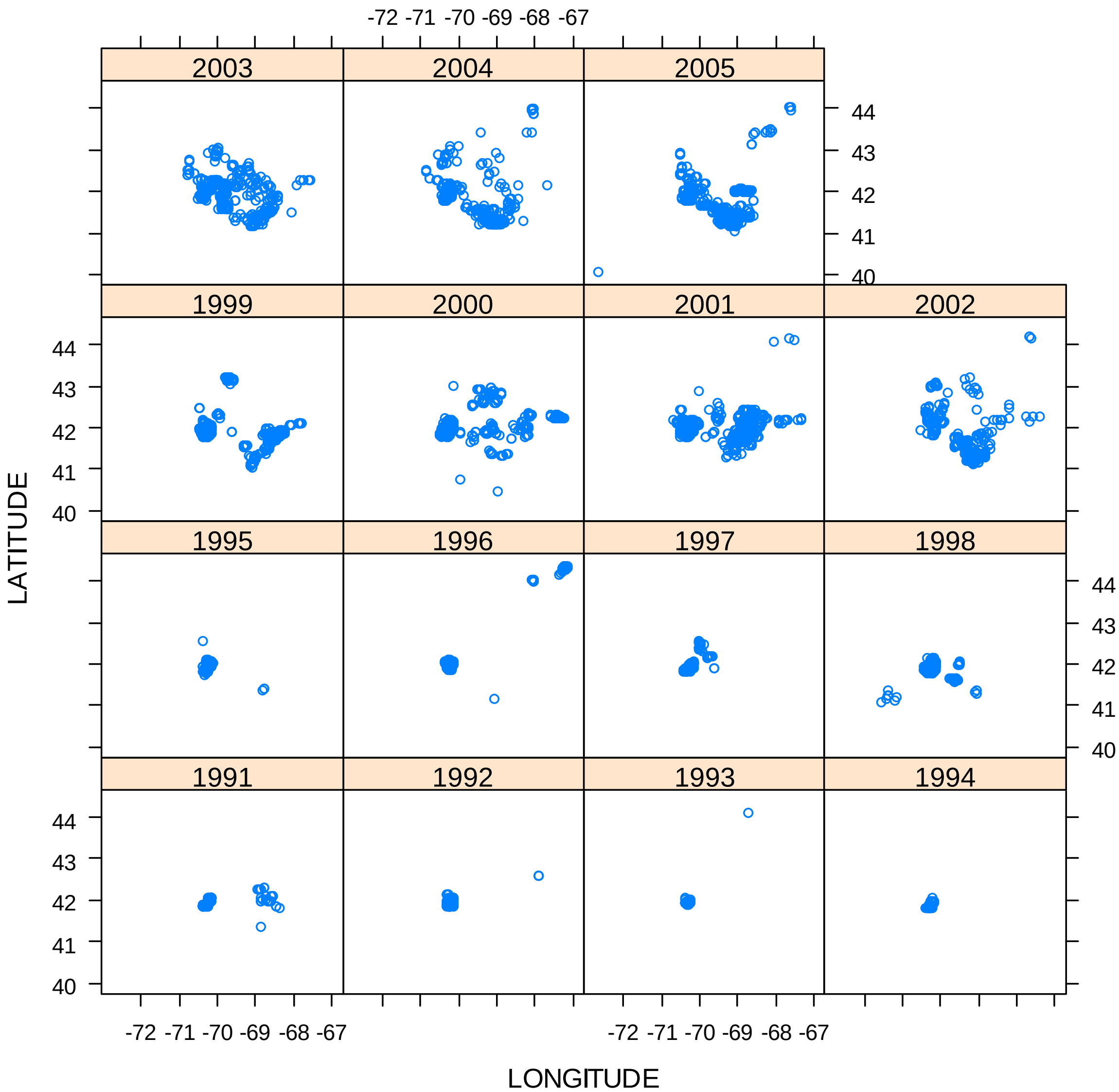


Figure 5. DAM-qualified (and other right whale) sightings with stippled density–specific radii, during 1970-2005 in northeastern U.S. waters showing right whale foraging region in New England.

