Conceptual food web model for Cape Cod Bay, with associated environmental interactions

Massachusetts Water Resources Authority

Environmental Quality Department
Report ENQUAD 98-04

Citation:

Kelly JR, Davis CS, Cibik SJ. 1998. Conceptual food web model for Cape Cod Bay, with associated environmental interactions. Boston: Massachusetts Water Resources Authority. Report ENQUAD 98-04. 9 p.

TECHNICAL MEMORANDUM
March 31, 1998

Conceptual Food Web Model for Cape Cod Bay, with Associated Environmental Interactions

Jack Kelly, Jack Kelly Consulting
Cabell Davis, WHOI
Steve Cibik, ENSR

Purpose
The endangered North Atlantic right whale visits and forages in Cape Cod Bay. Its attraction to this habitat appears to relate to feeding on dense aggregations of selected copepod prey species. Although Cape Cod Bay lies some distance from the present and future MWRA effluent outfall, there are concerns about how the future outfall discharge into western Massachusetts Bay may affect the feeding habitat of the right whale. This technical memorandum was undertaken to:

- outline the basic understanding of what we know about the food web in Cape Cod Bay involving right whales, and
- suggest generally how the food web may be structured by environment or affected by a future outfall.

The following simplifies a complex biology and ecology; it is intended to scope out the important elements for a model of the food web. Moreover, it is a "working concept" to serve as the simple framework for continuing discussions of food web change in Massachusetts and Cape Cod Bay and the MWRA outfall area, especially as related to monitoring and research needs.

Critical Points of the Biological Food Web
As a first step in understanding the relationship, if any, between the MWRA effluent outfall and the North Atlantic right whale population in Cape Cod Bay, a conceptual model of the whale/plankton food web is needed to show the various linkages and potential transfer pathways in the bay. A simplified food web is shown in Figure 1. Note that the diagram emphasizes flows from nutrients to whales, because of an emphasis on the outfall, but the model also depicts predators that in essence compete with right whales for their prey. There are several significant flow paths (although simplified), particularly:

- a direct ("grazing") path to whales: nutrients-net phytoplankton-copepods-whales;
- an indirect ("microbial loop") path that can lead to whales: nutrients-nanophytoplankton-microheterotrophs-copepods-whales; and
- a detrital (shunt) path dominated by colonial *Phaeocystis*: nutrients-*Phaeocystis*-detritus-nutrients.

Many biological components are depicted, none with life history detail, but including:

- the main prey of the right whale, copepods with oil sacs, i.e. *Calanus* and *Pseudocalanus*;
- many other predators that haven't been routinely sampled well; and
- other aspects of the microbial loop (e.g.. detritus-bacteria-microheterotrophs).

The preferred prey organisms of the right whales in Cape Cod Bay appear to be two copepod species, *Calanus finmarchicus* and *Pseudocalanus* spp. (*P. moultoni* or *P. newmani*), both of which carry wax ester lipid reserves in pronounced "oil sacs" within their bodies. The data of Mayo and Marx (1990) clearly demonstrate that these species are the dominant ones present in the vicinity of feeding right whales in Cape Cod Bay during most years. In only two years out of the 10-year sampling period were other zooplankton dominant in the vicinity of feeding whales (Mayo and Marx, 1990; Mayo, unpublished data). It is likely that the oil in these copepod species is a main energy source for the whales, and it is possible that other copepod species are less desirable because they do not contain these oil storage sacs. Changes in abundance of *Calanus* and *Pseudocalanus* then could potentially affect the food levels available to the whales.

Abundance of these copepods is affected by availability of their own prey and losses to predation (Figure 1). Advection in and out of the bay is also a factor affecting abundance. Copepods feed on both phytoplankton and microheterotrophs (e.g., protozoans). The most direct food chain is from nutrients to diatoms to copepods. Other indirect routes involving the microbial loop may also be important. In the latter case, nutrients are taken up by nanophytoplankton which are consumed by microheterotrophs. Decomposition of detritus by bacteria replenishes the nutrient pool and may also release carbon to the microheterotrophs. Bacteria also can take up dissolved nutrients and can be consumed by microheterotrophs. A shunt to the nitrogen cycling can occur during blooms of the nuisance alga *Phaeocystis pouchetii,* which can take up nutrients and form large colonies which may be unavailable to size-dependent grazers. These colonies ultimately die, with some fraction returning nutrients, via detritus and bacteria, to the nutrient pool, while the remaining fraction may once again become available to grazers as the colonies are disrupted. Nitrogen is returned by the various groups via egestion, excretion, and death/decomposition.

The main predators of the copepods are not the whales themselves of course, but various planktonic invertebrates and planktivorous fishes. Invertebrate predators include gelatinous organisms such as medusae (both hydro and schypho) and ctenophores (e.g., Mnemiopsis and Pleurobrachia), as well as chaetognaths, decapods, and mysids. Planktivorous fishes include mackerel and alewives, both of which are present during spring when the *Calanus/Pseudocalanus*/right whale interactions exist. In addition to right whales, another marine mammal, the humpback whale, feeds on other copepod predators, especially sand eels and mackerel (Figure 1).

