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# Predicting Right Whale Distribution

*Report of the Workshop Held on October 1 and 2, 1998, in Woods Hole, Massachusetts*

by

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# EXECUTIVE SUMMARY

The northern right whale (*Eubalaena glacialis*) is among the rarest of the world's cetaceans with the western North Atlantic population numbering only about 300 animals. Although the large-scale geographic and migration patterns of the North Atlantic right whale stock are broadly known, detailed knowledge is lacking regarding the factors determining fine-scale temporal and spatial distributions. The ability to predict localized distribution patterns of this endangered species would be extremely valuable. Such an ability would be useful in maximizing the efficiency of assessment surveys, in potentially identifying currently unknown right whale habitats, and in crafting and implementing management measures to mitigate human-related conflicts. Accordingly, a multi-disciplinary workshop was held in Woods Hole during 1-2 October 1998 to evaluate the possibility of predicting the distribution of right whales from environmental data.

The workshop reviewed current knowledge concerning population status and range of the northern right whale population, known habitat characteristics, prey preferences, and the likely primary and secondary determinants of right whale distribution. The workshop recognized the importance of scale in predicting the distribution of animals, as effects can occur at scales ranging from a single prey patch to an entire ocean basin. The workshop further noted that the reliability of any predictions will be influenced by the choice of scale. Several remotely detectable environmental features were discussed including sea-surface temperature fronts, internal waves, and ocean color/chlorophyll distribution. Approaches to prediction of right whale distribution included retrospective studies (notably those involving time periods in which major changes in distribution had been noted), GIS-based work, front-related studies, animal-based investigations (notably satellite tracking), and development of models of right whale foraging and energetics. The workshop also discussed statistical considerations including multivariate approaches, individual-based models, additive models, logistic regression, cluster analysis, and analysis of variance with an error structure to accommodate spatial autocorrelation. Multivariate analyses were considered promising in helping to explain some of the observed variance in distribution patterns, and in highlighting areas that required the collection of additional process-oriented data.

A summary of available databases relating to physical, biological and other variables, with an emphasis on the North Atlantic and the Gulf of Maine, was prepared for the workshop and is appended to the workshop report.

## REPORT OF THE WORKSHOP ON PREDICTING RIGHT WHALE DISTRIBUTION

The Workshop was held in the Candle House of the Marine Biological Laboratory in Woods Hole, Massachusetts, on October 1st and 2nd, 1998. It was preceded by a half-day Symposium at Redfield Auditorium (Woods Hole Oceanographic Institution). The Symposium and Workshop were convened and hosted by the Northeast Fisheries Science Center.

Clapham (Workshop Chairman) welcomed the participants to the meeting and thanked them for taking the time to attend. Particular appreciation was extended to individuals who had presented review talks during the Symposium, and to Sara Wetmore for undertaking many of the meeting's logistical arrangements.

### Workshop background and objectives

The northern right whale (*Eubalaena glacialis*) is arguably the rarest of the world's whales (IWC 1998). The western North Atlantic population of this species is believed to number approximately 295 animals (Knowlton *et al.* 1994), and despite more than six decades of protection from whaling there is no clear sign of recovery in this stock (IWC 1998). Human-related mortality (notably from ship strike and fishing gear entanglement) is known to be frequent (Kraus 1990). The management and recovery of this population is a high priority for the U.S. National Marine Fisheries Service (NMFS). A Recovery Plan is in effect for the northern right whale (NMFS 1991), and a revised, updated version is expected to be completed in 1999.

Although some of the factors determining the distribution of right whales are broadly understood, more detailed knowledge of this issue is lacking. The ability to predict the distribution of this species would be extremely valuable; such an ability would serve to maximize the efficiency of assessment surveys, and to potentially identify currently unknown right whale habitats. In addition, a reliable predictive system could greatly facilitate real-time management measures aimed at mitigating conflicts with both fishing and shipping.

The primary objective of the Workshop was to evaluate the possibility of predicting right whale distribution from environmental data, and to do this with sufficient reliability to be of use in improving research and management of this species. The Workshop focused largely on the well-studied western North Atlantic population, although it was recognized that a predictive system developed in this region would likely be applicable to right whale populations elsewhere. Discussion was focused primarily on the feeding range rather than the calving ground or the migratory path.

## PRIMARY DETERMINANTS AND CHARACTERISTICS OF RIGHT WHALE DISTRIBUTION

### Population status and known range

Kraus (Symposium) provided an overview of knowledge concerning the abundance, distribution, migratory movements, reproduction and life history of western North Atlantic right whales. A recent review of this and other populations of right whales was undertaken by the International Whaling Commission's (IWC) workshop on comprehensive assessment of right whales worldwide (IWC 1998; see also Clapham *et al.* 1999). The most recent estimate of abundance for this population is 295 animals (Knowlton *et al.* 1994). Although recent modeling has suggested that the population may be declining (Caswell *et al.* 1999), trends in abundance or recruitment remain unclear (IWC 1998). Mortality from ship strike and entanglement is known to be high (Kraus 1990), and there is evidence that reproductive rates are significantly lower than those observed in populations of the southern right whale (*E. australis*). The eastern North Atlantic population appears to be virtually extinct. In the North Pacific, the western population may number in the low hundreds, while the eastern stock is clearly very small, and may have suffered irreparable damage from illegal Soviet whaling in the 1960's (Brownell *et al.* 1999).

In the western North Atlantic, the remaining population occurs primarily in a range from the southeastern United States (where females calve in winter) to Maritime Canada (Winn *et al.* 1986). Known areas of seasonal concentration include inshore waters off Georgia/Florida (peak occurrence from December to March), Cape Cod and Massachusetts Bays (January to April), the Great South Channel (April to June), the Bay of Fundy (summer and fall), and various banks and basins on the Scotian Shelf (summer and fall).

Occasional observations are reported from areas further north, including the Gulf of St Lawrence, Newfoundland, Iceland and the British Isles; the identity of these "outlying" animals is generally unknown, and it is currently believed that the number of right whales inhabiting such areas is small. Historically, the range of the northern right whale extended much further north and east than it appears to today. Overexploitation by the whaling industry decimated or extirpated right whales in many areas, including Greenland (the Cape Farewell Ground), the west coast of Africa (Cintra Bay, which may have been a major calving ground for the eastern North Atlantic population), Labrador (the site of an active Basque fishery in the 16th century) and Europe (where commercial exploitation of right whales began as early as the 11th century).

A concentration of supposed right whale catches plotted by Matthew Fontaine Maury in mid-ocean some 300 miles west of the Azores remains a mystery, since Maury's notes have been lost and the basis for these plots is therefore unknown (Reeves & Mitchell 1986). It is possible that these represented mislabelled sperm whale catches. However, it is important to realize that the common characterization of right whale distribution as "coastal/shelf waters" is heavily biased by the locations of most historical catches and recent sighting effort. Furthermore, given that there is considerable evidence for offshore (pelagic) occurrence of right whales in the North Pacific

(Brownell *et al.* 1999), such a distribution in the North Atlantic may be more common than is presently supposed. In addition to the historical data, recent satellite tagging has recorded forays into deep water (Mate *et al.* 1997); accordingly, it is possible that significant habitats for this species exist far from land.

Although the broad migratory characteristics of this population are known, major gaps in knowledge exist. The whereabouts of significant portions of the population are unknown for virtually all months of the year. Furthermore, recent genetic and sightings data indicate that, while many mature females consistently take their calves to the Bay of Fundy during the summer, a significant number do not. Whether these latter females congregate in a second (undiscovered) nursery area, or instead exhibit a scattered distribution, is unclear.

As in many species, patterns of distribution and movement probably differ among individuals, contingent upon sex, age or reproductive condition. A well-known example of this concerns mature females, who are observed significantly less frequently in years when they are either pregnant or have recently weaned a calf than in years when they have a calf with them.

**Characteristics of specific habitats**

At the most basic level, right whale feeding habitats are characterized by a set of features which serve to create variability in structure, leading to aggregation or concentration of acceptable zooplanktonic prey. Factors which influence this "collecting mechanism" can include bathymetry, vertical density structure of the water column, current patterns and a behavioral tendency of prey to aggregate. Since right whales ultimately go where their food is, areas which possess persistent prey-concentrating mechanisms will likely be persistent right whale habitats.

*Great South Channel*

The Great South Channel is a major feeding habitat for right whales in spring and early summer. Here, patterns of sea surface temperature (SST) together with the bathymetry (notably the shape of the basin) work in concert with currents to seasonally concentrate prey. Tidal mixing occurs within areas of reduced bottom depth, leading to the formation of a temperature front which separates the warmer, less saline waters to the north containing late-stage *Calanus* from the colder, tidally mixed waters south of the front. Right whales are found in the deeper basin north of both the 100-m isobath and the thermal front which parallels this bathymetric feature (Brown & Winn 1989, Chen *et al.* 995, Kenney *et al.* 1995). Within a particular season, right whales tend to be concentrated in a single area; although some movement of this aggregation is evident in some years, shifts to the other side of the Great South Channel have not been recorded.

A comprehensive study, the South Channel Ocean Productivity Experiment (SCOPEX), was conducted in the region in 1988/89 and represents the most detailed attempt to date to link right whale distribution with environmental factors (Kenney & Wishner 1995). Kenney (Symposium) summarized SCOPEX; details can be found in the volume devoted to this project (Kenney & Wishner 1995). The study found right whales associated with dense patches of the copepod *Calanus finmarchicus* (primarily stages IV and V), known to be a major prey item. The oceanographic studies suggested that the occurrence of these patches in the area was due to advection and concentration (by currents and oceanographic processes) in combination with a behavioral tendency of *Calanus* to aggregate; the work did not support the idea that right whales occurred there because of high *in situ* primary or secondary productivity.