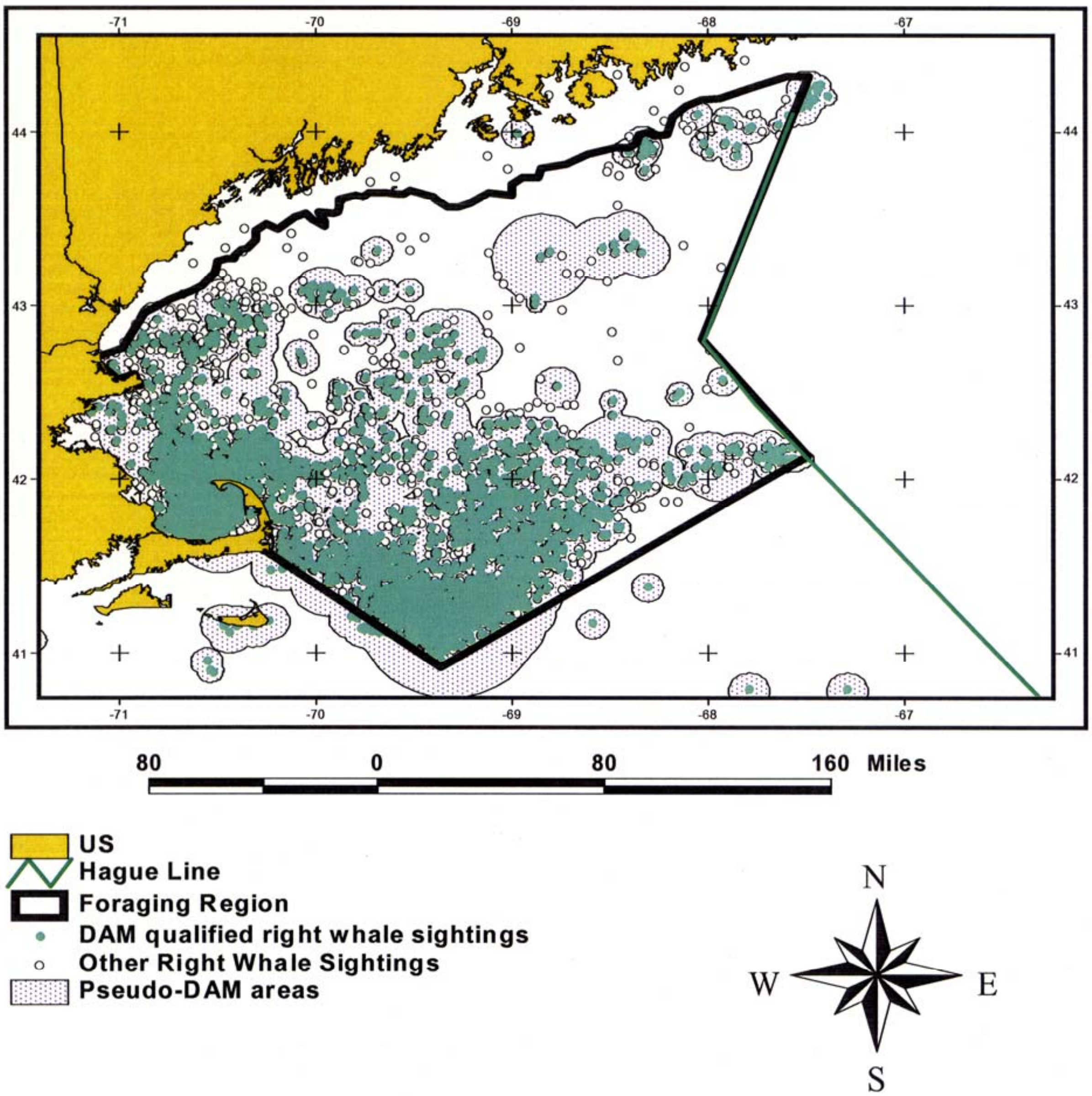


Figure 6. Monthly distributions of DAM-qualified right whale locations extracted from the NARWC sightings database 1970-2005. Also included here are 35 DAM qualified sightings submitted by NEFSC for evaluation by NERO for actual DAMs during 2006-2007. Data were not adjusted for varying spatial and temporal effort or differential platform efficiency.

