Chapter 1. Introduction (Rodney Rountree)

Context: Our estuaries have been impacted by human activity for several centuries. These impacts relate to shore structures, channels, damming, nutrient introductions, sedimentation, toxics introduction, thermal modification, and fishing. But it has been only in the last few decades that public awareness of these various impacts has reached a point of regulating these impacts. As a result, many regulations have been promulgated to control or mitigate the mix of effects of human activity. Given that many aspects of human activity are difficult to modify, it is important to develop public policy that correctly link observations of effect (i.e., "the bay is dying," "the fish are disappearing," "the jellyfish have taken over") with their causes. Without understanding the effects and their causes, we are likely to focus attention on the issues that are simple rather than those that are most harmful. Only by carefully linking cause and effect can we develop appropriate, cost effective, focused remedies to correcting, modifying, or mitigating the effects.

The problem is not simple. A multiplicity of human impacts or "causes" interact in a complex and non-linear way. These multiple causes, in turn, interact with a similar multiplicity of natural changes in the environment (for example, the recent global warming trends). It has become apparent that environmental issues can no longer be addressed by narrow studies that take into account only one or two causal variables. We can no longer study the issues with disjoint theory and observation. Rather, we need to develop a more hands-on approach combining theory and observation in a laboratory setting. Traditionally it is in the laboratory setting where observations are made, data are collected, and experiments are formulated.

It is from this vantage point that we are working to create a natural laboratory in Mt. Hope Bay. The natural laboratory is intended to be a total systems analysis of the biological and physical dynamics of Mt. Hope Bay. As such, we will be viewing the chemistry, biology, and the physics of Mt. Hope Bay in terms of its internal and external dynamics. This approach will provide a unique understanding of the factors that influence change in Mt. Hope Bay. For example, from an internal dynamics point of view, we will be examining how nutrients, sedimentation, and local thermal inputs contribute to modifying the oxygen concentration and light availability in the water column. In turn, from an external point of view, we will be examining how the Taunton and Lee's river watershed and Narragansett Bay, itself, affect the nutrients, sedimentation, and thermal structure of Mt. Hope Bay. In a similar manner, to consider the effects on both recruitment and the adult stock of fish, we will need to consider the fish stocks not only just in Mt. Hope Bay but also throughout their entire range of activity. The idea of the natural laboratory is to not only address issues focused in Mt. Hope Bay, but to use Mt. Hope Bay to construct new and unique approaches to addressing the complex of human and natural factors that influence the estuarine environment in general and to contribute to improving public policy on estuarine management.

What is the MHBNL: The Mt. Hope Bay Natural Laboratory (MHBNL) program is a 5-year interdisciplinary program to examine the temporal and spatial variability of the Mt. Hope Bay ecosystem. Emphasis is on the relative contributions of naturally occurring to anthropogenic factors in inducing changes to the bay's ecosystem. An overriding theme of the MHBNL is to quantify how various processes come together to produce the ecosystem and how that ecosystem evolves, both from naturally occurring as well as anthropogenic factors. It is a "laboratory" in that a variety of tools will be used for observation, experimentation and hypothesis testing. These tools are: numerical modeling, usage of existing data and results of ongoing monitoring programs, new *in situ* observations, and data assimilation, the latter being the "glue" which brings together all of the other tools. The Natural Laboratory approach will allow individual sources of the Bay's variability to be isolated and quantified in their importance to environmental, habitat, and fish population changes.

Location: Mt. Hope Bay is an ideal site for a natural laboratory. It is inland and enclosed, has well defined locations of inflow and outflow, and has had a large amount of observations made on its fish populations as well as a limited amount of measurements on its physical environment and habitats. Because of its limited size and access to land it is relatively easy to perform *in situ* deployments of instrumentation, for example for the monitoring of: (1) the tide, (2) river runoff, and (3) meteorological forcing, and (4) inflow and outflow through connecting passages. Note that exchange with coastal marine waters occurs only through the passages connecting the Sakonnet River and Narragansett Bay. Mt. Hope Bay is also the sink for the second largest watershed in Massachusetts with relatively little research on the impact of this watershed on the bay. Mt. Hope Bay is less well studied than other Massachusetts estuaries because of its geography. It is located in the northeast corner of Narragansett Bay and lies partially within both Massachusetts and Rhode Island. The boundary between the two states bisects Mt. Hope Bay, effectively isolating it from other Massachusetts waters. Thus Rhode Island monitoring programs typically only sample the lower MHB, while Massachusetts programs tend to overlook MHB entirely. This happenstance of geography, together with recent public concern over the decline in fish stocks and habitat quality in MHB, has resulted in a growing need for improved monitoring of the Bay's environment and biological communities.