Right whales were virtually absent from the Great South Channel in 1992, and this shift was paralleled by a lower abundance of copepods. A paucity of sightings in 1998 may have reflected earlier than usual departure from the region, as occurred in 1985; however, to date there has been no attempt to correlate these patterns with changes in local prey abundance. It has been hypothesized, based on data from 1979-1992, that the distribution of right whales in the Great South Channel can be predicted from water temperature data in Wilkinson Basin ($\approx$42° N, 69° W) in early May (R. Kenney, unpublished data). Specifically, during years when the temperature is above 8° C, right whales should be found on the western side of the Great South Channel. If the temperature is below 8° C, the whales will concentrate on the eastern side of the Channel, or will not occur in the region at all if the water is significantly colder than this. The basis for this hypothesis concerns the ectothermic nature of copepods and the time it takes for them to moult into the older life stages acceptable to right whales; in cold years, this process takes longer, and by the time these older life stages have been attained, currents have swept the copepods further east. However, as noted by C. Davis (*in litt.*), extensive dispersion of the spring *Calanus* population in time and space may cause abundance in the Great South Channel not to be as tightly linked to temperature and transport as this hypothesis would predict.

*Cape Cod Bay*

Right whales occur in Cape Cod Bay, and in adjacent areas, in winter and early spring. While the timing of their occurrence exhibits some interannual variability, in most years peak concentrations occur in February, March and early April (Hamilton & Mayo 1990). Cape Cod Bay is a shallow system with nearshore upwelling on the western side; there is substantial input of water from the Gulf of Maine, and residence time for water masses may be on the order of a month in the deeper regions of the bay. Other physical characteristics of the area may include Langmuir cells; these are wind-driven multiple counter-rotating cells with alternating streaks of divergence/convergence or upwelling/downwelling parallel to the wind. However, the local oceanography has not been studied in sufficient detail to validate this comparison. Internal waves also occur in the region (notably north of the Bay on Stellwagen Bank), and may propagate features that lead to the concentration of zooplankton, but this hypothesis remains untested.

Right whales generally appear to enter Cape Cod Bay on the western side and move to the bay's eastern margin, and finally out of the area, over the course of weeks (Hamilton & Mayo 1990). A similar pattern of movement is observed among southern right whales at Peninsula Valdes, Argentina; Valdes is at approximately the same latitude as Cape Cod Bay, but the significance of this similarity (if any) is unknown. Surface skim feeding by right whales appears to occur with significantly more frequency in Cape Cod Bay than elsewhere in the known range of this population (Mayo & Marx 1990). If Langmuir cells are indeed features of the Bay, this would tend to concentrate zooplankton at the surface at one end of the cell, with downwelling and deeper concentrations of prey occurring at the cell's other margin. Skim feeding occurs only during relatively calm conditions, presumably because copepod aggregations are broken up by strong winds.

Another proposed hypothesis for dense patch formation in eastern Cape Cod Bay (Davis *et al.* in prep.) states as follows: tidally induced surface convergence acts together with surface-keeping behavior by the dominant copepods *Calanus* and *Pseudocalanus* to cause the copepods to accumulate in convergent tidal fronts. The steep topography in eastern Cape Cod Bay is similar to that found in the Great South Channel region. In both locations, the 60 m isobath turns abruptly northward as it approaches Cape Cod from the west, and along-isobath flows may be caused to subduct or converge as they are forced to turn northward by the bathymetry. In these locations, copepods may aggregate at the convergence zones.

Although right whales are less commonly observed in Cape Cod Bay during the summer months, and residency time of individuals appears to be very short, an exception occurred in 1986 when a concentration of right whales became semi-resident in the Bay for several weeks (Hamilton & Mayo 1990). This phenomenon appears to have been associated with a reduction in the local abundance of sand lance (*Ammodytes* sp.) and a concomitant increase in the availability of copepods (Payne *et al.* 1990).

*Bay of Fundy and Scotian Shelf*

The peak occurrence of right whales in the Bay of Fundy, as well as on banks and in basins of the Scotian Shelf, is during summer and fall (Kraus *et al.* 1986, Mitchell *et al.* 1986). Their distribution there appears to be correlated with transition zones from mixed to stratified waters (Gaskin 1987, Woodley & Gaskin 1996). The sea floor in these areas occurs at depths greater than 100 m; it is relatively flat but is adjacent to steep slopes on one or both sides. As in the Great South Channel, this is believed to facilitate the formation of a tidal mixing front on the shallow side of the slope. Right whales appear to arrive in the Bay of Fundy after stratification has occurred, and this event is generally associated with water temperatures rising to 8°C. It is not clear whether copepods are advected into the region by current regimes, or whether the area possesses high *in situ* productivity. Observations of right whales in the Bay of Fundy with mud on their heads suggest that they feed at depth there; surface skim feeding is uncommon, but has occasionally been recorded in some years (most recently 1998).

Major summer concentrations of right whales were found in the Browns Bank/Roseway Basin region until 1993, when the habitat appears to have been largely abandoned for reasons that are not clear. This phenomenon has persisted through 1998; although right whales have occasionally been observed in the area in summer, the large concentrations recorded prior to 1993 have not. The distribution of right whales on other portions of the Scotian Shelf, to the east, is less well known. Sighting data from the whaling station at Blandford, Nova Scotia (which closed in 1972) indicate that right whales occurred in Lahave Basin, Emerald Basin, Emerald Bank and near the 100-fathom isobath to the south of the latter (Kenney 1994). Sighting surveys conducted by East Coast Ecosystems and the Northeast Fisheries Science Center in the summer of 1998 confirmed this distribution. There has been no attempt to characterize the oceanography or other relevant features of this region with regard to right whale occurrence.

*Georges Bank*

Right whales are known to occur in various locations in the Georges Bank region, notably the Northeast Peak, Northeast Channel and Georges Basin. All three areas are characterized by sloping bathymetry, but how prey concentrates there is unclear. A seasonally high abundance of *Calanus* occurs on the Northeast Peak and on the southern flank of Georges Bank; few right whales have been recorded in the latter area despite relatively high observer effort.

*Bering Sea*

Tynan (Symposium) summarized recent studies of North Pacific right whales in the Bering Sea, and their association with the southeastern Bering Sea shelf. The eastern shelf of the Bering Sea is more than 500 km wide and is divided into distinct hydrographic domains by three fronts: an Inner Front at the 50 m isobath separates the Coastal Domain from the Middle Shelf Domain; a Middle Front at approximately the 100 m isobath separates the Middle and Outer Shelf Domains; and a salinity front at the shelf-break separates the Outer Shelf and slope domains (Coachman 1986). Results of a 1997 survey, and a retrospective analysis of sighting data, show that a remnant population of North Pacific right whales predictably occupies the middle shelf and near-Inner Front regions of the southeast Bering Sea shelf during summer (Tynan 1998, 1999). The present distribution of some species of mysticetes differs from that of the historical whaling era and suggests that preferred foraging grounds have shifted from the shelf edge and slope regions (Nasu 1974, Omura *et al.* 1969) to the shallower Middle Shelf Domain (50-100 m) (Tynan 1998). However, surveys encompassing a greater portion of historical habitat are required to confirm this belief.

Both the hydrographic structure and the ecosystem of the southeastern Bering Sea are highly variable on interannual and decadal time scales. During the summer of 1997, anomalous oceanographic conditions in the southeastern Bering Sea included sea surface temperatures 2-4° C warmer than in 1996 and the development of an extensive coccolithophore bloom (Vance *et al.* 1998). On longer time scales, the combination of climate regime shifts such as that of the late 1970s, in concert with intensive human exploitation of predators (forage fish and whales) has produced an ecosystem dominated by walleye pollock (National Research Council 1996). As a consequence, the community structure and function of the Bering Sea is now significantly different from that of the pre-whaling era. It is important to continue to monitor the effects of such large ecosystem changes on the distribution and foraging ecology of this most endangered stock of right whales. The population is very small as a result of extensive exploitation (including illegal Soviet catches in the 1960's; Brownell *et al.* 1999).

*Georgia/Florida*

The inshore waters of Georgia and Florida represent the only known calving area for western North Atlantic right whales (Kraus *et al.* 1986, Winn *et al.* 1986). Right whales are found there in winter, and the local population is heavily dominated by parturient females (including many who do not take their calves to the Bay of Fundy later in the year). Some non-calving females and immature animals of both sexes have also been observed, but mature males appear to be virtually absent from this habitat. Feeding has not been recorded. Most whales are found in shallow water, in association with relatively flat bottom topography, and in a cold-water wedge where the surface temperature is between 10° and 14° C. It is not clear what factors determine the preference for this area as a calving ground, but calm water (the lowest sea state anywhere in the western North Atlantic in winter) is likely a major effector. Whatever the relevant characteristics, it seems clear that the factors determining the distribution of whales in this area are fundamentally different from those operating on the feeding grounds to the north. Thus, any predictive system developed for this habitat would have to be based upon different assumptions and data.

