Chapter 7. Summary and Conclusions (Rodney Rountree)

A great deal of research has been conducted on the physical and biological environment of Mt. Hope Bay and the adjacent Narragansett Bay. However, limited work has concentrated on the problem of main interest to the Mt. Hope Bay Natural Laboratory project, namely, quantification of the sources of temporal variation of the Mt. Hope Bay environment and fish stocks. Biological trends in Mt. Hope Bay appear, for the most part, to mirror trends in greater Narragansett Bay and the surrounding Rhode Island Sound geographical regions, although some trends appear to be specific to Mt. Hope Bay, itself. For example, temporal trends in habitat loss and in winter flounder population dynamics both mirror trends in Narragansett Bay and in the northeast geographic region.

Physical Environment

Understanding the physical environment of Mt. Hope Bay is the foundation of all other components of the Mt. Hope Bay Natural Laboratory Program and is critical to its success. Temporal variation in nutrients and in plankton, crustacean, and fish populations cannot be fully understood without a detailed understanding of the physical environment, its sources of variation, and its interaction with the biological community. As is evident in the review in Chapter 2, there is a significant amount of environmental data for MHB that can be used to build the program; however, gaps in our knowledge need to be addressed. Priority observational data needs for the physical environment include the following:

1) *Long-term monitoring of spatial and temporal patterns in water properties,* including temperature, salinity, DO, and turbidity, is needed to provide adequate input into physical models of the Bay. Previous work has been short-term and cannot be used to fully characterize seasonal and interannual variations. Just as importantly, long-term observational data is critical to understanding the importance of episodic events and their interactions with physical processes on various temporal and spatial scales. Such data would allow for the detailed characterization of water mass boundaries in the Bay, and the identification of stratification boundaries, upwelling and downwelling zones, mixing zones, and sediment resuspension zones.
2) *Tidal and wind-driven water circulation patterns* need to be observed on a fine-scale grid throughout the bay and over time scales sufficient to characterize monthly and seasonal variations and interactions with seasonal and episodic weather patterns. Of special interest are circulation interactions between the open bay and the shallow subtidal and intertidal estuarine fringe areas that function as the primary nursery grounds for many estuarine fishes including winter flounder. Attempts to model fish egg, larvae and plankton movements through the bay will be ineffective without this effort. It is critical that the tidal and non-tidal water exchange patterns between Mt. Hope Bay and the

adjacent Sakonnet River and Narragansett Bay be well understood in order to model input and output of nutrients, plankton, and fish eggs and larvae for the Bay.

3) Similarly, *data on the freshwater discharge from the Taunton, Lee, Cole, Kickamuit, and Quequechan Rivers* into Mt. Hope Bay need to be obtained over a sufficient period to allow modeling of seasonal, interannual, and episodic patterns. From data presented in Chapters 2 and 3, it is clear that the seasonal timing and magnitude of peak discharge varies greatly among years. Interannual and weather-related changes in discharge patterns may be especially important to understanding larval fish movement patterns, as well as Mt. Hope Bay hydrography changes.

4) *Observational data collection and modeling of the thermal discharge plume* from the Bryton Point Power Plant can be improved. Of special interest is the interaction of the plume with shallow subtidal and intertidal waters along the Bay fringe, since these are the primary nursery habitats and foraging grounds for winter flounder and many other fishes and invertebrates of concern.

Habitats and Habitat Quality

The historic, present, and future changes in habitat distribution and habitat quality in Mt. Hope Bay, and the causes of those changes, are poorly understood at present. Current evidence suggests that dramatic changes in habitat distribution and type have occurred over the last century and accelerated in recent decades. In addition to their impacts on the fisheries resources, many of these changes endanger the habitats themselves, which are in their own right a valuable resource in need of protection. Critically important habitats such as saltmarshes and eelgrass beds have been especially hard hit. Although available habitat mapping data have not been analyzed specifically for Mt. Hope Bay, it is thought that as much as 70% of the saltmarshes in Narragansett Bay have been modified by human activity. Eelgrass beds, once considered a vital habitat for winter flounder, have vanished from Mt. Hope Bay and are restricted mainly to the lower Narragansett Bay. Detailed data on habitat types based on emergent vegetation and shoreline characteristics are available from several sources but have not been summarized specifically for Mt. Hope Bay. A comparison between present vs. predicted future habitat distributions should be an important component of the MHBNL program. In addition, detailed sediment type mapping should be conducted throughout the Bay.

