Report for the Department of the Interior

Recommendations for assessing the effects of the DOI Hurricane Sandy Mitigation and Resilience Program on ecological system and infrastructure resilience in the Northeast coastal region

The Department of the Interior Metrics Expert Group

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Executive Summary

Through the Disaster Relief Appropriations Act of 2013 (P.L. 113-2), Congress appropriated $829 million ($786.7 after sequestration) for the Department of the Interior (DOI) and its bureaus to address impacts from Hurricane Sandy. Of these funds, $360 million ($341.9 million after sequestration) was allocated to DOI for projects that promote improvements in community and ecological system resilience. DOI distributed these funds internally among DOI bureaus, and externally through a competitive grant process administered by the National Fish and Wildlife Foundation. Assessing results of these projects will be useful for developing best practices, determining gaps in knowledge, sustaining or enhancing improvements in coastal resilience created by project activity, and communicating the effective use of tax dollars to the American people. Therefore, DOI is initiating a resilience assessment that will (a) establish criteria for determining project success and (b) establish metrics to quantify changes in resilience resulting from project actions at multiple scales.

The DOI convened a team of physical science, ecosystem science, and socio-economic experts (the metrics expert group: MEG) to recommend performance metrics for measuring changes in resilience resulting from the DOI-sponsored projects. To accomplish this task, the MEG reviewed the various DOI project proposals, participated in several conference calls, and held one face-to-face meeting in Albany, NY. A sub-team drafted the recommendations report, which was then reviewed and commented on by the various MEG members and submitted for a DOI-sponsored peer review, with reviewer recommendations from the Office of Science and Technology Policy (OSTP). This report represents the first product of the MEG, and establishes suites of recommended performance metrics for ecological systems and data management. A second product that integrates ecological and socio-economic metrics will be completed in the coming months, following an evaluation of socio-economic metrics.

Scoping the Problem

Improving the resilience of the northeastern coastline of the United States is a massive and complex task. Developing accurate and sensitive performance metrics for detecting and assessing change in resilience is equally complex. Similarly, determining the relationships between changes in ecological system resilience and changes in community resilience is a complicated and under-examined area of research; however, it is integral to ensuring projects are strengthening desired societal outcomes.

The DOI projects were designed to directly improve coastal resilience, to increase knowledge critical to understanding and supporting management decisions, or to collect data required for assessing current status and trends in coastal processes. Challenges in measuring the success of those projects include:

- Many of these projects are already underway, therefore rapid development of a data collection strategy is crucial.
- Improved data management is needed to enhance data sharing data and synthesis.
- Early detection of resilience change is needed to inform management decisions.
- A natural coast is constantly changing, so change must be part of a resilience strategy.
- Determining thresholds of resilience to cumulative stressors (e.g. sea-level rise, development) will be required to make sound decisions on the management of ecological systems and communities.

Developing Metrics and Building the Resilience Assessment Strategy

To address these challenges, the MEG adopted several principles for metrics development. These can be summarized as follows:

- Resilience of specific natural and artificial coastal features is dependent on different sets of controlling factors and stressors; thus assessing resilience requires performance metrics that address those differences.
- Measurements of baseline conditions before project actions influence resilience are necessary to detect a resilience change.
- Detecting change in the resilience of coastal ecological systems and communities within the short timeframe needed to inform urgent resource management decisions will require utilizing existing and new data across a range of science disciplines and scales. No single agency or institution has the capacity to meet this challenge alone.
- The limited timeframe for implementing the Hurricane Sandy projects (three years) is not likely to allow for robust measurements of changes in resilience, so additional post-project monitoring will be needed to accurately assess changes to resilience attributable to these projects.
- The resilience of ecological systems and socio-economic systems are not independent, and thus require methods to integrate metrics associated with each system.
- Establishing a set of performance metrics for effective data management and sharing across existing and new data collection programs is critical for a successful resilience assessment.

To apply these principles, the MEG identified natural and artificial coastal features most affected by Hurricane Sandy along the Northeast coast (e.g., marshes, beaches, estuaries) and recommended metrics that would indicate resilience change in those features. This report provides a brief definition of each coastal feature, a range of project benefits associated with that coastal feature, performance metrics to assess success at achieving the project objectives, and select standard protocols for those metrics. The coastal features and metrics identified in this document are not comprehensive. They are intended to address the suite of DOI-funded projects implemented through the Disaster Relief Appropriations Act, and were developed to yield information sufficient for assessing the utility of DOI project results in enhancing coastal resilience to future large storms such as Hurricane Sandy.

The list of recommended performance metrics is quite extensive, given the diversity of coastal features and objectives, so a subset of recommended core metrics is also provided. Finally, the MEG recommended establishing operational frameworks of data collection and synthesis that link information across projects for describing regional scale changes in resilience, and across ecological and socio-economic systems to inform local to regional management decisions.

Next Steps

To expedite the assessment of the DOI coastal resilience projects, the MEG supported the following efforts currently underway:

- Continued optimization of the core ecological performance metrics for specific coastal features and projects.
- Rapid application of the core metrics to establish project baseline conditions.

- Development and testing of socio-economic performance metrics to measure changes in the valuation and application of ecosystem services, and associated effects of those services on ecological systems and coastal communities.
- Integration of the socio-economic and ecological performance metrics, and application of those integrated metrics where advantageous to the assessment process.
- Further integration of the DOI resilience assessment efforts with other Federal and non-Federal resilience efforts.

In addition, the MEG also recommended new efforts to ensure the assessment is successful:

- Ensure measurements continue after project completion for a period sufficient to detect changes resulting from the project actions.
- Compilation of project metadata into a GIS database, and establishing common standards for data sharing.
- Integrate existing data and alternative analysis methods that expedite detection or prediction of resilience change.
- Completion of the coastal resilience assessment for DOI-funded projects, and application of the assessment results to further improve resilience in the Northeast coast.

These recommendations are intended to provide the DOI with a strategy for conducting an effective assessment of coastal resilience change enabled by the DOI-sponsored projects, and a road-map to best practices for improving coastal resilience into the future.

Contents

Introduction

Through the Disaster Relief Appropriations Act of 2013 (P.L. 113-2), Congress appropriated $829 million ($786.7 after sequestration) for the Department of the Interior (DOI) and its bureaus to address impacts from Hurricane Sandy. Of these funds, $360 million ($341.9 million after sequestration) was allocated to DOI for projects that promote improvements in community and ecological system resilience. DOI distributed these funds internally among DOI bureaus, and externally through a competitive grant process administered by the National Fish and Wildlife Foundation (NFWF). Over 140 projects within the northeastern U.S. (Figure 1) were funded with common goals to: (a) increase the resilience and capacity of coastal habitat, communities, and infrastructure (Federal, State, Local, and commercial) to withstand storms (i.e., reduce the risk and amount of damage caused by such storms) and (b) improve the ability of our coastal communities and ecological systems to maintain critical natural resource functions that are valuable to stakeholders. These projects encompass a wide array of activities such as: community planning, storm monitoring networks, storm water management, dam removal, culvert replacement, and marsh restoration, as well as a variety of science projects designed to reduce uncertainty and inform management decisions.

Assessing results of these projects, individually or as a group, will be useful for developing best practices, determining gaps in knowledge, sustaining or enhancing improvements in coastal resilience created by project activity, and communicating the effective use of tax dollars to the American people. As such, DOI is initiating a resilience assessment that will establish criteria for determining project success and establish measurements for quantifying changes in resilience resulting from the specific, DOI-project actions.

The DOI convened a team of physical science, ecosystem science, and socio-economic experts (the Metrics Expert Group: MEG) in July, 2014 to recommend performance metrics for these DOI-sponsored resilience projects and to garner advice on conducting the resilience assessment (see Appendix A for MEG members). This report is the first product of this effort. It includes recommended ecological performance metrics for an assessment of regional changes in resilience along the Northeast coast and how these projects may increase resilience of ecological systems since Hurricane Sandy. A sub-team drafted the recommendations report, which was then reviewed and commented on by the various MEG members and submitted for a DOI-sponsored peer review, with reviewer recommendations from the Office of Science and Technology Policy (OSTP). The metrics selected and reported on in this document are not intended to be comprehensive for assessing resilience of all ecological and social systems in the coastal region. However, establishing baseline and post-project measurements of the core metrics recommended in this report should yield information sufficient for assessing the utility of DOI project results in enhancing coastal resilience to future large storms such as Hurricane Sandy.

This report also recommends potential strategies for completing a comprehensive resilience assessment of these projects. The MEG recognizes the importance of the inherent connections among socio-economic, engineered, and natural systems. To be truly meaningful, any thorough assessment of coastal resilience should integrate performance metrics that measure the resilience of all of these systems. The MEG recommends that the resilience assessment strategy include: (a) setting common performance metrics, (b) implementing baseline and trend monitoring and modeling as needed to apply those performance metrics, and (c) synthesizing the monitoring and modeling results in a comprehensive assessment of resilience change in the coastal Northeast.

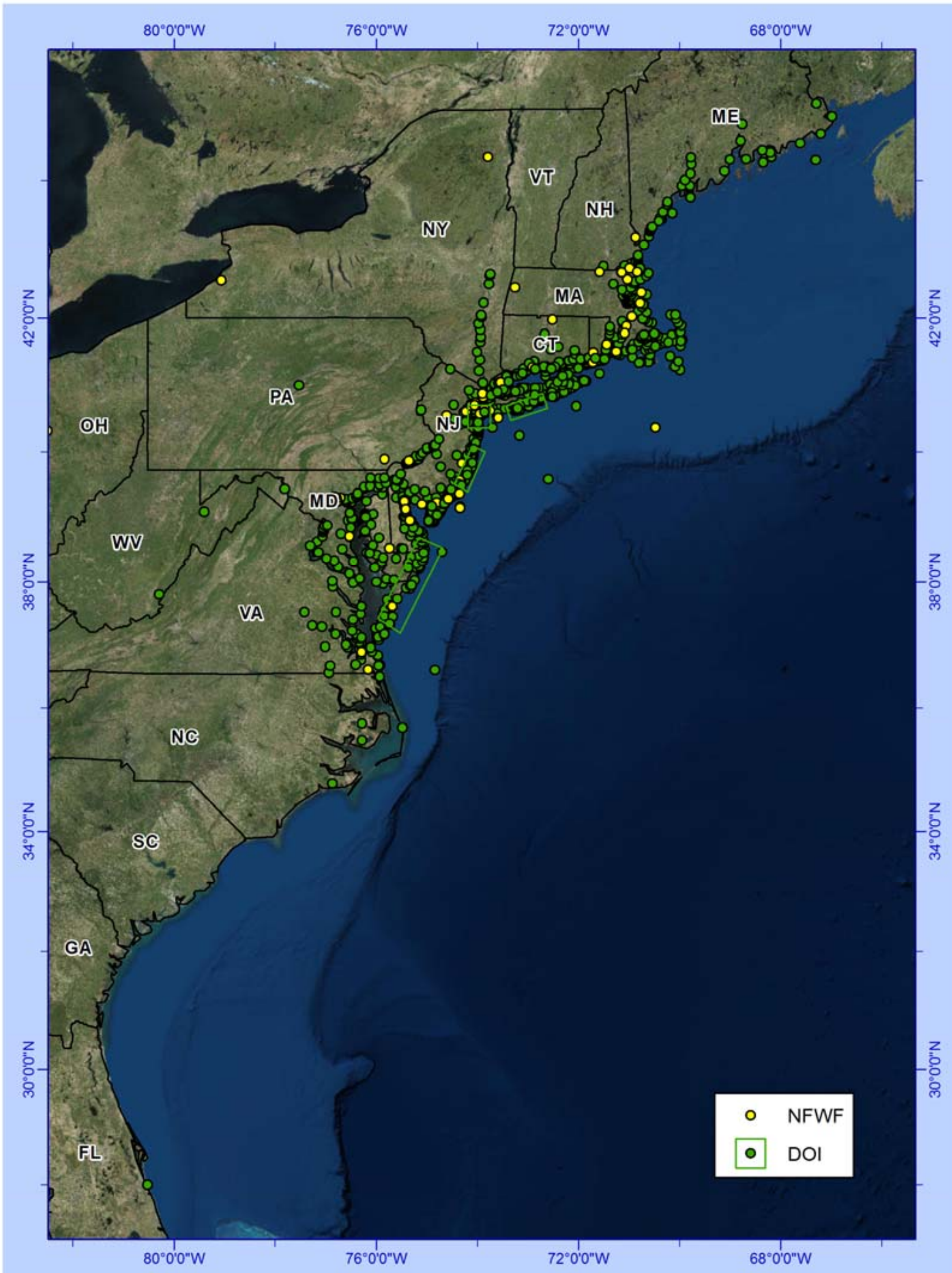

Figure 1: Map of the Eastern United States coastal region for the DOI Hurricane Sandy projects overseen by U.S. Geological Survey (USGS), National Park Service (NPS),U.S. Fish and Wildlife Service (USFWS) (green dots and rectangles), and NFWF (yellow dots).

While preparing this report, the MEG realized that additional time and resources were needed to (a) fully develop performance metrics for socio-economic systems, and (b) establish baseline conditions and trends in those conditions so that a change in resilience can be detected. Filling gaps in scientific and socio-economic data or understanding is therefore a critical early step in the DOI resilience assessment process. DOI is working with the NFWF, OSTP Coastal Green Infrastructure and Ecosystem Services Task Force (CGIES), the DOI Bureaus, and non-DOI partners to define and develop measurements for core socio-economic metrics of resilience, and anticipates that the results of these additional efforts will be available in the coming months. The White House Natural and Green Infrastructure Committee (NGI), formerly the Natural and Nature-based Features Committee (NNBF), is also working on developing ecological and socio-economic metrics. DOI Bureaus will ensure that the efforts of these groups are integrated, with the goal of generating a common set of core metrics for application within and beyond the DOI projects.

Improving our data management and sharing practices is also seen by the MEG as critical to an effective assessment of coastal resilience, so metrics of data management improvement are provided in this report. All four of the above-mentioned assessment components (ecological performance metrics, socio-economic performance metrics, data management metrics, and filling of baseline data and information gaps) will be established before implementing the resilience assessment.

Purpose of the DOI Resilience Assessment

The primary goals of the DOI assessment of coastal resilience projects are to (a) document how projects have changed the resilience of their immediate footprint since Hurricane Sandy, and the regional resilience of the coastal feature(s) the project addressed; (b) identify what project adjustments or new projects would help to improve mitigation or restoration actions, and fill the gaps in knowledge or planning needed to assess and sustain resilience across the region; and, (c) determine whether the projects have improved our ability to maintain the critical functions (e.g., surge and wave attenuation by marshes; fish and wildlife habitat provided by marshes, beaches and dunes; landscapes that divert floodwaters away from infrastructure) necessary for coastal communities and natural resources to prepare for, absorb, recover from, and adapt to coastal threats in the future.

Definitions of resilience and ecological system:

To maintain consistency among resilience projects across the Federal sector, the DOI MEG adopted the recent definition of resilience established by White House Executive Order 13653 (Section 8c). The Order defines **resilience** as *"the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions"* (http://www.whitehouse.gov/the-press-office/2013/11/01/executive-order-preparing-united-states-impacts-climate-change).

This definition acknowledges that not all changes to ecosystems are disruptions, so resilience can be defined by a system's capacity to respond to any change in environmental stress without a fundamental change in ecological system or infrastructure state. This resilience could be achieved in a specific location, or by moving (e.g., marsh migration), or by evolving in a manner that doesn't diminish the functionality of the system. The DOI definition of increased resilience also includes improved scientific or socio-economic understanding, since that knowledge can be used to improve mitigation or restoration practices, decrease uncertainty in models, and support more resilient management decisions. In particular, this definition includes science projects that enhance our understanding of both coastal processes and resilience thresholds (i.e., the stress conditions that, if surpassed, result in a state change in the ecological system or community in question; e.g., surge levels that overtop and erode a marsh). Knowing these vulnerability thresholds, and the likelihood that they will be surpassed by future disturbances, could determine if a restoration effort will be cost effective.

The definition of **ecological system** (i.e., ecosystem) used in this report incorporates humans and all other living organisms, their physical environment, and the biologic, geologic, and biogeochemical processes that together control the form and function of a particular unit of landscape or water body. Therefore, references to ecological systems in this report include both the biological and physical components of the coastal feature being assessed, and the biogeochemical and physical processes that affect those features from within or outside of the coastal feature. Ideally, performance metrics of resilience should allow us to distinguish between changes in ecological system function that are natural in a dynamic coast, and those that are altered by human-induced factors such as climate change, development, and resource use. This differentiation will help determine what mitigation or restoration actions are sustainable and in balance with the natural cycles of coastal environments.

Hurricane Sandy altered ecological systems along the northeastern coast, but the response of an ecological system must also be viewed as the result of numerous, cumulative evolutionary changes that occurred well before Hurricane Sandy. The combined disruptions caused by commerce, infrastructure development, sea level rise, and more frequent or stronger storms are the focus of this report. For this reason, the MEG recommends that the assessment of changes in resilience include determination of resilience thresholds (levels of stress above which a change in state occurs); and, anticipated changes in stressors like sea level rise, increased storm surge, increased flood frequency and peak flows as well as socio-economic changes like increased development, conflicting resource use, nonpoint source pollution, and shifting demographics. Therefore, performance metrics of resilience and resilience thresholds should be sensitive to shifts in these changing stress factors to enable early detection of resilience change.

Scoping the Problem

Improving the resilience of the northeastern coastline of the United States is a massive and complex task. Developing accurate and sensitive performance metrics for detecting and assessing change in resilience is equally complex. Similarly, determining the relationships between changes in resilience of ecological systems and changes in community resilience is a complicated and under-examined area of research; however, it is integral to ensuring projects are strengthening desired societal outcomes.