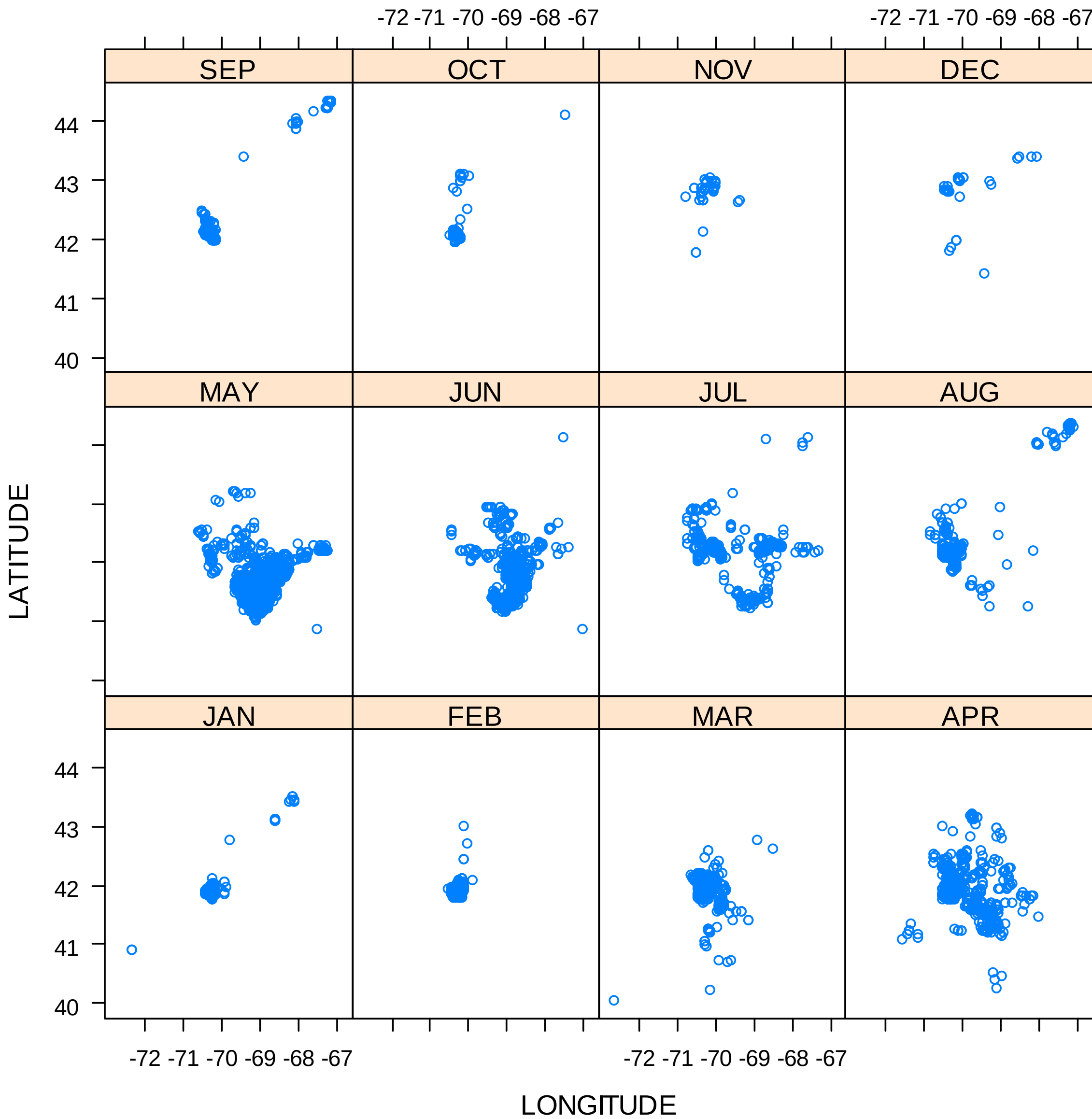


Figure 7. DAM-qualified sightings with stippled density–specific radii, inferred seasonal foraging areas for right whales during 1970-2005, in northeastern U.S. waters: Cape Cod Bay, Great South Channel, Jordan Basin, Wilkinson Basin, Western Gulf of Maine, and Northern Edge of Georges Bank.