Besides the basic step of mapping habitat type distributions in the bay, an understanding of factors affecting habitat quality is of great importance. Nutrient loading into Mt. Hope Bay is probably one of the most significant factors regulating the Bay's habitat quality. Quantitative data is currently insufficient to model nutrients in the system; however, the conclusion that the Bay is likely nutrient-enriched and eutrophic seems justified.

Because excessive nutrient loading is clearly having a significant impact on habitat quality in Mt. Hope Bay and Narragansett Bay, it is critical that eutrophication models be used to determine the effect of increasing development on habitat quality. A comprehensive program to monitor nutrient inputs and outflows from Mt. Hope Bay and the Taunton River system is needed. An evaluation of the relationship between freshwater discharge and the dissolved oxygen levels of the Bay's bottom waters would be one important component of such a program. Quantitative observations and subsequent modeling of the spatial and temporal patterns of low dissolved oxygen concentrations in Mt. Hope Bay bottom waters are particularly important to assess habitat quality.

Significant data on the benthic community and production in Mt. Hope Bay is available, but linkages between pelagic and benthic trophic systems and interactions with nutrient availability and environmental conditions need to be examined. Environmental modeling of the Bay's hydrography and identification of vertical mixing zones and sediment re-suspension zones are important to this effort. Emphasis on the production of prey species and environmental factors regulating their spatial and temporal distribution patterns would be especially useful for the study of winter flounder post-settlement larvae and juveniles. A determination as to whether winter flounder larval settlement is matched with benthic prey abundance peaks is an important consideration. Monitoring of the distribution patterns of important biotic integrity indicator species such as *Ampelisca, Mediomastus* and *Nucula* is also an effective tool for assessment of habitat quality and should be done on a broader spatial scale along the estuarine gradient.

Plankton

Quantification of plankton dynamics in Mt. Hope Bay is essential for understanding larval fish survival and growth patterns in the Bay. Extensive plankton work in Narragansett Bay provides a sound basis for expected plankton processes in Mt. Hope Bay, but site-specific factors affecting Mt. Hope Bay spatial and temporal plankton distribution need to be identified. Currently, only a basic knowledge of species compositions is available for Mt. Hope Bay itself. Plankton dynamics are dependent on hydrography and nutrient availability. In addition, because phytoplankton and zooplankton are important components of crustacean and fish food webs, especially for the larvae, observational and modeling data on plankton abundance and distribution problems are important to understanding fish population dynamics. Better seasonal and spatial coverage of phytoplankton, zooplankton, and ichthyoplankton abundances are needed to allow analysis of match and mismatch between fishes and their food resources. In particular, correspondence between plankton/zooplankton blooms and the timing of spawning and larval fish immigration into the estuary is of considerable importance. For example, if winter flounder spawning and/or egg hatching occurs out of phase with zooplankton prey peak abundance patterns, excessive larval mortality can occur. Interannual variation in predator and prey matching is an important contributor to annual variations in larval survival. A well-performing model of Mt. Hope Bay water circulation and tidal flow patterns--one which incorporates water quality parameters such as temperature and nutrient availability--is an important preliminary to modeling of phytoplankton, zooplankton, and ichthyoplankton distribution and dispersal patterns. Behavioral responses of zooplankton and ichthyoplankton to water quality parameters should also be incorporated into the models. This is especially important for the ichthyoplankton, for which starvation is of prime importance. Short of starvation, lesser effects of variability in food availability may be important in tandem with physiological responses to environmental conditions. For example, a poorly fed larval fish may be further weakened if forced to expend its energy reserves in response to even small changes in water density (e.g., for osmoregulation and buoyancy control), temperature and dissolved oxygen (e.g., for metabolism, thermoregulation, etc.).