Stressors such as sea level rise, storm surge, other climate-driven stressors of coastal systems and accelerating development pressures in the coastal region are affecting much, if not all, of the northeastern coast. Sea level has been rising in this region for approximately 20,000 years, sometimes at rates higher than we are seeing today (W. Schwab, USGS, written communication 2014), and is likely to continue into the future. Average global sea level has raised an average of 2 mm/year between 1971 and 2010, and is expected to continue to rise at even higher rates (IPCC, 2014). Major storms have perennially impacted the coast, and coastal ecological systems are adapted to a natural disturbance regime. Thus, in many ways, attempting to preserve existing features is actually a disturbance to the natural system. Some current coastal infrastructure and resource uses are already unsustainable, so trade-offs will need to be considered and resilience requirements for critical functions that sustain coastal ecological systems, communities, and commerce will need to be defined. Determining thresholds of resilience to cumulative stressors beyond which ecological system change or infrastructure damage occurs would help managers make sound decisions on the management of ecological systems and communities. In some locations, managed retreat of infrastructure may be required, both as an economic reality and to protect unique coastal ecological systems that depend on the dynamic nature of the coastal zone.

Providing answers within the resilience assessment timeframe

The DOI projects were designed to directly improve coastal resilience, to increase knowledge critical to understanding and supporting management decisions, or to collect data required for assessing current status and trends in coastal processes. Many of these projects are already underway, and either are developing or implementing performance monitoring concurrent with the preparation of this report. Development of a data collection strategy for assessing changes in resilience associated with these DOI projects is therefore crucial to ensuring that the DOI projects measure performance using standard metrics and protocols that can be integrated successfully in the resilience assessment. Application of measurement methods that enable early detection of resilience change is necessary to inform management decisions in the near term.

For the proposed DOI assessment to inform decisions on coastal resilience, supplementing the results of the new projects with available data from longer-term, existing projects and programs is critical. These data sets also provide historical context for rates of environmental and ecological system change and ecological system recovery that will be useful for assessing the contributions of the DOI projects towards coastal resilience. Establishing a set of performance metrics for effective data management and sharing across existing and new data collection programs is, therefore, also critical for a successful resilience assessment. To facilitate the use of existing data, projects should establish data management and sharing protocols that are inter-operable with other programs that hold existing data, and projects should use established measurement protocols in new data collection wherever feasible.

There are also investigative techniques that, if applied, could improve the chances of detecting early changes in resilience. The application of coastal vulnerability indices based on decades of previous monitoring and modeling of ecological system dynamics will be effective in some locations for forecasting future processes and conditions (USGS, 2014). Decreased uncertainty in models being developed or enhanced by the DOI projects could provide indications of the likely outcomes of projects if those models were to be applied directly to the DOI-funded resilience projects. Several demonstration projects that test different best practices for enhancing resilience may yield measureable results in the short term, but could also be modeled to indicate the likely resilience outcomes there and in other similar locations. Nesting the projects within existing long-term datasets in the region surrounding the project footprint, and collecting new measurements consistent with the long-term datasets at the project site can improve our capacity to separate natural trends from project-induced changes. Care should be taken to quantify uncertainties while linking existing and new data for this integrated analysis to be useful. Past performance of similar projects, preferably within a physical and biological setting similar to the new project, could be used as an indicator of what to expect for outcomes given parallel practices and conditions.

Space-for-time substitution studies, which compare similar physical and biological settings that are receiving different levels of stress across a region, provide a surrogate for extended monitoring at a specific location and may provide the quickest determination of best approaches to improving coastal resilience. For example, results from existing projects on living shorelines in other regions with different climate, storm intensity, or biogeochemical conditions could be compared to northeastern studies to define a range of possible outcomes, thus allowing us to estimate how new locations might perform in the future if living shorelines are applied there.

Strategies for addressing longer-term change

Some benefits of natural features, in comparison to built/grey infrastructure (like seawalls), are that natural infrastructure (a) can be self-maintaining (Gedan et al., 2011), (b) have the potential over varied timeframes to self-repair to former or at least functional natural morphology after major damaging events (Ferrario et al., 2014), and (c) may have the ability adapt to long-term changes (Sutton-Grier et al., 2015). For example, oyster reefs have recently been shown to increase in height at least as quickly as predicted sea level rise through 2100 (Rodriguez et al., 2014). However, restoring an ecological system takes time, as natural processes respond to our human interventions. For example, an ecological system needs time to establish and grow healthy vegetation, so restored ecological systems grow stronger with time but often need years and even decades to reach maturity (Craft et al., 1999; 2002; 2003). In addition, protecting existing natural ecological systems by reducing stressors is usually a more cost effective strategy than restoration when possible (Elliott et al., 2007). We are still learning how best to protect and restore ecological systems, so monitoring these types of projects is critical for determining best practices. Knowledge gained within the DOI project footprints could have significant transfer value to natural system applications throughout the region.

The limited timeframe for implementing the Hurricane Sandy projects (three years) is not likely to allow for robust measurements of changes in resilience or determining best practices. Most of these projects will take all of this time to be completed, leaving little if any time for post-project monitoring. Regional indications of changes in coastal resilience will take longer to detect; therefore, more meaningful and accurate assessments will require data collection and analysis beyond the current, project timeframe of three years. Lessons learned from the Hurricane Sandy projects are essential for DOI to plan future coastal resilience improvements, and are dependent on timeframes that allow for natural disturbance recovery rates. To address the time constraints, the MEG recommends that DOI implement the following for a meaningful assessment of changes in resilience:

- Extend the observing period for detecting changes in resilience by extending resilience monitoring beyond the end of the Disaster Relief Recovery Act project period.
- Integrate data collected outside of the Hurricane Sandy projects into the assessment.
- Support development of ways to measure or infer early indications of resilience change, including decreasing uncertainty in models; linking demonstration projects; nesting the projects within existing long-term datasets; collecting new measurements consistent with the long-term datasets; and using space-for-time substitution studies.

Establishing monitoring of core performance metrics for detecting change in resilience at project locations, and incorporating existing data from monitoring programs in similar landscapes or waters, will improve detection of project effects on resilience in the short term, and provide early warning of resilience degradation or approaching stress thresholds in the long term for sustaining the project objectives.

Recommendations for Resilience Performance Metrics

Resilience of specific natural and artificial coastal features (see Table 1 and Appendix C) can be dependent on different sets of controlling factors and stressors, and thus can require different performance metrics to determine if the DOI projects have affected the future resilience of that feature. If we define performance metrics too narrowly, existing measurements of resilience may be difficult to integrate with new measurements to extend data timelines; define those same performance metrics too broadly and we introduce varied methods of measurement that increase noise and uncertainty in the results. A combination of project-specific and common or "core" performance metrics will likely yield the most robust assessment of changes in resilience across the region.

These performance metrics will be used to assess the progress and limitations in meeting project objectives. Additionally, these metrics should be able to measure changes in resilience of the entire Northeast coastal region or specific sub-regions. The key factor in developing such metrics is that they provide quantitative descriptions of specific conditions. Ecological systems and ecosystem services require different measurements to define performance than community resilience factors such as how prepared a community is for hazardous storms. To that end, the MEG concluded that the resilience measurements of ecological systems (e.g., the status and trends of applied technology and infrastructure and the status and trends of ecological systems, natural controlling processes, and ecosystem services), and socio-economic systems (e.g., the status and trends of commerce, regulation, decision systems, and community health and safety) should serve as the broadest groupings of performance metrics to be developed for the resilience assessment. This grouping also allows the DOI to continue development of socio-economic metrics through the collaboration with CGIES.

Effective data management and data sharing capabilities are also important to tracking and communicating the progress or functionality of the resilience projects. Consequently, the MEG developed performance metrics of success for a data management system that will facilitate the resilience assessment, as well as support future resilience data analysis for the Northeast coast.

Sorting the Hurricane Sandy projects

Sorting projects into categories is necessary to generate meaningful performance metrics of how the individual projects have influenced coastal resilience. In this document, we define a **performance metric** as a quantitative measurement or suite of measurements (index) that can be used to detect and assess a change in DOI coastal resilience. We define an **index** as a derived mathematical construct of multiple measurements that serves as an integrated measure of the status and trends of coastal ecological systems, communities, commerce, health, or a range of other factors. **Indicators** are specific aspects of the coastal ecological systems, infrastructure, and communities (e.g., marsh accretion rates, wave reduction by living shorelines, citizens trained in hazard mitigation) that can imply a resilience outcome through their condition or their direction and rate of change. Most, if not all, of the performance metrics identified in this document are indicators.

The proposed categories of performance metrics, (ecological systems, socio-economic systems, and data management systems) do not provide all of the specificity needed to create meaningful performance metrics for detecting changes in resilience for each project. For the ecological and data management systems categories, the MEG created a subset of categories. Scientific research has developed robust and long-tested measurements for detecting differences in the condition and functionality of specific coastal features, so organizing ecological performance metrics around these features is expected to provide the best opportunity for early detection of changes in resilience with the least uncertainty. Therefore, for ecological systems, the MEG identified natural and artificial coastal features most affected by Hurricane Sandy along the Northeast coast (e.g., marshes, beaches, estuaries) as the sub-categories. For data management systems, the MEG used critical elements of data collection, sharing, and archiving (e.g., standards, enterprise networks, communication networks). Specific coastal features and their metrics, and data management categories, are presented in Appendix C.

Establishing ecological system metrics and protocols

After determining which coastal features were best suited to encompass the activities of the DOI-funded projects, the MEG compiled primary objectives and ecosystem services that the projects may address. The MEG then identified an associated suite of potential metrics that could measure success at achieving these objectives and services (see Appendix C1). The MEG further refined the suite of metrics to a set of core metrics. These core performance metrics are to be applied to multiple projects and at the full range of temporal and spatial scales to help detect changes in resilience in one or more coastal features across multiple scales (Table 1). Each DOI project will be assigned to one or more of the coastal features for ecological systems so that: (a) application of similar performance metrics allows quantifiable comparison among project results, and (b) the results of projects within a grouping can be summarized as components of the larger coastal system for integrated assessment of region-wide resilience.

For measurements to be comparable across projects, a set of common, or quantitatively-comparable, protocols also need to be established for the assessment. As mentioned above under providing answers within the resilience assessment timeframe, many projects will need to use existing data to have a sufficient timeline of data to discern natural variation from project-induced change. In those cases, new measurements will need to utilize the same or easily comparable protocols to the ones used in the past. This report provides as set of recommended protocols for many of the performance metrics (Appendix C2). The MEG recognizes that this is a preliminary list of protocols, additional, appropriate protocols will be added as they are identified. Specific metrics and protocols for species-specific objectives were not included because of the sheer number and diversity of species. Projects with objectives that include or are specifically designed to contribute to a species' sustainability should measure species and related habitat responses using protocols that are routinely used and accepted by the larger community of practitioners associated with that species or group of species.

Table 1. Recommended ecological core performance metrics by coastal feature for Department of the Interior Resilience projects funded through the Disaster Relief Recovery Act of 2013.

Natural and Artificial Coastal Features	Primary Objectives and Ecosystem Services	Recommended Core Performance Metrics
Beach System: Beach, Barrier Island, and Dunes (for back bay areas, see Estuaries and Ponds)	<u>Beaches and Dunes:</u> 1) Restore or improve beach habitat to enhance resilience of fish, wildlife, and plants, and their habitats (e.g., spawning, migration stopovers, critical habitats) 2) Restore/improve dune habitat to enhance resilience of coastal infrastructure by reducing flooding extent and attenuating wave energy 3) Improve/sustain beach/barrier island ecological system and community resilience to storm surge events 4) Enhance understanding of natural system dynamics including immediate storm responses, natural recovery from disturbance events, and natural adaptation capacities and tendencies. 5) Improve recreation/aesthetics <u>Breaches:</u> 1) Manage breach occurrences to maximize ecosystem function and reduce risks to built infrastructure, human health, and human safety.	<u>Beaches and Dunes:</u> Biotic • Vegetation cover of dunes pre and post event • Fish and wildlife population/ recruitment/ overwintering/stopover weight/health relative to other mitigating factors (e.g. other threats throughout range: site and species specific) Abiotic • Post-storm volume of sand in the active shoreface • Recovery rates of beach and dunes Structural/Engineering • Beach width, elevation, volume, shoreline position (post-event) • Dune characterization (height, width, length, texture, substrate) <u>Breaches:</u> Biotic • Fish and wildlife population/ recruitment/ overwintering/ stopover weight/health changes relative to other mitigating factors (e.g. other threats throughout its range: site and species specific) Abiotic • Volumes of material in flood and ebb shoals • Water flow and current dynamics • Water quality: temperature, salinity, pH, dissolved oxygen, turbidity, nutrients, contaminants • Water level changes, especially in back bays Structural/Engineering • monitoring of breach morphologic changes

Natural and Artificial Coastal Features	Primary Objectives and Ecosystem Services	Recommended Core Performance Metrics
Nearshore Shallow and Nearshore Deep	1) Restore, improve, or maintain benthic habitat and species diversity 2) Improve water quality by reducing warm-water runoff, nutrient and contaminant rich runoff, and flushing of bays through new breaches 3) Detect changes in sand movement and vegetation, particularly as they relate to storm events by describing and mapping submerged substrate 4) Reduce or control invasive species 5) Attenuate waves by decreasing wave runup and beach/dune erosion 6) Improve resource maps and increase affordability of methods for repeat mapping	Biotic: • Vegetation, e.g., biomass, species, density, extent, health • Pre and post changes in target organism population (e.g., reproductive success) for specific indicator species (e.g., seagrasses, scallops, etc.) • Changes in habitat quantity and quality Abiotic: • Surge, wave height • Sand movement (erosion and deposition, sources and sinks) • Water quality: dissolved oxygen, nutrients, temperature, salinity, algae in runoff and nearshore coastal water • Flushing rates of back bays Structural/Engineering • Substrate morphology (mapping) • Bathymetric mapping
Riverine and Riparian Zone	Remove dams, remove or right-size culverts, and restore riparian areas to: 1) Improve aquatic organism passage and enhance resilience/increase populations (e.g., fish, invertebrates; other vertebrates (e.g. Diamond back terrapin)) 2) Enhance resilience of coastal infrastructure by reducing risk of flooding upland habitats and artificial infrastructure 3) Improve water quality; decrease contamination of rivers and coast 4) Restore/improve sediment transport 5) Restore/improve riparian habitat to enhance resilience of fish, wildlife, and plants, and their habitats (e.g., spawning, migration, critical habitats) 6) Improve recreation/aesthetics	Biotic • Fish migration rates and patterns • Invasive species extent, mobility • Fish assemblage/fish abundance pre and post project • Riparian plant community pre and post • Habitat availability: Stream miles made accessible to aquatic species upstream, pre and post project Abiotic: • River flow and depth • Flooding extent and depth (stormwater retention capacity) • Inundation area (pre and post project) • Sediment composition and contaminants (pre and post project) • Water temperature and salinity Structural/Engineering • Number of barriers removed or remediated

Natural and Artificial Coastal Features	Primary Objectives and Ecosystem Services	Recommended Core Performance Metrics
Marshes and Wetlands	1) Mitigate coastal flooding by restoring or improving marsh hydrology and tidal dynamics 2) Improve water quality and reduce contaminant levels 3) Provide high quality habitat for salt marsh biota 4) Decrease erosion and enhance marsh accretion and resilience to sea level rise 5) Maintain and enhance shoreline integrity; preserve marsh area and distribution to support migration corridors, e.g., maintaining marsh and wetland habitat in flyways 6) Dissipate wave energy from storm surges associated with coastal storms to protect fish and wildlife habitat and human communities 7) Increase infiltration and decrease erosion by reducing impervious surface effects on resilience 8) Use information and modeling to help articulate community risk reduction benefits of marshes and wetlands	Biotic • Salt marsh plant community monitoring (e.g., species composition, percent cover, areal coverage of the high and low marsh community type) • Nekton abundance, species richness Abiotic • Marsh accretion and erosion • Groundwater dynamics • Water quality: salinity, conductivity, temperature, dissolved oxygen, pH Structural/Engineering • Marsh surface elevation change trend - long-term 3+ years and short term
Uplands and Watersheds	Uplands: 1) Restore, improve, or maintain habitat for resilient/healthy fish and wildlife populations 2) Protect uplands for potential marsh migration Watersheds: 1) Sustain natural sediment and nutrient transport 2) Mitigate flood impacts from runoff associated with intense storms, rapid snowmelt, and ice breakup. 3) Establish information and metrics for integrating watershed and coastal management as one system. 4) Protect/restore riparian habitat for fish and wildlife, including those that use adjacent aquatic habitats (see riverine/riparian zone feature above). 5) Improved flooding vulnerability maps	Biotic • Vegetation condition, type, and health • Forest fragmentation and development • Land cover (LIDAR and other imagery)- especially as land use may restrict marsh migration • Riparian and channel habitat measurements (species specific) Abiotic • Inundation frequency • Soil salinity, soil leachate chemistry • Rates of watershed and near-coast erosion (pre and post event) • Water levels, flows, near-coast wave heights • Riparian and channel habitat measurements (species specific)

