# IMPROVING RIGHT WHALE MANAGEMENT AND CONSERVATION THROUGH ECOLOGICAL RESEARCH

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## WORKING GROUP ON IMPROVING RIGHT WHALE MANAGEMENT AND CONSERVATION THROUGH ECOLOGICAL RESEARCH

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### Introduction

The working group was convened by the Northeast Fisheries Science Center (NEFSC) and met at the Woods Hole Oceanographic Institution on 16th April 2004.

Management of the critically endangered North Atlantic right whale (*Eubalaena glacialis*), and mitigation of some specific issues facing this population, requires better data on the foraging ecology of the animals. For example, knowledge of how right whales use the water column when foraging would likely assist the development of gear design or other mitigation strategies aimed at reducing entanglement risk. Similarly, foraging ecology can potentially provide invaluable information to characterize habitats that are important to right whales, and this information can subsequently be used to better understand their distribution (both overall and in relation to threats such as fishing gear and ship traffic).

The working group held an informal one-day meeting to discuss critical knowledge gaps regarding North Atlantic right whale diving behavior, foraging ecology and habitat, and how studies of these topics can assist management. The major objectives of the meeting were to identify research objectives and methods that: (i) provide data to assist development of mitigation measures for fishing gear entanglements; (ii) better characterize habitats important to right whales; and (iii) improve our ability to predict the distribution of right whales from environmental variables.

### Summary of management issues

#### *Entanglement*

Entanglements in fishing gear represent a serious problem for right whales (Knowlton and Kraus 2001). Mitigating entanglements through modification of gear requires knowledge of how right whales behave, notably how they dive and forage in the water column relative to the presence and configuration of fishing gear (especially lines). Both ground lines and vertical lines are known to present a risk for right whales and other large whale species (Kozuck *et al.* 2004). Examination of the amount of gear in the water by season suggests that summer in the northeastern U.S. and Atlantic is a particularly high-risk time for right whales.

With ground line, a potential solution has been suggested in that the replacement of floating line with sinking or neutrally buoyant line would reduce the line's profile in the water and thus potentially reduce risk. However, the major question to be addressed on this topic is whether ground line should be *on* the bottom, or slightly above it (e.g. floating line modified by attaching weights to lower the profile). Line on the bottom abrades faster and may get fouled on the bottom, and is thus a problem for fishermen, while line that is above the ocean floor might represent a greater entanglement risk. Resolution of this problem requires better information on how right whales forage, and whether in doing so they move above, or are in contact with, the sea floor. Similarly, studying foraging behavior elsewhere in the water column will help to understand the nature of risk that right whales face relative to fishing gear, and may thus assist the development of mitigation strategies.

#### *Predictive modeling*

Although the large-scale geographic and migration patterns of the North Atlantic right whale stock are broadly known, detailed knowledge is lacking regarding the environmental (and perhaps social) factors determining fine-scale temporal and spatial distributions. The ability to predict localized distribution patterns of this 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 (notably entanglement and ship strikes).

**Summary of current and past work**

The following section provides capsule summaries of past and current work relating to foraging ecology and predictive modeling. Summaries were provided by working group participants.

*CETAP*

The Cetacean and Turtle Assessment Program (CETAP) was a multi-year study (1978-1982) designed to characterize the spatio-temporal distributions and abundances of whale, dolphin and sea turtle populations off the northeastern U.S., as baseline environmental information for potential oil and gas leasing. One component of the project included focused studies on a particular high-use habitat, the Great South Channel region east of Cape Cod, in collaboration with the NMFS MARMAP sampling and with a NASA-funded remote-sensing study called the "Nantucket Shoals Experiment." Using a variety of aerial and shipboard sampling methods, there was an attempt to simultaneously assess physical oceanographic parameters, phytoplankton, zooplankton, and whales, and their ecological inter-connections. The results (CETAP, 1982) showed that right whale aggregations were located in the vicinity of the densest concentrations of *Calanus finmarchicus* sampled in the Gulf of Maine to that time. It was hypothesized that the *Calanus* concentrations were the result of topographically-induced upwelling. These results later became background data for planning the SCOPEX study (see below). One portion of the study included estimation of the threshold average zooplankton concentration that right whales require to break even energetically over the long term. This was further refined and published separately (Kenney *et al.* 1986); the mid-point of the estimated range suggested that right whales needed to feed on average in patches with densities exceeding tens of thousands of stage C-V *Calanus* per cubic meter of water.

