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Strategy for Enhanced Monitoring of Natural Resource Condition in North Atlantic Coastal Parks to Address the Effects of Rapid Climate Change

Natural Resource Report NPS/NCBN/NRR—2010/272

ON THE COVER
Coastline and salt marsh at Sandy Hook Unit, Gateway National Recreation Area.
Photograph by: Robin Baranowski

Strategy for Enhanced Monitoring of Natural Resource Condition in North Atlantic Coastal Parks to Address the Effects of Rapid Climate Change

Natural Resource Report NPS/NCBN/NRR—2010/272

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Executive Summary

In response to the growing knowledge and awareness of the effects of climate change on federal lands, the National Park Service (NPS) has developed a national Climate Change Response Strategy (NPS 2010). The science goals described in the national strategy include developing and applying climate science, collaborating with scientific agencies and institutions, and identifying and conducting scientific studies and resource monitoring activities. The NPS Inventory and Monitoring Program (I&M) will play a major role in meeting these goals by providing sound scientific information and data to parks on the effects of climate change on park natural resources, as well as contribute towards a multi-agency collaboration (e.g. Landscape Conservation Cooperatives and Climate Science Centers) to better understand these effects at both regional and national scales.

In (FY) 2010 several groups of I&M Networks were provided funding to review their existing monitoring programs in light of climate change and propose appropriate enhancements. One of these groups was the North Atlantic Coast, which includes three networks; the Northeast Coastal and Barrier Network (NCBN), the Northeast Temperate Network (NETN), and the National Capital Region Network (NCRN). These networks were directed to use the new funding to extend existing partnerships and expand collaboration with other federal agencies collecting similar monitoring data and information on natural resources. The NETN, NCBN and NCRN, with the input of federal partners and scientists from academic institutions, have developed this document to describe their process for identifying critical monitoring needs to meet these objectives while also enhancing each park's understanding of the effects of climate change on specific coastal ecosystems. This includes existing monitoring needing enhancement, as well as new monitoring to better understand the effects that rapid climate change has on parks. This document describes the vital sign prioritization and selection process and the final vital signs chosen for monitoring. It includes options for enhanced monitoring based on anticipated project budgets (for all three networks combined) ranging from $200,000 to $400,000 annually.

The highest priorities were determined to be:

- Expand existing interagency collaborative effort to monitor salt marsh capital along the Atlantic coast in 10 national parks in conjunction with 12 coastal United States Fish and Wildlife Service (USFWS) sites, as well as National Estuarine Research Reserve sites (NOAA, NERR) along the North Atlantic. This effort will include standardized protocols, databases and data collection.
- Expand analysis, synthesis and reporting of datasets produced by other agencies and organizations such as climate, tide, sea level, and remotely-sensed data to park managers and others to enhance our understanding of the effects of climate change.
- Expand the existing interagency effort to monitor breeding marsh birds in North Atlantic parks within Bird Conservation Area 30 (BCR 30) through the Northeast Coordinated Bird Monitoring Partnership.

These projects will continue collaborative efforts among the I&M Networks, USFWS, National Oceanic and Atmospheric Administration (NOAA), the United States Geological Survey (USGS), state wildlife agencies, universities, and non-governmental organizations (NGOs).

Acknowledgments

NCBN and NETN Program Managers, Sara Stevens and Brian Mitchell and, NCR Regional I&M Program Coordinator, Pat Campbell would like to thank several people for their assistance and review of this plan. First both Marcia Brown and Nick Salafsky from Foundations of Success for their outstanding assistance, guidance and facilitation in developing and drafting this workplan. Especially to Marcia who wrote the first draft of this document and worked tirelessly with us on developing the conceptual models and tables. Our core working group who participated in and traveled to two workshops, Adam Kozlowski, Dr. Megan Tyrrell, Erica Patenaude, Dr. John Paul Schmit, Marc Albert, Dr. Mary Foley, Dr. Charles Roman, Dr. Susan Adamowicz, Shelley Hall, and Trisha Towanda. We would also like to thank our conceptual ecosystem model reviewers who provided excellent feedback and suggestions, Suzanne Paton, Dr. Hilary Neckles, Dr. Stephen Smith, Dr. Ken Reposa, Dr. Cathy Wigand, Brian Sturgis, Dr. Bradley Peterson, Dr. Sofia Fox, Dr. Scott Nixon, Dr. Rebecca Beavers, Dr. Jodi Eshlemen-Coastal Engineer, Courtney Schupp, Dr. Cheryl Hapke, Dr. Norb Psuty, Tanya Silviera, Dr. Henry J. Bokuniewicz, Dr. Jeff Cross, Dr. Candace Oviatt, Dr. Jeremy Long, Dr. Peter Petraitis, Dr. Tom Trott, and Dr. Geoffrey Trussell. Finally, we thank John Karish for his guidance and review of our final work plan and Robin Baranowski for assisting us with formatting.

Introduction

In response to the growing knowledge and awareness of the effects of rapid climate change on federal lands, the National Park Service (NPS) has developed a national Climate Change Response Strategy (NPS 2010). This strategy provides guidance and direction to the Service and its employees to properly respond to and address the effects of climate change on park lands. The strategy describes goals and objectives under four main components: science, adaptation, mitigation, and communication. The NPS vision, as described in the national Climate Change Response Strategy is to adapt to climate change and effectively preserve and restore park resources and opportunities for visitor enjoyment. This will be achieved through collaboration among NPS employees, partners, and the public to promote climate change science and apply best management practices and sustainable behaviors toward reducing climate change and its impacts. The specific science goals of the national strategy include: (1) developing and applying climate science, (2) collaborating with and among scientific agencies and institutions to advance climate science at the local to national level, and (3) identifying and conducting scientific studies and resource monitoring activities necessary to support NPS mitigation, adaptation, and communication. In keeping with the main objective of the National Park Service's Inventory and Monitoring Program (NPS I&M), the NPS Climate Change Response Strategy states that only the best available scientific data and knowledge will be used to inform decision making about climate change.

Early in 2009 the Interior Secretary issued a Secretarial Order (Secretarial Order 3289) that initiated the creation of eight Regional Climate Change Response Centers and a number of Landscape Conservation Cooperatives (LCCs) to begin coordinating a collaborative effort among all Department of the Interior (DOI) agencies. At the same time, along with other DOI agencies, the NPS I&M Program received a base funding increase to enhance monitoring climate change effects on park natural resources. The NPS I&M program will play a major role in meeting the scientific and partnership goals of the national response strategy by providing sound scientific information and data to parks on the effects of climate change on park natural resources while also contributing to multi-agency collaboration geared towards understanding the effects at both the regional and national scale.

In fiscal year (FY) 2010, a number of biogeographical areas were identified by the NPS as being highly vulnerable to climate change: high elevation, high latitude, coastal and marine, and arid lands. I&M Networks that overlapped one of these biogeographical areas were provided funding for the development of a long-term funding proposal to enhance their existing monitoring efforts, develop new interagency partnerships, and strengthen existing interagency monitoring coordination. The North Atlantic Coast Networks: the National Capital Region Network (NCRN), the Northeast Coastal and Barrier Network (NCBN), and the Northeast Temperate Network (NETN), were jointly provided funding to develop and enhanced monitoring plan. In (FY) 2010, the three North Atlantic Coast Networks, with the input of federal partners and scientists from academic institutions began reviewing their existing monitoring plans and partnerships in order to meet the goals of the Climate Change Response Strategy and Secretarial Order 3289. This document describes the strategy developed by the networks to monitor climate change impacts and its effects on NPS coastal resources in the North Atlantic, as well as the vital sign prioritization and selection process and the final vital signs chosen for new and enhanced

monitoring. It includes options for monitoring based on anticipated project budgets (for all three networks combined) ranging from $200,000 to $400,000 annually.

The objectives of this strategy document are to:

1. Describe the predicted impacts of climate change on specific ecosystems (e.g., tidal marshes or estuaries) in graphic form, using conceptual models;
2. Show in graphic form how current and potential monitoring indicators link to these conceptual models and contribute to understanding some of the predicted impacts of climate change;
3. Describe the criteria used for prioritizing potential indicators or vital signs;
4. Define the three networks' priorities for additional monitoring of climate change impacts on coastal resources, including what indicators the networks propose to measure, and what additional indicators should be kept in mind for future consideration; and
5. Identify how the networks will collaboratively work within the Department of the Interior Landscape Conservation Cooperative (LCC) and Climate Science Center (CSC) frameworks and partner with United States Fish and Wildlife Service (USFWS), United States Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), and other federal agencies, states, and academic institutions to make efficient and effective use of staff and funds and to standardize data collection, analysis, and reporting procedures.

The scope of this monitoring strategy includes coastal U.S. national parks in the North Atlantic. The coastal parks from each of the three I&M Networks include:

- NCBN: Cape Cod National Seashore, Fire Island National Seashore, Gateway National Recreation Area, Assateague Island National Seashore, Colonial National Historical Park, Sagamore Hill National Historic Site, and George Washington Birthplace National Monument
- NETN: Acadia National Park, Boston Harbor Islands National Recreation Area, Saugus Iron Works National Historic Site, and Roosevelt-Vanderbilt National Historic Sites
- NCRN: George Washington Memorial Parkway and National Capital Parks-East

Additional Coastal parks currently not members of the I&M Networks, but that will indirectly benefit from this monitoring effort and data compilation include:

- Fort McHenry National Monument and Historic Shrine, New Bedford Whaling Museum National Historical Park, and Salem Maritime National Historic Site

These parks include at least one of the following ecosystems: uplands and freshwater ecosystems, rocky intertidal ecosystems, tidal marshes, estuaries, beaches, dunes and bluffs, and nearshore ocean ecosystems. Appendix 1 provides a table describing the ecosystems that represent significant resources in each of the national parks as well as those ecosystems that are present, but not significant.

Approach

This Coastal Climate Change Monitoring Strategy was developed by a Core Team and a broader Working Group. Core Team members included:

1. Brian Mitchell (NETN Program Manager)
2. Sara Stevens (NCBN Program Manager)
3. Patrick Campbell (NCRN Program Manager)
4. Erika Patenaude (NCBN Salt Marsh Monitoring Biologist)
5. John Paul Schmit (NCRN Quantitative Ecologist)

The Working Group included all of the Core Team members, plus:

1. Adam Kozlowski (NETN Data Manager)
2. Megan Tyrrell (Cape Code National Seashore Prototype Monitoring Program Manager)
3. Charles Roman (North Atlantic Coast Cooperative Ecosystem Studies Unit Coordinator)
4. Marc Albert (BOHA and SAIR Natural Resource Manager)
5. Sue Adamowicz (Northeast Region USFWS Coastal Biologist)
6. Trisha Towanda (National Science Foundation IGERT Grad Student Intern, URI)
7. Shelley Hall (Cape Cod National Seashore Chief of Resource Management)
8. Mary Foley (NPS Northeast Region Chief Scientist)

Foundations of Success (Nick Salafsky and Marcia Brown) facilitated the development of the strategy. A list of the people that peer reviewed and provided input into portions of the strategy is included in Appendix 2. These included scientists from the State University of New York, University of Rhode Island, USGS, and USFWS.

Development of the strategy included several steps. First, the Core Team and then the Working Group met in March 2010 to begin the development of conceptual models to describe in graphic form the predicted impacts of climate change on each park ecosystem. The Working Group developed an initial overall conceptual model during this first workshop. Following this, the Core Team then developed six individual conceptual models for specific ecosystems (Appendices 3-8), including (1) uplands and freshwater, (2) rocky intertidal, (3) tidal marshes, (4) estuaries, (5) beaches, dunes and bluffs, and (6) nearshore ocean ecosystems.

As an example, Figure 1 includes the conceptual model developed for tidal marsh ecosystems. Arrows represent what the Working Group and peer reviewers believe to be the most important causal relationships (e.g., their theory of predicted change). Agents of change cause stressors that then cause ecological responses. For example, global climate change leads to regional climate

change; altered water and air temperature regime leads to changes in storm intensity, frequency and timing; and an accelerated rate of sea level rise leads to several response factors, including altered habitat, altered water quality, altered soil chemistry, altered salinity pattern, altered hydrology, and altered wave, wind and spray patterns.

Second, after developing the individual ecosystem conceptual models, the Core Team identified an initial list of indicators that would contribute to understanding the predicted impacts of climate change on each ecosystem. Some of these indicators are currently being monitored by the networks and others are not. The Core Team developed tables in which, for each indicator, they defined the relevant monitoring framework category and Vital Signs, associated factors in the conceptual models, the current status of monitoring efforts, the level of priority of this indicator for monitoring impacts of climate change, and the estimated annual cost for new monitoring work. All of this information was used to help prioritize indicators and determine the best allocation of additional funds for monitoring the effects of climate change on coastal resources. These tables are included in Appendices 3-8.

Third, the Core Team sent the draft conceptual models and indicator tables out for peer-review and revised them based on inputs received from outside experts (including federal and academic scientists) and feedback received during the second meeting of the Working Group in July 2010. Appendix 2 provides the list of reviewers.

Fourth, during a workshop, the Working Group conducted a “knock-off prioritization” exercise that focused on prioritizing among the indicators considered very high and high priority for monitoring the effects of climate change. This prioritization exercise took into account whether the indicator would provide information for one or more ecosystems, whether it would rely on new primary (new field work including enhancing existing monitoring) or secondary (existing data collected by other agencies) data, and the startup and ongoing costs of the monitoring. The Working Group developed an initial list of very high priority indicators and established a cut-off line once the cumulative, ongoing cost of the indicators reached $200,000, the lowest level of funding likely available. The group had a lengthy discussion to settle on the final prioritization. During the discussion, if anyone wanted to move an indicator up above the cut-off line they had to move one or more other indicators down, so that the total cost would not exceed $200,000.

Once the prioritization exercise was complete, the Core Team revised each of the six conceptual models by adding symbols showing currently monitored indicators and those proposed for monitoring that would provide information about specific factors. Figure 2 includes the tidal marsh model with the indicator symbols, and shows that currently-collected indicator data provide information about altered runoff, altered sediment processes, altered community composition, species survival and reproduction, altered habitat and altered water quality.

The indicator codes are also included in the tables, where one can find not only the indicator name, but also monitoring methods and other information. Appendices 3-8 include the six conceptual ecosystem models and their associated tables.

Finally, based on all of the previous inputs, the Core Team developed budgets for $200K, $245K, and $400K that define personnel and other expenses needed to set up and enhance monitoring activities and gather existing data for the proposed very high and high priority indicators, including data analysis and communication of results. The Core Team feels that the $245K budget will significantly enhance the value of this program over the $200K budget by allowing the networks to partner closely with the USFWS on a major new marsh bird monitoring effort in the Northeast. The $400K budget would further enhance collaboration among the three networks by expanding existing data collection of salt marsh plants, nekton, phenology and water quality consistently across all three.