Natural and Artificial Coastal Features	Primary Objectives and Ecosystem Services	Recommended Core Performance Metrics
	6) Improve understanding of historical change and define disturbance levels that cause system damage	Structural/Engineering • Topography/Slope • Elevation
Maritime Forests and Shrublands	1) Restore, improve, or maintain coastal forest health and areal extent for resilient/healthy fish and wildlife populations 2) Maintain migratory bird habitat in coastal flyways 3) Maintain coastal groundwater sources for drinking water 4) Protect for potential marsh migration	Biotic • Vegetation/wildlife condition, type, and health • Forest fragmentation and development • Land cover (LIDAR and other imagery)- especially as land use may restrict marsh migration Abiotic • Inundation frequency • Soil salinity, soil leachate chemistry • Rates of watershed and near-coast erosion (pre and post event) • water levels, flows, near-coast wave heights Structural/Engineering • Topography/Slope • Elevation
Estuaries and Ponds (including back bay areas)	1) Maintain or improve water quality 2) Restore, improve, or maintain habitat for fish, wildlife, and plants (e.g., spawning and rearing habitat for fish populations) 3) Restore/improve hydrology 4) Improve recreation opportunities/aesthetics 5) Improve understanding and compilation of historical change in physical and biological processes 6) Define and detect change in thresholds of estuarine ecological system and physical resilience to the common coastal stressors (e.g., sea level rise, surge and waves, pollution, climate, development) to help inform decision-making	Biotic • Submerged aquatic vegetation (SAV) (e.g., seagrass), species, density, extent, health (disease/epiphytes) Abiotic • Water depths • Inundation extent, rates, and frequency • Water temperature and salinity

Natural and Artificial Coastal Features	Primary Objectives and Ecosystem Services	Recommended Core Performance Metrics
Built Environment: Grey infrastructure	1) Protect or improve water quality by decreasing runoff of contaminants and nutrients 2) Protect coastal infrastructure by reducing flooding extent and wave energy 3) Decrease duration of flood events by enhancing nearshore drainage to divert floodwaters back to the coast, protecting storm drains from inundation, etc. 4) Improve understanding and compilation of historical change in physical and biological processes 5) Protect key natural resources.	Biotic: • Colonization by mollusks, fouling effects • Fish population data • Invasive species Abiotic • Water depth • Inundation extent, rates, and frequency • Water quality: temperature, salinity, pH, dissolved oxygen, turbidity, nutrients, chlorophyll a; • Area flooded during storm events • Erosion assessment (recommend 5 year)
Green Infrastructure: Living shorelines (key component of several projects, so separated out for easy reference)	1) Stabilize and potentially enhance shoreline integrity (e.g., reduce erosion, promote plant colonization) to protect important natural features 2) Stabilize and potentially enhance shoreline integrity to protect artificial infrastructure (e.g., roads, dikes, buildings) 3) Improve water quality to benefit fish, wildlife, and people 4) Restore, improve, or maintain habitat for fish, wildlife, and plants (e.g., spawning and rearing habitat for fish populations) 5) Enhance health of living shoreline (oysters, sea grasses) populations	Biotic • Oyster length frequency - growth rates, age structure etc. • Oyster coverage • Oyster population • Vegetation cover Abiotic • Wave heights, frequency, direction • Water temperature, salinity Structural/Engineering • Structure resilience to waves (movement, percent intact) • Vertical accretion rates • Shoreline position and topography
Green Infrastructure: Other methods (permeable road surfaces, flood diversion berms, holding ponds, etc.)	1) Protect or improve water quality by decreasing runoff of contaminants and nutrients; 2) Protect coastal infrastructure by reducing flooding extent and wave energy (i.e., buffer storm surge) and decreasing vulnerability to salt-water intrusion from storms and sea level rise 3) Decrease negative effects of flood events.	Examples, actual project metrics will be site and method specific: Biotic • Health of green infrastructure biology pre and post installation • Fish and wildlife population/ recruitment/ overwintering/stopover weight/health relative to other mitigating factors (e.g. other threats throughout range: site and species specific)

Natural and Artificial Coastal Features	Primary Objectives and Ecosystem Services	Recommended Core Performance Metrics
	4) Stabilize and potentially enhance shoreline integrity (e.g., reduce erosion, promote plant colonization) to protect important natural features 5) Restore, improve, or maintain habitat for fish, wildlife, and plants (e.g., spawning and rearing habitat for fish populations) 6) Improve understanding and compilation of historical change in physical and biological processes 7) Determine thresholds for sustaining living shore populations 8) Investigate how various infrastructure approaches affect sediment flows. 9) Determine threshold hardening characteristics for local wave/surge characteristics	Abiotic • Water quality: contaminants; sedimentation (site and method specific) • Storm surge heights, direction, wave heights, frequency, direction Structural/Engineering • Shoreline position and topography

Special consideration of socio-economic performance metrics

There is an intrinsic connection between socio-economic, engineered, and natural systems (Sutton-Grier et al., 2015). Understanding how the human condition will change based on changes in the ecological systems is critical to any assessment aimed at measuring coastal resilience. Performance metrics for detecting change in resilience in ecological systems are similar in many circumstances, but the socio-economic systems need different performance metrics that measure changes in the valuation and application of ecosystem services.

As mentioned in the introduction, the MEG recognizes the need for additional time and resources for identifying and developing applicable socio-economic metrics, so these metrics are not presented here. Many other entities are working on this issue as well. As previously discussed, DOI is working with NFWF, CGIES, the DOI Bureaus, and non-DOI partners to define the core services needed to enhance resilience to climate impacts and developing consistent methods to classify, measure, and value changes in ecosystem services. These methods can then be tested and applied at one or more scales, e.g., community, sub-region, or regional. When completed, socio-economic performance metrics will be integrated with the ecological performance metrics identified in this document, and will be made publicly available.

Project benefits

The primary objectives and ecosystem services provided in the metrics table describe many benefits that could be accrued from the DOI projects, and from the effective measurement of resilience change resulting from project actions. Compilation of resilience benefits provided in documents authored by the ACOE, NOAA, and others generally reflect the benefits that members of the DOI Metrics Expert Group have also recommended (e.g., ACOE, 2013; NOAA 2013; Abt Associates, 2014). When looking at ecological systems, it is important those benefits to society and communities to be understood in the context of dynamic, natural coastal systems with dynamic processes. Consequently, a resilient coastal feature is one that can function within an environment of constant flux. A favored beach for tourism, for example, requires the persistent sources of sand to be sustained, so those sources of sand cannot be removed to give resilience to other valued features. A marsh that has the space to migrate may be more resilient than a marsh that is stationary in a world of rising sea levels. In this latter case, the benefits (i.e., ecosystem services) of the marsh have to, therefore, also migrate with it.

DOI supported several projects through the Sandy supplemental funds that were designed to increase scientific knowledge of natural and disturbed coastal processes. This information is critical for understanding how these coastal systems function and the potential outcomes of management decisions. Engineered solutions to problems like beach replenishment or marsh accretion and erosion may not stand the test of time if the magnitude, direction, or frequency of disturbance pressures change. Improving the understanding and valuation of natural systems, for their own preservation beyond the direct benefits to humans, could lead to more sustainable management practices. Examples of beneficial outcomes of the science projects include model validation and decreases in model uncertainty, determining thresholds of disturbance beyond which recovery potential diminishes, describing natural and disturbance-based trends in physical environments and ecological system health, establishing faster and more reliable early warning of storm dangers, improving methods of observation and interpretation; mapping vulnerability to floods, contaminants, and wave damage, and improving habitat and living conditions for trust resources of the coastal Northeast. This improved understanding, and more refined maps of coastal conditions and features it supports, is critical to establishing coastal management best practices that will survive changes resulting from climate change, development pressure, and the natural progression of coastal features. The clear benefit is that better, more long-lasting decisions will be possible with this new science available to decision-makers. Defining benefits within the context of the DOI Bureau missions, therefore, requires both human and natural system considerations.

Assessing Whole-system Changes in Resilience

The coastal features selected for sorting the DOI projects do not operate as free-standing units. To deliver on lasting strategies for protecting, sustaining, and potentially enhancing coastal resilience, we need to understand and address the complex interactions among ecological, engineered, and socio-economic systems both within each of the major coastal features (e.g., beaches, bays, marshes), in sub-regions where coastal features interact and influence each other (e.g., Jamaica Bay, its watersheds, and adjacent ocean waters), and for the northeastern coast as a whole (e.g., North Carolina to Maine considered as a unit). Some tested measurements are available to assess the complex interactions of biotic and physical components within coastal features as discrete sub-systems (e.g., water, chemistry and energy budgets developed from watershed biogeochemistry research). Less developed are effective measurements for assessing the overall resilience of a place or region resulting from the interactions of natural, engineered, and socio-economic factors, and how that place or region might respond to a range of management decisions.

The MEG recommends interpretive frameworks be established for both linking across spatial scales and ecological and socio-economic conditions. The MEG therefore considered two examples: (1) a multi-scale framework for assessing "whole-system" resilience of the DOI projects, and (2) a matrix approach for linking resilience conditions (ecological and socio-economic) to assess overall resilience of communities as well as identifying areas where additional efforts would improve resilience.

Framework for integrating the nation's environmental monitoring and research networks and programs

Most management decisions regarding coastal resilience are local in extent. However, a regional understanding of resilience, and the knowledge gained from observing recovery from Hurricane Sandy in similar coastal features across a range of regional stress conditions, will be invaluable to local decision-makers, allowing more informed policy at the local, state, and national scale.

Recommended core requirements for multi-disciplinary, multi-scale assessments include:

a) The method of data collection and analysis should be appropriate to the scale at which the data are intended to represent.
b) Models alone are insufficient for scaling up or down from a given dataset—verification data are essential to trust the model output.
c) A multi-scale, integrated data and modeling system is achievable if similar data are collected at each scale being compared, and comparable standards and protocols are used for the collection, analysis, and management of those data.

The National Science and Technology Council (NSTC) Committee on Environmental and Natural Resources (CENR) published a *Framework for Integrating the Nation's Environmental Monitoring and Research Networks and Programs* in 1997 that recommends a method for linking multi-scale datasets and models to address broad regional issues (NSTC, 1997). The method nests intensive data collection research stations, periodic regional surveys and inventories of a suite of core parameters, and remote sensing of key features. It links these across the datasets through modeling to generate information across broad scales of both time and space. This approach could be applied to address specific regional issues along the northeastern coast by linking results from the multiple DOI projects with other research, monitoring, and modeling activities in the region. Initiatives are underway within the Northeast region for compiling such integrated datasets and geographic coverages. The goal of the EPA-sponsored Integrated Sentinel Monitoring Program (ISMP), for example, is to "improve our ability to detect and understand the causes of long-term change in the composition, structure, and function of northeastern U.S. and Canadian maritime coastal ecosystems" (Jeffrey Runge, University of Maine, written communication, September 3, 2014). Coordinating and assimilating these ongoing data integration efforts would be a cost-effective way to build toward regional interpretation of coastal resilience in the Northeast.

Matrix approach for linking ecological and socio-economic conditions

To help determine the expected effect of the DOI projects on the entire integrated coastal system of the Northeast (i.e., the combined resilience of ecological systems and socio-economic considerations), the MEG considered the method developed by the U.S. Army Corps of Engineers (USACE) which applies a matrix approach for linking resilience conditions and capabilities to the stages of an environmental disturbance and post-disturbance recovery (Figure 2; Linkov et al., 2013). The resilience matrix contains a y-axis representing the current environmental status of a system and our capabilities for maintaining that status (engineered, information, management staff and plans, and community support), and an x-axis representing four stages of an event that stresses that system (Figure 2). These four stages are defined as follows:

- Prepare: Management, knowledge development, protection, design, and engineering in anticipation of a stress event
- Absorb: Measure impacts of the event and apply contingency plans as the event progresses
- Recover: Engineered actions or natural processes that allow recovery of functionality in the system, and restoration of ecosystem services
- Adapt: Adjust the overall system to be more resilient in future events, including possible reductions of human influence on the system through managed retreat

This is a decision-support framework. The MEG believes this application may be useful for assessing gaps in the DOI resilience program. Three primary concerns were raised by DOI MEG members regarding the matrix approach. However, each of these concerns can potentially be addressed to enable effective application of the matrix tool. The first concern is the ability of the matrix approach to address changing baseline conditions like sea level, temperature, and storminess. This can be addressed by making the matrix analysis compliant with the MEG definition of resilience, which includes consideration of temporal trends in both the coastal features being assessed and the stressors affecting the equilibrium of those features. The second concern is the capacity to recommend managed retreat as an adaptation option. This can be addressed by including managed retreat as an adaptation that improves the resilience of the system. For example, if the performance metric for the ability of the human community to socially absorb a storm event is inversely correlated with how many people are in the flood plain, managed retreat would lower the number of people in the area and potentially increase the resilience performance metric. Similarly, if the ability of an ecological system to adapt to changing conditions is measured by how much room there is for upslope marsh migration, allowing developed areas to become open spaces would increase that resilience performance metric. The last concern is the potential to quantify qualitative information resulting in a false sense of statistical interpretability. This concern requires consistent and detailed definitions of data standards so that the comparison of project results is not based on ambiguous ratings of qualitative information.

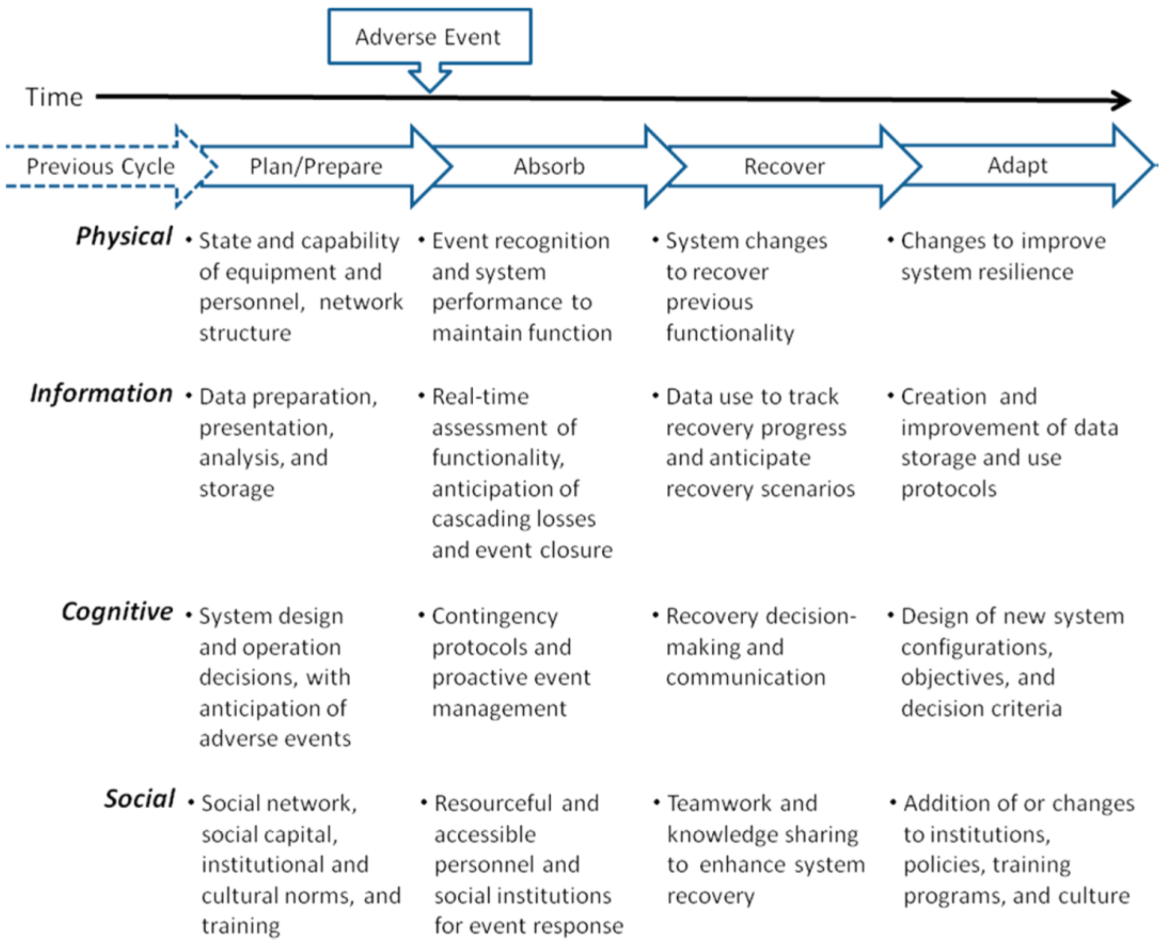

Figure 2: Schematic diagram of a resilience matrix for linking resilience conditions and capabilities to the stages of an environmental disturbance and post-disturbance recovery. This resilience matrix was published by Linkov et al., (2013), "Measurable Resilience for Actionable Policy" in Environmental Science and Technology, and shows descriptions of the types of performance metrics that could be used to determine improvements in system resilience.

The MEG concluded that, if this approach is used, the performance metrics selected should be compiled by natural and artificial coastal features, sub-regions, and regions within this matrix framework, to facilitate: (a) assessing programmatic gaps in resilience improvement or assessment, (b) detecting missing information and data, and (c) integrating project results for a sub-region or regional assessment of resilience improvement. This integrated approach could be applied to whole-system resilience assessments in specific geographic segments of the northeastern coast (e.g., Jamaica Bay and its watershed, Assateague Island) or for clusters of similar coastal features (e.g., marshes, beaches, communities). Aggregating resilience improvements by coastal feature or within geographic coastal segments would allow the assessment to analyze resilience as an integrated system, rather than simply evaluating project-specific resilience improvements (Linkov et al., 2014).

Recommendations for Post-Assessment Monitoring

The MEG recommends the development of a monitoring strategy that continues beyond the completion of the DOI projects. The monitoring should be designed to provide early warning of disturbance events as well as to detect trends in coastal resilience at the range of temporal and spatial scales needed to support management decisions at both the local and regional scales. The network design and protocols should be cost effective, but sufficient to detect changes in resilience if they occur within the monitoring timeframe. The monitoring network is critical for fully assessing changes in resilience since timeframes of 5 to 20 years are likely needed to detect changes in some measures of resilience (Kondolf and Micheli, 1995; Mitsch and Wilson, 1996).