Phases: Development of the MHBNL involves four temporally overlapping phases (Figure 1.1): 1) review and synthesis of research to date on the

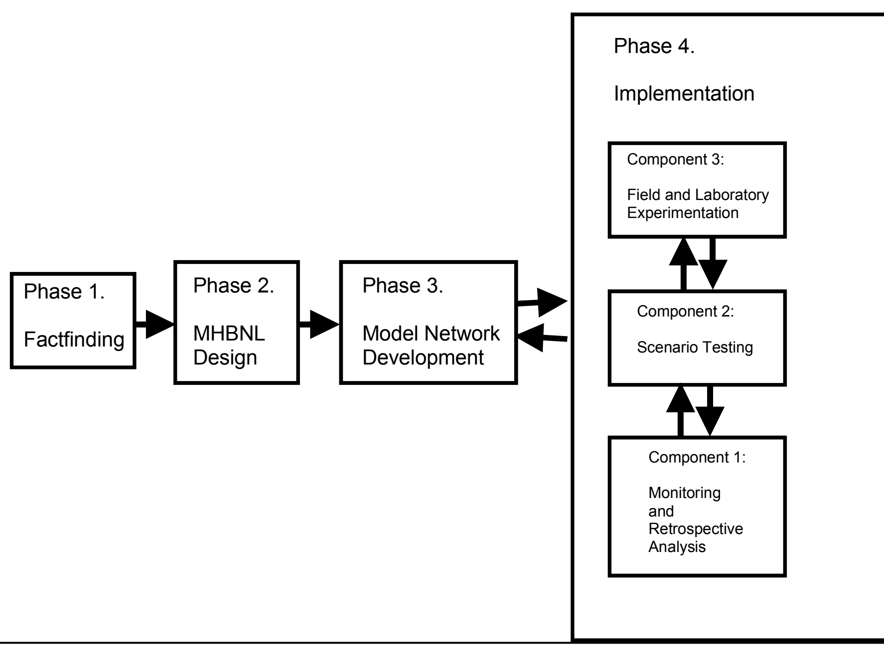

Figure 1.1. Schematic of the Mt. Hope Bay Natural Laboratory operations (see text). Arrows represent information flow and feedback loops.

Mt. Hope Bay ecosystem; 2) design of the natural laboratory structure; 3) development and validation of the model network; and 4) model network implementation and application to scenario testing. This report constitutes the completion of phase 1 and serves as the foundation for the program planning in Phase 2. Phase 2 will involve the planning and design of the MHBNL. Information contained in the Phase 1 report, together with retrospective analysis of data identified in the report, and comparison with previous estuarine modeling programs will be used to design the MHBNL program. During this phase we will identify the most promising existing models for incorporation into the MHBNL, as well as the appropriate observational variables and model input and outputs. In the third phase of the program, a network of integrated models of physical and biological processes operating in MHB will be developed. These models will be implemented and applied to scenario testing during the fourth phase. When integrated these models will allow the prediction of the impact of annual, seasonal, and episodic events on Mt. Hope Bay. The implementation itself will involve three iterative components (Figure 1.1), including monitoring, scenario testing, and experimentation. A carefully constructed monitoring program of the physical, biological and geochemical environment (e.g., spatial and temporal trends in salinity, temperature, DO, turbidity, nutrient loading, pollution, habitats and of the plankton, fish and invertebrate populations) is the critical foundation for the implementation. The availability of quantitative physical and biological data on the appropriate scales is essential for the success of the model scenario testing. The heart of the project is the use of model scenario testing to predict the effects of the various natural and man-made impacts on the MHB system, while the process oriented and hypothesis driven field and laboratory experimentation will be used for model and scenario testing validation. The three components–monitoring, scenario testing, and experimentation–will form a dynamic feedback loop to constantly improve the model performance, and allow us to improve our understanding of how the MHB system functions. The model scenario testing will dictate the types of field and laboratory testing that are conducted, and the results of the field and laboratory testing will be used to provide input into, and perhaps suggest model modifications for, the scenarios.