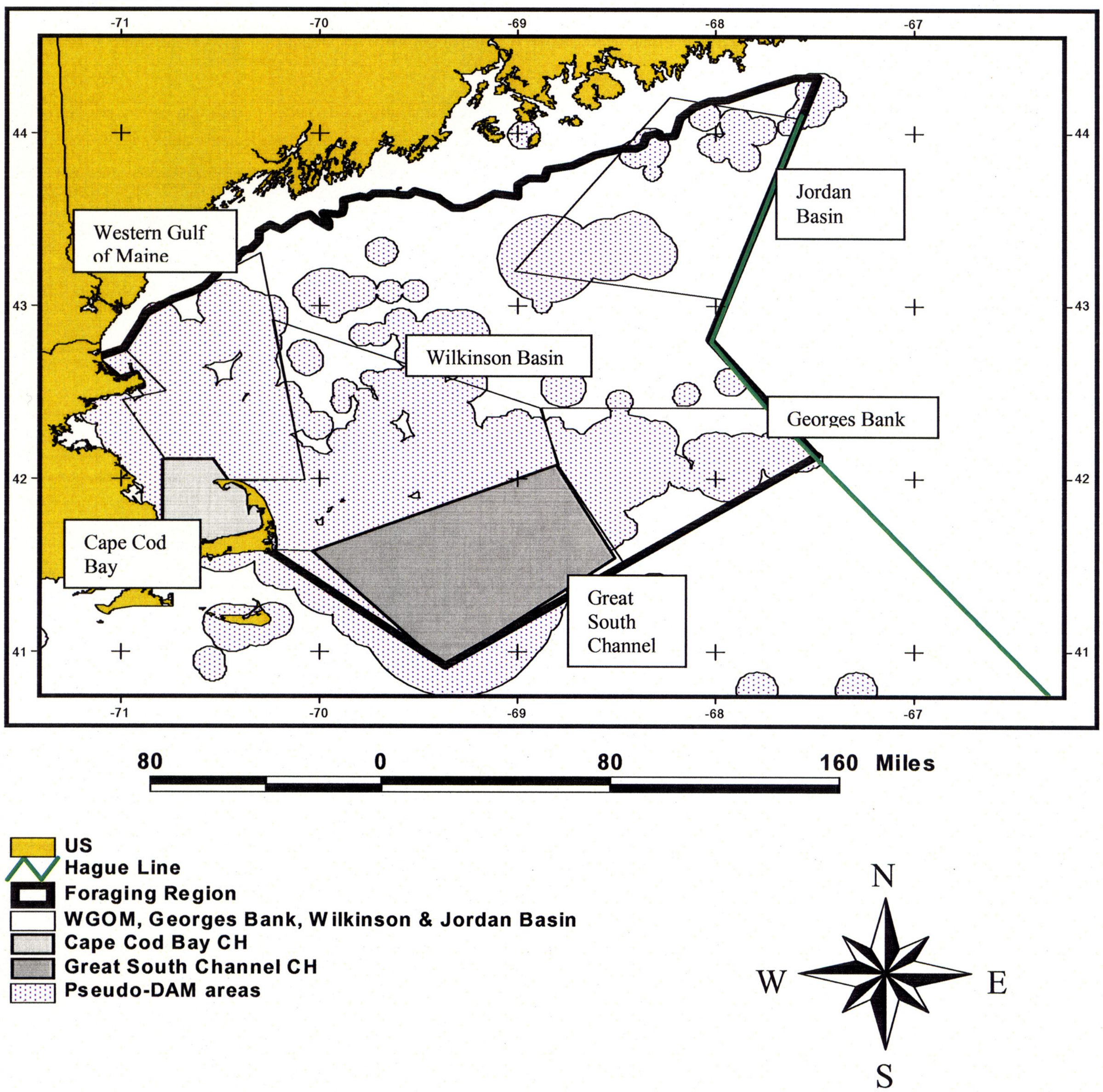


Figure 8. Chart of the Gulf of Maine and Georges Bank, showing typical water circulation patterns after stratification has been established in the spring. (From Miller et al. 1998)

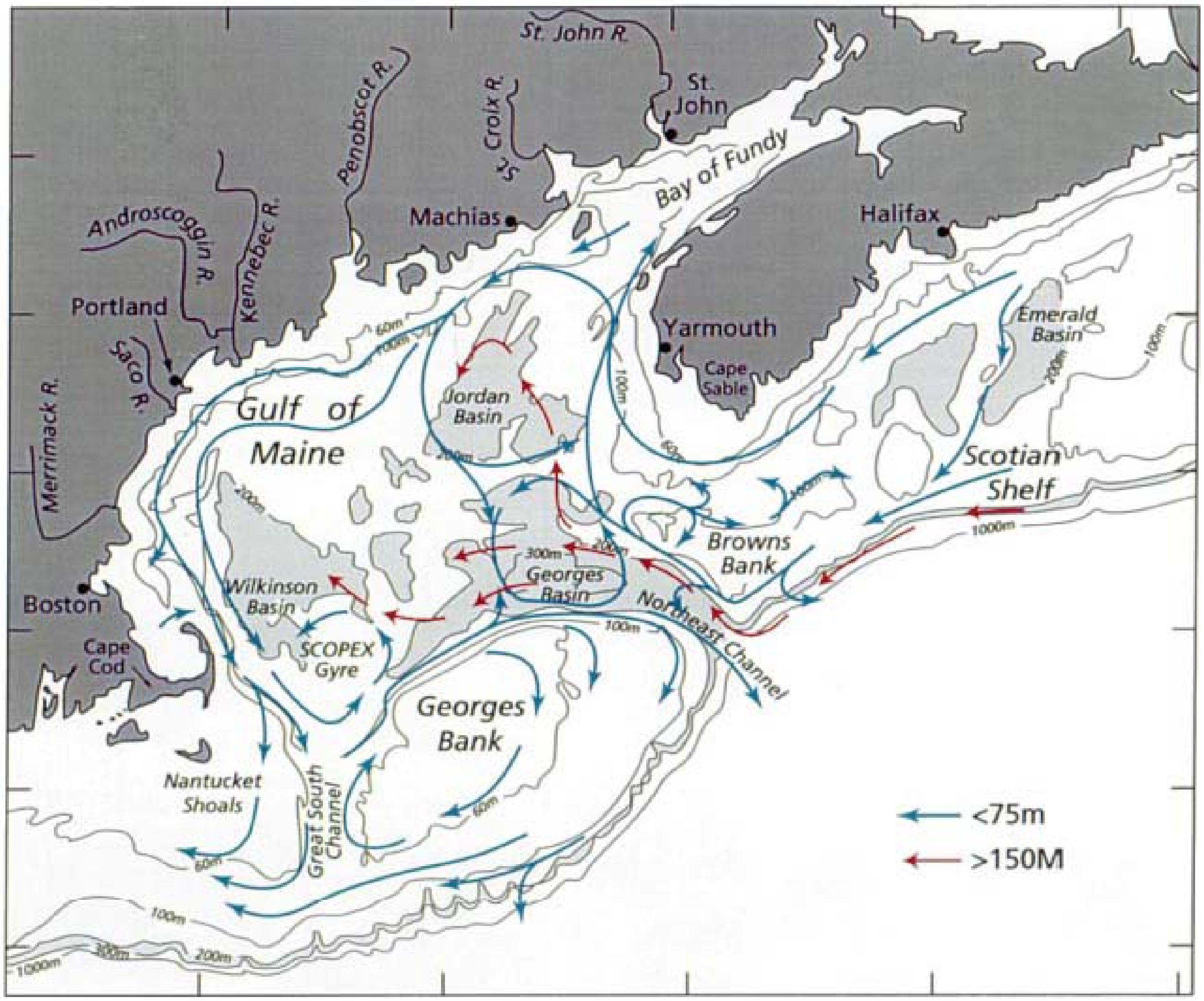
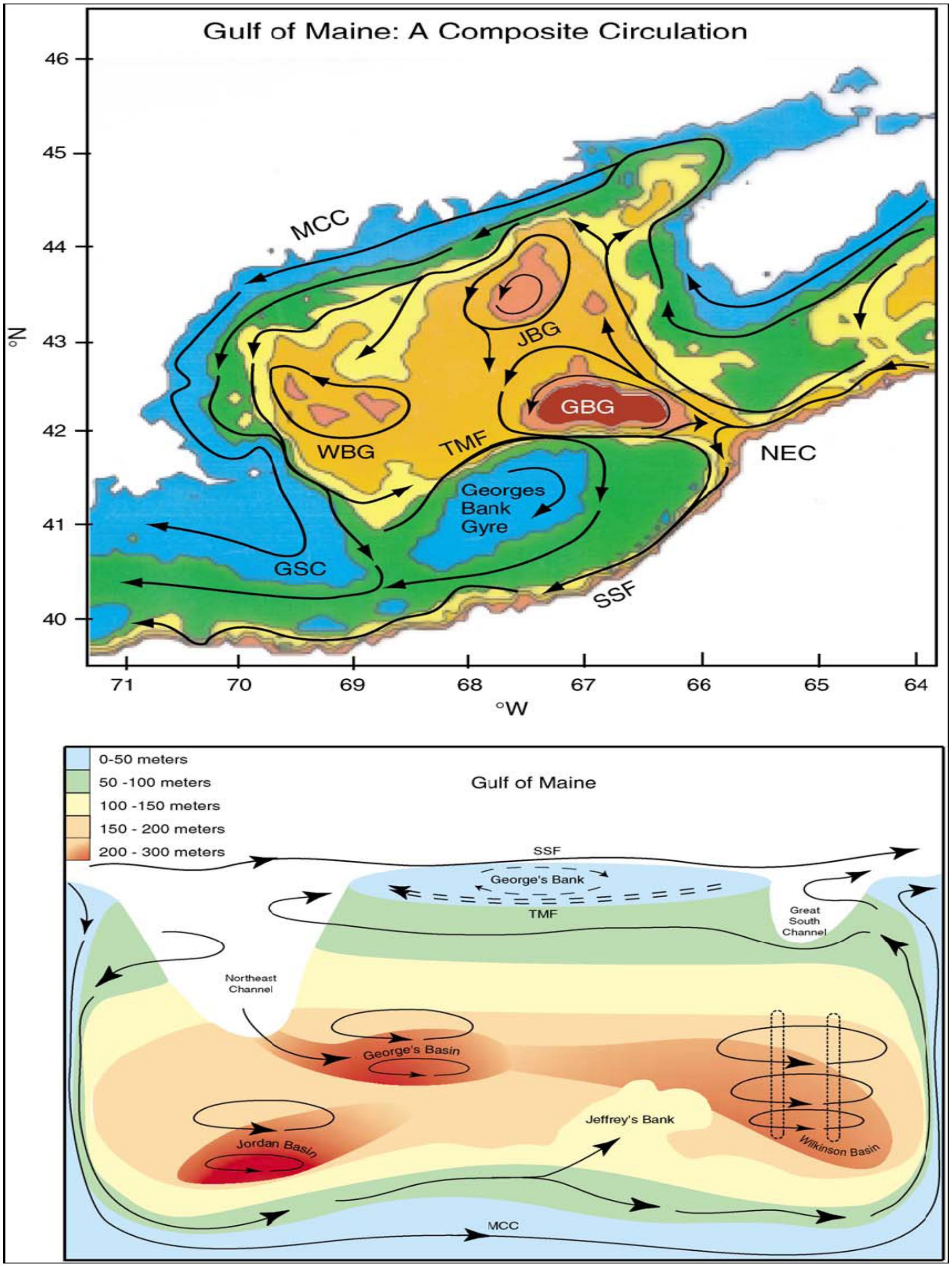
