

# **Vulnerability Assessments in Support of the Climate Ready Estuaries Program: A Novel Approach Using Expert Judgment**

## **Volume II**

### **Results for the Massachusetts Bays Program**

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## **ABSTRACT**

The Massachusetts Bays Program (MBP) and the Environmental Protection Agency (EPA) collaborated on an ecological vulnerability assessment, using a novel methodology based on expert judgment, to inform adaptation planning under EPA's Climate Ready Estuaries Program. An expert elicitation-type exercise was created to systematically elicit judgments from experts in a workshop setting regarding climate change effects on two key ecosystem processes within salt marsh systems: sediment retention and community interactions. Specific workshop objectives were to assess 1) the relative influences of physical and ecological variables that regulate each process, 2) their relative sensitivities under current and future climate change scenarios, 3) the degree of confidence about these relationships, and 4) implications for management. For each process, an influence diagram was developed identifying key process variables and their interrelationships (influences). Using a coding scheme, each expert characterized the type and degree of each influence to indicate its nature and sensitivity under current and future climate change scenarios. The experts also discussed the relative impact of certain influences on the endpoints. This report demonstrates how particular pathways in such diagrams can be linked to management options and examined in the context of planning documents to identify opportunities for 'mainstreaming' adaptation into strategic planning.

**Vulnerability Assessments in Support of the Climate Ready Estuaries Program: A Novel Approach Using Expert Judgment**

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## EXECUTIVE SUMMARY

The Massachusetts Bays estuaries are highly vulnerable to climate-related changes including changes in precipitation, altered hydrology, increased effects of winds and waves, and sea level rise. Impacts such as increased inundation of coastal wetlands, changes in water availability and quality, and altered patterns of sedimentation and erosion are increasingly interacting with other human stressors such as nutrient loading and land use changes. Thus it is essential that estuary managers become ‘climate-ready’ by: assessing the vulnerability of natural resources to climate change; choosing strategically among adaptation strategies in the near term; and engaging in longer term planning based on a range of plausible scenarios of future change. In an era of shrinking budgets coupled with increasingly complex decision-making needs – often taking place in a context of uncertainty and incomplete information – managing natural resources in the face of climate change will be challenging. There is a need for assessment methods that take advantage of existing scientific expertise to help identify robust adaptation strategies, weigh difficult trade-offs, and justify strong action, all in a timely and efficient manner.

The purpose of this project was to carry out a pilot vulnerability assessment for the Massachusetts Bays Program’s (MBP) natural resources using expert judgment, the results of which could be linked to adaptation planning. To this aim, EPA’s Office of Research and Development collaborated with MBP on a novel expert elicitation exercise for ‘rapid’ vulnerability assessment. A trial exercise was carried out during a two-day workshop in which two groups of seven experts each focused on two key salt marsh ecosystem processes: 1) sediment retention and 2) community interactions within saltmarsh sharp-tailed sparrow nesting habitat (Figure ES-1). The exercise, which was based on formal expert elicitation techniques but tailored specifically for qualitative analysis of ecosystem processes, was designed to glean expert judgments on the sensitivities of ecosystem process components under future climate scenarios. This was followed by group discussions of the implications of the results for management in light of climate change, as well as feedback on the exercise itself.

**Figure ES-1. Selected ecosystem processes for the pilot vulnerability assessment.**

### Sensitivities and Potential Adaptation Responses

*Using the experts’ judgments on the sensitivities of key ecosystem process components to future climate conditions, it is possible to identify ‘top pathways’ for which there are available adaptation options.* After creating influence diagrams showing the relationships among key process variables (Figures ES-2 and ES-3), the experts generated information on which relationships may show, under future climate change: 1) increasing relative impact on the

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overall process; 2) increasing sensitivity; and 3) abrupt threshold changes. Based on the amount of expert agreement on each relationship, it is possible to identify ‘top pathways’ of interest for management. Three top pathways for each process are described below, with accompanying discussion of adaptation options for management.

**Figure ES-2. Top pathways for management of the Sediment Deposition/Retention endpoint. Colors are used to distinguish different pathways. Red symbols highlight potential changes under future climate conditions.**

**Figure ES-3. Top pathways for management of the Saltmarsh Sharp-Tailed Sparrow Nesting Habitat endpoint. Colors are used to distinguish different pathways. Red symbols highlight potential changes under future climate conditions.**

Sediment Retention Purple pathway: In this pathway (Figure ES-2), the experts identified the potential for a threshold shift in the effect of marsh edge erosion on sediment deposition and retention, from a mild inverse effect to a much stronger inverse effect. Marsh edge erosion occurs when wave energy results in loss of sediment from the seaward edge of the marsh; under current conditions some sediment is re-deposited in the marsh, but some is lost. Under climate change, increased storm intensity in conjunction with sea level rise will expose the marsh edge to greater wave energy for longer periods of the tidal cycle. This will intensify sediment loss from the system as more sediment is carried out of the marsh, leading to an abrupt drop in sediment deposition and retention. Management options under this pathway include:

- Establishing “no wake” zones to reduce erosion due to boat wakes
- Protecting barrier beaches (which protect marshes during storms) through dune grass protection and restoration
- Developing new tools to reduce wave energy before it reaches the marsh edge, such as methods to establish oyster reefs adjacent to marshes
- Monitoring to detect threshold shifts, to identify areas losing sediment as priorities for action and to measure effectiveness of interventions.

Sediment Retention Green pathway: This pathway (Figure ES-2) contains a threshold shift in sediment deposition and retention in response to inundation regime (depth and duration of marsh flooding). Under current conditions, an increase in inundation leads to increased transport into, and deposition of sediment onto, the marsh. However, this relationship flips from a direct to an inverse effect under climate change, when sea level rise increases inundation to such an extent that increased tidal flow velocities suspend more sediment than is deposited, leading to a net decrease in deposition and retention. An increasing relative impact of sea level leads to this threshold through marsh high water level (the transition from marsh to upland

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vegetation). Given the significance of tidal restrictions in influencing inundation regime, this additional branch of the pathway has important implications for management. Options include:

- In the near term, relieving tidal restrictions to restore upstream hydrology, salinity and sediment transport, thereby supporting upland migration of marsh high water level
- In the longer term with sea level rise, using tide gates that can be closed prior to storms or spring tides to avoid peak flooding and associated high flow velocities during inundation
- Modifying ditches to restore more natural hydrology
- Removing barriers to upland migration such as roads and hardened shorelines
- Advancing policies and incentives that limit building of new barriers and encourage conservation easements and other protections.

Sediment Retention Blue pathway: Climate-related changes are expected in three influences along this pathway (Figure ES-2). Starting at the sediment deposition and retention endpoint, an increase in net accretion (net change in elevation) currently decreases sediment deposition by reducing flow velocities during inundation, such that much sediment drops out of suspension before making its way very far into the marsh; but with higher sea level under climate change, a threshold flip will occur where greater water depths during inundation result in higher flow velocities that carry suspended sediment further into the marsh. Net accretion is directly affected by below ground biomass, which is itself involved in a second threshold relationship with nutrient inputs. Nutrients currently have a positive effect on below ground biomass through stimulation of above ground growth; but under climate change this flips to a negative effect as excessive nutrients inversely affect below ground productivity and increase decomposition, with increasing relative impact on the end point. Finally, delivery of nutrients via freshwater flows is affected by percent impervious cover in the adjacent landscape; and the sensitivity of flows to impervious cover is expected to increase with climate change as storms and flashiness of precipitation events intensify. Management options under this pathway include:

- Improving stormwater management through the use of permeable pavements, rain catchers and buffers
- Upgrading sewage treatment plants to include tertiary treatment
- Upgrading combined sewer overflow systems to ensure all sewage passes through upgraded treatment
- Engaging in public outreach to inform homeowners of the best timing, placement and application rates for fertilizers.

Community Interactions Green pathway: The climate-related shift examined in this pathway (Figure ES-3) is the effect on marsh elevation of the ratio of native high marsh to invasive *Phragmites* (high marsh:Phrag). Marsh elevation is one of only three variables that feed directly into the nesting habitat endpoint, and all of the top pathways converge on this one relationship. Currently, a decrease in high marsh:Phrag leads to a modest increase in marsh

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elevation because *Phragmites* is more effective at trapping sediment (due to large rhizomes at the marsh surface). This relationship strengthens under the climate scenarios as a threshold shift to a stronger inverse relationship. With increasing sea level rise, *Phragmites* will be better equipped to maintain elevation and migrate landward to higher elevations while continuing to more effectively trap sediment in place, compared to native high marsh that would lose elevation rapidly. The remainder of the pathway includes the effect on high marsh:Phrag of nitrogen (which favors *Phragmites*) and the effect on nitrogen delivery of inundation affected by flows from residential runoff. Management options under this pathway include:

- Promoting more absorbent land cover (including permeable pavements)
- Ugrading treatment plants and improving stormwater management to reduce nutrient-rich runoff
- Creating incentives for decreased use of fertilizers on lawns, regular inspections of septic systems, and rain catchers to further reduce nutrient-rich runoff
- Coupling *Phragmites* control programs with removal of barriers to migration and protection of upland areas to allow native high marsh to expand as sea level rises.

Community Interactions Purple pathway: Starting at the nesting habitat endpoint and working backwards, the Purple pathway (Figure ES-3) corresponds with the Green pathway in its first two influences; so see above for discussion of the threshold effect of high marsh:Phrag on marsh elevation. The Purple pathway then diverges to focus on salinity's effect on high marsh:Phrag. Greater salinity inhibits *Phragmites* and thus has a direct positive effect on high marsh:Phrag, with high relative impact on nesting habitat. The high relative impact is due to a competitive interaction between salinity and nitrogen, where increased salinity has a negative impact on *Phragmites* while increased nitrogen has a positive effect. Salinity's high relative impact will increase more under climate change, as sea level rise leads to increased inundation of saline water for longer periods, higher into the marsh (placing greater pressure on *Phragmites*). Given the effect of freshwater flows (exacerbated by impervious surfaces in residential areas) in counteracting salinity maintenance, management options under this pathway include:

- Prioritizing the use of permeable pavements and rain catchers to reduce freshwater runoff, thereby helping to maintain natural salinity levels
- Controlling the hydrodynamic regime (e.g., through channel creation/ditch modification) to maintain salinity through unimpeded tidal inundation
- Restoring riparian buffers and upstream freshwater marshes to reduce freshwater flows and favor local infiltration and storage of rain water.

Community Interactions Blue pathway: The Blue pathway (Figure ES-3) focuses on marsh elevation from the perspective of sedimentation. Sedimentation directly affects marsh vertical accretion and is itself directly affected by above ground plant biomass as a source of organic sediment. Climate-related shifts occur in the way above ground plant biomass is

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affected by inundation regime (percent time high marsh is under water April-October). Currently, inundation regime favors above ground plant biomass since flushing via inundation prevents soil salinity from reaching levels that inhibit growth. Thus, just as an appropriate inundation regime is important for maintaining salinity (see Purple pathway above), it is also important for preventing salinity from becoming too high. Under climate change, however, this influence shifts from a direct to an inverse effect: as sea level rises, inundation frequency and duration are expected to reach levels that cause increased hypoxia and marsh die-back, with increasing relative impact on the endpoint. Management options under this pathway include:

- In the near term, restoring tidal connections (e.g., by removing tidal restrictions) to support appropriate inundation regimes
- In the longer term (at some point in the next 30-60 years with sea level rise), utilizing restrictions (e.g., through use of tide gates) to control flows appropriately
- Restoring native high marsh habitat in protected areas where marsh can grow and expand
- Prioritizing marsh restoration and protection activities in locations where natural flows and good sediment supplies are already in place.

***Based on the nature and timing of the sensitivity, some actions can be taken immediately while others require monitoring and planning for multiple potential futures.*** In the case of relationships that are well understood and for which there are management options available, the nature of an expected climate-related shift has implications for when managers may want to take action. In cases where the expected shift is toward increasing relative impact (and especially if the relationship is already of high relative impact today), actions can be taken immediately to implement management options to positively affect those pathways. In the case of relationships for which a change in sensitivity is possible under future climate scenarios, the expectation of increasing sensitivity should trigger further study of the relationship in order to anticipate the degree and timing of the impending sensitivity and prepare best management responses. Finally, thresholds are a particular challenge, as it is often impossible to predict exactly when a threshold change will happen. In these cases it will be important to monitor threshold variables to identify the shift when it occurs; in the meantime managers might act to keep the system ‘below’ the threshold as long as possible, while also preparing a plan for what to do when unavoidable shifts occur. After a shift occurs, managers may decide to manage the system differently in its new state, or take no action and instead shift priorities to other goals.

## **Adaptation Planning**

***Relating top pathways and associated adaptation options to existing management activities is a path forward for action.*** The top pathways described above were used to identify

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adaptation options that could be applied to sensitive ecosystem process components. Additional pathways and associated adaptation options can be further explored using the detailed tables of judgments and strategies provided in this report. The next step toward adaptation planning is to connect top pathways and adaptation options to existing management activities and plans.

Under its current goals, MBP is already undertaking a variety of activities that can be related to these adaptation options, as described in its annual, mid-term and long-term planning documents. These include specific restoration, nutrient management, monitoring and research projects and strategies. The climate change sensitivities and adaptation strategies identified in this report can be cross-referenced to activities and objectives in the Strategic and Annual Plans to identify where existing work can be adjusted to better support adaptation. Some examples of such cross-referencing are provided as a starting point for more comprehensive adaptation planning during future planning cycles. The broad goals and objectives articulated in the current Comprehensive Conservative and Management Plan (CCMP) allow for addition of new mid- and short-term actions; and the next revision of the CCMP will be an opportunity to incorporate new higher-level goals and objectives addressing climate impacts beyond sea level rise. The intent is that the results of this assessment will help inform priority investments in projects that take into account specific, known climate sensitivities and make use of particular adaptation options that will be most effective. The assessment results can also assist in priority-setting for long term research and monitoring investment and for partnership building with other organizations.

***‘Mainstreaming’ climate change adaptation into ongoing, iterative planning processes will increase the ability of managers to identify win-win options, weigh multiple trade-offs, and prepare for long-term changes.*** For MBP as well as other National Estuary Programs and organizations with well established planning processes, there are benefits to ‘mainstreaming’ (continuously integrating) adaptation into ongoing planning, rather than developing a stand-alone adaptation plan. The aim is to start with actions that have multiple benefits, i.e., that contribute to current management goals while also responding to climate change. For example, the same activities that can protect shellfish resources by using stormwater best management practices for runoff reduction will also benefit wetlands by favoring native high marsh over invasive *Phragmites* under climate change. Since climate change also has the potential to intensify and even create new trade-offs, mainstreaming adaptation into planning will also be important for identifying and weighing conflicts among adaptation options within the context of existing (and emerging) goals.

Given the long-term nature of the climate change challenge, mainstreaming has an additional advantage over a stand-alone plan in that it helps counteract the tendency to postpone adaptation actions in the face of more immediate challenges. It often may be possible to adjust current practices in ways that achieve adaptation while still fulfilling original goals. An example

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of this is removal of tidal restrictions; current practices for restoring natural hydrology include re-engineering the size of openings at road crossings to allow full tidal exchange. Tide gates have been used in other situations to allow the tide to pass in one direction but to restrict flow in the other. Installing tide gates in places where flooding may become a future problem is one way to adjust current practices since tide gates can be more actively managed (by opening and closing at particular times, such as during spring tides) to allow for full tidal exchange in some circumstances and restricted flow in others.

Finally, thinking ahead as part of planning is essential for anticipating which of today's best practices may become ineffective and even 'maladaptive' as sensitivities change and threshold shifts occur under climate change. Once thresholds have been crossed or other unavoidable changes of significance have occurred, some management goals may have to be revised. For instance, there may be a point in the future when the currently-beneficial effects of removing tidal restrictions will start to negatively impact certain habitat goals, necessitating re-evaluation of this technique as a restoration practice.

## **Evaluation of Expert Judgment Approach**

*A novel methodology based on expert elicitation was developed and piloted as a tool for 'rapid assessment' of ecological sensitivities to climate change.* The aim was to explore whether it is possible to synthesize useful information from experts on key climate sensitivities in the short time frame of a two-day workshop, using expert elicitation techniques. Expert elicitation is a multi-disciplinary process for using expert judgment to inform decision-making when data are incomplete, uncertainties are large, and multiple models can explain available data. The novel methodology introduced here is a modification of formal (usually quantitative) expert elicitation that uses qualitative judgments to explore complex ecological questions. Influence diagrams showing causal relationships among variables were used to capture the experts' collective understanding of selected ecosystem processes under current conditions and under two future (mid-century) climate scenarios. A coding scheme was used to record the judgments, with observational notes and group discussions used to gather additional information.

The result was three categories of information based on the influence diagrams: 1) the direction and strength of the relationships among variables, 2) the changing sensitivities (including potential threshold responses) to climate change of some relationships, and 3) the relationships of highest relative impact on the process as a whole. When this wealth of information is combined into a 'crosswalk' of all three categories, it is possible to identify top pathways (see above) comprised of relatively well-understood relationships that are sensitive to climate change and for which management are options available. Managers are encouraged to

further ‘mine’ the tables for other key pathways applicable to their specific sites and to identify potential research priorities based on information gaps.

***The expert elicitation exercise developed for this assessment has the potential to be useful for other sites, processes and ecosystems.*** While an example Great Marsh site was used as a means to focus the exercise, the variables that ended up in the final influence diagrams are common enough that most of the results may apply to other Massachusetts Bays marshes as well. It is likely that the influence diagrams also could be transferred for use with corresponding ecosystem processes in other northeast estuaries, with minor revisions for place-specific stressors or other process variables; however, the characterizations of variable relationships, sensitivities and relative impacts would have to be revised, particular to the location. Where information on completely different processes is needed, the general methodology should be transferable to other processes and ecosystems. The strengths of this method include its ability to capture more recent knowledge than would be available from a literature review and more knowledge of the type that is closely related to management. It is also effective at integrating across disciplines and scales, which is particularly important for ecosystem and climate change assessments.

As a proof of concept for a new type of assessment exercise, this method and the pilot results come with a number of caveats. This was not a comprehensive vulnerability assessment for the whole estuary, so prioritization based on these results should be considered in the broader context of other vulnerable processes, ecosystems and goals. Given the complexity of these systems and instances of uneven agreement among experts, actions based on the top pathways should be taken with care, with each manager considering the applicability of the information to his or her own specific system. Confidence estimates for individual judgments turned out to be challenging, so improvements have been suggested for strengthening this aspect in future assessments. There is also the potential to simplify the coding scheme based on what was learned in this trial run, to improve efficiency and allow experts more time to fill in data gaps. Regardless, the expert elicitation method developed for this study was well suited for achieving the goals of this assessment, and in a time frame much shorter than would be required for more traditional, detailed quantitative modeling. Having a well-supported and timely study to substantiate new and existing ideas on adaptation can position managers to justify the most appropriate management priorities. It also can validate research priorities by highlighting known research gaps. Overall, the method offers opportunities to capture and integrate the existing collective knowledge of local experts, while pushing the boundaries to develop a new understanding of the system and identify robust adaptation options in the face of climate change.



1 vulnerabilities with respect to management goals; and 5) explore implications for adaptation  
2 planning. Steps 1-2 were used to define the scope of the assessment, while steps 3-5 comprise  
3 the vulnerability assessment itself.

#### 4 5 **1.2.2. Scope**

6 The scoping process began with a review of the MBP Comprehensive Conservation and  
7 Management Plan in order to select key management goals upon which to focus the assessment.  
8 The key ecosystem-related goals selected by MBP in consultation with EPA ORD were:

- 9
- 10 • Protect and manage existing wetlands
  - 11 • Restore and enhance the habitat diversity and living resources of wetlands
  - 12 • Protect submerged aquatic vegetation; and
  - 13 • Prevent the spread of marine invasive species in order to maintain biodiversity.
- 14

15 After an information-sharing meeting with local experts to discuss the project and learn  
16 about climate change impacts and adaptation work in the region, salt marshes were selected as  
17 the focal ecosystem for study. Salt marshes were identified as highly relevant to MBP's  
18 management goals due to their ecological productivity, their habitat values for vulnerable  
19 species, their susceptibility to ongoing encroachment by invasive species, and their sensitivity to  
20 changes in climate-related variables such as sea level rise and altered hydrology. For more  
21 detailed information on goal and ecosystem selection processes, please see Appendix A.

22 The second step in the scoping process was the development of a conceptual model to  
23 understand the primary drivers and processes of salt marshes. The conceptual model was used to  
24 explore the linkages among key ecosystem processes within the ecosystem, major stressors of  
25 concern, and climate drivers causing altered or new stressor interactions. The model was refined  
26 to a set of six key ecosystem processes that are essential to the maintenance of salt marsh  
27 systems. Based on this general conceptual model, two specific processes of concern were  
28 selected for further analysis. The purpose was to select good processes for piloting the method,  
29 but the choice does not imply that these are necessarily the most important or the most  
30 vulnerable processes. The processes were selected based on the criteria of being integral to  
31 MBP's management goals, increasingly sensitive to climate change, and sufficiently well-studied  
32 by the scientific community to provide the basis for a more in-depth assessment.

33 The two processes selected for further analysis were sediment retention and community  
34 interactions. Sediment retention refers to the balance between the processes of removal and  
35 deposition of sediment onto a salt marsh. The topic of community interactions was narrowed to  
36 a tractable "storyline" involving several key species, which was selected based on discussions  
37 with local experts on the MBP staff. The storyline selected was the relationship of marsh  
38 vegetation zonation (between native *Spartina* and invasive *Phragmites* grasses) and the

1 availability of nesting habitat for the Saltmarsh Sharp-Tailed Sparrow (IUCN Red List  
2 vulnerable species). Expanded sub-models were developed for each of the two processes and  
3 served as the basis for designing the sensitivity analyses of the subsequent expert elicitation  
4 exercise. For more detailed information on process selection and conceptual model  
5 development, please see Appendix A.

6 The remaining steps of the assessment – the sensitivity analysis, vulnerability assessment,  
7 and analysis of management implications – were accomplished through an expert elicitation-  
8 style workshop, the results of which make up the core of this report. Expert elicitation is a multi-  
9 disciplinary process using expert judgment to inform decision-making when empirical data are  
10 incomplete, uncertainties are large, more than one conceptual model can explain available data,  
11 and technical judgments are required to assess assumptions. During a two day workshop, a  
12 novel application of the expert elicitation method was tested using two groups of seven expert  
13 participants each. A list of the expert participants for each breakout group is provided in Table  
14 1-1 (for additional information on participant selection criteria and credentials, please see  
15 Appendix B). The participants assessed the sensitivities of salt marsh sediment retention and  
16 community interactions to climate- and non-climate stressor interactions, with an eye toward  
17 informing adaptation strategies. The methodology and results of this expert elicitation exercise  
18 are described in the sections that follow.

19  
20 **Table 1-1. Breakout group participants for the expert elicitation workshop**  
21 **(see Appendix A for further details on selection criteria and credentials)**  
22

### 23 **1.3. ROADMAP FOR THE REPORT**

24 This report presents a summary of the entire project, including CCMP goal selection and  
25 conceptual modeling, the expert elicitation methodology, the results of the workshop, and  
26 implications for management. Figure 1-1 provides a flow chart of the assessment process and  
27 report structure.

28  
29 **Figure 1-1. Vulnerability assessment process.**  
30

31 Section 2 describes the expert elicitation exercise, including the approach, the exercise,  
32 and the results. Section 3 provides an analysis of the results with respect to how they may be  
33 used by estuary managers to understand ecosystem responses to climate change and engage in  
34 adaptation planning. Section 4 provides key conclusions of the assessment. The appendices  
35 provide additional detailed information on the activities conducted prior to and following the  
36 workshop. Appendix A summarizes the goal selection and conceptual modeling processes used  
37 for scoping the vulnerability assessment. Appendix B provides details on the expert elicitation  
38 pre-workshop preparations and post-workshop follow-up, including expert selection criteria, pre-

1 workshop preparations by participants, and expert feedback. Appendix C and Appendix D  
2 contain detailed information that was provided to the participants on the development of climate  
3 scenarios and the methodology for estimating confidence.  
4  
5

## 2. EXPERT ELICITATION EXERCISE

### 2.1. JUSTIFICATION FOR METHOD

#### 2.1.1. Definition and Uses

Expert elicitation is a multi-disciplinary process for obtaining the judgments of experts to characterize uncertainty and fill data gaps where traditional scientific research is not feasible or adequate data are not yet available. The goal of expert elicitation is to characterize each expert's beliefs about relationships, quantities, events, or parameters of interest. The expert elicitation process uses expert knowledge, synthesized with experiences and judgments, to produce conclusions about the nature of, and confidence in, that knowledge. Experts derive judgments from the available body of evidence, including a wide range of data and information ranging from direct empirical evidence to theoretical insights.

Because EPA and other federal regulatory agencies are often required to make important national decisions in the presence of uncertainty, EPA's Science Policy Council formed an Expert Elicitation Task Force in April of 2005 to investigate how to conduct and use this method to support EPA regulatory and non-regulatory analyses and decision-making. The result was an Expert Elicitation Task Force White Paper that affirms the utility of using expert elicitation and provides recommendations for expert elicitation "best practices" based on a review of the literature and actual experience within EPA. The draft paper (see <http://www.epa.gov/spc/expertelicitation/index.htm>) is currently under external peer review through EPA's Science Advisory Board. The best practices outlined in the draft White Paper formed the basis for the design of this project's expert elicitation-style workshop.

#### 2.1.2. Novel Application

The specific elicitation exercise used in this assessment was custom-designed by Dr. Max Henrion of Lumina Decision Systems, Inc. Dr. Henrion is a nationally-recognized authority on decision analysis methods and tools, dealing with uncertainty in environmental risk assessment, and expert elicitation. As a member of EPA's Expert Elicitation Task Force, he was uniquely qualified to assist in designing a novel application of expert elicitation methods for use in a two-day workshop format. Specifically, Dr. Henrion developed a qualitative coding scheme for expert judgments about the sensitivity of ecosystem processes to physical and ecological variables, using "influence diagrams" to depict the relationships among ecosystem process variables and external drivers such as climate change. This new methodology, described in detail below, explores the utility of expert elicitation for conducting "rapid vulnerability assessments" for ecological systems.