Information Management

The ability to develop and calculate performance metrics that evaluate ecological or societal change, resilience, or success at ecological system remediation and restoration, will require quality source-data from multiple projects implemented by a variety of agencies and organizations. This places data management and availability as high priorities. One of the priorities of the MEG is to ensure the preservation and long-term availability of data products that support and result from the various monitoring, restoration, and modeling efforts utilizing funds from the Disaster Relief Recovery Act. The MEG also recognizes the 2013 Federal 'Open Data Policy' mandates from the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB) that identify data as a valuable national resource and strategic asset that needs to be managed. These policies require Federally funded research to make publications and data available to the public and others in a timely manner at little or no cost, in a usable format, and to ensure that products are discoverable through a data catalog (such as Data.gov).

The MEG recommends that a data management plan be created and implemented that documents the research and data goals, data sources used, data processing activities and provenance, and data products created. Data should be made available using commonly accepted data formats, accompanied by ISO 19115-2 metadata and other documentation as necessary, and supplied with a Digital Object Identifier that can be used both for data citation and to associate the data with research papers and other information products that result from data use and reuse.

The MEG also recommends that agencies and organizations utilize a public data portal or other release mechanism for their project data, and make those data discoverable through a suitable data catalog service. Many data portals have already been created and are available to be leveraged for the DOI resilience assessment (e.g., NOAA Climate.gov 2015; USGS Coastal Change Hazards Portal, 2015; North Atlantic Landscape Conservation Cooperative Conservation Planning Atlas, 2015; Northeast Ocean Data Portal, 2015).

At a minimum, the MEG recommends adopting data standards, including metadata, to facilitate the assessment process and leveraging this work for the future. In addition, all models used in DOI projects should include open access to the input data, source code, and ensuing output, so that others can fully understand the development and application of the model.

Performance metrics for documenting improvements in data management can be found in Appendix C2. The MEG also recommends that DOI:

- Maintain a geo-spatial viewer of the DOI projects, color-coded by a range of metadata, for use in integrated assessments and presentations.
- Develop an inventory of on-going efforts to integrate datasets, and existing repositories for the data from DOI projects, as a critical first step early in the assessment process. This information should be integrated with the geo-spatial viewer above.
- Collaborate with the initiatives that are underway within the region for compiling integrated datasets and geographic coverages (e.g., EPA Sentinel Monitoring Program; the North Atlantic Landscape Conservation Cooperative; the USGS Climate Response Network; NROC Northeast Ocean Data Portal
- Ensure DOI projects that either develop or apply numerical modeling systems of any type provide indefinite access to source code, model documentation, input files, and model output via publication or a public interface.
- Develop performance metrics for measuring changes in data management of all of the systems (natural, engineered, and socio-economic) being assessed.

Next Steps

This report provides a suite of recommendations for completing a meaningful assessment of how DOI-administered projects have affected the resilience of the northeastern coast, and establishes a set of ecological performance metrics for detecting changes in resilience resulting from the project actions. Determining performance metrics of coastal resilience and organizing those performance metrics into a robust assessment is a significant challenge that multiple government, academic, and non-government organization committees outside of DOI are also trying to address concurrently with the MEG effort.

The MEG supports the following efforts currently underway:

- Continued optimization of the core ecological performance metrics for specific coastal features: The current table of core performance metrics represents the best ideas of the MEG and the colleagues the MEG members consulted, and was further refined through a peer review process. A workshop on core performance metrics that drew on our best coastal performance metrics experts nationally further refined the ecological performance metrics.

- Application of the core metrics to establish baseline conditions for the DOI projects. At a minimum, measurement of core performance metrics should be established at a subset of the DOI projects within selected areas of concentrated restoration actions (e.g., Jamaica Bay, Barnegat Bay, Assateague Island), and select core measurements should be established in a distributed regional network to allow a multi-scale assessment of resilience change.

- Development and testing of socio-economic performance metrics to measure changes in the valuation and application of ecosystem services, and associated effects on how the human condition changes based on changes in the ecological systems. Selection of core performance metrics for both immediate (baseline) and future (trends) monitoring of change in key coastal resilience characteristics will be completed following a short research solicitation.
- Integration of the socio-economic and ecological performance metrics.
- Comparison of these core performance metric recommendations to existing metrics being used by the projects to measure success in meeting project objectives.
- Further integration of the DOI resilience performance metrics effort with other Federal and non-Federal resilience efforts: DOI is in the process of determining how best to coordinate and integrate this performance metrics effort with other, similar efforts. The goal is to ensure broad Federal agency participation as a way to integrate Federal resilience efforts.
- Addition to and refinement of recommended protocols for the core performance metrics. The recommended performance metrics will not be comparable without common protocols established for field and laboratory measurements and derived variable equations.
- Compilation project metadata into a GIS database: A mapping tool is needed for effective comparison and grouping of projects for sub-regional assessments. Several mapper efforts are underway that should be integrated for this map. Continued coordination on this integration to complete the mapper is needed.
- Completion of the coastal resilience assessment for DOI-funded projects.

The MEG recommends some additional tasks be undertaken in the next few months to keep the DOI assessment process on track. These are briefly summarized as follows:

- Ensure measurements continue after project completion for a period sufficient to detect changes resulting from the project actions.
- Integrate existing data and alternative analysis methods that expedite detection or prediction of resilience change.

These efforts will provide a meaningful assessment of changes in resilience of coastal features and processes in the northeastern U.S. The MEG believes this recommended strategy for the resilience assessment will have transfer value to other regions of the U.S. coast and beyond, and will take the linkage of science, socio-economics, and adaptive management in solving America’s ecological issues to a new level of integration and effectiveness.

Appendices

Appendix A: Members of the DOI Metrics Experts Group (Alphabetical by Affiliation)

Name	Title	Affiliation
Mike Rasser	Regional Scientist	Bureau of Ocean Energy Management
Jeff Waldner	Regional Scientist	Bureau of Ocean Energy Management
Tracy Rouleau	Deputy Chief Economist	National Atmospheric and Oceanic Administration
Ariana Sutton-Grier	Ecosystem Science Advisor	National Atmospheric and Oceanic Administration
Mary Foley	Regional Scientist	National Park Service
Sophia Fox	Scientist, Cape Cod Seashore	National Park Service
Dan Odess	Science and Research Chief, Park Cultural Resources Programs	National Park Service
Charles Roman	Regional Scientist	National Park Service
Peter Sharpe	Regional Scientist	National Park Service
Lynn Bokamazo	Senior Coastal Engineer	U.S. Army Corps of Engineers
Cate Fox-Lent	Research Engineer	U.S. Army Corps of Engineers
Igor Linkov	Risk and Decision Science Focal Area Lead	U.S. Army Corps of Engineers
Sean Wallace	Research Engineer	U.S. Army Corps of Engineers
Rick Bennett (chair)	Regional Scientist	U.S. Fish and Wildlife Service
Lia McLaughlin	Assistant Coordinator for Hurricane Sandy Projects	U.S. Fish and Wildlife Service
Eric Schrading	Field Supervisor, New Jersey Field Office	U.S. Fish and Wildlife Service
Jed Wright	Scientist, Gulf of Maine Coastal Program	U.S. Fish and Wildlife Service
Don Cahoon	Research Scientist	U.S. Geological Survey
Neil Ganju	Research Scientist	U.S. Geological Survey
Harry Jenter	Assistant Chief, National Research Program, Eastern Branch	U.S. Geological Survey
Rachel Muir	Northeast Science Advisor	U.S. Geological Survey
Peter Murdoch (chair)	Northeast Science Advisor	U.S. Geological Survey
Bill Schwab	Research Scientist	U.S. Geological Survey
Carl Shapiro	Director, Science/Decision Center	U.S. Geological Survey
Steve Tessler	Ecologist, Database Modeler	U.S. Geological Survey
Informational Capacity Only:		
Mandy Chestnut	Senior Manager	National Fish and Wildlife Foundation
Matt Foster	Monitoring and Biodiversity Officer	National Fish and Wildlife Foundation

Appendix B: Definitions Required in Setting Metrics

To be clear on the goals of the MEG recommendations, a few terms from the resilience literature need specific definitions for the DOI assessment process. Those terms are briefly defined as follows:

Core Performance Metrics: Are a set of performance metrics that are applied to multiple projects and at the full range of temporal and spatial scales to help detect a change in resilience in one or more coastal features across multiple scales.

Ecological System (or Ecosystem): Humans and all other living organisms, their physical environment, and the biologic, geologic, and biogeochemical processes that together control the form and function of a particular unit of landscape or water body.

Indicator: For this report, an indicator is an ecological parameter for which we are able to measure its magnitude, extent, or trend using existing measurement techniques. A measurement must be measureable in the near term to be considered pertinent to the DOI assessment. Measurements which were either too costly or uncertain were not considered in the recommendations of the MEG.

Performance Metric: A qualitative or quantitative measurement or suite of measurements (index) that can be used to detect and assess a change in DOI coastal resilience objectives. Recovery Rapidity: As defined by Schultz et al. (2012), recovery rapidity is the lag time between when a system finishes absorbing the impacts of a stress, and the system has recovered to a similar level of functional performance prior to the stress.

Resilience: The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions. The DOI definition of increased resilience also includes improved scientific or socio-economic understanding that decreases uncertainty in the effects of management decisions on resilience.

Restoration: Returning an ecological system or community to a former state or condition. Ecological system or community restoration is a controversial topic, because simply restoring a system to its previous condition is not likely to sustain or improve its resilience as the baseline stressor conditions change. However, if a restoration buys society sufficient time to improve resilience, or avoids the loss of a critical resource until a more stable means of maintaining that resource can be developed, then the restoration of a coastal feature should be seen as aiding in the development of improved coastal resilience over time.

Robustness: As defined in Schultz et al. (2012), robustness is the capacity of a system to endure a stress and recover to a similar functional performance after that stress has been abated or adapted to.

Stressor: Any force of change that can potentially alter the functional performance of a system if that stress is of sufficient duration or magnitude. A stress that disrupts an engineered environment may cause only a minor fluctuation in a natural landscape or be necessary to sustain the long-term resilience of the physical or biologic system.

Threshold: For purposes of this report, thresholds are defined as the level of combined stress that results in a breakdown of system function and a change in state for that system.

Vulnerability: The likelihood that a system will be adversely affected by one or more stressors.

Coastal Feature Definitions:

Beach-Dune System: The Beach-dune system is a zone of sand accumulation and movement that starts at the most inland extent of the dune field and extends through the dry beach and the subaqueous portion of the beach that extends to the toe of the shoreface, but inclusive of nearshore shoals and barrier beaches.

Estuary: An estuary is a partially enclosed body of water, and its surrounding coastal habitats, where saltwater from the ocean mixes with fresh water from rivers or streams.

Green Infrastructure: An interconnected network of natural areas and engineered systems that mimic natural systems and processes designed to protect infrastructure and communities, support native species, maintain ecological processes, sustain air and water resources, and contribute to the health and quality of life for citizens.

Grey Infrastructure: The built environment; human-made surroundings that provide the setting for human activity, ranging in scale from buildings and parks or green space to neighborhoods and cities, including their supporting infrastructure, such as water supply transportation, or energy networks. Grey infrastructure for water includes conventional storage structures (reservoirs, detention ponds) and conveyances (pipes, canals) used to manage drinking, sewer, or storm water, and usually constructed of concrete or metal.

Living shorelines: A type of green infrastructure that is used to stabilize shorelines, protecting the coast from erosion while preserving or enhancing environmental conditions. Living shoreline projects utilize a variety of structural and organic materials, such as: wetland plants, submerged aquatic vegetation (e.g., sea grasses), oyster reefs, coir fiber logs, sand fill, and stone.

Maritime Forests and Shrublands: Coastline rimmed by terrestrial forests and shrubs that are infrequently submerged. A forest-shrubland mosaic encompassing a range of woody vegetation on barrier islands, near-coastal strands, and bluffs at the outer edge of the coastal plain.

Marshes: tracts of low wet land, often treeless and periodically inundated by fresh or salt water, generally characterized by a growth of grasses, sedges, cattails, and rushes.

Nearshore submerged: Nearshore submerged habitat includes the seafloor and water column found below the low tide line extending from the mouth of coastal rivers to a depth of about 100 feet. Nearshore submerged habitat is divided into two sub habitats by depth: nearshore shallow (0 to 20 feet) and nearshore deep (20 to 100 feet) habitats.

Pond: A natural or artificial body of water smaller than a lake.

Riverine: Flowing waters and near-channel landscape upstream of beach/dune systems. The Riverine System includes all wetlands and deepwater habitats contained within a channel, with two exceptions: (1) wetlands dominated by trees, shrubs, persistent emergent plants, emergent mosses, or lichens, and (2) habitats with water containing ocean-derived salts in excess of 0.5 ‰.

Riparian: The vegetation, soils, habitats, or ecological systems that are associated with bodies of water (streams or lakes)) or are dependent on the existence of perennial, intermittent, or ephemeral surface or subsurface water drainage.

Uplands: Uplands are any part of the earth's surface not covered by a body of water.

Watershed: An area of land that drains all the streams and rainfall to a common outlet such as the outflow of a reservoir, mouth of a bay, or any point along a stream channel. The watershed consists of surface water--lakes, streams, reservoirs, and wetlands--and all the underlying ground water. Larger watersheds contain many smaller watersheds.

Wetlands: A broad spectrum of landscapes that share three common characteristics: (1) Hydrology - Wetlands are periodically flooded or saturated with water during the growing season; 2) Soil - Wetlands have unique hydric soils (saturated most of the year); 3) Vegetation - Wetlands support hydrophytes (plant species adapted to wet conditions)

Appendix C: Tables with ecological performance metrics, core performance metrics, and protocols selected by coastal feature

This table provides the measurements recommended by the Department of Interior (DOI) Metrics Expert Group (MEG) for detecting change in resilience within the ecological systems and data management systems.

Table C1 groups performance metrics for ecological systems by coastal feature. Projects with objectives that include or are specifically designed to contribute to a species' sustainability should measure species and related habitat responses (metrics) using protocols that are routinely used and accepted by the larger community of practitioners associated with that species or group of species.

Project investigators can use this table to determine what coastal feature should be associated with their project, and the recommended resilience performance metrics for that feature. Several projects encompass more than one coastal feature, and will therefore have more than one set of recommended performance metrics. After project investigators determine their project's recommended core metrics, the MEG recommends that DOI project investigators review their planned measurements and compare that measurement plan with the MEG-recommended project metrics. Where gaps in collecting data for core metrics are detected for a project, managers will need to decide whether to add monitoring for those core metrics to that project.

For ease of reference, two additional tables are presented hererin. Table C2 includes some widely used protocols for some of the potential and core metrics organized by category of metric (i.e., biotic, abiotic, structural/engineering). The DOI MEG recognizes that this table is not complete. Appropriate, additional protocols will be incorporated as they are identified. Table C3 includes metrics from select indices and multi-metric protocols, grouped by index or protocol.

Data management performance metrics are presented in table C4. As with the ecological metrics, gaps between the planned project data management system and the recommended strategy will need to be reconciled so that adequate data archiving and sharing is established for the resilience assessment.

Appendix C1. Ecological performance metrics (including recommended core metrics) for Department of the Interior Resilience projects funded through the Disaster Relief Recovery Act of 2013.