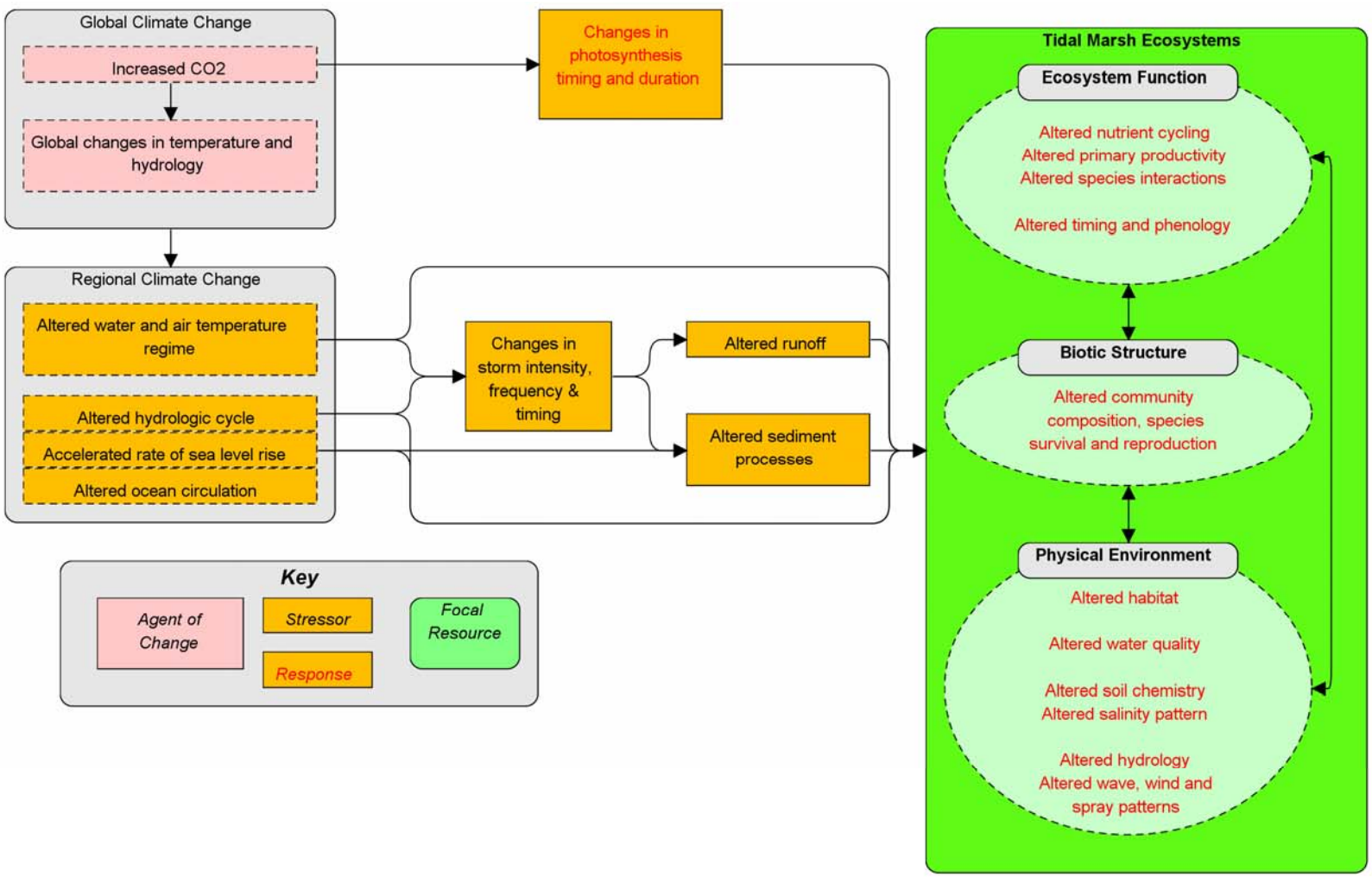

Figure 1. Conceptual model of predicted effects of climate change on tidal marsh ecosystems.

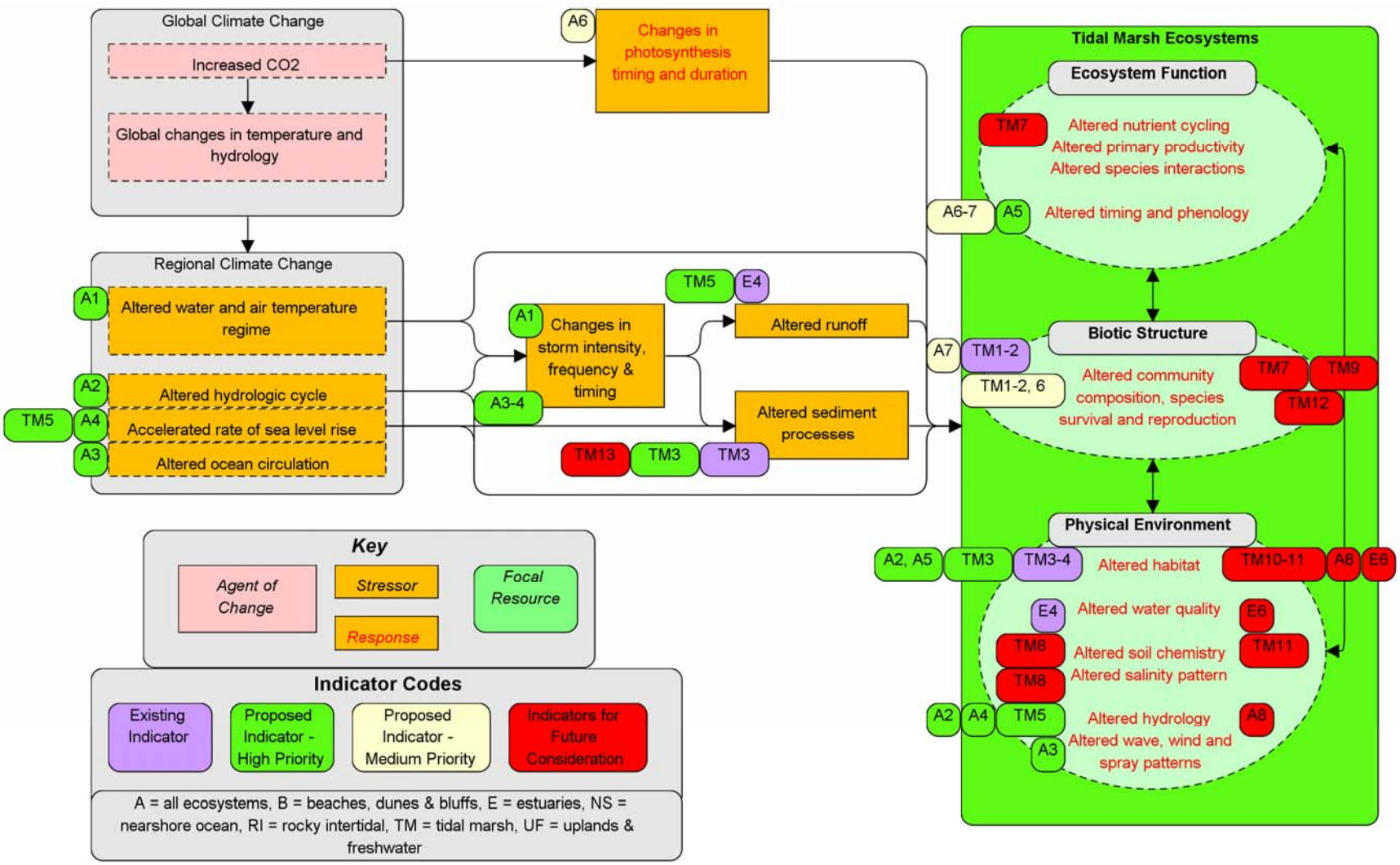

Figure 2. Conceptual model of predicted effects of climate change on tidal marsh ecosystems including symbols for currently monitored and potential indicators for monitoring.

Partnering

Numerous activities of the three networks, many of them stemming from partnerships that preceded the DOI Climate Change Adaptation funding, have laid the groundwork for substantial collaboration between the networks and other agencies. These partners for coastal climate change monitoring include individual USFWS refuges and the USFWS I&M program, the North Atlantic LCC, the USGS, and NOAA. The following is a list of activities conducted in 2009-2010 pertaining specifically to climate change monitoring.

Past and Present Collaborative Activities

- The NETN, NCBN, and NCRN overlap with the North Atlantic and Appalachian Landscape Conservation Cooperatives (LCC). The networks, particularly NCRN, have been active partners in the start-up of both LCCs and will continue to develop this partnership. To date activities have focused mostly on developing governance, identifying partnerships, and building relationships. The networks anticipate that in (FY) 2011 the LCC partners will initiate cooperative activities to inform integrated resource management. Both the NPS Northeast Region and National Capital Region are in the process of hiring Climate Change Coordinators whose role will be to link NPS activities, including the I&M coastal monitoring effort, with other partner activities. The networks anticipate that this may lead to cooperative monitoring efforts and sharing of data and lessons learned throughout the lands managed by DOI agencies, states, and other partners.
- Beginning in early 2009, the USFWS Maine Coastal Islands NWR joined with NETN to integrate their approaches to rocky intertidal monitoring. Refuge biologists participated in developing and testing the protocol, and will be implementing the NETN protocol at two offshore islands near Acadia NP. The sites will provide a useful contrast to the coastal sites at Acadia NP, and NETN will be assisting the USFWS by providing training and data management. Full monitoring will begin in 2011.
- In December 2009, NCBN collaborated with the North Atlantic CESU and the University of Rhode Island to hold a workshop with the goal to identify natural resource research, modeling, and monitoring needs that will assist in refining the understanding of potential responses of natural resources and processes to climate change. The two-day workshop was successfully held with participants from academic and federal agency partners of the North Atlantic Coast CESU and the NCBN. Breakout group topics included coastal birds, coastal physical processes, watershed hydrology, plant ecology, landscape ecology and migrations, salt marshes, invasive species, and others. Suggested research and monitoring were prioritized during the workshop. A workshop report has yet to be completed.
- In January 2009, NCBN partnered with the National Science Foundation (NSF) Integrative Graduate Education and Research Traineeship (IGERT) student intern program and the University of Rhode Island Coastal Institute to provide University of Rhode Island PhD candidates internships to work on specific National Park Service issues pertaining to climate change. In 2010, the first intern began developing an interactive climate change monitoring website for the North Atlantic coastal parks. The goal of this year's internship was to have the student work with the I&M program

networks and individual parks to develop a website using the conceptual models developed by the three networks as part of this year's climate change monitoring planning process. During her internship, the student also participated in a workshop in the NPS Northeast Regional office with regional interpretation staff and others to generate an ocean stewardship toolkit for park interpreters. During the workshop she assisted with the development of an Ocean Stewardship Issue-Template. This template will provide park interpreters and staff with information regarding many coastal challenges associated with climate change, from pollution to ocean acidification and sea level rise. The template is designed to provide an overview of each issue, the science behind it, how the parks are responding and what visitors can do to help.

- Staff from the NCBN, NETN, and NCRN traveled to Silver Spring, Maryland to participate in a joint NPS/NOAA/USFWS/USGS meeting held in the offices of NOAA's Estuarine Reserve Division on February 4-5, 2010. The purpose of this meeting was to talk about ways to standardize salt marsh monitoring along the Atlantic coast by participating agencies. It is in the interest of all the agencies that a unified monitoring effort be developed in support of the National Network of Sentinel Sites being developed by NOAA and the existing NPS I&M program. Areas of discussion included salt marsh elevation monitoring, salt marsh vegetation monitoring, fixed-station water quality monitoring, tide stations/water level monitoring, salt marsh soil monitoring, benchmark survey methodology and database management. The meeting was a huge success and definitely a great jump start to future partnering between NPS I&M Parks and NOAA National Estuarine Reserves.
- During 2010, NETN and Acadia staff held a series of discussions with the USFWS Maine Coastal Islands NWR to determine areas where greater collaboration would be possible. In addition to continuing their collaborative rocky intertidal monitoring effort, the participants decided to work towards shared monitoring of coastal breeding birds, as well as bird and bat migration. The USFWS has agreed to add some of Acadia's bird nesting islands to their regular monitoring rotation. The network, park, and refuge have also partnered with the University of Maine and others to support migration monitoring in fall 2010, with six total banding and acoustic monitoring stations in the park and refuge.
- In March 2010, staff from NCBN traveled to the Back Bay National Wildlife Refuge in NH to meet with the USFWS Regional Refuge Biologist Janith Taylor and northeast coastal refuge biologists and managers to present the NPS Inventory and Monitoring program. The NCBN presented the Network's coastal monitoring and data management program and discussed potential collaboration between the NPS I&M program and the newly developing USFWS I&M program, recently initiated in FY10. Action items include working towards sharing data management systems for our common monitoring programs, as well as sharing staff and positions to accomplish common program goals. Both NPS and USFWS staff agreed to continue discussions and, as new USFWS I&M staff are hired, NPS staff will be meeting with them individually to share "lessons learned" and to continue collaboration efforts.

- As a result of the March 2010 NCBN/USFWS meeting, the USFWS has requested that NCBN provide training to coastal USFWS managers using the NCBN Shoreline Change monitoring protocol. A training workshop with USFWS is planned for the fall of 2010. NCBN staff will organize and hold a joint workshop and training program for national park and refuge managers. The workshop will be planned by NCBN program manager and data manager along with NCBN cooperators from Rutgers University. Discussions on sharing staff to conduct shoreline monitoring and data management will take place between NPS and USFWS managers.

Future Collaborative Activities

- The networks will continue to work with the interagency partnership aimed at enhancing and standardizing salt marsh monitoring along the Atlantic coast. Salt marsh capital monitoring is a major component of this effort, and the networks will ensure that NPS methods are consistent with the interagency approach, from data collection through data management, analysis, and reporting.
- The NPS/NSF/URI partnership will continue with a new IGERT student starting in January 2011 to begin working to evaluate and standardize salt marsh monitoring protocols currently being used by NOAA's National Estuarine Research Reserves, USFWS, and four NPS Networks.
- The USFWS has funded a major project to begin monitoring marsh birds in the North Atlantic through a partnership with the University of Maine, University of Delaware, and others. The networks are already working with the specific principal investigators on a variety of projects, and have also funded a researcher at the University of Rhode Island to evaluate salt marsh bird monitoring methods for the networks. The networks will work closely with the USFWS and the university researchers to ensure that the final NPS protocol is compatible with the USFWS approach.
- A significant part of the networks' anticipated coastal climate change monitoring is the acquisition, analysis, and reporting of a variety of existing data sets. Other networks within the NPS and other agencies are currently engaging in similar projects, and the networks will work with organizations involved in related work to ensure that these projects are accomplished efficiently and to the maximum benefit of the partners.
- As the North Atlantic LCC and Northeast Climate Science Center develop, the networks will be available to share data and work towards more consistent and collaborative monitoring approaches.

Workplan and Budget

Priority Vital Sign Indicators

The Working Group prioritized two groups of Vital Sign indicators: one related to the collection and analysis of new data (including enhancing existing monitoring) and the second related to the analysis of secondary data sets (existing long-term data collected by other agencies and organizations). The highest primary data priorities included the following indicators focusing on tidal marshes:

- Tidal marsh surface elevation (sediment relative to elevation, accretion, erosion, and shallow subsidence)
- Tidal marsh tidal range
- Tidal marsh inundation
- Tidal marsh bird species composition and relative abundance

These priorities focus on assessing the impact of sea level rise on tidal marsh capital as well as the status of salt marsh breeding birds, and both are areas of ongoing interagency collaboration.