## 2.2. WORKSHOP DESIGN AND METHODOLOGY

### 2.2.1. Workshop Goals and Objectives

The overarching goals of the workshop were to: 1) improve the understanding of the sensitivity of salt marshes to the projected impacts of climate change; 2) improve the ability to identify adaptation management strategies that mitigate the impact of climate change in salt marshes, given the uncertainties; and 3) demonstrate the applicability of an expert elicitation approach to this type of analysis.

The workshop was held April 27-28, 2010, in Boston, Massachusetts, at the EPA Region 1 office. During the workshop, experts were divided into two breakout groups to consider each ecosystem process separately. The seven participants in each breakout group (see Table 1-1) were asked to provide judgments about the ecosystem process under consideration by their group. For each ecosystem process, the specific workshop objectives were to: 1) characterize the relative influences of physical and ecological variables that regulate the process; 2) assess the relative sensitivity of the ecosystem process to key stressors under current conditions and future climate scenarios; 3) assess the degree of confidence in judgments about these relationships; and 4) relate the results of the exercise to adaptation planning through group discussions. Given the range of habitats and issues in the entire Massachusetts Bays area, the participants were asked to consider Jeffrey's Neck Marsh (Great Marsh System) when a more specific spatial scope would be useful during the workshop exercise, as well as when considering management implications. However, issues and options that were not specific to Jeffrey's Neck Marsh were also considered during group discussions.

For further details on workshop preparation and implementation, including selection criteria for participants and details on Jeffrey's Neck Marsh, please see Appendix B.

### 2.2.2. Approach and Methodology

According to protocols put forth in EPA's Expert Elicitation Task Force White Paper, there are a variety of options for gathering and processing expert judgments. The specific elicitation approach used in this workshop was one that asked experts to give their individual judgments independently. This was done to reduce the tendency towards "group-think," i.e., the tendency for many people to go along with the most vocal participant, even if s/he is not the most knowledgeable. Participants had an opportunity to make adjustments to their judgments at any time during or after group discussions; however, consensus was *not* the goal of the exercise. Rather, the aim was to look at the expert judgments in aggregate, while also retaining information on variance in judgments. This approach is well-suited to the type of qualitative judgments participants were asked to make at the workshop.

### 1 2.2.2.1. *Influence Diagrams*

2 Each breakout group participated in the development of an influence diagram of the  
3 ecosystem process under consideration by their group. Decision analysts use influence diagrams  
4 as a way to define the qualitative structure of causal relationships among variables that experts  
5 believe are of greatest importance for understanding the problem being evaluated. Influence  
6 diagrams typically represent a subset of a larger, more detailed model such as the conceptual  
7 models developed previously (see Appendix A).

8 A simplified influence diagram for sediment retention is provided in Figure 2-1. By  
9 convention, the variables in an influence diagram are represented by rectangles (labeled boxes)  
10 while arrows between the variables represent causal relationships, or “influences” (labeled with  
11 letters). Sequences of arrows form pathways, all of which ultimately lead to the final variable, or  
12 endpoint, of concern. In Figure 2-1, the endpoint that is being evaluated is sediment  
13 deposition/retention. Interactive effects of multiple variables on each other, or on the endpoint,  
14 can occur where two “causal” variables both influence (have arrows into) a common “response”  
15 variable. In Figure 2-1, an example interaction is indicated by arrows C and D, where freshwater  
16 flow and coastal and nearshore erosion together could have an interactive effect on sediment  
17 supply.

#### 18 **Figure 2-1. Simplified influence diagram for sediment retention.**

19  
20  
21 In the case of community interactions, the influence diagram was constrained to a  
22 tractable number of species of interest for study. It focused on the relationship of marsh  
23 vegetation (native *Spartina* and invasive *Phragmites* grasses) and the resulting availability of  
24 nesting habitat for the Saltmarsh Sharp-Tailed Sparrow. The Saltmarsh Sharp-Tailed Sparrow  
25 prefers the native, upper marsh species *Spartina patens* for nesting habitat. This habitat is being  
26 infringed upon by invasive *Phragmites* from the landward side, and by lower marsh *Spartina*  
27 *alterniflora* (which is migrating upland with sea level rise) from the seaward side. Please see  
28 Appendix A for a more detailed explanation of this storyline.

29 While influence diagrams are widely used and relatively well-understood, our proposed  
30 use of qualitative degrees of influence is an innovation in expert elicitation. Typically, an expert  
31 elicitation seeks to obtain expert judgments about uncertain quantities in the form of numerical  
32 probability distributions. For the ecosystem processes considered during this workshop, there  
33 were information, data and time limitations that made quantifying the influences as probability  
34 distributions unrealistic. Instead, judgments were based on qualitative types (is the relationship  
35 direct, or inverse?) and degrees (is the response small, or large?) of influences. The use of  
36 qualitative degrees of influence provides much more detail than simply specifying causal  
37 influences with arrows alone, but less specificity than required for quantified probabilities.

1 Participants were provided with “straw man” diagrams (see Appendix B) prior to the  
2 workshop. They were asked to review these diagrams and submit their own revised versions the  
3 week before the workshop. Diagram submissions were combined into one consolidated draft  
4 diagram for each group that served as the starting point for discussion at the workshop. The  
5 workshop itself began with each group working together to refine their diagram into a “group  
6 diagram”. The group influence diagram was meant to distill the system to a tractable set of key  
7 variables and influences, and as such it was not comprehensive. The groups were given  
8 complete freedom to alter any part of the diagram, with the exception of the ecosystem process  
9 endpoint, as long as they constrained the diagram to a total of no more than 15 boxes. At the  
10 same time, participants were reminded to keep some of the top row stressor or management  
11 boxes, since these would serve as key linkages back to management options. Participants were  
12 also encouraged to minimize the total number of arrows in the diagram to include only the most  
13 key influences. The purpose was to capture the key components and relationships of each  
14 ecosystem process in a concise form that could be rapidly assessed in a workshop setting. Once  
15 the group diagrams were finalized, all of the participants made their judgments using the same  
16 diagram throughout the remainder of the workshop.

#### 17 18 **2.2.2.2. *Climate Scenarios***

19 Dr. Katharine Hayhoe of Texas Tech University, an experienced climate scientist with an  
20 extensive background in regional climate assessments, developed two climate change scenarios  
21 for use in the expert elicitation exercise (see Appendix C for more detailed information on the  
22 climate change scenarios). The scenarios represented two distinct but scientifically credible  
23 climate futures for a mid-century (2040-2069) time period. (The mid-century time frame was  
24 selected by the MBP partners because of its suitability for adaptation planning.) The projections  
25 were based on six leading climate models, using a lower emissions scenario (Climate Scenario  
26 A) and a higher emissions scenario (Climate Scenario B) to generate values for climate variables  
27 for use by the experts in making their judgments (see Table 2-1).

28  
29 **Table 2-1. Summary of Climate Scenario A (“Lower-Range” Scenario) and**  
30 **Climate Scenario B (“Higher-Range” Scenario): averages for mid-century**  
31

32 Under both climate change scenarios, Massachusetts will experience a significantly  
33 warmer climate, accompanied by increases in annual precipitation and higher sea levels. By  
34 mid-century, the “higher-range” Climate Scenario B (which includes higher emissions and a  
35 more sensitive climate) is projected to experience a warmer and somewhat wetter climate  
36 compared to the “lower-range” Climate Scenario A (with lower emissions and a lesser impact on  
37 Massachusetts’ climate).

1           At the workshop, Dr. Hayhoe provided the participants with an overview of major  
2 climate drivers and regional trends for Massachusetts. She discussed five main sources of  
3 uncertainty with climate projections, including: (1) the amount of future emissions; (2) the  
4 degree to which the influence of global climate change on local climate is modified by local  
5 factors; (3) the sensitivity of the climate system (as feedbacks are not well understood); (4) the  
6 ability of climate models to simulate climate both globally and locally; and (5) the natural  
7 variability of the climate system. Because of these factors, exact predictions of climate change  
8 are not possible. However, uncertainty can be dealt with by using multiple scenarios to bracket a  
9 range of plausible climate futures and identify key vulnerabilities in the system. In order to  
10 consistently “bound” the consideration of future climate changes in the workshop exercise, the  
11 participants were instructed to use the values provided under Climate Scenarios A and B (Table  
12 2-1) to contextualize their judgments about future effects on the ecosystem processes under  
13 consideration. For additional details on the climate scenarios, including data sources, please see  
14 Appendix C.

15

### 16 **2.2.2.3. *Expert Facilitation***

17           Due to the highly technical nature of the exercise, the complexity of the novel  
18 methodology that was being used, and the ambitious time line for accomplishing multiple  
19 outputs, it was essential that the workshop be run by skilled expert facilitators. The expert  
20 facilitators selected were Brock Bernstein, Independent Consultant and President, National  
21 Fisheries Conservation Center and Carlton Hunt, Research Leader with Battelle in Duxbury,  
22 Massachusetts. They were chosen based on a number of criteria including: proven expertise in  
23 facilitating science-based workshops; general knowledge of science behind estuary management  
24 (particularly wetlands ecology); and experience working on national coastal issues and/or issues  
25 in the Massachusetts Bays region. Dr. Hunt is an experienced and trained facilitator who has  
26 been working in Massachusetts Bay for several decades, and has served as the project manager  
27 and technical lead on Battelle’s Massachusetts Water Resources Authority program. Dr.  
28 Bernstein is a marine ecologist with research experience in a range of coastal and oceanic  
29 environments and has worked on a wide variety of management and policy issues. Dr. Hunt  
30 served as the facilitator for the Sediment Retention group, while Dr. Bernstein served as the  
31 facilitator for the Community Interactions group.

32           Prior to the workshop, both facilitators attended training calls in which they were fully  
33 briefed on the project background and conceptual models, the workshop goals and objectives,  
34 and the expert elicitation exercise. Working together and with the MBP/EPA team, the  
35 facilitators contributed to the refinement of the workshop agenda and improvements to the  
36 workshop process.

37

1 **2.2.2.4. Coding Scheme and Exercise**

2 Participants were asked to characterize each influence in their influence diagram  
3 according to the coding scheme presented in Table 2-2. Influences were characterized first under  
4 current conditions, and then under Climate Scenario A and Climate Scenario B. The extent to  
5 which participants agreed in their judgments was variable across the different influences. The  
6 rule that was adopted for determining agreement for each influence was that a majority (4 or  
7 more participants) had to have selected the same code. As this was not a consensus process, and  
8 the small group size limited statistics that could be done, majority was chosen as the most simple  
9 rule as a basis for agreement. A case could be made for a more restrictive rule on what  
10 constitutes agreement, but that would obscure the understanding of many of the influences.  
11 Agreement among four or more participants was considered to indicate substantial agreement  
12 across the group.

13  
14 **Table 2-2. Coding scheme used during the workshop exercise to characterize**  
15 **influences. “Small” and “large” changes in variables are defined relative to**  
16 **the current range of variation for each variable, with “small” indicating that**  
17 **the variable is within its current range of variation and “large” indicating**  
18 **that the variable has moved outside its current range of variation**  
19

20 Participants were also asked to characterize interactive influences of their choosing (i.e.,  
21 those they deemed important), under current conditions and under the climate change scenarios,  
22 according to the coding scheme presented in Table 2-3. Since participants were given the option  
23 to choose which interactive influences they considered significant and to provide judgments only  
24 for those influences, and were limited by time, there were often interactions where only one or  
25 two participants provided judgments. Only interactions scored by three or more participants  
26 were examined in order to focus on interactions judged by several participants to be significant.  
27 Three or more corresponding judgments were used to define agreement for interactive  
28 influences.

29  
30 **Table 2-3. Coding scheme used during the workshop exercise to characterize**  
31 **interactive influences**  
32

33 Finally, the participants were asked to assess their current level of scientific confidence in  
34 their judgments for each influence or interactive influence using the confidence coding scheme  
35 presented in Table 2-4. For each influence, each participant was asked to rate his/her confidence  
36 in their judgment based on: (1) the amount of scientific evidence that is available in the expert  
37 community to support the judgment; and (2) the level of agreement/consensus in the expert  
38 community regarding the different lines of evidence that would support the judgment. The  
39 coding options for “amount of evidence” were high (H) or low (L), based on whether available

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1 information is abundant and well-studied and understood, versus sparse and mostly  
2 experimental/theoretical. The coding options for “level of agreement” were high (H) or low (L),  
3 based on whether data, reports, and experience across the scientific community reflect a high or  
4 low level of agreement about the influence. Thus it was possible to have four combinations of  
5 evidence and agreement when assessing confidence: HH, HL, LH, and LL. The rule for  
6 determining agreement in confidence was the same as described above for influences: agreement  
7 was defined as a majority (four or more) of the same categorization of confidence level.  
8 Similarly using the same rule as above for interactive influences, agreement on confidence for  
9 interactive influences was defined as three or more of the same categorization of confidence. For  
10 additional details on the method used to assess confidence, please see Appendix D.

11

12 **Table 2-4. Coding scheme used during the workshop exercise to characterize**  
13 **confidence**

14

15 **2.2.2.5. *Typologies for Understanding Influences and Sensitivities***

16 *Type and degree of influence:*

17 The group’s level of understanding of the different influences (arrows) in the influence  
18 diagram can be gauged by the amount of agreement in participants’ selection of influence codes.  
19 Sometimes participants agreed on the type of influence, but not necessarily the degree (strength)  
20 of the influence. Codes 2-13 (Table 2-2) represent different combinations of types and degrees  
21 of influences that can be grouped according to the following typology:

22

23 Types:

24 Direct relationship = Codes 2, 3, 6, 8, 11, 13

25 Inverse relationship = Codes 4, 5, 7, 9, 10, 12

26 Degrees:

27 Proportional response of Y to X = Codes 2- 5

28 Disproportional response of Y to X = Codes 6-13

29

30 Codes can also be paired according to the same type and degree of influence, with the  
31 only distinction being whether one is considering “X” to be increasing or decreasing. For  
32 example 2/3 is a direct proportional influence, with 2 indicating when “X” increases, and 3  
33 indicating when “X” decreases, but in both cases “Y” is responding in a directly proportional  
34 way. Six combinations of pairings are possible:

35

36 Pairings by type and degree of influence (where “X” can go up or down):

37 Direct proportional = 2/3

38 Inverse proportional = 4/5

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- 1 Direct disproportional, strong response (xY) = 6/11
- 2 Direct disproportional, weak response (Xy) = 8/13
- 3 Inverse disproportional, strong response (xY) = 7/10
- 4 Inverse disproportional, weak response (Xy) = 9/12

5

6 In some cases, participants selected the same exact code, indicating that they had the  
7 same understanding of the influence in terms of both type and degree. Or, sometimes  
8 participants chose pairings such as 2/3 while their colleagues may only have noted a 2 or a 3; we  
9 consider these cases to also indicate a correspondence in understanding of type and degree of  
10 influence, since the only distinction was whether a participant was thinking of “X” as going up  
11 or down (or both).

12 In another group of cases, there was agreement on the type of influence (i.e., whether X  
13 affects Y directly or inversely), although there was lack of agreement on the degree of that  
14 influence. These latter cases amount to an understanding of how X affects Y, just not the  
15 magnitude. It may still be useful for management to know for which influences we at least have  
16 some understanding of the type of response, even if we are not sure of the magnitude.

17 Finally, there were cases in which there was such a mixture of codes selected as to  
18 indicate no agreement in either type or degree of influence. This indicated that, among this group  
19 of experts, the influence was poorly understood or poorly defined.

20

### 21 *Sensitivity*

22 It is also possible to establish a typology for assessing the sensitivity of each influence  
23 (i.e., how sensitive variable Y is to changes in X), especially with regard to how those may  
24 change under the climate scenarios. Several codes can indicate the same level of sensitivity, so  
25 the following groupings were used to indicate three levels of sensitivity:

26

27 Low sensitivity = Codes 8-9 & 12-13

28 Intermediate sensitivity = Codes 2-5

29 High sensitivity = Codes 6-7 & 10-11

30

31 This typology was used to document all judgments, along with the following additional  
32 categories of judgments:

33

34 No Influence = Code 0

35 Unknown influence = Code 1

36 None given = No judgment provided

37 Other = Response provided that does not fit into the coding scheme

*This document is a draft for review purposes only and does not constitute Agency policy.*

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### **2.2.2.6. *Understanding Relative Impacts of Influences***

While the coding scheme described above captures the nature of individual influences, it is also of interest to identify which influences and interactions the participants perceived to have the greatest relative impact on the ecosystem process endpoint. Here we define relative impact as the combination of not only sensitivity but also how greatly the variable is changing relative to other variables. Because relative impact is an emergent property that results from considering all influences in the diagram together, there was no coding for this in the workshop exercise; rather, this concept was explored through group discussions that looked at the influence diagram as a whole and identified influences of greatest relative impact in the context of the entire web of influences. During group discussions that spanned both days of the workshop, information was gleaned as to which influences participants perceived to have comparatively greater effects on the ecosystem process endpoints, and whether this varied under the climate scenarios. These discussions were captured in the workshop notes as well as in the influence diagrams, in which the participants identified influences and interactions of highest relative impact (see sections 2.3.1.4 and 2.3.2.4).

### **2.2.2.7. *Key Questions***

As described above, there are three categories of information that together comprise the collective understanding of each ecosystem process as represented by its influence diagram: 1) the type and degree of influences between variables, 2) the sensitivity of “response” variables to changes in “affecting” variables, and 3) the relative impact of each variable on the ecosystem process endpoint. For each of the three categories of information, the following key questions are addressed.

#### Types and Degrees of Influences:

- For which influences and interactions was there agreement in participants’ judgments (codes), and what were those codes?
- How did agreement on influences and interactions vary from current conditions to Climate Scenario A and Climate Scenario B?
- For influences and interactions for which there was agreement in judgments, how did confidence levels across the participants vary? Did this change under the climate scenarios?

#### Sensitivity of Influences:

- For which influences and interactions is there greatest sensitivity and least sensitivity in the response variable to changes in the “affecting” variable?
- Were there any influences or interactions where agreement on sensitivity across participants increased or decreased under the climate scenarios?



1           Relative Impact of Influences:

- 2           • Which influences and interactions did the participants indicate have the greatest  
3           relative impact on the ecosystem process endpoints?  
4           • Were there any influences or interactions for which relative impact changed under the  
5           climate scenarios?  
6

7           Using the data from the coding exercise as well as information that emerged during group  
8           discussions, these questions are explored in the results sections that follow.  
9

10   **2.3. RESULTS**

11           Major outputs of the expert elicitation exercise included the group influence diagrams,  
12           the judgments on influences (including interactive influences) along with their confidence  
13           estimates, information on sensitivities (including thresholds), and characterizations of relative  
14           impacts. For the purpose of this study, a threshold is defined (as per Groffman et al., 2006) as a  
15           point at which there is an abrupt change in an ecosystem property (such as a flip in influence  
16           type from direct to inverse), or where a small additional change in a driver produces a large  
17           response (such as a shift from a proportionate to a disproportionately strong response of variable  
18           Y to a change in variable X).  
19

20   **2.3.1. Sediment Retention**

21   **2.3.1.1. *Group Influence Diagram***

22           Figure 2-2 shows the group diagram developed by the Sediment Retention group.  
23           Variable definitions that were developed by the participants during the construction of the  
24           diagram are found in Table 2-5. The diagram highlights the balance of erosion and accretion  
25           processes in determining the Sediment Deposition/Retention endpoint. On the erosion side,  
26           Marsh Edge Erosion directly impacts the endpoint, while Coastal and Nearshore Erosion include  
27           impacts of erosion outside the marsh. Erosion from external sites can serve as a sediment source  
28           to the marsh and so acts through Sediment Supply, as well as impacting Tidal Exchange as  
29           erosion changes basin bathymetry and the resulting hydrodynamics. Both erosion variables are  
30           impacted by Storms, while Coastal and Nearshore Erosion is also influenced by Marsh High  
31           Water Level. Marsh High Water Level integrates sea level, topography and vegetation in that it  
32           is the transition between marsh and upland vegetation that is responsive to sea level, which is  
33           dependent on topography through slope.

34           On the accretion side, Net accretion accounts for the accretion component directly, and is  
35           a two-way influence on the endpoint. Below Ground Biomass and Surface Roughness also  
36           influence accretion related processes, the former accounting for below-ground accretion, the  
37           latter for above-ground accretion. Surface Roughness is another integrative variable. The  
38           characteristics of different grass species have differing impacts as water flows through them,

1 which influences the deposition and retention of sediment. Inundation Regime is another two-  
2 way influence on the endpoint, one that can contribute to either accretion or erosion on the marsh  
3 surface. The diagram shows a high degree of interconnectivity between variables, especially  
4 among these accretion related variables.

5 In addition, there are several feedback loops with the endpoint, including through Net  
6 Accretion and Inundation Regime. Inundation regime is itself influenced by multiple other  
7 variables, including Marsh High Water Level and Storms, as well as Tidal Exchange and  
8 Freshwater Flow. The management related variables at the top of the diagram include Nutrient  
9 Inputs, Altered Flows: Tidal Restrictions, and Land Cover: Percent Impervious Cover. Storms  
10 and Marsh High Water Level are additional stressor variables that are less clearly connected to  
11 management levers. The management options for Marsh High Water Level are one step  
12 removed and related to maintaining transitional uplands for upslope migration. These top level  
13 variables influence middle level ones which are primarily physical and hydrologic in nature.  
14 These include Tidal Exchange, Freshwater Flow, Sediment Supply, Coastal and Nearshore  
15 Erosion and Marsh Edge Erosion. Freshwater Flow and Inundation Regime both influence  
16 Sediment Deposition/Retention through Surface Roughness.

17  
18 **Figure 2-2. Sediment Retention group influence diagram.**

19  
20 **Table 2-5. Sediment Retention variable definitions**

21  
22 **2.3.1.2. *Influence Types and Degrees***

23 *Agreement*

24 The influences upon which participants agreed with respect to type and degree help to  
25 establish the nature of those relationships and indicate which are best understood. Table 2-6  
26 presents these results for the Sediment Retention group.

27  
28 **Table 2-6. Sediment Retention group influence judgments; columns A-Z**  
29 **represent individual influences (arrows) in the influence diagram and rows**  
30 **represent individual respondents: dark green = agreement on influence type**  
31 **and degree, light green = agreement on type but not degree, gray = no**  
32 **agreement; within columns, green numbers = same (majority) grouping of**  
33 **type (though degree may be different), pink numbers = disagreement about**  
34 **type, red outline = threshold response**

35  
36 In some cases, participants gave multiple codes for an arrow. When the multiple codes  
37 represented one of the pairing types described above in section 2.2.2.4 (e.g., 2/3), both codes are  
38 shown, separated by a “/”.

1           If multiple codes that do not fall into a pairing were given, both codes are shown,  
2 separated by a symbol indicating the nature of the combination. In the first type of combination,  
3 multiple codes with “X” going in the same direction (e.g., X is increasing in both codes) are  
4 separated by a “^” symbol; and where these codes conflict and would make a difference in  
5 determining agreement, those cells were not counted. In the second type of combination, codes  
6 with “X” going in different directions (e.g., X is increasing in one code and decreasing in the  
7 other) are separated by a “|”. Since the response to X can indeed be different depending on  
8 whether X is increasing or decreasing, these cells do not represent a conflict but rather the  
9 opportunity to consider agreement in both the “X-up” and “X-down” direction. In these cases it  
10 was possible to have agreement in one direction but not the other.

11           The columns in Table 2-6 represent individual influences (arrows) in the group influence  
12 diagram, and rows represent individual respondents. Dark green shaded columns indicate  
13 agreement on both type and degree of influence; light green shaded columns indicate agreement  
14 on type but not degree; gray shaded columns indicate no agreement. Within columns, numbers  
15 in green are those that fall into the same (majority) grouping in terms of type of influence (even  
16 though degree is different), while codes in pink indicate disagreement about type. Columns  
17 outlined in red indicate threshold influences where there was either: 1) a change in type of  
18 influence in the climate scenarios compared to current conditions (e.g., from a direct to an  
19 inverse relationship), 2) a change in sensitivity (e.g., a change from a proportional to  
20 disproportional response, or 3) an indication by multiple participants in their notes or in the  
21 group discussions that the influence was likely a threshold relationship (although they did not  
22 always know exactly which scenario in which this would occur). In these cases the type and/or  
23 degree of influence for the relationship would depend on a threshold, the exact location of which  
24 is uncertain.

25           Under current conditions, there were 20 influences for which there was agreement on  
26 both type and degree of influence. There were seven influences for which there was agreement  
27 on type but not degree. There was no agreement for five influences. Lack of agreement centered  
28 especially on Inundation Regime (Relationships S, Z, and BB), and Surface Roughness  
29 (Relationships S and U).

30           Under Climate Scenario A, there were 17 influences for which there was agreement on  
31 both type and degree. There was no agreement on type or degree of influence for Relationship  
32 AA (Marsh Edge Erosion on Sediment Deposition/Retention) under current conditions, but this  
33 changed to full agreement under Scenario A; meanwhile, for four of the influences with no  
34 agreement previously on both type and degree, there was agreement only on type under Climate  
35 Scenario A. There were nine relationships for which there was agreement on type but not degree  
36 and six relationships for which there was no agreement. The influences with no agreement

1 include four of the same ones as current and one for which there previously was agreement on  
2 type but not degree.

3 Under Climate Scenario B, there were 13 influences for which there was agreement on  
4 both type and degree. There were 13 relationships with agreement on type but not degree and six  
5 relationships with no agreement. Most of the changes in Climate Scenario B are influences  
6 losing agreement on degree or ones that had already changed in Climate Scenario A.