*SCOPEX*

The South Channel Ocean Productivity Experiment (SCOPEX) was a multi-disciplinary study of a whale-zooplankton predator-prey system in the Great South Channel region of the southwestern Gulf of Maine. The study focused on the oceanographic factors responsible for the development of dense patches of the copepod *Calanus finmarchicus*, which comprise the major prey resource for right whales. A pilot study was conducted in the spring of 1986 (Wishner *et al.* 1995), and more intensive sampling occurred during the spring season in both 1988 and 1989 (Kenney and Wishner 1995). Three non-mutually exclusive hypotheses underlay the study: patch development is due to (1) extremely high *in situ* primary and secondary productivity; (2) large numbers of *Calanus* are advected into the region and concentrated by hydrographic processes; and/or (3) a behavioral tendency of the copepods themselves to aggregate. The results confirmed the co-occurrence of right whales with high-density *Calanus* patches, and also demonstrated that right whales fed on patches with higher proportions of later life stages. The physical oceanographic studies supported the advection hypothesis, possibly augmented by a tendency of *Calanus* to aggregate, but there was little evidence to support the productivity hypothesis.

*GLOBEC*

The GLOBal ocean ECosystems dynamics (GLOBEC) Georges Bank program (Wiebe *et al.* 2001) seeks to understand the ecology and population dynamics of two important commercial fish species, cod and haddock, and of two key zooplankton groups, *Pseudocalanus* spp. and *Calanus finmarchicus.* Much of the GLOBEC field work concentrated on Georges Bank, a region that is seldom visited by right whales. However, GLOBEC research on the right whale's primary prey, *C. finmarchicus*, in the Gulf of Maine basin regions near Georges Bank has particular relevance to right whale ecological research (e.g., Meise and O'Reilly, 1996, Durbin *et al.* 1997, 2000, Conversi *et al.* 2001). Moreover, GLOBEC modeling efforts have provided the physical and biological framework to explore how and why *C. finmarchicus* accumulate in certain areas at certain times of the year, such as during the spring in the Great South Channel (Lynch *et al.* 1998, Miller *et al.* 1998). Although field work has ended, the GLOBEC program will soon begin the final analysis phase. The GLOBEC program will continue to improve our understanding of the Gulf of Maine ecosystem and should therefore be closely monitored by researchers interested in right whale ecology.

*Work by T. Woodley in the Bay of Fundy*

Woodley (1992) characterized right whale habitat in the lower Bay of Fundy by quantifying relationships (using habitat index equations) between 19 physical and environmental variables and the distribution and density of whales in 5X5km quadrats. Right whales were found to be distributed in the deeper areas of the Grand Manan basin where the bottom topography was flat, the water stratified, and tides were high. Within the central gyre of the Bay of Fundy, these characteristics contribute to aggregations of zooplankton, which were found in significantly higher concentrations in quadrats with right whales than those without. Variation in right whale density was primarily explained (42%) by the interaction of maximum depth and an index of mid-water prey abundance derived from echograms. Habitat use by right whales in the Bay of Fundy appears to be primarily associated with prey distribution and abundance, while the effects of physical environmental characteristics appear to be indirect.

*Doctoral work by J. Goodyear*

The University of Guelph conducted studies of right whale diel activity, diving and prey abundance in the lower Bay of Fundy during 1987-1990. These studies were part of the doctoral research of Jeff Goodyear (Goodyear 1996). Right whales were tagged primarily with radio transmitters that allowed monitoring of movements and dive durations, with some tags providing depth-of-dive data via an acoustic transmitter (Goodyear 1993). In contrast to the observations of Baumgartner and Mate (2003), a few of the tagged whales dove to and appeared to forage very near or at the sea floor. This behavior was most apparent in 1989. The long attachment durations of the Goodyear implanted tags also allowed the estimation of daily activity budgets. Right whales spent over half their day engaged in long dives, during which they were presumed to be feeding.

*Contemporary right whale energetics and prey-field studies in the Bay of Fundy*

Dalhousie University (C. Taggart and colleagues) are conducting a study in the Bay of Fundy of right whale energetics and the prey field. This research involves collaboration with a PhD student (J. Michaud). The study uses *in situ* zooplankton sampling across a range of seasonal, horizontal and vertical scales using direct (BONGO, RMT, BIONESS nets) and indirect (ADCP backscatter, optical plankton counter) sampling, lab-based estimates of individual and bulk zooplankton stages, size, biomass, lipid (Iatroscan) and energy (Parr Isoperbol calorimetry) content. CTD (water mass) and ship- and bottom-mounted ADPCs provide data for inferring circulation patterns. The research focuses on the temporal and spatial variation in the distribution, concentration, biomass, stage-development, and lipid and energetic content of the prey-field (primarily *C. finmarhicus*) collected in the vicinity and at the depths of feeding whales. The samples are being used for identification and staging and for estimating abundance, biomass, lipid content (mainly wax esters) and total energy content variation in time and space. These measures allow for inter-conversion of various metrics for direct comparison with literature values, as well as for deriving estimates (with uncertainty) of the energy available to the whales; these data are essential to any determination of if, and how, energy demands are being met and to estimate right whale carrying capacity from an energetics perspective.