Sources of variation in MHB: An overriding goal of the MHBNL is to determine how natural resources such as fish stocks and habitats are impacted by temporal changes in the environment and the biological community structure. Fish population dynamics are influenced by numerous natural and anthropogenic factors. Changes in interspecies interactions, environment quality, habitats, and fishing pressure all shape changes in populations. In addition, Mt. Hope Bay is not a closed system, and factors operating in adjacent areas can have a profound impact on its environment, fauna and flora. In particular, fish stocks in Mt. Hope Bay are not isolated, but rather in most cases represent small components of regional populations. Interactions between Mt. Hope Bay, Narragansett Bay and broader regional populations need to be examined. Although there are many potential sources of temporal variation that can affect Mt. Hope Bay fish stocks and faunal abundance patterns, we have identified at least six major categories in this report (Figure 1.2). These categories are not mutually exclusive and in fact are strongly interrelated. These sources of variation can be grouped into biological and environment sources as described below.

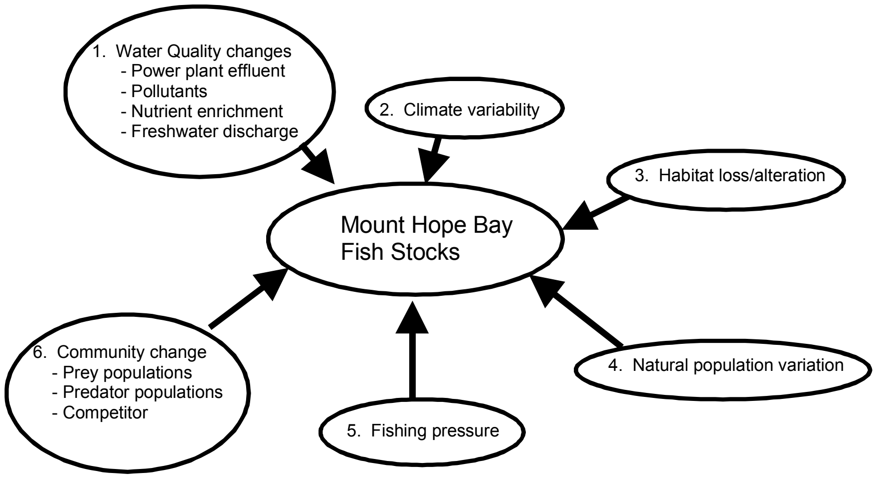

Figure 1.2. Diagram of selected sources of variation affecting Mt. Hope Bay fish stocks over annual, decadal and longer-term time scales.

1. Water Quality: Water quality can be affected by numerous factors; of particular concern in Mt. Hope Bay are Nutrient enrichment, environmental contaminants (pollution), and temperature changes resulting from the discharge of heated power plant effluent. Of these, nutrient enrichment and pollution are likely to be the most important, though the impact of the increase of water temperature has not been completely quantified. Mt. Hope Bay is well known to be seriously nutrient enriched. In effect this means that the bay has been over “fertilized” which can lead to eutrophication and result in profound changes in Mt. Hope Bay habitat quality and community structure. In severe cases, this can lead to sediment and habitat type changes in the system. For example, nutrient enrichment is often implicated in the demise of eelgrass habitat and their replacement with macroalgae beds and/or anaerobic mud flats (e.g., Short et al.1996). Similarly, other types of pollution, such as heavy metal accumulation in sediments and faunal tissues can directly impact habitat quality, fish mortality, and availability of fishery resources. Warming of Mt. Hope Bay waters can have several types of impacts on the system: 1) warming can result in local avoidance of habitats by some species or specific life stages of a species, 2) can increase local mortality of some species or life stages that can not avoid effected areas, 3) contrastingly, it could attract and/or increase survival of other species depending on their thermal preferenda and tolerances. In addition, any differences in seasonal warming patterns may affect seasonal migration behaviors of fauna and ontogenetic migrations of fauna among habitats, resulting in changes in trophic linkages among habitats. Just as importantly, small changes in temperature, well within a species' thermal tolerance, may still strongly affect its habitat use and migration patterns due to energetic effects (i.e., the cost of acclimation, Rountree 1992, Rountree and Able 1993, Craig and Crowder 2000).

2. Climate Variability: Mt. Hope Bay water temperature is strongly affected by natural variation and cycles in regional and global climate change. Local, short-term and long-term changes in climate can have a strong impact on the MHB environment and community structure. Warming of MHB waters can have similar effects to those described above for the effects of heated power plant effluent, and in fact the relative contribution of natural climate variability and power plant effects on temperature patterns in MHB can be difficult to determine. Finally, annual variation in the seasonal pattern of freshwater discharge from rivers feeding into Mt. Hope Bay can also impact the environment, habitats, and fauna in numerous ways. Most obvious would be changes in the salinity distribution in the bay, which can affect fauna distribution and habitat use patterns. Also of importance is the timing and magnitude of the discharge as larval ingress into the Bay can be strongly influenced by these factors. More subtly, changes in water volume of the discharge may alter the distribution and aerial coverage of shoreline and tidal flood plain habitats.