7

### 8 *Thresholds*

9 Relationship E (Nutrient Inputs on Below Ground Biomass) and relationship EE (Net  
10 Accretion on Sediment Deposition/Retention) were identified to be threshold relationships under  
11 the climate scenarios. In both of these cases the type of influence changed across the scenarios,  
12 with Relationship E changing from direct to inverse under Climate Scenario A, and Relationship  
13 EE changing from inverse proportional to direct proportional under Climate Scenario B. The  
14 sensitivity for both of these influences did not change across the scenarios.

15 The threshold of Relationship E is related to the vegetative response to nutrient inputs.  
16 An increase in nutrients can increase net below ground peat because it spurs above ground  
17 productivity, a portion of which adds to below ground peat. At the same time, nutrients decrease  
18 below ground production and increase decomposition. In the long term, the below ground  
19 effects of nutrients could outweigh the above ground ones and cause the relationship to change  
20 from direct to inverse.

21 The threshold of Relationship EE is related to the response of sediment deposition and  
22 retention to net accretion. A threshold could occur where a given location is under a different  
23 inundation regime due to sea level rise, and thus exposed to different tidal velocities and a  
24 different deposition regime. Where the marsh is shallow enough, an increase in accretion would  
25 decrease net sediment deposition because the water would have already been slowed during  
26 inundation and dropped its sediment load. However with a sufficient increase in sea level under  
27 climate change, the marsh could now be at a depth where the water would arrive at higher  
28 velocities during inundation, still carrying a high sediment load, such that now an increase in  
29 accretion would cause water to slow and increase deposition.

30 Relationship Z (Inundation Regime on Sediment Deposition/Retention) and Relationship  
31 BB (Inundation Regime on Below Ground Biomass) were identified to be threshold relationships  
32 under current conditions and the climate scenarios. Here the type and sensitivity of the  
33 influences did not change across the scenarios; there was no agreement on type or degree of  
34 influence in both cases, but this was because the codes were a mixture of direct proportional and  
35 inverse proportional, with some participants indicating both codes at once. It emerged through  
36 participant discussions that these are threshold relationships for which it is unclear exactly when  
37 the tipping points would occur (hence the inability to identify them as a change across scenarios).

1 For both of these influences, the threshold was indicated to be where too much inundation leads  
2 from a direct (positive) relationship to a tipping point (inverse relationship) with the response  
3 variable. In the case of Relationship Z, an increase in inundation would initially increase  
4 transport and deposition of sediment, but at some point too great an increase in inundation could  
5 lead to such an increase in erosion as to cause a net decrease in deposition and retention.  
6 Similarly for Relationship BB, while increased inundation initially supports productivity of  
7 below ground biomass, too great an increase in inundation would lead to low levels of oxygen  
8 and “smothering” of below ground biomass.

9 Relationship AA (Marsh Edge Erosion on Sediment Deposition/Retention) was identified  
10 as a threshold relationship under the climate scenarios in discussions. The type and sensitivity of  
11 the influence did not change across the scenarios (the relationship had no agreement under  
12 current conditions, and was identified as inverse proportional under the climate scenarios).  
13 However, it was identified in the later group discussion as an important potential threshold due to  
14 the sensitivity of marsh edge erosion to future increases in storm intensity (with a strong seasonal  
15 component), especially given sea level rise. The greater influence of storms under the climate  
16 scenarios would lead to increasing marsh edge erosion. The resulting effect on sediment  
17 deposition and retention would depend on where the sediment was transported – it could either  
18 be carried onto the marsh for potential re-deposition or lost from the system. The majority of the  
19 participants judged that under the climate scenarios, the sediment is more likely to be lost from  
20 the system due to the combined effects of sea level rise and changes in inundation and flow  
21 regimes. This will serve to greatly increase the inverse effect of marsh edge erosion on sediment  
22 deposition and retention. A threshold will occur when erosional losses from the marsh edge  
23 exceed the ability of the marsh to capture and retain enough sediment such that accretion no  
24 longer sufficiently counteracts losses and the marsh eventually collapses.

25 One possible reason why some thresholds identified in discussions did not show up in the  
26 coding as changes in sensitivity is because participants did not know where the threshold would  
27 occur, so they did not want to attach the shift to a particular climate scenario. Alternatively, it  
28 may be that there is a threshold that represents a state change that falls within the range of natural  
29 variability, so this method was not sensitive enough to identify the threshold.

### 31 **2.3.1.3. *Influence Sensitivity***

32 Figure 2-3 shows the sensitivity results using the influence diagram, indicating where  
33 there is agreement under current conditions. The typology described in Section 2.2.2.5 was used  
34 to code sensitivity, with an additional differentiation within the “no agreement” category. In all  
35 “no agreement” cases, there was a mixture of codes for intermediate sensitivity along with low  
36 and/or high sensitivity; if at least four participants provided judgments, and there were more high  
37 sensitivity judgments than low sensitivity judgments, then the dashed arrow was colored orange

1 to indicate intermediate-to-high sensitivity. Under current conditions, 23 influences with  
2 agreement were categorized as intermediate sensitivity. Relationship M (Coastal and Nearshore  
3 Erosion on Tidal Exchange) was the only influence categorized as “low sensitivity”. For  
4 Relationship J (Marsh High Water Level on Coastal and Nearshore Erosion), there was  
5 agreement that there is high sensitivity when marsh high water level is increasing and  
6 intermediate sensitivity when marsh high water level is decreasing. There was no agreement on  
7 sensitivity for six influences. Relationship G (Altered Flows: Tidal Restrictions on Freshwater  
8 Flow) was categorized as having no influence.

9  
10 **Figure 2-3. Sediment Retention group summary influence diagram of**  
11 **sensitivities under current conditions.**  
12

13 Figure 2-4 compares the sensitivities as in Figure 2-3, across the three scenarios. Under  
14 Climate Scenario A, Relationship J (Marsh High Water Level on Coastal and Nearshore Erosion)  
15 continued to show agreement on high sensitivity when marsh high water level is increasing,  
16 while agreement on sensitivity was lost when marsh high water level is decreasing. Relationship  
17 H (Land Cover: Percent Impervious Cover on Freshwater Flow) showed a trend from  
18 intermediate to intermediate-to-high sensitivity (orange arrow). Most of the other influences that  
19 were previously characterized as intermediate sensitivity remained the same, with the exception  
20 of: Relationship P (Freshwater Flow on Sediment Supply) and Relationship CC (Below Ground  
21 Biomass on Sediment Deposition/Retention), for which there no longer was agreement. There  
22 was no agreement on sensitivity under the climate scenarios for Relationship M (Coastal and  
23 Nearshore Erosion on Sediment Supply), which had low sensitivity under current conditions.  
24

25 **Figure 2-4. Sediment Retention group summary influence diagrams of sensitivities:**  
26 **variance across current conditions and two climate scenarios.**  
27

28 Under Climate Scenario B, four additional intermediate sensitivity influences dropped  
29 below the standard of agreement: Relationships I, C and K (Storms on Inundation Regime, on  
30 Freshwater Flow, and on Coastal and Nearshore Erosion), and Relationship Q (Coastal and  
31 Nearshore Erosion on Sediment Supply). However, in the case of Relationships I, C and K, the  
32 lack of agreement was due to a subset of participants indicating a change toward increasing  
33 sensitivity (orange arrows). Thus, these influences (along with Relationship J, which remained  
34 the same as in Climate Scenario A) are considered intermediate-to-high in sensitivity.

35 One reason for lack of agreement on changes in sensitivity across scenarios, as well as  
36 lack of agreement within scenarios, may have been the degree of variability among participants  
37 in their judgements. Overall, there was more variability among participants than across  
38 scenarios for any given participant. There were no patterns across participants, such as

1 characterizing only increasing sensitivity. Further description, as well as figures depicting  
2 variability in judgments across participants, can be found in Appendix B.

#### 4 **2.3.1.4. *Relative Impact***

5 Figure 2-5 presents the characterization of relative impacts for current conditions while  
6 Figure 2-6 compares the relative impacts across all three scenarios. Under current conditions, a  
7 total of 24 influences were identified as having high relative impact. The Sediment Retention  
8 group distinguished relative impact of the influences by indicating primary and secondary  
9 degrees of impact. Primary impact was indicated for 14 influences, while secondary impact was  
10 indicated for 10 influences. Influences of primary impact at the top of the diagram (which are  
11 associated with management options) include Relationships B and J (Marsh High Water Level  
12 on Inundation Regime and on Coastal and Nearshore Erosion), Relationship E (Nutrient Inputs  
13 on Below Ground Biomass), and Relationship F (Altered Flows: Tidal Restrictions on Tidal  
14 Exchange).

15 Under both Climate Scenarios, the influence of Relationship B (Marsh High Water Level  
16 on Inundation Regime) was identified as having increasing impact. Relationship E (Nutrient  
17 Inputs on Below Ground Biomass) and Relationship V (Surface Roughness on Sediment  
18 Deposition/Retention) were identified as having increasing impact under Climate Scenario B.  
19 Relationship CC (Below Ground Biomass on Sediment Deposition/Retention) increased from  
20 secondary impact under current conditions to primary impact under Climate Scenario A, yet  
21 decreased back to secondary impact under Climate Scenario B.

22  
23 **Figure 2-5. Sediment Retention influences indicated as having high *relative***  
24 ***impact* under current conditions.**

25  
26 **Figure 2-6. Sediment Retention influences indicated as having high *relative***  
27 ***impact*: variance across current conditions and two climate scenarios.**

#### 28 29 **2.3.1.5. *Confidence***

30 The confidence results shown in Table 2-7 are provided for the Sediment Retention  
31 influences for which there was agreement on type. The lack of agreement on confidence for  
32 almost half of the judgments is a significant gap, limiting our ability to prioritize around  
33 confidence judgments. All of the 12 influences for which there was agreement on confidence  
34 across all three scenarios were scored as high evidence and high agreement (HH). Relationship  
35 G (Altered Flows: Tidal Restrictions on Freshwater Flow), Relationship Y (Sediment  
36 Deposition/Retention on Inundation Regime), and Relationship FF (Below Ground Biomass on  
37 Net Accretion), which were categorized as HH under current conditions, showed declining  
38 agreement on confidence under the climate scenarios, with no agreement under Climate

1 Scenarios A and B. Relationship J (Marsh High Water Level on Coastal and Nearshore  
2 Erosion), as well as Relationship K (Storms on Marsh Edge Erosion), for which there was no  
3 agreement under current conditions, showed increasing agreement under the climate scenarios,  
4 with a score of HH under Climate Scenario A and Climate Scenario B.

5  
6 **Table 2-7. Sediment Retention group confidence for influences with**  
7 **agreement: NA = No agreement; HH = High evidence, High agreement; HL**  
8 **= High evidence, Low agreement; LH = Low evidence, High agreement; LL =**  
9 **Low evidence, Low agreement**

10  
11 The confidence results shown in Figure 2-7 total all judgments across all participants.  
12 The total number of HH and LH judgments decreased under the climate scenarios compared to  
13 current conditions, and the total number of HL and LL judgments increased under the climate  
14 scenarios compared to current conditions. The decrease in the total number of HH judgments  
15 from current conditions to the climate scenarios and the corresponding increase in the total  
16 number of LL judgments show that influences are less well-understood due to less information  
17 being available about future climate conditions. However, there was an increase in the total  
18 number of no answer given, and the decreases in LH and increases in HL are difficult to explain  
19 overall.

20  
21 **Figure 2-7. Sediment Retention group confidence results for all influences;**  
22 **HH = High evidence, High agreement; HL = High evidence, Low agreement;**  
23 **LH = Low evidence, High agreement; LL = Low evidence, Low agreement.**

#### 24 25 **2.3.1.6. Interacting Influences**

26 Table 2-8 presents the interactive influences upon which there was agreement for the  
27 Sediment Retention group. The interactive influence columns indicate the type of interactive  
28 influence and associated number of participants that chose that particular interactive influence  
29 type. The confidence columns indicate the confidence judgment and associated number of  
30 participants that chose that particular confidence score.

31  
32 **Table 2-8. Sediment Retention group interactive influences with agreement**  
33 **under current conditions and Climate Scenarios A and B: NA = No**  
34 **agreement; HH = High evidence, High agreement; HL = High evidence, Low**  
35 **agreement; LH = Low evidence, High agreement; LL = Low evidence, Low**  
36 **agreement; () = Number of respondents**

37  
38 Under current conditions, there were two interactive influences for which there was  
39 agreement among participants in the Sediment Retention group. For both of these interactive  
40 influences, Synergy was the type of influence chosen. These interactions included Relationship



1 B with C (Marsh High Water Level on Inundation Regime with Storms), and Relationship V  
2 with W (Surface Roughness on Sediment Deposition/Retention with Sediment Supply). There  
3 was only agreement on the confidence for the interactive influence of Relationship B with C,  
4 which was scored as high evidence and high agreement (HH).

5 Under both Climate Scenario A and Climate Scenario B, there was one of the previous  
6 two synergistic interactive influences for which there was agreement on synergy as the type of  
7 interactive influence (Relationship B with C). This interactive influence remained as HH under  
8 the climate scenarios. There were two new interactive influences for which there was agreement  
9 under the climate scenarios, both of which were scored as Synergy. These interactions included  
10 Relationship H with I (Land Cover: Percent Impervious Cover on Freshwater Flow with Storms),  
11 and Relationship W with V (Sediment Supply on Sediment Deposition/Retention with Surface  
12 Roughness). Confidence on both of these interactive influences was scored as HH under Climate  
13 Scenario A, though there was no agreement on confidence under Climate Scenario B for  
14 Relationship H with I.

15 There was no agreement on type of interactive influence under the climate scenarios for  
16 the interaction of Relationship V with W (Surface Roughness on Sediment Deposition/Retention  
17 with Sediment Supply), which was identified as Synergy under current conditions. Meanwhile,  
18 the Relationship W with V (Sediment Supply on Sediment Deposition/Retention with Surface  
19 Roughness) was identified as Synergy under the climate scenarios. The change from “V with  
20 W” to “W with V” distinguishes between the effect of Surface Roughness on the endpoint  
21 increasing with an increase in Sediment Supply, and the effect of Sediment Supply on the  
22 endpoint increasing with an increase in Surface Roughness. It is unclear whether participants  
23 intended to highlight this difference, or if there was confusion about the definition during the  
24 exercise. Both interactions may be important, but there may not have been time to explore  
25 interacting influence pairs separately across scenarios.

26 One additional interaction, Relationship J with K (Storms and Marsh High Water Level  
27 on Coastal and Nearshore Erosion), was only identified by two participants (as a Synergy) in the  
28 coding. However, this same interplay was brought up during group discussions as an interaction  
29 of potential importance under climate change, implying that further investigation into the  
30 relationship of these influences may be warranted.

31 The limited number of interacting influences for which there was agreement was  
32 primarily due to not having many influences with enough participants characterizing the same  
33 interacting influences. Of the 48 combinations of influences with interactions characterized by  
34 participants, only nine could be considered for agreement with at least three participants making  
35 a judgment; less than half of those had three participants in agreement.

1 **2.3.2. Community Interactions**

2 **2.3.2.1. Group Influence Diagram**

3 Figure 2-8 shows the group diagram developed by the Community Interactions group.  
4 Variable definitions that were developed by the participants during the construction of the  
5 diagram are found in Table 2-9. Three variables directly influence the endpoint of Saltmarsh  
6 Sharp-Tailed Sparrow Nesting Habitat: the Ratio of Low Marsh (*Spartina alterniflora*) to High  
7 Marsh (*Spartina patens*) species, Inundation Regime, and Marsh Elevation. The Ratio of Native  
8 High Marsh to invasive *Phragmites* is a key factor influencing the endpoint through the Ratio of  
9 Low Marsh to High Marsh as well as Marsh Elevation. The middle level in the diagram includes  
10 Salinity, Sedimentation, Nitrogen, Above Ground Plant Biomass, and Below Ground Plant  
11 Biomass. These variables and the ones that directly influence the endpoint are all highly  
12 interconnected, with Inundation Regime, Above Ground Biomass and both ratio variables  
13 serving as hubs.

14 The management and stressor variables include: Tidal Restrictions, Open Marsh Water  
15 Management (OMWM), Freshwater Flow, and Land Use/Land Cover: Residential Development.  
16 OMWM is a mosquito control technique that involves ponding and ditching marshes in order to  
17 restore hydrologic conditions to improve fish habitat and thus increase mosquito predation.  
18 Removing tidal restrictions, by increasing the size or lowering the opening in the crossing has  
19 been one of MBP’s management options that restores the inundation regime of the upstream  
20 marsh and improves freshwater flow through the restriction to the benefit of the downstream  
21 marsh. Soil Temperature and Sea Level are intermediate type variables that could be considered  
22 both stressor variables and system variables and are less clearly connected to management levers.

23

24 **Figure 2-8. Community Interactions group influence diagram.**

25

26 **Table 2-9. Community Interactions variable definitions**

27

28 **2.3.2.2. Influence Types and Degrees**

29 *Agreement*

30 Table 2-10 presents the results for the Community Interactions group. As in Table 2-6,  
31 the columns in Table 2-10 represent individual influences (arrows) in the group influence  
32 diagram, and rows represent individual respondents. Dark green shaded columns indicate  
33 agreement on both type and degree of influence; light green shaded columns indicate agreement  
34 on type but not degree; gray shaded columns indicate no agreement. Within columns, numbers  
35 in green are those that fall into the same (majority) grouping in terms of type of influence (even  
36 though degree is different), while codes in pink indicate disagreement about type. For further  
37 explanation of table details, see section 2.3.1.2.

38

1 **Table 2-10. Community Interactions group influence judgments; columns A-**  
2 **KK represent individual influences (arrows) in the influence diagram and**  
3 **rows represent individual respondents: dark green = agreement on influence**  
4 **type and degree, light green = agreement on type but not degree, gray = no**  
5 **agreement; within columns, green numbers = same (majority) grouping of**  
6 **type (though degree may be different), pink numbers = disagreement about**  
7 **type, red outline = threshold response**  
8

9 The participants agreed on the type and degree of influence for slightly fewer of the total  
10 number of influences than the Sediment Retention group did. Under current conditions, there  
11 were 18 influences for which there was agreement on both type and degree. These are spread  
12 throughout the diagram, but it is of note that there was agreement on type but no agreement on  
13 degree for all of influences going into the endpoint. There were eight influences for which there  
14 was agreement on type but not degree of influence. There was agreement on both type and  
15 degree of influence for many of the influences associated with management and stressor  
16 variables. There was no agreement for six relationships.

17 Under Climate Scenario A, the number of influences with agreement on both type and  
18 degree dropped to 15; three influences lost agreement on degree, but maintained agreement on  
19 type. There were eight relationships for which there was agreement on type but not degree.  
20 Relationship P (Inundation Regime on Saltmarsh Sharp-Tailed Sparrow Nesting Habitat) went  
21 from having agreement only on type under current conditions (inverse) to having agreement on  
22 inverse proportional under Climate Scenario A. There were nine relationships for which there  
23 was no agreement.

24 Under Climate Scenario B, there were 13 influences for which there was agreement on  
25 both type and degree. There were 10 relationships for which there was agreement on type but  
26 not degree. Relationship I (Inundation Regime on Above Ground Biomass), for which there  
27 previously was no agreement on type or degree, changed to agreement on type (inverse). There  
28 were nine relationships for which there was no agreement.

29 Agreement for the type and degree of influence remained consistent across the scenarios  
30 for 12 relationships. Agreement on type but not degree of influence remained consistent across  
31 the scenarios for four relationships. There were five relationships for which there was no  
32 agreement on type or degree of influence across the scenarios.

33 Compared to the results for the Sediment Retention group, the larger number of  
34 influences for which there was no agreement under all scenarios leaves more of a gap in  
35 understanding of the type or degree of influence for these relationships. It is difficult to  
36 differentiate between lack of response due to insufficient time and disinclination to answer due to  
37 lack of knowledge about the influence, however occasionally participants noted if a particular  
38 influence was not within their realm of expertise.  
39

1 *Thresholds*

2 Two relationships were identified as threshold relationships under the climate scenarios,  
3 based on the coding scheme, notes and discussions. These were: Relationship J (Inundation  
4 Regime on Above Ground Plant Biomass) and Relationship EE (Ratio of Native High Marsh to  
5 *Phragmites* on Marsh Elevation). There was no agreement on type or degree of influence for  
6 Relationship J under current conditions and Climate Scenario A; however, this was due to the  
7 participants recording a mixture of direct and inverse codes and accompanying notes indicating  
8 agreement that a threshold response would be expected at some point that is not currently  
9 possible to pinpoint. There was agreement on type (inverse) under Climate Scenario B, as a  
10 majority of participants agreed that by now the threshold would have likely been passed. The  
11 nature of the threshold relationship involves a tipping point in which inundation regime (percent  
12 time that high marsh is under water during April-October) at first has a positive effect on above  
13 ground plant biomass, but with a sufficient increase would trigger an abrupt decrease in above  
14 ground biomass. According to Morris et al. (2002), inundation of sufficient duration is  
15 beneficial in that it prevents soil salinity from reaching levels that inhibit growth. However, with  
16 sea level rise, inundation frequency and duration is expected to reach levels that cause increased  
17 hypoxia and result in marsh die-back (i.e., marsh drowning).

18 Relationship EE was identified as a threshold relationship because of changes in  
19 sensitivity under the climate scenarios. The type of sensitivity for this influence changed from  
20 low sensitivity under current conditions to intermediate sensitivity under the climate scenarios.  
21 Under current conditions, Relationship EE was identified as an inverse disproportional weak  
22 influence; a decrease in the Ratio of Native High Marsh to *Phragmites* would lead to a modest  
23 increase in marsh elevation because *Phragmites* is more effective at trapping sediment. Under  
24 the climate scenarios, Relationship EE was identified as an inverse influence, with no agreement  
25 on degree (due to a mixture of codes moving from an inverse weak relationship toward a more  
26 proportional one); here, rising sea levels were identified as the cause of the increasing sensitivity,  
27 as *Phragmites* would be better equipped to migrate landward to higher elevations while  
28 continuing to more effectively trap sediment in place.

29 One additional influence, Relationship P (Inundation Regime on Saltmarsh Sharp-Tailed  
30 Sparrow Nesting Habitat) was not coded in the exercise as a threshold occurring across the  
31 climate scenarios, but was discussed as a unique category of threshold that operates on a shorter  
32 time scale. This is an influence that can change dramatically with only slight changes in  
33 conditions. Availability of Saltmarsh Sharp-Tailed Sparrow nesting habitat is highly dependent  
34 on the timing and amount of inundation, even under current conditions, where nesting habitat can  
35 be abruptly flooded out if an even slightly amplified inundation event coincides with the critical  
36 nesting period. This phenomenon will become increasingly important as increases in sea level  
37 and other factors lead to increased frequency of such flooding events in the future.

1  
2 **2.3.2.3. Influence Sensitivity**

3 Figure 2-9 shows the sensitivity results using the influence diagram, indicating where  
4 there is agreement under current conditions. The typology described in Section 2.2.2.5 was used  
5 to code sensitivity, with an additional differentiation within the “no agreement” category. In all  
6 “no agreement” cases, there was a mixture of codes for intermediate sensitivity along with low  
7 and/or high sensitivity; if at least four participants provided judgments, and there were more high  
8 sensitivity judgments than low sensitivity judgments, then the dashed arrow was colored orange  
9 to indicate intermediate-to-high sensitivity. Under current conditions, 21 influences with  
10 agreement were categorized as intermediate sensitivity. Two influences were categorized as low  
11 sensitivity: Relationship D (Freshwater Flow on Inundation Regime), and Relationship EE (Ratio  
12 of Native High Marsh to *Phragmites* on Marsh Elevation). There was no agreement on  
13 sensitivity for nine influences; however, five of these influences are indicated in orange due to a  
14 combination of intermediate and high sensitivity codes. There were no instances of agreement on  
15 influences with high sensitivity.

16  
17 **Figure 2-9. Community Interactions group summary influence diagram of**  
18 **sensitivities under current conditions.**  
19

20 Figure 2-10 compares the sensitivities as in Figure 2-9, across the three scenarios. Under  
21 Climate Scenario A, 20 influences with agreement were categorized as intermediate sensitivity.  
22 One influence changed from low sensitivity under current conditions to intermediate sensitivity  
23 under the climate scenarios (Relationship EE). Relationship D was the only influence  
24 categorized as low sensitivity. No influences were categorized as high sensitivity. The number  
25 of influences with no agreement increased to 11; however, three of these are indicated in orange  
26 due to a combination of intermediate and high sensitivity. Such decreases in agreement highlight  
27 a trend of increasing sensitivity for some participants, but not enough to shift to agreement on a  
28 new category. It could be indicative of either disagreement about at what point such a shift  
29 would occur or of differing assumptions about what falls outside the current range of variability,  
30 which was left up to each participant to decide based on their own knowledge and intuition.

31  
32 **Figure 2-10. Community Interactions group summary influence diagrams of**  
33 **sensitivities: variance across current conditions and two climate scenarios.**  
34

35 Under Climate Scenario B, 17 influences with agreement were categorized as  
36 intermediate sensitivity. As with Climate Scenario A, only one influence was categorized as low  
37 sensitivity. The number of influences with no agreement increased further, to 14; however, four

1 of those are indicated as orange due to a combination of intermediate and high sensitivity. No  
2 influences were categorized as high sensitivity.

3 One reason for lack of agreement on changes in sensitivity across scenarios, as well as  
4 lack of agreement within scenarios, may have been the degree of variability among participants  
5 in their judgements. Overall, there was more variability among participants than across  
6 scenarios for any given participant. The majority of changes in sensitivity type across the  
7 climate scenarios are of increasing sensitivity. Further description, as well as figures depicting  
8 variability in judgments across participants, can be found in Appendix B.