*Historical variation in the right whale prey-field in the Bay of Fundy*

Dalhousie University is also engaged in investigating how much of the inter-annual variation in the abundance and quality of prey might explain inter-annual variations in right whale distribution (Bay of Fundy vs. Roseway Basin), whale condition/health and reproductive success (calving, calving intervals, etc.). The paucity of historical data on zooplankton abundance and quality make this question difficult to address. However, now available are the detailed contemporary data outlined above that form the basis for the inter-conversion and calibration of the various metrics necessary to go back in time to arrive at reasonable estimates of inter-annual variability in the prey-field. This can be achieved because the necessary historical data (including oceanographic measures) and the entire plankton sample material exist for the autumn, annually for the period 1972 to 1998 inclusive, in both the Bay of Fundy and in Roseway Basin. Furthermore, the historical collection methods match those used in some of the contemporary work. From the historical samples, inter-annual variation in the quantitative estimates of the planktonic prey-field can be derived (stage, size, abundance biomass) and expanded using the above inter-calibration conversions (lipid and energetic content).

*Cape Cod Bay Foraging Studies*

Studies of Cape Cod Bay and adjacent waters, including Stellwagen Bank and the northern near-shore portion of the Provincetown Slope, were first undertaken in the 1960's from aircraft and vessels by Bill Schevill and Bill Watkins of WHOI. Though much of their effort was directed at acoustic research and at the occurrence patterns of right whales in the region, their reports contain pertinent observational anecdotes describing the patterns of right whale habitat use that prevailed in the early years of their study. Striking among their observations were those of whales skim feeding in patches of orange-red plankton during the spring.

In 1984, guided by the early studies by Schevill and Watkins and by observations from whale watching boats, the Center for Coastal Studies (CCS) initiated work on the whales found in Cape Cod Bay during the winter and spring. The discovery in the mid-1980's of regular whale residency and feeding in the Bay during the early and mid-winter months stood in contrast to the previously held view that right whales were found in Cape Cod waters as part of a brief migration-related impulse in the mid spring. Work since 1984 by CCS has focused on a variety of aspects of habitat use and environmental correlates of whale occurrence and the continuing collection of basic photo-identification information for use by the New England Aquarium. Working in close proximity to whales feeding near or at the surface has permitted the identification of special characteristics of the plankton resource that release feeding behavior. Such work has led to a characterization of the environment favored by the whales. Among these are: (1) identification of small-scale foraging patterns in the vertical and horizontal planes that optimize food intake; (2) energetic calculations from the feeding cylinder of the whales that surpasses estimated requirements by a factor of more than two; (3) an estimated feeding threshold that governs the patterns of habitat use in the Bay; and (4) and a variety of characterizations of the resource patch that control feeding. Studies of the vertical structure of the acceptable patches and the use of zooplankton measures to manage the habitat with respect to fishing and shipping activities have been the focus of recent CCS research efforts.

Over the past decade scientists from several institutions have studied aspects of habitat use by right whales in the Bay. These include: Cabell Davis (WHOI, zooplankton distribution and patch formation), Chris Clark (Cornell University, using vocalizations to track the movements of right whales in Cape Cod Bay), Peter Tyack (WHOI, development of the DTAG), aircraft survey studies (CeTAP and recently CCS/DMF), and "critter cam" attachment and monitoring (to determine reaction of whales to vessels and orientation of whales during deep feeding bouts).

In summary, Cape Cod Bay offers an opportunity to study various aspects important to the management and conservation of right whales. Cape Cod Bay, though arguably an atypical right whale habitat, presents investigators with an opportunity to investigate issues of feeding, distribution, and management of the species which cannot be conducted or addressed in other habitats.

*Atlantic Zonal Monitoring Program*

In 1999, Canada's Department of Fisheries and Oceans began an environmental monitoring program at several stations on the Canadian shelf. Known as Atlantic Zonal Monitoring Program (AZMP), this program measures zooplankton and phytoplankton abundance, nutrient concentrations, and hydrographic data at monthly or more frequent intervals. The stations at Prince 5 near the Bay of Fundy and Station 2 off of Halifax should provide information most relevant to right whale ecology.