The highest priorities for the analysis of secondary data included the following:

- Weather and climate data for all ecosystems
- Marine hydrography data (ocean current, wave characteristics, tide range, water quality parameters) for all relevant ecosystems
- Tidal elevation data (water surface elevation, tidal range, water quality parameters) for all relevant ecosystems
- Habitat change of all ecosystems based on remote sensing (e.g., satellite imagery, LiDAR)

If the funding level is sufficient, the group's next priorities are to enhance several existing network protocols (including phenology and water quality) to make them consistent across the three networks, and to provide additional support for the analysis of secondary data sets including:

- Ice cover (landscape phenology) data from NASA
- Shoreline structures (type, location, and age) on beaches, dunes and bluffs
- Breeding bird phenology in upland and freshwater ecosystems
- Water quality and chemistry in nearshore ocean ecosystems

The Core Team used these Vital Signs priorities to develop budgets at three levels (a base budget of $200K (Table 1), a recommended budget of $245K (Table 2), and an enhanced budget for $400K (Table 3)). The base budget includes a full-time GS-9/11 biologist working on monitoring marsh capital, primarily based on sediment elevation tables (SETs), plus equipment, travel, and protocol development expenses for marsh capital monitoring. It also includes a half-time GS-9 Climate Change Data Manager position (the other 50% time will be funded by NETN and perform duties as the network's Assistant Data Manager). This person would be responsible for obtaining and analyzing existing weather, marine hydrography, and other high priority secondary data sets described above. The recommended $245K budget adds a half-time GS-7 biological

science technician and travel for salt marsh bird monitoring (the other half of the technician's time would be funded by NCBN and perform other network monitoring duties). Both the base and recommended budgets allocate some funds to cover operational costs and the time that existing staff will spend on supervision and science communication.

The highest priorities for enhanced monitoring are as follows for the proposed budget of $245K:

- Expand existing interagency collaborative effort to monitor salt marsh capital along the Atlantic coast in 10 national parks in conjunction with 12 coastal United States Fish and Wildlife Service (USFWS) sites, as well as National Estuarine Research Reserve sites (NOAA, NERR) along the North Atlantic. This effort will include standardized protocols, databases and data collection.
- Expand analysis, synthesis and reporting of datasets produced by other agencies and organizations such as climate, tide, sea level, and remotely-sensed data to park managers and others to enhance our understanding of the effects of climate change. ($200K)
- Expand the existing interagency effort to monitor breeding marsh birds in North Atlantic parks within Bird Conservation Area 30 (BCR 30) through the Northeast Coordinated Bird Monitoring Partnership. ($245K)

These projects will all continue collaborative efforts among the I&M Networks, USFWS, National Oceanic and Atmospheric Administration (NOAA), the United States Geological Survey (USGS), state wildlife agencies, universities and non-governmental organizations (NGOs). If funding is only available for the base budget, activities related to marsh bird monitoring will be reduced.

If there is sufficient funding up to $400,000, the three I&M Networks propose making the Climate Change Data Manager position a full-time GS-9/11 position and increasing the budgets for equipment, projects, and science communication. This will allow more secondary data analyses to be incorporated into the monitoring program, with a shorter interval between reports. This level of funding would also allow the networks to consistently monitor marsh vegetation and nekton, phenology, and freshwater quality across the three networks. Increasing the consistency of monitoring would greatly facilitate regional analyses, and would provide a foundation for extending monitoring to other agencies. Funding at this level will also allow more effort to be directed to finalizing protocols, collaborating among agencies, and producing products to communicate findings to parks and other agencies.

Budgets

Table 1. Base budget for monitoring indicators of climate change effects on NPS coastal resources.

	2011	2012	2013	2014	2015
Data Manager (50% GS-9)[1]	$33,800	$35,900	$38,200	$40,500	$41,800
Biologist - SETs (GS-9/11)	$89,700	$95,900	$102,400	$109,300	$113,150
Travel - SETs	$15,000	$15,400	$15,800	$16,100	$16,600
Vehicle - SETs	$6,000	$6,150	$6,300	$6,450	$6,650
Equipment	$13,000	$9,050	$9,700	$5,000	$5,000
Projects[2]	$30,000	$25,000	$15,000	$10,000	$4,050
Supervision / Operations	$10,000	$10,000	$10,000	$10,000	$10,000
Science Communication[3]	$2,500	$2,600	$2,600	$2,650	$2,750
TOTAL	***$200,000***	***$200,000***	***$200,000***	***$200,000***	***$200,000***

[1]Flexibility to withstand a potential 5% cut in 2012: $10,000 will be reduced from project funds in 2012, 2013, and 2014; in 2015, the project and science communication funds would be zeroed and supervisory funds reduced by $3,200 to balance the budget.
[2] the other 50% of the Data Manager's time will be funded by spent as the NETN's Assistant Data Manager
[3] Projects: Protocol development for analysis of existing data sets (e.g., consultation with experts) as well as SET review and upgrades for NCBN and NCRN
[4] Science Communication: 1 pay period per year of NETN science communication specialist time

Table 2. Recommended budget for monitoring indicators of climate change effects on NPS coastal resources. This budget adds marsh bird monitoring to the base budget.

	2011	2012	2013	2014	2015
Data Manager (50% GS-9)[1]	$33,800	$35,900	$38,200	$40,500	$41,800
Biologist - SETs (GS-9/11)	$89,700	$95,900	$102,400	$109,300	$113,150
Bio Tech - Birds (50% GS-7)[1]	$30,300	$32,400	$34,600	$36,900	$38,200
Travel - SETs	$15,000	$15,400	$15,800	$16,100	$16,600
Vehicle - SETs	$6,000	$6,150	$6,300	$6,450	$6,650
Travel - Birds	$8,000	$8,200	$8,400	$8,600	$8,900
Equipment	$15,000	$12,000	$9,700	$4,500	$5,000
Projects[2]	$34,700	$26,450	$17,000	$10,000	$2,000
Supervision / Operations	$10,000	$10,000	$10,000	$10,000	$10,000
Science Communication[3]	$2,500	$2,600	$2,600	$2,650	$2,750
TOTAL	***$245,000***	***$245,000***	***$245,000***	***$245,000***	***$245,000***

[1] the other 50% of the Data Manager's time will be funded by and spent as the NETN's Assistant Data Manager, and the other 50% of the Bio Tech's time will be funded by and spent as a NCBN Bio Tech
[2] Projects: Protocol development for analysis of existing data sets (e.g., consultation with experts) as well as SET review and upgrades for NCBN and NCRN
[3] Science Communication: 1 pay period per year of NETN science communication specialist time

Table 3. Enhanced budget for monitoring indicators of climate change effects on NPS coastal resources. This budget adds enhanced data management, consistent implementation of several protocols, and additional science communication time to the recommended budget.

	2011	2012	2013	2014	2015
Data Manager (GS-9/11)	$81,600	$86,850	$92,300	$98,100	$101,000
Biologist - SETs (GS-9/11)	$89,700	$95,900	$102,400	$109,300	$113,100
Bio Tech - Birds (50% GS-7)[1]	$30,300	$32,400	$34,600	$36,900	$38,200
Travel - SETs	$15,000	$15,400	$15,800	$16,100	$16,600
Vehicle - SETs	$6,000	$6,150	$6,300	$6,450	$6,650
Travel - Birds	$8,000	$8,200	$8,400	$8,600	$8,900
Equipment	$27,600	$18,300	$16,200	$9,000	$6,800
Projects[2]	$41,800	$34,550	$19,500	$11,200	$2,250
Supervision / Operations	$10,000	$10,000	$10,000	$10,000	$10,000
Science Communication[3]	$5,000	$5,125	$5,250	$2,650	$2,750
Marsh Veg and Nekton	$25,000	$25,625	$26,250	$27,000	$27,600
Phenology	$35,000	$35,875	$36,750	$37,700	$38,500
Freshwater Quality	$25,000	$25,625	$26,250	$27,000	$27,650
TOTAL	***$400,000***	***$400,000***	***$400,000***	***$400,000***	***$400,000***

[1] the other 50% of the Bio Tech's time will be funded by and spent as a NCBN Bio Tech
[2] Projects: Protocol development for analysis of existing data sets (e.g., consultation with experts) as well as SET review and upgrades for NCBN and NCRN
[3] Science Communication: 2 pay periods per year of NETN science communication specialist time through 2013, then 1 pay period

Budget Justifications

Funding at the $200K level will allow the three networks to continue collaborating with other agencies (including NOAA, USFWS and USGS) and other networks (Southeast Coast Network) on an Atlantic Coast monitoring program for salt marsh capital. Multiple agencies are using the same methods and working to collaborate on data management and analysis, and the Core Team feels that supporting a significant salt marsh capital monitoring program is essential. The other activities funded at the $200K level will support analysis and reporting of existing data sets from on-going non-NPS monitoring efforts. Since the data are being collected by other agencies, these monitoring products are a cost-effective way to provide important climate-change related information to park managers. Flexibility to withstand a potential 5% cut in 2012 includes a $10,000 reduction in project funds in 2012, 2013, and 2014. In 2015, the project and science communication funds would be zeroed and supervisory funds reduced by $3,200 to balance the budget.

Funding at the recommended $245K level would allow the networks to add an important additional indicator – salt marsh breeding birds – to the monitoring program. Salt marsh birds are a charismatic group that are expected to be highly sensitive to climate change and can be monitored with established methods. This group is important to park managers and visitors, and an area of considerable potential interagency collaboration. Funding at this proposed level will allow the networks to continue working with the USFWS and others to implement consistent salt marsh bird monitoring across the North Atlantic.

If enhanced funding is available up to the $400K range, the networks would use the funds to further support the analysis and reporting of existing data sets and ensure that key monitoring projects are implemented consistently across the networks. These additional projects – including methods for reporting existing data sets and well-established monitoring efforts for marsh vegetation, marsh nekton, phenology, and water quality – will be a tremendous benefit to network parks, regional NPS analyses, and other federal agencies.

Regardless of the final funding level, all of the projects proposed in the different budgets will benefit park management and planning (e.g., climate change vulnerability assessments) by providing early warnings of the effects of climate change and information that could inform scenario planning and adaptation and mitigation efforts. These data will also support the development and testing of regional climate change models based on down-scaled climate data. All of the projects, and particularly the projects funded in the recommended $245K budget, have strong interagency support and will be based on interagency data.

Project Management

The North Atlantic Coastal Climate Change Monitoring Program will be jointly managed by the National Capital Region's Regional I&M Program Manager, the Northeast Coastal and Barrier Network (NCBN) Program Manager, and the Northeast Temperate Network (NETN) Program Manager. These three individuals will meet as needed to discuss work planning, budget, and implementation of monitoring activities, and decisions will be made by consensus. As appropriate they will interact with staff from the North Atlantic LCC, Northeast CSC, USFWS I&M, and other federal agencies and academic partners. All monitoring funds will be managed from a single account within NCBN. Unless directed otherwise by the national Inventory and Monitoring Division Chief, the annual work plan and annual report for these funds will be drafted by the three program managers and incorporated into the annual reports for NCBN. The annual reports for climate change funds will require the approval of the Northeast Region I&M Program Manager and the Inventory and Monitoring Division Chief, following the timeline used for individual network reports.

New personnel hired using climate change funds will be stationed with the Northeast Temperate Network in Woodstock, Vermont (the Climate Change Data Manager) and the Northeast Coastal and Barrier Network in Kingston, Rhode Island (all other new staff). The data manager will be supervised by the NETN Data Manager, unless sufficient funds are provided to pay for a full time GS-11 data manager, in which case the NETN Program Manager will be the supervisor. All other staff hired with climate change funds will be supervised by the NCBN Program Manager or by a higher-grade NCBN biologist or ecologist.

The Climate Change Data Manager will be responsible for working with the SET biologist to implement data management procedures and systems as a top priority. This individual will also work to develop procedures and systems for acquiring and reporting a variety of existing data sets, including climate, tide, NASA TOPS model data, and more. The data manager will work with the program managers and other government or academic scientists as needed to determine appropriate reporting metrics and formats. Based on the funding level, NETN will advertise the Data Manager position in October or November 2010.

The SET Biologist will be responsible for evaluating existing NPS SET sites in the North Atlantic and proposing a timeline for making any changes needed to ensure that the program can monitor the effects of climate change on salt marsh capital. The biologist will also monitor existing NPS SET sites, repair the sites as needed, enter and manage data collected during monitoring, and write annual and trend reports that present the monitoring data. He or she will also coordinate with other agencies to ensure that NPS methods are consistent with their approach. Time permitting, the SET Biologist will participate in other monitoring activities, including participating in salt marsh bird monitoring or surveying rocky intertidal plots. NCBN and NETN are currently working together to recruit potential candidates for this position.

The NETN Science Communication Specialist will be responsible for developing interpretive materials that promote North Atlantic Coastal Climate Change Monitoring. The program managers will work with the Science Communication Specialist to identify publications and other communication tools (such as web sites and presentations) that the specialist will produce.

The Science Communication Specialist is already working for NETN, and will devote at least one pay period to climate change communication in FY 2011.

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Stevens, S., B. Milstead, M. Albert, G. Entsminger. September 2005. Northeast Coastal and Barrier Network Vital Signs Monitoring Plan. Technical Report NPS/NER/NRTR--2005/025. National Park Service. Boston, Massachusetts.

Appendix 1. Ecosystems types found in each North Atlantic coastal National Park

US National Park	Uplands	Freshwater Ecosystems	Rocky Intertidal Ecosystems	Tidal Marshes	Estuaries	Beaches, Dunes and Bluffs	Nearshore Ocean Ecosystems
Cape Cod National Seashore	X	X		X	X	X	X
Fire Island National Seashore	X	X		X	X	X	X
Gateway National Recreation Area	X	X		X	X	X	X
Assateague Island National Seashore	X	X		X	X	X	X
Colonial National Historical Park	X	X		X	X	X	
Sagamore Hill National Historic Site	X	X		X	X	X	
George Washington Birthplace National Monument	X	X		X	X	X	
Acadia National Park	X	X	X	X	X	–	X
Boston Harbor Islands National Recreation Area	X	–	X	X		X	X
Saugus Iron Works National Historic Site	X	X		X	X		
Roosevelt-Vanderbilt National Historic Sites	X	X		X			
George Washington Memorial Parkway	X	X		X			
National Capital Parks - East	X	X		X	–	X	
Other parks that will indirectly benefit from this monitoring							
Fort McHenry National Monument							
New Bedford Whaling Museum National Historical Park							
Salem Maritime National Historic Site							

X: Present, and a significant park resource
–: Present, but not a significant park resource

Appendix 2. List of peer reviewers of conceptual models and indicator tables

1. Suzanne Paton-USFWS
2. Dr. Hilary Neckles-USGS Patuxent
3. Dr. Stephen Smith-Cape Cod National Seashore Plant Ecologist
4. Dr. Ken Reposa-Narragansett Bay NERRS Coordinator
5. Dr. Cathy Wigand-EPA Salt Marsh Ecologist
6. Brian Sturgis-Assateague Island NS Hydrologist
7. Dr. Bradley Peterson-SUNY Stony Brook Seagrass Ecologist
8. Dr. Sofia Fox-Cape Cod National Seashore Aquatic Ecologist
9. Dr. Scott Nixon-University of Rhode Island, Professor of Oceanography
10. Dr. Rebecca Beavers-Coastal Geologist, NPS Geologic Resources Division
11. Dr. Jodi Eshlemen-Coastal Engineer, NPS Geologic Resources Division
12. Courtney Schupp-Assateague Island NS Coastal Geologist
13. Dr. Cheryl Hapke-USGS Coastal Geologist, Woodshole, MA
14. Dr. Norb Psuty-Rutgers University, Coastal Geomorphologist
15. Tanya Silviera, Rutgers University, Coastal Geomorphologist
16. Dr. Henry J. Bokuniewicz, SUNY Stony Brook, Coastal Geologist/Hydrologist
17. Dr. Jeff Cross, Ocean and Marine Resources, NPS Fort Collins
18. Dr. Candace Oviatt, University of Rhode Island Professor of Oceanography
19. Jeremy Long, San Diego State University
20. Peter Petraitis, University of Pennsylvania
21. Tom Trott, Suffolk University
22. Geoffrey Trussell, Northeastern University

