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EPA/600/R-11/058a
August 2011
External Review Draft

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

Volume I

Results for the San Francisco Estuary Partnership

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National Center for Environmental Assessment
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ABSTRACT

The San Francisco Estuary Partnership (SFEP), the San Francisco Bay Conservation and Development Commission, 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 designed to systematically elicit judgments from experts in a workshop setting regarding climate change effects on two key ecosystem processes: sediment retention in salt marshes and community interactions in mudflats. Specific goals 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 sensitivity of each influence under both current and future climate change scenarios. The experts also discussed the relative impact of certain influences on the endpoints. This report shows how particular pathways in such diagrams can be linked to management options in the context of planning documents to identify opportunities for 'mainstreaming' adaptation.

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

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ACKNOWLEDGMENTS

We would like to acknowledge the support of A. Grambsch and M. Slimak of EPA's National Center for Environmental Assessment in the Office of Research and Development, and especially our colleagues in EPA's Global Change Assessment Staff for many helpful discussions during this project. Special thanks to C. Weaver for technical contributions.

EXECUTIVE SUMMARY

The San Francisco Bay estuary is highly vulnerable to climate-related changes including increased water temperatures, changes in precipitation and winds, 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 extractive water uses and land use changes. Thus it is essential that estuary managers become 'climate-ready' by: assessing the vulnerability of natural resources to climate change; considering strategic choices 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 San Francisco Estuary Partnership's (SFEP) 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 SFEP and the San Francisco Bay Conservation and Development Commission 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 ecosystem processes: sediment retention in salt marshes and community interactions of shorebirds (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 information 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 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 Net Accretion/Erosion 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 Shorebirds endpoint. Colors are used to distinguish different pathways. Red symbols highlight potential changes under future climate conditions.

Sediment Retention Green pathway: Two relationships in this pathway (Figure ES-2) were indicated by the experts as having increasing relative impact on net accretion and erosion under climate change. The direct effect of organic accumulation through below-ground biomass production already has a high relative impact on the overall process, and this relative impact is expected to increase under sea level rise associated with climate change. Likewise, the effect on freshwater inflow of reservoir management is expected to be of increasingly high relative impact under climate change as freshwater supplies become increasingly variable and human demand continues to increase. Management options under this pathway include:

- Managing reservoirs for steady, lower-volume releases to regulate salinity and favor native marsh vegetative productivity
- Investigating optimal timing of releases relative to the growing season
- Prioritizing releases designed for salinity maintenance compared to high volume pulses to support mineral sediment transport
- 'Stepping up' Spartina (invasive cordgrass) eradication programs since increased salinity regimes favor this invasive species.

Sediment Retention Purple pathway: The climate-related shift in this pathway (Figure ES-2) involves an increase in the sensitivity of net mineral accumulation to changes in sediment size. This is a direct relationship, with larger grain sizes favoring net mineral accumulation since larger grains deposit more readily, are harder to re-suspend and provide larger building blocks for accretion. Increasing sensitivity of net mineral accumulation to sediment size relates to the fact that sediment flux, the other determinant of net mineral accumulation, is expected to continue to decrease because of continuing processes responsible for historical declines from peak sediment inputs in the past and because of potential changes in wave-driven erosive processes. Management options under this pathway include:

- Investigating how changes in land cover (including changes from impervious to permeable pavement systems) may affect sediment size

- Managing reservoirs for high volume pulses to increase transport of larger grain sediments to marshes
- Adjusting policies that prevent coarse sediment from entering the Bay, such as changing Total Maximum Daily Load requirements to allow an increase in sediment loads for streams that do not support salmonids
- Engaging with flood control districts to re-couple stream sediments to wetlands.