*Cornell University Right Whale Prediction System*

Researchers at Cornell University, the Center for Coastal Studies, the New England Aquarium, and the University of New Hampshire are collaborating to develop an operational system that will provide environmental information useful for predicting right whale movements. The ultimate goal is to develop data products indicating potential right whale feeding areas. At the center of this project is a model that predicts the distribution of the copepod *Calanus finmarchicus*, a key right whale food source. The system uses high-resolution satellite imagery of sea-surface temperature and chlorophyll to drive the dynamics of the model. The accuracy of these products is being assessed using comparisons with direct measurements of *Calanus* abundance and egg-production rate from Jeffreys Ledge, observations of zooplankton and right whales in Cape Cod Bay, and historical right whale and *Calanus* data. The forecast system will provide information on potential right whale feeding areas, predictions that should aid in the implementation of any dynamic management program.

This system has been operational since early 2004, and consists of three components: (1) routines to automatically retrieve and processes daily satellite measurements of sea surface temperature (SST), SST gradients (an indicator of fronts), and ocean color (an indicator of chlorophyll concentration); (2) a *Calanus* model that combines satellite information with circulation fields from the Gulf of Maine to predict the distribution of *Calanus finmarchicus*; and (3) a web interface to the data products.

*Duke University Predictive Modeling*

Duke University investigators are developing techniques for modeling marine mammal distribution. This effort focuses on the development of novel Bayesian techniques, as well as more spatially explicit methods. The effort is bringing together spatial modelers, Bayesian statisticians, marine mammalogists, ecologists and oceanographers. The goal of the program is to produce predictive models at spatial and temporal resolutions useful to managers.

*University of Massachusetts SST analysis*

J. Bisagni and S. Wagner (University of Massachusetts, Dartmouth) conducted a study using archived SST data to identify fronts, and to retrospectively link these fronts to past right whale distribution data. The study remains unpublished, but it is believed that no reliable associations between fronts and right whales were identified. Whether this was a result of deficiencies in statistical analytical techniques, poor resolution of SST data, or some other factors, is unknown.

*Tagging (satellite-monitored and TDR-based) in the Bay of Fundy and elsewhere*

Oregon State University (OSU) conducted several studies of right whale ecology in the summer habitats of the lower Bay of Fundy and the southwestern Scotian Shelf during 1999-2001. In the Bay of Fundy, these studies built upon the habitat research of Murison and Gaskin (1989) and Woodley and Gaskin (1996). The OSU research consisted of (1) a foraging ecology study based on suction-cup attached time-depth recorder data (Baumgartner and Mate 2003), (2) a distribution and habitat study based on simultaneous visual and oceanographic surveys (Baumgartner *et al.* 2003a), (3) a study of long-range movements using satellite-monitored radio tags (Mate *et al.* 1997; Baumgartner and Mate, submitted), and (4) a study of the relationship between right whale distribution and their prey's horizontal and vertical distribution over diel and tidal time scales (Baumgartner *et al.* 2003b). Each of these studies emphasized the importance of late-stage *Calanus finmarchicus* in the diet of right whales in these habitats. Baumgartner and Mate (2003) found that the *C. finmarchicus* upon which right whales fed during the day were aggregated in very discrete layers above a bottom mixed layer. These layers were comprised of *C. finmarchicus* fifth copepodites that were likely in diapause (Baumgartner *et al.* 2003b). Right whales occasionally dove to the bottom in the lower Bay of Fundy, but these dives appeared to be exploratory in nature. Observed foraging dives always occurred tens of meters above the bottom.

### *Digital tag (DTAG) research*

The digital acoustic recording tag (DTAG, Johnson and Tyack 2003) records the movements and orientation of animals, and has been used to record the swimming and diving behavior of right whales in the Bay of Fundy (Nowacek *et al.* 2001). Some of the data collected (such as orientation during foraging) may be useful for assessing risk factors associated with entanglement of whales in fishing gear. Information on entanglement risk can be gleaned from existing DTAG data: 1) orientation during foraging dives, e.g. "side-skimming" with the whale rotated with respect to its long axis (i.e. rolled) and, if present, whether these behaviors are transient or continuous; 2) significant heading changes (i.e. to stay in the patch); 3) amplitude and frequency of fluke stroke, especially during foraging versus "exploratory" or V-shaped dives, and specifically whether a whale's mouth is open or closed at this time; 4) occurrence underwater of "nodding" behavior frequently seen at the surface in Cape Cod Bay that may indicate a whale cleaning its baleen; and 5) how close to the bottom whales forage (using information on water depth derived from positional data).

## **Prey species and prey detection**

### *Prey species*

Work in Cape Cod Bay and elsewhere has indicated that right whales feed on various species of invertebrates, with calanoid copepods being dominant. Cape Cod Bay in 2004 was dominated by a bottom layer of *Centropages* in January, followed by surface layers of *Pseudocalanus* and then *Calanus*. This succession is not unusual, and also occurs in the Great South Channel over winter and into spring.