3. Habitat Loss/Change: Perhaps one of the most significant factors affecting Mt. Hope Bay fauna is that of habitat loss and change. It has long been recognized that specific habitats vary in their potential contribution to estuarine fauna populations, and especially for fish stocks, however in recent years it is becoming increasingly clear that habitats are linked to varying degrees by nekton movement patterns (e.g. Deegan et al. 2000). Habitat use by estuarine nekton varies among life stages, size classes within life stages, among seasons, and between day and tide cycles (Weinstein and Kreeger 2000). Because estuarine habitats are strongly linked by these processes, they cannot be considered in isolation. Quantification of the relative links among habitats, and their relative contribution to faunal production should be an important component of population models in order to fully explain population changes. Besides the obvious impact of loss of essential fish habitats (EFH), changes in the relative cover of Mt. Hope Bay habitats, and linkages among them, will likely have a strong impact on faunal abundances and local fish production.

4. Natural Population Variation. This arises from intrinsic mechanisms and long term population cycling. Intra-specific processes such as cannibalism and resource competition can also sometimes be important.

5. Fishing Pressure: Although fishing can be considered as a special case of a predator-prey relationship, we consider it separately because of its over-riding interest to the program and to distinguish “anthropogenic” from “natural” sources. Recreational and commercial fishing likely have a profound influence on the Mt. Hope Bay system and its faunal constituents. Just as for natural predator-prey sources of community change, both direct and indirect effects can be of significance. The obvious direct effect is mortality associated with the direct harvest of a species of interest. Several types of indirect effects include: the removal of a predator, prey or resource competitor for a species of interest through harvesting; cascading effects caused by removing one component of a food web and resulting in complex changes in species relationships; and habitat disturbance resulting from the fishing activity. More subtly, fishing activity in other geographic areas can also impact transient species that use Mt. Hope Bay. An extreme example of this might be the removal of adult winter flounder along the coast before they can return to the MHB to spawn.

6. Community Change: The changes in community structure, i.e. changes in relative species abundance, distributions, and food webs, can have large impact on individual species population dynamics. These result in changes in the direct and indirect interspecific interactions. Most important of these are predator-prey interactions, but competitive interactions and indirect interactions such as “trophic cascading" can sometimes be important. Unfortunately, all these types of interactions are often highly complex and difficult to quantify. Food habits studies provide perhaps the best source of data to define predator-prey relationships. Direct predator-prey relationships are the easiest to identify, but it is often very difficult to determine the strength of the relationship. This can often be supplemented or enhanced by stable isotope studies that can help determine the strength of trophic relationships among species. Changes in a prey species abundance for example, might result in changes in a predator species if the predator derives a significant component of its trophic resources from the species and it cannot switch to an alternate prey.

Report Contents: Extensive summaries of research to date on the Mt. Hope Bay physical, chemical, and biological environment have been performed by PG&E, Applied Science Associates (ASA), Marine Research, Inc. (MRI), various state and federal agencies, as well as by a number of academic researchers. This report will not duplicate these summaries but rather will highlight their important points and synthesize research to date with the objective of identifying gaps in our knowledge base related to the sources of variation identified above. The report is organized into seven chapters, including this introduction. The second chapter provides a general description of the MHB and summarizes important sources of environmental variability on various scales. The third chapter summarizes what is known of different habitat types in MHB and discusses potential sources of variation that can impact habitat quality. The major focus of this chapter is on nutrient loading to the Bay and how that affects habitat quality. The fourth chapter summarizes what is known about the plankton community of MHB and its temporal patterns, including the phytoplankton, zooplankton and ichthyoplankton components. In the fifth chapter we summarize what is known about the nekton community in MHB, emphasizing fishery species. However, rather than repeat extensive summaries of data on the fish community available in previous reports, we concentrate on the life history and ecology of winter flounder. We feel that identification of key data gaps for winter flounder, and eventual modeling of winter flounder population dynamics and ecological interactions will provide a solid foundation for modeling of other fishes. The sixth chapter reviews models that have been specifically applied to the MHB system, but does not attempt to review model applications to other estuaries (that will be one focus of the MHBNL planning stage). Finally, Chapter seven summarizes the report findings and provides an analysis of the major data gaps for the MHB system in the context of understanding the six sources of variation described in the introduction.