#### 10 **2.3.2.4. *Relative Impact***

11 Figure 2-11 presents the characterization of relative impact between current and future  
12 climate scenarios (the group's discussion did not differentiate between the two future climate  
13 scenarios). This group distinguished among the influences by indicating primary impact,  
14 interactive influences with high relative impact, and influences that had some agreement but no  
15 consensus on relative impact. Under current conditions, nine influences were indicated as  
16 having high relative impact, based on the discussion. Influences of primary impact at the top of  
17 the diagram (which are associated with management options) include Relationship A (OMWM  
18 on Inundation Regime), Relationship C (Freshwater Flow on Salinity), Relationship E (Land  
19 Use/Land Cover: Residential Development on Freshwater Flow), and Relationship DD (Tidal  
20 Restrictions on Inundation Regime). Two influences were indicated as having some agreement  
21 on high relative impact: Relationship X (the Ratio of Native High Marsh to *Phragmites* on the  
22 Ratio of Low Marsh to High Marsh), as well as Relationship BB (the Ratio of Low Marsh to  
23 High Marsh on Saltmarsh Sharp-Tailed Sparrow Nesting Habitat). Two pairs of interactive  
24 influences were indicated as having high relative impact: Relationship O with R (Inundation  
25 Regime on the Ratio of Low Marsh to High Marsh with Nitrogen), as well as Relationship S with  
26 V (Nitrogen on the Ratio of Native High Marsh to *Phragmites* with Salinity).

#### 28 **Figure 2-11. Community Interactions influences indicated as having high 29 *relative impact* under current conditions and the climate scenarios.**

31 Under the climate scenarios (Figure 2-11) it is assumed that the same relationships are  
32 still of high impact, and only additions or changes in relative impact are shown in the second  
33 panel. Three influences were indicated as increasing in relative impact under climate change  
34 conditions for the Community Interactions group: Relationship L (Inundation Regime on  
35 Sedimentation), Relationship O (Inundation Regime on the Ratio of Low Marsh to High Marsh),  
36 and Relationship V (Salinity on the Ratio of Native High Marsh to *Phragmites*). The interactive  
37 influence of Relationship H with J (Soil Temperature on Above Ground Biomass with

1 Inundation Regime) was indicated as having increasing relative impact under the climate  
2 scenarios.

#### 4 **2.3.2.5. Confidence**

5 The confidence results shown in Table 2-11 are provided for the Community Interactions  
6 influences for which there was agreement on type. The lack of agreement on confidence for  
7 almost half of the judgments is a major gap, limiting our ability to prioritize around confidence  
8 judgments. Three of the four influences for which there was agreement on confidence across all  
9 scenarios were scored as high evidence and high agreement (HH). Relationship AA (Marsh  
10 Elevation on Saltmarsh Sharp-Tailed Sparrow Nesting Habitat) was scored as low evidence high  
11 agreement (LH) across all scenarios. The HH type of confidence was the most common  
12 judgment. The dominant pattern on confidence across the climate scenarios was a decrease in  
13 the number of influences on which there was agreement.

14  
15 **Table 2-11. Community Interactions group confidence for influences with**  
16 **agreement: NA = No agreement; HH = High evidence, High agreement; HL**  
17 **= High evidence, Low agreement; LH = Low evidence, High agreement; LL =**  
18 **Low evidence, Low agreement**

19  
20 The confidence results shown in Figure 2-12 total all judgments across all participants.  
21 In total, confidence decreased from current conditions to the climate scenarios, with a decrease in  
22 the total number of HH judgments, and an increase in LL judgments. The decrease in the total  
23 number of HH judgments from current conditions to the climate scenarios and the corresponding  
24 increase in the total number of LL judgments show that influences are less well-understood due  
25 to less information being available about future climate conditions. However, there was an  
26 increase in the total number of no answer given, and the decreases in LH and increases in HL are  
27 difficult to explain overall.

28  
29 **Figure 2-12. Community Interactions group confidence results for all**  
30 **influences; HH = High evidence, High agreement; HL = High evidence, Low**  
31 **agreement; LH = Low evidence, High agreement; LL = Low evidence, Low**  
32 **agreement.**

#### 33 34 **2.3.2.6. Interacting Influences**

35 Under all scenarios, the interaction of Relationship A with B (OMWM on Inundation  
36 Regime with Sea Level) was the only interactive influence with agreement among participants.  
37 Synergy was the type of influence chosen; this means that the effect of open marsh water  
38 management (which creates and connects ponds and pools) on inundation regime is intensified  
39 with sea level rise. There was no agreement on the confidence for this interactive influence.

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1 The lack of agreement on any other potential interacting influences was primarily due to  
2 not having many instances of enough participants characterizing the same interactions. Of the 25  
3 combinations of influences with interactions characterized, only two could be considered for  
4 agreement with at least three participants making a judgment; only one of those had three  
5 participants in agreement. One of the interactions that was only identified by one participant in  
6 the coding, Relationship H with J (Soil Temperature with Inundation Regime on Above Ground  
7 Plant Biomass, Competition) was brought up in the group discussion as an interplay of  
8 increasing relative impact under climate change (see Figure 2-9), indicating that further  
9 investigation of this interaction may be desirable.

10 Finally, two additional interactions that were not coded by individual participants were  
11 identified by the group as interactions of high relative impact under current conditions (Figure 2-  
12 9). These were the effects of: 1) nitrogen with inundation regime on ratio of low marsh to high  
13 marsh; and 2) nitrogen with salinity on ratio of high marsh to *Phragmites*. The first interaction is  
14 a synergy between inundation regime and nitrogen. Low marsh plants are better at dealing with  
15 inundation than high marsh plants due to their greater tolerance of high salinity and low soil  
16 oxygen content; and the high marsh species dominate the upper zone due to their superior  
17 competitive ability in obtaining below-ground nutrients (Bertness and Pennings, 2007). Under  
18 climate change, nitrogen may no longer be limiting due to greater nutrient runoff, while greater  
19 inundation of saline water is also expected; together these factors will synergistically favor low  
20 marsh species. The second interaction – the effect of nitrogen with salinity on ratio of high  
21 marsh to *Phragmites* -- is a competition, where increased nitrogen has a positive impact on  
22 *Phragmites* while increased salinity has a negative effect.

#### 24 **2.4. DISCUSSION OF ADAPTATION STRATEGIES**

25 With a structure for considering management priorities provided by MBP, the workshop  
26 participants discussed the implications of the exercise results for management. Workshop  
27 observers also participated in the discussion. Table 2-12 lists adaptation strategies that emerged  
28 during the group discussions. The experts discussed a variety of general adaptation strategies as  
29 well as some specific adaptation activities that would be responsive to key potential climate-  
30 related changes identified through their judgments. The strategies fall into several broad  
31 categories including Restoration & Conservation, Reducing Non-Climate Stressors and  
32 Monitoring & Planning. While some of the strategies were specifically generated for  
33 management of one or the other ecosystem process, many are applicable to both Sediment  
34 Retention and Community Interactions and to salt marsh ecosystem processes not included in the  
35 workshop.

37 **Table 2-12. Adaptation strategies and associated top pathways for**  
38 **management (see section 3.2 for pathways). SG=Sediment Retention Green**

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1 pathway; SB=Sediment Retention Blue pathway; SP=Sediment Retention  
2 Purple pathway; CG=Community Interactions Green pathway;  
3 CB=Community Interactions Blue pathway; CP=Community Interactions  
4 Purple pathway.  
5

#### 6 **2.4.1. Restoration & Conservation**

7 Restoration and conservation together make a powerful adaptation strategy because they  
8 contribute to increased resilience of the overall system. General restoration guidelines that were  
9 discussed include restoring the “habitat mosaic” in order to provide a connected landscape that  
10 maintains biodiversity in case of disturbance of individual pieces of the mosaic. Conservation is  
11 implicit in consideration of where to prioritize restoring habitats within the existing landscape  
12 continuum of healthy to degraded habitats, with a need to conserve the habitats that are adjacent  
13 to or otherwise complementary to ones which are restored. Conservation strategies include  
14 acquiring and protecting areas where existing marsh can expand. Adjusting development  
15 practices that will interfere with upland marsh expansion or future restoration opportunities is  
16 another important strategy. Conservation policy options include incentives to remove barriers to  
17 marsh migration and regulations that support development practices that protect sensitive  
18 resource areas where there is potential for adjacent restoration. This may include identifying  
19 areas for restoration adjacent to current healthy marshes and protecting those healthy marshes,  
20 especially where the adjacent uplands currently include complementary habitats that would  
21 contribute to a diverse landscape.

22 Sustaining new habitats that are created when current ones become unviable under future  
23 conditions will be an emerging management challenge. Choices will have to be made between  
24 enabling a transition versus aggressive restoration in the face of unsuitable conditions. Also  
25 important for restoration is creating conditions conducive to marshes being able to “restore  
26 themselves”, e.g., through ditch modification to increase hydrologic connectivity or by working  
27 to reduce localized non-climate stressors that can be controlled (see next section).

28 A more specific restoration project identified is removing tidal restrictions. Restoring  
29 tidal connections and removing or reengineering restrictions (e.g., culverts, road crossings, and  
30 tide gates) are already important management tools. Tidal restrictions -- including levees, dikes,  
31 dams, and filling and channeling activities -- change the natural flow of freshwater and sediment  
32 into the marsh. Restoring tidal connections enables sediment and tidal flows to distribute along  
33 natural gradients throughout the marsh, which may help the marsh to respond to changes in  
34 climate and keep pace with sea level rise. Since changing conditions may impact the amount and  
35 timing of freshwater flow, it will be important to use up-to-date precipitation and flow data and  
36 consider potential future climate scenarios when making assessments regarding reengineering  
37 designs. Once tidal restrictions have been removed, the most efficient way to achieve upstream  
38 restoration may be to facilitate favorable conditions for the marsh to “restore” itself. For

1 instance, as the salinity regime adjusts to the restored flows, invasive *Phragmites* will die back,  
2 and the key will be to manage the transition so that native high marsh can return to fill that space.  
3 Controlling invasive species was another specific restoration project discussed. Since one  
4 characteristic of invasive species is the ability to thrive after disturbance, reducing the prevalence  
5 of invasive species aids adaptation by restricting competition while native species recover after  
6 future climate related disturbances. *Phragmites* was the invasive species discussed at the  
7 workshop and is one of MBP’s current invasive removal priorities, but MBP also currently  
8 controls for other marsh species such as pepperweed and is monitoring emerging threats such as  
9 invasive tunicates, algae and crabs.

#### 11 **2.4.2. Reducing Non-Climate Stressors**

12 Reducing non-climate anthropogenic stressors of concern is another category of  
13 recommended adaptation strategies, one that especially needs to be considered in conjunction  
14 with conservation and restoration efforts. Healthy habitats will be better able to survive climate  
15 related stressors if they are not also struggling under the pressure of non-climate stressors. This  
16 applies to both maintaining healthy priority conservation sites and in ensuring that restoration  
17 projects are successful and able to become established.

18 Some of the management strategies discussed for reducing non-climate stressors include  
19 nutrient management and methods to limit erosion. Excess nutrients favor invasive *Phragmites*  
20 over native marsh species. For reducing excess nutrient inputs, both point and non-point nutrient  
21 sources are of concern. Tools include upgraded wastewater treatment, upgraded combined sewer  
22 overflow systems and stormwater best management practices that slow the flow of stormwater  
23 (e.g. swales or buffers) and provide opportunities for nutrient filtration before it reaches the  
24 marsh. These practices also include land use policies that promote more absorbent land cover  
25 (e.g. through landscaping best management practices and policies that reduce impervious cover)  
26 and “rain catchers”. Erosion control options discussed include creating “no wake zones” in areas  
27 where wave energy from boat wakes is contributing to marsh edge erosion. Erosion control  
28 structures have the potential to be maladaptative (i.e., when structures designed to protect  
29 infrastructure redirect wave energy or interrupt sediment supply to the adjacent marsh). This risk  
30 that can be minimized through planning processes for protecting coastal infrastructure that are  
31 required to demonstrate that they will not magnify erosion effects on adjacent marshes. There is  
32 also the opportunity to highlight the buffering capacity of healthy marshes when planning efforts  
33 highlight potential trade-offs between protecting both infrastructure and marsh, in order to build  
34 support for marsh conservation and restoration efforts.

#### 36 **2.4.3. Planning & Monitoring**

1           The last category of adaptation strategies discussed at the workshop addresses planning  
2 and monitoring, and the above categories each have planning and monitoring aspects to them.  
3 Many of the recommendations in Table 2-12 are based on planning, including prioritizing.  
4 Information needs were the basis of much of the discussion, including an exploration of a  
5 number of potential indicators of ecosystem responses to climate change. These indicators can  
6 help managers articulate some of the characteristics of the marsh that need to be examined first,  
7 in order to decide where to most effectively focus. Planning for restoration was discussed only  
8 so far as to recommend prioritizing restoring highest value habitats, leaving the question of how  
9 to determine which habitats have the highest value up to MBP. A related planning aspect related  
10 to conservation is how to determine where change is unavoidable, in order to manage the  
11 transition to a new habitat and the values that new habitat will provide. There is a need for  
12 management to have two plans: one to follow as long as maintaining current conditions is still  
13 possible, and another plan to follow once an unavoidable threshold is reached.

14           Monitoring priorities was another major aspect of the discussion. These included  
15 variables such as composition and structure of sediments, the position of the transition between  
16 high and low marsh and maximum growth rates. The ability to determine what the maximum  
17 level of vegetation growth is relative to sea level rise, and then to monitor changes in rates of  
18 growth and sea level rise, will be important for anticipating the threshold after which accretion  
19 will no longer keep pace vertically with sea level rise. Additional understanding of sediment fate  
20 and transport is needed. Storms and sea level rise will require attention in terms of how they  
21 impact sediment supply and erosion. Prioritization among management options for the two  
22 different types of erosion for Sediment Retention will depend on how storms and sea level  
23 differentially affect nearshore and coastal erosion versus marsh edge erosion.

24           The discussion of adaptation strategies described above was broad and free-ranging. The  
25 next section will combine the analysis of the exercise results with the ideas in Table 2-12 to  
26 discuss top pathways for management given climate change and to identify specific adaptation  
27 options in response.

1 **3. MAKING THE LINK TO MANAGEMENT**

2  
3 As detailed above, the workshop resulted in a large volume of information on the  
4 sensitivities of the sediment retention and community interactions processes to stressor  
5 interactions under current conditions and future climate scenarios. The next step lies in  
6 organizing this information into a form that managers can use to identify influences of particular  
7 importance upon which to focus management interventions and adaptation planning.  
8

9 **3.1. USING INFORMATION ON INFLUENCE TYPE & DEGREE, SENSITIVITY**  
10 **AND RELATIVE IMPACT TO IDENTIFY KEY MANAGEMENT PATHWAYS**

11 In the workshop exercise and group discussions, the experts generated three categories of  
12 information about the relationships in the influence diagrams: 1) the type and degree of each  
13 influence; 2) the sensitivity of each influence (including thresholds); and 3) the high relative  
14 impact of certain influences on the endpoints. All three categories of information should be  
15 considered in concert when interpreting management implications. This can be done by  
16 performing a “crosswalk” of all three categories of information in order to identify pathways of  
17 particular interest that connect each endpoint (Sediment Deposition/Retention or Saltmarsh  
18 Sharp-Tailed Sparrow Nesting Habitat) to stressors or drivers that can be addressed through  
19 particular management activities. The crosswalks as well as example pathways are presented  
20 below.  
21

22 **3.1.1. Crosswalks: Influence Type & Degree, Sensitivity and Relative Impact**

23 The crosswalks for Sediment Retention and Community Interactions are presented in  
24 Tables 3-1 and 3-2. For each influence, information on type and degree, sensitivity, and relative  
25 impact is listed side-by-side, first for current conditions, followed by Climate Scenarios A and B.  
26 This allows for easy comparison of all three categories of information, across all three scenarios.  
27 The influences have also been rank-ordered based on the amount of information available for  
28 each in terms of agreement on influence type, degree, sensitivity, relative impact and threshold  
29 potential.  
30

31 **3.1.1.1. *Sediment Retention Crosswalk***

32  
33 **Table 3-1. Sediment Retention group crosswalk for comparison of influence**  
34 **type and degree, sensitivity and relative impact for current conditions and**  
35 **climate scenarios. NA = No agreement; Prop = Proportional; Disprop =**  
36 **Disproportional; L = Low sensitivity; I = Intermediate sensitivity; H = High**  
37 **sensitivity; H-trend = No agreement but trending toward high sensitivity; ↑ =**  
38 **Increasing relative impact from current; () = Number of respondents;**

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1           **Ranking column orders the influences according to completeness of**  
2           **information**  
3

4           For Sediment Retention (Table 3-1), there was agreement on type/degree and sensitivity  
5 across all three scenarios for over one third of the influences. Especially when coupled with a  
6 designation of high relative impact, these influences are of special interest for management  
7 because we have a good understanding of the nature of the relationships, their sensitivity to  
8 changes now and in the future, and their high relative impact on the endpoint of Sediment  
9 Deposition/Retention. Therefore these are influences for which management interventions are  
10 most likely to have the intended effects. Influences ranked number one in Table 3-1 fall into this  
11 category. Influences of ranking two are of almost equal status, as each has only one instance of  
12 lack of agreement in sensitivity or type/degree under only one scenario.

13           Influences of ranking three and four were almost all identified as having high relative  
14 impact and quite a bit of agreement on type/degree and sensitivity, as well. However, these  
15 influences each had more than one instance of lack of agreement, i.e., gaps across multiple  
16 information categories and/or across multiple climate scenarios.

17           The remaining rankings (five through 10) continue the pattern of gradual loss of  
18 information. Some influences had high relative impact but lacked agreement on many (or even  
19 all) other categories of information. For these influences the implication is that, while each is  
20 believed to have significant potential to impact the end point, there is little concurrence on the  
21 actual mechanics of the relationship. However, it should be noted that Relationship BB  
22 (Inundation Regime on Below Ground Biomass) was tagged as a likely threshold relationship by  
23 the participants, where an inability to explain where the threshold might occur contributed to the  
24 lack of agreement (due to a mixture of codes) for this influence (see threshold discussion in  
25 section 2.3.1.2 for further details).

26           In general, lack of agreement on one or more of the type/degree and sensitivity categories  
27 may be an indication that more information is needed to understand the particular influence. It  
28 does not imply that the relationship is not potentially important, but rather that there was not  
29 sufficient concurrence by this specific group of experts for managers to be confident about the  
30 response to either climate change or to associated management interventions. Relationship S  
31 (Inundation Regime on Surface Roughness) and Relationship U (Freshwater Flow on Surface  
32 Roughness) are interesting cases in that there was no agreement on influence type/degree or  
33 sensitivity, but there was agreement on high relative impact across all scenarios. In the case of  
34 these influences as well as others with multiple gaps in agreement, priorities for further  
35 investigation (through literature reviews and further basic research where needed) could be based  
36 in part on which of these influences are most critical to understand since they have a high  
37 relative impact or have links to other influences of special importance to the endpoint.  
38

1  
2 **3.1.1.2. *Community Interactions Crosswalk***  
3

4 **Table 3-2. Community Interactions group crosswalk for comparison of**  
5 **influence type and degree, sensitivity and relative impact for current**  
6 **conditions and climate scenarios. NA = No agreement; Prop = Proportional;**  
7 **Disprop = Disproportional; L = Low sensitivity; I = Intermediate sensitivity;**  
8 **H = High sensitivity; H-trend = No agreement but trending toward high**  
9 **sensitivity; ↑ = Increasing relative impact from current; () = Number of**  
10 **respondents; Ranking column orders the influences according to**  
11 **completeness of information**  
12

13 For Community Interactions (Table 3-2), there was agreement on both type/degree and  
14 sensitivity across all three scenarios for just over one third of the influences. Those coupled with  
15 a designation of high (or increasing) relative impact across the scenarios may be of special  
16 interest for management since they are well understood in terms of the nature of each  
17 relationship, its sensitivity to changes now and in the future, and its high relative impact on the  
18 Saltmarsh Sharp-Tailed Sparrow Nesting Habitat endpoint. These are the influences for which  
19 management interventions are most likely to have the intended effects. All of the influences of  
20 ranking one in Table 3-2 fall into this category. Within ranking two, there are two additional  
21 influences (L: Inundation Regime on Sedimentation and V: Salinity on Ratio of Native High  
22 Marsh to *Phragmites*) that are of nearly equal status in that they have high relative impact and  
23 nearly full agreement on type/degree and sensitivity across all scenarios, with the single  
24 exception of losing agreement on sensitivity under Scenario B.

25 Even though not designated as highest relative impact, the remaining influences of ranking  
26 two are equally important to consider. These are influences for which there was agreement on  
27 type/degree and sensitivity across all scenarios. While not of highest relative impact, these  
28 relationships are well understood and sensitive to change, and may be linked with other influences  
29 for important cumulative effects on the endpoint.

30 The rest of the influences ranked three to 11 follow a pattern of gradually increasing lack  
31 of agreement across multiple scenarios on type/degree and/or sensitivity. Again, lack of  
32 agreement on one or more of the type/degree and sensitivity categories indicates that more  
33 information is needed on the particular influence. It does not imply that the relationship is not  
34 potentially important, but rather that there was not sufficient concurrence by this specific group  
35 of experts, and more information is needed. In the case of Relationship H (Soil Temperature on  
36 Above Ground Biomass) and Relationship J (Inundation Regime on Above Ground Biomass),  
37 there was very low agreement for each on type/degree and sensitivity across the scenarios, yet  
38 there was agreement on high relative impact of the two relationships working together as an  
39 interactive influence under the climate scenarios. In the case of these influences as well as others

1 with multiple gaps in agreement, priorities for research could be based in part on which of these  
2 influences are most critical to understand since they have a high relative impact or have links to  
3 other influences of special importance to the endpoint.

### 4 5 **3.1.1.3. *Information Gaps***

#### 6 *Crosswalks*

7       Patterns of information gaps in the crosswalk tables were similar for Sediment Retention  
8 (Table 3-1) and Community Interactions (Table 3-2). Over one third of the influences for both  
9 groups were well understood across type/degree and sensitivity categories of information across  
10 all scenarios. In quite a few additional cases, there was agreement on type although not on  
11 degree. Another common pattern for both groups is that influences of progressively lower rank  
12 tend to show lack of agreement under the climate scenarios first, while agreement under current  
13 conditions is often better. This drop in agreement across the scenarios is consistent with greater  
14 uncertainty about future conditions and ecological responses compared to current conditions.  
15 With such a variety of information gaps, it will be necessary to prioritize targeted literature  
16 reviews and/or basic scientific research to focus on key process components of interest. A  
17 starting point would be to establish a basic understanding of type and degree under current  
18 conditions for influences within otherwise well-understood pathways that link to rich  
19 opportunities for management. From there, the next step would be improving understanding of  
20 type/degree and sensitivity under potential future climate conditions, which will be less likely to  
21 be fully supported in the existing literature and may require theoretical approaches. Another  
22 method for sorting through and prioritizing “non-agreement” influences for further study might  
23 be to start from the perspective of management opportunities. Managers could look at their most  
24 tractable and effective management levers currently available, and trace pathways from those  
25 down to the endpoint of interest, as a means of identifying and selecting priority influences for  
26 research. Examples of promising pathways are presented in section 3.1.2 below.

#### 27 28 *Confidence*

29       Confidence estimates were not included in the crosswalk tables or used as a means of  
30 identifying management pathways because of extensive information gaps in the form of missing  
31 estimates. It is possible that this was partly due to time limitations as participants prioritized  
32 characterizing the influences before marking confidence. This may have been exacerbated by  
33 lack of familiarity with the coding scheme and the limited time that was available to discuss the  
34 definitions of high and low evidence and agreement.

35       Another problem that may have led to gaps was that the confidence exercise did not take  
36 into account specialty areas of participant knowledge. Due to the complex and interdisciplinary  
37 nature of the influence diagrams and the individual specialties of the participants, some

1 participants may have been asked to make judgments on influences for which they felt they had  
2 insufficient expertise. In some cases they may have elected to leave those cells blank rather than  
3 indicate low confidence, as that would have incorrectly indicated that the participant knew that  
4 the scientific literature is lacking evidence or agreement on the influence, when really it was a  
5 case of lacking familiarity with the literature.

6 Thus the large number of missing cells for confidence could have been due to one or  
7 more of the following: 1) lack of time; and 2) confusion about the confidence definitions and  
8 coding scheme; and 3) inability to judge confidence in certain influences due to lack of expertise.  
9 These problems could be corrected in subsequent workshops through pre-workshop trainings to  
10 increase familiarity with using the coding scheme; provision of a code to allow participants to  
11 indicate lack of expertise as a reason for leaving a cell blank; and additional time to complete the  
12 exercise.

### 14 **3.1.2. Identifying Key Pathways for Management**

15 Using the crosswalk tables (Tables 3-1 and 3-2), it is possible to identify influences that  
16 are well understood, become more sensitive, and have a greater relative impact under future  
17 climate scenarios. By combining a series of such influences into a pathway to the endpoint, we  
18 can begin to identify key responses and changes in variables of interest to management. A  
19 “pathway” is defined as a series of connected variables and their influences, beginning with a  
20 driver or stressor variable and ending at the endpoint. The purpose is to be able to apply  
21 management interventions in order to impact the endpoint. “Management levers” are those  
22 variables for which it is possible to intervene with management options; the clearest connections  
23 to management options are for the top level variables that are drivers or stressors. When  
24 multiple management levers are available for a pathway, the one that was more completely  
25 characterized or that had potential changes under the climate scenarios identified was selected.  
26 Two example pathways are discussed below, one for Sediment Retention and one for  
27 Community Interactions, to show the process by which these types of pathways can be identified.  
28 These will be followed in the next chapter by summary diagrams showing the top three pathways  
29 of interest for each process, along with discussion of specific management options.

#### 31 **3.1.2.1. *Sediment Retention Example***

32 The influence diagram for Sediment Deposition/Retention (Figure 3-1) distinguishes the  
33 contributions of two major types of erosion (Marsh Edge Erosion, and Coastal and Nearshore  
34 Erosion), which have different relationships with climate drivers and by which sediment follows  
35 a different path to the endpoint. This example focuses on the pathway of Storms to Marsh Edge  
36 Erosion (Relationship L) to the endpoint, connecting through Relationship AA (Marsh Edge  
37 Erosion on Sediment Deposition/Retention. For type and degree of influence, Relationship L



1 was characterized as a direct proportional influence under all scenarios. For sensitivity,  
2 Relationship L was characterized as having intermediate sensitivity under all scenarios, but was  
3 noted as a potential threshold relationship that could transition to high sensitivity (i.e., shift from  
4 direct proportional to direct disproportionately strong) at some point under the climate scenarios.  
5 In terms of relative impact, Relationship L was characterized as having secondary impact under  
6 all scenarios.