Natural and Artificial Coastal Features	Objectives and Ecosystem Services	Potential Performance Metrics	Recommended Core Performance Metrics
Beach System: Beach, Barrier Island, and Dune (for back bay areas, see Estuaries and Ponds)	<u>Beaches and Dunes:</u> 1) Restore or improve beach habitat to enhance resilience of fish, wildlife, and plants, and their habitats (e.g., spawning, migration stopovers, critical habitats) 2) Restore or improve beach habitat to enhance resilience of coastal communities (includes tourism, etc.) 3) Restore/improve dune habitat to enhance resilience of coastal infrastructure by reducing flooding extent and attenuating wave energy 4) Improve/sustain beach/barrier island ecosystem and community resilience to storm surge events 5) Enhance understanding of natural system dynamics including immediate storm responses, natural recovery from disturbance events, and natural adaptation capacities and tendencies. 6) Reduce health advisories; avoid beach contamination associated with replenishment actions (no control of contamination from storms) 7) Improve recreation/aesthetics <u>Breaches:</u> 1) Manage breach occurrences to maximize habitat and hazard mitigation benefits at least cost	Biotic • Fish and wildlife population/ recruitment/ overwintering/stopover weight/health relative to other mitigating factors (e.g. other threats throughout its range: site and species specific) • Intra-faunal abundance and diversity (for invertebrates); • Vegetation cover of dunes pre and post events Abiotic • Surge, Wave, and Tide Hydrodynamic Network (SWaTH)*: Storm surge and wave sensor transects nearshore to inland; event- based attenuation rates • Pre and post storm wave height, inundation level • Water flow velocity and current dynamics (includes diurnal and storm-induced flow rates) • Water levels (including back bays) • Pre and post storm rates of erosion • Volumes of material in flood and ebb shoals • Change in near shore sediment character and movement • Post-storm sand volume in active shoreface • Sediment availability for recovery • Water quality, e.g., temperature, salinity, pH, dissolved oxygen, turbidity, nutrients, contaminants Structural/Engineering • Dune characterization (height, width, length, texture, substrate) • Beach width, elevation, volume, shoreline position • Breach morphology • Shoreline position and topography	<u>Beaches and Dunes:</u> Biotic • Vegetation cover of dunes pre and post event • Fish and wildlife population/ recruitment/ overwintering/stopover weight/health relative to other mitigating factors (e.g. other threats throughout range: site and species specific) Abiotic • Post-storm volume of sand in the active shoreface • Recovery rates of beach and dunes Structural/Engineering • Beach width, elevation, volume, shoreline position (post-event) • Dune characterization (height, width, length, texture, substrate) <u>Breaches:</u> Biotic • Fish and wildlife population/ recruitment/ overwintering/stopover weight/health changes relative to other mitigating factors (e.g. other threats throughout its range: site and species specific) Abiotic • Volumes of material in flood and ebb shoals • Water flow and current dynamics • Water quality: temperature, salinity, pH, dissolved oxygen, turbidity, nutrients, contaminants • Water level changes, especially in back bays

Natural and Artificial Coastal Features	Objectives and Ecosystem Services	Potential Performance Metrics	Recommended Core Performance Metrics
			Structural/Engineering • monitoring of breach morphologic changes
Nearshore Shallow and Nearshore Deep	1) Restore, improve, or maintain benthic habitat and species diversity 2) Improve water quality by reducing warm-water runoff, nutrient and contaminant rich runoff, and flushing of bays through new breaches 3) Detect changes in sand movement and vegetation, particularly as they relate to storm events by describing and mapping submerged substrate 4) Reduce or control invasive species 5) Attenuate waves by decreasing wave runup and beach/dune erosion 6) Improve resource maps and increase affordability of methods for repeat mapping	Biotic • Vegetation, e.g., biomass, species, density, extent, health (disease/epiphytes) • Pre and post changes in target organism population (e.g., reproductive success) for specific indicator species (e.g., seagrasses, scallops, etc.) • Benthic biodiversity • Changes in habitat quantity and quality Abiotic • Surge, wave height (SWaTH*) • Sand location • Sand mass • Sand movement (erosion and deposition, sources and sinks) • Water quality: dissolved oxygen, nutrients, temperature, salinity, algae in runoff and nearshore coastal water • Substrate composition • Flushing rates of back bays Structural/Engineering • Substrate morphology (mapping) • Bathymetric mapping	Biotic: • Vegetation, e.g., biomass, species, density, extent, health • Pre and post changes in target organism population (e.g., reproductive success) for specific indicator species (e.g., seagrasses, scallops, etc.) • Changes in habitat quantity and quality Abiotic: • Surge, wave height • Sand movement (erosion and deposition, sources and sinks) • Water quality: dissolved oxygen, nutrients, temperature, salinity, algae in runoff and nearshore coastal water • Flushing rates of back bays Structural/Engineering • Substrate morphology (mapping) • Bathymetric mapping
Riverine and Riparian Zone	Remove dams, remove or right-size culverts, and restore riparian areas to: 1) Improve aquatic organism passage and enhance resilience/increase populations (e.g., fish, invertebrates; other vertebrates (e.g. Diamond back terrapin)) 2) Enhance resilience of coastal infrastructure by reducing risk of flooding upland habitats and artificial infrastructure 3) Improve water quality; decrease contamination of rivers and coast	Biotic • Fish species health/recruitment stressors • Fish migration rates and patterns • Invasive species extent, mobility • Fish assemblage/fish abundance pre and post project • Biomass diversity • Macro invertebrates pre-post • Riparian plant community pre-post • Biologic assimilation of contaminants • Riparian and channel habitat measurements (species specific)	Biotic • Fish migration rates and patterns • Invasive species extent, mobility • Fish assemblage/fish abundance pre and post project • Riparian plant community pre and post • Habitat availability: Stream miles made accessible to aquatic species upstream, pre and post project Abiotic: • River flow and depth • Flooding extent and depth (stormwater retention capacity)

Natural and Artificial Coastal Features	Objectives and Ecosystem Services	Potential Performance Metrics	Recommended Core Performance Metrics
	4) Restore/improve sediment transport 5) Restore/improve riparian habitat to enhance resilience of fish, wildlife, and plants, and their habitats (e.g., spawning, migration, critical habitats) 6) Improve recreation/aesthetics	• Habitat availability: Stream miles made accessible to aquatic species upstream, pre and post project Abiotic • River flow and depth • Flooding extent and depth to create a volumetric measurement of stormwater retention capacity • Flow rates across obstruction(s) • Inundation area pre-post engineered change • Sediment composition and contaminants (pre and post project) •Modeled potential for changes in flood regime upstream/ downstream following dam removal or culvert re-design (LIDAR-based inundation maps; groundwater levels, high-water marks) • Water quality: temperature, salinity, pH, dissolved oxygen, turbidity, nutrients, contaminants • River biogeochemistry: flow-weighted water quality parameters • Observed water levels (surface and ground) • Coastal hydrology- changes in flooded riparian area (observed water levels, inundation models) • Erosion rate and changes to sediment transport processes of system pre and post project Structural/Engineering • River hydrology: geomorphic mapping (pre and post constriction removal) • Minimum change in connectivity needed to allow fish passage • Elevation change across obstruction(s) • River Hydrology Change (percentage of flood-risk reduction, riparian buffer dimensions, position) (pre and post project) • Number of barriers removed or remediated	• Inundation area (pre and post project) • Sediment composition and contaminants (pre and post project) • Water temperature and salinity Structural/Engineering • Number of barriers removed or remediated

Natural and Artificial Coastal Features	Objectives and Ecosystem Services	Potential Performance Metrics	Recommended Core Performance Metrics
Marshes and Wetlands	1) Mitigate coastal flooding by restoring or improving marsh hydrology and tidal dynamics 2) Improve water quality and reduce contaminant levels 3) Provide high quality habitat for salt marsh biota 4) Decrease erosion and enhance marsh accretion and resilience to sea level rise 5) Maintain and enhance shoreline integrity; preserve marsh area and distribution to support migration corridors, e.g., maintaining marsh and wetland habitat in flyways 6) Dissipate wave energy from storm surges associated with future coastal storms to, protecting habitat and communities 7) Increase infiltration and decrease erosion by reducing impervious surface effects on resilience 8) Use information and modeling to help articulate community risk reduction benefits of marshes and wetlands	Biotic • Dominant vegetation health (estimates of growth rates related to inundation regimes, effects of sediment composition on growth range and production) • Decomposition rates of vegetation • Salt marsh plant community monitoring (e.g., species composition, percent cover, areal coverage of the high and low marsh community type) • Areal coverage of the high and low marsh community type (pre and post storm/event), • Fish and wildlife population metrics (weight gain, nesting success, etc.) • Measures of game species, rare and declining species, representative species (e.g., brant geese), and habitat for fish • Abundance of bioengineers • Nekton abundance, species richness • Above and below ground biomass of cordgrass • Algal abundance • Depth of peat with vegetation sampling • Acres and distribution of future salt marsh habitat protected for marsh upland advancement to sustain coastal species. Abiotic • Surge, wave height (SWaTH*) • Inundation • Marsh accretion trend and erosion • Tidal range • Vertical tidal datums • Local sea-level trend • Local suspended sediment supply • Water Quality: temperature, salinity, pH, dissolved oxygen, turbidity, nutrients, contaminants, conductivity, sulfides • Groundwater dynamics • Sediment composition (percent organic matter, bulk density, percent fines), contaminants, and associated biological activity;	Biotic • Salt marsh plant community monitoring (e.g., species composition, percent cover, areal coverage of the high and low marsh community type) • Nekton abundance, species richness Abiotic • Marsh surface elevation change trend - long-term 3+ years and short term • Marsh accretion and erosion • Groundwater dynamics • Water quality: salinity, conductivity, temperature, dissolved oxygen, pH Structural/Engineering • Marsh surface elevation change trend - long-term 3+ years and short term

Natural and Artificial Coastal Features	Objectives and Ecosystem Services	Potential Performance Metrics	Recommended Core Performance Metrics
		• Water current profiling Structural/Engineering • Adjacent impervious surface miles mapped and strategic removal/replacement with porous material • Shoreline loss or gain (change in shoreline position) • Marsh surface elevation change trend - long-term 3+ years and short term, marsh profile • Shear vane strength of peat banks/platform • Position and amount of marsh edge Index • Salt Marsh Integrity Index (SMI)*	
Uplands and Watersheds	Uplands: 1) Restore, improve or maintain habitat for resilient/healthy fish and wildlife populations 2) Protect uplands for potential marsh migration Watersheds: 1) Sustain natural sediment and nutrient transport 2) Mitigate flood impacts from runoff associated with intense storms, rapid snowmelt, and ice breakup. 3) Establish information and metrics for integrating watershed and coastal management as one system. 4) Protect/restore riparian habitat for fish and wildlife, including those that use adjacent aquatic habitats (see riverine/riparian zone feature above). 5) Improved flooding vulnerability maps	Biotic • Vegetation condition, type, and health • Forest fragmentation and development • Land cover (LIDAR and other imagery)- especially as land use may restrict marsh migration • Edge of vegetation • Riparian and channel habitat measurements (species specific) Abiotic • Inundation frequency • Soil salinity, soil leachate chemistry, oxidation-reduction activity, carbon • Rates of watershed and near-coast erosion (pre and post event) • Water levels, flows, near-coast wave heights (SWaTH*) • Duration and frequency of terrestrial flooded area - observed water levels • Relative sea level position • Tide range • Water quality: temperature, salinity, pH, dissolved oxygen, turbidity, nutrients, contaminants, specific conductance	Biotic • Vegetation condition, type, and health • Forest fragmentation and development • Land cover (LIDAR and other imagery)- especially as land use may restrict marsh migration • Riparian and channel habitat measurements (species specific) Abiotic • Inundation frequency • Soil salinity, soil leachate chemistry • Rates of watershed and near-coast erosion (pre and post event) • Water levels, flows, near-coast wave heights • Riparian and channel habitat measurements (species specific) Structural/Engineering • Topography/Slope • Elevation

Natural and Artificial Coastal Features	Objectives and Ecosystem Services	Potential Performance Metrics	Recommended Core Performance Metrics
	6) Improve understanding of historical change and define disturbance levels that cause system damage	Structural/Engineering • Topography/slope • Elevation • Periodic surveyed coastline, nearshore terrestrial edge, vegetation condition. • Dune, beach, cliff, and bluff morphology • Near shore morphology (pre and post project or storm)	
Maritime Forests and Shrublands	1) Restore, improve, or maintain coastal forest health and areal extent for resilient/healthy fish and wildlife populations 2) Maintain migratory bird habitat in coastal flyways 3) Maintain coastal groundwater sources for drinking water 4) Protect for potential marsh migration	Biotic • Vegetation/wildlife condition, type, and health • Forest fragmentation and development • Land cover (LIDAR and other imagery)- especially as land use may restrict marsh migration • Riparian and channel habitat measurements (species specific) Abiotic • Inundation frequency • Soil salinity, soil leachate chemistry, oxidation-reduction activity, carbon • Rates of watershed and near-coast erosion (pre and post event) • Water levels, flows, near-coast wave heights (SWaTH*) • Duration and frequency of terrestrial flooded area - observed water levels • Relative sea level position • Tide range • Water quality: temperature, salinity, pH, dissolved oxygen, turbidity, nutrients, contaminants Structural/Engineering • Topography/Slope • Elevation • Shoreline position and topography (LIDAR); erosion/ accretion rates • Dune, beach, cliff, and bluff morphology • Near shore morphology (pre and post project or storm event)	Biotic • Vegetation/wildlife condition, type, and health • Forest fragmentation and development • Land cover (LIDAR and other imagery)- especially as land use may restrict marsh migration Abiotic • Inundation frequency • Soil salinity, soil leachate chemistry • Rates of watershed and near-coast erosion (pre and post event) • water levels, flows, near-coast wave heights Structural/Engineering • Topography/Slope • Elevation

Natural and Artificial Coastal Features	Objectives and Ecosystem Services	Potential Performance Metrics	Recommended Core Performance Metrics
		• Adjacent impervious surface miles/area mapped • Strategic removals of barriers to habitat migration (position, type, physical features of removal)	
Estuaries and Ponds (including back bay areas)	1) Maintain or improve water quality 2) Restore, improve, or maintain habitat for fish, wildlife, and plants (e.g., spawning and rearing habitat for fish populations) 3) Restore/improve hydrology 4) Improve recreation opportunities/aesthetics 5) Improve understanding and compilation of historical change in physical and biological processes 6) Define and detect change in thresholds of estuarine ecological system and physical resilience to the common coastal stressors (e.g., sea level rise, surge and waves, pollution, climate, development) to help inform decision-making	Biotic • Submerged aquatic vegetation (SAV) biomass (e.g. seagrass), species, density, extent, health (disease/epiphytes) • Invasive species • Invertebrate fauna (e.g., in mudflats) • Migratory shorebirds (e.g., the red knot) • Species composition and abundance for fish, plankton, and the benthic animal community Abiotic • Sediment character: define • Water depths- transects shore to vegetation perimeter (edge of seagrass bed • Water flow patterns (circulation within an estuary, and ground and surface water inputs) • Inundation extent, rates, and frequency • Water levels, flows, wave heights (SWaTH*) • Water quality: temperature, salinity, pH, dissolved oxygen, turbidity, nutrients, chlorophyll a, contaminants Structural/Engineering • Physiographic characteristics (depth, fetch, substrate, perimeter characteristics, flow patterns)	Biotic • Submerged aquatic vegetation (SAV) (e.g. seagrass), species, density, extent, health (disease/epiphytes) Abiotic • Water depths • Inundation extent, rates, and frequency • Water temperature and salinity
Built Environment: Grey infrastructure	1) Protect or improve water quality by decreasing runoff of contaminants and nutrients; 2) Protect coastal infrastructure by reducing flooding extent and wave energy 3) Decrease duration of flood events by enhancing nearshore drainage to divert floodwaters back to the coast, protecting storm drains from inundation, etc.	Biotic: • Colonization by mollusks, fouling effects (effects integrity of the structure when substantially fouled) • Fish population data • Invasive species (sources). Abiotic • Pre and post hydrologic properties (current, surge, wave, tide) • Pre and post contaminant condition (concentration/load)	Biotic: • Colonization by mollusks, fouling effects • Fish population data • Invasive species Abiotic • Water depth • Inundation extent, rates, and frequency

Natural and Artificial Coastal Features	Objectives and Ecosystem Services	Potential Performance Metrics	Recommended Core Performance Metrics
	4) Improve understanding and compilation of historical change in physical and biological processes 5) Protect key natural resources 6) Enhance physical and mental health/well-being in urban setting.	• Water depth • Inundation extent, rates, and frequency • Wave height and period; water level (SWaTH*)(seawalls, surge barriers, breakwaters, levees) • Longshore transport rates and distribution of sediment (groins) • Land fill flooding • Storm drain overflow • Sewage overflow • Surface and drinking water quality (pre and post storm): temperature, salinity, pH, dissolve oxygen, turbidity, nutrients, chlorophyll a, organics, contaminants (ID sources, sinks, pathways during storms) • Shadowing, materials, surface area (not sure what this means, needs some additional details) • Erosion assessment (recommend 5 year) Structural/Engineering • Structure height (surge barriers, groins, breakwaters, levees) • Length, orientation, permeability, spacing, depth at sea-ward end (groins, breakwaters) • Slope, crest, and width (levees) • Shoreline position and topography • Scour protection (sea walls) • Erosion rate and changes to sediment transport processes near seawalls, groins, and other built features • Landscape elevation; pre and post structural characteristics, • Landscape channelization • Sewering (map, capacity, combined sewer overflow systems) • Amount of impervious surface • Change in amount of open spaces and zoning	• Water quality: temperature, salinity, pH, dissolved oxygen, turbidity, nutrients, chlorophyll a • Area flooded during storm events • Erosion assessment (recommend 5 year)

Natural and Artificial Coastal Features	Objectives and Ecosystem Services	Potential Performance Metrics	Recommended Core Performance Metrics
Green Infrastructure: Living shorelines (focus of many of the projects, so separated out for easy reference)	1) Stabilize and potentially enhance shoreline integrity (e.g., reduce erosion, promote plant colonization) to protect important natural features 2) Stabilize and potentially enhance shoreline integrity to protect artificial infrastructure (e.g., roads, dikes, buildings) 3) Improve water quality to benefit fish, wildlife, and people 4) Restore, improve, or maintain habitat for fish, wildlife, and plants (e.g., spawning and rearing habitat for fish populations) 5) Enhance health of living shoreline (oysters, sea grasses) populations	Biotic • Oyster biomass extent • Oyster population (recruitment) • Oyster coverage • Organism health (diseases, survivability of oysters or other organisms) • Oyster length frequency - growth rates etc. • Vegetation cover • Recruitment of juvenile fish, crustaceans, and mollusks • Measure bacterial and viral pathogens • Extent and condition of adjacent habitats (marsh or seagrass) that are benefiting from the project Abiotic • SWaTH* (Storm surge heights, direction, wave heights, frequency, direction) • Water quality: water temperature, water salinity, pH, dissolved oxygen, turbidity, nutrients, contaminants • Water depth • Inundation extent, rates, and frequency Structural/Engineering • Topography slope • Elevation • Vertical accretion rates • Shoreline position and topography • Structure resilience to waves (movement, percent intact) • Shear strength of oyster beds, grass beds, etc.	Biotic • Oyster length frequency - growth rates, age structure etc. • Oyster coverage • Oyster population • Vegetation cover Abiotic • Wave heights, frequency, direction • Water temperature, salinity Structural/Engineering • Structure resilience to waves (movement, percent intact) • Vertical accretion rates • Shoreline position and topography
Green Infrastructure: Other methods (permeable road surfaces, flood	1) Protect or improve water quality by decreasing runoff of contaminants and nutrients 2) Protect coastal infrastructure by reducing flooding extent and wave energy and decreasing vulnerability to salt-water intrusion from storms and sea level rise	Examples, actual project metrics will be site and method specific: Biotic • Health of green infrastructure biology pre and post installation • Biomass • Aerial extent of green infrastructure installation	Examples, actual project metrics will be site and method specific: Biotic • Health of green infrastructure biology pre and post installation

Natural and Artificial Coastal Features	Objectives and Ecosystem Services	Potential Performance Metrics	Recommended Core Performance Metrics
diversion berms, holding ponds, etc.)	3) Decrease negative effects of flood events. 4) Stabilize and potentially enhance shoreline integrity (e.g., reduce erosion, promote plant colonization) to protect important natural features 5) Restore, improve, or maintain habitat for fish, wildlife, and plants (e.g., spawning and rearing habitat for fish populations) 6) Improve understanding and compilation of historical change in physical and biological processes 7) Enhance physical and mental health/well-being of people 8) Improve recreation/aesthetics, e.g., greenways and blueways (beautification); 9) Increase the livability of a community through beautification and enhanced access to our coastal shorelines and riverfronts 10) Mitigate some effects of climate change through carbon sequestration 11) Determine thresholds for sustaining living shore populations 12) Investigate how various infrastructure approaches affect sediment flows. 13) Determine threshold hardening characteristics for local wave/surge characteristics	• Extent and condition of adjacent habitats (marsh or seagrass) that are benefiting from the project • Fish and wildlife population/ recruitment/ overwintering/ stopover weight/health relative to other mitigating factors (e.g. other threats throughout range: site and species specific) Abiotic • Storm surge heights, direction, wave heights, frequency, direction (SWaTH*) • Aerial extent of green infrastructure installation • Continuity of habitat and structure • Erosion rate and changes to sediment transport processes • Pre and post hydrologic properties • Water depth • Inundation rates and extent • Storm drain overflow • Sewage overflow • Surface and drinking water quality (measure pre and post storm): temperature, salinity, pH, dissolve oxygen, turbidity, nutrients, chlorophyll a, organics, contaminants (ID sources, sinks, pathways during storms) Structural/Engineering • Landscape, channel or basin physiography • Imported resource quality (e.g. fill quality, quantity, contaminant content) • Shoreline position and topography	• Fish and wildlife population/ recruitment/ overwintering/stopover weight/health relative to other mitigating factors (e.g., other threats throughout range: site and species specific) Abiotic • Water quality: contaminants; sedimentation (site and method specific) • Storm surge heights, direction, wave heights, frequency, direction Structural/Engineering • Shoreline position and topography

* Additional details on these metrics are included in Appendix C3 - Select Indices and Multi-metric Protocols

Appendix C2. Protocols for measuring potential performance metrics for Department of the Interior Resilience projects funded through the Disaster Relief Recovery Act of 2013.