Interaction of Biology with the Environment, an Ecosystem Perspective

The biological food web is embedded in an ecological setting where a variety of physical and biogeochemical features can shape dynamics of the food web in time and space (Figure 2). The precise interplay between biological species, as well as between biology and the environment, that leads to suitable foraging habitat for right whales (or to any other upper-level consumer of the food web) is poorly known and not predictable from year to year. Nonetheless it is possible to indicate principal features of the ecosystem that have influence. Such factors are listed in Figure 2, which organizes the influences at "levels" of the food web and emphasizes "scales" of significance for the critical zooplankton prey species of the right whale.

Many factors (Figure 2) influence the dominant food "chain" (Figures 1 and 2) developing in space and time. The chain most directly supporting right whales is a simple, short grazing chain with diatoms species as the food for the preferred zooplankton species. Whales typically visit Cape Cod Bay in March/April. Historically, a *Phaeocystis* bloom can follow or supplant a diatom bloom around this time. A strong *Phaeocystis* (or other nuisance algae) bloom may inhibit feeding of whales (e.g., baleen clogging or palatability inhibition) even if preferred zooplankton are present. *Phaeocystis* may also disrupt the food web by outcompeting diatoms for nutrient resources and supporting the development of detrital community or lead to less-preferred zooplankton species. Conditions determining whether *Phaeocystis* strongly develops in a given year in Massachusetts and Cape Cod Bays are not well described. The third main "chain" starts with a "microbial loop" plankton community; this community less directly and strongly leads to the preferred zooplankton species (Figure 1). This third community is most typically found in situations when the surface water is warm and when the water column is stable and vertically stratified. Nutrients are often depleted in surface water under such conditions and rapid recycling within the microbial loop maintains the plankton community. Since these conditions do not usually occur in March or April when right whales visit, it is not clear that this third type of chain is in competition for nutrient resources with the direct grazing chain which actively supports whale feeding.

Zooplankton are influenced by the availability of their food resources, which typically are select phytoplankton but can include *Phaeocystis* colonies that are not too large (< 300 *u*m), non-phytoplankton organic matter and protozoans, depending on the zooplankton species. Besides physical influences on the phytoplankton community, Figure 2 depicts the zooplankton community as being bracketed by environmental influences at broad regional scales and finer localized scales. As examples at a regional scale, temperature of the water carrying a developing *Calanus* population can influence the time of development through a series of life stages from egg to mature adults. Right whales prefer the larger juvenile and adult size classes. Similarly, a relatively "warm" winter may produce a sizable overwintering population of larger stages of copepods, yielding both larger numbers of preferred prey as well as introducing an "altered" grazing pressure on primary producers. The latter may itself influence the composition of the seasonal phytoplankton assemblage.

Salinity can influence what species of copepod is dominant; some species have wide, and some narrow, salinity tolerances and the preferred salinity range varies among species. Advection of water helps transport populations into or out of a broad geographic area. Currents and circulation in general help establish residence times of water in different basins and areas of both Massachusetts and Cape Cod Bays, which can have a bearing on how both phytoplankton and zooplankton communities develop during the winter-spring period of any given year.

The factors suggested to have a regional influence, as well as additional ones, are important when one moves to a finer scale of interest (Figure 2). At the fine scale, physics and biology may be critically important to the dynamics of zooplankton patch formation and patch persistence that attract right whales for foraging. In this sense, behavior of zooplankton is important. Do they vertically migrate such that directional currents transport them to a certain location? Do they aggregate themselves (around food?) or is aggregation into patches more a function of stratification and fine-scale turbulence that creates “windrows” of passive particles as well as more motile organisms like zooplankton? Among important physical aspects, winds, tides and local climate can establish whether water column structure and turbulence promote a “ripe” situation for accumulation of zooplankton into patches.

Points of Interaction with the Outfall: Hypothetical Effects Pathways

Besides scoping basic elements of the biological food web and its interaction with the environment, it’s also important to have a conceptual model for how the future MWRA offshore outfall could influence right whale foraging areas. Figure 3 illustrates that some local change is expected in close proximity to the offshore outfall and change may involve nutrients, toxins, turbidity, sedimentation, as well as water column T, S and vertical structure. Certain types of change in the biological community and organic food resources near the outfall may attract mobile species (e.g. lobsters, fish, or mammals) to the area. But the principal issue regarding the right whale foraging habitat in Cape Cod Bay is whether it will be altered due to the new outfall. This is a challenging question, especially considering the background variability known for the area: for example, even prior to the offshore outfall, whale visits to Cape Cod Bay, formation of suitable zooplankton patches, and/or whale feeding all vary substantially from year to year.

Figure 3 suggests the three general pathways by which distant effects (i.e., such as in Cape Cod Bay) could occur. The first is a biological transport (path 1) from near-outfall biological change; the other paths involve direct transport of elements from the effluent to points far removed as a means for stimulating effects there. The diagram ascribes no likelihood to these pathways for effects; in general, physical and water quality modeling suggest the likelihood is not high. More importantly, the diagram simply suggests that a distant *expression* of change, due to an outfall, again will depend on the variety of biological and environmental influences that establish the food web (Figs. 1, 2).

The point of Figure 3 is to frame the pathways, not to enable prediction of an obviously complex biophysical setting. Moreover, the intent is to provide a basis for discussion of how monitoring and research should continue to provide guidance on the issue. A brief perspective on this guidance is offered next.

