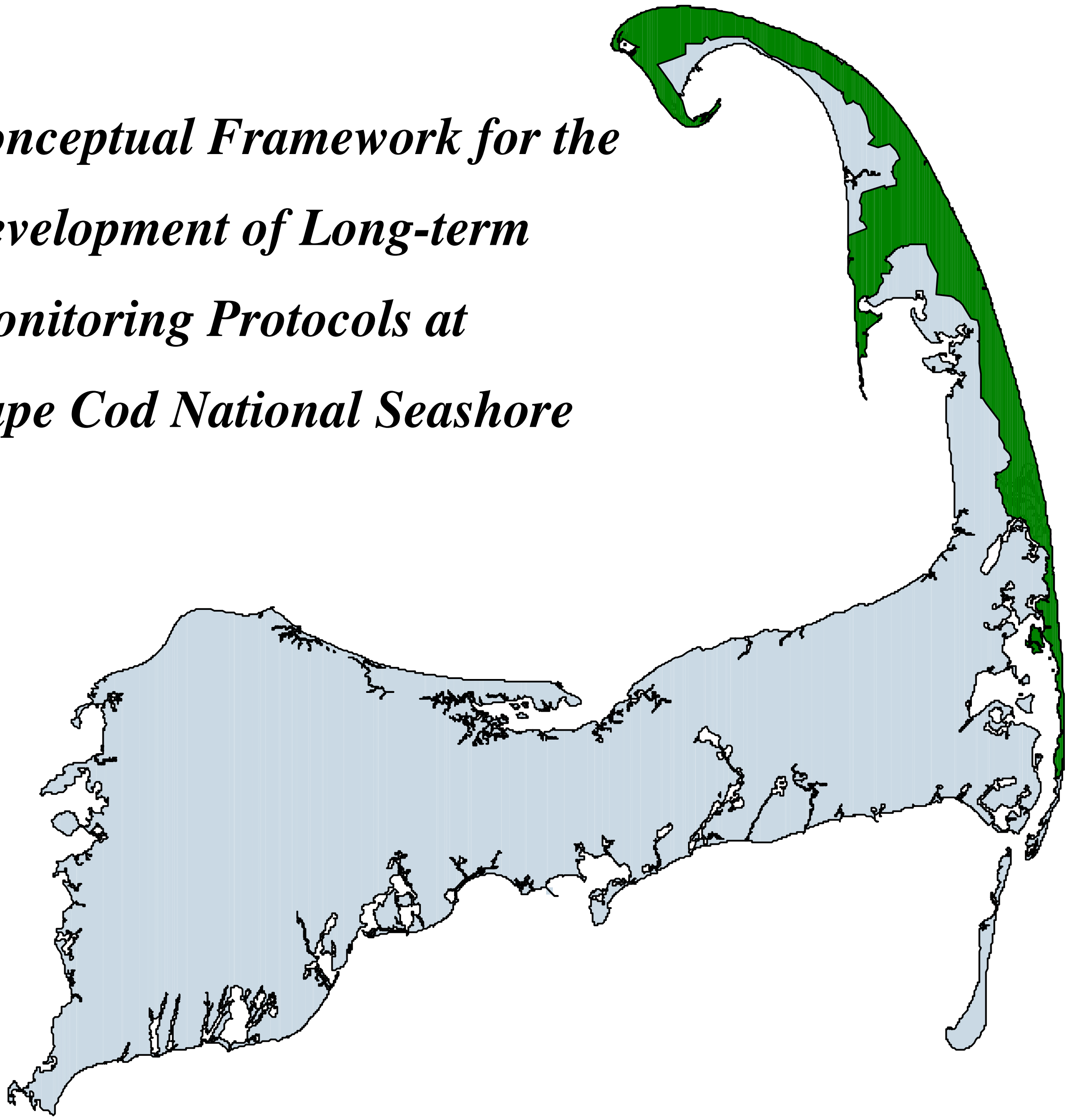
Conceptual Framework for the Development of Long-term Monitoring Protocols at Cape Cod National Seashore



USGS Patuxent Wildlife Research Center
Cooperative National Park Studies Unit
University of Rhode Island
Narragansett, RI 02882

Conceptual Framework for the Development of Long-term Monitoring Protocols at Cape Cod National Seashore

CHARLES T. ROMAN
USGS Patuxent Wildlife Research Center
Cooperative Park Studies Unit
University of Rhode Island
Narragansett, RI 02882
401-874-6886
charles_roman@usgs.gov

NELS E. BARRETT
Graduate School of Oceanography
University of Rhode Island
c/o Cape Cod National Seashore
99 Marconi Site Rd.
Wellfleet, MA 02667
508-487-3262, ext. 112
nels_barrett@nps.gov

April 1999

SUMMARY

Cape Cod National Seashore serves as the National Park Service prototype monitoring park for the Atlantic and Gulf Coast biogeographic region. The USGS-Biological Resources Division, in cooperation with the National Park Service, is charged with designing and testing monitoring protocols for implementation at Cape Cod National Seashore. It is expected that many of the protocols will have direct application at other Seashore parks within the biogeographic region.

This document presents a conceptual framework for the development of monitoring protocols for the Long-term Coastal Ecosystem Monitoring Program at Cape Cod National Seashore. The Program is ecosystem-based and issue-oriented. The ecosystem perspective recognizes the environmental processes and human activities that operate at various temporal and spatial scales. The issues-oriented emphasis acknowledges natural and human-induced threats to ecosystems and responses to those threats.

For each major Seashore ecosystem type (Estuaries and Salt Marshes; Barrier Islands/Spits/Dunes; Ponds and Freshwater Wetlands; Coastal Uplands), conceptual models were developed to explain complex relationships among Agents of Change (natural processes or human activities), Stresses (problems emerging from or related to the agents of change), and Ecosystem Responses (detectable changes in structure, function or process). For each ecosystem the models, presented as matrix tables, demonstrate that natural processes or human activities can be the source of stresses that result in ecosystem changes, some of which may be considered deleterious. Selection of the specific agents of change, stresses and ecosystem responses to be included in the monitoring program was based on a review of the conceptual models and on discussions from technical workshops.

Part One of this report presents a conceptual framework as an objective basis for selecting monitoring components of the Long-term Coastal Ecosystem Monitoring Program. Part Two provides summaries of the monitoring protocols that are being developed, including: a statement of the problem, a series of monitoring questions, the general monitoring approach, and a statement of management applications.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

FIGURES

TABLES

ACKNOWLEDGEMENTS

Thanks are extended to the Superintendent of Cape Cod National Seashore and the Seashore natural resource management staff for their complete involvement during the preparation of this report. Robert Cook, Charles Farris, Krista Lee, John Portnoy, and Mike Reynolds all reviewed this report and participated in technical workshops that provided a foundation for many of the ideas presented herein. Special acknowledgement goes to Alan Bennett, the Seashore Inventory and Monitoring Coordinator, for sharing his insights regarding the development of a comprehensive long-term monitoring program. Thanks also go to the many scientists and environmental professionals for their participation in our technical workshops; Laurel Bennett (NPS), P.A. Buckley (USGS), Thomas Cambareri (Cape Cod Commission), Elizabeth Colburn (Mass. Audubon), Courtney Conway (Syracuse), Sam Droege (USGS), Michael Erwin (USGS), Howard Ginsberg (USGS), Evan Gwilliam (URI), Eleanor Kinney (URI), Dennis Leblanc (USGS), Larry Martin (NPS), Scott Melvin (MA DEP), Barbara Nowicki (URI), Allan O'Connell (USGS), William Patterson (UMass), Kenneth Rahn (URI), Gerry Sheehan (MA DEP), Robert Sobzack (Cape Cod Commission), H. Brian Underwood (USGS), Alan Vanarsdale (US EPA), Cathy Weathers (Inst. for Ecosystem Studies), Peter Weiskel (USGS). Finally, we acknowledge the external peer reviews provided by Dr. Robert Zampella (NJ Pinelands Commission) and an anonymous reviewer.

Preparation of this report was supported by the USGS-Biological Resources Division, with special thanks to Dr. Norita Chaney (USGS, Reston).

INTRODUCTION

The National Park Service (NPS) has selected Cape Cod National Seashore as a prototype monitoring park for the Atlantic and Gulf Coast biogeographic region. Coastal ecosystems are inherently dynamic. Placed in a geophysical setting shaped by the land and the sea, Cape Cod National Seashore, like other coastal ecosystems, is a highly variable environment subject to diverse natural processes. Also, like other NPS units, Fish and Wildlife refuges, and federal/state/local/private natural areas within the coastal zone, Cape Cod is experiencing intense pressure from increased urbanization and recreation. About one-half of the total population of the contiguous United States resides in the coastal zone. The coastal zone is an area representing only 11% of the nation's entire land area, and projected to increase another 15% by the year 2010 (Culliton *et al*. 1990). With over 5 million visitors annually, coupled with neighboring development activities, the natural resources of Cape Cod National Seashore are continually threatened. In addition, Cape Cod ecosystems have experienced over three centuries of intervention by an industrially-equipped human society. Human activities dramatically alter the quality or integrity of coastal ecosystems, and perhaps, the resilience of ecosystems to catastrophic events (*e.g.,* hurricanes, oil spill) and chronic events (*e.g.*, nutrient inputs, sea level rise) (Holling 1973, Denslow 1985).

These circumstances provide a compelling justification for establishing a long-term monitoring program at Cape Cod National Seashore and other park units within the coastal zone. A long-term monitoring program is proposed which is based on our best understanding of processes and component interactions governing the coastal ecosystem, and focused on addressing management issues that confront coastal parks. An ecosystem-based, issues-oriented, long-term monitoring program is proposed to detect ecosystem changes, to examine contributing factors and consequences of ecosystem changes, and to inform park management of the salient issues that such ecosystem changes represent. Monitoring is a fundamental tool for park units that have moved beyond passive protection and are engaged in adaptive natural resource management (Christensen *et al.* 1996, Holling 1978, Lancia *et al.* 1996). Ultimately, monitoring provides a scientific basis for management decisions leading to effective protection and restoration of coastal ecosystems.

The USGS-Biological Resources Division (USGS-BRD), in collaboration with the National Park Service, is responsible for the design and testing of monitoring protocols that will constitute the Long-term Coastal Ecosystem Monitoring Program (LTEM) at Cape Cod National Seashore. The National Park Service will implement the program, with technical assistance provided by the USGS-BRD and others, including universities, government agencies, and conservation-oriented organizations.

Part One of this document is intended to accomplish the following;

- Briefly define the overall goal and approach of the Long-term Coastal Ecosystem Monitoring Program, and
- Present a conceptual framework that serves as an objective basis for selecting protocols and protocol attributes to be developed.

Part Two extends the conceptual framework to include

- Summaries of monitoring protocols that are currently proposed for the program.

As the monitoring program develops and the need to develop addition protocols occurs, sections of this document will be updated.

PART ONE

OVERALL GOAL, APPROACH, AND LIMITATIONS OF THE MONITORING PROGRAM

DETECTING, PREDICTING, AND UNDERSTANDING CHANGE

The overall goal of the Long-term Coastal Ecosystem Monitoring Program (LTEM) at Cape Cod National Seashore is:

- to *detect* changes in particular attributes of the coastal ecosystem and determine if those changes are within the bounds of natural or historic variability;
- to *predict* how those changes relate to natural processes and human-influences; and,
- to *understand* how such changes, ultimately, affect the condition of the coastal ecosystem.

It is important to the note that the term change is applied broadly to express trends (value differences) in several measures including: the rates of change (*e.g.*, annual, decadal, or centurial time scales), the extent of change (*e.g.*, site-specific *versus* regional/global spatial scales), and the intensity of change (*e.g.*, magnitude of the effect).

Generally, the aim of the LTEM program at Cape Cod National Seashore is: (1) to validate model assumptions and predictions that explain how (and why) changes occur; (2) to forecast potentially adverse changes that provide "early warning" capabilities; (3) to inform whether and when management intervention is necessary; and (4) to evaluate the effectiveness of management, *i.e.,* how well an ecosystem is being sustained in accordance with current management practices and regulatory compliance (National Research Council 1990, Spellerberg 1991).

Most importantly, the information generated from the monitoring program is intended to assist the park manager in clarifying and addressing issues as part of the decision-making process. Do the observed changes represent current problems or forecast emerging problems that might adversely affect the ecological integrity of the coastal ecosystem? Do the problems require immediate action? Can the problems be remedied by management actions? Understanding the dynamic nature of coastal ecosystems and the consequences of human activity is essential for management decision-making aimed to maintain, enhance, or restore the ecological integrity of the coastal ecosystem and to avoid, minimize, or mitigate ecological threats to the coastal ecosystem.

ECOSYSTEM-BASED AND ISSUE-ORIENTED MONITORING

The approach of the LTEM Program at Cape Cod National Seashore is an ecosystem-based approach to monitoring coupled with an issues-oriented emphasis. The ecosystem concept recognizes that inevitable changes to the ecosystem result from interactions between biota and the environment operating at many different spatial and temporal scales (Holling 1992, Woodley *et al.* 1993). Although no one scale is appropriate for monitoring all ecosystem processes or components, characteristic spatial and temporal scales commonly form natural, ecological hierarchies (Urban *et al.* 1987, King 1993) governed or constrained by the physical dimensions of the landscape (Rowe 1988). While these natural subdivisions are primarily derived from landscape criteria and other environmental dissimilarities (Avers *et al.*1994, Rowe and Shead 1981), they constitute an ecological setting or context that governs human land use practices and other activities (McDonnell and Pickett 1993). As such, the ecosystem-based approach uses natural, hierarchical dimensions of the coastal landscape as a suitable template for monitoring changes in ecological phenomena associated with both natural and human causes. Cape Cod National Seashore constitutes a landscape mosaic represented by several distinctive geomorphologic types: estuaries/salt marshes, ponds/freshwater wetlands, barrier islands/spits/dunes, and coastal uplands of predominantly heathlands and pine or oak forests.

The issues orientation focuses on the relevance of the monitoring results to meet the goals of management directed at sustaining the quality or the integrity of the coastal ecosystem and eliminating threats from natural or human causes. Problems are anticipated when particular measures of change exceed acceptable bounds that are often defined by historic or natural limits or standards set by policy guidelines. The role of monitoring is crucial in detecting meaningful levels of change from which critical threshold values or policy standards are determined.

The emphasis on issues explores our knowledge of cause-and-effect relations by incorporating two complementary strategies, threat-specific monitoring and effects-oriented monitoring. A presupposition of causality usually supports threat-specific monitoring. Whereas for effects-based monitoring, the focus is on tracking trends that are indicative of ecosystem integrity, such as acceptable values of biological diversity or primary productivity. The issue-oriented emphasis combines both threat-specific and effects-oriented monitoring in order to achieve a sufficient level of predictability to better guide management action. As stated at a national workshop entitled, "Ecological Resource Monitoring: Change and Trend Detection", sponsored jointly by the Ecological Society of America, the American Statistical Association and the US Environmental Protection Agency, simultaneous monitoring of trends in both ecosystem effects and ecosystem stresses can improve the interpretation of monitoring results (Dixon *et al*. 1997, Olsen *et al.* 1997).