Sediment Retention Blue pathway: In this pathway (Figure ES-2), the experts identified the potential for an abrupt threshold change in the effect of wind-generated waves on sediment flux, from a direct to an inverse relationship of increasing relative impact on the overall process. Under current conditions, wind-driven wave action has a net positive effect on sediment flux onto salt marshes, as greater wave energy can mobilize and increase rates of sediment transport from bays and adjacent mudflats deep into marsh systems. However, under future climate conditions a threshold may be crossed because of a change in wave character as water depth increases due to sea level rise. In deeper water, waves behave differently, with less wave energy available for re-suspension of bottom sediments and more energy delivered to the marsh edge, leading to increased erosion. Management options under this pathway include:

- Monitoring wind, waves and sediment fluxes to detect the threshold shift when it occurs, and in the meantime preparing a response plan for after the shift
- Building berms or restoring oyster reefs as protective barriers against wave energy
- Locating sites to deposit dredge materials with a goal of enhancing sediment concentrations on mudflats adjacent to marshes
- Prioritizing development of new tools for reducing wave action on the front of marshes.

Community Interactions Green pathway: Both relationships in this pathway (Figure ES-3) were indicated as having increasing relative impact on the shorebirds endpoint under climate change. A strong direct effect of landscape mosaic (defined as a mixture of habitats for secondary foraging, roosting, and cover from predators that support efficient use of mudflat feeding habitat) already has a high relative impact on shorebirds; and this may increase even further under climate change as mudflat habitats become scarcer and smaller in extent. Likewise, the effect on landscape mosaic of restoration is expected to be of increasingly high relative impact under climate change as individual habitats within the mosaic are differentially impacted by temperature increases, altered precipitation patterns, and water diversions in a context of continuing land use change. Management options under this pathway include:

- Assessing and mapping landscape mosaics to detect changes and support management at the landscape scale
- Managing landscape mosaics through spatial planning designed to prioritize where and how to restore which habitats, in order to ensure a continuum of wetland and upland ecosystems which could migrate inland as sea level rises

- Including ‘threshold landscapes’ (those about to change from one set of dominant processes to another, or from one state to another) in consideration for restoration
- Supporting legislation or incentives that encourage moving back or blocking of development on lands where there is restoration potential now or in the future.

Community Interactions Purple pathway: This pathway (Figure ES-3) shows a high relative impact of mudflat prey populations on shorebirds. The abundance of prey per unit area will become increasingly important (of increasing relative impact) under climate change as spatial extent of mudflats shrink with sea level rise. Also, there is an abrupt threshold response of the prey community itself to water quality (specifically, dissolved oxygen), from a direct to a very strong direct effect under climate change. As decreases in dissolved oxygen occur with climate change due to increased temperatures and/or eutrophication, prey communities may flag. A critical threshold may occur in the future if dissolved oxygen reaches low enough levels to cause prey populations to crash. Management options under this pathway include:

- Protecting water quality through integrated water resources management, including stormwater management and rainwater-harvesting (which also benefits water conservation)
- Using permeable rather than impervious surfaces to reduce runoff
- Restoring riparian zones to act as natural filters.

Community Interactions Blue pathway: This pathway (Figure ES-3) contains two relationships that the experts identified as sensitive to climate change. The extent of mudflat available for foraging (i.e., the number of hours per acre that mudflats are exposed and therefore accessible) has a direct effect on shorebird populations, and this may become increasingly strong as a threshold effect under climate change. This is because extent of mudflat may become limiting as sea level rises, with available foraging habitat becoming too limited to support shorebird populations. At the top of the pathway, there is a relationship of increasing sensitivity of freshwater inflow to water management practices (specifically, reservoir management and upstream operations). This effect will become increasingly strong as freshwater flows from alternate sources such as precipitation and tributaries become more variable and/or scarce under climate change. This relationship connects back down to the shorebirds endpoint through a series of linked variables having to do with sediment supply, transport and effects on bathymetry (which helps determine extent of mudflat). Management options under this pathway include:

- Managing reservoir water releases to mobilize and transport sediments (e.g., through the use of sediment maintenance flushing flows)
- Improving upstream operations to ensure greater availability of water (for more frequent and/or intense pulse releases)
- Employing integrated water resources management, with an emphasis on shifting from storage more toward conservation uses

- Developing methods for moving coarse sediments into the bay (e.g., by strategically locating dredge spoil sites to enhance sediment supplies to mudflats).