*Other historically important areas*

Right whales are known to have occurred in significant numbers off Long Island and off the Carolinas; evidence for their historical occurrence in Delaware Bay is sparse. In April 1998, a concentration of surface-skim-feeding right whales was recorded in Block Island Sound, an area which may have within the range of operation for Long Island whalers at the turn of the century. Little is known about the characteristics of these areas, or about those of historical habitats further afield such as Newfoundland, Labrador, the Gulf of St Lawrence, eastern Greenland, Iceland, the Bay of Biscay and the British Isles.

*Summary*

The common characteristic of the various known right whale feeding habitats is a series of processes (hydrographic and behavioral) which together lead to acceptable concentrations of prey. The factors involved in these processes vary by area, and the linkage between local characteristics and whale distribution is often unclear. An essential consideration is that of scale, since the processes involved in concentration of food will differ depending on the scale involved (e.g. within a zooplankton patch *versus* along the length of a front).

## SECONDARY DETERMINANTS OF RIGHT WHALE DISTRIBUTION

Although it is generally assumed that the distribution of right whales in higher latitudes is largely determined by the distribution of prey, secondary factors cannot be excluded.

Social factors which may influence the distribution of mature female right whales include sheltered water for calves, protection from harassment by mature males, and freedom from predation (although predation on right whales has never been directly observed). The presence of an acoustic environment which facilitates communication may be a significant consideration, and it is possible that historic habitats which no longer appear to host right whales have been abandoned because of ship noise. Mature males clearly seek out females at virtually all times of year, but presumably the distribution of the females is largely governed by the abundance of prey.

Little is known for certain, however, and the scale on which such factors may operate is not clear. For example, social behavior may affect fine-scale distribution of lactating females within a particular area rather than dictating the choice of the area itself (over others).

Plasticity in the social component of distribution is evident in the major shift which occurred in 1993 away from Browns Bank and Roseway Basin. Prior to this shift, this area had been dominated by mature males. In contrast, mature males were found significantly less frequently in the Bay of Fundy. This pattern of segregation was stable for twelve years, but broke down in 1993. Following the abandonment of Browns/Roseway, mature males appeared in the Bay of Fundy and the local population has been largely mixed in subsequent years.

With the possible exception of social aggregating areas that may be predictable at gross scales for periods of several years (e.g. Browns/Roseway prior to 1993), it is unlikely that secondary determinants can be used to predict right whale distribution since they are not based upon detectable environmental features.

## PREY

### Known prey species

Western North Atlantic right whales are known to feed on a variety of zooplanktonic prey. Recorded species include *Calanus finmarchicus, Centropages, Pseudocalanus* spp., *Temora, Nanocalanus*, juvenile euphausiids, ciprids and nauplii.

It has been assumed by many observers that the primary (i.e. preferred) prey is *C. finmarchicus*, notably the older life stages. Certainly, *Calanus* is larger than most other prey items, and stages IV and V have a high lipid content which may be energetically important to right whales. However, the Workshop cautioned that evidence for this assertion is inconclusive, and the diet of right whales may be significantly more varied than is currently assumed. For example, *Centropages* has been frequently documented as right whale prey in Cape Cod Bay, and appeared to be the focus of surface skim-feeding bouts observed in the Bay of Fundy in the late summer of 1998 (Mayo, Symposium). Similarly, very dense aggregations of *Pseudocalanus* (adult females carrying egg sacs) have been observed in association with skim-feeding right whales (Davis *et al.* in prep.) A review of the energetic/nutritional value of the different prey species has yet to be undertaken, and such a review might significantly illuminate the nature and likely basis of right whale prey choice.

It is curious that northern right whales have rarely been documented as feeding on euphausiids, given that krill is a common prey for *E. australis*. If euphausiids are eaten in significant numbers by western North Atlantic northern right whales, the most likely species are either *Meganyctiphanes norvegica* or *Thysanoëssa inermis*, which are common in both the Bay of Fundy and on the Scotian Shelf in summer. Inclusion of these species in a review of the energetic and nutritional value of prey would be important.

**Prey densities**

Reliable estimation of the densities of prey upon which right whales feed is complicated by the difficulty of obtaining samples representative of those encountered by the whales themselves. Work by Mayo and colleagues (Mayo & Marx 1990, Symposium, unpublished data) has shown that the intra-patch variability in density is considerably greater than was previously assumed, both horizontally and vertically. Micro-patches of extraordinarily high density (on the order of millions of organisms per $m^3$) have been documented next to feeding right whales. In contrast, other patches (or portions of patches) are of relatively low density. The best estimate for the minimum threshold value that triggers feeding is currently 4000 organisms/$m^3$, but this may vary with the species being consumed.

***Calanus finmarchicus***

As noted above, right whale diet and prey preferences may be more complex than many observers have assumed. With this caveat in mind, the Workshop reviewed knowledge concerning the biology and distribution of *Calanus finmarchicus*, which is clearly a major prey item of right whales, and the one which has to date received the most study in this regard.

Durbin (Symposium) summarized what is known of the distribution and life history of *Calanus finmarchicus* in the Gulf of Maine and Georges Bank region. The species spends late summer and fall primarily as copepodite stage V in the deeper, cooler waters of the Gulf of Maine, coming up in January and reproducing in winter/spring. The young develop between February and June, during which time *Calanus* from the Gulf of Maine are swept south by currents onto Georges Bank and through the Great South Channel. There is time for two generations in the Gulf of Maine/Georges Bank region. The origin of the *Calanus* found on the Scotian Shelf is unclear; these may come from either slope water and the large North Atlantic population, or from the Cabot Strait. In the Bay of Fundy, there appears to be a resident population, but others may also be transported into the Bay from elsewhere.

As noted, the seasonal abundance and concentration of *Calanus* in the Great South Channel appears to be a function of advection into the area in combination with a behavioral tendency of the species to aggregate (Kenney & Wishner 1995). Whether similar processes underlie the occurrence of the species in other right whale habitats is unclear, since no other area has been subject to a similar level of research effort as the Great South Channel. A pilot study in Cape Cod Bay, using the Video Plankton Recorder to follow skim-feeding right whales, found dense aggregations of *Calanus* and *Pseudocalanus* in a surface front along steep topography (Davis *et al.* in prep.)

There is much recirculation which affects the distribution of *Calanus* in ways that are not well understood. This circulation is variable; in the Gulf of Maine, for example, the regime consists of a series of linked gyres which at times combine into a single gyre. Furthermore, different circulation patterns exist at the surface and at depth. Although both temperature and currents will influence the distribution and abundance of *Calanus*, other factors may also be significant, notably predation and food limitation.

It is not clear whether there is a predictable relationship between the abundance of *Calanus* and chlorophyll. The 45-70 day maturation time of *Calanus* means that no relationship may be found, notably involving the later life stages, which are less dependent upon primary productivity than earlier stages.

## KEY VARIABLES AND RELATED FACTORS

### The importance of scale

Several Workshop participants emphasized the importance of establishing scale in any effort to predict right whale distribution from environmental data, since impacts that are significant at one scale may be negligible at others. A schematic representation of relevant spatial and temporal scales is shown in Figure 1.

From the point of view of a right whale, processes and decision-making will presumably be very different at different scales. At one extreme are factors impacting the density gradient of prey within a particular portion of a patch, necessitating movement and foraging decisions on the scale of meters. Absence of suitable prey (or a suitable density of prey) in a small area within a habitat presumably leads to searching behavior elsewhere in the habitat, cued by some unknown combination of physical features and direct prey detection. A habitat whose overall suitability falls below a key threshold due to meso-scale physical or biological processes may be abandoned as whales move over scales of tens of miles to search other habitats. Larger-scale processes (e.g. changes in major water transport patterns) may or may not result in similarly major shifts in the movements and distribution of right whales.

An illustration of a scale question concerns a recent apparently substantial change in the water properties of the Georges Bank region, and documented by the Georges Bank GLOBEC project (P. Wiebe, pers. comm.) Within the last year (1997/8) there has been a reversion to colder temperatures last recorded in the 1960's; the duration of this phenomenon is presently unknown. The effect of this change on *Calanus* (and indirectly on right whales) is unknown. At the largest scale - that of the North Atlantic Ocean - there is now evidence for a correlation between the state of the North Atlantic Oscillation (NAO) and the relative abundance of major copepod species (Lambert 1998; see also Planque & Fromentin 1996, Planque & Reid 1997). Specifically, negative NAO winters are correlated with increased abundance of *Calanus*, while positive NAO winters correlate with a decline in *Calanus* and an increase in the abundance of *Centropages*.

The NAO can shift the position of the Labrador Current, influencing water properties and transport in the Gulf of Maine which in turn affects the formation and location of tidal mixing fronts and other oceanographic features. Whether such large-scale climatic changes can be correlated with the distribution and reproduction of right whales is unknown; Kenney (unpublished data) notes an apparent correlation between right whale calf output and the Southern Oscillation Index from the previous year, as well as with the NAO two years before. However, scale is again a key issue here. As noted above (and conceptualized in Hierarchy Theory), changes at one scale may have little impact on organisms operating at another scale. For example, large-scale (basin-wide) changes such as those precipitated by the NAO may have major impact on overall species dominance yet not diminish the abundance of suitable prey (at the scale of the front or the patch) to the point where it negatively affects right whales.

Central to any effort to predict right whale distribution is the question of the desired scale and reliability of the prediction. If the goal is to predict the location of concentrations of right whales within the broad region from Cape Cod to the Scotian Shelf, then the scale of features being employed as predictors will be very different from those utilized to predict the location of individual whales within one particular habitat (e.g. Cape Cod Bay).