MONITORING PROGRAM LIMITATIONS

Limitations of monitoring exist because of the inherent complexity of coastal ecosystems. Insufficient scientific information and challenges in distinguishing natural variability from the range of human impacts make it difficult to clarify monitoring issues and develop specific monitoring objectives. Further limitations of monitoring exist because institutional resources devoted to monitoring practices are often constrained by time, finances, and personnel. The LTEM Program simply cannot address all resource management interests. Rather, the intent of the Program is to monitor a select set of ecosystem processes and components that reflect the status of the coastal ecosystem and are relevant to management issues. This information will collectively provide a foundation for building a more flexible monitoring program. As monitoring proceeds, as data sets are interpreted, as our understanding of ecological processes is enhanced, and as trends are detected, future issues will emerge. Adjustments can be made to the Program to address changing needs. For example, objectives specific to monitoring protocols may need refinement, and the frequency or intensity of monitoring may require modification. Furthermore, as the monitoring program develops, additional management strategies may be warranted. Occasionally, some management decisions, often those with narrowly-defined objectives, will require specific information that may necessitate the initiation of research projects with funding independent of the monitoring program. However, it is expected that information gathered from the monitoring program will be interpreted in conjunction with results from the independent studies in order to develop appropriate management scenarios for the particular issues.

THE CONCEPTUAL FRAMEWORK FOR DEVELOPING PROTOCOLS

THE DESIGN MATRIX AS A WORKING MODEL

Cape Cod National Seashore has been divided into four major ecosystem components or landscape types generally representative of all coastal park units from Massachusetts to Texas: Estuaries/Salt Marshes, Ponds/Freshwater Wetlands, Barrier Islands/Spits/Dunes, and Coastal Uplands. Although these natural subdivisions provide a hierarchical, landscape context for the program, it is clearly recognized that interactions occur within and across the landscape continuum.

For each of the four landscape types, a simple design matrix was developed to assist in identifying important issues confronting these ecosystems, and ultimately, to assist with selection of specific variables to monitor. As a working model, each matrix is a conceptual construct used to explain the complex relations among agents of change, associated stresses, and ecosystem responses. ***Agents of change*** are mechanisms defined as natural processes and events, or human activities. Agents of change can operate within the range of natural variability and acceptable limits of change or they may not. If not, they are the source of stresses. ***Stresses*** are the associated problems or products of human activities or natural events (agents) that diminish the quality or integrity of the ecosystem. ***Ecosystem responses*** are defined as detectable changes or trends in any measurable value of the coastal ecosystem's structure, function, or process, that is considered indicative of ecosystem quality or integrity. For example, within the estuarine ecosystem, septic systems are agents of change that can stress estuarine systems through excessive nutrient loading, which can result in an ecosystem response of altered primary productivity patterns.

To derive a preliminary list of *agents of change* appropriate to the coastal ecosystem, broad categories were considered: Land Use, Natural Disturbances including Physical and Biotic Forces, Pollution, Recreational Use, Resource Extraction and Exploitation, and Unknown Agents of Change (Table 1). How each agent might contribute to a problem was considered and a list of potential *stresses* was compiled (Table 2). To account for relevance to management concerns, each stress was matched to general management issues identified in the Cape Cod National Seashore natural resources management plan (National Park Service 1992). These management issues include: impacts of adjacent development on groundwater quality and quantity, accelerated rates of freshwater and coastal marine eutrophication, impacts of recreation on natural resources, effects of landscape changes since European settlement, protection and restoration of Federal and/or State-listed rare species and communities, consumptive uses of resources, air pollution, and sea level rise. Note that any one issue may be attributed to several stresses and that any single stress may relate to several issues. To derive a preliminary list of *ecosystem responses*, several broad categories of ecological phenomena were considered, Biogeochemical Cycling, Productivity and Biomass, Biological Diversity/Abundance, Life History of Rare or Key Species, Landscape & Habitat Diversity, and Unknown responses (Table 3).

The final step in the development of the design matrix involved coupling the agents of change, stresses, and ecosystem responses for each of the four ecosystem types. Matrix tables are presented separately for each individual ecosystem type as synoptic representations of interactions to consider for monitoring (Tables 4a-d). These are working models that highlight which particular issues are relevant to which coastal landscape type and how agents of change, stresses, and ecosystem responses relate. The design matrices are not intended to represent a comprehensive account of the entire coastal ecosystem, nor merely a list of mechanisms and outcomes as features of ecosystem change. Instead, they present a conceptual framework to help select and develop monitoring protocols. Components of the monitoring program are organized according to an ecosystem basis that emphasizes the relationships among various agents of change, associated stresses, and ecosystem responses that define salient issues. While these simplified, conceptual models may understate the comprehensive nature of the coastal ecosystem; they serve to demonstrate the complexity of coastal ecosystem relations, many of which are unknown. However, it is clearly illustrated that multiple agents of change can lead to multiple stresses, resulting in multiple ecosystem responses.

As working models, the matrix tables clearly demonstrate the relational scheme of natural processes or human activities being the source of stresses that result in detectable changes to the ecosystem, some of which may be considered deleterious. For example, by following intersections in Table 4a, the Estuarine and Salt Marsh design matrix shows that leachate from septic systems may contribute to the problems of nutrient loading which results in a variety of ecosystem responses, such as changes in porewater chemistry, algal production, eelgrass decline, etc. Relationships among agents of change, stresses and ecosystem responses can also be presented graphically (Fig. 1). The relations as illustrated in the design matrix reveal which agents of change are likely to be implicated in any particular problem and which ecological responses are likely to ensue from such problems.

TABLE 1. *Agents of Change* listed according to broad categories.

AGENTS OF CHANGE
LAND USE
Construction - dams, dikes, culverts, revetments, *etc*.
Development / Agriculture / Aquaculture
Dredging / Disposal
Dune building / Beach nourishment
Mosquito control
NATURAL DISTURBANCES / PHYSICAL & BIOTIC FORCES
Adverse weather / Storm surges
Fire / Fire suppression
Grazing / Browsing
Ground water influx
Inlet / Landform migration
Sea level rise
Species additions / Species removals (natives & exotics)
UV-B (Solar radiation)
POLLUTION
Atmospheric deposition
Fertilizers / Pesticides
Oil / Toxic spills
Ozone
Septic systems
RECREATIONAL USE
Recreational use - boating, ORVs, trampling, biking, *etc*.
RESOURCE EXTRACTION & EXPLOITATION
Ground water withdrawal
Fishing / Shellfishing
UNKNOWN?

TABLE 2. Ecological *Stresses* and their relevancy to Park management issues.

	Management Issues							
STRESSES	*Groundwater Quality / Quantity*	*Eutrophication*	*Recreational Impacts*	*Human-altered Landscapes*	*Species / Habitat Restoration*	*Resource Consumptive Uses*	*Air Quality / Pollution*	*Sea Level Rise*
PHYSICAL								
Altered tidal circulation				x				x
Freshwater discharge alteration	x			x				
Microclimatic change								
Suspended particles		x	x					
Water table alterations	x	x				x		x
CHEMICAL								
Acidification	x	x			x		x	x
Nutrient loading	x	x	x					
Toxins	x	x					x	
BIOLOGICAL								
Exotics, over/under-abundant spp.					x			
Human presence / conflict			x	x				
Overgrazing / defoliation					x			
Over-harvests (fish / shellfish)						x		

TABLE 3. *Ecosystem Responses* listed according to general categories.

ECOSYSTEM RESPONSES
BIOGEOCHEMICAL CYCLING
Algal nitrogen content
Freshwater chemistry
Soil chemistry - mineral nutrients, pH, *etc*.
PRODUCTIVITY / BIOMASS CHANGE
Algal production
Eelgrass decline
Freshwater plankton production
Landbird production
Nekton production
Plant biomass
Wildlife production
BIODIVERSITY / ABUNDANCE
Amphibian and reptile abundance
Aquatic invertebrate abundance
Beach invertebrate community change
Benthic community change
Deer abundance
Nekton community change
Small mammals abundance
Vegetation development
Waterbird community change
Red Fox and Coyote abundance
LIFE HISTORY / RARE OR KEY SPECIES
Population dynamics of rare or key species
LANDSCAPE / HABITAT DIVERSITY / ABUNDANCE
Geomorphic change - shoals, shores, dunes, *etc*.
Habitat loss / gain
Hypoxia / Anoxia
Light limitation
UNKNOWN?

Table 4a. *ESTUARIES & SALT MARSHES DESIGN MATRIX*

STRESSES	Altered tidal circulation	Human presence / conflict	Exotics, Over- & Under-abundant Spp.	Nutrient loading	Over-harvests (fish/shellfish)	Suspended particles	Toxins	Unknown?
AGENTS OF CHANGE								
LAND USE								
Construction - dikes, culverts, revetments, *etc.*	x	x	x	x		x		
Development / Agriculture	x	x	x	x		x		
Dredging / Disposal	x		x	x		x	x	
Mosquito control	x		x				x	
NATURAL DISTURB. / PHYSICAL & BIOTIC FORCES								
Adverse weather / Storm surges	x		x	x				
Ground water influx				x				
Inlet / Landform migration	x							
Sea level rise	x							
Species additions/removals (natives & exotics)		x	x					
POLLUTION								
Atmospheric deposition				x			x	
Oil / Toxic spills							x	
Septic systems				x				
RECREATIONAL USE								
Recreational use - boating, ORVs, etc.	x	x	x			x	x	
RESOURCE EXTRACTION & EXPLOITATION								
Fishing / (Shellfishing)		x	x		x			
Ground water withdrawal								
UNKNOWN?								x
ECOSYSTEM RESPONSES								
BIOGEOCHEMICAL CYCLING								
Porewater chemistry	x			x			x	
Wet deposition chemistry				x				
PRODUCTIVITY / BIOMASS CHANGE								
Algae production	x			x				
Eelgrass decline	x			x		x	x	
Nekton production				x				
BIODIVERITY / COMMUNITY COMPOSITION								
Benthic community change	x		x	x		x	x	
Nekton community change	x	x	x	x	x	x	x	
Vegetation development	x		x	x			x	
Waterbird community change		x	x		x		x	
LIFE HISTORY / KEY OR RARE SPECIES								
Population dynamics of rare or key spp.			x					
LANDSCAPE / HABITAT DIVERSITY / ABUNDANCE								
Geomorphic change - shoals, shores, *etc.*	x							
Habitat loss / gain	x							
Hypoxia / Anoxia	x			x				
Light limitation						x		
UNKNOWN?								x

Table 4b. *BARRIER ISLANDS, SPITS, & DUNES DESIGN MATRIX*

STRESSES	Acidification	Human presence / conflict	Microclimatic change	Nutrient loading	Overgrazing / defoliation	Exotics, Over- & Under-abundant Spp.	Toxins	Water table alterations	unknown?
AGENTS OF CHANGE									
LAND USE									
Construction - dikes, culverts, revetments, *etc.*		x	x	x		x			
Development / Agriculture		x	x	x		x	x	x	
Dredging / Disposal				x		x	x		
Dune Building / Beach nourishment			x			x		x	
NATURAL DISTURB. / PHYSICAL & BIOTIC FORCES									
Adverse weather / Storm surges			x	x		x			
Fire / Fire suppression			x			x			
Inlet / Landform migration			x			x			
Sea level rise								x	
Species additions / removals (natives & exotics)		x			x	x			
POLLUTION									
Atmospheric deposition	x			x			x		
Oil / Toxic spills							x		
Ozone			x				x		
Septic systems				x					
RECREATIONAL USE									
Recreational use - trampling, ORVs, *etc.*		x				x	x		
RESOURCE EXTRACTION & EXPLOITATION									
Ground water withdrawal								x	
UNKNOWN?									x
ECOSYSTEM RESPONSES									
BIOGEOCHEMICAL CYCLING									
Wet deposition chemistry	x		x	x					
Soil chemistry	x			x					
PRODUCTIVITY / BIOMASS CHANGE									
PLANT BIOMASS	x	x	x	x	x			x	
BIODIVERSITY / ABUNDANCE									
Beach invertebrate community change		x				x	x		
Deer abundance		x			x		x		
Landbird population change		x				x	x		
Small mammals abundance					x	x	x		
Vegetation development	x	x	x	x	x	x	x	x	
Waterbird abundance change		x				x	x		
Wildlife abundance		x				x	x		
LIFE HISTORY / KEY OR RARE SPECIES									
Population dynamics of rare or key species						x			
LANDSCAPE / HABITAT DIVERSITY / ABUNDANCE									
Geomorphic change - shores, dunes, *etc.*			x					x	
Habitat loss / gain	x		x						
UNKNOWN?									x

Table 4c. *PONDS & FRESHWATER WETLANDS DESIGN MATRIX*

STRESSES	Acidification	Human presence / conflict	Microclimatic change	Nutrient loading	Overgrazing	Over-harvests (fish/shellfish)	Exotics, Over- & Under-abundant Spp.	Stage / discharge alteration	Suspended particles	Toxins	Water table alterations	Unknown?
AGENTS OF CHANGE												
LAND USE												
Construction - dams, culverts, *etc.*		x	x	x			x	x	x		x	
Development / Agriculture		x	x	x			x	x	x	x	x	
Dredging / Disposal				x			x	x	x	x		
Mosquito control							x	x		x		
NATURAL DISTURB. / PHYSICAL & BIOTIC FORCES												
Adverse weather / Storm surges			x	x			x	x	x		x	
Grazing / Browsing					x		x					
Ground water influx				x				x			x	
Species additions / removals (natives & exotics)		x			x		x					
UV-B (Solar radiation)			x				x					
POLLUTION												
Atmospheric deposition	x			x						x		
Fertilizers / Pesticides				x						x		
Oil / Toxic spills										x		
Septic systems				x								
RECREATIONAL USE												
Recreational use - boating, ORVs, *etc.*		x		x			x		x			
RESOURCE EXTRACTION & EXPLOITATION												
Fishing		x				x	x					
Ground water withdrawal												
UNKNOWN?												x
ECOSYSTEM RESPONSES												
BIOGEOCHEMICAL CYCLING												
Freshwater chemistry	x			x						x		
PRODUCTIVITY / BIOMASS CHANGE												
Macrophyte production	x		x	x		x	x		x	x		
Freshwater plankton production	x		x	x		x	x		x	x		
BIODIVERSITY / ABUNDANCE												
Amphibian & reptile abundance	x	x	x				x	x		x	x	
Aquatic Invertebrate abundance	x	x	x	x			x	x		x		
Fish community change	x	x				x	x	x	x	x		
Vegetation development	x	x	x	x	x		x	x		x	x	
LIFE HISTORY / KEY OR RARE SPECIES												
Population dynamics of rare or key species							x					
LANDSCAPE / HABITAT DIVERSITY / ABUNDANCE												
Geomorphic change - shorelines, *etc.*			x								x	
Habitat loss / gain			x					x		x	x	
Hypoxia / Anoxia	x			x				x				
UNKNOWN?												x