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 the expected climate-related shift has implications for when managers may want to take action. In the case of relationships for which the expected climate-related shift is toward increasing relative impact (and especially where the relationship is already of high relative impact under current conditions), action can be taken immediately to put management options into place for positive effects on those pathways. In the case of relationships for which a change in sensitivity is possible under future climate scenarios, the expectation of increasing sensitivity could be considered a 'notification' to managers to further study 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 response will occur. In these cases it will be important to monitor threshold variables to identify the shift when it occurs; in the meantime a manager might act to keep the system 'below' the threshold as long as possible, while preparing a plan for what to do if an unavoidable shift occurs. After a shift occurs, a manager could 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 adaptation options that could be applied to sensitive ecosystem process components. A variety of additional pathways and associated adaptation options can be further explored using the detailed tables of judgments and lists of strategies provided in this report. The next step toward adaptation planning is to connect the top pathways and adaptation options to existing management activities and plans. Under its current goals, SFEP 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, sediment management, monitoring and research projects and strategies. The climate change sensitivities and potential adaptation strategies identified in this report can be cross-referenced to these activities, goals and objectives 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 intent is that the results of this assessment can be used to prioritize increased investment in projects that take into account specific, known climate sensitivities and make use of particular adaptation options that will be most effective. Assessment results can also assist in priority-setting for long term research and monitoring investment. Besides identifying well-understood relationships, the exercise also revealed gaps in understanding of the system that indicate a need for further investigation of some sensitivities as well as tailored projects to develop new management tools in response.

'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 SFEP 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 objective 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, starting with the separate pre-existing plans in support of Baylands Ecosystem Habitat Goals, Subtidal Habitat Goals and Upland Habitat Goals, projects could be designed to coordinate across goals and restore landscape mosaics that will support valued species such as shorebirds not only today, but also under projected climate change (see Green pathway, Figure ES-2).

Since climate change has the potential to intensify and even create new trade-offs, mainstreaming climate change into planning is also important for identifying and weighing conflicts among adaptation options within the context of existing (and emerging) goals. One example identified in this study is the simultaneous need to reduce sediments in salmon stream habitats (under current SFEP goals) *and* increase coarse sediment transport to the Bay (as indicated by the Purple pathway in Figure ES-2). Another example based on comparing adaptation needs for two of the top pathways above is the trade-off between high volume pulses to enable large grain sediment transport (Purple pathway, Figure ES-2) and water availability for steady, lower-volume releases to favor vegetative productivity (Green pathway, Figure ES-2).

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. Furthermore, 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.

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 more than one model can explain available data. The novel methodology introduced in this study is a modification of formal (usually quantitative) expert elicitation that uses qualitative judgments in accordance with complex ecological questions. Influence diagrams (showing the structure of causal relationships among variables) were used successfully to capture the experts' collective understanding of the selected ecosystem processes, under current conditions and under two scenarios of future climate change for a mid-century time frame. A coding scheme was used by the experts to record their 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 of some relationships to climate change (including potential threshold responses), 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 North Bay 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 transfer to the entire Bay for these particular ecosystem processes. It is likely that the influence diagrams also could be transferred for use with like ecosystem processes in other estuaries, with minor revisions for place-specific stressors or other process variables; however the characterizations of variable relationships, sensitivity and relative impact 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 the 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 its 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 can position managers to justify the most appropriate management options and 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. INTRODUCTION