Appendix 3. Beaches, dunes and bluffs conceptual model and table of predicted effects of climate change as well as currently monitored and potential indicators for monitoring

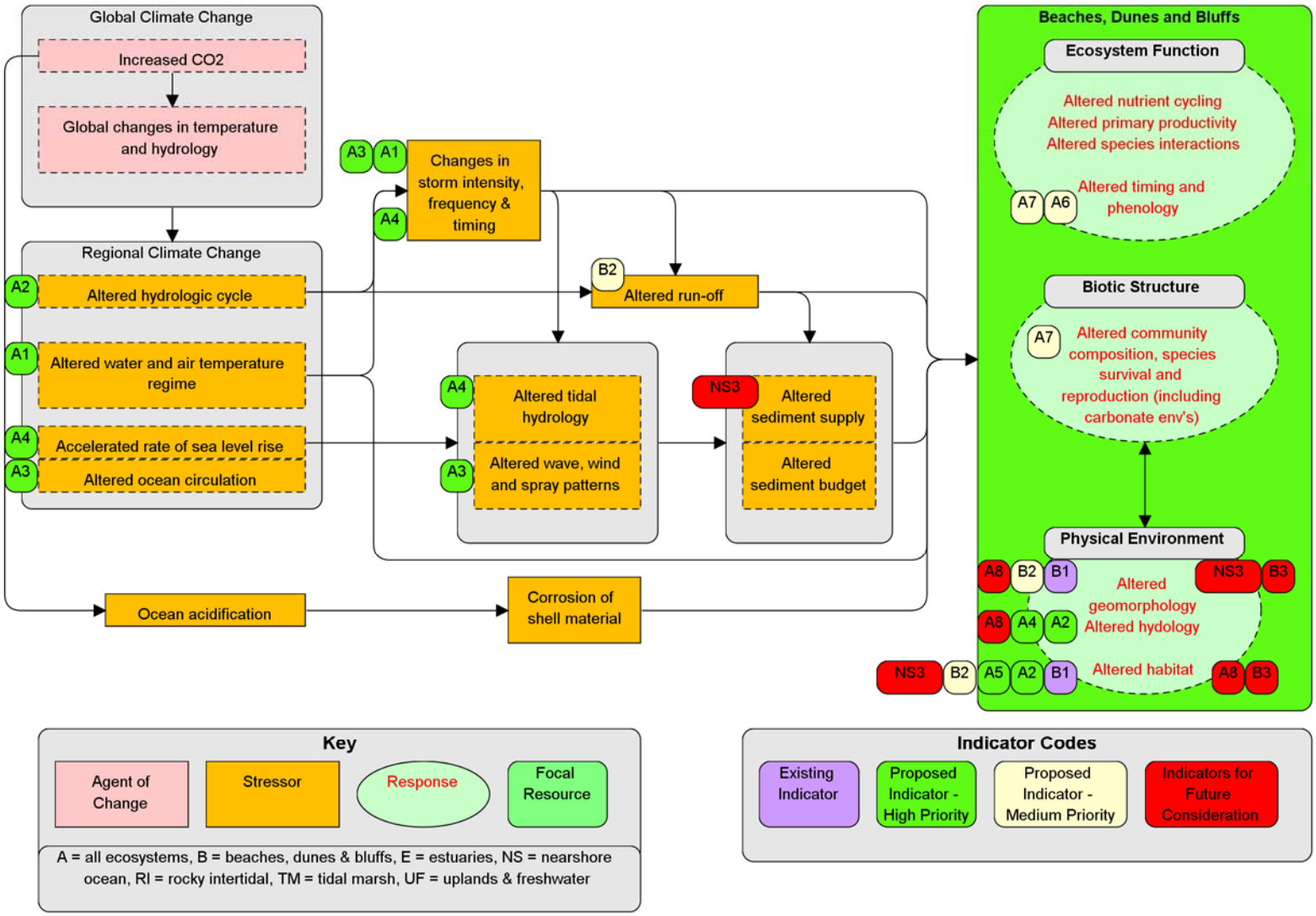

Table B1. Currently monitored indicators for beaches, dunes and bluffs ecosystems

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
B1	Coastal/ Oceanographic Features and Processes NCBN: Shoreline Position	Altered geo-morphology Altered habitat	NCBN – 1, since 2004	Ocean shoreline position	GPS survey biannually, spring and fall	VH	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NETN. Hapke suggested adding post-storm surveys.
B2	Coastal/ Oceanographic Features and Processes NCBN: Coastal Topography	Altered geo-morphology Altered habitat	NCBN – 3	Beach and dune topography, including dune height and width, berm height and width, cliff height, overwash fan locations, foreshore slope, cross-shore area change, along-shore area change, sediment budget, and edge of vegetation	GPS RTK survey and digital modeling biannually, spring and fall. Supplemental LiDAR.	VH	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NETN

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

Table B2. High and medium priority potential indicators for beaches, dunes and bluffs ecosystem monitoring.

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A1	Weather and Climate NCBN and NCRN: Weather NETN: Climate	Altered water and air temperature regime Changes in snow and ice cover; note that this factor is not in the beach model Changes in storm intensity, frequency & timing	NETN – 3, NETN has begun developing procedures and a database. Available data is generally 1950 and later.	Precipitation (annual totals, seasonal totals, event totals and variability, "flashiness") Snow depth (annual totals, seasonal totals, event totals and variability) Relative humidity (annual average, seasonal / monthly average and variability) Wind speed (annual average, seasonal and monthly average and variability, storm event max and average) Air temperature (annual average, seasonal and monthly average and variability)	Acquire and analyze daily weather summaries from weather stations in or near each park.	VH	$$$$	$$$	Weather and climate data will support all field monitoring activities; costs reflect time for ALL NETN / NCRN / NCBN parks

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A2	Weather and Climate NCBN and NCRN: Weather NETN: Climate	Altered hydrology Altered habitat Altered hydrologic cycle Changes in snow and ice cover; note that this factor is not in the beach model	No monitoring initiated	Snow cover Surface soil moisture Evapotranspiration	Remote sensing; NASA TOPS models and products	H	$$	$	Acquire, manage, and report existing data.
A3	Marine Hydrology and Water Chemistry NCBN: Marine Hydrography	Altered ocean circulation Altered wave, wind and spray patterns Changes in storm intensity, frequency & timing	No monitoring initiated	Ocean current, wave characteristics, tide range, and water quality parameters	Acquire and analyze data from existing networks, e.g. buoys, CODAR-Seasondes, and AUV sensors.	H	$$	$$	USACE data may be available for ASIS and FIIS (Courtney Schupp). GoMOOS has buoy data available for Gulf of Maine.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A4	Marine Hydrology and Water Chemistry NCBN: Marine Hydrography	Accelerated rate of sea level rise Altered hydrology Altered tidal hydrology Changes in storm intensity, frequency & timing	No monitoring initiated	Water surface elevation, tide range, water quality parameters Wave force	Acquire and analyze data from existing NOAA tide gages. Consider installing "whiffle-ball" wave impact gages at field sites	VH	$$	$$	Harvest existing data; there may be gaps for some parks. Cost to install one new long-term tide gage: $80-100K; cost for maintaining it is $30K/year
A5	Land Cover and Use NCBN: Landscape Change NCRN: Land Cover / Land Use NETN: Land Cover / Ecosystem Cover, Land Use	Altered habitat	No monitoring initiated	Change in vegetation types Change in extent of vegetation	Vegetation mapping and classification or use of NLCD data sets, every 10 years.	H	$$	$$	Analyze existing data; there are existing baseline vegetation maps for each park, and decadal National Land Cover Datasets (NLCD). Hapke recommended this for dune monitoring.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A6	Vascular Plants NETN: Phenology	Altered timing and phenology Changes in photosynthesis timing and duration; note that this factor is not in the beach model	No monitoring initiated	Landscape phenology Vegetation indices	Remote sensing; NASA TOPS models and products	H	$$	$$	Acquire, manage, and report existing data.
B3	Land Cover and Use NCBN: Anthropogenic Modifications and Landscape Change NCRN: Land Cover / Land Use NETN: Land Cover / Ecosystem Cover, Land Use	Altered geo-morphology Altered habitat Altered runoff	No monitoring initiated	Human manipulation of the shoreline, including type, number and location of shoreline structures, beach nourishment events, dates of installation and years of impact	GIS mapping based on existing data sources. Update every 5 to 10 years.	H	$$	$$	Potential data sources: USACE, State Agencies, Western Carolina U (Andy Coburn Coastal Engineering Inventory), Rebecca Beavers (NPS GRD).

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A7	Amphibians and Birds NCBN: Anurans, Marsh Birds NCRN: Amphibians, Landbirds NETN: Phenology, Breeding Birds, Amphibians and Reptiles	Altered community composition, species survival and reproduction Altered timing and phenology	No monitoring initiated	Breeding bird phenology Amphibian phenology	Automated recorders at index locations, with automated recognition of index species. NETN and USGS are currently developing methods.	VH	$$$$	$$$	Costs will vary depending on the number of index sites and the final data analysis costs.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

Table B3. Other potential indicators for beaches, dunes and bluffs ecosystem monitoring

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A8	Groundwater NCRN: Groundwater Dynamics NETN: Water Quantity	Altered geo-morphology Altered habitat Altered hydrology	No monitoring initiated	Depth to fresh water from surface, including variability and seasonality Salinity of groundwater	Wells with continuously recording (~ hourly) pressure transducers in a variety of habitats; particularly surrounding wetland, estuarine, and marine habitats.	H	$$$$$	$$$$$	Excludes other groundwater sampling (near SET sites and NETN vernal pools) that is already planned. It is unclear what sample sizes would be sufficient to understand groundwater dynamics.
NS3	Marine Features and Processes NCBN: Marine Hydrography and Offshore Topography	Altered geo-morphology Altered habitat Altered sediment supply Altered sediment budget	No monitoring initiated	Nearshore Topography / Bathymetry; bottom configuration, vectors of displacement, volume of surficial sand supply	Boat Based Survey, AUV, Interferometric side-scan or multibeam, pressure sensors, single-beam fathometer. Baseline Inventory needed and should include shallow nearshore waters.	VH	$$$$$	$$$$	Rotate through parks on multi-year cycle (perhaps 5 years). Recommended by Oviatt.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

Appendix 4. Estuarine conceptual model and table of predicted effects of climate change as well as currently monitored and potential indicators for monitoring

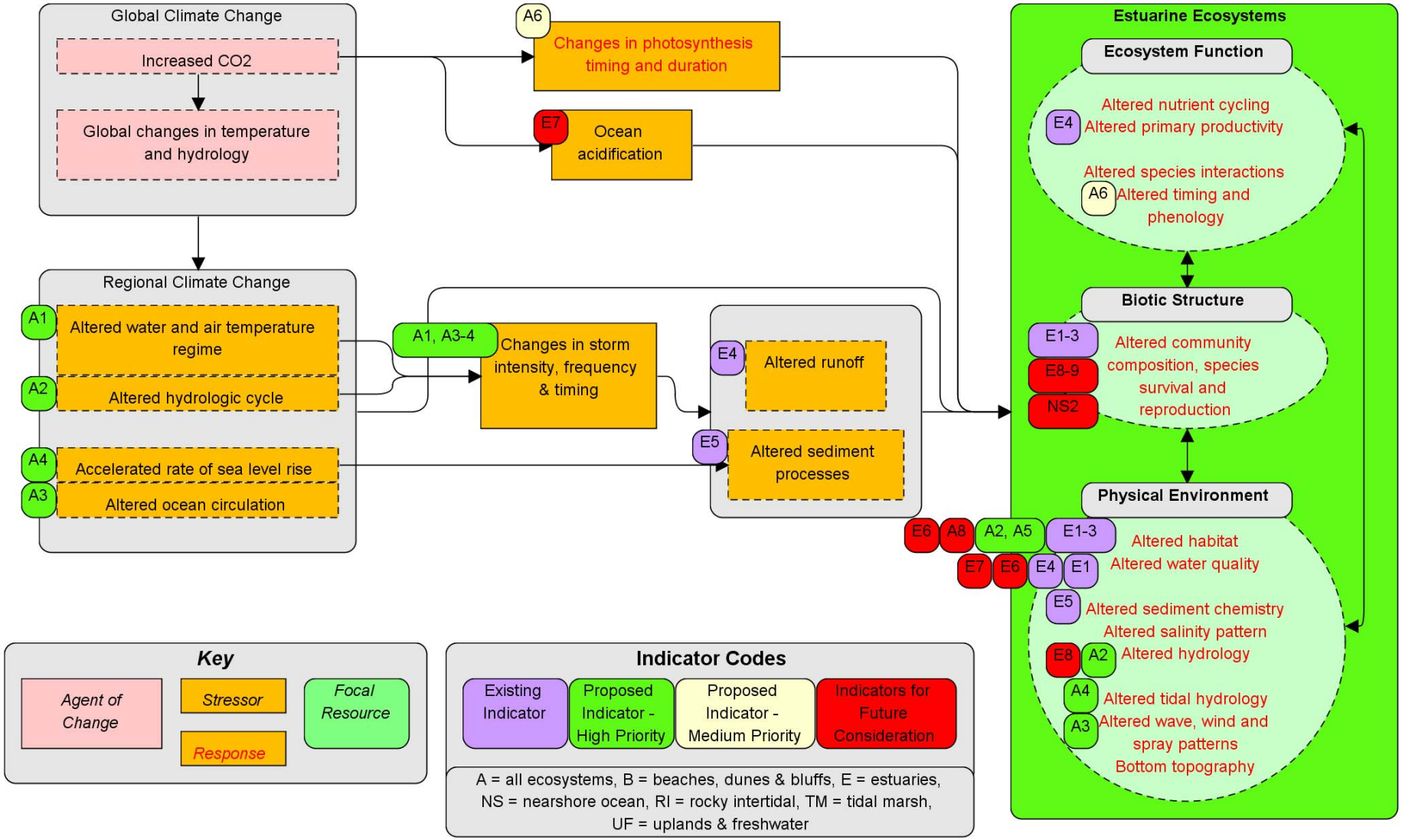

Table E1. Currently monitored estuarine indicators

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
E1	Subtidal Aquatic Beds NCBN: Seagrass Condition and Seagrass Distribution	Altered community composition, species survival and reproduction Altered habitat Altered water quality	NCBN – 1, since 2007	Seagrass / Submerged Aquatic Vegetation (SAV) bed size, SAV bed structure (cover class), SAV bed location, SAV density, SAV biomass, SAV canopy height, SAV percent cover, SAV seagrass depth limit, epiphyte Cover, grazing, wasting index, water temperature, salinity, light attenuation, sediment parameters	Biennial transect/SCUBA surveys at FIIS, CACO and ASIS	VH	N/A	N/A	Tier 3 (intensive) monitoring. Part of ongoing monitoring; no new costs unless expanded to NCRN and NETN. Nixon suggested adding root/shoot ratio.
E2	Subtidal Aquatic Beds NCBN: Seagrass Condition and Seagrass Distribution	Altered community composition, species survival and reproduction Altered habitat	NCBN – 2, since 2007	Seagrass / Submerged Aquatic Vegetation (SAV) % cover, maximum leaf length of 3 terminal grass shoots at each station, canopy height of the sample, water depth at each station	Biennial boat surveys at FIIS, CACO and ASIS.	VH	N/A	N/A	Tier 2 (moderately resolution) monitoring. Part of ongoing monitoring; no new costs unless expanded to NCRN and NETN.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
E3	Subtidal Aquatic Beds NCBN: Seagrass Distribution	Altered community composition, species survival and reproduction Altered habitat	NCBN – 3	Seagrass / Submerged Aquatic Vegetation (SAV) bed size, bay-wide distribution and absolute acreage	Boat surveys every 5 years at FIIS, CACO and ASIS.	VH	N/A	N/A	Tier 3 (extensive) monitoring. Part of ongoing monitoring; no new costs unless expanded to NCRN and NETN.
E4	Water Chemistry and Nutrient Dynamics NCBN: Estuarine Water Chemistry, Quality, and Clarity NCRN: Water Chemistry NETN: Water Chemistry and Estuarine Nutrient Enrichment	Altered primary productivity Altered runoff Altered water quality	NCBN – 1, start date varies NETN – 3	Water Chemistry-Dissolved oxygen, Water temperature, Salinity Water Quality-Chlorophyll a Water Clarity-PAR, Turbidity	Synoptic spatial sampling via boat surveys and continuous sampling at index sites using YSI sonde and lab analysis. Sample biennially during a 1 month summer index period.	VH	N/A	N/A	Part of ongoing monitoring; no new costs unless expanded to NCRN. Peterson and Sturgis recommended adding pH, but this parameter was excluded during protocol development. They also recommended sampling water column nitrogen levels, but this cannot be done cost-effectively.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
E5	Coastal/ Oceanographic Features and Processes NCBN: Estuarine Sediment Chemistry	Altered sediment chemistry Altered sediment processes	NCBN – 1, start date varies	Surficial sediment % organic carbon Surficial sediment C:N ratio	Grab samples collected and analyzed every 5 years	H	N/A	N/A	Part of ongoing monitoring; no new costs unless expanded to NCRN and NETN.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