The desired reliability of specific environmental features in predicting whale distribution will also affect the knowledge required in the exercise. For example, while concentrations of right whales are known to sometimes be associated with fronts (e.g. in the Great South Channel), not all fronts have right whales, and not all right whales are associated with fronts. Accordingly, considerable knowledge of underlying processes will be required if one seeks to identify only those fronts which produce right whale concentrations. In contrast, less knowledge will likely be needed if fronts are to be used as a hit or miss predictor (but one which nonetheless represents an improvement over current search methods, which do not incorporate environmental data).

## Review of past and ongoing work

Past work attempting to link the distribution of northern right whales to that of environmental features has occurred largely in the western North Atlantic. Studies include:

(i) intensive work in the Great South Channel under SCOPEX and earlier investigations (Brown & Winn 1989; Kenney & Wishner 1995 and various papers therein);

(ii) use of Geographic Information Systems to predict right whale habitat (Moses & Finn 1997, Comeleo *et al.* 1998);

(iii) relationship between right whale distribution/movements and zooplankton characteristics in Cape Cod Bay (Mayo & Marx 1989, Mayo unpublished data);

(iv) characteristics of right whale habitat in the Bay of Fundy (Woodley & Gaskin 1996);

(v) relationship between right whale movements and prey characteristics in the Bay of Fundy (Murison & Gaskin 1989).

In addition, recent work has attempted to find right whales by directing aerial surveys using likely locations of seasonal concentrations of *Calanus* (M. Brown, unpublished data) or satellite-derived frontal data (C. Mayo & M. Brown, unpublished data).

Ongoing investigations include a reanalysis of SCOPEX data using more refined methods to link satellite SST imagery to right whale distribution (Bisagni & Wagner, in progress), correlation of satellite-tag movement data with oceanographic characteristics (Kraus, in progress), and further exploration of right whale distribution using GIS (Kenney, in progress). Other projects related to environmental data and right whale distribution are being planned by graduate students.

## Environmental features and remote detection methods

### *SST fronts*

Fronts appear to represent one of the most promising features for predicting the distribution of right whales, as demonstrated by work in the Great South Channel (Brown & Winn 1989, Kenney & Wishner 1995). However, there are various types of fronts (tidal mixing, upwelling, river runoff, etc.) and it is important to be able to distinguish between them since not all fronts will facilitate the concentration of right whale prey. Future efforts need to identify tidal mixing fronts as these are features with which right whales are probably associated. Fronts are potentially detectable using SST imagery derived from satellites or aircraft. Maximum resolution for satellite-derived SST data is approximately 1 km with a navigational uncertainty of 1-2 km. Thus, processes with scales of less than 1 km will not be detectable. Long time series of satellite-derived SST images may aid in the location of persistent SST fronts.

In addition, fronts may predictably occur on a seasonal basis in certain areas (e.g. the Great South Channel). Major areas of right whale habitat are more likely to occur in those places characterized by more predictable, persistent fronts. Based upon past work, a working hypothesis would be that right whales should be associated with the stratified side of fronts.

C. Davis (*in litt.*) notes that in Cape Cod Bay in March, thermal gradients are often weak and that tidally driven convergence can occur in isothermal water; as a result, a convergence front can exist with little or no thermal signature.

### *Internal waves*

Internal waves can be detected by Synthetic Aperture Radar. Off California, the distribution of harbor porpoises (*Phocoena phocoena*) has been correlated with internal waves (Silber & Smultea 1990), but to date there has been no attempt to link these features to the distribution of right whales.

### *Ocean color/chlorophyll*

Ocean color/derived chlorophyll is detectable by the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) satellite, with other similar sensors coming online in the next few years. These data represent an index of standing stock and possibly primary productivity as reflected in chlorophyll production (although Sosik cautioned that standing stock and productivity are not necessarily related). Associations with right whale distribution have not been investigated. As noted above, chlorophyll abundance may be a poor predictor of right whale occurrence because of a potential lack of association between primary productivity and older life stages of prey species such as *C. finmarchicus*. The relationship is currently under investigation at the University of Massachusetts Dartmouth, using MARMAP zooplankton data and Coastal Zone Color Scanner (CZCS) pigment imagery.

## POSSIBLE APPROACHES TO PREDICTING RIGHT WHALE DISTRIBUTION

The following represents a summary of recommendations and considerations provided by Workshop participants. The Workshop acknowledged that successful prediction of the location of all right whales at any one time was likely impossible. However, the ability to at least predict the location of aggregations of right whales within their feeding range would be immensely valuable. For management purposes, the study focus could in some cases be narrowed to areas with greater probabilities of human impact on right whales, notably those regions characterized by high rates of shipping traffic or fixed fishing gear. The workshop recognized that some studies should receive higher priority than others, but did not attempt to undertake such prioritization in the time available.

**Retrospective studies**

The Workshop recognized the importance of conducting retrospective studies as a starting point in understanding the relationship between right whale distribution and environmental variables. Of particular value would be studies covering areas and time periods in which major shifts in distribution have been recorded. Examples which the Workshop recommended be pursued include:

(i) The Great South Channel, concentrating on the shift away from the area which occurred in 1992. Good right whale sighting data are available for this region from 1979 to 1989, but adequate sighting and environmental data may be available for the shift year to conduct such a study.

(ii) The Scotian Shelf, specifically the Browns Bank/Roseway Basin region, which experienced a longer-term shift away from the area beginning in 1993. Good right whale data are available for this region from 1985 to 1993, including the period of the shift itself.

(iii) Cape Cod Bay, which experienced prolonged residency of right whales in the summer of 1986. The existence of relevant environmental data for this period is unclear, but good sighting data exist for right whales from 1984 on.

In these studies, the focus should be on the nature and extent of multivariate differences in environmental characteristics between periods when whales were abundant and periods when they had abandoned the area concerned.

Additional retrospective studies were identified:

(iv) An investigation of the overall abundance and spatial distribution of *Calanus* relative to right whale distribution. However, it was recognized that areas for which good data for both species existed might be few.

(v) A study to repeat and expand upon work conducted by Comeleo *et al.* (1998), examining characteristics of right whale habitat using GIS or similar approaches. Such a study would focus on every month for every area for which good sighting data exist (and one month on either side); cross-area comparisons could then be made using the results.

(vi) Environment and reproduction studies: although not directly related to the prediction of distribution, Kenney's unpublished study of an apparent correlation between right whale reproduction and large-scale processes (such as the Southern Oscillation) is potentially important. It was recommended that review of this work be conducted, and that additional potential correlations between reproduction and environmental variables be investigated.

(vii) Diet overlap/interspecific competition studies: several participants noted the likelihood of diet overlap between right whales and other planktivores (notably fish), and stressed that the potential for interspecific competition should not be ignored (but see Clapham & Brownell 1996 for caveats concerning interspecific competition). If relevant data can be located, an investigation of the relative abundance and distribution of plankivorous fish and right whales might prove instructive.

**Real-time studies**

The Workshop agreed that a particularly productive approach in real-time investigations would be to concentrate on process-oriented studies in specific locations (such as occurred during the SCOPEX project in the Great South Channel). Such studies are likely to be expensive, however, and other (smaller-scale) projects of various types would undoubtedly be useful in filling gaps in knowledge.

**Front-related studies**

The Workshop recommended that retrospective and real-time tests of associations between fronts and right whale distribution represented a high priority in the development of a reliable predictive system. Such field tests would use the results of past work and ongoing retrospective studies to formulate hypotheses, and would involve either shipboard or aerial surveys of candidate fronts, as identified from satellite imagery (or other real-time sources, if available). The ability of satellite imagery to discriminate among different types of fronts is critical to this effort, and investigation of whether this is possible was considered another high priority by the Workshop. Satellite tagging of individual right whales, in combination with satellite imagery, represents another approach for discriminating among fronts.

Given that thermal gradients can be weak, and that convergence can occur in isothermal water, searches based upon any type of SST front will sometimes be unproductive. An alternative suggested by C. Davis (*in litt.*) is to search for copepod patches along steep topography where convergence occurs, and to do so at a time of year when copepods are in surface-keeping behavioral mode.

Obviously, field tests of front-related predictions should initially focus on determination of right whale presence and distribution in such areas, and on the probability of finding right whales at various distances from frontal boundaries. However, such field work should also employ oceanographic sampling to examine characteristics of the area. Collection of such data in areas without right whales, or during periods of frontal breakups, is also important.

The Workshop also recommended that studies be conducted to investigate the relationship (if any) between the occurrence of right whales and internal waves. As noted above, these may represent a prey-concentrating mechanism in the Stellwagen Bank area and elsewhere.

### Animal-based studies

The Workshop identified a number of animal-based studies of importance:

(i) Satellite tracking of individual whales of different sex, age and reproductive class. Although long-term attachment of tags remains difficult, recent work on other species indicates that tracks over periods of weeks or months are now attainable in many cases (Mate *et al.* 1998). When successful, such studies offer unparalleled opportunities to examine the movements of whales relative to oceanographic features, and are useful for illuminating the scale of an animal's decision-making. Satellite tagging can also provide critical information on the likely range of a population, and may also resolve the question of whether important right whale habitats exist far from land.

(ii) Focal animal studies. Following individual animals to collect data on their behavior and associated environmental/prey variables would undoubtedly provide insight into resource and oceanographic parameters associated with decision-making processes at various scales, as well as energetics. Such studies would expand upon work conducted by Mayo and associates, and should ideally garner statistically robust sample sizes on individuals of different sex, age and reproductive condition to examine inter-class variation.