1.1. BACKGROUND

The San Francisco Bay estuary is highly vulnerable to the impacts of climate change. Sea level rise, increased air and water temperatures, changes in precipitation, and changes in storm climatology and winds are already causing increased inundation of coastal wetlands and marshes, changes in water availability and quality, and altered patterns of sedimentation and erosion. These impacts are interacting with other anthropogenic stressors such as extractive water uses and land use changes to make management of estuarine ecosystems more challenging than ever. While there are many uncertainties regarding the nature of future climate changes and the response of ecosystems to those changes, estuary managers can 'ready' themselves by assessing the vulnerability of natural resources to climate change, making strategic choices about how to implement adaptation strategies[1] in the near term, and planning for longer term management under a range of plausible scenarios of future change. It is the aim of EPA's Climate Ready Estuaries (CRE) Program to assist National Estuary Programs (NEPs) in meeting such information and planning needs.

As part of the CRE Program, the San Francisco Estuary Partnership (SFEP), the San Francisco Bay Conservation and Development Commission (BCDC), and EPA's Office of Research and Development (EPA ORD) collaborated on the design and trial of a novel methodology for conducting vulnerability assessments for sensitive ecosystems of the San Francisco Bay estuary. The aim was to develop assessment capabilities using expert judgment to synthesize place-based information on the potential implications of climate change for key ecosystem processes, in a form that would enable managers to link the resulting information to adaptation planning.

1.2. PURPOSE AND SCOPE

1.2.1. Purpose

The purpose of this project was twofold: to conduct a vulnerability assessment using a novel, expert judgment approach based on expert elicitation methods, and to analyze the implications for adaptation planning. This was not a comprehensive vulnerability assessment for the whole estuary but rather a proof of concept for a new type of assessment exercise, using two key ecosystem processes of salt marsh and mudflat ecosystems as demonstration studies. This was accomplished through a series of steps to: 1) identify key management goals and ecosystem processes essential to meeting those goals; 2) create conceptual models of selected ecosystem

[1] Throughout this report, "adaptation" refers to management adaptation rather than evolutionary adaptation. Management adaptation refers to strategies for the management of ecosystems in the context of climate variability and change (CCSP, 2008a).

processes; 3) assess ecosystem process sensitivities to climate change; 4) consider resulting vulnerabilities with respect to management goals; and 5) explore implications for adaptation planning. Steps 1-2 were used to define the scope of the assessment, while steps 3-5 comprise the vulnerability assessment itself.

1.2.2. Scope

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

- Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources
- Protect and manage existing wetlands
- Restore and enhance the ecological productivity and habitat values of wetlands
- Stem and reverse the decline of estuarine plants, fish and wildlife and the habitats on which they depend; and
- Ensure the survival and recovery of listed and candidate threatened and endangered species, as well as special status species.

After an information-sharing meeting with local experts to discuss the project and learn about climate change impacts and adaptation work in the region, salt marshes and mudflats were selected as focal ecosystems for the study. These systems were identified as highly relevant to SFEP's management goals due to their ecological productivity, their habitat values for threatened and endangered species, and their sensitivity to changes in climate-related variables such as sea level rise and altered hydrology. For more detailed information on goal and ecosystem selection processes, please see Appendix A.

The second step in the scoping process was the development of conceptual models to understand the primary drivers and processes of salt marshes and mudflats. The conceptual models were used to explore the linkages among key ecosystem processes within each ecosystem, major stressors of concern, and climate drivers causing altered or new stressor interactions. The models were refined to a set of five or six key ecosystem processes that are essential to the maintenance of salt marsh and mudflat systems. Based on these general conceptual models, two specific processes of concern were selected for further analysis. The purpose was to select good processes for piloting the method, but the choice does not imply that these are necessarily the only important, or the most vulnerable, processes. The processes were selected based on the criteria of being identified by local experts as integral to ecosystem function, increasingly sensitive to climate change, and sufficiently well-studied by the scientific community to provide the basis for a more in-depth assessment.