Table 4d. ***COASTAL UPLANDS DESIGN MATRIX***									
AGENTS OF CHANGE									
LAND USE									
Construction - clearing, *etc.*		x	x			x		x	
Development / Agriculture		x	x	x	x	x	x		
Dredging / Disposal				x		x	x		
NATURAL DISTURB. / PHYSICAL & BIOTIC FORCES									
Adverse weather / Storm surges			x	x		x			
Fire / Fire suppression			x	x		x		x	
Grazing / Browsing					x	x			
Species additions/removals (natives & exotics)		x			x	x			
POLLUTION									
Atmospheric deposition	x			x					
Fertilizers / Pesticides						x	x		
Oil / Toxic spills						x	x		
Ozone			x			x	x		
RECREATIONAL USE									
Recreational use - ORVs, trampling, *etc.*		x				x			
RESOURCE EXTRACTION & EXPLOITATION									
UNKNOWN?									x
STRESSES	Acidification	Human presence / conflict	Microclimatic change	Nutrient loading	Overgrazing	Exotics, Over- & Under-abundant	Toxins	Water table	Unknown?
ECOSYSTEM RESPONSES									
BIOGEOCHEMICAL CYCLING									
Soil chemistry - mineral nutrients, pH, *etc.*	x		x	x					
PRODUCTIVITY/ BIOMASS CHANGE									
Plant biomass	x	x	x	x	x	x		x	
Landbird production		x	x			x	x		
BIODIVERSITY / ABUNDANCE									
Amphibian & reptile abundance		x				x	x		
Deer abundance		x			x	x			
Invertebrate abundance		x	x			x	x		
Red Fox and Coyote abundance		x				x			
Landbird population change		x	x			x	x		
Small mammals abundance					x	x			
Vegetation development	x	x	x	x	x	x	x	x	
Wildlife production		x				x			
LIFE HISTORY / KEY OR RARE SPECIES									
Population dynamics of rare or key spp.						x			
LANDSCAPE / HABITAT DIVERSITY / ABUNDANCE									
Geomorphic change								x	
Light variation						x			
Habitat loss / gain			x				x		
UNKNOWN?									x

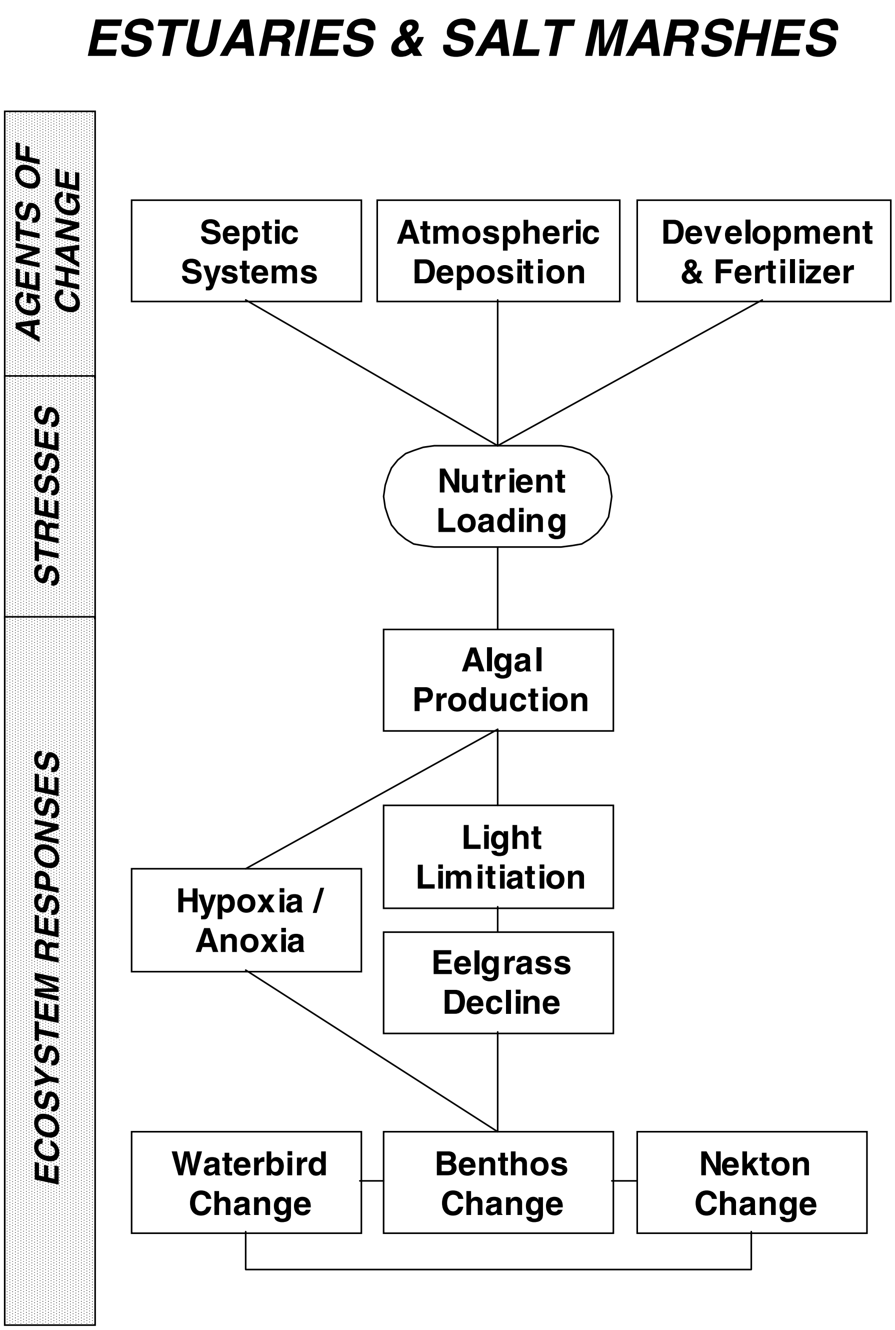


Figure 1. Conceptual model depicting the relations among agents of change, stresses, and ecosystem responses.

MODELS AS TOOLS FOR THE SELECTION OF MONITORING COMPONENTS

Selecting suites of agents, stresses or responses that could be developed into monitoring components was achieved, in part, by utilizing Tables 4a-d as explanatory design matrices (Holling 1978, NRC 1990). By examining the various relational pathways connecting agents-to-stresses-to-responses, the general trends imply that issues are rarely simple, and instead are likely to be quite complex. Some issues are inferred from stresses that originate from multiple agents of change or stresses that generate multiple ecosystem responses. Other issues involve a single agent of change or a single ecosystem response that is associated with multiple stresses.

The analysis that follows is not intended to be the only process used to identify the specific agents of change, stresses or ecosystem responses that are included in the monitoring program. However, the design matrices do provide some *objective* guidance to the selection process. The matrix analysis is useful at identifying suites of agents, stresses or responses that deserve careful consideration in the selection process. However, some issues may deserve priority consideration because of other factors (*e.g.,* important regulatory issue, management need, previous experience clearly demonstrates the importance of the issue, literature demonstrates strong cause and effect relationships, *etc*.).

ESTUARIES AND SALT MARSHES (Table 4a)

Land use activities (*e.g.,* dikes/culverts, revetments, development, dredging/disposal) and recreational use (*e.g.,* boating) are noted as agents of change that are the source of multiple stresses in estuarine and salt marsh environments. Numerous agents contribute to alter tidal circulation, the stress of which can elicit numerous ecosystem responses. Stresses produced by exotics, over- or under-abundant spp., and nutrient loading also appear to be influenced by many different agents. Stresses produced by altered tidal circulation and nutrient loading are also implicated by multiple ecosystem responses. In terms of ecosystem responses, changes in biodiversity (*e.g.,* nekton, benthos, vegetation, and waterbirds) and changes in productivity (*e.g.,* eelgrass decline, and algal production) respond to multiple stresses.

BARRIER ISLANDS, SPITS, AND DUNES (Table 4b)

Once again, land use activities clearly represent the agents of change that lead to multiple stresses. Stresses derived from exotics, over- or under-abundant spp. are brought about by multiple agents of change and contribute to numerous ecosystem responses. Other important issues relate to toxins and direct human pressure or conflict that contribute to multiple ecosystem responses. All of the ecosystem responses under the general category of biodiversity/abundance (*e.g.*, beach invertebrate communities, deer, landbirds, vegetation, *etc*.) are impacted by multiple stresses. As an ecosystem response, geomorphic change, is strongly linked to a number of physical stresses.

PONDS AND FRESHWATER WETLANDS (Table 4c)

Land use activities and adverse weather events are agents of change that cause a number of stresses within the pond and freshwater wetland ecosystem. Exotics, over- or under-abundant spp., as well as nutrient loading are stresses that originate from several different agents of change. Acidification, nutrient loading, microclimate, exotics, over- or under-abundant spp., surface water stage/discharge alteration, and toxins are all well documented stresses that lead to multiple ecosystem responses. Numerous ecosystem changes that respond to multiple stresses include macrophyte and algal production, the biodiversity or abundance of aquatic organisms, and the development of the vegetation.

COASTAL UPLANDS (Table 4d)

Land use activities, adverse weather events, and fire/fire suppression are agents of change that lead to multiple stresses. Stresses asociated with exotics, over- or under-abundant spp are brought about by multiple agents of change and contribute to numerous ecosystem responses. Other issues relate to human presence/conflict, microclimate, and toxins as stresses that lead to multiple ecosystem responses. Complex issues concern vegetation change and other ecosystem responses related to changes in productivity and biomass as well as biodiversity and abundance.

SELECTING COMPONENTS TO MONITOR

Using a design matrix as a working model provides an objective framework to begin constructing the LTEM at Cape Cod National Seashore. These conceptual models, coupled with technical workshops (Table 5), helped identify specific monitoring questions and helped select which suites of specific agents-of-change, stresses, and ecosystem responses to include in a long-term monitoring program. Technical workshops were convened and attended by agency and academic scientists and NPS natural resource management professionals.

Workshop discussions include: debating critical issues, defining the problem statement, identifying monitoring objectives, selecting quantifiable monitoring variables, setting or advising critical limits and thresholds, framing testable hypotheses and quantifiable trends, identifying field methods and experimental designs, and reporting procedures. While the use of a design matrix provides some objective guidance on the range of choices to consider; the technical workshops provided details regarding which monitoring questions, variables, and methods to pursue. The design matrix is an excellent foundation to help guide workshop discussions. Take note that the matrix tables presented in Table 4 were completed as a result of the workshops. Presented at the workshop was a general form of the matrix coupled with a request to identify likely agents-of-change, associated stresses, and ecosystem responses or indicators.

Table 6 lists the monitoring protocols that are presently operational and those that are under development or being developed by the USGS-BRD/NPS cooperative prototype program. The protocols are arranged separately according to ecosystem type or under a general park-

Table 5. Technical workshops, date convened or proposed, attendees or invitees

Monitoring Workshop Topic	*Date*	*Participants**
Estuarine nutrient loading	November 1997	URI, USGS-BRD, NPS-CACO,
Estuarine nekton	November 1997	URI, USGS-BRD, NPS-CACO
Aquatic Invertebrates & Amphibians	November 1997 and spring 1999	USGS-BRD, NPS-CACO, Mass. Audubon
Groundwater & Surface water	December 1997	URI, USGS-BRD, NPS-CACO, NPS-WRD, USGS-WRD, CCC
Shorebirds, Waterbirds, Landbirds	December 1997 and Jan 1999	URI, USGS-BRD, NPS-CACO, MA-DEP
Mammals	December 1997	URI, USGS-BRD, NPS-CACO
Vegetation	December 1997	URI, USGS-BRD, NPS-CACO, UMASS
Meteorology	November 1998	URI, USGS-BRD, NPS-CACO, MA-DEP, MIT
Land use	Spring 1999	URI, USGS-BRD, NPS-CACO, CCC
Visitor conflicts	Spring 1999	URI, USGS-BRD, NPS-CACO, NPS-BOSO, CCC
Data management	Spring 1999	URI, USGS-BRD, NPS-CACO
Modeling needs / applications	Fall 1999	URI, USGS-BRD, NPS-CACO

*key to participants:
URI, University of Rhode Island; USGS-BRD, United States Geological Survey-Biological Services Division; USGS-WRD, USGS-Water Resources Division; NPS-CACO, National Park Service-Cape Cod National Seashore; NPS-BOSO, NPS-Boston Region; NPS-WRD, NPS-Water Resources Division; CCC, Cape Cod Commission; MA-DEP, Massachusetts Dept. of Environmental Protection; MIT, Massachusetts Institute of Technology, UMASS, University of Massachusetts.

Table 6. Protocols of the Long-term Coastal Ecosystem Monitoring Program at Cape Cod National Seashore. Protocols are listed by ecosystem type and identified as presently operational by the park, under development by the USGS-BRD or NPS (as of FY98), or planned for subsequent fiscal years by the USGS-BRD.

ECOSYSTEM TYPE	*SHORT TITLE*
Estuaries and Salt Marshes	
Under Development	*Nutrient Enrichment*
Under Development	*Nekton (Fishes and Decapod Crustaceans)*
Under Development	*Waterbirds*
Under Development	*Sediment & Benthic Fauna Contaminants Baseline*
Barrier Islands/Spits/Dunes	
Under Development	*Geomorphic Shoreline Change*
Under Development	*Waterbirds*
Under Development	*Sediment & Benthic Fauna Contaminants Baseline*
Ponds and Freshwater Wetlands	
Operational[1]	*Pond Water Quality*
Under Development	*Pond and Wetland Surface Water Levels*
Under Development	*Stream Discharge Gauging*
Planned	*Aquatic Invertebrates*
Planned	*Amphibians*
Planned[1]	*Freshwater Fish*
Coastal Uplands	
Planned	*White-tailed Deer*
Planned[1]	*Red Foxes and Coyotes*
Under Development	*Landbirds*
Parkwide/Multiple Ecosystems	
Operational[1]	*Cover Type Mapping*
Operational & Planned[1]	*Meteorological and Atmospheric*
Under Development	*Permanent Vegetation Plots*
Under Development	*Groundwater Levels and Groundwater Quality*
Planned	*Sea Level*
Planned	*Land Use Activity and Visitor Use*

[1] Operational and planned monitoring protocols that have been, or will be, developed by the NPS. All other protocols are being developed by the USGS-BRD in association with cooperators.

wide/multiple ecosystem category. Often the protocols do not neatly fit within a specified landscape type category, pointing to the interactions and relationships among ecosystems. For instance, Landbirds, Deer and Red Fox and Coyote monitoring are all included within the Coastal Uplands ecosystem because most of the monitoring will probably be within these habitats; however, monitoring will occur in the other ecosystem units as well.

Figure 2 is intended to demonstrate linkages among the individual monitoring protocols that compose the initial program. For instance, interpretation of the ponds and wetlands water quality data sets will be dependent on the meteorological, atmospheric deposition, and land use data sets. Monitoring freshwater stream discharge represents a necessary component to documenting sources of nutrient enrichment in estuaries. Several other examples of the necessary linkages are presented in Fig. 2.

The discussion that follows briefly identifies the protocols to be developed. Part Two of this document provides the details of the protocols. The design matrices were instrumental in insuring that the LTEM Program endeavors to monitor agents of change and stresses (i.e., understand how the cause of an ecosystem response is changing), and monitor ecosystem responses (i.e., understand if and how the ecosystem is changing).