In the BOF in summer, the prey base is diapausing *Calanus* above the bottom mixed layer. The forage base is very different in the GSC in spring, with active, growing *Calanus* behaving in ways which are not well understood. Thus, extrapolating from one habitat to another may be inappropriate.

We currently know nothing of what right whale prey - and thus the whales themselves - are doing at night. In the BOF, acceptable layers of prey may sometimes occur close to the surface at night. Data from tagged whales suggest shorter dives and more time at the surface during the night-time period (Goodyear 1996).

### *Prey detection*

Little is known about how right whales use their sensory systems to detect and exploit prey patches.

Touch: the use of touch as a primary means of sampling prey density is likely, but this requires anatomical investigations of facial enervation, notably the configuration of the trigeminal nerve.

Smell: the olfactory lobe and nares are well developed in mysticetes (unlike in toothed whales), and use of smell to detect prey patches downwind at the surface is quite plausible (Cave 1988).

Taste: the role of taste is unknown, but it is likely to be important in assessing the quality of prey.

Sight: this is likely to be important at short distances (though constrained by underwater visibility). Color sensitivity in right whales is uncertain, but anatomical examination of the eyeball suggests that the resolution of the whale's eyesight is generally good.

Hearing: the role of hearing in prey detection is unknown, although right whales might exploit shadowing from copepod patches against the ambient noise field.

The group agreed that nothing could be pursued on this topic that would further management aims.

**Foraging questions relating to entanglement, and required research**

Videotaped observations of surface feeding indicate that the mouth of right whales is continuously open for long periods during foraging. It is almost certain that this also occurs during sub-surface foraging, anywhere in the water column. This likely explains why right whales become entangled through the mouth more often than humpback whales (Kozuck *et al.* 2004), which are gulp feeders.

The major questions about right whale foraging with implications for entanglement risk are given below, together with comments on information required to clarify the situation.

*1. Do right whales forage at or near the sea floor?*

It is known from work in Cape Cod Bay that ultra-dense layers of prey exist just above (and probably at) the bottom. It is not clear whether the results from Cape Cod Bay are representative of other areas, but Wishner *et al.* (1995) have documented bottom layers in various places in the world.

Mud has sometimes been observed on the heads of right whales, indicating that the animals are contacting the bottom (wholly or partly upside-down) when they feed. This phenomenon occurs in the Bay of Fundy, and has been observed occasionally in Cape Cod Bay (but which is largely sandy bottom) and never in the Great South Channel (which is also not mud bottom).

Right whales tagged by Baumgartner and Mate (2003) routinely went to the top of the bottom mixed layer, no matter where that was in the water column. Other data (Goodyear 1996) indicate that right whales dive and may forage at or near the bottom in the Bay of Fundy. Both Baumgartner and Nowacek report detached tags returning to the surface covered with mud, indicating that whales make contact with the sea floor.

In at least some habitats, right whales spend enough time at or very close to the bottom to generate high risk of entanglement with ground lines. Inspection of the anatomy of a right whale's head indicates that any line must be placed below the deflection point at the anterior tip of the rostrum so as not to be captured by an animal feeding upside down on the bottom; M. Moore (pers. comm.) estimates this distance to be approximately 1 foot (30 cm). The strong implication of these two factors is that ground lines in these habitats should be made of sinking rope, and located *on* the bottom, not right above it.

However, understanding whether this phenomenon occurs in all habitats is critical, and there is no point in requiring modification of ground lines in an area unless whales were feeding at the bottom there. As noted above, bottom layers occur in Cape Cod Bay and in the Bay of Fundy; it is not known whether this is the case in other habitats. Research to establish the characteristics and location of prey layers in other right whale feeding habitats, and documenting the foraging behavior of right whales in these areas should be a high priority.

Observations of a tagged whale (Van Halen) suggested the whale was diving to the bottom in all of its movements through the Gulf of Maine region. Thus, the risk-averse approach would be to require sinking line in all areas. It is possible that bottom layers of prey do not occur over rough bottom (which have higher turbulence); however, there is currently no evidence for this. The resolution of bottom type data is probably not good enough to correlate this with right whale distribution. Contacting USGS to investigate this further would be helpful.

There are no dive data or foraging information for right whales south of Cape Cod, so it is not clear whether sinking line should be required for this area (notably the mid- and southern Atlantic region).

*2. Do right whales on prospecting dives (e.g. while traveling) open their mouths?*

Whether right whales open their mouths on prospecting dives is an important question. Dive profiles derived from DTAG data suggest that right whales are prospecting and sampling the water column much of the time even while traveling. It is not known whether they open their mouths during prospecting, which would significantly increase their risk of entanglement.