Related monitoring and research

Issues for monitoring need to focus on *what can be measured* related to distant (Cape Cod Bay) change. This is not to say these issues have never been considered in development of the monitoring program, but revisiting the issue with the wealth of baseline data is a reasonable exercise. Following from Figure 3, there should be three general pathways of concern:

- near-outfall biological change, transport or migration potential
- transport and/or bioaccumulation of toxins
- transport of nutrients

For these transport aspects and related monitoring needs, the scale of focus is the nearfield and its relationship to broader regional patterns. Modeling has suggested that toxic and nutrient transport and accumulation in Cape Cod Bay will be small enough to be difficult to detect against the known background variability. Nonetheless, the question to be asked is: will the monitoring program detect changes of significance (i.e., related to these three paths) that could lead to distant effects? Will the baseline design of monitoring, supplemented with the planned plume tracking from the operating outfall, be able to show directional transport of materials over short and long time scales?

Issues for research need to focus primarily on finer scales so that, when the question of transport (the agent for change) is resolved by monitoring, there is a better sense of whether a certain *expression* of effect will occur in a given location. In short, the problem is: if any of the three mechanisms (Figure 3) for change in Cape Cod Bay were to happen to any significant degree, do we currently have ability to predict the biological outcome? Because of sufficient complexity in physical dynamics and geochemical cycling, the present predictive ability is limited, even with respect to predicting dynamics at the base level of the food web (Figure 1). It is not entirely clear what major autotrophic base will dominate, never mind whether sufficient density of copepod herbivores will occur.

Therefore, fundamental research on the food web leading to the right whale should encompass the following components:

- Identify environmental and biological features that create patches of prey acceptable for whale feeding. We believe this topic dictates a fine-scale, high-resolution sampling of patch dynamics and will strongly involve physical factors, many of which are not likely to be affected by moving the outfall. Advanced understanding of molding factors will not guarantee predictability of biological response and food web dynamics to a distant change.
- A prime goal of research in the context of the issues brought out here should be the identification of suitable measures that can be used and incorporated into a monitoring program if necessary. Suitable monitoring measures would be ones that act as indicators of biological food web change. The coarsest, but one of the most robust, of these indicators would be the presence of whales and their continued active feeding in the area, but successful research may provide additional measures.

References

Mayo, Charles A. and M. K. Marx. 1990. Surface foraging behaviour of the North Atlantic right whale, *Eubalaena glacialis*, and associated zooplankton characteristics. Can. J. Zool. 68: 2214-2220.