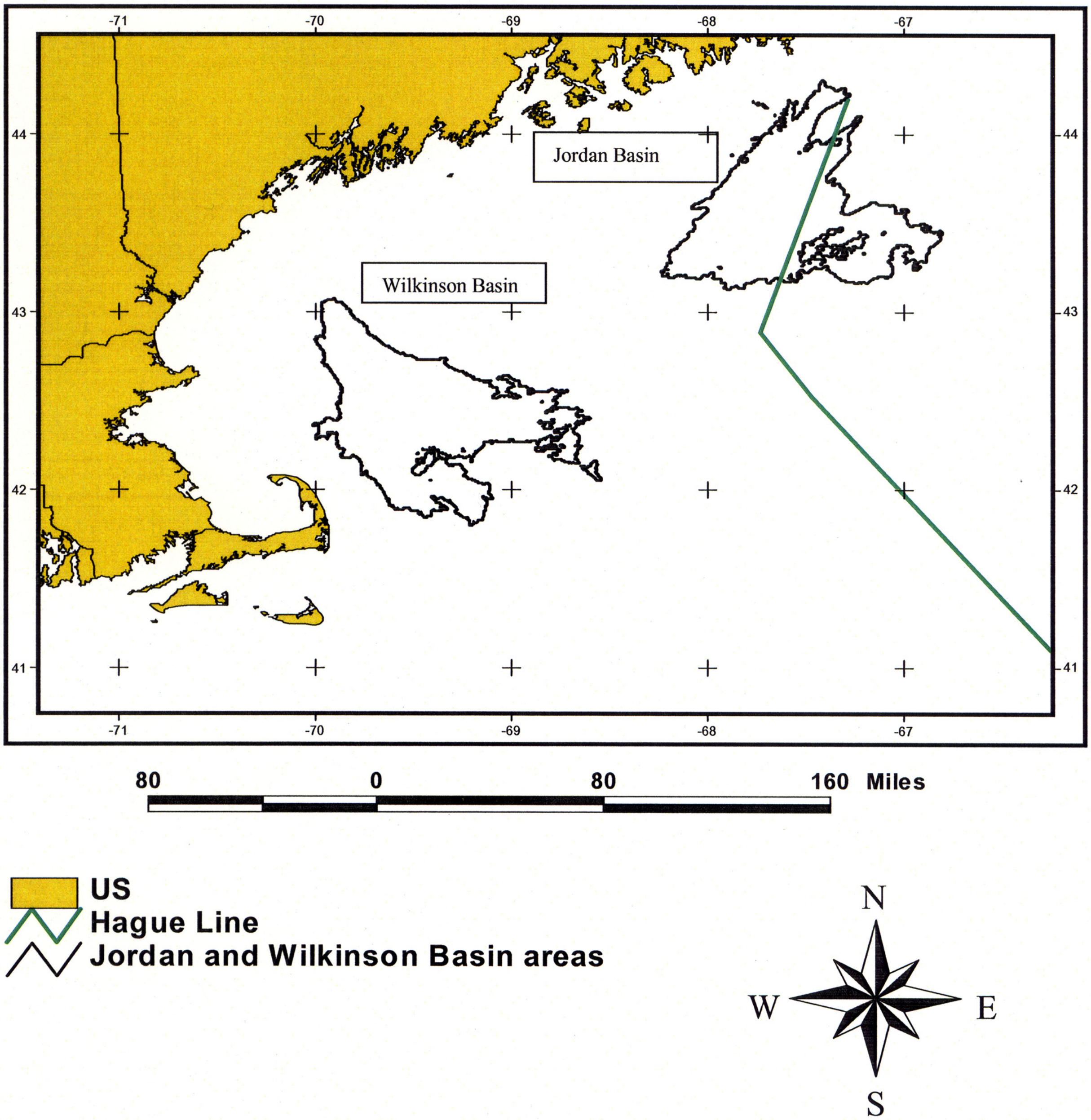


Figure 9. Schematic of Gulf of Maine and Georges Bank circulation system: upper panel major circulation features in plan view; lower panel 3D schematic showing the currents, sub-basin scale gyres, deep inflow and shallow outflow. (From Warn-Varnas et al. 2005)[7]



[7] Reprinted from Warn-Varnas, A., A. Gangopadhyay, J. A. Hawkins, and A. R. Robinson. 2005. Wilkinson Basin area water masses: a revisit with EOFs. Continental Shelf Research 25 [23]: 277-296. Copyright (2004), reprinted with permission from Elsevier.

Figure 10. Chart showing important source areas of Calanus finmarchicus, recognized generally as Jordan and Wilkinson Basins. Basins were identified by the 200m isobaths extracted from *Bathymetry of Gulf of Maine* (available from http://www.mass.gov/mgis/bathymgm.htm).



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