It is likely that open versus closed mouth behavior could be detected through high-amplitude fluke strokes or increased fluke stroke rates in the DTAG data, since an animal must generate more power to move with the mouth open. Preliminary analysis of existing DTAG data suggest that prospecting dives are not conducted with the mouth open. Ground-truthing this by tagging surface-feeding whales, where the mouth can be observed and correlated with the tag data (possibly in combination with a video tag) would be a useful approach. A joint DTAG/video (e.g. critter cam) deployment for diving whales would also be important to determine how movement changes when the mouth opens at depth, but positioning of the video sufficiently far forward on the whale to observe what the mouth was doing might be problematic.

*3. How do whales become entangled in surface system lines?*

It is relatively easy to envisage how whales feeding at depth (whether at the bottom or somewhere in the water column) would become entangled by contacting ground line or end line; an animal's orientation while feeding may be important. However, it is less clear how whales become entangled in surface system lines. Does this result from a whale directly contacting surface system gear while surface feeding, or from hitting line further down and subsequently becoming entangled in the surface system as the whale reacts and moves towards the surface (sliding up the line somehow)?

Without direct observations of foraging whales actually becoming entangled in gear at or below the surface, it is probably not feasible to address this question with additional research. Such observations would occur only by chance, and are thus unlikely.

*4. Other issues*

It was agreed that any foraging research needs to be conducted in the same locations in multiple years to account for inter-annual variability.

We do not currently know whether right whales forage while migrating off the U.S. mid-Atlantic states, or while in the southeastern U.S. calving area; this is generally thought to be unlikely. Given that this issue has important implications for entanglement risk (and therefore fisheries management), research to determine whether whales feed in these areas should be conducted. This might involve tagging, as well as stable isotope or fatty acid analysis.

Very few fatal entanglements were recorded prior to the 1990's, and also very few head wraps were observed among entangled whales; there seems to be an increasing trend towards head entanglements in the last decade or so. This should be quantified, and if a trend is evident it would raise the question of what changed in the 1990's. Possible explanations would be a change in fishing effort or a change in prey characteristics that would modify foraging behavior such that entanglement risk was increased. The collapse of the groundfish fishery in the 1990's and the subsequent expansion of lobster effort may offer an explanation; this should be investigated. Examining licensing and the trend towards areas which right whales are known to frequent might represent fruitful approaches.

It is not known how right whales are oriented when they feed along the bottom (i.e. do they swim parallel to the bottom or with the body angled up?) It would be useful to examine photographs of whales with mud on their heads to see if these can provide any insights.

Tag-based foraging studies in other areas (beginning with the Great South Channel and western Gulf of Maine and perhaps then moving to other areas) should be a priority. Baumgartner is attempting to pursue a rapid-response approach in which such work is conducted in areas where right whales are reported by surveys. Targeting future foraging research at areas where gear is concentrated would be useful. TDRs should be placed onto all tagged whales (including entangled animals).

**Habitat characterization and predictive modeling**

Although factors such as social behavior may to an extent determine where right whales are found (and while their occurrence during winter in the southeastern U.S. is likely not related to food), for the purpose of prediction it must be assumed that the primary effector of right whale distribution is prey. Accordingly, all predictive models seek to use environmental data to identify areas of prey concentration. From a management point of view, the important scale for prediction of right whale occurrence is on the order of kilometers (i.e. the extent of a right whale aggregation).

In terms of prey density, there are three thresholds that are important to right whales: (i) long-term average density that allows a whale to break even energetically; (ii) the long-term average density that allows a whale to add surplus energy (important for mature females but also other classes); and (iii) the immediate threshold which triggers feeding. It is taken as axiomatic that whales have evolved the ability to detect patches, detect gradient densities within patches, and assess prey quality (e.g. prey type and stage).

The key question is whether environmental variables (e.g. SST, sea-surface height - whether remotely sensed or otherwise) can *reliably* be used as an indicator of conditions likely to aggregate plankton in such a way that average density exceeds one or all of the three thresholds above. Also important to this effort is to explore the linkage between remotely sensed data and actual physical processes that may/may not aggregate prey.

Obtaining extensive data on right whale distribution is critical to any attempt to correlate environmental conditions with right whale presence *or* absence. Because both positive and negative data are essential in such analyses, it is critical that broad-scale surveys be conducted over several years to determine which areas are important every year, which are important in some years but not others, and which are not important at all. The broad-scale surveys currently being conducted by NEFSC, in combination with surveys by CCS and others, are beginning to provide such data for the Gulf of Maine region, and these data are expected to be a critical component in developing predictive models. Surveys in other areas (e.g. the mid-Atlantic and further south) will also be useful in this regard. The minimum duration of such surveys is unclear, but several years of data are essential to capture inter-annual variability in occurrence.