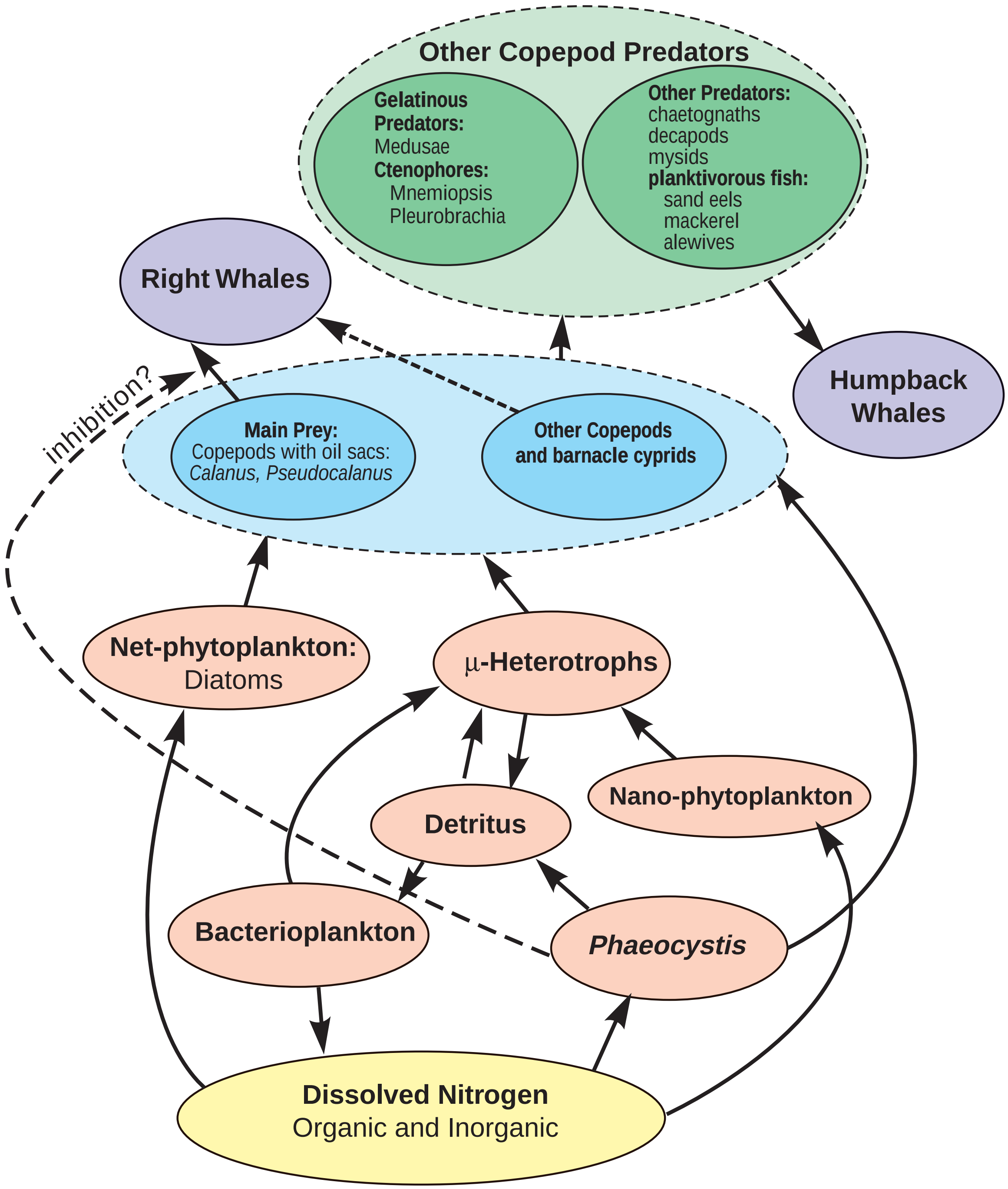


FIGURE 1
Conceptual schematic of right whale/ plankton food web in Cape Cod Bay

M980121

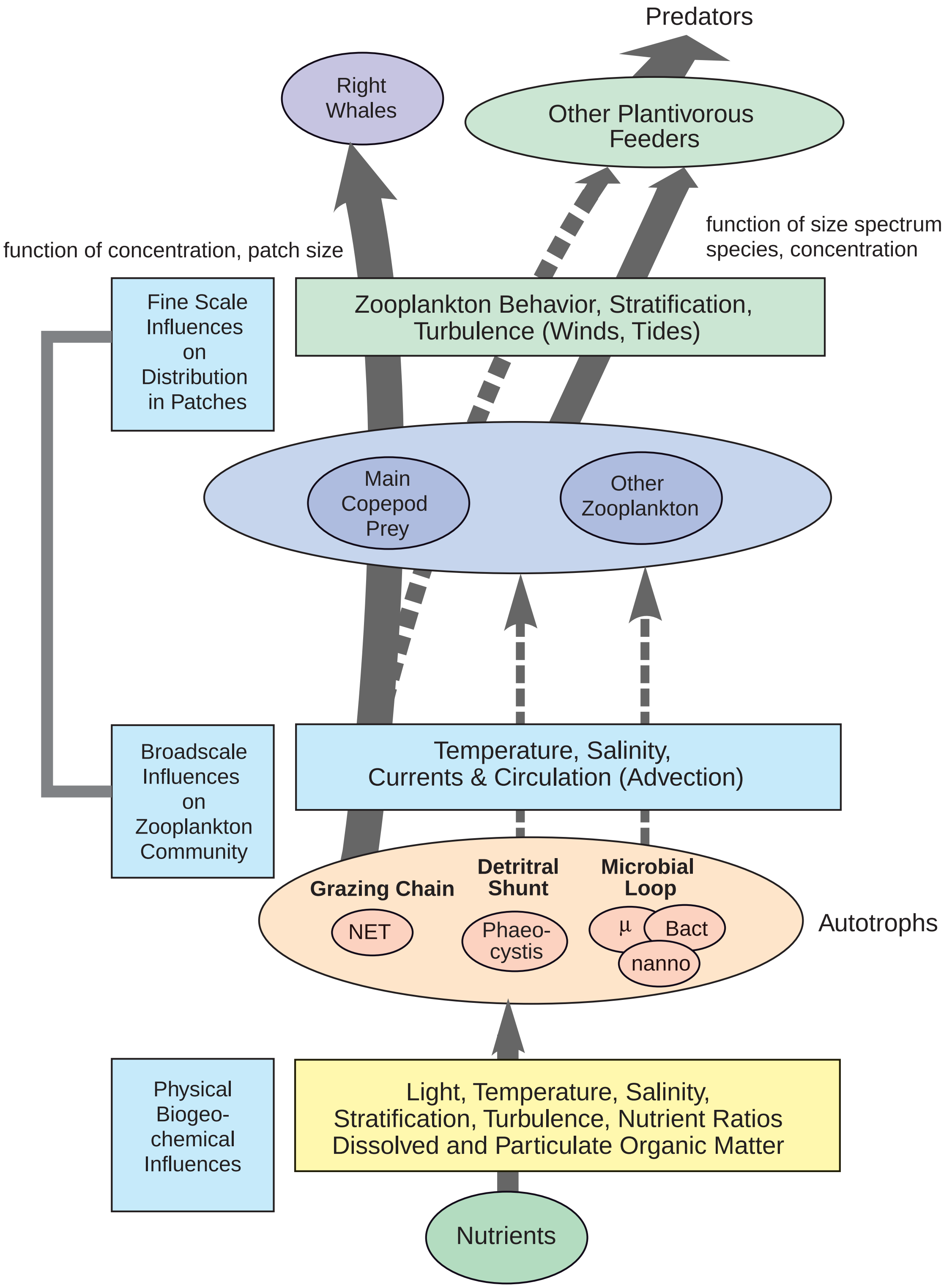


FIGURE 2

Factors at Different Scales and Levels Influence the Food Web

M980122

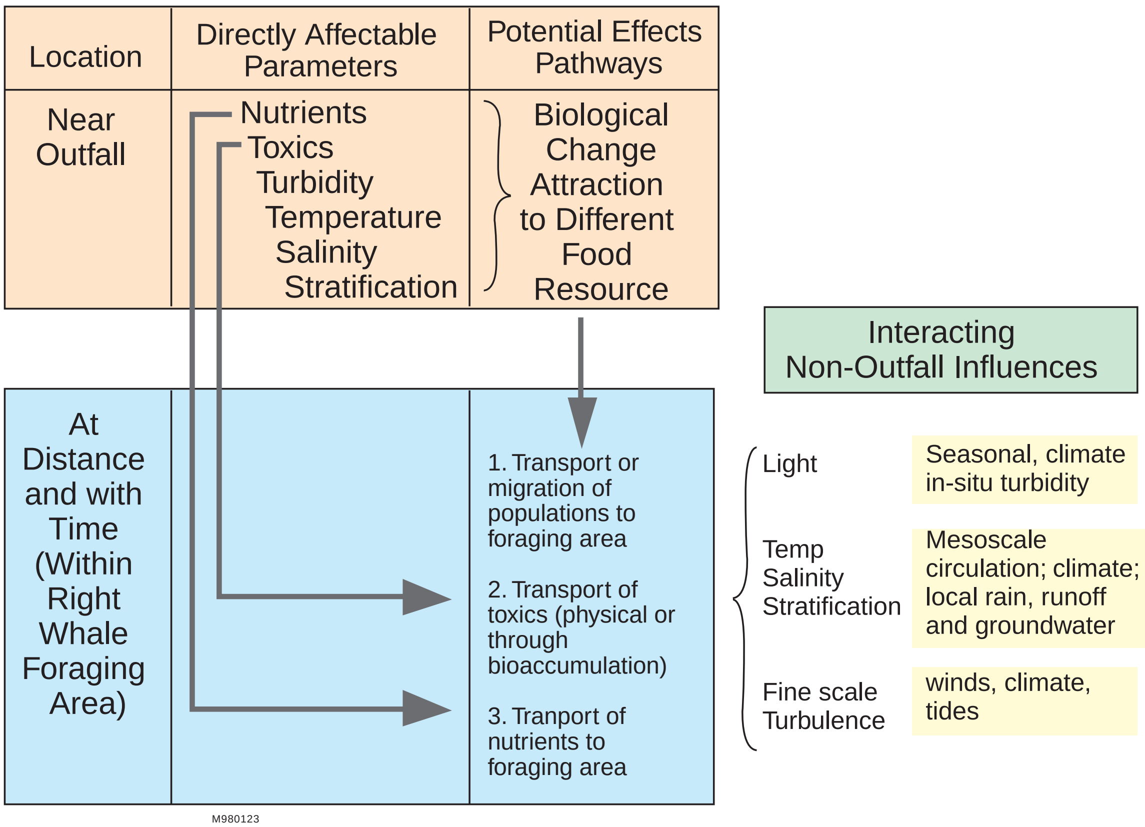


FIGURE 3
General Paths to Influence Cape Cod Bay Food Web.

Attached:

1. Comments by Dr. Robert D. Kenney, University of Rhode Island.
2. Clarification of the purpose of the exercise, by Dr. Matthew Liebman, US EPA Region I.

MEMORANDUM

TO: Dr. Michael J. Mickelson, Environmental Quality Dept., MWRA
FROM: Dr. Robert D. Kenney, University of Rhode Island
DATE: 2 June 1998
RE: Cape Cod Bay food web model

The draft NPDES permit for the relocated Boston Harbor sewage outfall includes a requirement for development of a scope of work for a model of the food web in Cape Cod Bay. While I believe that such a modeling exercise would prove to be a valuable scientific endeavor which would improve our understanding of the Bay marine ecosystem, I am concerned that a standard food web model will not be capable of addressing the questions being posed, nor will it have sufficient predictive power to fulfill MWRA's objectives.

Questions for a food web model:

The ultimate question of relevance to MWRA and the outfall is: ***Will relocation of the Boston sewage outfall cause detectable changes in the occurrence of northern right whales in Cape Cod Bay and/or Massachusetts Bay?*** By occurrence I mean the number of right whales in the Bays system, their locations over time, and the timing of their arrivals and departures (*i.e.* abundance, distribution, and residency). We are all working under the assumption (almost certainly a correct one) that right whales use the Bays system for feeding, so the proximate question becomes: ***Will the outfall relocation impact the availability of right whale prey?***

Food webs and right whale foraging:

The discussion to date within the OMTF seems to have been proceeding under the assumption that prey availability for right whales in Cape Cod Bay is exclusively or primarily a function of the abundance and productivity of zooplankton within the Bay. If that were the case, then a model of the local food web might reasonably be expected to have some predictive power concerning right whale occurrence. However, it is not that simple. Local zooplankton production is only one of the factors affecting prey availability for right whales, which in turn is only one of several factors controlling right whale occurrence.