### Models

In addition to the oceanographic modeling identified above, the Workshop noted the need for the following studies:

(i) A right whale foraging model, incorporating individual decision-making processes. Such a model would require better energetics data than currently exist for right whales, as well as information or simulations regarding the probability of detecting patches within a specific habitat. Such a model by necessity must include modeling of prey patch aggregation, since knowledge of the interaction between whale foraging behavior and zooplankton patch formation dynamics is critical.

(ii) An energetics model for right whales. Values for many of the key variables upon which such a model is contingent are unknown, and studies to obtain better data on such variables should be developed where possible. A comparative approach using data and methods developed from work with more accessible terrestrial mammals may prove productive. A reliable energetics model would be very valuable in understanding prey choice, resource thresholds, energy budgets and decision-making processes. Any such model should explicitly recognize that individual right whales of different sex, age and reproductive condition are likely to vary significantly in their energetic requirements.

**Other studies**

Additional work was identified as follows:

(i) In order to support energetics modeling, a review of the nutritional value of known right whale prey species is required.

(ii) Additional information on diet of right whales can be garnered from stable isotope studies (see Schell *et al.* 1989, Best & Schell 1996). Work by Wetmore (in progress) is intended to examine diet at several timescales by using a variety of material, including recent baleen, historical baleen and skin biopsies.

**Statistical considerations**

Garrison (Symposium) suggested that the multivariate nature of this ecosystem mandated multivariate analysis. He stressed the need to consider scale since this fundamentally affects the way in which statistical analysis is structured, and noted the importance of spatial autocorrelation in such an effort. Tynan disagreed somewhat, noting that canonical correspondence analysis (CCA) requires many variables and good data, and will not necessarily illuminate patterns. Palka suggested that existing information would inevitably explain some of the observed variance, and that the remainder could be investigated using directed collection of process-oriented data. She suggested using a variety of methods on the same data set to illuminate discrepancies. In addition to the multivariate CCA analysis discussed by Garrison, other possible methods include individual-based models, additive models, logistic regression, cluster analysis, and analysis of variance with an error structure to accommodate spatial autocorrelation. Overall, it was agreed that the statistical methods to be employed were contingent in part upon the hypothesis being tested, and the scale being examined.

Palka also noted also that modeling was useful in that it allowed one to organize an approach and to identify gaps in understanding. Butman pointed out that predictive models now exist for circulation and fronts in some areas, and that it might be possible to nest right whale analyses within these models. Participants emphasized the need to ground-truth modeling work with field studies.

**Data availability**

A summary of available databases relating to physical, biological and other variables, with an emphasis on the North Atlantic and Gulf of Maine, was prepared by the Northeast Fisheries Science Center and is appended to this report (Annex C); additional copies are available upon request. This summary was prepared as background to the Workshop and is likely to have utility in some of the right whale studies suggested above, as well as in other investigations using environmental data.

Data on right whale distribution and general biology are centrally archived in two locations. The North Atlantic Right Whale Catalogue, curated by the New England Aquarium in Boston, contains a centralized photo collection and associated sighting data for individually identified right whales. The Right Whale Database, curated by the University of Rhode Island, is a repository for all sighting data on right whales (and other cetacean species). Access to both databases is controlled by Right Whale Consortium data sharing protocols, a copy of which is available from either institution.

The Workshop noted that production of a right whale sighting "atlas" would be immensely valuable to a wide variety of studies on this and other topics. Standardization of these data by some measure of effort where possible is essential; this could be accomplished using lat/long 10 minute x 10 minute squares, with finer resolution possible in some areas (notably the Bay of Fundy, and Georgia/Florida).

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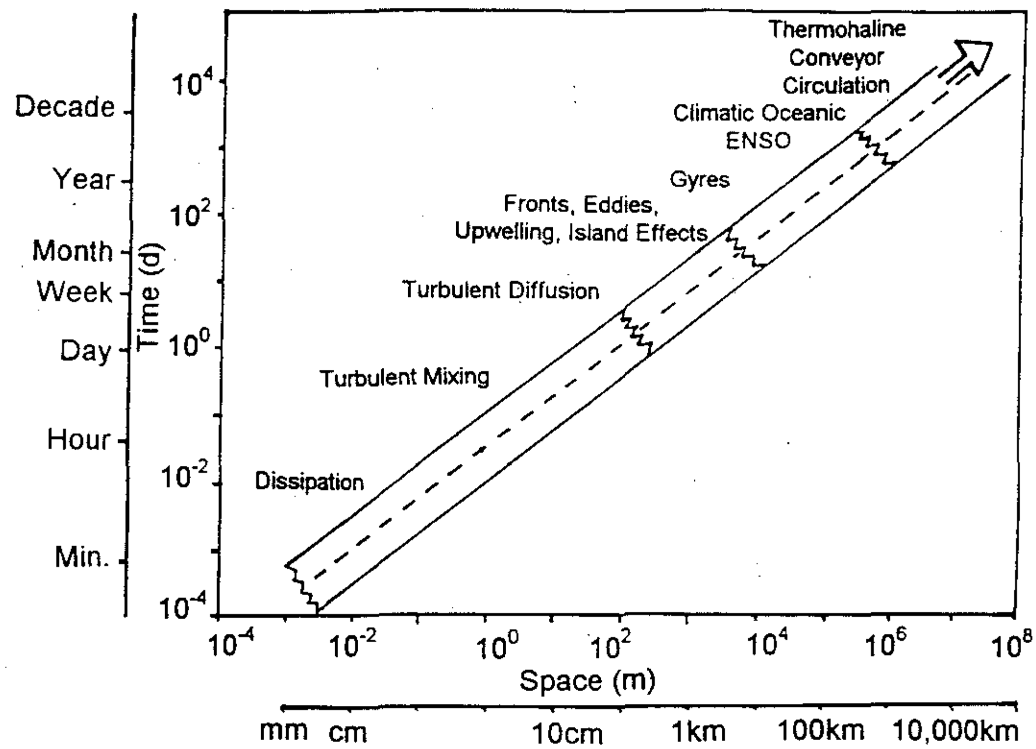
Figure 1. A schematic representation of relevant spatial and temporal scales in physical (a) and biological (b) processes and features. After IWC (1997).

(a)

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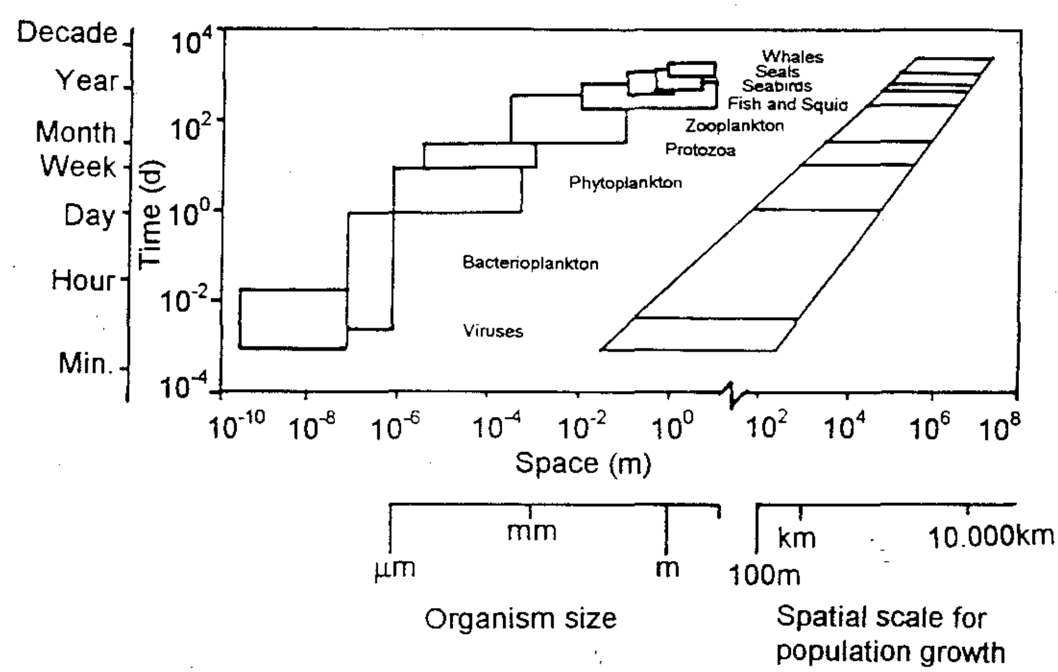

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**Annex B**
**Symposium Program**

# *SYMPOSIUM: PREDICTING RIGHT WHALE DISTRIBUTION*

*Sponsored by the Northeast Fisheries Science Center*

*Thursday, October 1st, 1998*
*Redfield Auditorium, Woods Hole Oceanographic Institution*

0830 **John Boreman** (Deputy Director, Northeast Fisheries Science Center, Woods Hole)
*Welcome*

0835 **Phil Clapham** (Northeast Fisheries Science Center, Woods Hole)
*Introduction*

0845 **Scott Kraus** (Right Whale Research Project, New England Aquarium, Boston)
*Right whales: an overview of status and known distribution*

0905 **Bob Kenney** (University of Rhode Island)
*A review of right whale habitat studies in the Great South Channel*

0930 **Stormy Mayo** (Center for Coastal Studies, Provincetown)
*The right whale/zooplankton relationship: characteristics of plankton patches which trigger feeding*

0950 **Cyndy Tynan** (University of Washington & National Marine Mammal Lab, Seattle)
*Right whale distribution in relation to fronts in the Bering Sea*

1010 **Ted Durbin** (University of Rhode Island)
*Calanus finmarchicus: food of right whales*

1030 *break*

1045 **Jim Bisagni** (University of Massachusetts, Dartmouth)
*Satellite-derived sea surface temperature fronts for studies of northern right whale habitats*

1105 **Jack Finn** (University of Massachusetts, Amherst)
*Using GIS to predict North Atlantic right whale habitat*

1125 **Lance Garrison** (National Research Council and Northeast Fisheries Science Center)
*Linking prey and environment with species distribution: statistical considerations*

1145 **Questions**

1200 *Adjourn*

# Annex C
# A Summary of Available Regional Databases Containing Information on Environmental Variables

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## *Introduction*

The following represents a summary compilation of information on regional data sets relating to marine environmental (biological and physical) variables. The geographic scope of these data sets varies from highly localized to North-Atlantic-wide; however, the focus in this compilation is on the waters of the Gulf of Maine and adjacent areas. This summary was produced as background to an effort to link environmental variables to the distribution of northern right whales (*Eubalaena glacialis*), but the information summarized here may be of some value to investigators studying the distribution of other marine species.