Table E2. High and medium priority indicators for additional estuarine monitoring

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A1	Weather and Climate NCBN and NCRN: Weather NETN: Climate	Altered water and air temperature regime Changes in snow and ice cover; note that this factor is not in the estuarine model Changes in storm intensity, frequency & timing	NETN – 3, NETN has begun developing procedures and a database. Available data is generally 1950 and later.	Precipitation (annual totals, seasonal totals, event totals and variability, "flashiness") Snow depth (annual totals, seasonal totals, event totals and variability) Relative humidity (annual average, seasonal / monthly average and variability) Wind speed (annual average, seasonal and monthly average and variability, storm event max and average) Air temperature (annual average, seasonal and monthly average and variability)	Acquire and analyze daily weather summaries from weather stations in or near each park.	VH	$$$$	$$$	Weather and climate data will support all field monitoring activities; costs reflect time for ALL NETN / NCRN / NCBN parks

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A2	Weather and Climate NCBN and NCRN: Weather NETN: Climate	Altered hydrology Altered habitat Altered hydrologic cycle Changes in snow and ice cover; note that this factor is not in the estuarine model	No monitoring initiated	Snow cover Surface soil moisture Evapotranspiration	Remote sensing; NASA TOPS models and products	H	$$	$	Acquire, manage, and report existing data.
A3	Marine Hydrology and Water Chemistry NCBN: Marine Hydrography	Altered ocean circulation Altered wave, wind and spray patterns Changes in storm intensity, frequency & timing	No monitoring initiated	Ocean current, wave characteristics, tide range, and water quality parameters	Acquire and analyze data from existing networks, e.g. buoys, CODAR-Seasondes, and AUV sensors.	H	$$	$$	USACE data may be available for ASIS and FIIS (Courtney Schupp). GoMOOS has buoy data available for Gulf of Maine.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A4	Marine Hydrology and Water Chemistry NCBN: Marine Hydrography	Accelerated rate of sea level rise Altered tidal hydrology Changes in storm intensity, frequency & timing	No monitoring initiated	Water surface elevation, tide range, water quality parameters Wave force	Acquire and analyze data from existing NOAA tide gages. Consider installing "whiffle-ball" wave impact gages at field sites	VH	$$	$$	Harvest existing data; there may be gaps for some parks. Cost to install one new long-term tide gage: $80-100K; cost for maintaining it is $30K/year
A5	Land Cover and Use NCBN: Landscape Change NCRN: Land Cover / Land Use NETN: Land Cover / Ecosystem Cover, Land Use	Altered habitat	No monitoring initiated	Change in vegetation types Change in extent of vegetation	Vegetation mapping and classification or use of NLCD data sets, every 10 years.	H	$$	$$	Analyze existing data; there are existing baseline vegetation maps for each park, and decadal National Land Cover Datasets (NLCD). Hapke recommended this for dune monitoring.
A6	Vascular Plants NETN: Phenology	Altered timing and phenology Changes in photosynthesis timing and duration	No monitoring initiated	Landscape phenology Vegetation indices	Remote sensing; NASA TOPS models and products	H	$$	$$	Acquire, manage, and report existing data.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

Table E3. Other potential indicators for estuarine monitoring

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A8	Groundwater NCRN: Groundwater Dynamics NETN: Water Quantity	Altered geo-morphology; note that this factor is not in the estuarine model Altered habitat Altered hydrology	NETN – 3	Depth to fresh water from surface, including variability and seasonality Salinity of groundwater	Wells with continuously recording (~ hourly) pressure transducers in a variety of habitats; particularly surrounding wetland, estuarine, and marine habitats.	H	$$$$$	$$$$$	Excludes other groundwater sampling (near SET sites and NETN vernal pools) that is already planned. It is unclear what sample sizes would be sufficient to understand groundwater dynamics.
E6	Landsape Dynamics and Water Chemistry NCBN: Landscape Change and Estuarine Nitrogen Loading NETN: Land Cover / Ecosystem Cover	Altered habitat Altered water quality	No monitoring initiated; NCBN piloted in 2003	% Natural Vegetation-Nitrogen Inputs, % Impervious Surface-Nitrogen Inputs, %Agriculture-Nitrogen Inputs, % Turf-Nitrogen Inputs, %Wastewater-Nitrogen Inputs, Total Nitrogen Inputs to Estuary	GIS analysis, ten year interval, based on landscape metrics (roads, septic, census data, etc…), using Valiella (1997) model.	H	$$$	$$	Cost assumes one park per year, on 10-year rotation.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
NS2	Shallow Sea	Altered community composition, species survival and reproduction	No monitoring initiated	Benthic habitat mapping, benthic community composition	Acoustic Survey, CEMCS Classification scheme, grab samples. Initial inventory to determine status. Repeat schedule not determined.	VH	$$$$	$$$	Rotate through parks on multi-year cycle (perhaps 5 years). Recommended by Oviatt.
E7	Water Chemistry NCRN and NETN: Water Chemistry	Altered water quality Ocean acidification	No monitoring initiated	Estuarine total dissolved inorganic carbon (DIC), alkalinity, and partial pressure CO_2	Grab samples analyzed in a lab.	H	$$$$	$$$$	Recognized importance, and will hopefully be addressed by partner agencies.
E8	Toxics	Altered community composition, species survival and reproduction	No monitoring initiated	Presence and extent of harmful algal blooms	Acquire and report existing data.	M	$$	$$	There may not be a regionally consistent data source.
E9	Invertebrates and Plants NCBN and NETN: Exotic Plants, Exotic Animals NCRN: Invasive / Exotic Plants	Altered community composition, species survival and reproduction	No monitoring initiated	Invasive species – Early Detection	Boat-based surveys for key invasive plants and animals	M	$$$	$$$	

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

Appendix 5. Nearshore ocean conceptual model and table of predicted effects of climate change as well as currently monitored and potential indicators for monitoring

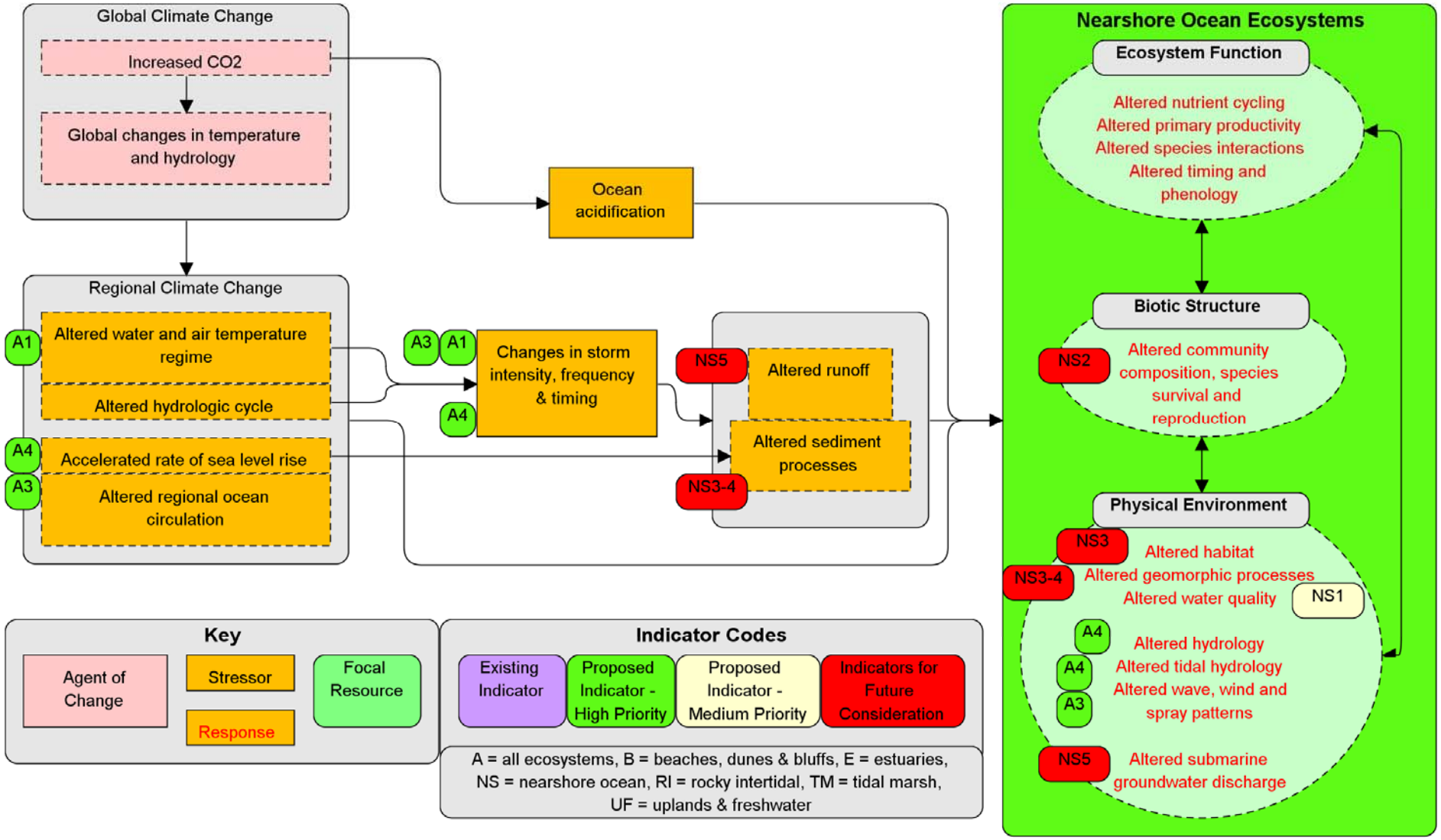

Table NS1. High and medium priority indicators for additional monitoring of nearshore ocean ecosystems

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A1	Weather and Climate NCBN and NCRN: Weather NETN: Climate	Altered water and air temperature regime Changes in snow and ice cover; note that this is not a factor in the nearshore model Changes in storm intensity, frequency & timing	NETN – 3, NETN has begun developing procedures and a database. Available data is generally 1950 and later.	Precipitation (annual totals, seasonal totals, event totals and variability, "flashiness") Snow depth (annual totals, seasonal totals, event totals and variability) Relative humidity (annual average, seasonal / monthly average and variability) Wind speed (annual average, seasonal and monthly average and variability, storm event max and average) Air temperature (annual average, seasonal and monthly average and variability)	Acquire and analyze daily weather summaries from weather stations in or near each park.	VH	$$$$	$$$	Weather and climate data will support all field monitoring activities; costs reflect time for ALL NETN / NCRN / NCBN parks

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A3	Marine Hydrology and Water Chemistry NCBN: Marine Hydrography	Altered regional ocean circulation Altered wave, wind and spray patterns Changes in storm intensity, frequency & timing	No monitoring initiated	Ocean current, wave characteristics, tide range, and water quality parameters	Acquire and analyze data from existing networks, e.g. buoys, CODAR-Seasondes, and AUV sensors.	H	$$	$$	USACE data may be available for ASIS and FIIS (Courtney Schupp). GoMOOS has buoy data available for Gulf of Maine.
A4	Marine Hydrology and Water Chemistry NCBN: Marine Hydrography	Accelerated rate of sea level rise Altered hydrology Altered tidal hydrology Changes in storm intensity, frequency & timing	No monitoring initiated	Water surface elevation, tide range, water quality parameters	Acquire and analyze data from existing NOAA tide gages. Consider installing "whiffle-ball" wave impact gages at field sites	VH	$$	$$	Harvest existing data; there may be gaps for some parks. Cost to install one new long-term tide gage: $80-100K; cost for maintaining it is $30K/year
NS1	Water Chemistry NCRN and NETN: Water Chemistry	Altered water quality	No monitoring initiated	Dissolved oxygen, Water temperature, Salinity, pH, Chlorophyll a	Various methods implemented by multiple agencies; harvest existing data sources.	VH	$$$	$$	Analyze existing data. Recommended by Oviatt and Cross.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

Table NS2. Other potential indicators for nearshore ocean monitoring

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
NS2	Shallow Sea	Altered community composition, species survival and reproduction	No monitoring initiated	Benthic habitat mapping, benthic community composition	Acoustic Survey, CEMCS Classification scheme, grab samples. Initial inventory to determine status. Repeat schedule not determined.	VH	$$$$	$$$	Rotate through parks on multi-year cycle (perhaps 5 years). Recommended by Oviatt.
NS3	Marine Features and Processes NCBN: Marine Hydrography and Offshore Topography	Altered geomorphic processes Altered habitat Altered sediment processes	No monitoring initiated	Nearshore Topography / Bathymetry; bottom configuration, vectors of displacement, volume of surficial sand supply	Boat Based Survey, AUV, Interferometric side-scan or multibeam, pressure sensors, single-beam fathometer. Baseline Inventory needed and should include shallow nearshore waters.	VH	$$$$$	$$$$	Rotate through parks on multi-year cycle (perhaps 5 years). Recommended by Oviatt.
NS4	Marine Features and Processes NCBN: Marine Hydrography	Altered geomorphic processes Altered sediment processes	No monitoring initiated	Marine sediment characteristics—composition and physical characteristics	Grab Samples and lab analysis	H	$$$	$$	
NS5	Marine Features and Processes NCBN: Marine Hydrography	Altered runoff Altered submarine groundwater discharge	No monitoring initiated	Groundwater discharge into marine waters	Infrared photography taken from low flying aircraft	M	$$$$$	$$$$	Recommended by Oviatt.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

Appendix 6. Rocky intertidal habitat conceptual model and table of predicted effects of climate change as well as currently monitored and potential indicators for monitoring