For *Estuaries and Salt Marshes*, workshop discussions and the analysis of issues (Table 4a) highlighted *nutrient loading*, with multiple agents of change and multiple ecosystem responses, as a key focal point for the monitoring program. The threat of catastrophic and chronic oil spills in the coastal environment strongly justifies the need for establishing *sediment and benthic fauna contaminant* baseline levels and monitoring within estuarine and salt marsh habitats. Coastal storm events (hurricanes and nor'easters) are considered as major factors controlling *geomorphic shoreline change*.

Within the *Barrier Islands, Spits, and Dunes* complex, where the habitats are governed strongly by physical shoreline processes, protocols for *geomorphic shoreline change* monitoring are under development. As noted above, contaminants monitoring and storm surge monitoring are also essential here. For *Ponds and Freshwater Wetlands*, pond water quality monitoring (an operational program at Cape Cod National Seashore) is considered paramount to addressing complex issues related to acidification, nutrient loading, exotics, over- and under-abundant species, and land use. In addition, workshop discussions strongly recommended the need to monitor pond and wetland water levels and freshwater stream discharge as fundamental variables needed to interpret the response of these freshwater environments to natural and human-induced stresses. Monitoring of aquatic biota (as planned) will address multiple stresses.

The influence of exotics, as well as problems related to over- and under-abundant species are the most persistent issues confronting *Coastal Uplands*, and thus, vegetation monitoring is essential and under development (see park-wide/multiple ecosystems). Workshop discussions also identified white-tailed deer monitoring as important at Cape Cod and other coastal parks.

Cover type monitoring and permanent vegetation plot monitoring, included under the *Parkwide/Multiple Ecosystem* category, are in response to multiple stresses identified throughou

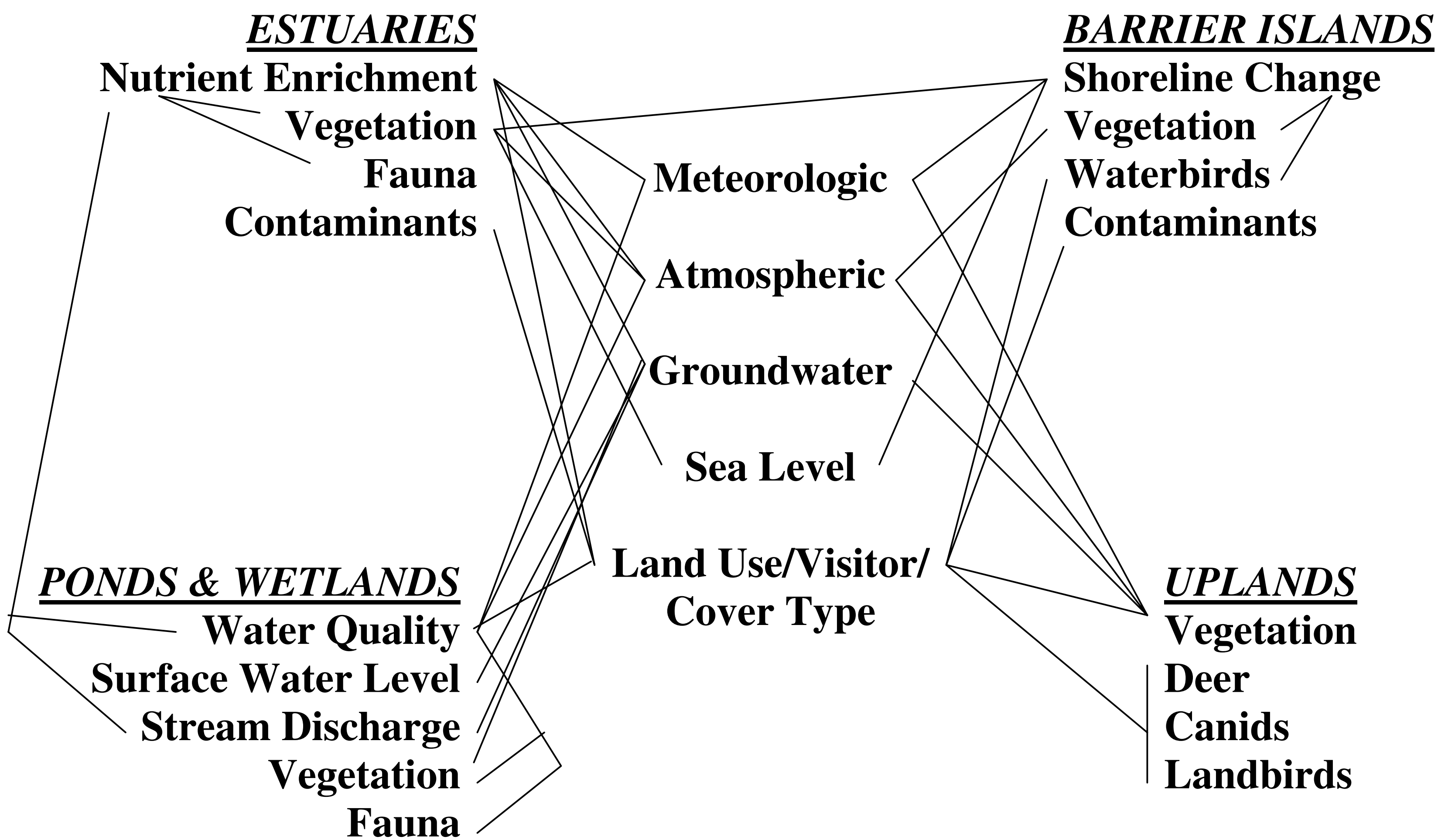


Fig. 2. Some interactions among the various monitoring protocols.

all of the ecosystem types (Tables 4a-d). Land use is an important agent of change linked to the most stresses in all the ecosystem types; thus, a planned monitoring protocol for assessing land use activity and visitor use. Meteorological/Atmospheric deposition and Groundwater monitoring are fundamental variables needed to interpret the response of all habitats to natural and human-induced stresses.

The protocols listed in Table 6 are suggested as the initial core of the Long-term Coastal Ecosystem Monitoring Program at Cape Cod National Seashore. These protocols should provide an excellent foundation from which the monitoring program can evolve over the next several decades. The intent of the monitoring program is to be well balanced, focusing on human constraints to the coastal ecosystem, but also accounting for natural processes and associated ecosystem responses, to better understand natural variability and functions of ecosystems. The protocols encompass sufficient breadth to provide guidance for natural resource management, while not being too cumbersome to execute effectively. In addition, the program is flexible, inviting the development of new protocols: as issues emerge, as the interpretation of monitoring data identifies agents or responses that are now unknown, as predictive modeling efforts require additional information, or as new monitoring techniques are developed. The monitoring program will not be static, but dynamic and building upon the fundamental program.

INTEGRATING PROTOCOL DEVELOPMENT AND PROGRAM IMPLEMENTATION

The Long-term Coastal Ecosystem Monitoring Program includes two phases: a Protocol Development phase, being led by the USGS-BRD with extensive input and cooperation from the NPS, and a Program Implementation phase, conducted by the NPS with continuing technical input from the USGS-BRD. Figure 3 identifies the major aspects and relationships between both phases of the Program. As noted, the design matrix models (Table 4a-d) and technical workshops formed the basis for selection of components or variables to be included in the monitoring program. The process of designing and field testing the protocols is presently underway. Upon completion and training, the NPS will implement the protocols, manage and interpret the data, and apply the monitoring findings to natural resource management decisions. It is also noted in Figure 3, that as the Program evolves, it may be determined that new protocols are needed. Finally, the results from monitoring, complemented by comprehensive research data specific to Cape Cod National Seashore, will form the basis for development of conceptual and numerical models aimed at predicting the response of ecosystems, or components therein, to natural and human-induced processes.

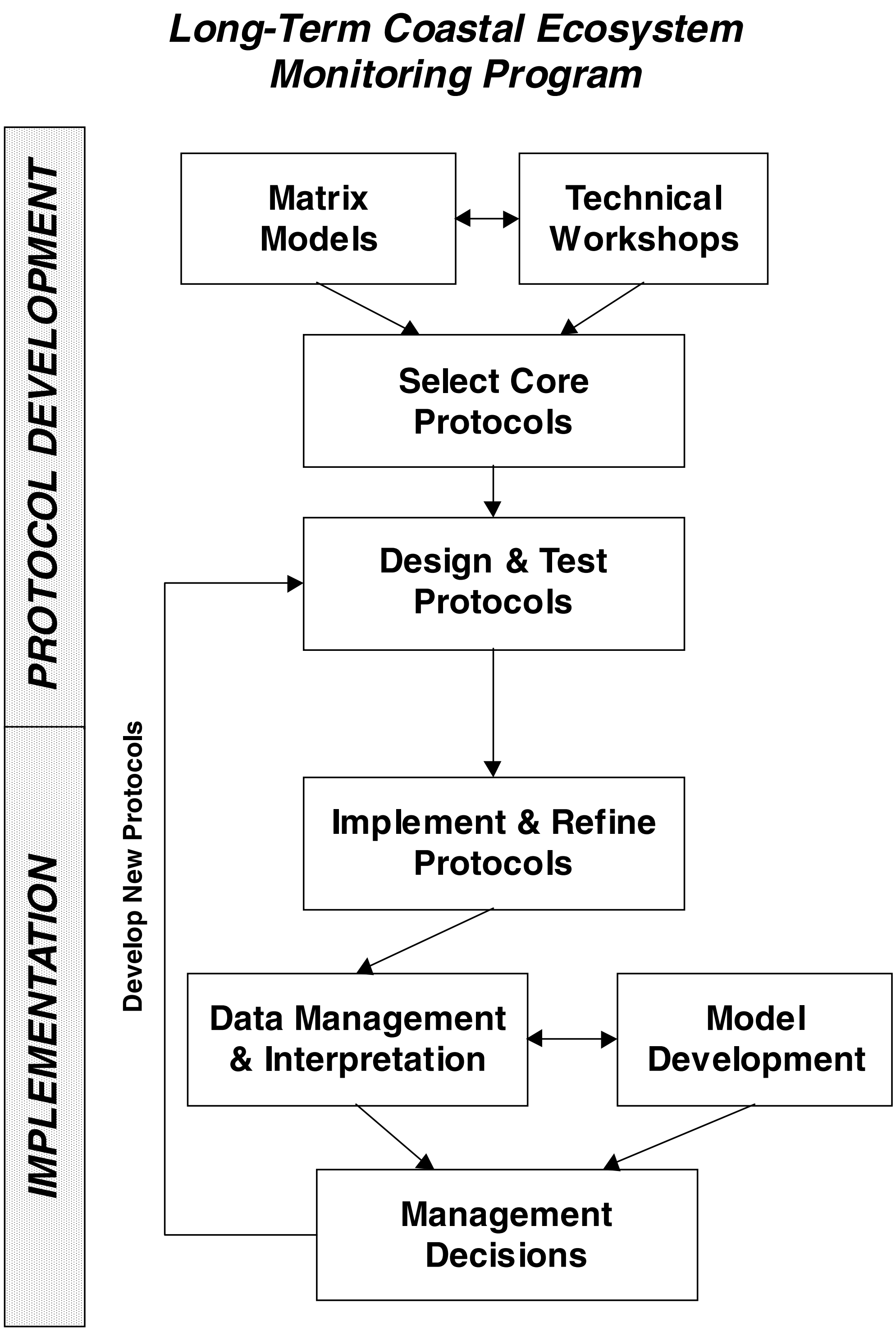


Figure 3. Relationships between the protocol development and implementation phases of the LTEM Program.

LITERATURE CITED

Avers, P. E., D. T. Cleland, W. H. McNab, M. E. Jensen, R. G. Bailey, T. King, C. B. Goudey, and W. E. Russell. 1994. *National Hierarchical Framework of Ecological Units*. Washington DC: USDA Forest Service 15p.

Christensen, N. L. (Chair), A. M. Bartuska, J. H. Brown, S. Carpenter, C. D'Antonio, R. Francis, J. F. Franklin, J. A. MacMahon, R. F. Noss, D. J. Parsons, C. H. Peterson, M. G. Turner, R. G. Woodmansee. 1996. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. *Ecological Applications* 6:665-691.

Culliton, T. J., M. A. Warren, T. R. Goodspeed, D. G. Remer, C. M. Blackwell, and J. J. McDonough, III. 1990. Fifty Years of Population Change along the Nation's Coasts, 1960-2010. NOAA, Strategic Assessment Branch. Rockville, MD. 41p.

Denslow, J. S. 1985. Disturbance-mediated coexistence of species. Pages 307-323 *in* S. T. A. Pickett and P.S. White (Eds.), *The Ecology of Natural Disturbance and Patch Dynamics*. Academic Press, NY.

Dixon, P. M., A. R. Olsen, B. M. Kahn. 1997. Measuring trends in Ecological Resources. *Ecological Applications* 8:225-227.

Holling, C. S. 1973. Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics* 4: 1-23.

Holling, C. S., (Ed.). 1978. *Adaptive environmental assessment and management*. J. Wiley and Sons, Chichester.

Holling, C. S. 1992. Cross-scale morphology, geometry, and dynamics of ecosystems. *Ecological Monographs* 62:447-489.

King, A. 1993. Considerations of scale and hierarchy. Pages 190-39 *in* Woodley, S., J. Kay, and G. Francis (Eds.). 1993. *Ecological Integrity and the Management of Ecosystems*. St. Lucie Press. 220 pp.

Lancia, R. A., C. E. Braun, M. W. Collopy, R. D. Dueser, J. G. Kie, C. J. Martinka, J. D. Nichols, T. D. Nudds, W. R. Porath, and N. G. Tilghman. 1996. ARM! For the future: adaptive resource management in the wildlife profession. *Wildlife Society Bulletin* 24: 436-442.

McDonnell, M. J. and S. T. A. Picket (Eds.). 1993. *Humans as Components of Ecosystems*. Springer-Verlag, New York. 364 pp.

NPS (National Park Service). 1992. *Resource Management Plan Cape Cod National Seashore*. Cape Cod National Seashore, Wellfleet, MA.

NRC (National Research Council). 1990. *Managing Troubled Waters: the Role of Marine Environmental Monitoring.* Committee on a Systems Assignment of the Marine Environment Monitoring, Marine Board, Commission on Engineering and Technical Systems, National Research Council, National Academy Press, Washington DC. 125 pp.

Olsen, T., B.P. Hayden. A.M. Ellison, G.W. Oehlert, S.R. Esterby, and B.M. Kahn. 1997. Ecological resource monitoring change and trend detection workshop. *Bulletin of the Ecological Society of America* 78: 11-13.

Rowe, J. S. 1988. Landscape Ecology: the study of terrain ecosystems. Pages 35-42 *In* M. Moss (Ed.). *Landscape Ecology and Management*. Proc. 1st Symposium Canadian Society for Landscape Ecology and Management, University of Guelph, May 1987. Polyscience Publ. Inc., Montreal. 240 pp.