This list is unlikely to be exhaustive; suggestions for additions or amendments are welcome. The most recent additions to any of the data sets summarized may not be publically available at this time; the data managers identified should be contacted for further details on access. The list is current as of October 1998; additional copies are available upon request, in either printed or electronic form, from the Northeast Fisheries Science Center. A tabular version is also available.

## BIOLOGICAL DATA

Content: MARMAP - zooplankton, CTD data

Contact: Julien Goulet, NMFS Narragansett

MARMAP data consists of zooplankton abundances from 1977-present from the Northeastern continental shelf (Cape Hatteras-Nova Scotia). Data consists of 6-12 surveys/yr in 1977-1987, 2-3 surveys/yr in 1987-1991 and 6 surveys/yr from 1991-present. From 1977-1987 chlorophyll, CTD, nutrients and weather observations were also collected as part of the MARMAP program. The data are in an oracle database located in Narragansett and can be accessed by contacting Julien Goulet who will either create an anonymous ftp server to contact for limited information, or will create an account to provide long term access.

Content: **CPR** data

Contact: Jack Jossi, NMFS Narragansett

CPR (Continuous Plankton Recorder) data date back from 1961-present for the Gulf of Maine. Every month the CPR is dragged through a commercial route linear transect survey from Boston to Nova Scotia. From 1993-present data from the outer flank of Georges Bank are also available. Zooplankton are identified to species and stage, phytoplankton and fish larvae are also counted and some are identified. Data are available in SAS data bases at NMFS Narragansett Lab and can be accessed by contacting Jack Jossi who can create a temporary ftp site with data in SAS or ASCII format.

Content: Zooplankton data

Contact: Mike Mickelson/Wendy Leo MWRA

MWRA has collected zooplankton data from 1992-1994 in Massachusetts and Cape Cod Bays. To request use of this data contact Wendy Leo. Data are available in oracle databases. MWRA has contracted ENSR to produce a report summarizing zooplankton abundance in Massachusetts and Cape Cod Bays using data resources from MWRA, NOAA compact disks, CCS and WHOI. A draft of the report is currently available, but the final summarization is not (will possibly be available at the end of June 1998). The report will be distributed to OMTF members, there will be a limited amount for outside distribution.

Content: SCOPEX - zooplankton data

Contact: Karen Wishner, URI GSO

The SCOPEX project covered the Great South Channel from 1988-1989, the zooplankton data are located in macintosh excel databases at URI.

Content: SCOPEX - zooplankton data, nutrient and chlorophyll, US GLOBEC zooplankton data

Contact: Ted Durbin, URI GSO

SCOPEX zooplankton data from the Great South Channel in May 1988 and May/June 1989 are located in macintosh excel data bases at URI. Nutrient and chlorophyll data are also in macintosh excel data bases from March/April 1988 and June 1989. US GLOBEC zooplankton data from Georges Bank are located in an oracle data base also at URI from Jan-June 1994-1998. Contact the US GLOBEC website for more information http: //globec.gso.uri.edu.

Content: MARMAP - zooplankton abundance

Contact: Cabell Davis, Dennis McGillicuddy, WHOI

From the website http://www.whoi.edu/mcgillic/ objectively analyzed copepod and chlorophyll distributions can be viewed. Raw data are also available and are from the Georges Bank/Gulf of Maine region.

Content: VPR data

Contact: Cabell Davis, WHOI

Cabell Davis surveyed zooplankton in conjunction with Stormy Mayo and the CCS in March 1996-1998 in Cape Cod and Massachusetts Bays. The VPR (Video Plankton Recorder) data is not yet available, but future internet access is expected possibly at the end of the summer 1998.

Content: Primary productivity

Contact: Jay O'Reilly, NMFS Narragansett

Data are sporadic and not suitable for use in a model, but summaries of long-term data can be reviewed in a book entitled *Georges Bank*, ch 21 on primary productivity (edited by Backus MIT press, 1987) available at the MBL/WHOI library or NMFS NEFSC library. Also, review Deep Sea Research Special Edition vol. 43 #7-8 1996 Physical and Biological Interactions on Georges Bank and its Environ.

Content: Groundfish and trawl surveys

Contact: Tom Azarovitz, Bill Michaels, NMFS NEFSC, Tom Currier, Massachusetts Division of Marine Fisheries

Groundfish surveys cover the Northeast area ranging from Cape Hatteras to Nova Scotia and date back 30-35 years. Surveys are done in the spring and fall in random sample sites. Data are archived at NMFS, woods hole. Contact Tom Azarovitz to request access to groundfish survey data bases and Data Management Systems (DMS) at NMFS will set up an oracle account. Massachusetts Division of Marine Fisheries has spring and fall coastal trawl data available from 1978-present in the Cape Cod Bay area. Contact Tom Currier at the Massachusetts Division of Marine Fisheries for questions related to the data. Data is also accessible via oracle account through NMFS. The Coastal Ocean Project (COP) surveyed the southern flank of Georges Bank, specifically trawling for herring and mackerel while researching predator prey interactions. Data will be available in the future for May of the years 1992-1996. An acoustic survey for herring and mackerel will be conducted in September 1998 from Jeffreys ledge north along the Maine coast and eastward to Georges Bank, contact Bill Michaels or Jason Link for more information.

Content: Stock Assessment and Stock Status Reports

Contact: Jackie Riley, NMFS NEFSC librarian

Herring and mackerel Northeast Regional Stock Assessment Reports from the 1970's and into the 1990's (the 1998 stock assessment report of Atlantic Herring is currently being reviewed) are available at the NMFS library, review the 21st Northeast Regional Stock Assessment Workshop (21st SAW) for a list of species and dates of assessment. The Canadian Department of Fish and Oceans also publishes Stock Status reports on the Bay of Fundy and Georges Bank stocks of herring, contact Dr. Gary Melvin. The DFO also provides stock status reports annually summarizing different species distribution and abundances. Contact the NMFS NEFSC library for review of CAFSAC Research Documents 1977 to 1993, after 1993 they are called DFO Atlantic Fisheries Research Documents and the latest 1998 report is available.

Content: Commercial fisheries and sea sampling data

Contact: NMFS NEFSC

Commercial fisheries data bases from 1964-1996 for the Northeast coast are archived at NMFS, as are sea sampling data bases from 1989-1994 in which fishing vessels carrying NMFS observers record fish catch as well as incidental takes, contact DMS for oracle access.

Content: Gillnet fisheries data

Contact: Vin Malkoski, Massachusetts Division of Marine Fisheries

Historic gillnet fisheries data are available for herring and mackerel from 1970-1990's off of Plymouth in the Rocky Point area. Data were collected as part of a study of Pilgrim Power Plant. Sand Lance were also sampled using beach seines from 1981-1991 in stations relative to Plymouth Pilgrim Power Plant in Kingston Bay, Long point, Warren cove and Manomet. The data are available at Massachusetts Division of Marine Fisheries in an old R base format that will be converted to a more user friendly format. Call Vin Malkoski to set up an appointment to review data.

## BIOLOGICAL AND PHYSICAL DATA

Content: US GLOBEC - zooplankton abundance, fish larvae, acoustic, meteorologic, bathymetric, ADCP, CTD, satellite sea surface temperature, current meter, micro structure, wind stress and drifter data

Contact: Bob Groman (GLOBEC webmanager), WHOI

US GLOBEC Georges Bank project is a five-year survey of Georges Bank, 1992-present. Data sets can be viewed online - contact http: //globec.whoi.edu/globec-dir/data.html for the data directory. View http: //globec.whoi.edu/images/cf_z7cv7.gif for images of seasonal patterns in abundance and variation of calanus finmarchicus from 1977-1987. See acknowledgment for information http: //globec.whoi.edu/globec-dir/data-acknowledgment-policy.html.

Content: Zooplankton, phytoplankton, CTD data

Contact: Stormy Mayo, CCS

The Center for Coastal Studies holds long-term zooplankton and phytoplankton abundance and distribution data bases. Zooplankton data have been collected from 1984-present and phytoplankton data from 1977-1986 with a small amount of data from 1997. All data are collected in Cape Cod and Southern Massachusetts Bays. Physical CTD data are available from the years 1993-present. Data sampling takes place in the very near vicinity of feeding right whales and are extemely useful in characterizing feeding habitat conditions. The data are in IBM excel office 97, excel 4.0 format. The Center for Coastal Studies also archives an abundant amount of meteorological data corresponding to whale residence time as well as sightings and behavioral information.