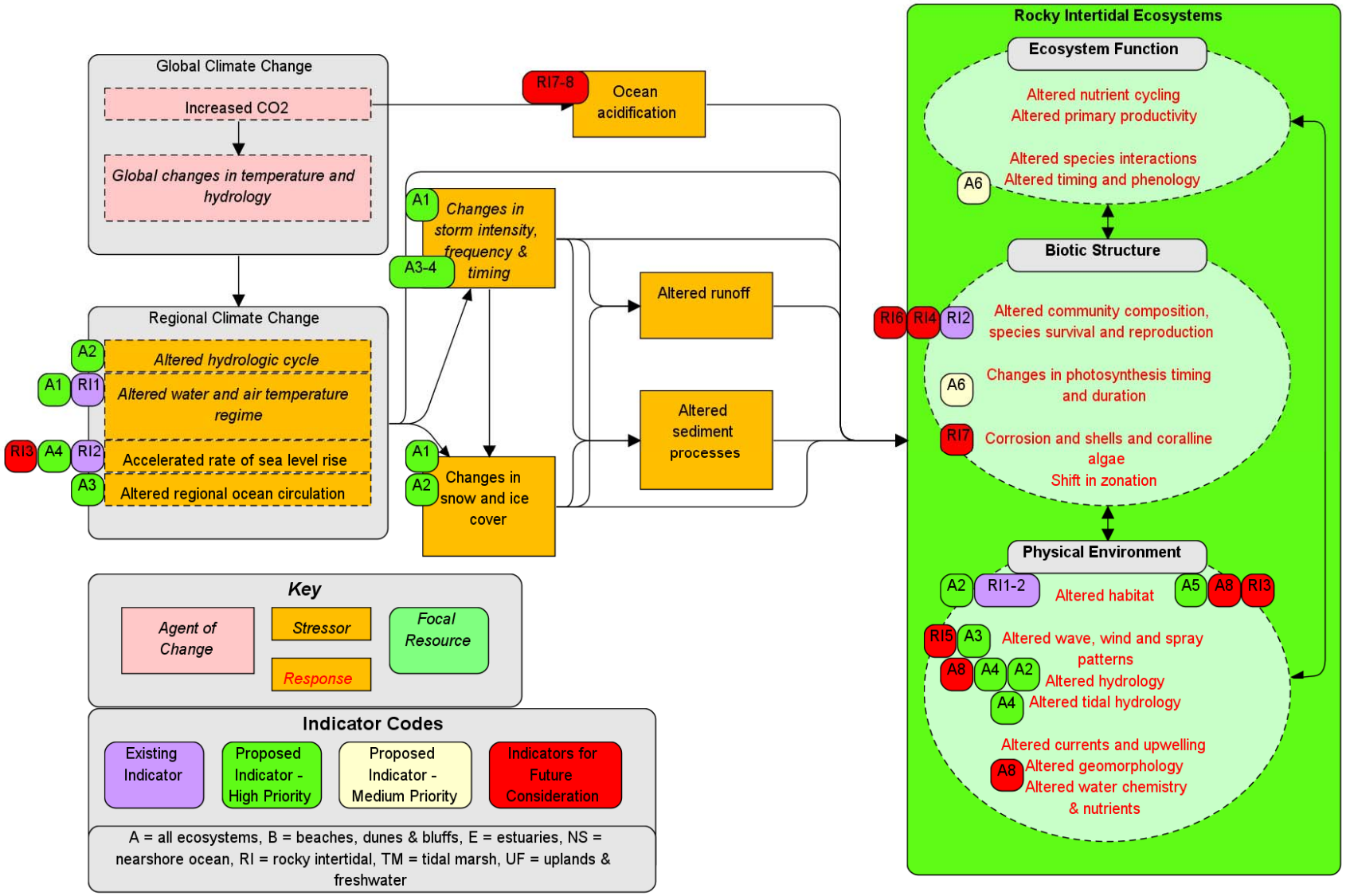

Table RI1. Currently monitored indicators for rocky intertidal ecosystems

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
RI1	Weather and Climate and Marine Hydrology NCBN: Weather and Marine Hydrography NCRN: Weather and Water Chemistry NETN: Climate and Water Chemistry	Altered habitat Altered water and air temperature regime	NETN – 2, since 2008	Air temperature during low tide Water temperature during high tide	"Tidbit" temperature sensors deployed in lower intertidal, three per index monitoring site, recording hourly. There are 3 index sites (BOHA) and 4 index sites (ACAD), downloaded once per year.	M or H (depending on correlation with buoy data)	N/A	N/A	
RI2	Rocky Shores NETN: Rocky Intertidal Community	Accelerated rate of sea level rise Altered community composition, species survival and reproduction Altered habitat	NETN – 2, since 2008	Annual barnacle recruitment, presence and abundance of sea stars and urchins, presence and abundance of motile invertebrates (snails), cover of key species (mussels, barnacles, *Fucus*, *Ascophyllum*), shift in zonation	Plot or transect sampling, 3 to 5 per metric, at 3 index sites (BOHA) and 4 index sites (ACAD), sampled once per year.	VH	N/A	N/A	

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

Table RI2. High and medium priority potential indicators for rocky intertidal ecosystems monitoring

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A1	Weather and Climate NCBN and NCRN: Weather NETN: Climate	Altered water and air temperature regime Changes in snow and ice cover Changes in storm intensity, frequency & timing	NETN – 3, NETN has begun developing procedures and a database. Available data is generally 1950 and later.	Precipitation (annual totals, seasonal totals, event totals and variability, "flashiness") Snow depth (annual totals, seasonal totals, event totals and variability) Relative humidity (annual average, seasonal / monthly average and variability) Wind speed (annual average, seasonal and monthly average and variability, storm event max and average) Air temperature (annual average, seasonal and monthly average and variability)	Acquire and analyze daily weather summaries from weather stations in or near each park.	VH	$$$$	$$$	Weather and climate data will support all field monitoring activities; costs reflect time for ALL NETN / NCRN / NCBN parks

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A2	Weather and Climate NCBN and NCRN: Weather NETN: Climate	Altered hydrology Altered habitat Altered hydrologic cycle Changes in snow and ice cover	No monitoring initiated	Snow cover Surface soil moisture Evapotranspiration	Remote sensing; NASA TOPS models and products	H	$$	$	Acquire, manage, and report existing data.
A3	Marine Hydrology and Water Chemistry NCBN: Marine Hydrography	Altered regional ocean circulation Altered wave, wind and spray patterns Changes in storm intensity, frequency & timing	No monitoring initiated	Ocean current, wave characteristics, tide range, and water quality parameters	Acquire and analyze data from existing networks, e.g. buoys, CODAR-Seasondes, and AUV sensors.	H	$$	$$	USACE data may be available for ASIS and FIIS (Courtney Schupp). GoMOOS has buoy data available for Gulf of Maine.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A4	Marine Hydrology and Water Chemistry NCBN: Marine Hydrography	Accelerated rate of sea level rise Altered hydrology Altered tidal hydrology Changes in storm intensity, frequency & timing	No monitoring initiated	Water surface elevation, tide range, water quality parameters	Acquire and analyze data from existing NOAA tide gages. Consider installing "whiffle-ball" wave impact gages at field sites	VH	$$	$$	Harvest existing data; there may be gaps for some parks. Cost to install one new long-term tide gage: $80-100K; cost for maintaining it is $30K/year
A5	Land Cover and Use NCBN: Landscape Change NCRN: Land Cover / Land Use NETN: Land Cover / Ecosystem Cover, Land Use	Altered habitat	No monitoring initiated	Change in vegetation types Change in extent of vegetation	Vegetation mapping and classification or use of NLCD data sets, every 10 years.	H	$$	$$	Analyze existing data; there are existing baseline vegetation maps for each park, and decadal National Land Cover Datasets (NLCD). Hapke recommended this for dune monitoring.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A6	Vascular Plants NETN: Phenology	Altered timing and phenology Changes in photosynthesis timing and duration	No monitoring initiated	Landscape phenology Vegetation indices	Remote sensing; NASA TOPS models and products	H	$$	$$	Acquire, manage, and report existing data.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

Table RI3. Other potential indicators for rocky intertidal ecosystems monitoring

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A8	Groundwater NCRN: Groundwater Dynamics NETN: Water Quantity	Altered geo-Morphology Altered habitat Altered hydrology	NETN – 3	Depth to fresh water from surface, including variability and seasonality Salinity of groundwater	Wells with continuously recording (~ hourly) pressure transducers in a variety of habitats; particularly surrounding wetland, estuarine, and marine habitats.	H	$$$$$	$$$$$	Excludes other groundwater sampling (near SET sites and NETN vernal pools) that is already planned. It is unclear what sample sizes would be sufficient to understand groundwater dynamics.
RI3	Rocky Shores NETN: Rocky Intertidal Community	Accelerated rate of sea level rise Altered habitat	No monitoring initiated	Shift in zonation	Enhanced point-intercept transects, using additional bolts and high accuracy surveying to establish elevation. Sampled at 3 transects at each of 3 index sites (BOHA) and 4 index sites (ACAD), visited annually; surveyed every 10 years	H	$$	$	
RI4	Rocky Shores and Other NCBN: Exotic Animals NETN: Exotic Animals and Rocky Intertidal Community	Altered community composition, species survival and reproduction	No monitoring initiated	Invasive and other species index Understory species cover and diversity	Timed search for invasive and other species not well sampled by the NETN protocol (e.g., crabs, sea cucumbers). Understory sampled using photoquadrats with cover species shifted, or grid sampling. 3 index sites (BOHA) and 4 index sites (ACAD), sampled once per year.	M	$$$	$$	

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
RI5	Marine Hydrology NCBN: Marine Hydrography	Altered wave, wind and spray patterns	No monitoring initiated	Wave force	Consider installing "whiffle-ball" wave impact gages at field sites.	H	$$	$$	Recommended at July 2010 workshop. This method's suitability and repeatability are not clear.
RI6	Rocky Shores NETN: Rocky Intertidal Community	Altered community composition, species survival and reproduction	No monitoring initiated	Annual mussel recruitment	Recruitment to artificial substrates	L	$$$	$$	This approach is not effective. Researchers who have used "tuffy" balls replace them weekly due to the high post-settlement mortality.
RI7	Rocky Shores NETN: Rocky Intertidal Community	Corrosion of shells and coralline algae Ocean acidification	No monitoring initiated	Shell thickness	Measurement of shell thickness of one or more mollusk species	L	$$	$$	Measurement is time consuming, and may be strongly affected by presence of predatory species.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
RI8	Water Chemistry NCRN and NETN: Water Chemistry	Ocean acidification	No monitoring initiated	Ocean acidity	Erosion of plaster blocks over fixed time periods	L	$$$	$	The effects of wave action, temperature and small variations in composition of the plaster could affect the results. This would be more effective as a laboratory study using seawater collected from different locations

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

Appendix 7. Tidal marsh conceptual model and table of predicted effects of climate change as well as currently monitored and potential indicators for monitoring

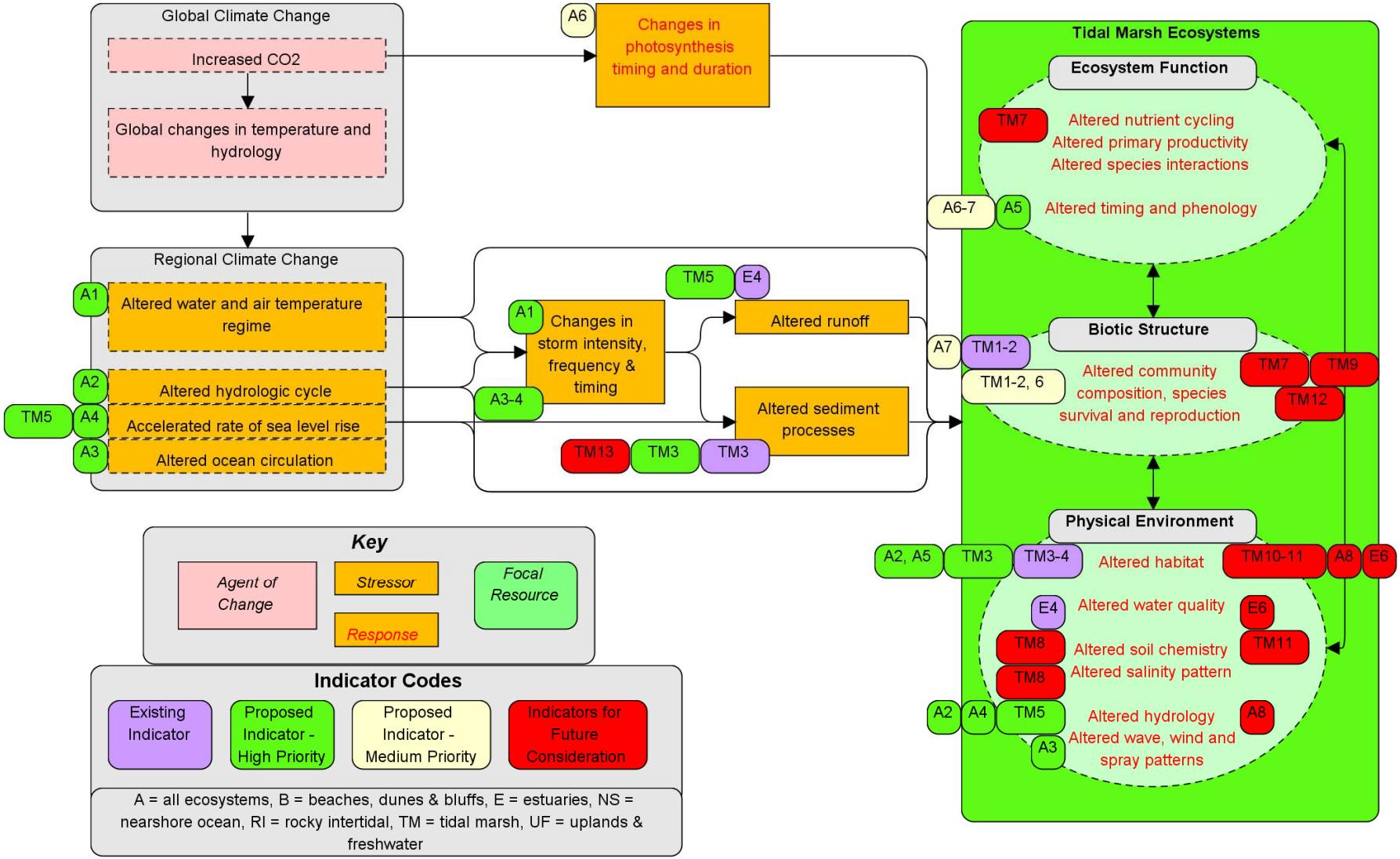

Table TM1. Currently monitored indicators for tidal marshes

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
TM1	Intertidal Marshes NCBN: Salt Marsh Vegetation Community Structure NETN: Salt Marsh Vegetation	Altered community composition, species survival and reproduction	NCBN – 1, since 2008 NETN – 2, since 2009	Tidal marsh vegetation percent cover, vegetation species composition, height of vegetation species of concern, and presence of key invasive plant species	NCBN samples 6-9 8 ha sites biennially per park, with 50 1-m^2 plots per site. Cover is estimated using cover classes. NETN samples index sites at ACAD, BOHA, and SAIR using NCBN methods, sites sampled every 3 years.	VH	N/A	N/A	Part of ongoing monitoring; no new costs unless expanded to NCRN.
TM2	Fishes and Invertebrates NCBN: Salt Marsh Nekton Community Structure NCRN: Fishes NETN: Fishes	Altered community composition, species survival and reproduction	NCBN – 1, since 2008	Tidal marsh nekton species abundance, nekton size structure, and invasive animals. Ancillary data includes pool/creek water temperature, DO, salinity, water depth.	Biennial sampling, with 2 samples per summer during sampling years. 15-21 1-m^2 throw traps (pools and creeks) or 8-10 ditch nets (mosquito ditches), with ancillary data collected at each sampling location using YSI handheld meter.	VH	N/A	N/A	Part of ongoing monitoring; no new costs unless expanded to NCRN and NETN.
TM3	Coastal/ Oceanographic Features and Processes NCBN: Salt Marsh Sediment Elevation NETN: Shoreline Geomorphology	Altered habitat Altered sediment processes	NCBN – 1, start date varies by park	Tidal marsh sediment relative elevation, accretion, erosion, and shallow subsidence	Surface Elevation Tables (SETs), sampled biannually in the spring and fall.	VH	N/A	N/A	NCBN sampling locations need to be evaluated for long-term value, and monitoring needs enhancement to be suitable for sediment budget calculations

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
TM4	Coastal/ Oceanographic Features and Processes	Altered habitat	NCBN – 2, since 2008	Tidal marsh pool, creek, and ditch size category and distribution	GPS and GIS data collected biennially as part of Nekton monitoring	VH	N/A	N/A	Part of ongoing monitoring; no new costs unless expanded to NCRN and NETN.
E4	Water Chemistry and Nutrient Dynamics NCBN: Estuarine Water Chemistry, Quality, and Clarity NCRN: Water Chemistry NETN: Water Chemistry and Estuarine Nutrient Enrichment	Altered runoff Altered water quality	NCBN – 1, start date varies NETN – 3	Water Chemistry-Dissolved oxygen, Water temperature, Salinity Water Quality-Chlorophyll a Water Clarity-PAR, Turbidity	Synoptic spatial sampling via boat surveys, and continuous sampling at index sites using YSI sonde and lab analysis. Sample biennially during a 1 month summer index period.	VH	N/A	N/A	For tidal marshes, sampling in estuaries is collocated and provides relevant data. Peterson and Sturgis recommended adding pH, but this parameter was excluded during protocol development. They also recommended sampling water column nitrogen levels, but this cannot be done cost-effectively.