In a 31 March 1998 Technical Memorandum ("Conceptual Food Web Model for Cape Cod Bay, with Associated Environmental Interactions") Jack Kelly, Cabell Davis, and Steve Cibik outline a description of a food web model. Their conceptual model focuses on the local food web and potential impacts on right whales via several mechanisms:

- changes in nutrient availability leading to changes in phytoplankton production and then to availability of zooplankton prey for right whales
- changes in nutrient availability leading to changes in the occurrence of blooms of nuisance (e.g. *Phaeocystis*) and/or toxic (e.g. *Alexandrium*) phytoplankton

- transfer of toxics from the outfall to right whales via the food chain.

My focus will be on the first, since I believe that food web modeling might not be the best way to address the other two concerns. It seems to me that the causative mechanisms underlying the occurrence of nuisance and toxic phytoplankton blooms are not sufficiently understood at present such that any food web model, no matter how sophisticated, would provide any predictive ability. And concern about toxic transfer to right whales via their prey might be better addressed by studies of the prey species, which I believe are on-going.

The accompanying figure is my attempt at a conceptual model of the wider assortment of factors influencing the abundance, distribution, and residency of right whales in the Bays system. Perhaps it is not all that different from the Kelly *et al*. conceptual model except in its focus. Their model focuses primarily on the local food web while also addressing the other factors which influence prey availability for right whales, while mine attempts to place the Cape Cod Bay food web (while ignoring the details within it) into the larger context with more emphasis on the probable relative importance of all the factors influencing prey availability.

In the figure, the rectangle at the top center is right whale occurrence (abundance, distribution, and residency) in the Bay – the phenomenon which we would like to be able to predict. Prey availability to right whales within the Bay is only one of several factors controlling that occurrence (although an assumption that it is the primary factor may be a reasonable one). Over the long term, how many right whales are in the population is a factor in how many enter the Bay. Within a season, whether right whales enter the Bay and how long they stay is a factor of their decision-making relative to the value of the prey resource in the Bay compared to known or potential prey in other feeding grounds (in turn influenced by larger-scale oceanographic and climatic factors).

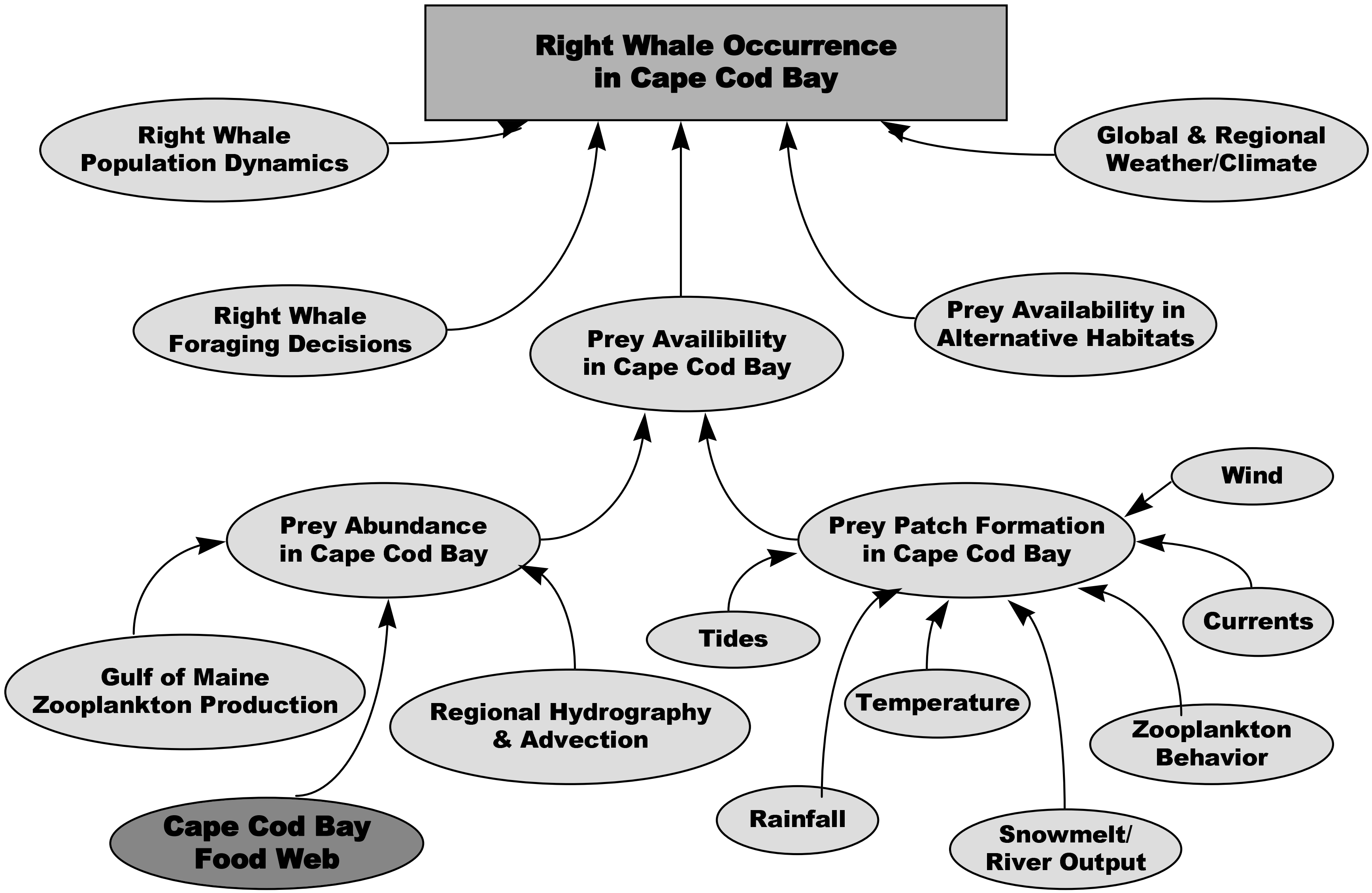
Prey availability for right whales, however, is much more than simply the abundance of zooplankton (whether abundance is considered for individual species or simply for a single zooplankton trophic level). From the point of view of a foraging right whale, a more important measure of availability is the concentration of zooplankton prey within small patches of exploitable dimensions. Overall prey availability to right whales therefore also includes the density of zooplankton within patches; the total number of patches; the sizes of the patches; the total areal extent of patch distribution; the persistence of patches in time; and the predictability of patch locations. Prey availability, as the diagram shows, is then a function of both zooplankton abundance <u>and</u> the entire suite of mechanisms, primarily physical/hydrographic mechanisms, which control how the zooplankton are aggregated into those patches.