The two processes selected for further analysis were sediment retention in salt marshes and community interactions in mudflats (see Executive Summary Figure ES-1). Sediment retention refers to the balance between the processes of removal and deposition of sediment onto a salt marsh. The topic of community interactions in mudflats was narrowed to a tractable "storyline" involving several interdependent species, which was selected based on interviews with local experts who were asked to identify climate-sensitive interactions of interest. The storyline selected was the relationship of two species of mudflat wading birds, the Marbled Godwit and the Western Sandpiper, to their predators and prey. Expanded sub-models were developed for each of the two processes and served as the basis for designing the sensitivity analyses of the subsequent assessment. For more detailed information on process selection and conceptual model development, please see Appendix A.

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

Table 1-1. Breakout group participants for the expert elicitation workshop (see Appendix B for further details on selection criteria and credentials)

1.3. ROADMAP FOR THE REPORT

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

Figure 1-1. Vulnerability assessment process.

Section 2 describes the expert elicitation exercise, including the approach, the exercise, and the results. Section 3 provides an analysis of the results with respect to how they may be used by estuary managers to understand ecosystem responses to climate change and engage in adaptation planning. Section 4 provides key conclusions of the assessment. The appendices provide additional detailed information on the activities conducted prior to and following the workshop. Appendix A summarizes the goal selection and conceptual modeling processes used for scoping the vulnerability assessment. Appendix B provides details on the expert elicitation pre-workshop preparations and post-workshop follow-up, including expert selection criteria, pre-workshop preparations by participants, and expert feedback. Appendix C and Appendix D contain detailed information that was provided to the participants on the development of climate scenarios and the methodology for estimating confidence.

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 selected salt marsh sediment retention and mudflat community interactions processes to the projected impacts of climate change; 2) improve the ability to identify adaptation strategies that mitigate those impacts, given the uncertainties; and 3) demonstrate the applicability of an expert elicitation approach to this type of analysis.

The workshop was held March 16-17, 2010, in San Francisco, California, at the BCDC offices. 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 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 San Francisco Bay area, the participants were asked to consider the North Bay (San Pablo Bay) when a more specific spatial scope would be useful during the workshop exercise. In addition, an example site in the North Bay, China Camp, was presented as a particular place upon which to focus when considering management implications; however, issues and options that were not specific to China Camp were also considered during group discussions.

For further details on workshop preparation and implementation, including selection criteria for participants, 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. Since participants varied in their expertise about different aspects of the system, they were encouraged to make adjustments to their judgments at any time based on any deeper understanding gained 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.

2.2.2.1. *Influence Diagrams*

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

A simplified influence diagram for sediment retention is provided in Figure 2-1. By convention, the variables in an influence diagram are represented by rectangles (labeled boxes) while arrows between the variables represent causal relationships, or “influences”. Sequences of arrows form pathways, all of which ultimately lead to the final variable, or endpoint, of concern. In Figure 2-1, the endpoint that is being evaluated is sediment retention. Interactive effects of multiple variables on each other, or on the endpoint, can occur where two “causal” variables both influence (have arrows into) a common “response” variable. In Figure 2-1, an example interaction is indicated by arrows B and C, where reservoir management and impervious cover together could have an interactive effect on freshwater inflow.

In the case of community interactions, the diagram was constrained to a tractable number of species of interest. It focused on the relationship of two species of mudflat wading birds, the medium-bodied Marbled Godwit and the small-bodied Western Sandpiper, to their predators and prey. Please see Appendix A for a more detailed explanation of this storyline.

Figure 2-1. Simplified influence diagram for sediment retention.

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

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

2.2.2.2. *Climate Scenarios*

Dr. Katharine Hayhoe of Texas Tech University, an experienced climate scientist with an extensive background in regional climate assessments, developed two climate change scenarios for use in the expert elicitation exercise. The scenarios represented two distinct but scientifically credible climate futures for a mid-century (2035-2064) time period. (The mid-century time frame was selected by the SFEP partners because of its suitability for adaptation planning.) The projections were based on six leading climate models, using a lower emissions scenario (Climate Scenario A) and a mid-high emissions scenario (Climate Scenario B) to generate values for climate variables for use by the experts in making their judgments (see Table 2-1).