7  
8 **Figure 3-1. Sediment Retention Example Pathway.**  
9

10 Relationship AA had slightly less agreement. Under current conditions, Relationship AA  
11 had no agreement on type or sensitivity. This was because some participants assumed that  
12 eroded sediment would be deposited on the marsh (direct relationship), while others thought it  
13 would be carried offshore and lost (inverse relationship). However, under the climate scenarios,  
14 Relationship AA was characterized as being an inverse proportional influence as the participants  
15 increasingly agreed that the sediment was more likely to be lost from the system due to the  
16 combined effects of sea level rise and changes in inundation and flow regimes. For sensitivity,  
17 Relationship AA was characterized as having intermediate sensitivity under all scenarios, but  
18 was noted as a potential threshold relationship that could transition to high sensitivity (i.e., shift  
19 from inverse proportional to inverse disproportionately strong) at some point under the climate  
20 scenarios as marsh area decreases and erosion increases. In terms of relative impact,  
21 Relationship AA was characterized as having secondary impact under all scenarios.  
22 Both influences are characterized as intermediate sensitivity, which indicates that they would be  
23 responsive to management actions. Both influences have high relative impact on the endpoint.

24 To manage along this pathway, an increased understanding of Relationship AA would be  
25 important. Understanding the specifics of how marsh edge erosion influences sediment  
26 deposition and retention (also taking into account other sources of sediment from coastal and  
27 nearshore erosion) would help with determining where, how and when to protect marshes against  
28 erosion due to storms. The first need is to identify where sediment starved areas (versus  
29 relatively sediment rich areas) are located. Management needs for sediment starved areas will  
30 then include guidelines for increasing sediment connectivity (e.g., through removal of groynes  
31 and jetties) and/or installing protective barriers (e.g., through establishment of oyster reefs).  
32 Since a threshold of intensifying erosion is anticipated, it will be important to implement such  
33 adaptations before – and in order to forestall – the threshold change. Thus monitoring of erosion  
34 and sediment transport at both the marsh edge and along the coastline will be increasingly  
35 important as the climate changes.

### 3.1.2.2. *Community Interactions Example*

The Community Interactions example pathway (Figure 3-2) is longer and more complex. The management lever is Land Use/Land Cover: Residential Development, which affects Freshwater Flow (Relationship E). The pathway then goes to Inundation Regime (Relationship D) to Nitrogen (Relationship K), to the Ratio of Native High Marsh to *Phragmites* (Relationship S), to Marsh Elevation (Relationship EE), to the Saltmarsh Sharp-Tailed Sparrow Nesting Habitat endpoint (Relationship AA). During discussions, several participants noted that the diagram lacked an arrow to show the direct influence of Residential Development on Nitrogen; however the diagram did capture the indirect linkages of Residential Development with Nitrogen through Freshwater Flow via Inundation Regime. Nitrogen is delivered to the marsh through a number of pathways such as marine and freshwater sources along with stormwater runoff. Both direct disturbance from development and changes in nitrogen in the marsh will impact marsh vegetation, differentially affecting native high marsh and *Phragmites* growth.

#### **Figure 3-2. Community Interactions Example Pathway.**

Relationship E was characterized as a direct proportional influence of intermediate sensitivity under all scenarios. It was also identified as of primary relative impact. Relationship D was characterized as disproportionately weak direct influence under all scenarios. It was characterized as a low sensitivity influence under all scenarios and not identified as having high relative impact. Relationship K was characterized under current conditions as a direct proportional influence with intermediate sensitivity. Under the climate scenarios Relationship K was less understood, with no agreement on type or degree of influence or sensitivity under either climate scenario. Relationship K was not identified as having high relative impact under any of the scenarios.

Relationship S had more agreement, as it was characterized as an inverse proportional influence with intermediate sensitivity under all scenarios. Relationship S was identified as having a high interactive impact with Relationship V (Nitrogen on the Ratio of Native High Marsh to *Phragmites* with Salinity), and this relative impact remained the same under the climate scenarios.

Relationship EE was characterized as an inverse, disproportionately weak influence under current conditions, and an inverse influence with no agreement on degree under the climate scenarios. For sensitivity, Relationship EE was characterized as having low sensitivity under current conditions and intermediate sensitivity under the climate scenarios, a change that indicates a threshold; as sea level rises, marsh elevation will become increasingly sensitive to the ratio of native high marsh to *Phragmites*. This is because *Phragmites* is more effective at trapping sediment (due to its large rhizomes located right at the surface) and thus better equipped

1 to migrate landward to higher elevations. Relationship EE was not characterized as an influence  
2 with high relative impact under any of the scenarios.

3 Relationship AA was characterized as a direct influence under all scenarios, with no  
4 agreement on the degree of influence. The coding for sensitivity indicated a trend from  
5 intermediate-to-high sensitivity under all scenarios. Under current conditions, Relationship AA  
6 was identified as having primary relative impact, and this remained the same under the climate  
7 scenarios.

8 While there are aspects of this pathway that are not fully understood, it is a pathway that  
9 may be responsive to a variety of management options when planning for climate change. The  
10 management lever of Land Use/Land Cover: Residential Development is an ongoing concern for  
11 salt marsh habitats. Nutrient inputs, especially nitrogen, favor *Phragmites* over native species  
12 such as *Spartina patens*. These inputs can come from point sources such as sewage plants or  
13 non-point sources in the form of runoff that is exacerbated by residential development and  
14 associated increases in impervious surface cover. New or expanded residential development can  
15 also cause disturbance when adjacent to the marsh, which favors invasive species such as  
16 *Phragmites*. Thus this pathway emphasizes the priority importance of focusing on management  
17 options that prevent or mitigate disturbance of adjacent marshes during residential development,  
18 improve sewage treatment practices, and promote use of buffers, rain catchers and absorbent  
19 surfaces to reduce runoff.

### 21 **3.2. TOP PATHWAYS AND IMPLICATIONS FOR ADAPTATION PLANNING**

22 Sections 3.1.2.1 and 3.1.2.2 above have used examples to demonstrate how the results of  
23 the expert elicitation exercise can be used to help identify key pathways for management. This  
24 method of identifying well-understood pathways that can be traced from endpoints of concern to  
25 management levers is a useful way to explore the implications of the workshop results for  
26 adaptation planning. In some cases it may be possible to identify management actions for  
27 immediate implementation, i.e., where there is sufficient understanding of the relationships  
28 among the variables as well as their sensitivities to act with relative confidence in the effects of  
29 management interventions. Additional pathways of interest can be identified through further  
30 examination of the crosswalk tables (Table 3-1 and Table 3-2), using amount of information with  
31 agreement (to identify current best-understood influences) as well instances of climate thresholds  
32 (indicating potential climate-induced shifts) to identify “top pathways” of interest for  
33 management. This section describes three “top pathways” for the Sediment Retention and  
34 Community Interactions processes, as well potential adaptation responses. This is followed by a  
35 brief review of MBP planning documents and discussion of where adaptation activities could be  
36 linked into these existing plans and strategies.

### 3.2.1. Top Pathways and Associated Adaptation Options

Three top pathways for each process are presented in Figure 3-3 (Sediment Retention) and Figure 3-4 (Community Interactions). For ease of viewing, each pathway is highlighted by a color (green, purple or blue), and influences that undergo changes under the climate scenarios are highlighted with red boxes indicating the nature of the change. Dashed lines indicate inconsistent agreement among participants in at least one scenario. The order in which the pathways are presented below is not an indication of order of importance. These are all management pathways with notable potential for addressing the climate sensitivities identified.

**Figure 3-3. Top pathways for management of the Sediment Deposition / Retention endpoint. Green, blue and purple colors are used to distinguish different pathways. Red boxes highlight changes under future climate conditions. ^ indicates increasing relative impact under future conditions. 1° indicates primary relative impact under current conditions. 2° indicates secondary relative impact under current conditions. A direct to inverse threshold occurs where there is a direct effect under current conditions that may shift to an inverse effect under future climate conditions. Dashed lines indicate inconsistent agreement across scenarios of current and future conditions.**

**Figure 3-4. Top pathways for management of the Saltmarsh Sharp-tailed Sparrow Nesting Habitat endpoint. Purple, blue and green colors are used to distinguish different pathways. Red boxes highlight changes under future climate conditions. ^ indicates increasing relative impact under future conditions. An inverse to strong inverse threshold occurs where there is an inverse effect under current conditions that may shift to a very strong inverse effect under future climate conditions. Dashed lines indicate inconsistent agreement across scenarios of current and future conditions.**

#### 3.2.1.1. *Sediment Retention Top Pathways*

##### *Purple pathway*

The Sediment Retention example pathway described in section 3.1.2.1 above is elaborated upon here as the Purple top pathway (Figure 3-3). Starting with the Sediment Deposition/Retention endpoint and working “up” the diagram, marsh edge erosion represents one major component of how sediment can be lost to the marsh. The relationship is an inverse effect where increased erosion leads to decreased sediment retention, and this was identified by the workshop experts as an effect of high relative impact (secondary category). Marsh edge erosion occurs when wave energy from wind-driven waves (especially during storms), boat wakes, and ice scour (removal of vegetation and underlying peat by tidal movement of overlying ice) lead to loss of sediment from the seaward edge of the marsh. The proportion of the eroded material that the marsh is able to retain through sediment trapping by marsh vegetation plays a major role in whether the marsh is able to rebuild along the eroded edge and to accrete vertically to keep pace

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1 with sea level rise within the interior. A threshold in sensitivity of the influence of erosion on  
2 sediment retention is explained below.

3 At the next level up the pathway, storms are a major contributor to marsh edge erosion;  
4 they have a direct effect which was characterized as having high relative impact (secondary  
5 category) on the endpoint. Marsh edge erosion is considered a threshold variable that is sensitive  
6 to future increases in storm intensity (with a strong seasonal component), especially given sea  
7 level rise. At a higher sea level, the marsh edge is exposed to storm surge and wave energy from  
8 storms for longer periods of the tidal cycle. Also, under Climate Scenario B, between 5 and 15%  
9 of East Coast storms (an additional 1 storm per year) are expected to move northward during late  
10 winter (Jan, Feb, March), further increasing storm energy effects in the Northeast. The greater  
11 influence of storms under the climate scenarios will intensify marsh edge erosion, and sediment  
12 eroded during storms will be more likely to be transported outside of the local marsh. The  
13 combined effects of sea level rise and changes in storms are likely to cause a threshold shift,  
14 where much of the sediment eroded from the marsh edge will no longer be available for  
15 accretion within the system, leading to an abrupt drop in sediment deposition and retention.

16 The management implications for adaptation under this pathway begin with a need to  
17 apply current erosion control tools, such as “no wake” zones to reduce erosion due to boat  
18 wakes. Barrier beaches that protect marshes from storms can be conserved through dune grass  
19 protection and restoration. Next, new tools for reducing wave action on the front edge of  
20 marshes need to be developed. These could include methods to establish oyster reefs adjacent to  
21 marshes exposed to storms or alternative protective barriers that reduce wave energy before it  
22 reaches the marsh edge. For these options to be successful, an improved understanding of the  
23 specifics of the local sediment budget, including coastal and nearshore sediment sources, will be  
24 needed for determining how, when and where to protect marshes against erosion due to storms.  
25 Monitoring of erosion and sediment transport at both the marsh edge and along the coastline will  
26 be increasingly important as the climate changes in order to detect threshold shifts, to identify  
27 areas losing sediment as priority sites for management intervention, and to measure effectiveness  
28 of such interventions. Another research area that would help prioritize most vulnerable areas for  
29 protection is monitoring the structure of the peat along the marsh edge. The age and structure of  
30 the marsh peat may put some areas at risk of passing the threshold earlier than others,  
31 necessitating their placement as highest priority for protection.

### 32 33 *Green pathway*

34 Starting with the Sediment Deposition/Retention endpoint and working along the Green  
35 top pathway (Figure 3-3), inundation regime (frequency, depth and duration of marsh flooding)  
36 plays an important role in the delivery of sediment and the conditions necessary for its retention  
37 within the marsh. The relationship is considered a direct effect of high relative impact (primary

1 category) under current conditions, where an increase in inundation leads to increased transport  
2 into, and deposition of sediment onto, the marsh. Under climate change, a threshold flip from a  
3 direct to an inverse relationship is expected when too much inundation increases tidal flow  
4 velocities and suspends more sediment than is deposited, leading to a net decrease in deposition  
5 and retention.

6 At the next level up the pathway, inundation regime is directly affected by marsh high  
7 water level, which is an indicator of sea level marked by the transition from marsh to upland  
8 vegetation. The ability of this transition zone to migrate upland with sea level rise will  
9 determine the extent (and even the existence) of the future marsh, and inundation regime will  
10 change accordingly. So with climate change, as sea levels rise and cause increasing pressure on  
11 the transition zone of marsh high water level, this in turn will have a greater impact on  
12 inundation regime and, ultimately, on sediment deposition/retention; therefore this is an  
13 influence of increasing relative impact under climate change. Marshes with barriers to migration  
14 will be limited to responding to sea level rise through vertical accretion only, as they will be  
15 unable to move upland (i.e., by adjusting the location of the marsh high water level/transition  
16 zone).

17 Meanwhile, another important determinant of inundation regime is tidal exchange, and  
18 this relationship was identified by the experts as having a high relative impact (primary category)  
19 on the endpoint. Tidal exchange was defined by the participants as tidal prism, which is the  
20 difference between the volume of water at mean low tide and mean high tide. Tidal exchange is  
21 in turn inversely affected by tidal restrictions, again with high relative impact (primary category).  
22 Tidal restrictions occur where infrastructure (e.g. roads, bridges, railroads, causeways and  
23 footpaths) cross wetlands such that insufficiently large openings (such as culverts and pipes) at  
24 tidal creeks alter the hydrology and salinity of the upstream marsh. The smaller the opening is  
25 relative to the volume of flow that needs to pass through in a tidal cycle, the less the tidal  
26 exchange. Tidal restrictions also affect the flow of freshwater downstream of the restriction.

27 Management options for this pathway are to remove or re-engineer tidal restrictions and  
28 to remove barriers to upland migration of marsh high water level. In the near term, management  
29 options should continue efforts to relieve tidal restrictions in order to restore upstream  
30 hydrology, salinity and sediment transport across the restrictions. However, as sea level rise  
31 continues, it is possible that the inundation regime could reach a tipping point at which too much  
32 inundation could now have a negative effect on sediment deposition and retention. Tidal  
33 restrictions in the future could be managed to minimize excess inundation. Thus, this  
34 management lever will have to be used with care to avoid the unintended consequence of today's  
35 adaptation becoming tomorrow's 'maladaptation'.

36 One option to consider when re-engineering tidal restrictions is the addition of tide gates  
37 so that the hydrology of the upstream marsh can be managed more precisely under the greater

1 range of conditions expected in the future. Tide gates can be closed prior to storms or spring  
2 tides to avoid peak flooding, but reopened for normal tidal exchange. Other means to control  
3 hydrodynamic regime are through channel and ditch modification. Reduced flows gradually lead  
4 to wider and shallower channels; thus one way to restore hydrology is by cutting narrower,  
5 deeper channels. This would be especially effective in areas that have been diked or when done  
6 in conjunction with tidal restriction removals. Meanwhile, ditching has been used historically to  
7 increase drainage for mosquito control, and some ditch maintenance for that purpose continues  
8 today. There is an opportunity to work with the State Reclamation and Mosquito Control Board,  
9 which is responsible for ditch maintenance, to see where ditches have been maintained and  
10 compare their impacts on drainage and inundation regime to where they have been filled in or  
11 become re-vegetated. A long-term monitoring plan that includes sediment transport as well as  
12 inundation regime at different vegetation transition zones (including the marsh high water level)  
13 would allow for conditions to be consistently measured and may assist in understanding the level  
14 at which inundation causes a change in sediment deposition and retention in marshes.

15 Looking at marsh high water level together with tidal restrictions is important because  
16 tidal restrictions alter the marsh high water level upstream of the restriction. When prioritizing  
17 areas for removal or re-engineering of tidal restrictions to restore upstream hydrology, there  
18 needs to be consideration of what the marsh high water level will adjust to once the vegetation  
19 adjusts to the restored hydrodynamic regime. Ideally, this can be done in such a way as to take  
20 advantage of the marsh's ability to 'restore' itself under the right conditions. Restoration  
21 prioritization should go to places where there is room for the restored marsh high water level to  
22 further migrate upland with sea level rise. Whether or not there is a tidal restriction,  
23 management options for marsh high water level are to remove barriers to migration such as roads  
24 and hardened shorelines. In areas without barriers, where the adjacent slope, soil and vegetation  
25 are suitable to marsh migration, there is a need for policies and incentives that discourage new  
26 barriers from being built and encourage conservation easements or other protections.

27

### 28 *Blue pathway*

29 Starting from the Sediment Deposition/Retention endpoint, the Blue pathway (Figure 3-  
30 3) begins with a link to net accretion. Net accretion was defined by the group as referring to net  
31 change in elevation, which under current conditions has an inverse effect on sediment deposition  
32 and retention. Increased accretion decreases sediment deposition because the additional  
33 elevation reduces flow velocities during inundation to the point where more sediment will come  
34 out of suspension before it makes its way very far into the marsh. With higher sea level, a  
35 threshold shift could occur, changing this to a direct relationship. The mechanism behind this  
36 threshold is that when the marsh is at a greater depth during inundation, the water will arrive at

1 higher flow velocities, carrying sediment still in suspension further into the marsh to be  
2 deposited.

3 The next influence in this pathway is the effect on net accretion of below ground  
4 biomass, which comprises the biological component of net accretion. It has a direct effect and is  
5 of high relative impact (primary category). Nutrient inputs, in turn, have a direct impact on  
6 below ground biomass under current conditions, also of high relative impact (primary category).  
7 This relationship works through nutrient additions being beneficial to above ground productivity,  
8 a portion of which adds to below ground peat. However, a threshold can occur where excess  
9 nutrients will have a negative impact on below ground productivity and increase decomposition.  
10 In the long term under the climate change scenarios, these effects are likely to outweigh the  
11 benefits of above ground productivity and cause the relationship to change from direct to inverse.  
12 This threshold change would increase the already high relative impact of this influence.

13 In the next step of the pathway, freshwater flow directly affects nutrient inputs, with high  
14 relative impact (secondary category) on the endpoint. Finally, at the management lever end of  
15 the pathway, freshwater flow is directly influenced by the amount of impervious cover, which  
16 delivers a greater portion of precipitation to rivers and streams, circumventing infiltration. The  
17 relationship is of high relative impact (secondary category). This relationship is likely to  
18 increase in sensitivity under the climate scenarios, as the effects of storms and flashiness of  
19 precipitation events increase.

20 Management options under this pathway should focus on both reducing nutrient sources  
21 and reducing delivery of nutrients through improved stormwater management. Stormwater  
22 management policies can promote the use of absorbent land cover (e.g., permeable  
23 pavements), rain catchers and buffers. In order to reduce direct nutrient sources, sewage  
24 treatment plants can be upgraded to tertiary treatment, which removes nutrients. Likewise,  
25 combined sewer overflow (CSO) systems can be upgraded to ensure that all sewage passes  
26 through upgraded treatment. CSO upgrades will become a high priority under climate change as  
27 larger precipitation events that trigger overflows are expected to become more frequent. Septic  
28 systems should be appropriately sited, regularly inspected and properly maintained. Education  
29 and outreach efforts can inform homeowners of proper timing (not directly before or after any  
30 rainfall event), placement and application rates for fertilizers.

31

### 32 **3.2.1.2. *Community Interactions Top Pathways***

#### 33 *Green pathway*

34 The Community Interactions example pathway described in section 3.1.2.2 above is  
35 elaborated upon here as the Green top pathway (Figure 3-4). Starting with the Saltmarsh Sharp-  
36 Tailed Sparrow Nesting Habitat endpoint and working “up” the diagram, nesting habitat is  
37 directly dependant on marsh elevation, as nests must be located high enough to avoid inundation



1 at maximum tide during the incubation period. Therefore this is a direct relationship of high  
2 relative impact. Because this is one of only three variables that feed directly into the nesting  
3 habitat variable in the influence diagram, and because all of the top pathways converge on this  
4 one relationship, marsh elevation is arguably the most essential feature of this diagram.

5 At the next level up the pathway, we look at the effect on marsh elevation of the ratio of  
6 native high marsh to *Phragmites*. Under current conditions, this relationship is considered a  
7 weak inverse influence; a decrease in the ratio of native high marsh to *Phragmites* would lead to  
8 a modest increase in marsh elevation because *Phragmites* is more effective at trapping sediment  
9 (due to its large rhizomes located right at the marsh surface). The relationship strengthens under  
10 the climate scenarios, where there is a mixture of codes moving from weak to intermediate; the  
11 workshop participants identified this as a threshold shift to a stronger inverse relationship. They  
12 cited rising sea levels as the cause of the increasing sensitivity, as *Phragmites* would be better  
13 equipped to migrate landward to higher elevations while continuing to more effectively trap  
14 sediment in place; thus *Phragmites* is expected to better maintain marsh elevation compared to  
15 native high marsh, which may lose elevation more rapidly. This leads to a trade-off between  
16 maintenance of marsh elevation/extent in the face of sea level rise (favored by *Phragmites*) to  
17 preserve filtration and coastal protection functions, versus maintenance of native high marsh  
18 grasses (preferred sparrow nesting habitat) that will more rapidly be overcome rising seas. This  
19 greater vulnerability of native high marsh underscores how critical it will be for management of  
20 sparrow nesting habitat to include provision of adjacent upland areas to allow migration of native  
21 high marsh in advance of rising sea levels (see management discussion below).

22 Next, ratio of native high marsh to *Phragmites* is inversely affected by nitrogen since  
23 nitrogen favors *Phragmites* growth over that of native high marsh. This is considered an effect  
24 of high relative impact on the endpoint. Nitrogen is in turn directly affected by inundation  
25 regime, which distributes and pools nitrogen-rich waters over the marsh. Inundation regime was  
26 defined slightly differently by the Community Interactions group compared to the Sediment  
27 Retention group, as the percent time the high marsh is under water during April-October.  
28 Inundation regime can be weakly affected (direct positive effect) by freshwater flow through its  
29 contribution to longer periods of inundation over the marsh. Finally, freshwater flow is directly  
30 affected by residential development, which has a high relative impact because increased  
31 impervious cover leads to greatly increased runoff.

32 Management options for adaptation based on the relationships in this pathway should  
33 simultaneously address both maintenance of marsh elevation and control of *Phragmites*. A good  
34 starting point would be intensifying efforts that mitigate the negative effects of residential  
35 development, which are already an ongoing concern for salt marsh habitats. The most direct  
36 options would be to promote more absorbent land cover (including permeable pavements) while  
37 also placing a priority on upgrades to treatment plants (to tertiary treatment) and improved

1 stormwater management to reduce nutrient-rich runoff to marshes. At the same time, public  
2 programs can continue to raise awareness and create incentives for decreased use of fertilizers on  
3 lawns, regular inspections of septic systems, and use of rain catchers to reduce the volume of  
4 runoff during large rain events.

5         Meanwhile, management actions to preserve native high marsh while also maintaining  
6 marsh elevation will be essential. *Phragmites*, while better at maintaining marsh elevation, is  
7 undesirable as sparrow nesting habitat compared to native high marsh. *Phragmites* control  
8 programs (e.g., through mechanical harvesting or application of herbicides) should be targeted  
9 for implementation during or immediately after disturbance events from development projects  
10 (since disturbance favors invasions). However, it will be essential to couple this with removal of  
11 any barriers to marsh migration and protection of upland areas for native high marsh to grow and  
12 expand as sea level rises. Identification, acquisition and protection of such areas for marsh  
13 migration should focus on locations where room for marsh expansion is available and nitrogen  
14 sources are currently under best control for water quality maintenance.

#### 15 16 *Purple pathway*

17         Starting with the Saltmarsh Sharp-Tailed Sparrow nesting habitat endpoint, the Purple  
18 pathway (Figure 3-4) follows the Green pathway (see above) in its first two influences. As  
19 explained for the Green pathway, marsh elevation directly affects sparrow nesting habitat  
20 through a positive relationship of high relative impact. Marsh elevation is in turn inversely  
21 affected by the ratio of native high marsh to *Phragmites* (hereafter referred to as native high  
22 marsh: *Phragmites*); this inverse relationship is expected to intensify in the form of a threshold  
23 under climate change.

24         At this point the Purple pathway diverges from the Green pathway to focus on the effect  
25 of salinity on native high marsh: *Phragmites*. Greater salinity levels inhibit *Phragmites*, so any  
26 increase in salinity has a direct positive effect on native high marsh: *Phragmites*, and this  
27 influence is considered one of high relative impact on the end point. The designation of high  
28 relative impact for salinity – and also for nitrogen (Green pathway) -- under current conditions is  
29 due to a competitive interaction between salinity and nitrogen that was identified by the  
30 workshop experts. Increased salinity has a negative impact on *Phragmites* while increased  
31 nitrogen has a positive effect. Salinity is expected to have an increasingly high relative impact  
32 under climate change as sea level rise leads to increased inundation of saline water for longer  
33 periods of time, and higher into the marsh (placing greater pressure on *Phragmites*). This is an  
34 instance in which a climate change effect actually supports the goal of maintaining native high  
35 marsh.

36         The last influence in this pathway is the effect on salinity of freshwater flows. This is an  
37 inverse effect because freshwater flow counteracts salinity through dilution. This is considered

1 an influence of high relative impact under current conditions. Since both climate scenarios  
2 project an increase in precipitation in winter, spring, summer and fall (with the single exception  
3 of fall in Climate Scenario B), there is potential for this effect to increase in the future.