Nekton

Although we have identified a strong foundation of biological data on fishes for Mt. Hope Bay, data on other nektonic components of the system are lacking. Monitoring of key decapod crustaceans in the Bay is vital to understanding predator-prey relationships and food habits of the fish stocks. At the minimum, data on the population dynamics of the shrimp *Crangon septemspinosa* should be sought, as it is known to contribute to larval settlement and juvenile winter flounder mortality. Historical monitoring programs for the fishes provide a strong foundation for the MHBNL, and should be continued, but some important data gaps are evident here, too. One of the most important data gaps is the complete lack of food habitat data needed to determine trophic linkages and predator-prey relationships among fishes. Piscivory is likely an important component of natural mortality in the system and should be included in the MHBNL modeling efforts.

Habitat use patterns by various life stages of winter flounder need to be determined. Some effort has been directed towards identification of winter flounder habitats, but further efforts are required to more fully identify and characterize important spawning, larval settlement, juvenile nursery, age-1 nursery, age-2 nursery, and adult habitats. Identification of settlement habitats/areas and post-settlement habitat use patterns is especially important, as the settlement period is generally considered the most significant mortality bottleneck for flatfishes. The exchange of winter flounder of all life history stages among Mt. Hope Bay, Narragansett Bay, Sakonnet River, and Rhode Island Sound needs to be quantified. The contribution of Mt. Hope Bay-spawned winter flounder to local and regional recreational and commercial landings is unknown. What percentage of spawning adult winter flounder in the Bay are removed by the fishery? How rapidly can such removal be compensated by immigration of adults/juveniles from other areas?

In this report we identify at least eight key factors that should be considered in the the MHBNL assessment of fish stocks: 1) estuarine residence/fidelity; 2) contribution of Mt. Hope Bay to both recreational and commercial fishery stocks (i.e., the percentage of harvested fish that are derived from the Bay, and conversely, the percentage of Mt. Hope Bay stocks that are harvested); 3) emigration and immigration timing, and identification of environmental migration triggers; 4) spawning, including habitat identification, timing, triggers and behavior; 5) larval: mortality, tidal transport behavior, dispersal patterns, intra- and extra-bay sources (i.e., component of larvae derived from spawning within Mt. Hope Bay versus larval influx through the East Passage and the Sakonnet River passage), and energetic response to physiological demands under different environmental conditions; 6) estuarine movements, including daily home range and exchange between MHB and adjacent estuarine areas; 7) estuarine growth in different habitat types and under various environmental conditions; and 8) relative contribution of estuarine and coastal marine nursery areas. Although these factors are discussed in detail for winter flounder, most also apply to other species.

Models

A number of hydrodynamic, water quality, and fish modeling studies of Mt. Hope Bay have been conducted with the principal goal of assessing the impact of the Brayton Point Power Station (BPPS) thermal plume on local fish populations. Modeling efforts in the Bay have been restricted to a few efforts with specific objectives. No attempts have been made to incorporate predator-prey interactions into fish stock models. Although the fish models include a consideration of temperature and dissolved oxygen tolerances, they do not attempt to incorporate behavior effects such as selective tidal-stream transport, energetics, and behavioral thermoregulation on fish movements and habitat-specific use patterns. More subtly, they do not currently incorporate ontogenetic and seasonal shifts in temperature tolerances.

Sources of variation

As described in the introduction, one of the major goals of the MHBNL is to determine how natural resources such as fish stocks are impacted by sources of temporal variation. Our review of research in Mt. Hope Bay suggests much more work is needed before these natural and anthropogenic sources of population variation can be modeled.

Water Quality: We have only limited data on factors affecting water quality in Mt. Hope Bay. The effects of the BBPS on the Bay's water temperature has received the most attention, and is perhaps best understood. Although modeling of the spatial resolution and variation in the thermal plume can be further enhanced, an analysis of the interaction between the thermal plume and the shallow nursery habitats for winter flounder is perhaps most in need of improvement. Quantification of the interaction of the heated discharge with daily and tidal cycles in temperatures, and of the seasonal changes in these patterns, is perhaps of greater importance to understanding habitat suitability for winter flounder than is the knowledge of absolute warming effects. Similarly, if the seasonal rate of change in water temperature is an important trigger for spring and fall migrations of juvenile and adult winter flounder, then annual variation in seasonal rates of change can have important consequences for fish stocks. Nutrient enrichment of the system is probably one of the most important sources of variation to be considered by the MHBNL program. It impacts habitat quality and plankton dynamics. Loss of habitat, changes in sedimentation, changes in dissolved oxygen levels, and ultimately changes in trophic structure associated with eutrophication can have profound impacts on community structure and fish populations in the Mt. Hope Bay.