		Protocol Name	Performance Metric(s)	Citation/Source
Biotic	**Fish and Wildlife Species**	Projects with objectives that include or are specifically designed to contribute to a species' sustainability should measure species and related habitat responses using protocols that are routinely used and accepted by the larger community of practitioners associated with that species or group of species.	• Fish and wildlife population: productivity (reproductive success), recruitment, overwintering, migratory stopover weight, health [stabilizes or improves relative to other mitigating factors (e.g. other threats throughout its range: site and species specific)] • Intra-faunal abundance and diversity (for invertebrates); • Fish species health/recruitment stressors • Fish migration rates and patterns • Invasive species extent, mobility • Fish assemblage/fish abundance pre-post • Biomass • Macro invertebrates pre-post • Nekton abundance, species richness	
		Salt Marsh Integrity Index (SMI)	• Necton density and species richness • Fundulus length • Willett abundance • Abundance of tidal marsh obligate birds	Shriver, W. G., Wiest, W. A., Adamowicz, S. C., Tymkiw, E. L., Chadbourne, K. A., and King, E. 2015. Northeast Regional Protocol for the Inventory and Monitoring of Salt Marsh Integrity. USFWS Region 5, Hadley, MA. 240 pp.
		Saltmarsh Habitat and Avian Research Program (SHARP)	• Marsh birds - point counts - visual • Marsh birds - call counts (call back) Salt Marsh Breeding Birds: • Adult survival rates • Reproductive success (fledging rates) • Sex • Age, chick, adult, egg • Wing length • Head length • Tarsus length • Body mass • Total culmen (bill length) • Nalospi – the distance from the bill tip to the nostril • Bill width at the anterior nares • Bill depth at the anterior nares • Fat scoring (condition) • Pectoral muscle scoring	Saltmarsh Habitat and Avian Research Program (SHARP) http://www.tidalmarshbirds.org/

		Protocol Name	Performance Metric(s)	Citation/Source
			• Feather condition (photos) • Population genetics • Paternity analysis • Contaminant exposure • Hormone levels • Diet • Nest location • Number of eggs and chicks in the nest • Whether eggs were warm or not • Nest bowl was wet or not • Age of any chicks • Any dead eggs or chicks • Female was seen to flush • Distance of observer when the female flushed, • Female chipped at you while you were visiting the nest • Nest status • Maximum number of eggs and chicks • Number of fledged chicks • Number of eggs and chicks found flooded/depredated/missing/etc. • Estimated hatch date and fledge date • Nest fate	
		Dam Removals/Fish Passage: NOAA Restoration Center Fish Passage Barrier Removal Performance Measures and Monitoring Worksheet and Guidance	Pre and Post Implementation: • Upstream status of target fish species (presence/absence) • Life stages present of target fish species (adult/juvenile) • Other fish species (presence/absence)	This is not a formal protocol with methods, it provides guidance on what metrics to measure but not how to measure them. Additional metrics on maintenance costs and public safety are included but not presented here. http://www.habitat.noaa.gov/toolkits/restoration_center_toolkits/forms_and_guidance_documents/ori_monitoring_sheet_w_guidance.pdf
		Oyster habitat restoration monitoring and assessment handbook	• Live Oyster Density (including recruits) • Oyster Size-Frequency Distribution • Presence of Predatory, Pest, and/or Competitive Species • Disease Prevalence and Intensity • Oyster Condition Index • Gonad Development Status	Baggett, L.P., S.P. Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, and S. Morlock, 2014. Oyster habitat restoration monitoring and assessment handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/wp-

		Protocol Name	Performance Metric(s)	Citation/Source
			• Oyster Sex Ratio • Shell Volume for Determination of Shell Budget • Nearby-Reef Oyster Density and Associated Size-Frequency Distributions • Nearby-Reef Large Oyster Abundance • Density of Selected Species and/or Faunal Groups • Seston and/or Chlorophyll a Concentrations	content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pdf
		National Park Service, Inventory and Monitoring, Southeast Coast Network (USGS Elevation Protocols)	• Nekton species composition and lengths • Nekton species abundance	DeVivo, J. C., J. Asper, S. Eastman, N. M. Rankin, L. C. Baron, A. C. Curtis, C. J. Wright, E. Thompson, M. B. Gregory, and M. W. Byrne. 2013. Protocol for monitoring coastal salt marsh elevation and vegetation communities in Southeast Coast Network parks. Natural Resource Report NPS/SECN/NRR—2013/xxx. National Park Service, Fort Collins, Colorado. http://science.nature.nps.gov/im/units/secn/monitor/saltmarsh.cfmhttp://science.nature.nps.gov/im/units/secn/publications.cfm?tab=2&SaltmMarshElevation=open#ProtocolSaltmMarshElevation
	Habitat	Tidal Marsh Vegetation Transects and Survey Plot Standard Operating Procedures	• Plant species • Absolute percent cover • Rooted stem count • Maximum height for each species	US Geological Survey. 2011. Vegetation standard operating procedures. Unpublished protocols. USGS, Western Ecological Research Center, San Francisco Bay Estuary Field Station, Vallejo, CA. http://tidalmarshmonitoring.org/monitoring-methods-vegetation.php
		Salt Marsh Integrity Index (SMI)	• Plant species richness • Percent cover brackish terrestrial border veg • Percent cover open water • Percent cover pannes, pools, creeks • Percent cover high marsh • Percent cover low marsh • Percent cover saltmarsh terrestrial border vegetation • Percent cover upland • Percent cover invasive plants • Ratio of open water to vegetation	Shriver, W. G., Wiest, W. A., Adamowicz, S. C., Tymkiw, E. L., Chadbourne, K. A., and King, E. 2015. Northeast Regional Protocol for the Inventory and Monitoring of Salt Marsh Integrity. USFWS Region 5, Hadley, MA. 240 pp.

		Protocol Name	Performance Metric(s)	Citation/Source
		Saltmarsh Habitat and Avian Research Program (SHARP)	• Estimated percent cover for plant communities and open water features • Number of dead snags • Plant species	Saltmarsh Habitat and Avian Research Program (SHARP) http://www.tidalmarshbirds.org/ based on: Shriver, W. G., Wiest, W. A., Adamowicz, S. C., Tymkiw, E. L., Chadbourne, K. A., and King, E. 2015. Northeast Regional Protocol for the Inventory and Monitoring of Salt Marsh Integrity. USFWS Region 5, Hadley, MA. 240 pp.
		Dam Removals/Fish Passage: NOAA Restoration Center Fish Passage Barrier Removal Performance Measures and Monitoring Worksheet and Guidance	• stream miles made accessible upstream	This is not a formal protocol with methods, it provides guidance on what metrics to measure but not how to measure them. Additional metrics on maintenance costs and public safety are included but not presented here. http://www.habitat.noaa.gov/toolkits/restoration_center_toolkits/forms_and_guidance_documents/ori_monitoring_sheet_w_guidance.pdf
		Oyster habitat restoration monitoring and assessment handbook	• Percent cover of reef substrate • Density and percent cover of marsh and mangrove plants • Submerged aquatic vegetation • Seston and/or chlorophyll a concentrations	Baggett, L.P., S.P. Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, and S. Morlock, 2014. Oyster habitat restoration monitoring and assessment handbook. The Nature Conservancy, Arlington, VA, USA., 96pp.http://www.oyster-restoration.org/wp-content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pdf
		Sea Grass	• Distribution and abundance of submerged aquatic vegetation beds • Shoot density • Percent cover • Biomass	http://science.nature.nps.gov/im/units/ncbn/monitor/estuaries.cfm
		Benthic Habitat Mapping: NOAA	• Spatial extent and distribution of habitats within the photic zone • Habitat fragmentation (expressed as a percent bottom-cover value) • Qualitative measures of biomass (in the case of submerged aquatic vegetation).	NOAA Guidance for Benthic Habitat Mapping: A photographic approach. http://coast.noaa.gov/digitalcoast/_/pdf/bhmguide.pdf
		Benthic Habitat Mapping: USGS	• Biotic cover (biological features of the benthos at various scales, including faunal cover and flora cover)	http://pubs.usgs.gov/of/2010/1264/

		Protocol Name	Performance Metric(s)	Citation/Source
		Benthic Habitat Mapping: VIMS	• Distribution and abundance of submerged aquatic vegetation • Species of submerged aquatic vegetation	William and Mary College: Virginia Institute of Marine Science: http://web.vims.edu/bio/sav/
		National Park Service, Inventory and Monitoring, Southeast Coast Network (USGS Elevation Protocols)	• Submerged aquatic vegetation cover • Marsh vegetation species composition • Vegetation: percent cover of each species of vegetation present in the plots (Braun-Blanquet method)	Vegetation protocol still in development. DeVivo, J. C., J. Asper, S. Eastman, N. M. Rankin, L. C. Baron, A. C. Curtis, C. J. Wright, E. Thompson, M. B. Gregory, and M. W. Byrne. 2013. Protocol for monitoring coastal salt marsh elevation and vegetation communities in Southeast Coast Network parks. Natural Resource Report NPS/SECN/NRR—2013/xxx. National Park Service, Fort Collins, Colorado. http://science.nature.nps.gov/im/units/secn/monitor/saltmarsh.cfm http://science.nature.nps.gov/im/units/secn/publications.cfm?tab=2&SaltmMarshElevation=open#ProtocolSaltmMarshElevation Braun-Blanquet, J. 1932. Plant Sociology (Transl. G.D. Fuller and H.S. Conrad). McGraw-Hill, New York, 539pp. (percent cover)
		Forest Health Monitoring: Mid-Atlantic Network forest vegetation monitoring protocol (NPS)	• Tree species, basal area, and density • sapling and shrub species, basal area, and density • Seedling regeneration by species	Comiskey, J. A., J. P. Schmit, and G. Tierney. 2009. Mid-Atlantic Network forest vegetationmonitoring protocol. Natural Resource Report NPS/MIDN/NRR—2009/119. National ParkService, Fort Collins, Colorado.http://science.nature.nps.gov/im/units/ncbn/monitor/forests.cfm
		Northeast Temperate Network long-term forest monitoring protocol (NPS)	• Forest stand structure • Tree condition, regeneration, growth, and mortality rates • Snag abundance • Coarse woody debris volume • Understory plant species composition and abundance • Forest floor condition (trampling impacts and earthworm presence)	Northeast Temperate Network long-term forest monitoring protocol: 2012 revision. Natural Resource Report NPS/NETN/NRR—2013/639. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/App/Reference/DownloadDigitalFile?code=516412&file=NETN_Forest_Monitoring_2014_Revision.pdf

		Protocol Name	Performance Metric(s)	Citation/Source
		Forest Inventory and Analysis National Core Field Guide (USFS)	• Tree species, diameter (at breast height, DBH, or at root collar, DRC), length/height • Canopy cover • Land use/land cover (non-forest) • Forest type • Stand size class • Regeneration status (artificial, includes species, count) • Tree density • Stand Age • Disturbance • Slope and aspect • Snow or water depth • Tree damage (damage agents) • Tree mortality/decay • Coarse and Fine woody materials • Vegetation structure and dominant species composition for vascular plants (invasive plants, plant species, distribution and abundance) • Duff and litter depth	FOREST INVENTORY AND ANALYSIS NATIONAL CORE FIELD GUIDE VOLUME II: FIELD DATA COLLECTION PROCEDURES FOR PHASE 2 PLOTS Version 6.0.1 U.S. Department of Agriculture, Forest Service. 2012. Forest Inventory and Analysis National Core Field Guide: field data collection procedures for phase 2 plots. Version 6.1. http://www.fia.fs.fed.us/library/field-guides-methods-proc/
		Monitoring and evaluating the ecological integrity of forest ecosystems	• Stand structural class • Snag abundance • Coarse woody debris volume • Tree regeneration • Tree condition • Biotic homogenization • Indicator species - non-native, invasive species • Indicator species - deer browse • Tree growth and mortality rates	Monitoring and evaluating the ecological integrity of forest ecosystems Geraldine L. Tierney1, Don Faber-Langendoen, Brian R. Mitchell, W. Gregory Shriver, and James P. Gibbs Front Ecol Environ 2009; 7(6): 308–316, doi:10.1890/070176 http://www.esajournals.org/doi/pdf/10.1890/070176
		Multiple National Park Service Protocols	Resource for NPS protocols by category	NPS Integrated Resource Management Applications Portals:http://www.nature.nps.gov/publications/nrpm/https://irma.nps.gov/App/ProtocolTracking
	Landscape Context Metrics	Salt Marsh Integrity Index	• Landscape position • Percent agricultural land w/in 150m • Percent natural land w/in 150m • Percent natural land w/in 1km	Shriver, W. G., Wiest, W. A., Adamowicz, S. C., Tymkiw, E. L., Chadbourne, K. A., and King, E. 2015. Northeast Regional Protocol for the Inventory and Monitoring of Salt Marsh Integrity. USFWS Region 5, Hadley, MA. 240 pp.

		Protocol Name	Performance Metric(s)	Citation/Source
		Tidal Marsh Vegetation Transects and Survey Plot Standard Operating Procedures	• Land use survey in a 100 m diameter survey plot, buffer around study quadrants	US Geological Survey. 2011. Vegetation standard operating procedures. Unpublished protocols. USGS, Western Ecological Research Center, San Francisco Bay Estuary Field Station, Vallejo, CA. http://tidalmarshmonitoring.org/monitoring-methods-vegetation.php
		Northeast Temperate Network long-term forest monitoring protocol (NPS)	• Change in the landscape context of forest plots over time	Northeast Temperate Network long-term forest monitoring protocol: 2012 revision. Natural Resource Report NPS/NETN/NRR—2013/639. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/App/Reference/DownloadDigitalFile?code=516412&file=NETN_Forest_Monitoring_2014_Revision.pdf
Abiotic	**Hydrology/ Wave Energy**	Inland Storm-Tide Monitoring (ISTM) Program and Surge, Wave, and Tide Hydrodynamic (SWaTH) Network Standard Operating Plan	• Water level • Wave height • Wave frequency • Tidal crest-stage	http://www.usgs.gov/hurricane/sandy/ http://www.usgs.gov/hurricane/sandy/#research_themes.html!research_theme_coastal_hydrology.html http://water.usgs.gov/osw/programs/storm_surge1.html
		Computation of discharge in tidally affected areas	• Measured water levels • Measured index velocity • Discharge is calculated as the product of the area and mean velocity.	Ruhl, C. A., & Simpson, M. R. (2005). Computation of discharge using the index-velocity method in tidally affected areas. US Department of the Interior, US Geological Survey. http://pubs.usgs.gov/sir/2005/5004/sir20055004.pdf
		Oyster habitat restoration monitoring and assessment handbook	• Wave energy • Tidal water flows	Baggett, L.P., S.P. Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, and S. Morlock, 2014. Oyster habitat restoration monitoring and assessment handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/wp-content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pdf
		Salt Marsh Integrity Index	• Tidal flushing • Ditch density • Mean flood depth • Percent of time marsh flooded	Shriver, W. G., Wiest, W. A., Adamowicz, S. C., Tymkiw, E. L., Chadbourne, K. A., and King, E. 2015. Northeast Regional Protocol for the Inventory and Monitoring of Salt Marsh Integrity. USFWS Region 5, Hadley, MA. 240 pp.