Content: CTD, zooplankton

Contact: Ivar Babb, NURC

The National Undersea Research Center for the North Atlantic and Great Lakes supports research projects in the North Atlantic region and has been doing its own research since 1984. CTD data are collected for each of their dives, along with other data specific for each project. There have been several supported zooplankton studies and a research project entitled *Estimating the in situ Acoustic Target Strength, Distribution and Abundance of Diapausing Calanus finmarchicus and its Invertebrate Predators in the Deep Basins of the Gulf of Maine* is currently underway. Contact http://www.nurc.uconn.edu/index.htm for information on past and present NURC research projects. Contact Ivar Babb who will determine the most appropriate data contact. Principal investigators of each project may be contacted also for data inquiries.

Content: Zooplankton, CTD, chlorophyll, nutrients, moored current meter data

Contact: ICES, Oceanographic data center (International Council for Exploration of the Sea)

All project data are available online via anonymous ftp server. To request data follow instructions at website. Contact http://www.ices.dk/ocean/ocean.htm or email ocean@ices.dk for more information. The data is stored in pkzip files in ICES format and can be converted to ASCII. The data range from 1950-1990's and cover the North Atlantic Ocean region. Zooplankton (Calanus) population dynamics from 1996-1998 in the North Atlantic are also available, contact http://www.ices.dk/ocean/ocean.htm.

Content: Sea surface temperature and phytoplankton pigment imagery, ocean winds, wind stress, wind vectors and global heat and momentum flux data

Contact: PODAAC (Physical Oceanography Distributed Active Archive Center)

Data are available for the global oceans, sea surface temperature data from 1981-1986 are coregistered with phytoplankton data from 1978-1986 in HDF format. Weekly global sea surface temperature data from 1987-1993 are available, as are monthly averages in sea surface temperature from 1991-1992, global sea surface temperature data from 1981-1996, ocean wind products from 1996-1997 and heat and momentum flux data from 1987-1988. Most data are in HDF format and are available via ftp server and/or can be ordered online as tape or cd rom. Contact http://podaac.jpl.nasa.gov for information regarding data sources, coverage, format and ordering.

## PHYSICAL DATA

Content: Hydrographic database

Contact: Maureen Taylor/Dave Mountain, NMFS NEFSC

CTD data are available from the Gulf of Maine from Groundfish, MARMAP, GLOBEC and marine mammal surveys (any survey that NMFS NEFSC is involved with and has collected CTD data are kept in this database) for the years 1991-1998. The database is located at NMFS NEFSC. The information is in a collection of ASCII files on an FTP site ftp/pub/hydro. Look at the file names beginning with "hydro" for cruise summaries. The raw data need explanation, see FIGURE 1 for details. If interested in using this data please contact NMFS to review the data policy.

Content: Hydrographic data base, climatologic and sea surface temperature data

Contact: Yan Shi, Brookhaven National Laboratory

Contact http://www.oasdpo.bnl.gov/mosaic/omp/ompsql.html for information on how to retrieve data from the BNL hydrographic data base. Contact http://www.weather.bnl.gov for climatological data-monthly means in precipitation, snowfall, temperature as well as meteorological extremes and daily temperature statistics from 1949-present on Long Island, NY. Real-time meteorological and sea surface temperature can also be accessed.

Content: Hydrographic data

Contact: Rich Signell, USGS

CTD data and station information from 5 hydrography cruises in the Western Gulf of Maine are available by first contacting http://rossby.unh.edu/edims/documents/wegomex/report.html to review the hydrography report and next contacting http://opal-www.unh.edu/redims.html to review the data. Data are in ASCII format. The hydrography survey was conducted in 1994-1995 through the Regional Marine Research Program and the Ocean Process Analysis Laboratory (OPAL) at the University of New Hampshire.

Content: XBT and surface salinity data

Contact: Robert L. Benway/Jack Jossi NMFS Narragansett

Expendable bathythermograph and surface salinity data are available from 1978-present from monthly ship of opportunity cruises between Massachusetts and Cape Sable, Nova Scotia. Data are available in SAS databases located at NMFS Narragansett Lab and can be accessed by contacting Robert Benway or Jack Jossi who can create a temporary ftp site with data in SAS or ASCII form.

Content: Historical hydrographic data

Contact: Ken Drinkwater, Fisheries and Oceans Canada Bedford Institute of Oceanography

Online long-term time series hydrographic data (1912-present) from the Gulf of Maine and the Scotian shelf can be accessed by contacting http://opal-www.unh.edu/datasets/afap/afap.html. The data are in ASCII file format and the website has information on how to interpret the data set.

Content: SCOPEX - Acoustic and hydrographic data

Contact: Robert Beardsley/Richard Limeburner, WHOI

Contact Robert Beardsley for acoustical data from SCOPEX 1988, 1989. The data are in MATLAB format and can be converted to ASCII , the units are biomass/cubic meter. Contact Richard Limeburner for a cd rom of CTD data from SCOPEX. Also available is a technical report entitled CTD Observations in the Great South Channel during SCOPEX May-June 1989, to help summarize the data. In addition there is a reference entitled Biological and Hydrographic Station Data in the Vicinity of Nantucket Shoals May 1978-1979, that is also helpful.

Content: Oceanographic profiles, environmental data, currents

Contact: George Heimerdinger, WHOI - USNODC representative

The NODC provides ocean profile data, CTD, oxygen, chlorophyll and nutrients from 1886-1996 in all oceans. Environmental buoy data consists of: wind, wave, air temperature, pressure, wind speed, direction, and sea surface temperature from 1970-present. Global ocean temperature and salinity databases from 1990-present can be ordered. Ocean current data in the North Atlantic range from 1972-1992. Archived data can be provided via magnetic media/cd rom and a limited amount of data can be downloaded via ftp server. Contact http:// www.nodc.noaa.gov for specific data available and instructions on downloading, email services@nodc.noaa.gov with questions.
The NODC has published The World Ocean Atlas 94 which includes data on oxygen, salinity, temperature and nutrients as well as the Global Ocean Temperature and Salinity Profiles cd rom.

Content: Satellite sea surface temperature imagery

Contact: Shannon Wagner, CCS

The Center for Coastal Studies has produced a hardcopy of satellite images of sea surface temperature from Feb - April 1997 in the Gulf of Maine.

Content: Sea surface temperature imagery, meteorological data

Contact: SAA NOAA's Satellite Active Archive

The SAA is a library of real-time and historical satellite imagery and data from NOAA's orbiting satellites. AVHRR satellite sea surface temperature imagery from the global oceans from 1978-present and is located at the SAA. Atmospheric temperature data bases from 1997-present are also stored here. Data are available as magnetic tape, data sets larger than 10 MB must be ordered. Users can ftp limited amounts of data. Contact http: //www.saa.noaa.gov for information.

Content: Sea surface temperature imagery

Contact: Frank Monaldo, Ocean Remote Sensing Group at The Johns Hopkins University Applied Physics Laboratory

Sea surface temperature imagery for the Gulf Stream in 1998 are located at The Johns Hopkins University Applied Physics Laboratory and are available online. Contact http: //fermi.jhuapl.edu/avhrr or Frank Monaldo at Frank_Monaldo@jhuapl.edu.

Content: Sea surface temperature imagery

Contact: Peter Cornillon, URI GSO

The University of Rhode Island Graduate School of Oceanography Satellite Image Archive has sea surface temperature imagery from the North Atlantic coast from 1985-1996. Contact http://dcz.gso.uri.edu/avhrr-archive/archive.html. The images here are course and more processed images can be accessed by contacting Peter Cornillon. Also, contact http://petes.gso.uri.edu/~pete/fronts/fronts-97.html for weather front imagery which will be available in the future via CoastWatch.

Content: Sea surface temperature imagery

Contact: Andrew Thomas, UMAINE

The University of Maine has sea surface temperature satellite imagery processed from Jan 1997-present in the Gulf of Maine region. Contact http://wavy.umeoce.maine.edu. Andrew Thomas will set up an ftp account to access the imagery.

Content: Sea Surface temperature imagery, current, temperature, salinity, pressure and sea level data

Contact: Karen Garrison, Ocean Process Analysis Laboratory (OPAL) at UNH

Contact http://rossby.unh.edu/datasets/sst/sst.html for Gulf of Maine sea surface temperature data. Data is available monthly from 1993-present. Images are obtained from NOAA and mapped by the Ocean Process Analysis Laboratory (OPAL) at UNH, contact Karen Garrison with questions. Images are saved in Graphics Interchange Format (gif 89a) and compressed binary files. Current, temperature, salinity, pressure and sea level data are also available, contact http://opal-www.unh.edu/datasets/massbay/massbay.html for datasets from a physical oceanographic study of Massachusetts and Cape Cod Bays in 1990-1991. The data are measurements from the National Ocean Service (NOS). The data are in ASCII file format and can be directly accessed online.

Content: Real-time sea surface temperature imagery

Contact: Coastal Remote Sensing (CRS) High Resolution Picture Transmission (HRPT) ground station

Data are retrieved by the Coastal Remote Sensing (CRS) High Resolution Picture Transmission (HRPT) ground station from NOAA's polar orbiting satellites. From this data sea surface temperatures are calculated for the current day and last three days in the Gulf of Maine. A limited amount of data can be accessed via ftp site, for more data contact the Satellite Active Archive

(SAA). Images are available in two file formats: JPEG and TIFF. Contact the website http://www.csc.noaa.gov/crs/real_time/composite/3day/compimage.html for more information.