In this regard, it should be noted that right whales have been documented to use a particular area heavily for several years, then abandon it for a decade, a problem which greatly complicates efforts to assess the value of specific habitats using data collected over shorter periods. Roseway Basin is the best example of this phenomenon: it was heavily used in the 1980's, then virtually abandoned after 1992. The working group noted that, had several years of surveys been initiated after 1992, the results would have led us to the erroneous conclusion that Roseway was of little or no importance to this species.

However, from a scientific point of view such dramatic changes are potentially very useful. Examining characteristics of specific habitats with and without right whales in certain years (notably the Great South Channel in 1992 and adjacent years, and Roseway Basin before and after 1993) would likely produce important insights into the environmental characteristics that determine habitat suitability. Alternatively, it is possible that such analyses might highlight our inability to do this at all.

On a shorter timescale, if whales are observed to remain in a particular area for a protracted period, this suggests that the area is significant for foraging (although social factors may also be important). Conversely, an area in which whales do not remain is presumably one which does not have adequate prey or one which, while remaining "acceptable", is less valuable as a foraging location than other adjacent habitats with which it may unfavorably "compete". Characterizing such areas, examining whether they can be distinguished using environmental data and, if so, using such data to identify other potentially suitable/unsuitable habitats, would be a significant step towards developing a predictive model.

This leads to the question of which characteristics should be examined in suitable/unsuitable habitats, and whether the data are of sufficient resolution to use reliably as a predictor of right whale occurrence/absence. Using satellite data - which largely tells what is happening at or close to the surface, which in itself is indicative of growth rates of copepods - may be useful in predicting habitat during spring and autumn; it is perhaps not useful in summer, when copepods go into diapause at depth.

Baumgartner commented that right whales do not appear to be associated with fronts, but Pershing noted that the scale of detection is a problem and that much smaller-scale features may be important in concentrating prey, but that these may be difficult to detect with current sampling.

Overall, a better understanding is required of vertical distributions of both the processes and the prey organisms. Distribution of prey layers is being studied in Cape Cod Bay and the Bay of Fundy, but the micro-scale physics that drive the formation of these layers (causing aggregation) are less well known. The behavior of copepods is also important; layer formation may be impossible if animals are not actively attempting to somehow hold their place in the water column. Are the diapausing layers there because of passive aggregation from physical factors, or some other reason? All of this will potentially vary by habitat and by season, so work across areas and times to examine this variability is important.

Among other things, predictive modeling may always be flawed because a remnant population is likely well below carrying capacity, and thus truly suitable habitats may not necessarily be occupied by whales (i.e. there are too few whales in the population to exploit all suitable areas). Overall, the working group recognized that the various efforts described above will certainly contribute to the goal of developing predictive models, but that the outcome was presently unclear.

It was acknowledged that ongoing work should be coordinated so that data and analytical approaches could be used to the greatest effect. In this regard, Nowacek agreed to chair a small working group to coordinate research; the group is charged with summarizing current knowledge and potential directions to assess whether predictive modeling is truly feasible to the extent that it could at some point be of practical use to management.

**Literature cited**


Baumgartner, M.F. and Mate, B.R. Summer and fall habitat of North Atlantic right whales inferred from satellite telemetry. *Canadian Journal of Fisheries and Aquatic Sciences* (submitted).

Baumgartner, M.F. and Mate, B.R. 2003. Summertime foraging ecology of North Atlantic right whales. *Marine Ecology Progress Series* 264:123-135.

Baumgartner, M.F., Cole, T.V.N, Clapham, P.J. and Mate, B.R. 2003a. North Atlantic right whale habitat in the lower Bay of Fundy and on the SW Scotian Shelf during 1999-2001. *Marine Ecology Progress Series* 264:137-154.

Baumgartner, M.F., Cole, T.V.N., Campbell, R.G., Teegarden, G.J. and Durbin, E.G.. 2003b. Associations between North Atlantic right whales and their prey, *Calanus finmarchicus*, over diel and tidal time scales. *Marine Ecology Progress Series* 264:155-166.

Cave, A.J.E. 1988. Note on olfactory activity in mysticetes. *Journal of Zoology London* 214: 307-311.

Cetacean and Turtle Assessment Program, University of Rhode Island (CETAP). 1982. Abundance and distribution of cetaceans in the Great South Channel area in relation to physical and biological variables. Special Topic C in: A Characterization of Marine Mammals and Turtles in the Mid- and North Atlantic Areas of the U.S. Outer Continental Shelf, Final Report. Contract number AA551-CT8-48. U.S. Dept. of the Interior, Bureau of Land Management, Washington, DC.