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[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

Table TM2. High and medium priority indicators for additional monitoring of tidal marsh

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
TM3	Coastal/ Oceanographic Features and Processes NCBN: Salt Marsh Sediment Elevation NETN: Shoreline Geomorphology	Altered habitat Altered sediment processes	NCBN – 1, start date varies by park	Tidal marsh sediment relative elevation, accretion, erosion, and shallow subsidence Tidal marsh capital and sediment budget	Surface Elevation Table (SETs) read biannually (spring and fall); data is part of information needed for calculating tidal marsh capital and sediment budget.	VH	$$$$$	$$$$$	Expand monitoring to additional parks. Analyze several indicators to calculate marsh capital. Evaluate existing SET locations and change if needed.
TM5	Groundwater Dynamics and Surface Water Dynamics NCRN: Groundwater Level NCBN: Salt Marsh Sediment Elevation NETN: Shoreline Geomorphology	Accelerated rate of sea level rise Altered hydrology Altered runoff	No monitoring initiated	Tidal marsh tidal range Tidal marsh frequency of inundation	Groundwater wells with pressure transducers (e.g., Aquatrolls), recording continuously or only in the summer; data is part of information needed for calculating tidal marsh capital and sediment budget.	VH	$$$$$	$$	Suggested by Suzanne Paton and Kenny Reposa.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A1	Weather and Climate NCBN and NCRN: Weather NETN: Climate	Altered water and air temperature regime Changes in snow and ice cover; note that this factor is not in the tidal marsh model Changes in storm intensity, frequency & timing	NETN – 3, NETN has begun developing procedures and a database. Available data is generally 1950 and later.	Precipitation (annual totals, seasonal totals, event totals and variability, "flashiness") Snow depth (annual totals, seasonal totals, event totals and variability) Relative humidity (annual average, seasonal / monthly average and variability) Wind speed (annual average, seasonal and monthly average and variability, storm event max and average) Air temperature (annual average, seasonal and monthly average and variability)	Acquire and analyze daily weather summaries from weather stations in or near each park.	VH	$$$$	$$$	Weather and climate data will support all field monitoring activities; costs reflect time for ALL NETN / NCRN / NCBN parks

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[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A2	Weather and Climate NCBN and NCRN: Weather NETN: Climate	Altered hydrology Altered habitat Altered hydrologic cycle Changes in snow and ice cover; note that this factor is not in the tidal marsh model	No monitoring initiated	Snow cover Surface soil moisture Evapotranspiration	Remote sensing; NASA TOPS models and products	H	$$	$	Acquire, manage, and report existing data.
A3	Marine Hydrology and Water Chemistry NCBN: Marine Hydrography	Altered ocean circulation Altered wave, wind and spray patterns Changes in storm intensity, frequency & timing	No monitoring initiated	Ocean current, wave characteristics, tide range, and water quality parameters	Acquire and analyze data from existing networks, e.g. buoys, CODAR-Seasondes, and AUV sensors.	H	$$	$$	USACE data may be available for ASIS and FIIS (Courtney Schupp). GoMOOS has buoy data available for Gulf of Maine.

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[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A4	Marine Hydrology and Water Chemistry NCBN: Marine Hydrography	Accelerated rate of sea level rise Altered hydrology Altered tidal hydrology Changes in storm intensity, frequency & timing	No monitoring initiated	Water surface elevation, tide range, water quality parameters Wave force	Acquire and analyze data from existing NOAA tide gages. Consider installing "whiffle-ball" wave impact gages at field sites	VH	$$	$$	Harvest existing data; there may be gaps for some parks. Cost to install one new long-term tide gage: $80-100K; cost for maintaining it is $30K/year
A5	Land Cover and Use NCBN: Landscape Change NCRN: Land Cover / Land Use NETN: Land Cover / Ecosystem Cover, Land Use	Altered habitat	No monitoring initiated	Change in vegetation types Change in extent of vegetation	Vegetation mapping and classification or use of NLCD data sets, every 10 years.	H	$$	$$	Analyze existing data; there are existing baseline vegetation maps for each park, and decadal National Land Cover Datasets (NLCD). Hapke recommended this for dune monitoring.

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[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A6	Vascular Plants NETN: Phenology	Altered timing and phenology Changes in photosynthesis timing and duration	No monitoring initiated	Landscape phenology Vegetation indices	Remote sensing; NASA TOPS models and products	H	$$	$$	Acquire, manage, and report existing data.
TM1	Intertidal Marshes NCBN: Salt Marsh Vegetation Community Structure NETN: Salt Marsh Vegetation	Altered community composition, species survival and reproduction	NCBN – 1, since 2008 NETN – 2, since 2009	Tidal marsh vegetation percent cover, vegetation species composition, height of vegetation species of concern, and presence of key invasive plant species	NCBN samples 6-9 8 ha sites biennially per park, with 50 1-m^2 plots per site. Cover is estimated using cover classes. NETN samples index sites at ACAD, BOHA, and SAIR using NCBN methods, sites sampled every 3 years.	VH	$$$	$$$	Existing NCBN and NETN project; expansion to include NCRN.
TM2	Fishes and Invertebrates NCBN: Salt Marsh Nekton Community Structure NCRN: Fishes	Altered community composition, species survival and reproduction	NCBN -1, since 2008	Tidal marsh nekton species abundance, nekton size structure, and invasive animals. Ancillary data includes pool/creek water temperature, DO, salinity, water depth.	Biennial sampling, with 2 samples per summer during sampling years. 15-21 1-m^2 throw traps (pools and creeks) or 8-10 ditch nets (mosquito ditches), with ancillary data collected at each sampling location using YSI handheld meter.	VH	$$$	$$$	Existing NCBN project; expansion to include NCRN and NETN.

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[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
TM6	Birds NCBN: Marsh Birds NCRN: Landbirds NETN: Breeding Birds	Altered community composition, species survival and reproduction	No monitoring initiated	Species composition and relative abundance	Annual point count surveys incorporating call-back protocol for secretive species.	VH	$$$$	$$$$	Carol Trocki is developing protocol in FY2011. Recommended by Suzanne Paton.
A7	Amphibians and Birds NCBN: Anurans, Marsh Birds NCRN: Amphibians, Landbirds NETN: Phenology, Breeding Birds, Amphibians and Reptiles	Altered community composition, species survival and reproduction Altered timing and phenology	NETN – 3	Breeding bird phenology Amphibian phenology	Automated recorders at index locations, with automated recognition of index species. NETN and USGS are currently developing methods.	VH	$$$$	$$$	Costs will vary depending on the number of index sites and the final data analysis costs. There is a Brown University student currently studying *Spartina* phenology

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[2] Priority: VH = very high; H = high; M = medium; L = low
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Table TM3. Other potential indicators for tidal marsh

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A8	Groundwater NCRN: Groundwater Dynamics NETN: Water Quantity	Altered geo-morphology; note that this factor is not in the tidal marsh model Altered habitat Altered hydrology	NETN – 3	Depth to fresh water from surface, including variability and seasonality Salinity of groundwater	Wells with continuously recording (~ hourly) pressure transducers in a variety of habitats; particularly surrounding wetland, estuarine, and marine habitats.	H	$$$$$	$$$$$	Excludes other groundwater sampling (near SET sites and NETN vernal pools) that is already planned. It is unclear what sample sizes would be sufficient to understand groundwater dynamics.
E6	Landsape Dynamics and Water Chemistry NCBN: Landscape Change and Estuarine Nitrogen Loading NETN: Land Cover / Ecosystem Cover	Altered habitat Altered water quality	No monitoring initiated; NCBN piloted in 2003	% Natural Vegetation-Nitrogen Inputs, % Impervious Surface-Nitrogen Inputs, %Agriculture-Nitrogen Inputs, % Turf-Nitrogen Inputs, %Wastewater-Nitrogen Inputs, Total Nitrogen Inputs to Estuary	GIS analysis, ten year interval, based on landscape metrics (roads, septic, census data, etc…), using Valiella (1997) model.	H	$$$	$$	Cost assumes one park per year, on 10-year rotation.

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[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
TM7	Intertidal Marshes NCBN: Salt Marsh Vegetation Community Structure NETN: Wetland Vegetation	Altered primary productivity Altered community composition, species survival, and reproduction	No monitoring initiated	Below ground biomass	Sample roots and rhizomes by taking soil cores and sieving (roots and rhizomes held on a 1 mm sieve); sample every 5 years or so.	H	$$$	$$	EPA is testing a new method: CT imaging method to monitor roots, rhizomes,and peat that might make monitoring belowground structure easier and more affordable. Suggested by Cathy Wigand.
TM8	Soil Function and Dynamics	Altered salinity pattern Altered soil chemistry	No monitoring initiated	Salinity of soil pore water	Pore water samples, sampling frequency not determined.	VH	$$$	$$	Integrate into salt marsh vegetation and nekton protocols
TM9	Introduced Vegetation and Other NCBN and NETN: Exotic Plants, Exotic Animals NCRN: Invasive / Exotic Plants, Forest Insect Pests	Altered community composition, species survival and reproduction	No monitoring initiated	Tidal marsh invasive species early detection	Surveillance monitoring of priority invasive plants and animals; methods and sampling design not determined.	H	$$$	$$	Recommended by participants in July 2010 meeting.

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[2] Priority: VH = very high; H = high; M = medium; L = low
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#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
TM10	Soil Function and Dynamics	Altered habitat	No monitoring initiated	Tidal marsh soil temperature	Take temperature with soil probe, in conjunction with nekton and vegetation sampling.	H	$$	$	Method probably not repeatable; high natural variability over day and season.
TM11	Soil Function and Dynamics	Altered habitat Altered soil chemistry	No monitoring initiated	Tidal marsh soil percent organic matter and bulk density	Take soil cores, measure volume, dry subsamples, weigh, measure loss on ignition. Sampling frequency not determined.	H	$$$	$$$	Suggested by Cathy Wigand.
TM12	Invertebrates	Altered community composition, species survival and reproduction	No monitoring initiated	Fiddler crabs, especially *Sesarma* crabs	Index based on numbers of crab burrows; sampling frequency not determined.	M	$$$	$$	Suggested by Stephen Smith.
TM13	Coastal/ Oceanographic Features and Processes NCBN: Estuarine Sediment Chemistry	Altered sediment processes	No monitoring initiated	Sediment processes	Methods and sampling not yet determined.	M	$$$$$	$$$$$	Recommended by July 2010 workshop participants.

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Appendix 8. Freshwater and coastal uplands conceptual model and table of predicted effects of climate change as well as currently monitored and potential indicators for monitoring