Rowe, J. S. and J. W. Sheard. 1981. Ecological land classification: a survey approach. *Environmental Management* 5:451-464.

Spellerberg, I. 1991. *Monitoring Ecological Change*. Cambridge University Press, Cambridge. 334p.

Urban, D. L., R. V. O'Neil, and H. H. Shugart, Jr. 1987. Landscape ecology. *Bioscience* 37:119-127.

USEPA (United States Environmental Protection Agency). 1989. *Environmental Monitoring and Assessment Program: Overview*. Office of Research and Development, U. S. Environmental Protection Agency, Washington DC.

Woodley, S., J. Kay, and G. Francis (Eds.). 1993. *Ecological Integrity and the Management of Ecosystems*. St. Lucie Press. 220 p.

PART TWO

SUMMARIES OF MONITORING PROTOCOLS

The following section summarizes the monitoring protocols that are proposed for inclusion in the Program. The summaries are arranged according to ecosystem type or under a general parkwide category (see Table 6). Each summary includes a problem statement, a series of monitoring questions, general monitoring approach to be developed, and a statement of management applications that may result upon implementation of the protocol. These are brief summaries. Additional detail for each protocol is obtained from peer-reviewed protocol development and testing proposals.

ESTUARIES AND SALT MARSHES

Protocol: ESTUARINE NUTRIENT ENRICHMENT

Problem Statement/Justification

- Barnstable County, MA, is one of the leading counties in the northeastern US expected to increase in population at an alarming rate from 1988-2010 (Culliton *et al.* 1990)…
- Increasing residential development adjacent to park boundaries creates potential for excess nitrogen loading to estuaries and coastal waters (Valiela *et al.* 1990, 1992). Sources of land use derived nitrogen include, on-site septic systems, fertilizer applications, and runoff.
- In the northeastern U.S. atmospheric deposition has also been identified as a dominant source of nitrogen to estuaries and associated watersheds (Jawowski *et al.* 1997).
- Nitrogen-loading leads to eutrophication, particularly in shallow estuarine embayments (e.g., Nauset Marsh, Pleasant Bay, Wellfleet Harbor-Herring River).
- Eutrophication leads to shifts in the dominant primary producers (e.g., macroalgae may replace eelgrass), which can lead to declines in dissolved oxygen, altered benthic community structure, altered fish and decapods communities, and higher trophic responses (e.g., shorebirds, waterbirds). See D'Avanzo and Kremer 1994, Short and Burdick 1996, Valiela *et al.* 1997, Kinney and Roman 1998.

Monitoring Questions and Approach

<u>Monitor Nutrient Inputs</u>

Is nitrogen loading to estuaries changing in response to land use derived and atmospheric sources?

- Monitor housing density, conversion of summer to year-round residences, and water use in estuarine drainage basins.
- Quantify and monitor nitrogen loading via groundwater to estuaries within developed and undeveloped drainage basins.
- Develop predictive relationships between groundwater nitrate concentration and nitrate loading, thus minimizing long-term monitoring effort.
- Quantify and monitor atmospheric nitrogen loading onto estuarine drainage basins.

<u>Monitor Estuarine Responses</u>

What is the response of the estuarine ecosystem to changing magnitudes of nutrient loading?

- Monitor biomass of the major primary producers (eelgrass, epiphytes, macroalgae, phytoplantkon). Focus on enclosed basins within larger estuarine ecosystems because of their increased susceptibility to eutrophication.
- Develop relationships between macroalgal tissue nitrogen content and nitrogen loading, thus minimizing long-term monitoring effort.
- Monitor dissolved oxygen and light levels as water quality parameters. These represent good integrative measures.
- Quantify fish and decapod crustacean (nekton) utilization of estuarine habitats (see separate protocol summary).

- Quantify waterbird utilization of estuarine habitats (see separate protocol summary)

Determine Thresholds of Ecosystem Change

What magnitude of nitrogen loading causes shifts in dominant primary producers?

What are the key factors mediating the effects of nitrogen loading (e.g., basin flushing time)?

- Conduct controlled nitrogen loading experiments in the field environment to evaluate the response of eelgrass, epiphytes and macroalgae to different levels of nitrogen loading.
- Based on these experiments, establish thresholds of nitrogen loading critical to changing plant community structure. Knowledge of thresholds will enable managers to anticipate levels of nitrogen that may lead to eutrophication.
- Employ the gradient approach to the monitoring program, sampling in developed *versus* undeveloped shoreline habitats and well-flushed *versus* poorly flushed basins, in order to develop predictive relationships between nitrogen loading and estuarine responses.

Management Applications

- Tracking changes in nutrient enrichment as part of a LTEM program will enable the protection or restoration of estuarine habitat and function of the estuarine ecosystem.
- Work cooperatively with local governments to establish land use practices that reduce nitrogen loading.
- Assist with design and placement of park on-site septic systems.
- Establish habitat restoration programs if deemed appropriate (e.g., eelgrass restoration).

References Cited

Culliton, T. J., M. A. Warren, T. R. Goodspeed, D. G. Remer, C. M. Blackwell and J. J. McDonough III. 1990. 50 years of population change along the Nation's coasts, 1960-2010. NOAA, Strategic Assessment Branch, National Ocean Service. Rockville, MD. 41p.

D'Avanzo, C. and J. N. Kremer. 1994. Diel oxygen dynamics and anoxic events in an eutrophic estuary of Waquoit Bay, Massachusetts. *Estuaries* 17: 131-139.

Jaworski, N .A., R. W. Howarth and L. J. Hetling. 1997. Atmospheric deposition of nitrogen oxides onto the landscape contributes of coastal eutrophication in the northeast United States. *Environmental Science & Technology* 31: 1995-2004.

Kinney, E. H. and C. T. Roman. 1998. The response of primary producers to nutrient enrichment in a shallow estuary. *Marine Ecology Progress Series* 163: 89-98.

Short, F. T. and D. M. Burdick. 1996. Quantifying eelgrass habitat loss in relation to housing development and nitrogen loading in Waquoit Bay, Massachusetts. *Estuaries* 19: 730-739.

Valiela, I., G. Collins, J. Kremer, K. Lajtha, M. Geist, B. Seely, J. Brawley, and C. H. Sham. 1997. Nitrogen loading from coastal watersheds to receiving estuaries: new method and application. *Ecological Applications* 7: 358-380.

Valiela, I., J. Costa, K. Forman, J. M. Teal, B. Howes and D. Aubrey. 1990. Transport of groundwater-borne nutrients from watersheds and their effects on coastal waters. *Biogeochemistry* 10: 177-197.

Valiela, I., K. Forman, M. LaMontagne, D. Hersh, J. Costa, P. Peckol, B. DeMeo-Anderson, C. D'Avanzo, M. Bafione, C. Sham, J. Brawley and K. Lajtha. 1992. Couplings of watersheds and coastal waters: sources and consequences of nutrient enrichment in Waquoit Bay, Massachusetts. *Estuaries* 15: 443-457.

ESTUARIES AND SALT MARSHES

Protocol: ESTUARINE NEKTON (Fish and Decapod Crustaceans)

Problem Statement/Justification

- Nearly two-thirds of all commercially important fishery species depend on estuaries for at least part of their life cycle (McHugh 1966).
- Estuarine habitats at Cape Cod provide valuable habitat for commercial and recreational species (*e.g.,* winter flounder, striped bass, herrings, American lobster, hard clam, American oyster, others) and species of trophic significance (*e.g.,* mummichog, silversides, sand lance, grass shrimp, others) (Able *et al.* 1988, Heck *et al.* 1989, Ayvazian *et al.* 1992).
- Shallow estuarine habitats, including salt marshes, eelgrass beds, macroalgal beds, and others, are constantly changing in response to storms and geomorphic processes and habitat loss from development and tidal restrictions.
- Eutrophication leads to shifts in dominant habitat types (*e.g.*, macroalgae may replace eelgrass), which can lead to declines in dissolved oxygen, altered fish and decapod community structure, and ultimate impacts on higher trophic levels.

Monitoring Questions and Approach

<u>Quantitative Sampling Methods</u>

What are the most appropriate gear types to use when quantitatively sampling nekton in shallow estuarine habitats?

- Determine the effectiveness of utilizing a $1m^2$ throw trap (after Rozas and Minello 1997) for nekton sampling.
- Compare with results from beach seines.

<u>Spatial and Temporal Variability</u>

What estuarine habitats should be sampled in the nekton monitoring?

- At 3 sites (Nauset Marsh, Herring River, Hatches Harbor), and satellite sites in Rhode Island, numerous habitats will be sampled with the throw traps, including; eelgrass beds, salt marsh pools, intertidal and subtidal creeks, flats adjacent to fringing marsh, and *Phragmites* shoreline.
- Comparisons of nekton species composition and density will by determined by multivariate ordination techniques.

What is an appropriate frequency of sampling?

- Nekton will be sampled bi-weekly at Hatches Harbor for a 1-yr period and the data analyzed by ordination techniques.
- Previous studies suggest that spatial variability in nekton sampling often exceeds temporal variability and that sampling less frequently with numerous replicates is an efficient approach (Peterson and Rabeni 1995).

<u>Salt Marsh Nekton Ecology</u>

Are nekton abundance and distribution patterns in salt marshes related to preferential selection of

specific microhabitat types by individual species?
Where does the common mummichog, an abundant salt marsh fish, overwinter in New England salt marshes?
Do salt marshes receiving reduced tidal flow continue to support nekton communities, but with different species composition and abundance than references marshes?
What is the response of nekton communities to restoration of tidal exchange?

Management Applications

- Seasonal species composition and abundance data are essential to assessing the effects of chronic pollution (e.g., nutrient loading) and human-induced and natural catastrophic events (e.g., oil spills, hurricanes).
- Nekton sampling is essential to documenting the ecological success of salt marsh restoration efforts.

References Cited

Able, K. W., K. L. Heck, M. P. Fahay, and C. T. Roman. 1988. Use of salt-marsh peat reefs by small juvenile lobsters on Cape Cod, Massachusetts. *Estuaries* 11: 83-86.

Ayvazian, S. G., L. A. Deegan, and J. T. Finn. 1992. Comparison of habitat use by estuarine fish assemblages in the Acadian and Virginian zoogeographic provinces. *Estuaries* 15: 368-383.

Heck, K. L., K. W. Able, M. P. Fahay, and C. T. Roman. 1989. Fishes and decapod crustaceans of Cape Cod eelgrass meadows: species composition, seasonal abundance patterns and comparison with unvegetated substrates. *Estuaries* 12: 59-65.

McHugh, J. L. 1966. Management of estuarine fisheries. *Trans. Am. Fish. Soc. Suppl*. 95: 133-154.

Peterson, J. T., and C. F. Rabeni. 1995. Optimizing sampling effort for sampling warm water stream fish communities. *North Am. J. Fish. Management* 15: 528-541.

Rozas, L. P., and T. J. Minello. 1997. Estimating densities of small fishes and decapod crustaceans in shallow estuarine habitats: a review of sampling design with focus on gear selection. *Estuaries* 20: 199-213.

ESTUARIES AND SALT MARSHES

Protocol: WATERBIRDS

Problem Statement/Justification

- Estuarine wetlands are used seasonally by a wide assemblage of birds including obligate species that breed and forage only in salt and brackish habitats, and facultative species, which breed or forage in other habitats as well.
- Breeding bird communities of salt marshes are affected by changes in salinity, depth and frequency of flooding, heterogeneity of the plant community, competition between bird species, and history of human use. Human-induced reductions in water level (tidal restriction) and salinity have adversely effected bird diversity and abundance.
- Human activities adversely affect avian populations in other ways including altering foraging patterns; distribution and habitat use; and increasing energy expenditures. Sea level rise and storm events affect the spatial distribution of estuarine habitats and are likely to alter waterbird populations.

Monitoring Questions and Approach

<u>Estuarine Habitats and Environmental Change</u>

What are the fundamental site-specific factors controlling waterbird populations and habitat use?

- Monitor landward migration of barrier beaches, overwash events, estuarine water quality, and changes in the extent and spatial distribution if estuarine habitats (separate protocols).
- Monitor changes in hydrology and habitat associated with sea level rise and restoration of tidal flows.
- Monitor direct and indirect human disturbance in estuaries such as recreational boating and shellfishing.

<u>Waterbird Responses</u>

Is waterbird foraging activity shifting in response to human disturbance or changes in the extent, quality, and distribution of estuarine marsh habitats?

Does waterbird species frequency of occurrence or relative density significantly change after tidal flow is restored to restricted marshes?

How does waterbird foraging change with restored hydrology?

- Monitor spatial and temporal patterns in frequency of occurrence, species richness, relative density, and habitat use of waterbird assemblages in estuarine and brackish salt marshes.
- Monitor changes in breeding season bird communities before and after restoration or other management actions.

Management Applications

- Basic seasonal abundance data on migratory waterbird populations is fundamental to assessing the effects of chronic pollution and catastrophic natural and anthropogenic events such as hurricanes and oil spills.
- Waterbird monitoring data will be useful in predicting and evaluating the success of adaptive

management actions such as salt marsh habitat restorations.

- Waterbird monitoring will facilitate conservation efforts for rare or declining species such as American bitterns and black ducks and enhance public support for habitat restoration and protection.

References Cited

Beatty, L. L., Nowicki, B. L. A. A. Keller, R. A. Wahle, C. L. LaBash, P. V. August. 1994. A plan for inventory and monitoring of estuarine resources at Cape Cod National Seashore. Tech Rpt. NPS/NAROSS/NRTR-94/21.

Brown, J.M. 1994. Species composition, migration chronology, and habitat use of waterbirds at Cape Cod National Seashore. *M.S. Thesis*, Univ. Rhode Is. 152 p.

Erwin, M. R. 1996. Dependence of waterbirds and shorebirds on shallow-water habitats in the mid-Atlantic Coastal Region: An ecological profile and management recommendations. *Estuaries* 19:213-219

Grande, J. W., IV. 1972. Winter ecology of maritime black ducks in Massachusetts: with special reference to Nauset Marsh, Orleans and Eastham. *PhD thesis*, Univ. Mass., Amherst. 93 p.

Lewis, C. and D. G. Casagrande. 1997. Using avian communities to evaluate salt marsh restoration. Pp. 204-236 *in* D. Casagrande (ed.), Restoration of an urban salt marsh: An interdisciplinary approach. Yale School of Forestry and Environmental Studies Bulletin 100.

ESTUARIES AND SALT MARSHES

Protocol: SEDIMENT AND BENTHIC FAUNA CONTAMINANTS

Problem Statement/Justification

- Benthic estuarine habitats are sinks for the accumulation of anthropogenic pollutants including petroleum hydrocarbons (Trowbridge *et al.* 1996). Sources of hydrocarbons in Seashore estuaries include chronic inputs from road runoff, transport, recreational and commercial boating; and catastrophic events such as oil tanker spills.
- Because of their relative immobility and slow metabolic rates, benthic fauna such as mussels bioaccumulate petroleum hydrocarbons that accumulate in sediments (Glegg and Rowland 1996).
- Benthic fauna include commercially and ecologically important members that serve as food for higher trophic consumers or other commercial species. An important long-term effect on mussels and other benthic fauna is that caused by passing on concentrated contamination to sensitive consumer species, ultimately affecting the predator's growth and survival.