Content: Sea surface temperature imagery
Contact: James Bisagni, UMASS Dartmouth

Contact James Bisagni to discuss use of the data. Satellite derived sea surface temperature images on Georges Bank for Winter-spring 1992-1993 are available as well as sea surface temperature and ocean color variability on Georges Bank for 1993-1998. Monthly images for this data are in DSP format, but you may request a conversion. Also accessible are Gulf of Maine and Georges Bank sea surface temperature frontal data for 1985-1995 contact http://kraken.cmast.umassd.edu/bisagni.html.

Content: Sea surface temperature imagery, surface solar irradiance
Contact: SeaWiFS

Data include solar zenith angle, ozone, total precipitable water, surface pressure, surface reflectance, cloud cover and optical thickness, land-water fraction, snow and ice cover, clear sky irradiance, total irradiance including clouds and photosynthetically active solar irradiance. The data are available as daily and monthly averages, monthly data sets from July 1983 through June 1991 can be accessed as Unix compressed ASCII files. Data are available via anonymous ftp server. Sea surface temperature are also available currently, you can find IF images of EPS analyzed sea surface temperature data for the North Atlantic as well as OATS imagery for 1997 in the Gulf of Maine. Contact Cepheus http://seawifs.gsfc.nasa.gov/SEAWIFS.html or John Sapper - j.sapper@nesdis.noaa.gov.

Content: Global sea surface temperature
Contact: NCAR, National Center for Atmospheric Research Data Support Section (DSS)

Contact http://www.ncar.ucar.edu for global sea surface temperature analysis for 1970-1981.

Content: Climatological data
Contact: NCDC

The National Climate Data Center is a source for environmental satellite data and information. Satellite data are available as digital information and as hard copies collected from NOAA environmental satellites. Request data by contacting the Satellite Services Group at NCDC or contact http://www.ncdc.noaa.gov/ol/satellite/satelliteresourcesabout.html for more information. The website lists dates and instrument data available. The satellites collect global data on a daily basis including weather, sea surface temperature, atmospheric soundings of temperature and humidity and ocean dynamics data most of which have been collected since 1960. NCDC also provides access to global buoy data from 1994-present, upper air data from 1992-present, US climatological averages and normals as well as archives of surface marine observation data. Contact http://www.ncdc.noaa.gov/ncdc.html for email addresses of contacts for specific questions.

Content: Climatological data

Contact: The SOC Global Air-Sea Heat and Momentum Flux Climatology

Contact http://ingrid.ldeo.columbia.edu/SOURCES/.SOC/.GASC97/ for monthly climatological means for heat flux latent surface, net heat flux, total precipitation, LW radiation net surface, SW radiation net surface, eastward surface wind stress and northward surface wind stress for January - December 1997.

Content: NOAA meteorological data

Contact: Website

Meteorological data from the Gulf of Maine, Nantucket, Georges Bank, Boston, and the Isles of Shoals are being archived in EDIMS (Environmental Data and Information Management System) central on a daily basis. Data are collected by the NDBC ocean buoys and C-Man island stations. Data are in ASCII format from 1992-1996, to access data contact http://opal-www.unh.edu/datasets/noaa_met/noaa_met.html.

Content: Velocity, salinity, temperature, attenuation and meteorological data

Contact: Rich Signell, USGS

Data collected during the Western Gulf of Maine Red Tide Project in 1993 and 1994 included velocity, salinity, temperature and attenuation. Data are available in NetCDF format or in ASCII or Matlab format via the JGOFS system. Hourly meteorological data like wind, air temperature, sea surface temperature, wave height, wave period, and atmospheric pressure are also accessible from 1989-1994 as a 1.7 mb NetCDF file. Contact http://crusty.er.usgs.gov/wgulf/data.html to view the data.

Content: Current meter data, temperature, salinity, light attenuation, sub-surface pressure and digital bathymetry data

Contact: Brad Butman, USGS

Low pass time series data and hourly time series data for currents, temperature, salinity, light attenuation and sub-surface pressure are archived at USGS from 1975-present for the Northeast. Contact http://crusty.er.usgs.gov/epic/ to review data. Most of the Georges Bank and Great South Channel current data are summarized in articles in the *Georges Bank* book (edited by Backus MIT press, 1987). There are also summary volumes from the SCOPEX and GLOBEC studies. See FIGURE 2 for references. Digital bathymetry for the Gulf of Maine is available online and is updated as new data becomes available contact http://oracle.er.usgs.gov/gomaine/ bathy/index.htm to download files.

Content: Ocean currents, hydrography, sea surface temperature, meteorological and North Atlantic Oscillation data

Contact: Doug Gregory, Ocean Sciences-Ocean Data and Information

Contact http://www.maritimes.dfo.ca/science/ocean/ocean_data.html#envtimser for monthly maximum observed current, monthly mean speed and direction and variability of currents on the Canadian east coast during the 1980's. Data on mean position and anomaly for the

Gulf Stream (1973-1992) and slope fronts are available as are tables, contour maps and seasonal cycle plots of monthly temperature and salinity. Seasonal maps of mean surface and bottom temperature and salinity for the Scotian Shelf/Gulf of Maine are accessible. Annual averages and seasonal cycles of sea surface temperature for Boothbay, St. Andrews and Halifax harbors (1920-present), meteorological data from Halifax, Sable Island and Yarmouth from the 1950's-1990's are accessible. Monthly mean air temperature, annual averages and seasonal cycles of air temperature for sites ranging from Cape Hatteras to Iqualuit (1900's-present) and North Atlantic Oscillation winter mean surface air pressure data from 1961-1996 are also available. Data can be viewed graphically online.

Content: SCOPEX - ADCP and subtidal current data

Contact: Changseng Chen, University of Georgia

ADCP and subtidal current data from the SCOPEX project (1988, 1989) are available in ASCII file format, contact Changseng Chen.

Content: Environmental buoy data

Contact: NDBC, National Data Buoy Center

Contact the website http://seaboard.ndbc.noaa.gov/index.html to locate moored buoy and C-MAN stations for the Northeast US region. There is a large amount of data available to review-standard meteorological, acoustic doppler current profiler (ADCP), continuous winds, spectral wave density, spectral wave direction, water level, and surface ocean current data. Real-time data can be accessed via NDBC ftp server in tabular form. Historical data (meteorological data from 1982-1997, continuous winds data from 1988-1997, and spectral wave density data from the years 1996-1997) can be accessed in one of two ways, by downloading a Gzip compressed file or downloading the file as text. Climatic summary tables and plots for wind speed, air and sea temperatures, sea level pressure, peak wind, wind gust, significant wave height, average wave period, and dominant wave period can be accessed directly from the website for years 1982-1993.

Content: Bathymetry and coastline data set

Contact: Website

A data set consisting of bathymetry and coastline data from 1965 with latitude and longitude can be accessed to create maps of the Gulf of Maine region. Contact http://opal-www.unh.edu/datasets/bathymetry/bathymetry.html for data.

Content: Bathymetry, global topography data

Contact: Dan Metzger/Robin Warnken, NOAA NGDC

Bathymetric and global topographic data bases are available through NOAA NGDC (National Geophysical Data Center) for the global oceans from 1939-present. Data are available online and in cd rom. Contact http: //www.ngdc.noaa.gov/ngdc.html, Dan Metzger (dmetzger@ngdc.noaa.gov) or Robin Warnken (rwarnken@ngdc.noaa.gov) or contact data center for ordering information.

Content: Bathymetry maps

Contact: Joe Kelley, University of Maine, Maine Geological Survey

Bathymetry maps in 10 meter contour intervals are available from the shores of Massachusetts to Canada and out to the 100 m isobath from the Maine Geological Survey, contact website to order Intercontinental Shelf maps at http://www.state.me.us/doc/nrimc/nrimc.htm or call (207) 287-2801.

Content: Topographic sea floor map

Contact: Page Valentine, USGS

Contact Page Valentine for access to a 1995 topographic sea floor map of Massachusetts and Cape Cod Bays, Stellwagen Bank, parts of Jeffreys Ledge and Scantum Basin.

Content: Outfall water column monitoring data

Contact: Mike Mickelson, MWRA

The MWRA has technical reports summarizing results of the outfall water column monitoring program for the inshore waters of Massachusetts and Cape Cod Bays from 1991-1997. Data include temperature, salinity, dissolved oxygen, plankton, nutrients and chlorophyll measurements. The data are available electronically in oracle tables. Contact MWRA library to copy reports at (617) 242-6000 ext. 4175 or the Boston Public library, contact //world.std.com/~enquad for more information.

Content: Oceanographic datasets

Contact: COADS

COADS global sea surface temperature and global climatology data from 1981-present are available. Data including monthly sea surface temperature summaries 1990, global ocean surface temperature atlas March 1990, an atlas for oceanographic modeling, global ocean wind stress climatology 1980-1989, monthly mean global wind stress 1988, a surface marine atlas derived from COADS 1945-1989, global land elevation/ocean depth data, and the hydrography of the North Atlantic Ocean in the early 1980's. Contact COADS for more information http://www.cdc.noaa.gov/coads/. Small datasets are available via ftp or online, larger datasets are stored on tape or other media and can be ordered.