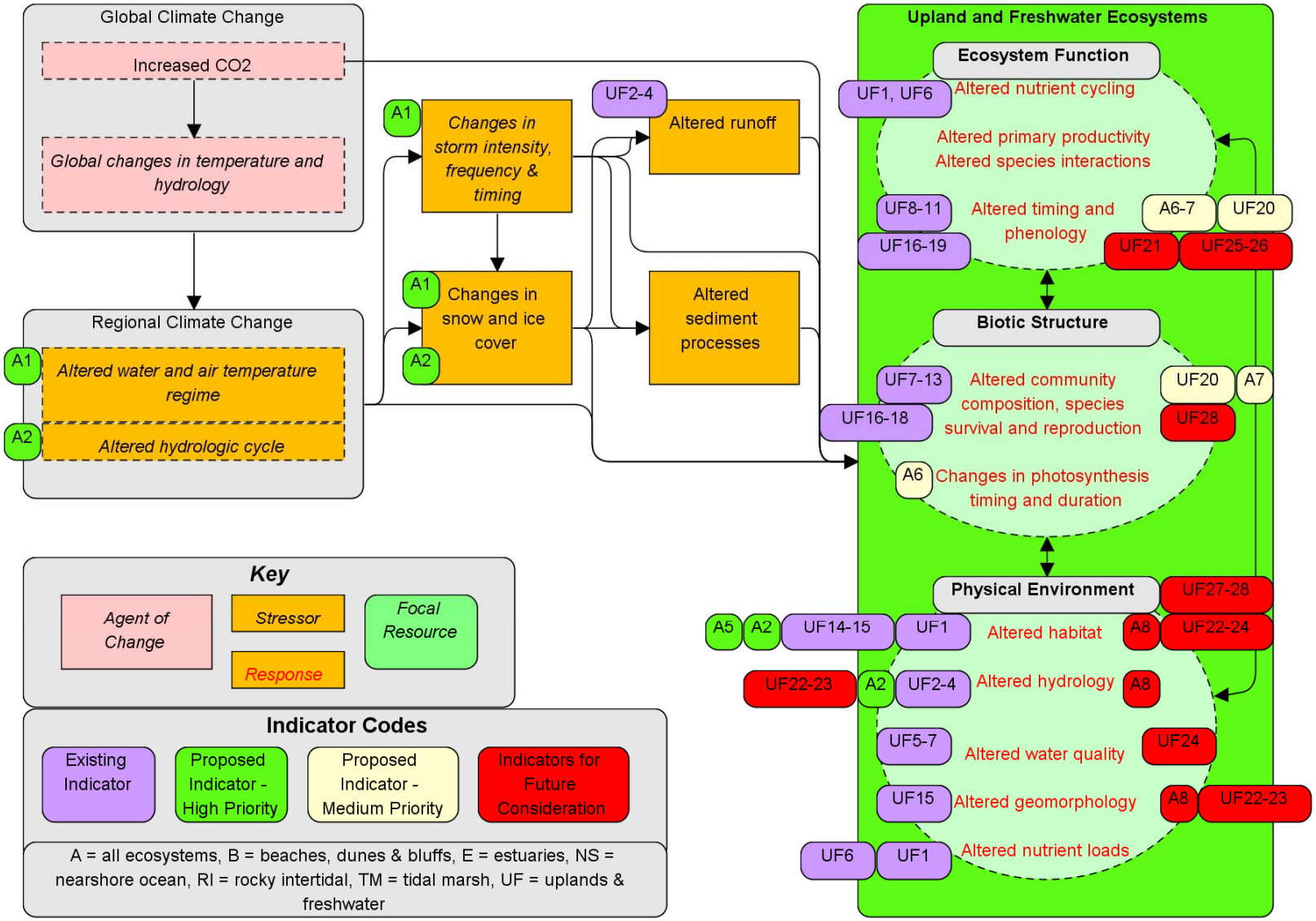

Table UF1. Currently monitored indicators for uplands and freshwater

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
UF1	Soil Function and Dynamics NCRN: Forest Soil NETN: Forest Soil Condition	Altered habitat Altered nutrient cycling Altered nutrient loads	NCRN – 1, since 2007 NETN – 1, since 2006	NCRN & NETN: Forest soil Ca:Al, C:N, exchangeable cations, LOI NCRN: Forest soil filtration, compaction aggregation	NCRN: Randomly sampled forest plots once every 8 yrs. Variety of samples in forest plots. NETN: Randomly located forest and woodland plots sampled every 4 years. Three cores or 10 cm quadrats per plot, composited by layer or depth.	M	N/A	N/A	Part of ongoing monitoring; no new costs unless expanded to NCBN.
UF2	Surface Water Dynamics NCRN: Surface Water Dynamics NETN: Water Quantity	Altered hydrology Altered runoff	NCRN – 1, since 2005 NETN – 1, since 2006	Stream flow	Synoptic sampling with flow meter Monthly sampling of most streams at fixed and representative location. NCRN samples year-round, NETN samples May through October.	H	N/A	N/A	Part of ongoing monitoring; no new costs unless expanded to NCBN.
UF3	Surface Water Dynamics NCRN: Surface Water Dynamics NETN: Water Quantity	Altered hydrology Altered runoff	NCRN – 1, since 2005 NETN – 1, since 2006	Stream flow	Continuous gage; there are 18 continuous flow gages in or near NCRN (16) and NETN (2) parks	VH	N/A	N/A	Part of ongoing monitoring; no new costs unless expanded to NCBN

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#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
UF4	Surface Water Dynamics NCRN: Surface Water Dynamics NETN: Water Quantity	Altered hydrology Altered runoff	NETN – 1, since 2006	Lake and pond level	Weekly to monthly monitoring of major water bodies. Record water height relative to reference point	H	N/A	N/A	Part of ongoing monitoring; no new costs unless expanded to NCBN and NCRN.
UF5	Water Chemistry NCRN and NETN: Water Quality	Altered water quality	NCRN – 1, since 2005 NETN – 1, since 2006	Streams in NCRN and streams, ponds, and lakes in NETN. Record conductivity, pH, DO, and temperature (plus salinity in NCRN)	Monthly sampling of most sites at fixed and representative location. Sampling with sonde, including vertical profiles of lakes and ponds NCRN samples year-round, NETN samples May through October.	H	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN.
UF6	Nutrient Dynamics NCRN and NETN: Water Quality	Altered nutrient cycling Altered nutrient loads Altered water quality	NCRN – 1, since 2005 NETN – 1, since 2006	NCRN: Stream ANC, nitrogen, phosphorus NETN: Stream, pond, and lake alkalinity / ANC, nitrogen, phosphorus, color, chlorophyll a	Field collection and lab analysis. NCRN samples monthly, and NETN takes two samples per year (spring and summer) for most streams, ponds, and lakes at fixed and representative location; chlorophyll a only at ACAD lakes.	H	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN.

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#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
UF7	Aquatic Macro-invertebrates and Algae NCRN and NETN: Stream Macro-invertebrates	Altered community composition, species survival and reproduction Altered water quality	NCRN – 1, since 2005 NETN – 1, since 2006	Stream macroinvertebrate species abundance and community composition	Standard taxonomic identification and analysis. NCRN samples 36 stream sites (6 per year on 6 year panel). NETN has several index sites at ACAD; collect sample from bags of rocks using Maine protocol.	M	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and within NETN.
UF8	Amphibians NCBN: Anurans NCRN: Amphibians NETN: Phenology, Amphibians and Reptiles	Altered community composition, species survival and reproduction Altered timing and phenology	NCRN – 1, since 2005	Amphibian phenology	Acoustic monitoring. NCRN uses the USGS ARMI protocol at index sites.	VH	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and NETN.
UF9	Amphibians NCBN: Anurans NCRN: Amphibians NETN: Phenology, Amphibians and Reptiles	Altered community composition, species survival and reproduction Altered timing and phenology	NCRN – 1, since 2005	Amphibian phenology	Egg mass surveys at index vernal pools	M	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and NETN.

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#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
UF10	Birds NCRN: Landbirds NETN: Phenology, Breeding Birds	Altered community composition, species survival and reproduction Altered timing and phenology	NCRN – 1, since 2007 NETN – 1, since 2006	Breeding landbird community composition and abundance	10-minute point counts. NETN has one to three visits per year at systematically placed forest and grassland sites (random start at ACAD); NCRN has twice yearly sampling of randomly located forest points.	H	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN.
UF11	Birds NCBN: Marsh Birds NCRN: Landbirds NETN: Phenology, Breeding Birds	Altered community composition, species survival and reproduction Altered timing and phenology	NETN – 1, since 2008	Breeding coastal bird community composition and abundance	Annual census of coastal bird species at BOHA	H	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and NCRN.
UF12	Microbes, Invertebrates, and Plants NCBN and NETN: Exotic Plants, Exotic Animals NCRN: Invasive / Exotic Plants, Forest Insect Pests	Altered community composition, species survival and reproduction	NETN – 1, since 2010	Invasive species early detection	Surveillance monitoring of priority invasive plants and pests, via haphazard sampling by volunteers and staff	M	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and NCRN.

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[2] Priority: VH = very high; H = high; M = medium; L = low
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#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
UF13	Microbes, Invertebrates, and Plants NCBN and NETN: Exotic Plants, Exotic Animals NCRN: Invasive / Exotic Plants, Forest Insect Pests	Altered community composition, species survival and reproduction	NCBN – 1, since 2008 NCRN and NETN – 1, since 2006	Invasive species presence and abundance on fixed plots	Detections at randomly located forest monitoring plots. Plots are sampled every four years.	H	N/A	N/A	Part of planned monitoring; no new costs.
UF14	Land Cover and Use NCBN: Landscape Change NCRN: Land Cover / Land Use NETN: Land Cover / Ecosystem Cover, Land Use	Altered habitat	NCRN – 1, in progress	Change in land cover type	GIS analysis of remotely sensed data at 5 to 10 year intervals.	H	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and NETN.

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[2] Priority: VH = very high; H = high; M = medium; L = low
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#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
UF15	Permanent Rivers/Streams/ Creeks NCRN: Physical Habitat Index and Water Quality NETN: Water Quality	Altered habitat Altered geo-morphology	NCRN – 1, since 2005 NETN – 1, since 2009	Stream physical habitat index Stream geomorphology assessment	NCRN uses the Maryland Biological Stream Sampling methods, also some assessments made during visits to streams for chemistry, at 36 sites (6 sites per year on a 6-year rotating panel). NETN conducts an annual assessment of water monitoring sites using EPA methods.	L	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN.
UF16	Amphibians NCBN: Anurans NCRN: Amphibians NETN: Phenology, Amphibians and Reptiles	Altered community composition, species survival and reproduction Altered timing and phenology	NETN – 3, since 2010	Amphibian phenology	Acoustic monitoring; automated recorders at index sites followed by automated detection of indicator species.	VH	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and NCRN.
UF17	Amphibians NCBN: Anurans NCRN: Amphibians NETN: Phenology, Amphibians and Reptiles	Altered community composition, species survival and reproduction Altered timing and phenology	NETN – 3, since 2008	Amphibian phenology	Cover board surveys of arrays on index forested sites.	L	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and NCRN.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
UF18	Birds NCRN: Landbirds NETN: Phenology, Breeding Birds	Altered community composition, species survival and reproduction Altered timing and phenology;	NETN – 3, since 2010	Breeding landbird phenology	Acoustic monitoring; automated recorders at index sites followed by automated detection of indicator species.	VH	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and NCRN.
UF19	Vascular Plants NETN: Phenology	Altered timing and phenology	NETN – 3, since 2010	Individual plant phenology	Periodic observations of phenophases of specific individuals, using USA-NPN methods.	VH	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and NCRN.

[1] Monitoring Status: Network + status (1 = Protocol Implemented; 2 = Protocol Piloted; 3 = Protocol In Development)
[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

Table UF2. High and medium priority potential indicators for uplands and freshwater monitoring

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A1	Weather and Climate NCBN and NCRN: Weather NETN: Climate	Altered water and air temperature regime Changes in snow and ice cover Changes in storm intensity, frequency & timing	NETN – 3, NETN has begun developing procedures and a database. Available data is generally 1950 and later.	Precipitation (annual totals, seasonal totals, event totals and variability, "flashiness") Snow depth (annual totals, seasonal totals, event totals and variability) Relative humidity (annual average, seasonal / monthly average and variability) Wind speed (annual average, seasonal and monthly average and variability, storm event max and average) Air temperature (annual average, seasonal and monthly average and variability)	Acquire and analyze daily weather summaries from weather stations in or near each park.	VH	$$$$	$$$	Weather and climate data will support all field monitoring activities; costs reflect time for ALL NETN / NCRN / NCBN parks

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[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A2	Weather and Climate NCBN and NCRN: Weather NETN: Climate	Altered hydrology Altered habitat Altered hydrologic cycle Changes in snow and ice cover	No monitoring initiated	Snow cover Surface soil moisture Evapotranspiration	Remote sensing; NASA TOPS models and products	H	$$	$	Acquire, manage, and report existing data.
A5	Land Cover and Use NCBN: Landscape Change NCRN: Land Cover / Land Use NETN: Land Cover / Ecosystem Cover, Land Use	Altered habitat	No monitoring initiated	Change in vegetation types Change in extent of vegetation	Vegetation mapping and classification or use of NLCD data sets, every 10 years.	H	$$	$$	Analyze existing data; there are existing baseline vegetation maps for each park, and decadal National Land Cover Datasets (NLCD). Hapke recommended this for dune monitoring.
A6	Vascular Plants NETN: Phenology	Altered timing and phenology Changes in photosynthesis timing and duration	No monitoring initiated	Landscape phenology Vegetation indices	Remote sensing; NASA TOPS models and products	H	$$	$$	Acquire, manage, and report existing data.

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[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
UF20	Birds NCBN: Marsh Birds NCRN: Landbirds NETN: Phenology, Breeding Birds	Altered community composition, species survival and reproduction Altered timing and phenology	No monitoring initiated	Breeding bird phenology	e-Bird data, including first arrival, departure, and seasonal and annual community composition. Analysis of volunteer-contributed data for specific locations	VH	$$$	$$	Costs reflect acquiring e-Bird data for appropriate areas (parks), managing the data, and reporting.
A7	Amphibians and Birds NCBN: Anurans, Marsh Birds NCRN: Amphibians, Landbirds NETN: Phenology, Breeding Birds, Amphibians and Reptiles	Altered community composition, species survival and reproduction Altered timing and phenology	No monitoring initiated	Breeding bird phenology Amphibian phenology	Automated recorders at index locations, with automated recognition of index species. NETN and USGS are currently developing methods.	VH	$$$$	$$$	Costs will vary depending on the number of index sites and the final data analysis costs.

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Table UF3. Other potential indicators for uplands and freshwater monitoring

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
A8	Groundwater NCRN: Groundwater Dynamics NETN: Water Quantity	Altered geo-morphology Altered habitat Altered hydrology	NETN – 3	Depth to fresh water from surface, including variability and seasonality Salinity of groundwater	Wells with continuously recording (~ hourly) pressure transducers in a variety of habitats; particularly surrounding wetland, estuarine, and marine habitats.	H	$$$$$	$$$$$	Excludes other groundwater sampling (near SET sites and NETN vernal pools) that is already planned. It is unclear what sample sizes would be sufficient to understand groundwater dynamics.
UF21	Birds and Mammals NCBN: Marsh Birds NCRN: Landbirds NETN: Phenology	Altered timing and phenology	NETN – 3	Migratory bird and bat phenology	Acoustic monitoring, mist net stations, and radar conducted concurrently at index sites during fall migration.	H	$$$$$	$$$$$	Excellent partnership opportunity with FWS. Protocol development and pilot work initiated in 2010. Ongoing costs could vary widely depending on number of sites and methods used.

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[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
UF22	Surface Water Dynamics NCRN: Groundwater Dynamics NETN: Water Quantity	Altered geo-morphology Altered habitat Altered hydrology	NETN – 3	Freshwater wetland water level	Data logger in reference well; continuous logging in index wetlands.	H	N/A	N/A	Part of planned monitoring; no new costs unless expanded t NCBN and NCRN.
UF23	Surface Water Dynamics NCRN: Surface Water Dynamics NETN: Water Quantity	Altered geo-morphology Altered habitat Altered hydrology	NETN – 3	Vernal pool water level	Data logger in reference well; continuous logging in reference pools.	H	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and NCRN.
UF24	Water Chemistry NCRN and NETN: Water Quality	Altered habitat Altered water quality	NETN – 3	Wetland and vernal pool temperature	Data logger in reference well; continuous logging at index sites	H	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and NCRN.
UF25	Vascular Plants NETN: Phenology	Altered timing and phenology	NETN – 3	Individual plant phenology	Photo monitoring; time lapse photo observations of index plants.	VH	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and NCRN.
UF26	Vascular Plants NETN: Phenology	Altered timing and phenology	NETN – 3	Landscape phenology	Photo monitoring using PhenoCam methods – observations of forest stands.	VH	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and NCRN.

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[2] Priority: VH = very high; H = high; M = medium; L = low
[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

#	Monitoring Framework Category Vital Signs	Associated Factor from Model	Monitoring Status[1]	Metrics (Indicators)	Methods & Sampling	Priority for Monitoring CC[2]	Setup Cost[3]	Run Cost[3]	Notes
UF27	Permanent FW Marshes/Pools NETN: Wetland Vegetation	Altered habitat	No monitoring initiated	Freshwater wetland extent	Field mapping or remote sensing of freshwater wetland extent	M	$$$$$	$$$$	Costs depend on methods used and availability of existing methods and data.
UF28	Permanent FW Marshes/Pools NETN: Wetland Vegetation	Altered community composition, species survival and reproduction Altered habitat	NETN – 3	Wetland plant presence Wetland plant abundance Wetland quality	EPA NWCA intensive methods at 10 index sites at ACAD; USA-RAM methods (part of the NWCA) at random wetlands; 5 years sample rotation.	H	N/A	N/A	Part of planned monitoring; no new costs unless expanded to NCBN and NCRN.

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[3] Cost (annual cost for new work): $ = less than $3K, $$ = $3-10K, $$$ = $11-25K, $$$$ = $26-50K, $$$$$ = over $50K

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