		Protocol Name	Performance Metric(s)	Citation/Source
		National Park Service, Inventory and Monitoring, Southeast Coast Network (USGS Elevation Protocols)	• Tide direction (ebb, flood) • Water depth • Water tables	DeVivo, J. C., J. Asper, S. Eastman, N. M. Rankin, L. C. Baron, A. C. Curtis, C. J. Wright, E. Thompson, M. B. Gregory, and M. W. Byrne. 2013. Protocol for monitoring coastal salt marsh elevation and vegetation communities in Southeast Coast Network parks. Natural Resource Report NPS/SECN/NRR—2013/xxx. National Park Service, Fort Collins, Colorado.http://science.nature.nps.gov/im/units/secn/monitor/saltmarsh.cfmhttp://science.nature.nps.gov/im/units/secn/publications.cfm?tab=2&SaltmMarshElevation=open#ProtocolSaltmMarshElevation
	Water/Air Quality	Nutrients: Nitrogen	Nitrogen Loading Inputs: • Nutrient point source discharge permits • Livestock populations • Fertilizer consumption • Permitted water withdrawals for domestic and agricultural consumption • Wet deposition nitrogen chemistry	http://science.nature.nps.gov/im/units/ncbn/monitor/estuaries.cfm
		Estuarine Sediment Chemistry, Toxicity and Biological Assays	• Wastewater compounds and hormones • Air and water temperature • Specific conductance • Salinity • Weather conditions	Paper with references to protocols, as well as some methods information Fischer, J.M., Phillips, P.J., Reilly, T.J., Focazio, M.J., Loftin, K.A., Benzel, W.M., Jones, D.K., Smalling, K.L., Fisher, S.C., Fisher, I.J., Iwanowicz, L.R., Romanok, K.M., Jenkins, D., Bowers, L., Boehlke, A., Foreman, W.T., Deetz, A.C., Carper, L.G., Imbrigiotta, T.E., and Birdwell, J., (2015) Estuarine bed-sediment-quality data collected in New Jersey and New York after Hurricane Sandy, 2013: U.S. Geological Survey Data Series 905, 42 p., plus CD-ROM. http://pubs.usgs.gov/ds/0905/ or http://pubs.usgs.gov/ds/0905/support/pdf/ds905.pdf
		Inland Storm-Tide Monitoring (ISTM) Program and Surge, Wave, and Tide Hydrodynamic (SWaTH) Network Standard Operating Plan	• Barometric-pressure • Precipitation • Wind speed and direction • Air temperature • Relative humidity	http://www.usgs.gov/hurricane/sandy/ http://www.usgs.gov/hurricane/sandy/#research_themes.html!research_theme_coastal_hydrology.html http://water.usgs.gov/osw/programs/storm_surge1.html

		Protocol Name	Performance Metric(s)	Citation/Source
		Saltmarsh Habitat and Avian Research Program (SHARP)	• Water temperature • Ambient air temperatures at various locations	Saltmarsh Habitat and Avian Research Program (SHARP) http://www.tidalmarshbirds.org/
		U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data	Categories for analysis: • Organic-analyte Samples • Wastewater, Pharmaceutical, and Antibiotic Compounds • Arsenic • Low-level Mercury	U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A9, available online at: http://water.usgs.gov/owq/FieldManual/
		Oyster habitat restoration monitoring and assessment handbook	• Water Temperature • Salinity • Dissolved oxygen (subtidal reefs only) • Light penetration	Baggett, L.P., S.P. Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, and S. Morlock, 2014. Oyster habitat restoration monitoring and assessment handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/wp-content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pdf
		Tidal Marsh Vegetation Transects and Survey Plot Standard Operating Procedures	• Water depth	US Geological Survey. 2011. Vegetation standard operating procedures. Unpublished protocols. USGS, Western Ecological Research Center, San Francisco Bay Estuary Field Station, Vallejo, CA. http://tidalmarshmonitoring.org/monitoring-methods-vegetation.php
		Sea Grass	• Dissolved oxygen concentration • Turbidity • Attenuation of photosynthetically active radiation • Temperature • Salinity • Chlorophyll concentrations	http://science.nature.nps.gov/im/units/ncbn/monitor/estuaries.cfm
		National Park Service, Inventory and Monitoring, Southeast Coast Network (USGS Elevation Protocols)	• Water temperature • Salinity • Dissolved oxygen	DeVivo, J. C., J. Asper, S. Eastman, N. M. Rankin, L. C. Baron, A. C. Curtis, C. J. Wright, E. Thompson, M. B. Gregory, and M. W. Byrne. 2013. Protocol for monitoring coastal salt marsh elevation and vegetation communities in Southeast Coast Network parks. Natural Resource Report NPS/SECN/NRR—2013/xxx. National Park Service, Fort Collins, Colorado. http://science.nature.nps.gov/im/units/secn/monitor/saltmarsh.cfm http://science.nature.nps.gov/im/units/secn/publications

		Protocol Name	Performance Metric(s)	Citation/Source
				.cfm?tab=2&SaltmMarshElevation=open#ProtocolSaltmMarshElevation
		Benthic Habitat Mapping: USGS	• Water column (structure, hydroform, salinity, oxygen, temperature, turbidity, photic quality, trophic status, temporal persistence biotic group, biotope),	http://pubs.usgs.gov/of/2010/1264/
		Salt Marsh Integrity Index	• Surface water salinity	Shriver, W. G., Wiest, W. A., Adamowicz, S. C., Tymkiw, E. L., Chadbourne, K. A., and King, E. 2015. Northeast Regional Protocol for the Inventory and Monitoring of Salt Marsh Integrity. USFWS Region 5, Hadley, MA. 240 pp.
	Soils/Sediment	Flood Deposit Sediment Chemistry and Microbiology:	• Metals: lead, zinc, cobalt, cadmium, manganese, arsenic, and nickel, iron, aluminum, copper • Pyrite • Organic contaminants: Polycyclic aromatic hydrocarbons (PAHs), pesticides, and polychlorinated biphenyls (PCBs) • PAH benzo(a)pyrene, dieldrin (an organochlorine pesticide • Human enteroviruses in soils • Bacterial pathogens commonly found in soils	Paper on results, not a protocol Plumlee, G.S., Foreman, W.T., Griffin, D.W., Lovelace, J.K., Meeker, G.P., and Demas, C.R., 2007, Characterization of flood sediments from Hurricane Katrina and Rita and potential implications for human health and the environment, In Farris, G.S., Smith, G.J., Crane, M. P., Demas, C.R., Robbins, L.L., and Lavoie, D.L., (eds), Science and the storms: the USGS response to the hurricanes of 2005: U.S. Geological Survey Circular,1306, p. 246- 257. http://pubs.usgs.gov/circ/1306/pdf/c1306_ch7_i.pdf
		USEPA/USGS Sample Collection Protocol for Bacterial Pathogens in Surface Soil	• Detection of naturally occurring bacterial microorganisms • Soil moisture • Soil temperature • Soil pH	Bowling, C. and Griffin, D.W., 2014. USEPA/USGS Sample Collection Protocol for Bacterial Pathogens in Surface Soil, Vol. 1. U.S. Environmental Protection Agency, in review, 40 p. http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CCEQFjAA&url=http%3A%2F%2Fcfpub.epa.gov%2Fsi%2Fsi_public_file_download.cfm%3Fp_download_id%3D520008&ei=q-lcVZDDFbeZsQSIiIPwCA&usg=AFQjCNFtgWT8pokuKsxkARmvUrBpUO_anQ&bvm=bv.93756505,d.cWc
		Estuarine Sediment Chemistry, Toxicity and Biological Assays	• Trace metals• Polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and legacy pesticides • Organic carbon• Particle size analysis• Diatoms • Bioassays: measure perturbations in steroid hormones (estrogens and androgens), glucocorticoid hormones, and protein phosphatases • Sediment toxicity	Paper with references to protocols, as well as some methods informationFischer, J.M., Phillips, P.J., Reilly, T.J., Focazio, M.J., Loftin, K.A., Benzel, W.M., Jones, D.K., Smalling, K.L., Fisher, S.C., Fisher, I.J., Iwanowicz, L.R., Romanok, K.M., Jenkins, D., Bowers, L., Boehlke, A., Foreman, W.T., Deetz, A.C., Carper, L.G., Imbrigiotta, T.E., and Birdwell, J., (2015) Estuarine bed-sediment-quality

		Protocol Name	Performance Metric(s)	Citation/Source
			• Screening approaches for determining inorganic compound concentrations, the presence of organic functional groups, and the potential for sediment to inhibit biological activity • Soil pH • Salinity	data collected in New Jersey and New York after Hurricane Sandy, 2013: U.S. Geological Survey Data Series 905, 42 p., plus CD-ROM. http://pubs.usgs.gov/ds/0905/orhttp://pubs.usgs.gov/ds/0905/support/pdf/ds905.pdf
		Suspended sediment fluxes in a tidal wetland	• Water flux • Suspended sediment concentrations • Net sediment flux	Ganju, N. K., Schoellhamer, D. H., & Bergamaschi, B. A. (2005). Suspended sediment fluxes in a tidal wetland: Measurement, controlling factors, and error analysis. Estuaries, 28(6), 812-822 http://water.usgs.gov/fluxes/publications/ganju_et_al_bi.pdf
		Inferring tidal wetland stability from channel sediment fluxes	• Net sediment fluxes	Ganju, N. K., Nidzieko, N. J., & Kirwan, M. L. (2013). Inferring tidal wetland stability from channel sediment fluxes: Observations and a conceptual model.Journal of Geophysical Research: Earth Surface, 118(4), 2045-2058. https://pubs.er.usgs.gov/publication/70103852
		Tidal Marsh Vegetation Transects and Survey Plot Standard Operating Procedures	• Soil salinity	US Geological Survey. 2011. Vegetation standard operating procedures. Unpublished protocols. USGS, Western Ecological Research Center, San Francisco Bay Estuary Field Station, Vallejo, CA. http://tidalmarshmonitoring.org/monitoring-methods-vegetation.php
		National Park Service, Inventory and Monitoring, Southeast Coast Network (USGS Elevation Protocols)	• Description of sediment type • Soil salinity	DeVivo, J. C., J. Asper, S. Eastman, N. M. Rankin, L. C. Baron, A. C. Curtis, C. J. Wright, E. Thompson, M. B. Gregory, and M. W. Byrne. 2013. Protocol for monitoring coastal salt marsh elevation and vegetation communities in Southeast Coast Network parks. Natural Resource Report NPS/SECN/NRR—2013/xxx. National Park Service, Fort Collins, Colorado.http://science.nature.nps.gov/im/units/secn/monitor/saltmarsh.cfmhttp://science.nature.nps.gov/im/units/secn/publications.cfm?tab=2&SaltmMarshElevation=open#ProtocolSaltmMarshElevation

		Protocol Name	Performance Metric(s)	Citation/Source
		Northeast Temperate Network long-term forest monitoring protocol (NPS)	• Soil chemistry acid stress: Ca:Al ratio • Soil chemistry nitrogen saturation: C:N ratio	Northeast Temperate Network long-term forest monitoring protocol: 2012 revision. Natural Resource Report NPS/NETN/NRR—2013/639. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/App/Reference/DownloadDigitalFile?code=516412&file=NETN_Forest_Monitoring_2014_Revision.pdf
		Monitoring and evaluating the ecological integrity of forest ecosystems	• Soil chemistry acid stress: Ca:Al ratio • Soil chemistry nitrogen saturation: C:N ratio	Monitoring and evaluating the ecological integrity of forest ecosystems Geraldine L. Tierney1, Don Faber-Langendoen, Brian R. Mitchell, W. Gregory Shriver, and James P. Gibbs Front Ecol Environ 2009; 7(6): 308–316, doi:10.1890/070176 http://www.esajournals.org/doi/pdf/10.1890/070176
		Sea Grass	• Organic carbon concentrations in estuarine sediment	http://science.nature.nps.gov/im/units/ncbn/monitor/estuaries.cfm
		USEPA/USGS Sample Collection Protocol for Bacterial Pathogens in Surface Soil	• Soil moisture • Soil temperature • Soil pH	Bowling, C. and Griffin, D.W., 2014. USEPA/USGS Sample Collection Protocol for Bacterial Pathogens in Surface Soil, Vol. 1. U.S. Environmental Protection Agency, in review, 40 p. http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&ved=0CCEQFjAA&url=http%3A%2F%2Fcfpub.epa.gov%2Fsi%2Fsi_public_file_download.cfm%3Fp_download_id%3D520008&ei=q-lcVZDDFbeZsQSIiIPwCA&usg=AFQjCNFtgWT8pokuKsxkARmvUrBpUO_anQ&bvm=bv.93756505,d.cWc
Structural/ Engineering		Dam Removals/Fish Passage: NOAA Restoration Center Fish Passage Barrier Removal Performance Measures and Monitoring Worksheet and Guidance	Pre and Post Implementation: • Channel width • Channel slope • Maximum jump height (for fish)	This is not a formal protocol with methods, it provides guidance on what metric to measure but not how to measure them. Additional metrics on maintenance costs and public safety are included but not presented here. http://www.habitat.noaa.gov/toolkits/restoration_center_toolkits/forms_and_guidance_documents/ori_monitoring_sheet_w_guidance.pdf
		Oyster habitat restoration monitoring and assessment handbook	• Reef areal dimensions • Reef height	Baggett, L.P., S.P. Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, and S. Morlock, 2014. Oyster habitat restoration monitoring and assessment

		Protocol Name	Performance Metric(s)	Citation/Source
				handbook. The Nature Conservancy, Arlington, VA, USA., 96pp.http://www.oyster-restoration.org/wp-content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pdf
		Benthic Habitat Mapping: USGS	• Sub-benthic (structure and function of substrates and sub-benthic habitats) • Geoform (structure of the seafloor)	http://pubs.usgs.gov/of/2010/1264/
		Salt Marsh Integrity Index	• Marsh shape • Fragmentation • Amount of marsh edge	Shriver, W. G., Wiest, W. A., Adamowicz, S. C., Tymkiw, E. L., Chadbourne, K. A., and King, E. 2015. Northeast Regional Protocol for the Inventory and Monitoring of Salt Marsh Integrity. USFWS Region 5, Hadley, MA. 240 pp.
	Shoreline Position	National Park Service (NCBN) Coastal Shoreline Monitoring Protocol and Standard Operating Procedures	• Most recent and highest swash line • Neap high-tide swash line • Determining change in shoreline position	https://irma.nps.gov/App/Reference/DownloadDigitalFile?code=154166&file=NCBN_shoreline_FORMATTED.pdf https://irma.nps.gov/App/Reference/Profile/664308 and USFWS National Wildlife Refuge Companion Guide to the National Park Service (NCBN) Coastal Shoreline Monitoring Protocol and Standard Operating Procedures (2011)
		Oyster habitat restoration monitoring and assessment handbook	• Shoreline loss and gain (change in shoreline position)	Baggett, L.P., S.P. Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, and S. Morlock, 2014. Oyster habitat restoration monitoring and assessment handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/wp-content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pdf
	Coastal Topography/ Elevation (Estimations require collection of	National Park Service (NCBN) Coastal Topography Protocol	• Dune, beach, bluff, bluff morphology • easting and northing in Universal Transverse Mercator (UTM) units • Elevation relative to North American Vertical Datum of 1988 (NAVD 88) • Tidal datum	https://irma.nps.gov/App/Reference/DownloadDigitalFile?code=457501&file=NCBN_CoastalTopography_Protocol_25October2012.pdf https://irma.nps.gov/App/Reference/Profile/2190640

		Protocol Name	Performance Metric(s)	Citation/Source
	subsurface nearshore (0-20m water depth) geophysical data)	National Park Service, Inventory and Monitoring, Southeast Coast Network (USGS Elevation Protocols)	• Sediment surface elevation table (SET)	Based on USGS Patuxent Wildlife Research Center SET protocol. Vegetation protocol in developmentDeVivo, J. C., J. Asper, S. Eastman, N. M. Rankin, L. C. Baron, A. C. Curtis, C. J. Wright, E. Thompson, M. B. Gregory, and M. W. Byrne. 2013. Protocol for monitoring coastal salt marsh elevation and vegetation communities in Southeast Coast Network parks. Natural Resource Report NPS/SECN/NRR—2013/xxx. National Park Service, Fort Collins, Colorado.http://science.nature.nps.gov/im/units/secn/monitor/saltmarsh.cfmhttp://science.nature.nps.gov/im/units/secn/publications.cfm?tab=2&SaltmMarshElevation=open#ProtocolSaltmMarshElevation
		National Park Service, Inventory and Monitoring, Northeast Coastal and Barrier Network - Elevation	• Sediment surface elevation • Vertical accretion of sediment • Rate of shallow subsidence	http://science.nature.nps.gov/im/units/ncbn/monitor/saltmarsh.cfm?tab=0
		US Geological Survey Patuxent Wildlife Research Center, Surface Elevation Table (SET)	• Sediment surface elevation • Vertical accretion of sediment • Rate of shallow subsidence	USGS, Patuxent Wildlife Research Center, http://www.pwrc.usgs.gov/set/
		Oyster habitat restoration monitoring and assessment handbook	• Shoreline Profile/Elevation Change	Baggett, L.P., S.P. Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, and S. Morlock, 2014. Oyster habitat restoration monitoring and assessment handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/wp-content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pdf
		Salt Marsh Integrity Index (SMI)	• Marsh surface elevation (relative to a tidal datum such as mean high water or mean sea level)	Based on USGS Patuxent Wildlife Research Center SET protocol. Shriver, W. G., Wiest, W. A., Adamowicz, S. C., Tymkiw, E. L., Chadbourne, K. A., and King, E. 2015. Northeast Regional Protocol for the Inventory and Monitoring of Salt Marsh Integrity. USFWS Region 5, Hadley, MA. 240 pp.