Even the simple abundance of zooplankton is not entirely controlled by the productivity of the local food chain (shown as the darker-shaded component at the lower left), which has been the focus of the OMTF. Zooplankton populations within Cape Cod Bay certainly include both individuals produced within the Bay via the local food web and individuals produced in other locations within the broader Gulf of Maine system and advected into the Bay via the prevailing currents. I am not prepared to even speculate as to whether local production or advected production from elsewhere is the dominant contribution.

The results of the SCOPEX study of a right whale feeding habitat in the Great South Channel showed that, of the three mechanisms hypothesized for the development of dense zooplankton patches in that region, *in situ* production via the local food web was the least important. The most important factor was physical/hydrographic concentrating mechanisms, followed by the behavior of the zooplankton themselves (especially for *Calanus finmarchicus*, which seems to aggregate more than other zooplankton species occurring at the same locations). A reasonable extension of these results to an hypothesis for Cape Cod Bay is that the local process of nutrient concentration → phytoplankton productivity → zooplankton productivity is not likely to predict the occurrence of feeding right whales. However, a better understanding of the hydrographic mechanisms causing the aggregation of zooplankton into dense patches regardless of the actual abundance of zooplankton might give us greater predictive power.

Recommendations:

In my opinion, therefore, a food web model focusing on the trophic processes from nutrients to zooplankton in Cape Cod Bay would not address the issue of predicting right whale occurrence. In fact, one might predict in advance that the results of such a model would be that there would be no change in the occurrence of right whale prey, given the results of previous mixing/dilution models which essentially predict no detectable change in nutrients outside of the mixing zone near the diffusers. The physical factors which are more likely controlling right whale prey availability are much less likely to be impacted by the change in the outfall location, and are therefore outside of the area of responsibility of MWRA. From my scientific point of view as a right whale biologist, I see great value in understanding the mechanisms of zooplankton patch formation in Cape Cod Bay, but I find it difficult to justify requiring MWRA to conduct studies to that end. Absent additional justification, I would recommend at this time that MWRA proceed no further with Cape Cod Bay food web modeling than the scope of work required by the permit.


Right Whale Occurrence in Cape Cod Bay
Right Whale Population Dynamics
Global & Regional Weather/Climate
Right Whale Foraging Decisions
Prey Availibility in Cape Cod Bay
Prey Availability in Alternative Habitats
Prey Abundance in Cape Cod Bay
Prey Patch Formation in Cape Cod Bay
Wind
Currents
Tides
Gulf of Maine Zooplankton Production
Regional Hydrography & Advection
Temperature
Zooplankton Behavior
Cape Cod Bay Food Web
Rainfall
Snowmelt/ River Output

Clarification of the purpose of the exercise,
by Dr. Matthew Liebman, US EPA Region I.

The following was handed out at the OMTF meeting on April 29, 1998. It reflects EPA's position, at that time, regarding the requirement in section 7 of the March 1998 MWRA Draft NPDES permit for a scope of work for a food web model to characterize the seasonal abundance for important prey species of endangered species in Massachusetts and Cape Cod bays. Although the draft permit language provides some guidance for the MWRA, EPA's presentation was designed to provide further information for the MWRA and the Task Force and to promote a discussion of the issues involved in developing a food web model. Questions were raised during the discussion after the presentation. In addition, EPA Region 1 is seeking comments on the draft permit through a public process. As a result, the language in the draft permit may be modified.

RESPONSE TO OMTF ON WHAT EPA EXPECTS WITH REGARD TO THE FOOD WEB MODEL IN THE DRAFT MWRA NPDES PERMIT

April 29, 1998 Outfall Monitoring Task Force meeting
Matthew Liebman, EPA Region 1 (New England) Office of Ecosystem Protection, Water Quality Unit

1. Why did EPA request developing a scope of work for a food web model in the draft permit?

2. What does EPA expect in a scope of work for a food web model?

3. What are the potential uses and goals of the food web model?

4. What other issues should we consider and resolve?

Here are the details.