4 Management implications for adaptation under this pathway include some of the same  
5 actions as those discussed above for the Green pathway, as well as a few additional ones.  
6 Strategies for reducing freshwater runoff are further justified under this pathway since  
7 controlling runoff prevents salinity reductions that would favor *Phragmites* over the more  
8 salinity-tolerant native high marsh grasses. This places an even higher priority on the use  
9 permeable pavements and rain catchers to mitigate freshwater runoff, since these options reduce  
10 nitrogen runoff while also helping to maintain salinity.

11 Other actions to maintain appropriate salinity levels can also be considered. These  
12 include controlling the hydrodynamic regime (including through channel creation/ditch  
13 modification) to maintain salinity through unimpeded inundation. Also advantageous would be  
14 restoration of riparian buffers and upstream freshwater marshes to reduce freshwater flows and  
15 favor local infiltration and storage of rain water.

#### 16 17 *Blue pathway*

18 The Blue pathway (Figure 3-4) shares the same first influence as the previous two  
19 pathways, but then it diverges to explore another set of variables that contribute to marsh  
20 elevation. We have already established that Saltmarsh Sharp-Tailed Sparrow Nesting Habitat is  
21 directly affected by marsh elevation. Working “up” the blue pathway from here, marsh elevation  
22 is directly affected by sedimentation (the average concentration of suspended sediment in the  
23 water column), which contributes positively to marsh vertical accretion. The effect on  
24 sedimentation of above ground plant biomass is also direct and positive, as plant material serves  
25 as a source of organic sediment that contributes to sedimentation.

26 In the next step of this pathway, inundation regime (percent time the high marsh is under  
27 water during April-October) has an important threshold effect on above ground plant biomass.  
28 Under current conditions the influence is direct: inundation regime favors above ground plant  
29 biomass since sufficient flushing through inundation prevents soil salinity from reaching levels  
30 that inhibit growth. Thus, just as an appropriate inundation regime is important for maintaining  
31 salinity (see Purple pathway above), it is also important for preventing salinity from becoming  
32 too high. Under the climate change scenarios, however, this influence shifts from a direct to an  
33 inverse effect. As sea level (which directly affects inundation regime) rises, inundation  
34 frequency and duration is expected to reach levels that cause increased hypoxia and result in  
35 marsh die-back (i.e., marsh drowning); therefore this influence is expected to have increasing  
36 relative impact on the endpoint.

1 Finally, inundation regime is inversely affected (with high relative impact) by tidal  
2 restrictions such as road crossings or other barriers to tidal exchange. This is considered an  
3 influence of high relative impact.

4 Adaptation options under this pathway center on supporting an appropriate inundation  
5 regime and protecting the ability of above ground biomass and sedimentation to maintain marsh  
6 elevation. Management of tidal restrictions will require care, as plans for both pre- and post-  
7 threshold conditions will be needed, as well as an ability to switch with agility from one  
8 management plan to the other. In the near term (under current conditions), ongoing efforts to  
9 restore tidal connections (e.g., remove tidal restrictions) continue to be advantageous. However  
10 in the longer term (at some point in the next 30-60 years under future climate change), these  
11 same efforts could become disadvantageous due to sea level rise, such that management should  
12 then switch to utilizing restrictions to manage the flows (e.g., through use of tide gates that allow  
13 control of flows).

14 Meanwhile, regardless of when a potential threshold change may occur in the relationship  
15 of inundation regime to above ground plant biomass, priority can continue to be placed on  
16 management activities that directly support the maintenance of above ground biomass and the  
17 ability of the marsh to accrete both vertically and landward with sea level rise. This includes  
18 actions to: 1) identify, acquire and protect areas where marsh can grow and expand; 2) restore  
19 native high marsh habitat (with item #1 being a prerequisite); and 3) remove barriers to marsh  
20 migration. Furthermore all of these should be concomitant as much as possible with locations  
21 where natural flows and good sediment supplies are already in place.

22 To conclude this discussion of top pathways, it is worth noting that while this exercise  
23 has focused on management adaptations to climate change, there is also the potential for  
24 acclimation on the part of the Saltmarsh Sharp-Tailed Sparrow in the form of beneficial range  
25 shifts. Massachusetts is currently at the high end of the sparrows' range. Under a warming  
26 climate, the MBP region could become the middle of the range, which would be beneficial to the  
27 overall sparrow population in the region. Breeding season and incubation period could actually  
28 decrease with warming, especially if the food supply improves. Currently, the timing of the  
29 nesting cycle is relatively fixed (consistently close to 26 days). If the sparrows could gain an  
30 advantage of needing one day less to nest, this could have a beneficial impact that could  
31 counteract some of the impact of sea level rise on tidal flooding of nests.

### 32 33 **3.2.1.3. *Top Pathway Caveats***

34 Above we have described three pathways that scored as especially promising for  
35 successful management application in light of the information provided by the particular group  
36 of experts at this workshop. Given the complexity of these systems and instances of uneven  
37 agreement among participants, actions based on these pathways should be considered with care.

1 A different set of pathways could be chosen based on additional meaningful criteria that are site-  
2 specific and specific to individual managers' expertise. Based on their own knowledge of their  
3 sites, and/or input from different experts, managers are encouraged to examine the potential for  
4 additional top pathways for their own specific systems by examining the crosswalk tables and  
5 applying their unique knowledge.

6 While top pathways based on the expert knowledge from this workshop are useful, it is  
7 equally important to look at gaps in the crosswalk tables, where some influences did not show  
8 agreement in type, degree, and/or sensitivity. Lack of agreement does not necessarily mean there  
9 is no information available; often the experts did not agree based on competing evidence, or as a  
10 result of limitations of the expert elicitation process. In these cases, further investigation is  
11 needed. Where there are gaps in otherwise-strong pathways for management, further research –  
12 in the form of literature searches, data mining, or original research if needed – could be highly  
13 valuable.

14 A final consideration is that the influence diagrams do not explicitly represent temporal  
15 variability of stressors. In the Sediment Retention group, the issue of seasonality was raised.  
16 Components of seasonality can include storm frequency, timing and volume of precipitation,  
17 annual temperature range and number of days below freezing. These can affect multiple  
18 variables in the diagram such as storms, freshwater flow, nutrient inputs, sediment supplies, and  
19 biological factors such as below ground biomass. Just as managers need to consider the specifics  
20 of each site when making decisions about managing a particular pathway, they need to also  
21 account for timing considerations, including accounting for seasonality of certain stressors. For  
22 example, managers might focus on reducing boat wakes if marsh edge erosion is occurring in the  
23 summer, versus using protective barriers if marsh edge erosion is more of a problem during  
24 winter storms.

### 26 **3.2.2. Adaptation Planning**

27 There can be numerous approaches to climate change adaptation planning, including  
28 integrating adaptation into existing plans, or developing a stand-alone adaptation plan. This  
29 report focuses on the planning options for MBP, which as an NEP has several key management  
30 plans. The MBP management plans discussed here are used to demonstrate the type of  
31 adaptation planning that can be done to address the issues presented here. Other organizations  
32 can use their particular planning documents to apply the same approach.

33 MBP's planning documents include a Comprehensive Conservation and Management  
34 Plan (CCMP), which articulates long range goals and objectives, a Strategic Plan for mid-term  
35 objectives, and an annual Work Plan that lays out short-term actions to implement the goals and  
36 objectives. Each of these plans addresses climate change and climate related effects on some  
37 level, so it makes sense to use the results of this study to continue mainstreaming climate change

1 into each of these planning scales. The 1996 CCMP considers sea level rise, including the  
2 context of acceleration due to global warming, but the accompanying actions are limited due to  
3 the associated uncertainty. The 2009-2012 Strategic Plan advocates for managers to “Adapt for  
4 projected impacts of climate change” as an emerging priority action area for implementing the  
5 CCMP. The FY11 Annual Work Plan includes multiple proposed and ongoing projects with  
6 strong climate change connections. In this section we provide some links between MBP’s plans  
7 and the top pathways and management options discussed above; this set of examples is not  
8 comprehensive, but rather is meant to illustrate how the results of this study can be used to  
9 inform adaptation planning.

10 One management strategy outlined in the 1996 CCMP that pertains to the Purple  
11 Sediment Retention pathway (Figure 3-3) is Action 13.1: “Municipalities should adopt and  
12 implement strict development/ redevelopment standards within FEMA A and V flood hazard  
13 zones and other areas subject to coastal flooding, erosion, and relative sea level rise” (MBP,  
14 1996). The relevance of the pathway to this action is that development activities can impact both  
15 coastal/nearshore and marsh edge erosion and these effects can be exacerbated through increases  
16 in water level and storms depicted in this pathway. Additional management options listed in  
17 Table 2-12 relevant to these development/redevelopment standards include “Identify, acquire  
18 and/or protect potential areas where marsh can grow and expand, and remove barriers to marsh  
19 migration” and “Work with programs responsible for coastal infrastructure to ensure that marsh  
20 protection is included in management plans”. This CCMP action is also relevant to the Green  
21 Community Interactions pathway (Figure 3-4), as development standards affect how residential  
22 development impacts the ratio of native high marsh to *Phragmites* through disturbance or  
23 additional nutrient loading. Management options from Table 2-12 specific to these issues  
24 include “Improve stormwater management to reduce non-point source nutrient inputs into the  
25 marsh” and “upgrade sewage treatment plants (e.g., tertiary treatment) and combined sewer  
26 overflow systems to reduce the flow of excess nutrients into the marsh”.

27 Another strategy that relates to the Green Community Interactions pathway (Figure 3-4)  
28 is CCMP Action 11.2: “The Regional Planning Agencies, in collaboration with the Department  
29 of Environmental Protection and municipalities, should expand upon current Massachusetts Bays  
30 Program efforts to identify nitrogen-sensitive embayments, determine critical loading rates, and  
31 recommend actions to manage nitrogen so as to prevent or reduce excessive nitrogen loading to  
32 coastal waters and groundwater” (MBP, 1996). This CCMP action is also relevant to the Blue  
33 Sediment Retention pathway (Figure 3-3). While this action was likely designed in reaction to  
34 concerns about hypoxia in nitrogen-sensitive embayments, given that marshes are nitrogen  
35 sensitive, there is an opportunity to apply related actions to managing this pathway. There are  
36 multiple ways that residential development can increase nutrient loads. A starting point for  
37 determining where to focus nutrient reduction management actions is better information on the

1 relative contributions of point and non-point nutrient loadings. Especially when considering how  
2 the inundation regime may change nitrogen inputs to marshes under climate change, it is  
3 important to consistently monitor and manage nutrient loadings in the marsh. The 2009-2012  
4 Strategic Plan (MPB, 2009) highlights this through the action “Promote and expand the role of  
5 volunteers and local officials in monitoring stormwater and receiving water quality and  
6 identifying sources of non-point source pollutants”.

7 Wastewater carries high concentrations of nutrients that can be from either a non-point  
8 source such as areas around septic systems, or from a remote point such as sewage treatment  
9 plant outfalls. One applicable management option that several participants discussed would be to  
10 upgrade sewage treatment plants to tertiary treatment in order to reduce the flow of excess  
11 nutrients into the marsh. The 2009-2012 Strategic Plan articulates the means for implementing  
12 actions to manage nitrogen. One such action is to “Provide technical assistance to develop and  
13 implement wastewater management plans, including sewerage efforts aimed at managing  
14 contaminant and nutrient loading to local embayments”.

15 Additional nitrogen sources include lawn fertilizer and other landscaping sources. MBP  
16 is a key partner in the Greenscapes Massachusetts Program, which seeks to educate citizens and  
17 professionals about landscaping practices that have less adverse impacts on the environment.  
18 Residential development also affects stormwater management, which is another non-point  
19 nutrient source. The suggested management option in Table 2-12 of “Promote more absorbent  
20 land cover and “rain catchers” to prevent additional runoff” along with outreach, technical  
21 assistance and building guidelines are potential options for reducing nutrient loads from these  
22 non-point sources.

23 Many of the current projects in the 2010-2011 Annual Work Plan are examples of  
24 management options that potentially could be informed by the results of this study. For instance,  
25 many of the projects include restoration activities. For the Green Community Interactions  
26 pathway (Figure 3-4), one management option cited in Table 2-12 is “Control invasive species”.  
27 The “Great Marsh *Phragmites* Monitoring and Control” project is directly relevant to this  
28 pathway, and work to date has included the development of a *Phragmites* control prioritization  
29 plan and a proposal for use of aerial photography to prioritize *Phragmites* control efforts  
30 throughout the Great Marsh. Factors within this pathway that could be identified from aerial  
31 photography to consider in the prioritization plan would be residential development and the ratio  
32 of native high marsh to *Phragmites*. Before investing in invasive species control in areas with  
33 residential development, it may be worth first implementing efforts to reduce disturbance or  
34 nutrient inputs.

35 The “Restore tidal connections” management option (Table 2-12) is a major focus for  
36 both the Green Sediment Retention and Blue Community Interactions pathways, and for multiple  
37 projects in the Annual Work Plan. Implementation of the Cape Cod Natural Resources

1 Conservation Service Watershed Action Plan will include restoration of 26 tidally restricted salt  
2 marshes and is an excellent example of how important this management option is to MBP.  
3 These projects could also consider another management option from Table 2-12, “Recognize and  
4 take advantage of the ability of marshes to “restore” themselves under the right conditions”, as  
5 removing tidal restrictions can create the “right conditions”.

6         Within each plan are a variety of additional opportunities for incorporating the workshop  
7 results. The examples offered here are intended to demonstrate the links, but are not  
8 comprehensive. In addition to the adaptation of current management projects and strategies, this  
9 study has identified sensitivities that may require the development of entirely new management  
10 options. Planning for future projects should identify opportunities to fill those needs and test  
11 new methods. In some cases it may even be necessary to re-examine and modify goals. Where  
12 impending threshold changes are unavoidable, it would be advantageous to have two plans: one  
13 to follow while species maintenance is still possible, and another plan (and goal) for after a  
14 threshold change has occurred. Thresholds aside, climate change will also raise new issues of  
15 conflicting goals due to trade-offs, and may result in additional situations where previous goals  
16 are no longer attainable. One example of potential conflicting goals in the future is between  
17 managing for sediment retention versus Saltmarsh Sharp-Tailed Sparrow habitat. As native high  
18 marsh is lost to sea level rise, will there come a point when it is advantageous to stop controlling  
19 *Phragmites*, given its sediment trapping and nutrient filtering capabilities? Even though  
20 *Phragmites* does not have the same habitat value as the native marsh, it could serve as a fringing  
21 buffer, should mudflat habitat replace the salt marsh. Thus in some cases, trade-offs may  
22 necessitate re-evaluation of habitat goals, and even the application of a “triage” approach to  
23 prioritize certain habitats over others in the system.

24



## 4. CONCLUSIONS

This report has described the results of a vulnerability assessment aimed at synthesizing place-based information on the potential implications of climate change for key ecosystem processes, with the intent of enabling managers to undertake adaptation planning. The assessment involved identification of key management goals and ecosystem processes, conceptual modeling of those processes, a climate change sensitivity analysis in a workshop setting, and discussions/analysis of the potential applicability of the results for adaptation. The workshop exercise – an expert elicitation sensitivity analysis combined with management discussions – tested a novel approach for conducting “rapid vulnerability assessments” for ecological systems. The sections that follow discuss general observations, insights, and conclusions that emerged from the workshop exercise, from the analyses of management implications, and from our assessment of the methodology’s utility for potential use in other locations/ecosystems.

### 4.1. INSIGHTS FROM THE WORKSHOP EXERCISE

#### 4.1.1. Group Influence Diagrams

The group influence diagrams (Figure 2-2 and Figure 2-8) were developed by the workshop participants based on edits to straw man diagrams prior to the workshop, followed by group discussions and refinement of a final group diagram during the workshop. While the main purpose of the group influence diagrams was to establish a framework for the subsequent sensitivity analysis, these diagrams represent key outputs in and of themselves. The construction of the diagrams proved to be an interesting group exercise in building a highly constrained representation of a complex system, with only the most critical elements and interrelationships included. The iterative process of distillation into basic diagrams by the two interdisciplinary teams of experts resulted in some interesting differences in the Sediment Retention and Community Interactions diagrams.

The Sediment Retention group focused on the physical components of sediment processes as the highest priority factors influencing the balance of salt marsh accretion and erosion in their diagram, with less focus on biological factors. There appeared to be good familiarity with each piece of the diagram across all members of the group; this allowed them to be specific in defining (and hence envisioning the effects of) management-related variables (levers), which may have contributed to the high amount of agreement in judgments during the subsequent coding exercise. The participants reported that given the opportunity they would have added additional variables beyond the 15-variable constraint. Several participants noted that seasonality is an important variable that would have been added, especially as this variable would become even more of an issue under the climate scenarios. Components of seasonality

1 can include annual temperature range and number of days in growing season (or conversely  
2 number of days below freezing). The participants decided to create a separate diagram showing  
3 the variables that would be affected by seasonality as a “confounding factor”. Participants were  
4 asked to consider seasonality and include notations in the “Notes” section as to any effect of  
5 these considerations on their judgments.

6 The Community Interactions group was also successful in agreeing on an acceptable  
7 influence diagram for the exercise. As with the Sediment Retention group, their diagram was  
8 complex, with a mixture of both physical sediment processes (which maintain marsh elevation)  
9 and biological processes (which determine shorebird nesting habitat and vegetation). The  
10 management levers within the Community Interactions diagram were primarily climate change  
11 stressors (e.g., sea level, soil temperature) versus ongoing human influence stressors (residential  
12 development). Several participants noted a lack of expertise in certain areas of the diagram,  
13 which led to a higher number of blanks in judgments than in the Sediment Retention group.  
14 Despite these factors the level of agreement for the exercise was relatively consistent across the  
15 two groups.

16 A direct comparison of the Sediment Retention and Community Interactions diagrams is  
17 instructive in revealing important similarities and differences. There is significant overlap  
18 between the diagrams, which validates a common set of key “management lever” variables (i.e.,  
19 tidal restrictions, impervious cover/residential development, freshwater flow, and nutrient  
20 inputs/nitrogen) that were selected independently by both groups. Some sedimentation-related  
21 variables are embedded in the community diagram (i.e., inundation regime, net accretion/marsh  
22 elevation); which is appropriate since maintenance of marsh elevation through sediment  
23 processes is essential to provision of sparrow nesting habitat. At the same time , the community  
24 diagram shows less detail on sediment supply processes in order to include variables on plant  
25 relationships that determine nesting habitat. The erosion component is the main element of the  
26 sediment diagram that is not explicitly represented in the community diagram. The community  
27 diagram includes both above ground and below ground biomass variables while the sediment  
28 diagram only includes above ground biomass. The one common relationship with somewhat-  
29 conflicting results between the two groups is the influence of nutrients/nitrogen on below ground  
30 biomass. The Sediment Retention group identified this as an influence of increasing relative  
31 impact and a potential threshold, but the Community Interactions group did not. Hence this is a  
32 relationship for which further investigation is needed to explain the disparate findings.

33 In conclusion, while the two groups had different experiences and challenges in building  
34 their influence diagrams, both groups were effective in generating a useful representation of their  
35 ecosystem process for the sensitivity exercise. Participants reported that the highly constrained  
36 diagram-building procedure was productive in challenging them to focus on the most key  
37 elements of the system while still maintaining a sufficiently realistic model for sensitivity

1 analysis. Designing the diagrams while considering current conditions, then applying climate  
2 scenarios to the same diagrams during the sensitivity exercise, worked smoothly. The one  
3 exception was the seasonality variable that several participants wanted to add to the Sediment  
4 Retention diagram; this variable was not added to the final diagram in order to allow enough  
5 time to make judgments for all of the existing influences. This and other complications could be  
6 avoided in future workshops by allowing the participants one more “iteration” with the diagrams  
7 after being briefed on the climate change scenarios. This would allow them to account for how  
8 future climate might raise additional variables for priority consideration in the diagrams.

#### 10 **4.1.2. Characterization of Influences**

11 One technique for ensuring the effectiveness of expert elicitation is to break down the  
12 problem (i.e., what are the climate change sensitivities of the selected ecosystem processes?) into  
13 a set of distinct questions that clearly and explicitly define parameters and relationships of  
14 interest (see EPA’s white paper at <http://www.epa.gov/spc/expertelicitation/index.htm>). This  
15 was accomplished by way of a systematized coding exercise – using the influence diagrams as a  
16 framework – in which the experts made a series of judgments about individual components of  
17 the system, in order to ultimately better understand the system as a whole. For each individual  
18 influence arrow in the diagram, each expert was asked to characterize the effect of variable “X”  
19 on the response variable “Y”, including their confidence in that judgment. Based on the results  
20 of this novel methodology, some general observations of interest have emerged.

21 Participant notes and discussions revealed that for both processes, while there are many  
22 intermediate (and some high) sensitivity relationships among variables that are useful to be  
23 aware of for management, it was difficult to detect changes in sensitivities across the scenarios  
24 based on this method. Under the climate scenarios, one influence for the Sediment Retention  
25 group became highly sensitive while four others showed a trend (but no majority agreement)  
26 toward greater sensitivity; however, most of the sensitivities remained intermediate. For the  
27 Community Interactions group, there were two influences of low sensitivity, five influences with  
28 an intermediate-to-high sensitivity trend, and the majority being intermediate sensitivity under  
29 current conditions. Under the climate change scenarios there was one influence that decreased in  
30 sensitivity, while the majority of influences remained intermediate in sensitivity, or lost  
31 agreement. There were no influences which increased in sensitivity under the climate scenarios  
32 for the Community Interactions group. It was noted that the climate scenarios may cause  
33 thresholds to be reached in a number of different influences, though it was hard to determine at  
34 what point these thresholds would be reached. Two thresholds (Relationships E and EE, Table  
35 2-6) were indicated through coding in the Sediment Retention group, and one threshold  
36 (Relationship G, Table 2-10) was indicated through coding in the Community Interactions group.

1            Yet outside of the coding exercise, there were indications based on participant notes and  
2 discussions that additional potential threshold relationships do exist. Identifying thresholds is  
3 challenging because while there may be general recognition of the potential for certain threshold  
4 effects, it can be very difficult to identify where – and especially when – a threshold may occur.  
5 Multiple potential thresholds were identified in both processes, through one of two ways. In  
6 some cases, participants tried to indicate thresholds with their sensitivity codes, but did so by  
7 including two codes under each of the scenarios to signal uncertainty as to when the threshold  
8 might occur. Others did not indicate the threshold with their codes at all because they were not  
9 sure whether the climate scenarios represented a big enough change to cause a threshold to be  
10 exceeded. In these cases, the thresholds indicated in Table 2-6 and Table 2-10 were ultimately  
11 identified through the participants’ notes and discussions as relationships that could change  
12 dramatically at some point which is currently difficult to define.

13            Another way of identifying relationships of particular interest for management is to  
14 examine the relative impact of certain influences in the context of the whole process. For both  
15 processes, under current conditions the influences identified as having primary impact included  
16 variables spread throughout the diagrams, though there were several originating from the  
17 management levers and several closer to the endpoints (Figure 2-5 and Figure 2-11). Under the  
18 climate scenarios, several of the management levers and influences going directly to the endpoint  
19 increased in relative impact for the Sediment Retention group (Figure 2-6). The Community  
20 Interactions group only had a few influences increase in relative impact under the climate  
21 scenarios, none of which were directly linked to the endpoint (Figure 2-11). This implies that  
22 while some variables related to management levers may become increasingly important as  
23 climate changes, there are a number of these variables that are less understood and may require  
24 additional monitoring and research.

25            Finally, characterization of interactions and confidence were also included in the  
26 sensitivity exercise, with mixed results. Trying to consider interactive effects of multiple  
27 variables moves the exercise to a much greater level of complexity. The number of possible  
28 pair-wise interactions in the influence diagrams was very large, and the challenge of  
29 understanding combinations of effects could become very complicated. Thus the participants  
30 were not asked to attempt every possible pair-wise combination, but rather were asked to  
31 indicate which interactions “jumped out at them” as well understood and important. Of course,  
32 even looking at all pair-wise interactions would be a vast oversimplification because variables  
33 interact in greater multiples than just pairs. Nevertheless, while there were only a few pair-wise  
34 interactions identified by enough participants to stand out, clearly these are relationships that are  
35 sufficiently well understood to merit consideration in management planning. With regard to  
36 confidence, the exercise made a good start of acknowledging the need to gauge confidence in the  
37 judgments and providing a systematic way for doing so; however, the large number data gaps

1 indicate that there were difficulties with this part of the methodology. Potential reasons for these  
2 difficulties, as well as potential improvements, have been discussed in section 3.1.3.2. Both  
3 interactions and confidence are concepts that need further refinement and better estimation  
4 methods before they can be effectively interpreted for management planning.

## 6 **4.2. APPLICATION OF WORKSHOP RESULTS**

### 7 **4.2.1. Top Pathways for Management**

8 When using the workshop results, it is essential to examine all three types of information  
9 – influence type, sensitivity, and relative impact – when thinking about management  
10 applications. For some questions, one type of information may be useful individually, but  
11 because there are gaps and limitations within each type of information, a more complete  
12 management picture can be built using all three types together. It is helpful to focus on  
13 influences that are well understood, become more sensitive, and have a greater impact under  
14 future climate scenarios. In some cases, it is possible to connect a series of influences that meet  
15 these criteria to identify a path between the endpoint and a management lever. We have  
16 presented what we consider to be three top pathways for management (Figures 3-3 and 3-4) for  
17 each process based on the information currently available from the workshop results. These  
18 delineate relatively well-understood relationships that are climate sensitive and for which there  
19 are consequent implications for management adaptation.