Conversi, A., Piontkovski, S. and Hameed, S. 2001. Seasonal and interannual dynamics of *Calanus finmarchicus* in the Gulf of Maine (northeastern US shelf) with reference to the North Atlantic Oscillation. *Deep-Sea Research II* 48:519-530.

Durbin, E.G., Runge, J.A. Campbell, R.G., Garrahan, P.R., Casas, M.C. and Plourde, S. 1997. Late fall – early winter recruitment of *Calanus finmarchicus* on Georges Bank. *Marine Ecology Progress Series* 151:103-114.

Durbin, E.G., Garrahan, P.R. and Casas, M.C. 2000. Abundance and distribution of *Calanus finmarchicus* on the Georges Bank during 1995 and 1996. *ICES Journal of Marine Science* 57:1664-1685.

Goodyear, J.D. 1993. A sonic/radio tag for monitoring dive depths and underwater movements of whales. *Journal of Wildlife Management* 57:503-513.

Goodyear, J.D. 1996. Significance of feeding habitats of North Atlantic right whales based on studies of diel behaviour, diving, food ingestion rates and prey. Ph.D. dissertation. University of Guelph. 269 pp.

Johnson, M.P. and Tyack, P. 2003. A Digital Acoustic Recording Tag for Measuring the Response of Wild Marine Mammals to Sound. *IEEE Journal of Oceanic Engineering* 28 (1):3-12.

Kenney, R.D., Hyman, M.A.M., Owen, R.E., Scott, G.P., and Winn, H.E. 1986. Estimation of prey densities required by western North Atlantic right whales. *Marine Mammal Science* 2: 1-13.

Kenney, R.D. and Wishner, K.F. 1995. The South Channel Ocean Productivity Experiment. *Continental Shelf Research* 15: 373-384.

Knowlton, A.R. and Kraus, S.D. 2001. Mortality and serious injury of North Atlantic right whales (*Eubalaena glacialis*) in the North Atlantic Ocean. *Journal of Cetacean Research and Management* (Special Issue) 2: 193-208.

Kozuck, A., Salvador, G., Kenney, J., Robbins, J., Kraus, S., Landry, S. and Clapham, P. 2004. Analysis of fishing gear involved in entanglements of right and humpback whales. *Marine Mammal Science* (in review).

Lynch, D.R., Gentleman, W.C., McGillicuddy, Jr., O.J., and Davis, C.S. 1998. Biological/physical simulations of *Calanus finmarchicus* population dynamics in the Gulf of Maine. *Marine Ecology Progress Series* 169:189-210.

Mate, B.R., Nieukirk, S.L. and Kraus, S.D. 1997. Satellite-monitored movements of the northern right whale. *Journal of Wildlife Management* 61:1393-1405.

Meise, C.J. and O'Reilly, J.E.. 1996. Spatial and seasonal patterns in abundance and age-composition of *Calanus finmarchicus* in the Gulf of Maine and on Georges Bank: 1977-1987. *Deep-Sea Research* II 43:1473-1501.

Miller, C.B., Lynch, D.R., Carlotti, F., Gentleman, W. and Lewis, C.V.W. 1998. Coupling of an individual-based population dynamic model of *Calanus finmarchicus* to a circulation model for the Georges Bank region. *Fisheries Oceanography* 7:219-234.

Murison, L.D. and Gaskin, D.E. 1989. The distribution of right whales and zooplankton in the Bay of Fundy, Canada. *Canadian Journal of Zoology* 67:1411-1420.

Nowacek, D.P., Johnson, M.P., Tyack, P.L., Shorter, K.A., McLellan, W.A. and Pabst, D.A. 2001. Buoyant balaenids: the ups and downs of buoyancy in right whales. *Proceedings of the Royal Society of London* B, 268:1811-1816.

Wiebe, P.H., Beardsley, R.C., Bucklin A. and Mountain, D.G. 2001. Coupled biological and physical studies of plankton populations in the Georges Bank region and related North Atlantic GLOBEC study sites. *Deep-Sea Research II* 48:1-2.

Wishner, K.F., Schoenherr, J.R., Beardsley, R. and Chen, C. 1995. Abundance, distribution and population structure of the copepod *Calanus finmarchicus* in a springtime right whale feeding area in the southwestern Gulf of Maine. *Continental Shelf Research* 15: 475-507.

Woodley, T.H. 1992. A characterization of North Atlantic right (*Eubalaena glacialis*) and finback (*Balaenoptera physalus*) whale habitat in the lower Bay of Fundy, Canada. M.S. Thesis, University of Guelph, Guelph, Ontario, Canada. 104 p.

Woodley, T.H. and Gaskin, D.E. 1996. Environmental characteristics of North Atlantic right and fin whale habitat in the lower Bay of Fundy, Canada. *Canadian Journal of Zoology* 74:75-84.