Monitoring Questions and Approach

What are baseline levels of refined and unrefined petroleum hydrocarbons in estuarine sediments?

- Collect surficial sediments and analyze for total hydrocarbons [THC] and individual polynuclear aromatic hydrocarbons [PAHs].

Do concentrations and compositional patterns of petroleum hydrocarbons in sediments among sites within Seashore estuaries reveal any clear differences and spatial patterns in relation to possible non-point sources.

- Sample estuarine sediments at random multiple stations and measure abiotic environmental variables (such as sediment grain size and total organic carbon, salinity and pH) to use in interpreting accumulation patterns of contaminants.

Are there any significant correlations between patterns of sediment contamination, sediment toxicity, and chemical/physiological/biological conditions of resident benthic fauna (i.e. are patterns of petroleum accumulation in sediments linked to significant biological affects?)

- Collect and analyze an indigenous benthic organism (*Mytilis edulis*) for hydrocarbon tissue burdens, cytochrome P450 (Anderson *et al.* 1996), and Shell Condition Index (wet weight of animal tissues/shell volume) as an indication of physiological condition. Hydrocarbon sampling of sediment alone may not indicate hydrocarbon contamination when tissue samples do (Short and Round 1993).

Management Applications

- Hydrocarbon "fingerprints" from sediment and bivalve tissue analysis will help determine the source and age of petroleum hydrocarbons in estuaries.
- Continued monitoring of the estuaries will allow collection of a baseline data set that could be used to identify future chronic inputs of hydrocarbon contaminants as well as acute

impacts that could take place in a short period, such as an oil spill.

References Cited

Anderson, J. W., T. V. K. Bothner, and R.H. Tukey. 1996. Using a biomarker (P450 RGS) Test Method on Environmental Samples, Pp. 277-286 *in* G.K. Ostrander (Ed.) Techniques in Aquatic Toxicology, Lewis Publishers, Bocha Raton, Fl. 233 p.

Glegg, G. A. and S. J. Rowland 1996. The Braer Oil Spill-hydrocarbon concentrations in intertidal organisms. *Marine Pollution Bulletin* 32:486-492.

Short, J. and P. Rounds. 1993. Determination of petroleum-derived hydrocarbons in sediments following the Exxon Valdez oil spill. Pp. 57-59 *in* Exxon Valdez Oil spill Symposium, EVOS Restoration Office, Anchorage, AK.

Trowbridge, C., T. T. Baker, and J. D. Johnson. 1996. Effects of hydrocarbons on bivalves. Fish/shellfish Study 13, Exxon Valdez Oil Spill State/Federal Natural Resource Damage Assessment Final Rpt. Alaska Dept. of Fish and Game, Anchorage, AK 187 p.

BARRIER ISLANDS/SPITS/DUNES

Protocol: SHORELINE CHANGE

Problem Statement/Justification

- Relative rise in sea level results in a net landward migration of the shoreline and alters the physical aspects of shoreline habitats. In response to global warming and increased carbon dioxide emissions, it is predicted that sea level will rise at an accelerated rate over the next century (Titus and Barth 1984).
- A landward migration of the shoreline is a natural process in response to storms and sea-level rise, but it can cause an eventual loss of resources, including static biological resources (e.g., coastal bluffs) and cultural resources (e.g., buildings, roads). The structure of mobile coastal habitats (e.g., barrier islands, spits) may change, but the resource is generally not lost.
- Storm events and post-storm swells effect the transfer of sediment at the shoreline interface (Zeigler *et al.* 1959, Giese and Aubrey 1987).
- Human activities, such as shoreline armor or inlet stabilization, dune rehabilitation (Zak and Evangel 1963) or beach nourishment, and recreational use (Steiner and Leatherman 1979) may directly or indirectly affect shoreline change by interfering with natural process.

Monitoring Questions and Approach

<u>Define spatial and temporal variability of shoreline change</u>
Survey shoreline profiles along historic permanent transects (Marinden 1889) across coastal landforms to:

- complete a 110 year record and benchmark sites for future monitoring updates, and
- quantify the magnitude of single events, seasonal cycles, and interannual variability.
- Conduct repeated, planimetric surveys of the Mean High Water line using a Global Positioning System (GPS) in order to analyze seasonal and annual trends in shoreline shifts. Results are to be compared with historic shoreline data sets (Allen and LaBash 1997).
- Utilize Remote Video Monitors (Holman *et al.* 1993) for intensive examination of nearshore wave characteristics associated with shoreline configuration and nearshore bathymetry.
- Interpret orthogonal aerial photographs and historic aerial photographs as a means to map shoreline features beyond the ocean/beach contact that are not easily mapped by GPS, such as the summits of escarpments and margins of salt marshes.

<u>Determine Thresholds of Shoreline Change</u>
What are the shoreline areas of critical concern to park managers?

- Guidelines will be developed to determine how site-specific trends in shoreline change may pose any threat to critical areas.
- Knowledge of coastline dynamics will enable managers to anticipate areas where shoreline retreat or advance becomes at issue.

Management Applications

- With the implementation of a long-term Seashore monitoring program, it is expected that coastal processes affecting shoreline change will proceed naturally.
- Encourage practices that avoid known risks associated with dynamic shorelines (e.g., restrict constructing facilities at the retreating edge of land)
- Reduce the imminent threat of shoreline change by manipulating the resource (e.g., moving facilities away from the retreating edge of land; transplanting endangered plants).
- Work cooperatively with local agencies and landowners to discourage activities that constrain natural shoreline processes (e.g., revetments, beach nourishment).

References Cited

Allen, J. R. and C. L. LaBash, 1997. Measuring shoreline change on Fire Island. *Maritimes* 39:13-16.

Giese , G. S. and D. G. Aubrey, 1987. Bluff erosion on outer Cape Cod. Proceedings Coastal Sediments '87, ASCE Vol. II: 1871-1876.

Holman, R. A., A. H. Sallenger, T. C. Lippman, and J. W. Haines, 1993. The application of video image processing to the study of nearshore processes. *Oceanography* 6:78-85.

Marindin, H. L., 1889. Encroachment of the sea upon the coast of Cape Cod, cross-sections of the shores between Chatham and Highland Lighthouses, Annual Rpt., U.S.C.&G.S. Appendix 12:403-407; Appendix 13:409-457.

Steiner, A. J. and Leatherman, S. P. 1979. An Annotated Bibliography of the Effects of Off-Road Vehicle and Pedestrian Traffic on Coastal Ecosystems. UM-NPSCRU Report Number 45.

Titus, J. G., and M. C. Barth. 1984. An overview of the causes and effects of sea level rise. Pp. 1-56 *in* Greenhouse effect and sea level rise, M.C. Barth and J.G. Titus, editors. Van Nostrand Reinhold Co., NY.

Zak, J. M., and Evangel, B.. 1963. Dune Stabilization at Provincetown, Massachusetts. *Shore and Beach* 31:19-24.

PONDS AND FRESHWATER WETLANDS

Protocol: WATER QUALITY AND LIMNOLOGICAL MONITORING

Problem Statement/Justification

- The 20 kettle ponds within Cape Cod National Seashore are outstanding natural and recreational resources (Martin *et al.* 1993).
- Heavy recreational use and conversion of seasonal residences into year-round residences can contribute to pond eutrophication from septic effluent, fertilizer applications, and eroded soils. Of primary concern, is phosphorus loading from sources outside the watershed and internal loading of phosphorus during hypolimnetic oxygen depletions.
- In the Northeastern United States, acid rain can alter pond water quality through acidification or disturbance to sedimentary sulfur, iron, and phosphorous chemistry (Caraco *et al.* 1989).
- Pond liming, to enhance recreational fisheries, as a historical practice and as currently proposed at several outer Cape ponds, adversely impacts the oligotrophic status of these natural acidic ponds (Soukup 1977).

Monitoring Questions and Approach

<u>Limnological Monitoring</u>
What are the seasonal variations and annual changes in the water quality/trophic status of the ponds?

- Monitor variables that are linked to seasonal aspects of nutrient loading such as water column characteristics and water quality, e.g., Temperature, conductivity, dissolved oxygen (DO), light intensity [Secchi depth and illumination meter], and total nitrogen (TN), total phosphorus (TP), total sulfide (TS), ferrous iron (Fe+2) and major ions (H, Na, Ca, Mg, Fe, SiO2, SO4, NO3, PO4, NH4, HCO3, and Cl.)

What changes are evident in limnological processes that relate to water quality?

- Monitor limnological processes that respond to nutrient loading, e.g., Chlorophyll florescence and light penetration to index productivity, hypolimnetic anoxia following thermal stratification (vertical profiles of temperature, conductivity, DO, and reduced iron and sulfides.

Management Applications

- Long-term limnological information is essential for detecting natural trends and the effects of anthropogenic impacts upon water quality.
- Limnological monitoring data is necessary to guide and evaluate management actions directed at reducing nutrient inputs.

References Cited

Caraco, N. F., J. J. Cole, and G. E. Likens. 1989. Evidence of a sulfate-controlled release from sediments of aquatic systems. *Nature* 341:316-381.

Martin, L., J. Portnoy, and Charles Roman. 1993. Water Quality Monitoring and Research Plans for Kettle Ponds, Cape Cod National Seashore. Technical Report NPS/NRWRD/NRTR-93/15. 56 pp.

Soukup, M. A. 1977. Limnology and management of freshwater ponds of Cape Cod National Seashore. Technical Report, NPS, Boston. 73 p.

PONDS AND FRESHWATER WETLANDS

Protocol: SURFACE WATER LEVELS AND STREAM BASEFLOW

Problem Statement/Justification

- Surface water level in kettle ponds and wetlands is a major factor controlling ecological processes (e.g., vegetation species composition and structure, amphibian life history, waterbird utilization, etc.).
- Surface water levels fluctuate on seasonal and annual or inter-annual time scales in response to seasonal and extreme meteorological events (e.g., storms, drought), land use factors (e.g., land clearing, vegetation change), groundwater withdrawal, and other factors.
- Understanding empirical relationships between surface water levels and groundwater is essential to the development of hydrologic models aimed at predicting impacts of groundwater withdrawal or runoff alterations.
- Freshwater baseflow in Seashore river valley estuarine systems (e.g., Herring River, Pamet River) is essential for development of a natural freshwater to seawater estuarine gradient, and associated maintenance of diverse estuarine habitats.
- With groundwater withdrawal, interbasin transfers, and vegetation and land use changes, stream baseflow will change.

Monitoring Questions and Approach

<u>Surface Water Levels</u>

What are seasonal and inter-annual fluctuations in pond and freshwater wetland surface water levels and what factors contribute to those fluctuations?

- Establish permanent water level recording devices at all 20 kettle ponds of the Seashore and a representative number of seasonally-flooded wetlands (e.g., Red Maple swamps, Cedar Swamp, shrub-dominated wetlands).

<u>Stream Discharge</u>

What are the trends in stream discharge?

- At the Seashore's major river systems (Herring River and Pamet River) stage-discharge relationships will be established.

Management Applications

- Knowledge of long-term fluctuations in surface water levels or stream discharge is necessary to understanding if the ecology of an aquatic system is changing in response to natural factors (e.g., drought, excess rainfall) or human-induced factors (e.g., groundwater withdrawal).
- The network of surface water level monitoring stations, coupled with groundwater level monitoring wells, and stream discharge estimates are essential to support groundwater models aimed at predicting impacts of groundwater withdrawals, interbasin transfers, seawater intrusion, and contaminant loading.
- Information on stream discharge is essential to the Seashore's efforts of predicting and modeling salinity distributions in estuaries being restored.

PONDS AND FRESHWATER WETLANDS

Protocol: FRESHWATER FISH

Problem Statement/Justification

- Freshwater fish communities in both lakes and streams are affected by a complex host of changes in physical aspects of the habitat, environmental factors, and biotic factors (He and Kitchell 1990; Hearn 1987; McQueen *et al.* 1989; Poff and Allan 1995; Power, M. E. 1992; Putman *et al.* 1995;Tonn and Magnuson 1982; Rahel 1984;Weaver *et al.* 1997; Welker *et al.* 1994).
- The sustainability of freshwater fisheries may also be adversely affected by human activities that result in hydrologic alterations, acidification, nutrient loading from adjacent development, exotic fish introductions, and harvest pressures of recreational fishing (Manny 1984; Soranno *et al.* 1996; Wichert 1995).
- Freshwater fish, being key predators and consumers in the aquatic food web (Carpenter *et al.* 1987) are excellent indicators of change in the freshwater ecosystem.
- Freshwater fish provide recreation for both anglers and non-anglers.
- A comprehensive and current freshwater fish inventory is lacking for many regional parks.

Monitoring Questions and Approach

<u>Freshwater Habitats and Environmental Change</u>
What are the historical circumstances and site specific factors influencing fish abundance and distribution?

- Compile records pertaining to fish surveys, stocking, chemical treatment, and changes in land use.
- Characterize waterbody attributes relating to morphometry, adjacent landscape use, environmental parameters (physical and chemical: includes pond water quality monitoring - separate protocol), trophic structure, food availability, and human impacts.

<u>Freshwater Fish Responses</u>
What are the geographic and seasonal differences in the composition of the fish community?

- Determine the composition of the fish community at all sites in all major habitats across different seasons.

How do changes in fish species composition affect the trophic structure of specific waterbodies?

- Quantify the distribution and abundance of fish predators, planktivorous fish, migratory or seasonally abundant fish, zooplankton species.

How are fish communities responding to anthropogenic changes?

- Analyze the inventory of fish and their food base in relation to abiotic, biotic, landscape, historical, and anthropogenic factors (including the introduction of exotics and fishing pressure).
- Construct a simplified, conceptual model of determinants of freshwater distribution in a selected suite of freshwater ponds.

Management Applications

- Fundamental information of freshwater fish ecology is essential to assessing the effects of change due to natural or anthropogenic events.
- A rudimentary model of freshwater fish dynamics in relation to changes in habitat and trophic structure will guide management efforts to preserve, enhance, and restore freshwater ecosystems.

References Cited

Carpenter, S. R., J. F. Kitchell, J. R. Hodgson, P. A. Cochran, J. J. Elser, M. M. Elser, D. M. Lodge, D. Kretchmer, X. He, and C. N. von Ende. 1987. Regulation of lake primary productivity by food web structure. *Ecology* 68:1863-1876.

He, X. and J. F. Kitchell. 1990. Direct and indirect effects of predation on a fish community: a whole lake experiment. *Transactions of the American Fisheries Society* 119:825-835.

Hearn, W. E. 1987. Interspecific competition and habitat segregation among stream dwelling trout and salmon: a review. *Fisheries* 12:24-31.

Manny, B. A. 1984. Potential impacts of water diversions on fisheries resources in the Great Lakes. *Fisheries* 9:19-23.

McQueen, D. J., M. R. S. Joannes, J. R. Post, T. J. Stewart, and D. R. S. Lean. 1989. Bottom-up and top-down impacts on freshwater pelagic structure. *Ecological Monographs* 59:289:309.