20 The climate-related changes of interest in the top pathways are of three main types: 1)  
21 changes in relative impact under climate change; 2) changes in sensitivity under climate change;  
22 and 3) threshold shifts under climate change. In the case of the influences for which relative  
23 impact is likely to increase under one or both future climate scenarios, and especially where  
24 relative impact is already high under current conditions as well, action could be taken  
25 immediately. These are influences for which there is sufficient understanding and opportunity to  
26 connect to management options that favor desirable outcomes, with increasing relative impact on  
27 the process as a whole as climate change continues. In the case of influences for which an  
28 increase in sensitivity is expected under climate change, there is still time to further study and  
29 anticipate the degree and timing of the sensitivity and to prepare best management responses.  
30 An expectation of increasing sensitivity could be considered a notification to managers to  
31 monitor and plan for when and how management practices should be adjusted to account for the  
32 impending change. Finally, in the case of thresholds, there is often a strong expectation that a  
33 threshold shift is likely, but usually a great deal of uncertainty as to exactly when the threshold  
34 will be crossed. Monitoring of threshold variables is needed so that managers will be alerted  
35 immediately to the shift when it occurs. In the meantime, actions can be taken to attempt to  
36 prevent the shift by keeping the system “below” the threshold as long as possible, while  
37 preparing a plan for what to do if an unavoidable shift occurs. After a shift occurs, managers

1 should have a plan as to how they will manage the system differently in its new state, or whether  
2 they will take no action and instead shift their priorities to other goals.

3 It is important to note at this point that each pathway sits in the context of other  
4 influences with which there could be important interactions, so there may be opportunities for  
5 management options beyond those most directly evident from the main pathways. In the case of  
6 other management pathways for which there are currently information gaps based on the  
7 workshop results, it is vital to remember that lack of agreement does not mean zero  
8 understanding of influences or zero degree of sensitivity. Closer inspection can show that the  
9 agreement may be split between intermediate and high sensitivity, so the understanding that the  
10 sensitivity of the influence is important may be obscured by the distinctions between categories.  
11 It is of note that for influences for which there was agreement, the variation among participants  
12 was greater than that between scenarios. This could be due to a number of reasons: a limited  
13 range between the two mid-century climate scenarios; the number of assumptions each  
14 participant was required to make individually for each judgment; and the interdisciplinary and  
15 complex nature of the questions. This is an indication that these types of questions do not lend  
16 themselves to consulting a single expert, but rather require the combined judgments of a group of  
17 experts to complete the full picture. This also highlights the need for caution against relying  
18 solely on combined (agreement) information: the nature of the variation across participants is  
19 also important to consider.

20 Thresholds are clearly relevant to management, but usable information on thresholds  
21 remains elusive. Thresholds are considered likely, but can be difficult to identify in terms of  
22 how and when they will occur. A greater understanding of the location of potential thresholds –  
23 and the system’s current proximity to reaching those thresholds – will be needed before  
24 managers can benefit from this type of information. Similarly, the data on interacting influences  
25 and confidence also raise some interesting issues, but should not be relied upon heavily for  
26 management decisions until their methodologies and comprehensiveness can be improved.  
27 Thresholds, interactions, and confidence are all important, but complex, issues surrounding the  
28 understanding of ecosystem processes and vulnerability that are not regularly included in studies.  
29 Though they have not been fully integrated into this analysis, the results are an important step  
30 forward in our understanding of the system, and in the development of study methods.

#### 31 32 **4.2.2. Mainstreaming Adaptation into Planning**

33 The vulnerability assessment results for the two ecosystem processes presented here are a  
34 big first step in the climate change adaptation planning process. We have given examples of  
35 ways to tie the vulnerability assessment results to potential management options as a starting  
36 point, but incorporating adaptation fully into management planning will require a more  
37 systematic and comprehensive process. Planning is an iterative process, especially for climate

1 change adaptation, which is still a nascent field. Due to this iterative nature, the planning  
2 recommendations presented here are based on mainstreaming planning into existing planning  
3 mechanisms and documents, rather than developing a comprehensive, stand-alone adaptation  
4 plan. For MBP, nearer-term planning includes a multi-year Strategic Plan and an Annual Work  
5 Plan, both of which provide ways to insert specific management options into projects that are  
6 currently underway. In future plans, new projects that specifically incorporate climate adaptation  
7 priorities can be added. Repeating vulnerability assessments – once management options have  
8 been tested through project implementation – should be part of the iterative process. Finally, this  
9 study only covered two ecosystem processes and did not attempt to evaluate relative  
10 vulnerability or resilience across different ecosystem processes. The vulnerabilities of additional  
11 ecosystems, processes and goals will need to be assessed, taking into account what was most  
12 useful in the results of this study for adaptation. It may be useful to bring together a group of  
13 experienced resource managers to discuss the results of this expert elicitation and the resulting  
14 refined conceptual models and discuss how the results could be used to help MBP develop a set  
15 of specific climate change adaptation recommendations.

16         Thresholds remain a major unknown, and while much can be done to improve our  
17 understanding of factors affecting thresholds, some may only be revealed after they have been  
18 crossed. Thus it would be advisable for monitoring plans to be put into place to track indicators  
19 of state changes. Contingency plans for management actions once a system has changed states  
20 could be developed, as well as contingency planning for ways to respond to catastrophic events  
21 such as levee failures or earthquakes. Successful implementation of contingency responses will  
22 require that the political and scientific base be put into place now for responding properly  
23 following catastrophes or threshold changes.

24         In the meantime, when prioritizing implementation of adaptation actions, it is easiest to  
25 start with win-win options that contribute to current management goals and efforts while also  
26 responding to current and future climate change. Looking beyond the win-win options, many  
27 other actions will force managers to confront trade-offs that will require difficult policy  
28 decisions. One example highlighted in section 3.2.2 is the trade-off between increasing coarse  
29 sediment supply from tributaries, which comes into conflict with current sediment reduction  
30 efforts for species habitats (such as oyster habitat). While a first step is to set up different best  
31 practices for species habitats, beyond that there may come a decision point when it is no longer  
32 possible to meet both goals, so a choice between the two conflicting goals will be necessary. As  
33 climate change progresses, there are likely to be more trade-offs, often between short and long  
34 term goals. Mainstreaming adaptation planning will provide a better chance of foreseeing  
35 conflicts between long and short term goals and identifying opportunities to build support for  
36 hard decisions and creative solutions.

37

### 1 **4.3. GENERAL CONCLUSIONS**

#### 2 **4.3.1. Transferability of Results and Method**

3 The results of this study were developed for two specific ecosystem processes within a  
4 salt marsh ecosystem. Therefore the question arises as to how transferable the results may be.  
5 The sensitivities examined in this study are specific to sediment retention and community  
6 interactions in salt marshes, so the characterizations of influence type, sensitivity and relative  
7 impact cannot be transferred directly to other ecosystems and do not apply to different processes  
8 within these ecosystems. However, an example site was used as a way to focus the exercise and  
9 was chosen as a representative example of intact ecosystems, thus the results could be  
10 transferable to other Massachusetts Bays locations in which the same ecosystem processes are  
11 present. The variables that ended up in the group influence diagrams are general enough that  
12 most of the results may transfer to the entire Massachusetts Bays system, with only a few  
13 specific enough to only apply to the Jeffrey’s Neck Marsh. In addition, it is likely that the  
14 influence diagrams could also be transferred for use with like ecosystems in other estuaries, with  
15 minor revisions for place-specific stressors or other process variables. The characterizations of  
16 influence type, sensitivity and relative impact would have to be revisited, particular to that  
17 location.

18 Where the specific results are not transferable, the methodological process is certainly  
19 transferable to other processes, ecosystems and locations. The methodology used for this  
20 assessment – an analysis of key ecosystem processes through expert elicitation – is a useful  
21 framework for understanding the current state of knowledge and research. The experts in this  
22 study were able to share their combined understanding of key processes and how they are  
23 expected to respond to climate change. The expert elicitation process also helped to identify  
24 where key gaps in understanding exist, what type of research is necessary, and how management  
25 should proceed. This methodology is transferrable in that the process used to compile, distill,  
26 and assess key information can be replicated. Expert elicitation is used in many fields of study  
27 and has been demonstrated here to be especially useful in understanding localized climate  
28 change impacts. Experts can think integratively across studies and disciplines and often have  
29 access to more current research and data than is currently available or published. As the climate  
30 change research is consistently evolving, this type of process is useful for synthesizing the most  
31 current information available. However, as climate change research is consistently changing,  
32 new information and research will need to be integrated concurrent with management decisions.

#### 34 **4.3.2. Utility of Method for Rapid Vulnerability Assessments**

35 Given that the method is transferable, the question of utility arises: in what cases is this  
36 method advantageous? This method could be used again as a “rapid” vulnerability assessment,  
37 with opportunity for some of the improvements that have been suggested for some of the



1 limitations. By “rapid”, we mean assessments that can be carried out within six months to a  
2 year, as opposed to assessments based on detailed quantitative modeling that can take multiple  
3 years. Another advantage is that this method is able to capture more recent knowledge than  
4 would be available from a literature review. It is also better able to capture more knowledge of  
5 the type that is closely related to management, which is less frequently published than scientific  
6 studies. Finally, the information is more integrated across disciplines and scales and is designed  
7 to better match the scale of adaptation decisions. In some cases new insights about management  
8 effectiveness may arise while in other cases existing understanding may be validated. Having a  
9 well supported study to substantiate new and existing ideas can position managers to justify the  
10 most appropriate management options and priorities. It also can validate research priorities by  
11 highlighting known research gaps.

12 The disadvantages are that this method is designed to focus only on a specific piece of the  
13 system, compared to initial assessments that often rely on surveying the system more  
14 comprehensively (though less deeply), often through literature reviews. The amount of caution  
15 required to properly interpret the results is another disadvantage, given multiple limitations and  
16 caveats. The method is not intended as a consensus exercise, and the large number of influences  
17 without agreement present challenges to either fill those research gaps to improve agreement or  
18 to manage around limited information. In addition, this is only one group of experts, and another  
19 group could reach different conclusions. Group selection is critical to making sure appropriate  
20 areas of expertise and conflicting views on the system are represented. This is another reason  
21 why in addition to looking for areas of agreement, the results of individual judgments should also  
22 be examined. At the same time, since no participant can have complete expertise in every facet  
23 of a system, it is also important that participants have the opportunity to confer amongst  
24 themselves and adjust their judgments based on what they learn from each other.

25 Overall, the expert elicitation method developed for this study was well suited for  
26 achieving the purpose and goals of the assessment. In addition to achieving the workshop goals,  
27 several unexpected benefits emerged from the workshop. Participants reported that the  
28 combination of the development of the influence diagrams with systematic judgments facilitated  
29 thinking about the system and questions of climate change vulnerability in a different way than  
30 they had previously. Several expressed an intention to explore adapting the method for use in  
31 other workshop or classroom settings. Many participants found that the multidisciplinary  
32 interactions with colleagues were a valuable, personal learning experience, and that the group  
33 together generated new insights about the system and links to management that may not have  
34 been seen by individuals. In short, the method tested in this project offers opportunities to  
35 capture and integrate the existing collective knowledge of local experts, while pushing the  
36 boundaries to develop a new understanding of the system and management options in the face of  
37 insufficient data and deep uncertainty about future climate.

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1 **APPENDIX A. DEVELOPMENTAL PROCESS FOR**  
2 **CLIMATE READY ESTUARIES VULNERABILITY ASSESSMENT**

3  
4 **A.1. SELECT KEY GOALS, ECOSYSTEMS, AND ECOSYSTEM PROCESSES**

5 The MBP partners participated in several discussions and meetings to outline  
6 management priorities, key resources to consult, and other considerations for selecting key goals  
7 for the assessment. As a starting point, MBP’s Comprehensive Conservation and Management  
8 Plan (CCMP) (MBP, 1996; MBP, 2003) was examined and discussed to select four to six key  
9 management goals as a focus of the assessment. These goals would help to further refine the  
10 analysis to specific ecosystems, ecosystem processes, stressors of concern, and indicators for  
11 measuring changes in the ecosystem. Selected management goals included:

- 12 • Protect and manage existing wetlands
- 13 • Restore and enhance the habitat diversity and living resources of wetlands
- 14 • Protect submerged aquatic vegetation; and
- 15 • Prevent the spread of marine invasive species in order to maintain biodiversity.

16  
17 Following an October 2008 kickoff meeting with MBP staff and other local experts to  
18 gather scientific and management background information on the system, salt marshes were  
19 selected as the wetland habitat of focus for the project. These systems were identified as highly  
20 relevant to MBP’s management goals due to their diversity, their habitat values for threatened  
21 and endangered species, their vulnerability to invasive species, and their sensitivity to climate-  
22 related variables such as sea level rise and altered hydrology. As a starting point for exploring  
23 linkages among such climate-related variables, their interactions with non-climate stressors of  
24 concern, and the key ecosystem processes that maintain the system, a general conceptual model  
25 was developed.

26  
27 **A.2. CONCEPTUAL MODELS**

28 The conceptual models were intended to serve as a framework for further analysis in the  
29 vulnerability assessment. The models depicted likely pathways by which climate drivers may  
30 directly or indirectly affect interacting stressors that impact ecosystem processes. The process is  
31 intended as iterative, as we learn from exploring the first two ecosystem processes, next steps  
32 can involve focusing on additional ecosystem processes, or for repeating a similar analysis for  
33 additional habitats. The development of the conceptual model has also served to help with  
34 narrowing process; we began with a comprehensive list of ecosystem processes and indicators  
35 and then chose those more important to and best representing healthy salt marsh functioning.  
36 The total number of possible ecosystem processes was narrowed down to five to six key ones for  
37 the ecosystem. The models also included a similar number of variables that may serve as  
38 indicators for the status of these endpoints. Ecosystem processes and indicators were identified

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1 in discussions among MBP and EPA ORD, as well as through examination of the Delta Regional  
2 Ecosystem Restoration Implementation Plan’s conceptual models developed by the CALFED  
3 Bay-Delta Program (Schoellhamer et al., 2007; Kneib et al., 2008, San Francisco Estuary  
4 Indicators Team, 2008). To ensure consistency with current research, these ecosystem processes  
5 and indicators were cross-walked with locally-specific literature on climate change impacts  
6 (Ashton et al., 2007; Cavatorta et al., 2003; Frumhoff et al., 2007; Orson et al., 1998), as well as  
7 research on metrics and indicators for the region (Massachusetts Department of Coastal Zone  
8 Management, 2003; USGS-FWS, 2008).

9         Stressor interactions are stressors that may work independently or together to affect  
10 ecosystem functioning. These included both non-climate and climate-related influences that  
11 stress salt marsh ecosystems. Pre-existing stressors and stressor interactions were identified  
12 during the development of salt marsh conceptual model, and impacts of these stressors of  
13 concern were identified using the MBP Comprehensive Conservation and Management Plan.

14         Climate drivers are climate variables that may impact ecosystem processes directly (e.g.,  
15 raise water temperature) or indirectly (e.g., cause changes in nutrient inputs). The climate  
16 drivers relevant to salt marshes were identified by first examining climate drivers for estuarine  
17 systems outlined in Synthesis and Assessment Product 4.4: *Preliminary review of adaptation*  
18 *options for climate-sensitive ecosystems and resources* (CCSP, 2008), followed by extensive  
19 discussions among the MBP partners. The climate drivers were then mapped to the key  
20 processes of the ecosystem, either directly or through interactions with pre-existing stressors.  
21 These pathways provided the basis for the development of the conceptual models. The pathways  
22 included are intended as a heuristic, without distinguishing between the magnitudes between  
23 them. It is not possible to include all possible system components, nor connections between  
24 them. The general salt marsh model is first presented, and then additional detail for individual  
25 ecosystem processes is described in the two sub-models.

## 26 27 **A.2.1. General Models**

### 28 **A.2.1.1. Salt Marshes**

29         The general model for salt marshes is presented in Figure A-1. Climate drivers in the salt  
30 marsh conceptual model include: changes in air temperature, changes in precipitation, sea level  
31 rise, and changes in storm climatology and wind. Changes in air temperature refers to the  
32 variation from the climatological mean surface air temperature in a particular region. Changes in  
33 precipitation refers to variation from the climatological mean of the amount, intensity, frequency  
34 and type of rainfall, snowfall and other forms of frozen or liquid water falling from clouds in a  
35 particular region, changes refer to both the form and flow of precipitation. Sea level rise is  
36 defined as “relative sea-level rise,” the change in sea level relative to the elevation of the  
37 adjacent land, which can also subside or rise due to natural and human induced factors. Relative

1 sea-level changes include both global sea-level rise and changes in the vertical elevation of the  
2 land surface. Changes in storm climatology and wind refers to the variation from the  
3 climatological mean of the frequency, intensity and duration of extreme events (such as  
4 hurricanes, heavy precipitation events, drought, heat waves, etc.) and the changes in the direction  
5 and timing of the dominant seasonal winds.

6

7 **Figure A-1. Salt Marsh Conceptual Model.**

8

9 Stressor interactions within the salt marsh conceptual model include: changes in water  
10 temperature, changes in salinity, flooding, sedimentation and erosion, invasive species,  
11 pollutants, other human uses, altered flows, and land use/land use change. Changes in water  
12 temperature refers to variation in the climatological mean surface water temperature in a  
13 particular region. Changes in salinity are measured by variations in salinity concentration, with  
14 respect to lateral gradient or vertical stratification. Flooding is defined as an excess of water that  
15 does not recharge ground water beyond time frames typical for watersheds due to high  
16 precipitation events, storm surge, or infrastructure damage. Sedimentation and erosion includes  
17 the transport, deposition, and removal of soil and rock by weathering, mass wasting, and the  
18 action of streams, waves, winds and underground water. Invasive species are plants, animals or  
19 microbes not native to an area that are able to exploit a niche and disrupt native species, with  
20 negative impacts. Pollutants include any substance introduced into the environment that,  
21 because of its chemical composition or quantity, prevents the functioning of natural processes  
22 and produces undesirable environmental and health effects. Other human uses is a catch all  
23 category based on the CCMP which includes the use of the marsh and surrounding area for  
24 activities such as fishing, shipping and ports, dredging, transportation projects, sand mining,  
25 recreational use, marinas, and industrial uses that may impact the marsh. Altered Flows refers to  
26 tidal restrictions or upstream water diversions for agricultural, industrial, transportation, or urban  
27 uses that change the natural flow of freshwater and sediment into the marsh, including leveeing,  
28 diking, damming, filling, or channeling. Land use/land use change is defined as the current use  
29 of marsh and human-induced changes to the marsh or surrounding land, including wetland  
30 alteration and expansion of the built environment.

31 Ecosystem processes in the salt marsh conceptual model include: community  
32 interactions, primary productivity, sediment retention, water retention, nutrient cycling, and  
33 water purification. Community interactions is defined as the interrelations among species within  
34 the ecosystem. Primary productivity is the production of energy by plants and phytoplankton  
35 within the entire system. Sediment retention is the balance between the processes of removal  
36 and deposition of suspended sediment. Water retention is defined as the capability to buffer  
37 against flooding. Nutrient cycling is the process of transfer of nutrients between organisms and

1 the water. Water purification is defined as the removal of pollutants and harmful  
2 microorganisms.

3 Indicators within the salt marsh conceptual model include: species population size, water  
4 quality standards, freshwater inflow, sediment quantity, extent of aquatic habitat, biomass, and  
5 invertebrate index. Species population size is defined as the number of similar organisms  
6 residing in a defined place at a certain time, including threatened and endangered species, native  
7 species, and invasive species. Water quality standards are provisions of State or Federal law  
8 which consist of designated uses for waters of the United States, and water quality criteria for  
9 such waters based upon such uses. Criteria address the values for water quality indicators (e.g.,  
10 water temperature, salinity, water contaminant exposure, biological thresholds for water  
11 contamination, nutrient concentrations, water toxicity) that are required to support designated  
12 uses. Freshwater inflow is the amount of freshwater inflow to the estuary from the watershed.  
13 Sediment quantity is defined as suspended sediment concentration. Extent of aquatic habitat is  
14 defined as the area of all contiguous, vegetated salt and brackish wetland, or mean width of  
15 marsh (may be divided into low or high marsh or by dominant species). Biomass is the presence  
16 and abundance of different species. The invertebrate index is the collection of metrics that are  
17 aggregated into a single score to measure the composition of the invertebrate community.

18 The salt marsh conceptual model focuses on a limited number of ecosystem processes  
19 that are key to the habitat and region. In some instances, a component of the system may fill  
20 roles at multiple levels, and the model does not represent all possible roles a particular  
21 component may fill. The model does not take the cumulative effects of climate stressors or  
22 tipping points/critical thresholds into account. The model does not include ocean acidification as  
23 a climate driver, as current understanding of salt marshes indicate it as secondary compared to  
24 the other stressors.

25



1 **A.2.2. Sub-models**

2 Following the development of the general salt marsh ecosystem model, two ecosystem  
3 processes within the model were chosen for more detailed investigation. The purpose was to  
4 select good processes to start with to test out the method, but the choice does not imply that these  
5 are necessarily the most important, or the most vulnerable, processes. Sediment retention was  
6 identified as a key salt marsh process because of the importance of sediment supply to allow for  
7 marsh development and growth. In the Massachusetts Bays, sediment supply is influenced by a  
8 number of factors, including storms, heavy precipitation events, and human influences such as  
9 tidal restrictions and development. MBP and other regional partners have done extensive work  
10 on examining changes in sediment and how these changes may be influenced by changes in  
11 climate. This provided the basis for the development of the sediment retention submodel.

12 Community Interactions was chosen as the second ecosystem process of focus. To select  
13 a specific well-constrained “storyline” of interactions between 2-4 species for this process, ICF  
14 and EPA consulted with MBP and regional experts on key sensitivities for this process within the  
15 Massachusetts Bays system. The storyline focuses on the relationship of 4 species (*Spartina*  
16 *alterniflora*, *Spartina patens*, *Phragmites australis*, *Ammodramus caudacutus*). The Saltmarsh  
17 Sharp-Tailed Sparrow (*Ammodramus caudacutus*) prefers the native species of *Spartina patens*  
18 as habitat over the invasive *Phragmites*. The lower marsh *Spartina alterniflora* is likely to  
19 migrate upland with pressure from sea level rise, perhaps infringing on the upper marsh *Spartina*  
20 *patens*. Changes in freshwater flow will affect the less salt tolerant *Phragmites* with a major  
21 question of whether it will expand into the upper marsh range of *Spartina patens*. This storyline  
22 provided the basis for the development of the community interactions submodel.

23

24 **A.2.2.1. Sediment Retention**

25 The sediment retention submodel is presented in Figure A-2. It focuses on the balance  
26 between the processes of deposition and retention of sediment within a salt marsh and the  
27 resultant ability of the marsh to persist in the face of climate change. The accumulation of  
28 sediments and marsh vertical accretion result from interactions among tidal imports, vegetation  
29 dynamics, and depositional processes (Reed, 1995). Freshwater runoff and coastal storms  
30 transport and deposit sediments onto the marsh surface, and the roots and stems of marsh  
31 vegetation retain sediment that would otherwise be carried away from the marsh by wind and  
32 waves (Roman et al., 1997). Over time, the accumulation of dead and dying organic matter  
33 produces peat, and the combination of peat accumulation and sediment deposition gradually  
34 builds up the marsh surface. Ultimately it is the balance between marsh vertical accretion and sea  
35 level rise that determines whether a tidal marsh at any given location will persist in the face of  
36 rising seas by migrating inland or will convert to tidal flats or open water (Reed, 1995).

37

1           **Figure A-2. Sediment Retention sub-model.**  
2

3           A number of key climate variables (air temperature, precipitation, storm climatology and  
4 wind, and sea level rise) and stressors (altered flows, other human uses, land use/land cover  
5 changes) may impact this process directly or indirectly. In New England marshes, altered  
6 hydrology typically includes tidal restrictions, which reduce the regular tidal flooding of marshes  
7 needed for marsh maintenance (Carlisle et al., 2002). At the upland edge, excess runoff from  
8 heavier precipitation events in areas with impervious surfaces may oversaturate marsh soils and  
9 reduce soil salinity. Increases in the frequency and intensity of storms can change the pattern of  
10 sediment transport along the shoreline, carrying more sediment away from the marsh and  
11 increasing erosion at some locations, reducing the sediment available for marsh development  
12 (Nyman et al., 1995).  
13

14 **A.2.2.2. Community Interactions**

15           The community interactions submodel is presented in Figure A-3. This submodel  
16 focuses on the relationship of marsh vegetation zonation and the availability of nesting habitat  
17 for the Saltmarsh Sharp-Tailed Sparrow, *Ammodramus caudacutus*, a high priority species for  
18 bird conservation in New England. The Saltmarsh Sharp-Tailed Sparrow nests in the high marsh  
19 zone to avoid nest flooding (DiQuinzio et al., 2002; Gjerdrum et al., 2005). Under undisturbed  
20 conditions, the low marsh is dominated by the tall form of *Spartina alterniflora*, and the high  
21 marsh zone is characterized by salt marsh hay (*Spartina patens*), black rush (*Juncus gerardi*) and  
22 the short form of *S. alterniflora*. This pattern of vegetation zonation results from a combination  
23 of plant competition and the physical characteristics of the intertidal zone. The tall form of *S.*  
24 *alterniflora* dominates the low marsh because it is able to tolerate the stress of inundation and  
25 low soil oxygen content, whereas high marsh plants are not. In contrast, *S. patens*, *J. gerardi* and  
26 the low form of *S. alterniflora* dominate the high zone to the exclusion of low marsh species  
27 because of the superior competitive ability of these plants in obtaining below-ground nutrients  
28 (Donnelly and Bertness, 2001; Bertness et al., 2002; Bertness and Pennings, 2007).  
29

30           **Figure A-3. Community Interactions sub-model.**  
31

32           A number of key climate variables (changes in air temperature, changes in precipitation,  
33 changes in storm climatology and wind, and sea level rise) and stressors (invasive species,  
34 altered flows, pollutants, land use/land cover changes) may impact this process directly or  
35 indirectly. As sea level rises, the dominant vegetation of the low marsh, the tall form of *S.*  
36 *alterniflora*, traditionally restricted to the low marsh zone by competition, can invade the high  
37 marsh zone because of its tolerance of inundation and salinity. This is already being observed in  
38 New England salt marshes (Donnelly and Bertness, 2001). At the same time, the high marsh

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1 may be invaded at its landward border by *Phragmites australis* because of nutrient-enrichment  
2 from adjacent residential development. This is because high nutrient availability may shift  
3 competition away from competition for below-ground nutrients to competition for light. Under  
4 these conditions, *Phragmites* is favored over native high marsh plants. Increased nutrient  
5 enrichment may also promote invasion of the high marsh at its seaward edge by *S. alterniflora* as  
6 it is released from competition for below-ground nutrients (Bertness et al., 2002).