		Protocol Name	Performance Metric(s)	Citation/Source
		Tidal Marsh Monitoring – Elevation	• Ground Based Topographic Mapping using RTK GPS • Bathymetric Mapping • Terrestrial and Aerial LIDAR	http://tidalmarshmonitoring.org/monitoring-methods-elevation.php
		Benthic Habitat Mapping: US Geological Survey	• Bathymetry • Surface geology (composition of the surface substrate)	http://pubs.usgs.gov/of/2010/1264/
		Saltmarsh Habitat and Avian Research Program (SHARP)	• Angle and bearing to maximum horizon • Angle and bearing to minimum horizon	Saltmarsh Habitat & Avian Research Program (SHARP) http://www.tidalmarshbirds.org/based on: Shriver, W. G., Wiest, W. A., Adamowicz, S. C., Tymkiw, E. L., Chadbourne, K. A., and King, E. 2015. Northeast Regional Protocol for the Inventory and Monitoring of Salt Marsh Integrity. USFWS Region 5, Hadley, MA. 240 pp.

Appendix C3. Select Indices and Multi-metric Protocols for Department of the Interior Resilience Projects Performance Metrics.

Index or Program Protocol	Performance Metrics	Citation/Source
NOAA Coastal Resilience Index	• Critical facilities and infrastructure • Transportation issues • Community plans and agreements • Mitigation measures, business plans and social systems	NOAA Coastal Resilience Index (w/ Louisiana and Miss Seagrant) - background: http://seagrant.noaa.gov/News/FeatureStories/TabId/268/ArtMID/715/ArticleID/49/The-Coastal-Community-Resilience-Index.aspx
Salt Marsh Integrity Index (SMI)	• Landscape position • Marsh shape • Fragmentation • Tidal flushing • Amount of marsh edge • Ditch density • Percent ag land w/in 150m • Percent natural land w/in 150m • Percent natural land w/in 1km • Ratio of open water to vegetation • Marsh surface elevation (= marsh elevation within the tidal frame, i.e., relative to a tidal datum such as mean high water or mean sea level) • Mean flood depth • Percent of time marsh flooded • Surface water salinity • Plant species richness • Percent cover brackish terrestrial border veg • Percent cover open water • Percent cover pannes, pools, creeks • Percent cover high marsh • Percent cover low marsh • Percent cover saltmarsh terrestrial border veg • Percent cover upland • Percent cover invasive plants • Necton density and species richness • Fundulus length • Willett abundance • Abundance tidal marsh obligate birds	Shriver, W. G., Wiest, W. A., Adamowicz, S. C., Tymkiw, E. L., Chadbourne, K. A., and King, E. 2015. Northeast Regional Protocol for the Inventory and Monitoring of Salt Marsh Integrity. USFWS Region 5, Hadley, MA. 240 pp.
Saltmarsh Habitat and Avian Research Program (SHARP)	Marsh birds: • Point counts - visual • Call counts (call back) Vegetation (modified from SMI above): • Estimated percent cover for plant communities and open water features • Number of dead snags • Plant species	Saltmarsh Habitat and Avian Research Program (SHARP) http://www.tidalmarshbirds.org/

	• Angle and bearing to maximum horizon • Angle and bearing to minimum horizon Salt Marsh Breeding Birds: • Adult survival rates • Reproductive success (fledging rates) • Sex • Age, chick, adult, egg • Wing length • Head length • Tarsus length • Body mass • Total culmen (bill length) • Nalospi – the distance from the bill tip to the nostril • Bill width at the anterior nares • Bill depth at the anterior nares • Fat scoring (condition) • Pectoral muscle scoring • Feather condition (photos) • Population genetics • Paternity analysis • Contaminant exposure • Hormone levels • Diet • Nest location • Number of eggs and chicks in the nest • Whether eggs were warm or not • Nest bowl was wet or not • Age of any chicks • Any dead eggs or chicks • Female was seen to flush • Distance of observer when the female flushed, • Female chipped at you while you were visiting the nest • Nest status • Maximum number of eggs and chicks • Number of fledged chicks • Number of eggs and chicks found flooded/depredated/missing/etc. • Estimated hatch date and fledge date • Water temperature • Ambient air temperatures at various locations • Nest fate	
USGS Inland Storm-Tide Monitoring (ISTM) Program and Surge, Wave,	• Water level • Wave height • Wave frequency • Tidal crest-stage • Barometric-pressure • Precipitation	http://www.usgs.gov/hurricane/sandy/ http://www.usgs.gov/hurricane/sandy/#research_themes.html!research_theme_coastal_hydrology.html

and Tide Hydrodynamic (SWaTH) Network Standard Operating Plan (DRAFT)	• Wind speed and direction • Air temperature • Relative humidity • High water mark	http://water.usgs.gov/osw/programs/storm_surge1.html
NPS Vegetation Classification Guidelines	• Systematic method for placing plant communities into categories	https://science.nature.nps.gov/im/inventory/veg/docs/NPSVI_Classification_Guidelines_nrpc_final.pdf
Oyster habitat restoration monitoring and assessment handbook	• Reef Areal Dimensions • Reef Height • Live Oyster Density (including recruits) • Oyster Size-Frequency Distribution • Water Temperature • Salinity • Dissolved Oxygen (subtidal reefs only) • Presence of Predatory, Pest, and/or Competitive Species • Disease Prevalence and Intensity • Oyster Condition Index • Gonad Development Status • Oyster Sex Ratio • Shell Volume for Determination of Shell Budget • Percent cover of reef substrate • Nearby-Reef Oyster Density and Associated Size-Frequency Distributions • Nearby-Reef Large Oyster Abundance • Density of Selected Species and/or Faunal Groups • Shoreline Loss/Gain (Change in Shoreline Position) • Shoreline Profile/Elevation Change • Density and Percent Cover of Marsh/Mangrove Plants • Submerged Aquatic Vegetation • Wave Energy and Tidal Water Flows • Seston and/or Chlorophyll a Concentrations • Light Penetration Measurements	Baggett, L.P., S.P. Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, and S. Morlock, 2014. Oyster habitat restoration monitoring and assessment handbook. The Nature Conservancy, Arlington, VA, USA., 96pp. http://www.oyster-restoration.org/wp-content/uploads/2014/01/Oyster-Habitat-Restoration-Monitoring-and-Assessment-Handbook.pd

NPS, Inventory and Monitoring, Southeast Coast Network (USGS Elevation Protocols)	• Nekton species composition and lengths • Nekton species abundance • Water temperature, salinity, water depth, dissolved oxygen, • Tide direction (ebb, flood), • Submerged aquatic vegetation cover • Description of sediment type • Description of surrounding marsh vegetation • Vegetation: percent cover of each species of vegetation present in the plots	DeVivo, J. C., J. Asper, S. Eastman, N. M. Rankin, L. C. Baron, A. C. Curtis, C. J. Wright, E. Thompson, M. B. Gregory, and M. W. Byrne. 2013. Protocol for monitoring coastal salt marsh elevation and vegetation communities in Southeast Coast Network parks. Natural Resource Report NPS/SECN/NRR—2013/xxx. National Park Service, Fort Collins, Colorado. http://science.nature.nps.gov/im/units/secn/monitor/saltmarsh.cfm http://science.nature.nps.gov/im/units/secn/publications.cfm?tab=2&SaltmMarshElevation=open#ProtocolSaltmMarshElevation Braun-Blanquet, J. 1932. Plant Sociology (Transl. G.D. Fuller and H.S. Conrad). McGraw-Hill, New York, 539pp. (percent cover)

Appendix C4. Recommended Core Metrics for Assessing Data Management Systems

Data System Tier	Data Management Objectives	Issues Addressed	Actions	Milestones and Metrics
Federal Open Data Requirements	Establish clear compliance criteria for federally funded projects to meet Open Data requirements, such as mandatory data management plans for projects, data acquisition and processing documentation, sharing machine-readable data products and metadata, and preservation of research data in an approved repository.	Not all projects are aware of their eventual responsibilities as these requirements are being phased in. Acknowledge that different agencies and organizations address these requirements and provide support to projects in different ways.	Identify criteria that must be met at different points in the research process, how federal partner agencies are currently addressing these criteria for their projects, and what guidance and support should be provided to non-federal entities that receive federal funds for research.	Use the common set of compliance criteria as a ratings checklist for projects. Created a matrix to track how projects are meeting requirements, and identified areas needing improvement. Developed support for non-agency researchers.
	Promote the National Archives and Records Administration (NARA) file format guidance for data products to maximize reuse and preservation potential (NARA Bulletin 2014-04).	Many data file formats are used in research but NARA has prioritized those suitable for long-term preservation and reuse. Project data products should meet exchange standards and future archival needs without reformatting.	Adopt the NARA electronic file format guidance to be used preferentially for sharing and archiving data. This may be in addition to primary data products released from a project using a different format. Identify or create tools to transform data from other formats to the preferred formats.	Use NARA-approved formats for research data products. Projects generated at least one copy of original data in the formats approved for archival purposes. Identified other common formats that require new tools to convert to preferred formats.
	Identify the minimum set of metadata elements to meet federal requirements, and document the required data elements within each of the common metadata standards. Make metadata translation services widely available.	Projects may document their data using any one of several acceptable metadata standards (ISO, FGDC, EML, etc.) having different syntax and organization of attributes. Downstream consumption of metadata into catalogs and data services requires syntactic translation from one format to another. Metadata should only need to be created once to be used in more than one system or context.	Identify existing metadata translation services and map out translation paths from each standard to expected federal data catalog formats (e.g., Data.gov).	Established a common service for translating between metadata standards and file formats (text, JSON, XML) and evaluating content for completeness. Included extraction services that create a valid subset of attributes for federal data catalogs.

Data System Tier	Data Management Objectives	Issues Addressed	Actions	Milestones and Metrics
Enterprise Data Systems (agency, initiative, or program-level focus)	Projects will produce and share high-quality and reviewed data products and metadata at the end of the project funding cycle. Failure to meet this requirement will negatively affect future funding opportunities.	Projects often do not budget or plan for end-of-project activities that were part of the funding contract agreement.	Develop a data management checklist to be used as a guide for planning, reviews during the research cycle, and to verify completion of responsibilities at the project close. Require periodic data management reviews during the project cycle that include a check on data management plan currency, data handling and storage practices, and production of data and process metadata. Include completion of data management objectives as a precondition for publication of research results. Develop a mechanism to intercept poor past performers that apply for new funding opportunities.	Projects maintain up-to-date documentation of their research activities and data. Provided a data management checklist to be used as a guide for planning, reviews during the research cycle, and to verify completion of responsibilities at the project close.
	Establish a minimum set of geospatial information that each project should produce for the proposal stage and at project completion.	It is difficult to map research areas, illustrate the scope of programs or funding venues, or investigate opportunities for collaboration when comparable project geospatial data are unavailable. Spatial details of where work was performed (e.g., general areas considered for random sampling, sampling locations) may not be managed as a product of research.	Establish a minimum set of geospatial attributes that each project will produce and make available, including a way to link to extended project information. Create a system to assemble these artifacts that includes a mechanism for updating or amending project spatial information	Published minimum criteria for a spatial representation of project work areas and sampling locations, both for the proposal stage and project finalization. Developed a framework for assimilating and sharing these data.

Data System Tier	Data Management Objectives	Issues Addressed	Actions	Milestones and Metrics
	Develop subject-area data models to communicate and improve our understanding of how different kinds of data are organized and used together to answer science questions and make decisions. Create basic generic data templates and guidance from these models that projects can use for storing and managing common data types.	Projects may not have guidance for building datasets for common data types, and ad hoc data structures may be incomplete with regard to compatibility with similar data or integration into larger systems. A unified framework of interrelated models will help communicate required and shared data elements and foster improved data exchange and integration processes.	Identify data themes for generic data models and have subject expert teams produce high-level conceptual and logical models that represent their data resources. Use the models to create an integrated data model that identifies key relationships between subjects, critical linking fields, and common domains. Strengthen existing data delivery mechanisms to serve data in the context of the integrated model.	Project data management plans include basic data models to illustrate what data are being used and how they are related. Established a web presence for the common subject-area and integrated data models, and provided templates that projects can use to develop their data. Identified model gaps and incompatibilities in the context of specific research questions, and continued to refine the models and their interactions.
	Identify authoritative data resources to be used preferentially by researchers as 'external data sources' to ensure the highest level of data quality and interoperability of research results. Where lacking, promote the development of new authoritative data resources for commonly used data types.	Data products and research results based on dissimilar sources of similar data may create comparability conflicts beyond the immediate project scope. Authoritative data resources represent fully documented and quality controlled data that are ready to use by projects as a 'data source' in research DMPs. Researchers can spend less time looking for and structuring data, and benefit from tools and processes developed for the data resource.	Identify major data themes (weather, hydrology, ecology, etc.) and available data resources within those themes to establish priority-use national or regional datasets that should be used preferentially by projects for 'source' data. Document best practices for acquiring, using, and combining data from authoritative sources.	Created a catalog of authoritative data resources, with annotations regarding best uses and alternatives. Provided examples of data acquisition and integration of data from the preferred data resources.
	Require the use of published methods for field research activities, or that new methods are published as part of the research project scope.	Projects may create custom methods for collecting or generating data when standard methods exist but were unknown to them. Embedding useful	Make the use of methods published in NEMI (National Environmental Methods Index) or a similar system of methodologies a requirement of field work. Have researchers	Added use of published methods to data management planning requirements and for data product metadata. When

Data System Tier	Data Management Objectives	Issues Addressed	Actions	Milestones and Metrics
		methodologies within published interpretive papers does not promote their reuse by a wider audience.	document any variations from standard methods to ensure data users understand possible incompatibilities with other data. When a project uses a new method it should be published and added to an appropriate methods catalog.	new methods are invented, they are published and submitted to an appropriate catalog as part of the project scope. New methods that are fully described in a research paper are acceptable for referencing and do not need a separate publication venue.
	Catalog important descriptive and classification domains that researchers should use preferentially to ensure the highest level of comparability of datasets.	Projects may create custom classification schemes and descriptive categories within their research data when appropriate standard domains exist but were unknown to them. Use of standardized, discipline supported classification schemes (e.g., land use classification, soil types, hydrologic regions, taxonomy) will increase a datasets' reuse potential by simplifying comparison and integration with other datasets.	Identify existing classification domains that are maintained by an agency or organization and whose terms should be used preferentially by projects (land use class, soil type, ecoregion, taxonomy, and others). Associate domains with appropriate subject areas and data themes.	Created a web catalog for finding and linking to existing domains, with annotations about related domains and best practices for use in different subject areas or themes.
	Require the use of well-maintained ontologies and thesauri to use for grouping terms and keywords that describe a project's scope, activities, and data.	Ad hoc attempts to develop terms for thematic or topical groupings are often not based on any organized method, resulting in uneven classification schemes and poorly defined terms and keywords. By providing a framework from which to extract terms, hierarchies and data leveling can be enhanced, and analysis of keyword use can lead to better ontologies. Semantic technologies require the use of formalized terms	Establish a priority ordering of thesauri to be used for harvesting terms used to classify and group projects, datasets, and data. Foster the use of fully defined terms as keywords, including the ability to cross-reference to related and subordinate terms.	Created a web catalog of available ontologies and thesauri, with annotations about best practices for use in different subject areas and cross-compatibility.

Data System Tier	Data Management Objectives	Issues Addressed	Actions	Milestones and Metrics
		to perform at a high level.		
	Establish a data dictionary for commonly used data attributes, such that new projects adopt established and defined data elements and data users can understand the broader context of data elements across the enterprise.	Data producers may invent and define attributes that make then unsuitable for use beyond the project scope when suitable alternatives were available but unknown. Reduce ambiguity in datasets that might use similar terms to mean different things.	Based on thematic models, provide a basic set of core attributes (fields) with definitions. Distinguish and reconcile 'similar' fields that are defined differently due to context (dissimilar). Highlight attributes that are shared across subject areas or that represent key linking fields for data integration.	Identified common attributes by subject areas and themes, equipped them with clear definitions, and provided examples of their use. Made this information available with the common subject area models.
Project-level Data Management	Require adherence to federal Open Data and appropriate enterprise data requirements outlined above.	Research projects are rightly focused on the research activities and interpretation of data, and may not understand the complete set of data requirements imposed by funding entities or sponsoring organizations.	Require projects to consult with a data manager before data collection begins. Identify agency resources to guide the project during the research cycle or provide direct support when needed.	Projects include the results of data management reviews and consultation as a part of periodic project status meetings.
	Provide for archival storage of research artifacts such as field records and physical samples. Federal guidelines may apply.	Projects need to follow basic records management practices, and that includes handling and retention of non-digital assets. Minimize the loss of important evidence related to the research.	Require projects to address the disposition of physical research assets in their data management plan.	Projects include a summary of physical asset management activities as a part of periodic project status meetings.
Local Systems Integration	Identify local system knowledge and data resources, and construct mechanisms for seamless data sharing.	Identify and resolve inconsistencies in measurements and data models (GAP). Promote a data sharing attitude among researchers.	Design a mechanism for cataloging and classifying local knowledge and data resources. Address GAP issues.	System is transparent and available and gathers feedback for improvement.
Communications and Decision Support Systems	Make decision support models and systems accessible.	Improve the timeliness and effectiveness of decision-making.	Provide enterprise resources for decision support tools	To be determined
	Establish systems for communicating about data portals, standards, models, and research products.	Create an environment where disparate activities are placed in context.	Provide enterprise web resources for communications and collaboration.	To be determined

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