Table 2-1. Summary of Climate Scenario A ("Lower-Range" Scenario) and Climate Scenario B ("Higher-Range" Scenario): averages for mid-century

Under both climate change scenarios, California will retain its Mediterranean climate (cool/wet winters and hot/dry summers) and continue to experience a high degree of variability in precipitation with rising sea levels. By mid-century, the "higher-range" Climate Scenario B (which includes higher emissions and a more sensitive climate) is projected to experience a warmer and somewhat drier climate compared to the "lower-range" Climate Scenario A (with lower emissions and a lesser impact on California's climate).

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

2.2.2.3. *Expert Facilitation*

Due to the highly technical nature of the exercise, the complexity of the novel methodology that was being used, and the ambitious time line for accomplishing multiple outputs, it was essential that the workshop be run by skilled expert facilitators. These were chosen based on a number of criteria including: proven expertise in facilitating science-based workshops; general knowledge of science behind estuary management (particularly wetlands ecology); and experience working on national coastal issues and/or issues in the San Francisco Bay region. The expert facilitators selected were Dr. Peter Schultz, Principal at ICF International, and Dr. Brock Bernstein, independent consultant and President of the National Fisheries Conservation Center. Dr. Schultz (who served as facilitator for the Sediment Retention group) has served as the Director and Associate Director of the U.S. Global Change Research Program Office, and has two decades of experience in climate and global change research, management, decision support, and communication. Dr. Bernstein (who served as facilitator for the Community Interactions group) is a marine ecologist with research experience in a range of coastal and oceanic environments, including San Francisco Bay, and has worked on a wide variety of management and policy issues.

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

2.2.2.4. *Coding Scheme and Exercise*

Participants were asked to characterize each influence in their influence diagram according to the coding scheme presented in Table 2-2, and to indicate their confidence in their judgments using the confidence rankings described below (see next section). Influences were characterized first under current conditions, and then under Climate Scenario A and Climate Scenario B. The extent to which participants agreed in their judgments was variable across the different influences. The rule that was adopted for determining agreement for each influence was that a majority (4 or more participants) had to have selected the same code. Majority agreement among four or more participants was considered to indicate substantial agreement across the group.

Table 2-2. Coding scheme used during the workshop exercise to characterize influences. "Small" and "large" changes in variables are defined relative to the current range of variation for each variable, with "small" indicating that the variable is within its current range of variation and "large" indicating that the variable has moved outside its current range of variation

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

Table 2-3. Coding scheme used during the workshop exercise to characterize interactive influences

Finally, the participants were asked to assess their current level of scientific confidence in their judgments for each influence or interactive influence using the confidence coding scheme presented in Table 2-4. For each influence, each participant was asked to rate his/her confidence in their judgment based on: (1) the amount of scientific evidence that is available in the expert community 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. The coding options for "amount of evidence" were high (H) or low (L), based on whether available information is abundant and well-studied and understood, versus sparse and mostly experimental/theoretical. The coding options for "level of agreement" were high (H) or low (L), based on whether data, reports, and experience across the scientific community reflect a high or low level of agreement about the influence. Thus it was possible to have four combinations of evidence and agreement when assessing confidence: HH, HL, LH, and LL. The rule for determining agreement in confidence was the same as described above for influences: agreement was defined as a majority (four or more) of the same categorization of confidence level. Similarly using the same rule as above for interactive influences, agreement on confidence for interactive influences was defined as three or more of the same categorization of confidence. For additional details on the method used to assess confidence, please see Appendix D.