Climate variability: Interannual variability, particularly of air temperature, wind patterns and rainfall, likely has an important impact on plankton population dynamics, including fish larvae. Of these, climate effects on water temperatures have been most thoroughly examined. However, interactions between annual temperature changes and community structure need clarification. For example, credible evidence has been presented for Narragansett Bay that suggests that winter flounder population fluctuations result not from direct temperature effects, but indirect effects where temperature mediates the mortality of winter flounder from *Crangon septemspinosa* predation. In warm years *C. septemspinosa* is more abundant and more active, resulting in increased predation on post-settlement winter flounder larvae and early juveniles. This illustrates the importance of incorporating predator-prey as well as environmental factors into fish population modeling efforts as part of the MHBNL program.

Interannual changes in rainfall result in interannual variation in freshwater input into Mt. Hope Bay. Correlations between freshwater discharge volume/timing and the timing of winter flounder spawning, larval hatching, and plankton and zooplankton blooms should be investigated. Once the relationship between freshwater discharge and low dissolved oxygen levels in the Bay's bottom waters is resolved, then annual variation in the occurrence of hypoxic waters can be better modeled and related to habitat suitability. Interannual variability in wind patterns may also result in annual differences in water circulation patterns, and/or in the timing of stratification events. In short, climate variability among years is likely to be a major factor controlling interannual variability in Mt. Hope Bay environment and community structure.

Habitat loss/change: Knowledge of habitat distribution, loss and change in Mt. Hope Bay is probably our weakest link. It is imperative that better information on habitat type distribution and coverage be obtained in order to understand past and future changes. Programs to map habitat type distribution and change in Mt. Hope Bay, from its connections with Narragansett Bay and the Sakonnet River to the tidal freshwater reaches of the Taunton, Lee, Cole, Kickamuit and Quequechan Rivers, should be a high priority. This includes mapping of vegetation types, tidal pools, tidal creeks, shoreline types, and sediment types. The availability of habitat maps upon which environmental parameters can be overlain to determine habitat suitability would provide a significant improvement in current modeling efforts. Fortunately, excellent raw data on emergent vegetation and shoreline habitat types, although not yet summarized specifically for Mt. Hope Bay, is available from various state and federal programs. Additional efforts to map subtidal habitat types, particularly those based on sediment type and grain size, should be considered.

Fishing pressure: It is clear from our review that fish population trends for Mt. Hope Bay reflect regional patterns that are likely to be driven by fishing pressure, though the contribution of habitat loss and habitat quality change are also likely to be important on a regional scale. However, a local effect is suggested by the apparent failure of the Mt. Hope Bay and greater Narragansett Bay winter flounder stocks to recover as rapidly as other Rhode Island stocks and those of Georges Bank and the Gulf of Maine.

One of the most important issues to address is whether winter flounder return to spawn in their respective natal estuaries each year, or whether substantial mixing occurs between the spawning populations of Mt. Hope and Narragansett Bay. Better data on the relative contribution of recreational and commercial fishing to intra-bay and extra-bay mortality of Mt. Hope Bay winter flounder is needed to help clarify this issue. The slow recovery in Mt. Hope Bay could result from excessive removal of the Bay's relatively small spawning stocks during their residence in coastal waters or during their migration to and from the coastal waters from the Bay.

Community Change: Although significant data resources are available from standard trawl and seine surveys in Mt. Hope Bay, only limited analysis of fish community change has been attempted. In particular, little effort has been directed towards relating changes in predator populations to winter flounder population dynamics. Known significant fish predators of winter flounder include summer flounder, striped searobin and bluefish. An assessment of their interrelationships is needed. Similarly, as mentioned previously, the shrimp *Crangon septemspinosus* has been implicated as a potential population regulator of winter flounder in Narragansett Bay and elsewhere, but has not yet been examined in Mt. Hope Bay. Unfortunately, historical data on its abundance patterns in Mt. Hope Bay do not appear to be available. Predator-prey dynamics and multispecies interactions are perhaps best quantified through food habit data, but such data appear to be lacking for Mt. Hope Bay. Initiation of food habit studies, particularly for winter flounder and its predators, would likely be an important component of the MHBNL program.