Poff, N. L. and J. D. Allan. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. *Ecology* 76:606-627.

Power, M. E. 1992. Habitat heterogeneity and the functional significance of fish in river food webs. *Ecology* 73:1675-1688.

Putman, J. H., C. L. Pierce, and D. M. Day. 1995. Relationships between environmental variables and size-specific growth rates of Illinois stream fishes. *Transactions of the American Fisheries Society* 124:252-261.

Rahel, F. J. 1984. Factors structuring fish assemblages along a bog lake successional gradient. *Ecology* 65:1276-1289.

Soranno, P. A., S. L. Hubler, S. R. Carpenter, and R. C. Lathrop. 1996. Phosphorus loads to surface waters: a simple model to account for spatial pattern land use. *Ecological Applications* 6:865-878.

Tonn, W. M. and J. J. Magnuson. 1982. Patterns in the species composition and richness of fish assemblages in northern Wisconsin Lakes. *Ecology* 63:1149-1166.

Weaver, M. J., J. J. Magnuson, and M. K. Clayton. 1997. Distribution of littoral fishes in structurally complex macrophytes. *Canadian Journal of Fisheries and Aquatic Sciences* 54:2277-2289.

Welker, M. T., C. L. Pierce, and D. H. Wahl. 1994. Growth and survival of larval fishes: roles of competition and zooplankton abundance. *Transactions of the American Fisheries Society* 123:703-717.

Wichart, G. A. 1995. Effects of improved sewage effluent management and urbanization of fish associations of Toronto streams. *North American Journal of Fisheries Management* 15:440-456.

PONDS AND FRESHWATER WETLANDS

Protocol: AQUATIC INVERTEBRATES

Problem Statement/Justification

- Aquatic invertebrates are dependent upon specific aquatic habitats, largely associated with the littoral zone of kettle ponds and vernal pool habitats. Hydrology and water chemistry are the chief factors affecting the distribution and abundance of aquatic invertebrates (Bailey 1996). The importance of these habitats is evidenced by the presence of rare species (Carpenter 1988).
- The importance of several small water bodies in close proximity that vary slightly in water chemistry and hydrology is suspected to enhance the regional biological diversity.
- Increasing human demand for groundwater supplies will have a direct impact upon the surface water levels and essential habitat for aquatic invertebrates.
- Other human activities linked to diminishing water quality related to acidification or nutrient enrichment will adversely affect the community composition, abundance, and diversity of aquatic invertebrates.
- Aquatic invertebrates, being sensitive to slight changes in hydrologic conditions and water quality, serve as important indicators of ecosystem integrity.

Monitoring Questions and Approach

<u>Aquatic Habitat Variability and Change</u>
What are the principal hydrological, habitat, and water quality gradients influencing the composition, abundance and diversity of aquatic invertebrates?

- Characterize the natural variability in surface water hydrology of selected kettle ponds and vernal pools (separate protocol) and aquatic flora (separate protocol) and water quality parameters (separate protocol).
- Model changes in hydrology, vegetation dynamics, and biogeochemical processes.
-

<u>Aquatic Invertebrate Responses</u>
To what extent is the invertebrate fauna dependent upon hydrologic and habitat factors?

- Determine the community and guild composition, abundance, and diversity of aquatic invertebrates for specific sites and habitats.

How are aquatic invertebrates responding to anthropogenic change?

- Analyze the inventory of aquatic invertebrates to drawdown events and water quality changes associated with various levels of eutrophication.

Management Applications

- Information pertaining to the fundamental ecology of aquatic invertebrates is essential to assessing the effects of change due to natural variation or anthropogenic events.
- A rudimentary model of aquatic invertebrate distribution will guide management towards critical habitat preservation.

- Using indicator species, evaluate the effects of human-related impacts to freshwater aquatic habitats.

References Cited

Bailey, R. 1996. Comparing predicted and actual benthic communities in test ecosystems. Pp. 55-68 in R. Bailey, R. H. Norris, T. B. Reynoldson (Eds.), Study design and data analysis in benthic macroinvertebrate assessments of freshwater ecosystems using a reference site approach. Technical information workshop, North American Benthological Society, 44th Annual Meeting, Kalispell, MT.

Carpenter, V. 1988. Dragonflies and Damselflies of Cape Cod. Cape Cod Museum of Natural History, Brewster, MA.

PONDS AND FRESHWATER WETLANDS

Protocol: AMPHIBIANS

Problem Statement/Justification

- Ten species of amphibians have been recorded on outer Cape Cod and additional species may occur. Two species, the eastern spadefoot toad and four-toed salamander are state-listed as threatened and of special concern respectively. The eastern spadefoot toad is an obligate of pitch pine barrens/coastal oak woodland interspersed with vernal pools. Four-toed salamanders are an obligate of red maple/cedar swamps and vernal pools.
- Species composition and/or species richness of amphibian communities change over gradients in precipitation, soil moisture, vegetation type, and vegetation structure. Amphibians have narrow physiological limits due to their moist permeable skin and susceptibility of eggs to desiccation.
- At Cape Cod, amphibians are among the top predators in vernal pools and kettle ponds and comprise a high proportion of the vertebrate biomass. Species such as the spotted salamander and wood frog breed exclusively in vernal pools and are sensitive to low pH and degradation in water quality.

Monitoring Questions and Approach

<u>Monitor amphibians and habitat variables</u>
Do changes to wetland hydrography or hydroperiod induced by groundwater withdrawal, sea level rise, or climatic change alter amphibian community composition or species abundance?
Are long-term changes in climate variables such as temperature, precipitation, UV-B radiation, surface water acidification, and atmospheric deposition of mercury affecting life history parameters of amphibians such as breeding phenology, rates of growth and development, or reproductive success?
Are trophic interactions within freshwater wetlands changing as a result of expanding bullfrog populations, alterations in invertebrate predator communities, or the availability of invertebrate prey? How do such trophic changes they affect the amphibian community?
Are amphibian population structure and numbers in the Seashore affected by factors such as highway mortality, predation from skunks, changes in forest vegetation structure associated with high densities of deer or establishment of invasive plant species?

- Monitor surface water chemistry, hydroperiod, plant species composition and community structure.
- Monitor atmospheric variables and inputs including precipitation, solar radiation, and precipitation chemistry. (separate protocol)
- Monitor aquatic invertebrate prey communities.
- Monitor changes in amphibian species richness and relative abundance.
- Construct habitat models for selected species that encompasses spawning sites, tadpole habitat, metamorphic sites, juvenile and adult feeding habitat, movement corridors, and hibernation sites.

Management Applications

- Through a long-term monitoring amphibian database, support land management decisions concerning land developments (new bike trail, parking lot, camp sites, exotic species), evaluation of the effects of development on property on land abutting the park, planning and implementation of habitat restoration within the Seashore, and understanding of impacts of environmental change such as climatic variation.
- Promote public understanding and support of measures to protect surface wetlands by regulating rates of groundwater withdrawal.
- Facilitate efforts with other natural resource conservation agencies and organizations to identify linkages between amphibian populations within the National Seashore and populations inhabiting property outside park boundaries and to evaluate existing and potential pressures on amphibian habitat within and outside park boundaries. Use this information to make management recommendations.
- Use amphibian population parameters as an important linkage with other LTEM monitoring components at the Seashore such as meteorology and hydrology to assist in interpreting cause and effect of ecosystem change.

References Cited

Blaustein, A. R., D.B Wake, and W. P. Sousa. 1994. Amphibian declines: judging stability, persistence, and susceptibility of populations to local and global extinctions. *Conservation Biology* 8:60-71.

Drost, C. A. and G. M. Fellers. 1 996. Collapse of a regional frog fauna in the Yosemite area of the California's Seirra Nevada. *Conservation Biology* 10;414-425.

Jones, L. K. 1992. Cape Cod National Seashore Reptile and Amphibian Survey. Unpubl. Rpt. 92-04, Cape Cod National Seashore, Wellfleet, MA 4 pp.

Phillips, K. 1994. Tracking the vanishing frogs. St. Martin's Press, New York. 231 pp.

Portnoy, J. W. 1987. Vernal ponds of Cape Cod National Seashore. Unpubl. Rpt., Cape Cod National Seashore, Wellfleet, MA .

COASTAL UPLANDS

Protocol: LANDBIRDS

Problem Statement/Justification

- Cape Cod National Seashore is an important breeding and migration stopover site for neotropical migrant landbirds and supports many state listed rare species
- Landbirds, because of their high body temperature, rapid metabolism, and high ecological position on most food webs, may be excellent indicators of the effects of environmental change in terrestrial and aquatic ecosystems. Furthermore, their abundance and diversity in virtually all habitats, diurnal nature, discrete reproductive seasonally, and intermediate longevity facilitate the monitoring of their population and demographic parameters
- Recent analyses of data from other regional monitoring programs such as the Breeding Bird Survey, suggest that populations of many landbirds, including forest, scrubland-and grassland-inhabiting species, appear to be in serious decline.

Monitoring Questions and Approach

Monitor avian productivity and survivalS

What is the temporal variation (e.g., long-term trends) in productivity indices and adult survival-rate estimates of landbirds within the Seashore and how are these trends affected by the composition and volume of vegetation types and park management practices?

Does the density or spatial distribution of houses and roads within and adjacent to the Seashore affect the composition and productivity of landbirds?

How are changes in landscape heterogeneity affecting individual (target) species of forest interior and edge or early successional landbirds?

Do landscape-level productivity indices for a given species in the Seashore change after the implementation of habitat restoration?

- Monitor annual indices of adult population size and post-fledging productivity from data on the numbers and proportions of young and adult birds captured.
- Monitor annual adult survivorship, adult population size, and recruitment into the adult population from mark-recapture data on adult birds.

Management Applications

- Facilitate the planning of management actions and conservation strategies to reverse population declines; and to aid in evaluating the effectiveness of the management and conservation actions implemented.
- Landbird population performance will be a useful measurement in evaluating the success of land management actions such as prescribed fire in mimicking natural landscape patterns and patch dynamics.

Aid in evaluating effects of specific human-related actions and natural events on landbirds such as aerial communication towers and hurricanes.

References Cited

CACO. 1992. Resources Management Plan Cape Cod National Seashore. Unpubl. Rpt., Cape Cod National Seashore, Wellfleet, MA 196 pp.

DeSante, D. F. (in press) Management implications of patterns of productivity and survivorship from MAPS Program. Pp. x-x, *in* R. Bonney (Ed.), Proceedings of the 1995 Partners in Flight International Workshop, Cape May, NJ.

DeSante, D. F. 1992. Monitoring avian productivity and survivorship: a sharp, rather than blunt tool for monitoring and assessing land bird populations. Pp. 511-521 *in* McCullogh, D. C. and R. H. Barrett, (Eds.) Wildlife 2001:Populations Elsvier Applied Sciences, London UK.

NPS. 1992. National Park Service Neotropical Migratory Bird Conservation Program Plan and Strategy. April 1992. National Park Service, Washington, D.C., 20 pp.

Peach, B. G., S. T. Buckland, and S. R. Baillie. 1996. The use of constant effort mist-netting to measure between year differences in the abundance and productivity of common passerines. *Bird Study* 43:142-156.

Peterjohn, B. G., J. R. Sauer, and C. S. Robbins. 1995. Population trends from the N. American Breeding Bird Survey, New York: Oxford Press.

Petit, L. J., D. R. Petit, and T.E. Martin. 1995. Landscape-level management of migratory birds: looking past the trees to see the forest. *Wildlife Society Bulletin* 23:420-429.

Pyle, P., D. R. O'Grady, and D. F. DeSante. 1997. The 1996 annual report of the MAPS program in Region 1 and Region 6 of the USDA Forest Service. Unpubl. Rpt., The Institute for Bird Populations, Pt. Reyes Station, CA.

Temple. S. A. and J. A. Weins. 1989. Bird populations and environmental changes: can birds be bio-markers? *American Birds* 43:260-270.

COASTAL UPLANDS

Protocol: WHITE-TAILED DEER

Problem Statement/Justification

- White-tailed deer are the dominant herbivore in forested ecosystems of Cape Cod National Seashore and are an important regulator of ecosystem processes.
- In high densities, deer may change the tree species composition of forests, species diversity and abundance of herbaceous understories, and affect other species of birds and mammals.
- In suburban landscapes, deer pose special management problems because they present safety hazards to motorists, consume ornamental shrubs, and are perceived as agents in Lyme disease transmission.

Monitoring Questions and Approach

<u>Monitor deer abundance coinciding with natural and human influences</u>
Are white-tailed deer numbers increasing or are distribution patterns changing on the Seashore?

- Monitor deer abundance (population index) and distribution.

Is hunter effort and deer harvest rate changing and how are those changes affecting abundance and composition of the herd?

- Monitor harvest rate, sex, age, weight, antler-beam diameter of yearling males, and female reproductive rates.

<u>Monitor Ecosystem Responses to deer activity</u>
What are the effects and impending ecological changes from increasing deer densities?
Are plant species being eliminated as a result of browsing by deer?
How will changes in landscape and vegetation influence deer population dynamics?
Are deer adversely effecting forest-nesting birds?

- Monitor plant community structure and composition, browse availability, mast availability, plant succession, and prevalence of exotic plant species.
- Monitor landbird community composition, abundance, and reproductive rates.
- Monitor deer/auto collisions rates, property damage and landowner complaints.

Management Applications

- Gain support of hunters and non-hunters for deer population regulation by hunting or other means.
- Define management alternatives for regulating deer numbers and provide background information for management planning.

References Cited

Porter, W. F., D. L. Garner and W.F. Seybold. 1994. Ecology and monitoring of white-tailed deer on Cape Cod National Seashore. Tech. Rpt. NPS/NAROSS/RTR-94/17.

Porter, W.F. 1991. White-tailed deer in eastern ecosystems: Implications for management and research in National Parks. Nat Resources Rpt. NPS/NRSUNY/NRR-91/05.

Shafer-Nolan, A. L. 1997. The science and politics of deer overabundance at Cuyahoga Valley National Recreation Area, Ohio. *Wildlife Society Bulletin* 25:457-461.

Walker, D. M. and W. S. Alverson. 1997. The white-tailed deer: a keystone herbivore. *Wildlife Society Bulletin* 25:217-226

COASTAL UPLANDS

Protocol: RED FOX AND COYOTE

Problem Statement/Justification

- Red fox often become locally abundant in fragmented heterogeneous landscapes such as Cape Cod.
- Predation by red fox can be a major limiting factor on the productivity of ground nesting birds such as the federally protected piping plover and least tern.
- Coyotes influence red fox density and distribution when the two species are sympatric and coyotes can affect neonatal survival rates of white-tailed deer fawns.
- In human dominated landscapes, canids often prey on pets and are perceived as vectors of disease transmission.

Monitoring Questions and Approach

Do landscape features, such as human settlements, influence fox and coyote abundance or patterns of distribution?

- Monitor vegetation composition and structure; forage availability (mast); small mammal and invertebrate prey base (separate protocols).
- Monitor abundance of free-ranging domestic dogs and cats.

Is fox-coyote spatial avoidance operating and how is it effecting fox distribution and habitat use?