7         These considerations suggest that the combination of increased sea level rise and nutrient  
8 enrichment from residential development may promote invasion of high marsh by *S. alterniflora*  
9 at its seaward border and *Phragmites* at its landward border. This could greatly reduce the  
10 availability of the traditional high marsh nesting habitat of the Saltmarsh Sharp-Tailed Sparrow.

### 11 12 **A.3. CONCLUSIONS**

13         The analysis of available data for potential indicators and of existing models indicated  
14 that there was insufficient information available on metrics for the indicators to answer the  
15 sensitivity questions of this assessment using quantitative modeling. However, it was also  
16 evident that a vast amount of information local knowledge was available through consultation  
17 with regional experts in the processes of interest. This led to the development of the expert  
18 elicitation workshop approach described in Chapter 2 of this report. The workshop was meant to  
19 serve as an opportunity to supplement current knowledge based on background research and  
20 examine potential changes that may occur due to climate influences. The conceptual diagrams  
21 described above provided the basis for the development of the initial influence diagrams used at  
22 the workshop (as described in Chapter 2 of this report) as well as context for how these  
23 ecosystem processes of focus fit with the rest of the ecosystem.

1                   **APPENDIX B. EXPERT ELICITATION WORKSHOP PREPARATION**  
2   **AND IMPLEMENTATION**

3  
4 **B.1. PRE-WORKSHOP**

5 **B.1.1. Selecting Workshop Participants**

6           The MPP partners developed a list of criteria for selecting highly qualified local experts  
7 who spanned the range of disciplines, science and management continuum, and empirical versus  
8 theoretical research experience needed to collectively characterize the ecosystem processes under  
9 consideration. Criteria for selecting participants included:

- 10  
11           • Demonstrated understanding of the body of literature with regard to sediment  
12 retention OR community interactions (depending on which breakout group), as  
13 evidenced by academic training, research, and publications;  
14           • Demonstrated ability to think of uncertainty in qualitative terms ;  
15           • Knowledge of science behind estuary management, as evidenced by academic  
16 training, research, and publications;  
17           • Knowledge of estuary management issues as evidenced by academic training,  
18 research, and publications;  
19           • Past work in MBP region; and  
20           • Past work with salt marsh development/sediment retention processes (the balance of  
21 sediment supply versus loss) OR salt marsh community interactions (interactions of  
22 shorebird nesting habitat and vegetation zonation), depending on the candidate’s  
23 proposed breakout group.  
24

25 These criteria were considered in developing a list of qualified candidates for each breakout  
26 group. Candidates were then contacted to determine their availability and interest in testing a  
27 new method for vulnerability assessment. Workshop participants included the following  
28 individuals:  
29

30 **Sediment Retention Breakout Group:**

31 Susan Adamowicz, Rachel Carson National Wildlife Refuge  
32 Britt Argow, Wellesley College  
33 Chris Hein, Boston University  
34 David Ralston, Woods Hole Oceanographic Institution  
35 John Ramsey, Applied Coastal Research and Engineering, Inc.  
36 Peter Rosen, Northeastern University  
37 John Teal, Woods Hole Oceanographic Institution

- 1 **Community Interactions Breakout Group:**
- 2 Walter Berry, U.S. EPA Atlantic Ecology Division
- 3 Robert Buchsbaum, Massachusetts Audubon Society
- 4 Dave Burdick, University of New Hampshire
- 5 Michele Dionne, Wells National Estuarine Research Reserve
- 6 David Johnson, Woods Hole Marine Biological Laboratory
- 7 Gregg Moore, University of New Hampshire
- 8 Cathy Wigand, U.S. EPA Atlantic Ecology Division
- 9

10 The expertise of each of the individual participants contributed to the interdisciplinary  
11 complexity of the group. Experts were selected from the management and adaptation research  
12 communities, and represented federal and state government agencies, research and consulting  
13 organizations, non-governmental organizations and academia. The credentials for each of the  
14 participants, including past and current work and research and areas of expertise, are summarized for  
15 the Sediment Retention group in Table B-1, and for the Community Interactions group in Table B-2.

16

17 **Table B-1. Sediment Retention breakout group participants, affiliations, and**  
18 **qualifications**

19

20 **Table B-2. Sediment Retention breakout group participants, affiliations, and**  
21 **qualifications**

22

### 23 **B.1.2. “Straw Man” Influence Diagrams**

24 An initial “straw man” influence diagram (Figure B-1 and Figure B-2) for each breakout  
25 was developed by ICF, EPA, and MBP prior to the workshop based on the more detailed salt  
26 marsh conceptual model and sediment retention and community interactions submodels  
27 developed previously (see Appendix A). The “straw man” influence diagrams differed from the  
28 more comprehensive conceptual models in that they focused on only those elements of the model  
29 that participants believe are most critical for understanding responses of the ecosystem process to  
30 the human and climate stressors under consideration. The “straw man” influence diagrams were  
31 used in the pre-workshop briefing and homework assignment in order to further refine the  
32 sediment retention and community interactions influence diagrams.

33

34 **Figure B-1. Sediment Retention “straw man” influence diagram.**

35

36 **Figure B-2. Community Interactions “straw man” influence diagram.**

37

### 38 **B.1.3. Pre-workshop Briefing and Homework Assignment**

39 Participants participated in two pre-workshop briefing calls and a homework assignment  
40 that would be used to develop consolidated influence diagrams to be used at the workshop. The  
41 pre-workshop briefing calls were held on January 14 and 28, 2010. These calls gave participants

1 a briefing on the background of the project, work to date, the purpose of the workshop, and an  
2 overview of the homework assignment. The first call covered the larger context of the project as  
3 part of the CRE Program and the purpose for MBP being involved in this study. The  
4 development of the conceptual models (see Appendix A), and how these led to the ecosystem  
5 processes of focus was also covered. Finally, the expert elicitation approach was explained in  
6 the context of how it would be used for the purposes of the workshop. The second call went into  
7 more detail about the exercise, introducing the influence diagrams and example reference site.  
8 Participants were given an opportunity to ask questions regarding these initial diagrams in  
9 preparation for completing the homework assignment.

10 Part of the background material presented was information on an example site for  
11 participants to consider when more spatial specificity would be useful during the workshop  
12 exercise and to provide context for management discussions. The Jeffrey's Neck or Little Neck  
13 Marsh, in Ipswich, Massachusetts, is located within the Great Marsh, and was chosen because it  
14 includes classic New England salt marsh features and species composition. Its natural features  
15 include the high marsh/low marsh dynamic examined by the Community Interactions group.  
16 There is an extensive system of creeks and channels, as well as large areas of bordering  
17 vegetated edge and upland. The example site is subject to a number of stressors common to  
18 marshes in the region, including: development surrounding the marsh; tidal restrictions (this  
19 particular site has two, one of which that has been restored); a significant amount of invasive  
20 *Phragmites*; extensive mosquito ditching; and other hydrologic modifications such as road  
21 crossings and barriers to migration.

22 The homework assignment asked participants to review a number of items: (1) selected  
23 articles relevant to the ecosystem process breakout group to which they were assigned (for the  
24 Sediment Retention breakout group: Cavatorta et al., 2003; Donnelly and Bertness, 2001; Scavia  
25 et al., 2002; Schmitt et al., 1998; for the Community Interactions breakout group: Bertness et al.,  
26 2002; DiQuinzio et al., 2002; Donnelly and Bertness, 2001; Gjerdrum et al., 2005; and Scavia et  
27 al., 2002); (2) conceptual models of the ecosystem and ecosystem process to which they were  
28 assigned; and (3) the draft influence diagram for the ecosystem process to which they were  
29 assigned. Participants were asked to review the draft influence diagram and provide  
30 recommendations on what should be added or removed. Participants were asked to add or  
31 subtract variables or relationships until the preliminary influence diagram matched their  
32 understanding of the process. We asked participants to include no more than 10-15 variables in  
33 the diagram in order to keep it focused on the highest priority influences. We also asked  
34 participants to focus on current conditions (including current climate) when reviewing and  
35 commenting on the diagram.

36 Participants were asked to provide a quantitative definition for each variable, a metric for  
37 measuring the variable, and a range of values for the metric. Participants were also asked to

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1 assign values to the metrics they selected. This could include actual measured values (e.g., 35  
2 km<sup>3</sup> of inflow) as well as a range of values (e.g., 5 to 50 km<sup>3</sup> of inflow).

#### 3 4 **B.1.4. Consolidated Influence Diagrams**

5 The preliminary diagram for each breakout group was revised prior the workshop based  
6 on the participants' homework responses. The process involved examining the participants'  
7 responses and constructing a tally of the variables used and influences (arrows) included.  
8 Variables and influences that were most frequent across all responses were included in the  
9 consolidated influence diagrams. For the both the Sediment Retention and Community  
10 Interactions groups, all of the participants provided comments on the preliminary influence  
11 diagram. In addition, due to the rescheduling of the initial MBP workshop, two of the original  
12 participants were not able make the new date, but their homework was taken into account when  
13 developing the consolidated diagrams. Based on the responses from the participants,  
14 consolidated influence diagrams were developed for the workshop.

### 15 16 **B.2. WORKSHOP**

#### 17 **B.2.1. Group Influence Diagrams**

18 Group influence diagrams were developed during the first day of the workshop. Within  
19 their breakout groups, the participants discussed how the consolidated influence diagrams should  
20 be refined for use as a final "group" influence diagram. The participants added, removed, or  
21 redefined variables based on a group discussion. The group diagrams were to become the basis  
22 for the expert elicitation exercise of assigning judgments about influences among variables. The  
23 Sediment Retention and Community Interactions group influence diagrams are provided in  
24 Chapter 2.

#### 25 26 **B.2.2. Introduction to Climate Scenarios and Confidence**

27 The participants received two handouts designed to orient them to the climate scenarios  
28 and to the methodology for assessing confidence. The first handout contained a summary of  
29 Climate Scenarios A and B, which was used by the participants in assessing the sensitivity of salt  
30 marshes and mudflats across a range of plausible scenarios of climate change. It explained the  
31 development of two climate futures in a mid-century (2040-2069) time frame. Participants used  
32 these scenarios on Day 2 to make new judgments compared to their judgments under "current  
33 conditions" on Day 2. The full climate scenarios handout can be found in Appendix C.

34 The second handout presented explanatory information and a coding scheme for use by  
35 the participants in assessing their confidence in each of their judgments under both current  
36 conditions and under Climate Scenarios A and B. The full handout may be found in Appendix  
37 D.

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### **B.2.3. Coding Exercise**

Following the development of the group influence diagrams, participants were asked to make their individual judgments on the diagram using the coding scheme. As described in Chapter 2, the participants used the coding scheme to make judgments on the following: (1) type and degree of influence for each relationship included in the influence diagram; (2) the associated confidence for each influence judgment; (3) type of interactive influences for relationships of their own choosing; and (4) the associated confidence for each interactive influence judgment. These judgments were done for current conditions (on the first day of the workshop), and Climate Scenario and Climate Scenario (on the second day of the workshop). Example handouts that participants used to make their judgments are provided in Tables B-3, B-4, and B-5.

**Table B-3. Example of expert elicitation handout for influences under current conditions (Sediment Retention group)**

**Table B-4. Example of expert elicitation handout for influences under climate scenarios (Community Interactions group)**

**Table B-5. Example of expert elicitation handout for interactive influences under climate scenarios (Sediment Retention group)**

### **B.2.4. Variation Across Participants in Sensitivity Judgments**

For both the Sediment Retention and Community Interactions groups, variability among participants in their judgments contributed to lack of agreement on sensitivities for some influences. Figure B-3 presents the full range of variation among participants of the Sediment Retention group by showing the same trio of figures as shown in Figure 2-4 but broken out for each individual participant. Looking across all the participants, there was more variability between participants than across scenarios for any given participant. There were no patterns across participants, such as characterizing only increasing sensitivity. The changes across the scenarios made by Participants 3, 6, and 7 were of only increasing sensitivity, and Participants 1, 2, 4, 5 had both increases and decreases, sometimes across the scenarios for one influence.

For the Community Interactions group, Figure B-4 presents the full range of variation among participants by showing the same trio of figures as those shown in Figure 2-10, but broken out for each individual participant. Looking across all the participants, we see that there is again more variability between participants than across scenarios for any given participant. The majority of changes in sensitivity type across the climate scenarios are of increasing sensitivity. The changes across the scenarios made by Participants 1 are of only increasing



1 sensitivity; Participants 2, 3, 4, 6, and 7 had both increases and decreases, but more of the  
2 former; Participant 5 had no changes across the scenarios, and only categorized influences as  
3 intermediate sensitivity or provided no answer.

#### 4 5 **B.2.5. Exercise Discussions and Report-outs**

6 After participants made their individual judgments on the influence diagram using the  
7 coding exercise, the participants reconvened in their breakout groups for a group discussion.  
8 Participants discussed their reactions to the exercise and how it was structured, individual  
9 judgments on type and degree of influence, individual judgments on confidence, key issues and  
10 gaps in understanding. This group discussion often helped to clarify issues that participants may  
11 have had in understanding the coding scheme or understanding influences.

12 Based on this group discussion, the facilitator helped the participants to identify some key  
13 points that emerged. These key points addressed issues such as key influences, important  
14 pathways, thresholds, significant changes associated with climate change, management  
15 implications, etc. The facilitator from each breakout group presented these key points to the  
16 larger group to summarize the discussion.

#### 17 18 **B.2.6. Discussion of Management Implications**

19 Following the breakout group discussions and exercise of making individual judgments,  
20 participants gathered in the larger group to discuss management implications. This discussion  
21 would help MBP to examine some of the key issues that emerged from the expert elicitation  
22 exercise and how to translate those issues into action. The facilitator led the discussion by  
23 asking participants to consider how climate stressors might impact the estuary across a range of  
24 management scenarios. The discussion also explored research and data needs, suggestions for  
25 habitat restoration and reducing existing stressors, and fundamental shifts in management that  
26 may be necessary.

1 **B.3. POST-WORKSHOP**

2 **B.3.1. Review of Workshop Report**

3 A report was developed subsequent to the workshop documenting key outputs in two  
4 sections: key results and workshop discussions. This report provides a documentation of all of  
5 the participant materials, including: participant guidance documents, participant homework  
6 responses, handouts and other materials used at the workshop, and individual participant  
7 judgments. Key points that emerged during the breakout group and larger group discussions are  
8 summarized, as well as the discussion on management implications. Participants were asked to  
9 review this report and provide any comments. These comments were incorporated into a final  
10 workshop report, which is available upon request from the authors.

11

12 **B.3.2. Synthesis of Results**

13 A synthesis of results was developed in order to analyze the participants' individual  
14 judgments made at the workshop. The synthesis reviews the objectives of conducting the expert  
15 elicitation workshop and identifies key questions that the synthesis of judgments seeks to answer.  
16 It reviews the coding schemes used by participants during the workshop and summarizes a  
17 coding typology that was used to group codes to characterize types and degrees of influences and  
18 sensitivities. Finally, it describes the methodology for analyzing the available judgments and  
19 presents key results in the form of tables and figures. The contents of this synthesis comprise  
20 much of the substance of the results sections of this report.

21

22 **B.3.3. Review of Draft Report**

23 The workshop report and preliminary results reports were used to develop this technical  
24 report to present the synthesis results and place them in the larger context of the implications for  
25 management and MBP's capacity to respond. The report will be subjected to a separate letter  
26 review, which will be done through an EPA external peer-review process. Following this  
27 review, the final report will be developed, which responds to the peer-review comments. An  
28 additional report that focuses on lessons learned across the two assessments for SFEP and MBP  
29 will also be developed.

1                   **APPENDIX C. PARTICIPANT HANDOUT ON CLIMATE SCENARIOS**

2

3   **MBP Workshop Climate Change Scenarios**

4

5   This handout is intended to assist participants in assessing the sensitivity of salt marshes across a  
6   range of plausible scenarios of climate change. It provides the details of two distinct but  
7   scientifically credible climate futures for a mid-century (2040-2069) time period. Participants  
8   will use these scenarios in revisiting their assessments of influence completed on the first day.

9

10   **Two Climate Change Scenarios: “Lower-Range” and “Higher Range”<sup>2</sup>**

11

12   Relatively more mild and more severe mid-century climate change scenarios were selected to  
13   bound plausible futures. Overall, both describe a significantly warmer climate accompanied by  
14   increases in annual precipitation and higher sea levels, but the degree of change is much greater  
15   in the “higher range” compared to the “lower range” scenario. In addition, there are differences  
16   in the seasonality of the changes captured in the two futures, particularly as related to  
17   precipitation amount and intensity and streamflow.

18

19   **Development of the Climate Scenarios**

20

21   These two bounding scenarios were developed directly from the climate projections used in the  
22   Northeast Climate Impacts Assessment (NECIA).<sup>3</sup> Three leading climate models were used to  
23   develop these projections: U.S. NOAA’s Geophysical Fluid Dynamics Laboratory (GFDL)  
24   CM2.1; the United Kingdom Meteorological Office’s Hadley Centre Climate Model, version 3  
25   (HadCM3); and the National Center for Atmospheric Research’s Parallel Climate Model (PCM).  
26   These three models were selected to provide a range of climate sensitivity representative of the  
27   current models used by the IPCC.<sup>4</sup> The models were run with both a lower greenhouse gas  
28   emission scenario (B1 SRES) and a higher emission scenario (A1Fi SRES) to capture a range of  
29   possible future emissions trajectories. The “lower-range” and “higher-range” temperature and  
30   precipitation scenarios for 2040-2069 compared to 1961-1990 baseline conditions were  
31   developed by averaging the three climate models’ results for the lower and higher emissions  
32   futures, respectively, and then statistically downscaling these results to the 1/8-degree grid  
33   representative of the Ipswich, MA area. Sea level rise information was provided by the Sea  
34   Level Affecting Marshes Model (SLAMM 5.0). The “lower-range” eustatic sea level rise  
35   scenario is based on the conservative IPCC mean A1B SRES, and the “higher-range” eustatic sea  
36   level rise scenario is consistent with estimates provided by Rahmstorf (2007).<sup>5,6</sup>

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<sup>2</sup> The usage of the terms “lower-range” and “higher-range” refers to the scenarios provided in this handout and are not intended to reflect the lowest and highest possible futures.

<sup>3</sup> As described in NECIA (2006) and at <http://www.northeastclimatedata.org/>.

<sup>4</sup> “Climate sensitivity is the temperature change resulting from a doubling of atmospheric carbon dioxide concentrations relative to pre-industrial times” (NECIA 2006).

<sup>5</sup> Rahmstorf (2007) derived a historical semi-empirical relationship between temperature and sea level rise and applied this relationship to IPCC projected estimates of temperature rise.

<sup>6</sup> Note that these projections do not account for changes in dynamic sea level rise or changes in land elevation through subsidence or uplift. For example, by the end of the century, Yin et al. (2009) suggest changes in sea level rise resulting from ocean circulation could be of the same order in magnitude as the eustatic sea level rise estimates for the Boston area.

1  
2  
3

**Summary of Climate Scenarios: Averages for 2040-2069 compared to 1961-1990**

		<b>“Lower Range” Scenario (3-model average of B1)</b>	<b>“Higher Range” Scenario (3-model average of A1Fi)</b>
<b>Temperature</b>	Annual Average	<b>+3.6 °F</b>	<b>+5.6 °F</b>
	Geographically	<b>Boston “moves” to Philadelphia, PA</b>	<b>Boston “moves” to Washington, DC</b>
	Days > 90 °F <sup>7</sup>	<b>20 days</b>	<b>34 days</b>
	Coldest Day of Year	<b>+4.3 °F</b>	<b>+6.5 °F</b>
	Growing Season	<b>+3 weeks</b>	<b>+4 weeks</b>
<b>Precipitation</b>	Winter Change	<b>+10.6%</b>	<b>+15.1%</b>
	Summer Change	<b>+7.9%</b>	<b>+11.2%</b>
	Spring Change	<b>+15.0%</b>	<b>+14.1%</b>
	Fall Change	<b>+1.9%</b>	<b>-2.2%</b>
	Heavy Events	<b>~8% increase in the max amount of precip to fall within a 5-day period</b>	<b>~12.5% increase in the max amount of precip to fall within a 5-day period</b>
	Yearly Snow Depth	<b>-9 cm</b>	<b>-11 cm</b>
<b>Sea Level</b>	Total Increase	<b>17 cm (SLAMM model A1B scenario)</b>	<b>41 cm (SLAMM mid-century model estimate using 1.5 m scenario by end of century)<sup>8</sup></b>
<b>Storms/Wind</b>	<p>NECIA (2006) suggests little change in the frequency of winter-time storms for the East Coast. However, under the “higher range” scenario, between 5 and 15% of these storms (an additional 1 storm per year) will move northward during late winter (Jan, Feb, March), affecting the Northeast. (No change for the “lower range” scenario.) In addition, the impact of a higher sea level will increase the likelihood of storm damage to coastal locations.</p> <p>For hurricanes, the most current understanding is that rising sea surface temperatures will increase evaporation, increasing the amount of rainfall associated with any given hurricane, but there is too much uncertainty in projections of hurricane frequency and wind intensity to say much about future trends.</p>		

4

<sup>7</sup> Compared to the 1960-1990 annual average of 9 days with temperatures above 90°F.

<sup>8</sup> The total difference in range between mean and spring tides of 1.3 ft (39.6 cm) is very close to the higher emission scenario rise of 41 cm. Based on data for Plum Island Sound (south entrance), the spring high tide is generally 0.65 feet (19.8 cm) higher than the mean high tide. <http://tidesandcurrents.noaa.gov/tides10/tab2ec1b.html#8>.

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1 **What else do these changes mean for our system?**

2

	<b>“Lower Range” Scenario (3-model average of B1)</b>	<b>“Higher Range” Scenario (3-model average of A1Fi)</b>
<b>Ice-out</b>	2 weeks earlier	4 weeks earlier
<b>Spring peak flow period</b>	7 days earlier	10 days earlier
<b>Summer low flow period</b>	1 week longer	2 weeks longer
<b>Drought<sup>9</sup> frequency</b>	2 every three years (compared to 1 every 2 years today)	
<b>Winter flooding events</b>	2-fold increase in number of events	
General increases in salinity of estuarine waters, freshwater tributaries, and coastal aquifers during summer		

3

4 **Where can I find additional information?**

5

6 The Northeast Climate Impacts Assessment (NECIA) was conducted in 2006/2007. Statistically  
7 downscaled climate projections results are discussed in the report, Climate change in the U.S.  
8 Northeast. The report and information is available at [www.northeastclimateimpacts.org](http://www.northeastclimateimpacts.org) and  
9 [www.climatechoices.org/ne](http://www.climatechoices.org/ne). The data presented in the scenarios above is available at the NECIA  
10 website ([www.northeastclimatedata.org](http://www.northeastclimatedata.org)).

11

12 The U.S. Global Change Research Program (USGCRP) developed another set of climate  
13 projections through statistical downscaling of climate models and provides regional summaries  
14 of projected changes in climate and the potential impacts in the publication, Global Climate  
15 Change Impacts in the United States. This data is also available online at: [http://gdo-  
16 dcp.ucllnl.org/downscaled\\_cmip3\\_projections/dcpInterface.html](http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html).

17

18 **Works Cited**

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<sup>9</sup> Defined as the monthly soil moisture is more than 10% below the long-term mean (relative to historic simulations).  
*This document is a draft for review purposes only and does not constitute Agency policy.*

## APPENDIX D. PARTICIPANT HANDOUT ON CONFIDENCE

### Method for Assessing Confidence in Expert Judgments

Characterization of uncertainty is a critical component of assessment science. Thus this workshop exercise includes a component in which the expert participants will assess their current level of scientific confidence in each influence for which they are making a judgment. The aim is to provide information on not only degrees of influence among variables, but also the degree of uncertainty associated with each judgment, given the current state of knowledge in the scientific community.

The design of this analysis is derived from general guidance on uncertainty from recent large assessment efforts such as those of the Intergovernmental Panel on Climate Change (IPCC) and the U.S. Climate Change Science Program (CCSP) [e.g., see Moss and Schneider, 2000; IPCC, 2004; IPCC, 2005; CCSP, 2008; CCSP, 2009]. One fundamental principle is the distinction between uncertainty expressed in terms of “likelihood” of an outcome versus “level of confidence” in the science underlying the finding. Likelihood is relevant when assessing the chance of defined future occurrence or outcome, and involves assigning numerical probabilities to qualifiers such as “probable,” “possible,” “likely,” “unlikely” (CCSP 2009). In contrast, level of confidence refers to the (qualitative) degree of belief within the scientific community that knowledge, models, and analyses are accurate, based on the available evidence and the degree of consensus in its interpretation. We are taking this latter approach.

Each expert is asked to rate his/her confidence in each judgment about degree of influence based on: (1) the amount of scientific evidence that is available to support the judgment; and (2) the level of agreement/consensus in the expert community regarding the different lines of evidence that would support the judgment. These confidence attributes are further described below:

*High/low amount of evidence:* Is the judgment based on information that is well-studied and understood, or mostly experimental or theoretical and not well-studied? Does your experience in the field, your analyses of data, and your understanding of the literature indicate that there is a high or low amount of information on this influence? Sources of evidence – in order of relative importance – include: 1) peer-reviewed literature; 2) grey literature; 3) data sets; 4) personal observations and personal communications.

*High/low amount of agreement:* Do the studies and reports across the scientific community, as well as your own experience in the field or analyzing data, reflect a high degree of agreement about the influence, or do they lead to competing interpretations?

Based on the above, levels of confidence in judgments can be sorted into four general categories:

- Well established = high evidence/high agreement (HH);
- Competing explanations = high evidence/low agreement (HL);
- Established but incomplete = low evidence/high agreement (LH);
- Speculative = low evidence/low agreement (LL).

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