State of knowledge of MHB

Mt. Hope Bay has been subjected to significant environmental and biological change over the last three decades. The Bay has followed a regional warming trend due to climate warming; this has been enhanced by additional warming resulting from thermal discharge of the Brayton Point Power Station. At the same time, the Bay has suffered strong declines in important estuarine habitats such as its saltmarshes and eelgrass beds. In fact, historically important eelgrass beds probably completely disappeared from the Bay sometime during the last three or four decades. Water quality has also declined sharply due to increasing nutrient loading resulting from human population increases and development in the Bay's watershed. Nutrient enrichment in turn modifies habitat availability and quality through eutrophication processes. One impact of this has been the increased prevalence of hypoxic bottom waters in the Bay during the summer months. Finally, some Mt. Hope Bay fish populations, such as winter flounder and tautog, have declined dramatically since the early 1980s, while others have increased. However, each of these patterns appears to result from processes operating on a broader geographic scale, though the magnitude of the effects in Mt. Hope Bay may be influenced by processes specific to the Bay itself.

Although there are many unknown details of concern, there are a few general areas in which our lack of knowledge is most limiting of our understanding of Mt. Hope Bay as an ecosystem. To address these deficiencies, we recommend the following research goals: 1) quantification of the distribution and percent cover of specific habitat types, historic changes in distribution and coverage, and trophic linkages among them; 2) identification of essential habitats for each life stage of key fishes and invertebrates; 3) quantification of nutrient loading to the bay and its impact on dissolved oxygen levels and other attributes of habitat quality; 4) acquisition of food habits data are needed to examine intra- and inter-specific interactions and their impact on community structure; 5) understanding of the exchange of fishes, through tidal, daily, ontogenetic and seasonal movements, between Mt. Hope Bay, its rivers, and Narragansett Bay; 6) quantification of the fidelity of individual winter flounder to Mt. Hope Bay, and of the contribution of within-bay and extra-bay sources of mortality to the population specific to MHB; 7) linking of multispecies population models to environmental processes such as habitat suitability, larval dispersal, and predator and prey population dynamics; and 8) more broadly, integration of a network of models of the Mt. Hope Bay environment, including temperature regimes, dissolved oxygen distribution levels, stratification and water circulation patterns, nitrogen loading and eutophication, nutrients, phytoplankton, zooplankton and ichthyoplankton retention and dispersal patterns, and fish population dynamics.

This review has found that there are significant data resources available on the environment and fish stocks of Mt. Hope Bay that can serve as a strong foundation for the Mt. Hope Bay Natural Laboratory. The report also identifies key data gaps that can be addressed to enhance the program. However, although some data gaps are qualified as "important" or "critical," we do not attempt herein to prioritize study areas for inclusion in the Mt. Hope Bay Natural Laboratory. These data gaps will be further identified and prioritized in the planning phase of the program. It is not expected that the MHBNL will directly address all of these areas. Instead, we will focus on areas that we feel represent the strongest regulators of the Mt. Hope Bay environment and community structure and which are most suitable for our modeling efforts.

Mt. Hope Bay Natural Laboratory Design

The MHBNL is envisioned as a total systems study of Mt. Hope Bay. Its purpose is to explain and forecast the interactions among natural and anthropogenic and internal and external dynamics on the Mt. Hope Bay ecosystem. The resulting program will provide scientists, resource managers, and the public with a better understanding of how Mt. Hope Bay and similar estuarine ecosystems function and how they can be managed in the face of competing multiusers.

The Mt. Hope Bay Natural Laboratory will be constructed in a modular format. Currently, we anticipate the modeling to include at least 6 interacting modules: 1) physical-chemical-geological environment (including habitat), 2) phytoplankton, 3) zooplankton, 4) benthos, 5) decapod crustaceans and 6) fish. Modeling of these modules will commence once sufficient observational data has been obtained for proper parameterization. Efforts will initially emphasize nowcasting, then move into hindcasting of historical trends, and culminate in forecasting and scenario testing. The next report will provide a comprehensive description of the Mt. Hope Bay Natural Laboratory design.