- Monitor distribution and abundance (index) of red fox, coyote, and other medium-sized mammal populations.

Is red fox population abundance positively correlated with tern and plover nest predation rates?

- Monitor causes of reproductive failure among ground nesting birds.
- Monitor incidence of rabies and human/candid interactions.

Management Applications

- Support identification of management alternatives for managing predators to enhance survival and productivity of threatened species.
- Facilitate public education concerning the role of canids in the Cape Cod ecosystem.
- Support land management actions, such as the use of prescribed fire, that perpetuate grassland and heathland habitats of value to canid prey species.

References Cited

Gese, E. M.. T. E. Stotts, and S. Grothe. 1996. Interactions between coyotes and red foxes in Yellowstone National Park, Wyoming. *J. Mammalogy* 77:377-382.

Jones, K.L. 1997. Piping plover habitat selection, home range, and reproductive success at Cape Cod National Seashore. Tech Rpt. NPS/NESO-RNR/NRTR/97-03. National Park Service, Boston, MA 96pp.

Melvin, S. M., L. H. MacIvor, and C. R. Griffin. 1992. Predator enclosures: a technique to reduce predation at piping plover nests. *Wildlife Society Bulletin* 20:143-147.

Travaini, A., R. Laffitte, and M. Dilibes. 1996. Determining the relative abundance of European red foxes by scent station methodology. *Wildlife Society Bulletin* 24:500-504

Reynolds, J. C. and S. C. Tapper. 1995. The ecology of the red fox in relation to small game in rural southern England. *Wildlife Biology* 2:105-117.

Sargent. A. B and S. H Allen. 1988. Observed interactions between coyotes and red foxes. *J. Mammalogy* 70:631-633.

PARK-WIDE COASTAL ECOSYSTEM

Protocol: METEOROLOGY AND ATMOSPHERIC WET DEPOSITION

Problem Statement/Justification

- The Ecology of Cape Cod, characterized by its terrain, soils, vegetation, and fauna are governed, in part, by the prevailing, maritime climate (Winkler s.n.; Godfrey 1977; Strahler, 1966).
- Human-induced global climate change is predicted to affect local weather patterns which will likely influence the structure and function of ecosystem components near the coast:
- Storm surges of sufficient magnitude will alter the configuration of the shoreline and beach profile (Zeigler *et al.* 1959, Giese and Aubrey 1987); enhance the retreat of escarpments and dune mobility; alter estuarine circulation, sedimentation, and inlet migration in estuaries (Zamermba and Leatherman 1984).
- Extended periods of drought or excess precipitation will influence seasonal water balance affecting wetlands, waterbodies, and groundwater supplies (Leblanc *et al.* 1986).
- Drought coupled with fire suppression generates increasing fuel loads and escalates fire management issues (Patterson *et al.* 1984).
- Wet deposition (precipitation, salt spray, fog) contribute to and eutrophication of water bodies, inland wetlands estuaries (Jaworski *et al.* 1997), as well as enrich impoverished soils of upland sites (Kimball et. al. 1988,van der Valk 1974)

Monitoring Questions and Approaches

<u>Monitor standard meteorological parameters at "sentinel" fixed weather stations</u>

What are the predominant trends in the weather pattern?

- Measure wind speed/direction, air temperature, precipitation amount and duration, relative humidity, total solar radiation, net radiation, and photosynthetically active radiation.

What is the contribution and quality of atmospheric water chemistry inputs (precipitation and aerosols including salt spray and fog)?

- Measure the wet deposition of H^+, K^+, Na^+, Ca^{2+}, Mg^{2+}, NO_3^-, Cl^-, SO_4^{2-}, PO_4^3, Hg^{2+}.

What are the predominant trends in air quality?

- Measure inputs of SO_2, O_3, CO, NO_2, NO, NO_x, PM-10, TSP, VOC.

Management Applications

- A long term meteorological monitoring program is essential to evaluate how meteorological agents of change influence the function of the coastal ecosystem.
- A "sentinel" fixed weather station enables the park to participate in a national monitoring network.

References Cited

Giese , G. S. and D. G. Aubrey, 1987. Bluff erosion on outer Cape Cod. Proceedings: Coastal

Sediments '87,ASCE Vol. II: 1871-1876.

Godfrey, P.J. 1977. Climate, plant response, and development of dunes on barrier beaches along the U.S. East Coast. International Journal of *Biometeorology* 21: 203-215.

Jaworski, N. A., R. W. Howarth, and L. J. Helting. 1997. Atmospheric deposition of nitrous oxides onto the landscape contributes to coastal eutrophication in the northeastern United States. *Environmental Science and Technology* 31:1995-2004.

Strahler, A. N. 1966. A Geologist's View of Cape Cod. Natural History Press, Garden City, NY. 115 pp.

Kimball, K. D., R. Jagels, G. A. Gordon, K. C. Weathers, and J. Carlisle. 1988. Differences between New England coastal fog and mountain cloud water chemistry. *Water, Air, and Soil Pollution* 39:383-393.

LeBlanc, D. R.; Guswa, J. H.; Frimpter, M. H., and Londquist, C. J. 1985. Groundwater resources of Cape Cod, Massachusetts. Boston, MA: U.S. Geological Survey; Hydrologic Investigations Atlas HA-692. 4 sheets.

Patterson, W. A.,III; Saunders, K. E., and Horton, L. J. 1984. Fire regimes of Cape Cod National Seashore. Denver, CO: U.S. Department of Interior, National Park

van der Valk, A. G. 1974. Mineral cycling in coastal foredune plant communities in Cape Hatteras National Seashore. *Ecology* 55:1349-1358.

Winkler, M. G. s.n. Final Report. Geologic, Chronologic, Biologic and Chemical Evolution of the Ponds within the Cape Cod National Seashore: Historic and Prehistoric Trends in Pond Acidity in the Cape Cod National Seashore as Interpreted from Diatom Assemblage Changes. National Park Service. Project No. CA1600-6-0004. 41 pp. + Tables & Figures.

Zeigler, J. M., C. R. Hayes, S. D. Tuttle. 1959. Beach changes during storms on Outer Cape Cod, Massachusetts. *Journal of Geology* 3: 318-336.

PARK-WIDE COASTAL ECOSYSTEM

Protocol: VEGETATION

Problem Statement/Justification

- The vegetation of coastal landscapes is constantly changing in response to both natural and human-induced factors, including storms, fire, ORV/pedestrian trampling, grazing, development, atmospheric inputs, and others (Godfrey *et al.* 1979, Ehrenfeld 1990).
- At Cape Cod, over three centuries of agrarian land use history (clearing, plowing, grazing) has interrupted vegetation development and altered vegetation structure and composition.
- Patterns of human development have necessitated fire suppression (Patterson *et al.* 1984, Dunwiddie and Adams 1995).
- Introduced pests, such as Brown Tailed Moth and Gypsy Moth are often responsible for extensive defoliation (Chokkalingam 1995).
- Non-native (Purple Loosestrife) and invasive species (Common Reed) often displace native species.
- Alterations to surface water level or flow regime, modifies the habitat and vegetation in both salt marshes (Roman *et al.* 1995) and freshwater wetlands (Bachand and Patterson 1993).
- Regional trends toward a more homogeneous vegetation (Foster *et al.* 1998) may be accompanied by a decline in biological diversity affecting ecosystem function (Chapin *et al.* 1998).
- Rare and endangered species.

Monitoring Questions and Approach

<u>Monitor Vegetation Change and Processes/Factors Contributing to Change</u>

How do the structure and composition of vegetation change in response to natural processes (e.g., storms, salt spray, windthrow), site-specific human-related factors (e.g., fire suppression, altered water table level) or regional factors (e.g., acid deposition)?

- Quantify characteristics of the landscape/habitat/environment (e.g., topography, soil resources, and microclimate) that pertain to different sites.
- Quantify coarse scale disturbance regime and site history (e.g., fire, clearing, grazing, flooding, etc.) in terms of size, severity, frequency, and dispersion on the landscape.
- Quantify vegetation structure, dominant physiognomy, floristic composition, and cover across gradients of landscape representing a range in habitats and site history.

Management Applications

- A network of permanent plots is essential to track and explain long-term changes in the vegetation and the influence of humans.
- Support land management decisions concerning the maintenance of natural and cultural landscapes.
- Foster an understanding of vegetation dynamics and support conservation plans for underrepresented community types or rare species.

References Cited

Bachand, R. R., and W. A. Patterson III. 1993. Identifying upland-to-wetland transitions in the Cape Cod National Seashore: a multivariate approach to long-term monitoring. Pp. 283-295 *in* Proceedings of the 7th Conference on Research and Resource Management in Parks and Public Lands: Partners in Stewardship, W. E. Brown and S. D. Veirs, (Eds.). The George Wright Society, Hancock, Michigan.

Chapin III, F. S., O. E. Sala, I. C. Burke, J. P. Grime, D. U. Hooper, W. K. Laurenoth, A. Lombard, H. A. Mooney, A. R. Mosier, S. Naeem, S. W. Pacala, J. Roy, W. L. Steffen, and D, Tilman. 1998. Ecosystem consequences of changing biodiversity: experimental evidence and a research agenda for the future. *Bioscience* 48:45-53.

Chokkalingam, U. 1995. Recent disturbance-mediated vegetation change at Cape Cod National Seashore, Massachusetts. Technical Report NPS/NESO-RNR/NRTR/96-09. National Park Service, New England System Support Office, Boston, MA.

Dunwiddie, P.W., and M. B. Adams. 1995. Fire suppression and landscape change on outer Cape Cod, 1600-1994. Technical Report NPS/NESO-RNR/NRTR/96-08. . National Park Service, New England System Support Office, Boston, MA.

Ehrenfeld, J. G. 1990. Dynamics and processes of barrier island vegetation. *Reviews in Aquatic Sciences* 2: 437-480.

Foster, D. F., G. Motzkin, and B. Slater. 1998. Land use history as long-term broad-scale disturbance: regional forest dynamics in central New England. *Ecosystems* 1:96-119.

Godfrey, P. J., S. P. Leatherman, R. Zaremba. 1979. A geobotanical approach to classification of barrier island systems. Pages 99-126 in Barrier Islands from the Gulf of St. Lawrence to the Gulf of Mexico (S. P. Leatherman, ed.). Academic Press, NY, NY.

Patterson, W. A., III, K. E. Saunders, and L. J. Horton. 1984. Fire regimes of Cape Cod National Seashore. USDI, NPS Office of Scientific Studies, Report OSS 83-1.

Roman, C. T., R. W. Garvine, and J. W. Portnoy. 1995. Hydrologic modeling as a predictive basis for ecological restoration of salt marshes. *Environmental Management* 19: 559-566.

PARK-WIDE COASTAL ECOSYSTEM

Protocol: BASELINE GROUNDWATER HYDROLOGY AND QUALITY

Problem Statement/Justification

- High soil permeability and the unconfined nature of the outer Cape Cod aquifer dictate that the elevation and slope of the groundwater table is crucial to understanding present landscape patterns.
- An understanding of water table levels is required for predicting the effects of natural and human-induced hydrological changes (e.g., sea level rise, drought conditions, municipal groundwater withdrawal) and the fate of contaminants (e.g., landfill leachate) (Weiskel and Howes 1992, Martin 1993, Urish *et al.* 1993).
- Groundwater-delivered nutrients are a major source of nutrients loading to Cape Cod estuaries and kettle ponds (Giblin and Gaines 1990, Portnoy *et al.*, in press).
- Freshwater baseflow in Seashore river valley estuarine systems (e.g., Herring River, Pamet River) is from groundwater discharge.
- Sources of groundwater contamination (excess nutrients, metals, organics) within the Seashore include, landfills, wastewater treatment facilities, development, and spills (Persky 1986).

Monitoring Questions and Approaches

Monitor Groundwater Levels

What are the seasonal and inter-annual fluctuations in groundwater levels throughout the Seashore?

Is the existing network of index wells (maintained by the Cape Cod Commission) appropriate, at spatial and temporal scales, for park-wide monitoring of groundwater elevation and appropriate to support development of hydrologic groundwater models?

Does the groundwater level monitoring network effectively evaluate sites of ecological sensitivity to hydrologic change (e.g., freshwater wetlands, ponds, estuaries), sites with artificially increased recharge due to interbasin transfers (e.g., Provincetown Center, Coles Neck), outlying park sites (e.g., Griffin Island), and sites of known or anticipated sources of contamination (e.g., downgradient of landfills, park boundaries where development is proposed).

- Review data associated with existing network of monitoring wells within the Seashore and vicinity, and data from wells associated with research, modeling and monitoring programs conducted over the years by the NPS, USGS, Cape Cod Commission and others. Based on this quantitative review, recommend a network of wells and sampling protocol.

Monitor Groundwater Quality

What is the magnitude of point source and concentrated non-point source contaminant sources on groundwater quality?

What are temporal and spatial trends in contaminant source plumes?

What are threshold levels of particular water quality constituents, upon which management actions should be implemented?

- Review existing and historic groundwater quality data sets
- Identify sites for groundwater quality monitoring (e.g., landfills, wastewater facilities, residential development, baseline reference locations).
- Determine appropriate frequency of sampling (e.g., monthly, seasonal, annual).
- What water quality constituents should be monitored (e.g., nutrients, conductivity, VOCs, etc.)?

Management Applications

- The network of groundwater level monitoring wells is essential to support groundwater models aimed at predicting impacts of groundwater withdrawals, interbasin transfers, seawater intrusion, stream baseflow, and contaminant loading.
- Understanding changes in vegetation, water level fluctuations in ponds and wetlands and stream discharge are all directly linked to groundwater levels and hydrology.
- Work cooperatively with local governments to establish land use practices that reduce groundwater contamination.

References Cited

Giblin, A. E., and A.G. Gaines. Nitrogen inputs to a marine embayment: the importance of groundwater. *Biogeochemistry* 10: 309-328.

Martin, L. 1993. Investigation of effects of groundwater withdrawals from the Pamet and Chequesett aquifers, Cape Cod National Seashore. Technical Report, NPS Water Resources Division, Ft. Collins, CO. NPS/NRWRD/NRTR-93/15.

Persky, J.H. 1986. The relation of groundwater quality to housing density, Cape Cod, Massachusetts. Water Resources Investigations Report 86-4093, USGS, Boston, MA.

Portnoy, J. W., B. L. Nowicki, C. T. Roman, and D. W. Urish. IN PRESS. The discharge of nitrate-contaminated groundwater from developed shoreline to marsh-fringed estuary. *Water Resources Research*.

Urish, D. W., M J. O'Reilly, R. M. Wright, and R. K. Frohlich. 1993. Assessment of ground and surface water impacts: Provincetown landfill and septic disposal site, Provincetown, Massachusetts. Technical Report, NPS Coastal Research Center, Univ. RI. NPS/NARURI/NRTR-93/01. 243 pp.

Weiskel, P. K. and B. L. Howes. 1992. Differential transport of sewage-derived nitrogen and phosphorous through a coastal watershed. *Environmental Science & Technology* 26: 352-360.

Protocol Summary Statements to be developed in conjunction with upcoming workshops

- Land Use
- Visitor Use
- Data Management
- Ecosystem Modeling