1. Why we requested it:

There is uncertainty in:
a) What controls the distribution and movement and feeding behavior of humpback and right whales in Mass and Cape Cod bays, acknowledging that zooplankton abundance is a key factor for right whales;
b) Right whales are among the most endangered mammals on earth; and
c) The outfall will probably effect phytoplankton to some degree, and therefore may have an effect on zooplankton populations.

Therefore, a precautionary approach is suggested.

By the way, the Northeast Implementation Team's Habitat Subgroup is developing a conceptual model for habitat in the Northwest Atlantic. Contact: Mona Haebler, EPA Narragansett.

2. What do we expect?

Q: What do you mean by a **scope of work**?

A: We expect a **scope of work** for a food web model. A descriptive plan for conducting a task. In this case, we aren't asking for a food web model, but a plan of action for constructing and implementing a food web model. This would include a brief description of the potential type of model that might be constructed, the data needs that may be necessary to help calibrate or validate the model, the types of output expected from the model, and a plan for actually implementing, or running the model.

Q: What do we mean by a food web model?

A: A model describes, or re-creates the state variables of interest, such as zooplankton abundance, planktivorous fish abundance, and the factors that control abundance in space and time.

> The model can be quantitative or qualitative. A model could start with a conceptual model, e.g. a set of boxes representing population abundance or biomass, with links between the boxes, representing energy flow, or transfer of contaminants.
>
> Food web -- the transfer of energy from one trophic level to another; zooplankton eat phytoplankton. In addition, a food web is also the composition of species or groups of species linked to other trophic levels.
>
> The data needs for the model may include physical processes, kinetics of nutrient uptake, phytoplankton growth rates, zooplankton prey selectivity, grazing rates by zooplankton on phytoplankton, growth rates of zooplankton species, seasonal distribution of zooplankton species, life history characteristics of prey and predators, planktivorous fish and chaetognath or ctenophore predation rates, patch sizes for right whale foraging, right whale feeding selectivity and behavior, etc.

Q. What should the focus of the model be?

A. The focus should be on the prey species of the right whales, specifically zooplankton, and on the factors that control its abundance, and on noxious algae that may affect zooplankton or right whales directly. The threshold abundance for calanoid copepods in Cape Cod Bay is an important factor in determining right whale distribution and foraging activity.

Q: Should the model be predictive?

A. No, the model should be practical and descriptive, and not necessarily predictive. However, the model can be constructed to allow for what-if scenarios, or sensitivity analyses.

3. What are the <u>potential</u> uses and/or goals of the food web model?

(This is not meant to be exclusive or inclusive.)

Understand the linkages between trophic levels, and among species within trophic levels. Going through the exercise is very important, as it builds a framework for further study.

Understand which factors, including stressors and climate, are most responsible for creating the distribution and abundance of prey species, e.g. nutrients, phytoplankton distributions, or circulation or other physical factors, top-down fisheries, etc. Stressors include the outfall discharges, atmospheric deposition and other usual suspects. Other external factors include boat strikes, long-term cycles, year-to year variability, etc.

Understand which parameters are most important to estimate or need further study.

Suggest possible locations for monitoring, or parameters to monitor.

Suggest testable hypotheses to better characterize the system.

Provide a framework to answer some nagging questions, such as:

What is the likelihood that a species shift in phytoplankton result in a species shifts in zooplankton?

What is the likelihood that changes in carbon or energy flows in lower trophic levels can affect higher trophic levels?

What is the likelihood that the outfall's discharge of nutrients in a certain nutrient ratio are affecting higher trophic levels?.

Are PCBs or other contaminants accumulating in right whales through the food chain?

4. What other issues should we consider and resolve?

(Not meant to be exclusive or inclusive.)

Q: What is the spatial scale of the model?
Mass Bay, Cape Cod Bay or east and west Cape Cod Bay?

Q: What is the temporal scale?
2 Seasons within one year, such as winter/spring and summer, or a simple yearly average?

Q: What is the level of uncertainty or variability?

There is probably year to year variability, based perhaps on Gulf of Maine long term cycles. Would the model yield an average value, or would it ascribe a range to a variety of parameters and provide an idea of variability?

Q: Will this be an Eulerian or a Lagrangian model?

An Eulerian model can describe abundance at particular locations, as a 3-dimensional model currently in place, with explicit zooplankton variables explicitly added.
Or, a Lagrangian model can track particles of zooplankton as it moves through Mass Bay, exposed to a field of phytoplankton.

Q: Can we make a simple model out of a complex system?

Is it possible, for example, to construct a simple N-P-Z model, with fewer boxes, if it adequately describes the dynamics of the system on an appropriate scale.

Q: Should we consider *Phaeocystis*?

A: Yes.

Q: If the OMSAP reviews the scope of work for the model favorably, will the EPA require MWRA to proceed with implementing the model?

A: Cannot answer that yet. However, EPA will not proceed until the OMSAP reviews and comments on the scope of work.

Massachusetts Water Resources Authority
Charlestown Navy Yard
100 First Avenue
Boston, MA 02129
(617) 242-6000