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

2.2.2.5. *Typologies for Understanding Influences and Sensitivities*

Type and degree of influence

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

<u>Types</u>:
Direct relationship = Codes 2, 3, 6, 8, 11, 13
Inverse relationship = Codes 4, 5, 7, 9, 10, 12
<u>Degrees</u>:
Proportional response of Y to X = Codes 2- 5
Disproportional response of Y to X = Codes 6-13

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

<u>Pairings by type and degree of influence (where "X" can go up or down)</u>:
Direct proportional = 2/3
Inverse proportional = 4/5
Direct disproportional, strong response (xY) = 6/11
Direct disproportional, weak response (Xy) = 8/13
Inverse disproportional, strong response (xY) = 7/10
Inverse disproportional, weak response (Xy) = 9/12

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

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

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

Sensitivity

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

<u>Low sensitivity</u> = Codes 8-9 & 12-13
<u>Intermediate sensitivity</u> = Codes 2-5
<u>High sensitivity</u> = Codes 6-7 & 10-11

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

<u>No Influence</u> = Code 0
<u>Unknown influence</u> = Code 1
<u>None given</u> = No judgment provided
<u>Other</u> = Response provided that does not fit into the coding scheme

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. There was no coding for this in the workshop exercise; rather, this concept was an emergent property of 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 influence 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 was 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?

Relative Impact of Influences:

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

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

2.3. RESULTS

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

2.3.1. Sediment Retention

2.3.1.1. *Group Influence Diagram*

Figure 2-2 shows the group diagram developed by the Sediment Retention group. Variable definitions that were clarified by the participants during the construction of the diagram are found in Table 2-5. Two main variables, Net Mineral Accumulation and Net Organic Accumulation, influence the endpoint of the balance between Net Accretion and Erosion. Organic and inorganic sediment accumulation processes are both influenced by Inundation Regime, which is influenced by Relative Sea Level and Tides. There is a feedback loop from the endpoint to Inundation Regime. The middle level in the diagram includes Tides, Relative Sea Level, Freshwater Inflow, Sediment Flux, Sediment Size and Wind and Waves. Freshwater Inflow and Inundation Regime are key factors influencing Net Organic Accumulation through plant community composition and production. Of the management and stressor variables, three are related to Water Resource Management: Delta Outflow, Reservoir Management and Channelization. These influence a combination of Sediment Flux and Size and Freshwater Inflow.

Figure 2-2. Sediment Retention group influence diagram.

Table 2-5. Sediment Retention variable definitions clarified during group discussion

The 15-box constraint meant that the freshwater and sediment supply variables were not split between Delta and tributary sources, even though much of the discussion on the diagram highlighted the differences in those sources. Without separate variables differentiating between local tributary and Delta freshwater inflow, Delta Outflow and Freshwater Inflow could be considered to effectively act as a single variable. The fourth stressor variable is a Land Use and Land Cover Change variable: Impervious Cover.

2.3.1.2. *Influence Types and Degrees*

Agreement

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

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

In some cases, participants gave multiple codes for an arrow. When the multiple codes represented one of the pairing types described above in section 2.2.2.5 (e.g., 2/3), both codes are shown, separated by a "/".

If multiple codes that do not fall into a pairing were given, both codes are shown, separated by a symbol indicating the nature of the combination. In the first type of combination, multiple codes with "X" going in the same direction (e.g., X is increasing in both codes) are separated by a "^" symbol; and where these codes conflict and would make a difference in determining agreement, those cells were not counted. In cases where a reason was given for multiple codes (such as when boxes had "lumping" problems and participants specified different codes for different variables within the box), then the code that logically corresponded best to other participants' codes (based on the notes column and other inferences) was used.

In the second type of combination, codes with "X" going in different directions (e.g., X is increasing in one code and decreasing in the other) are separated by a "|". Since the response to X can indeed be different depending on whether X is increasing or decreasing, these cells do not represent a conflict but rather the opportunity to consider agreement in both the "X-up" and "X-down" direction. In these cases it was possible to have agreement in one direction but not the other.

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

Under current conditions, there were 16 influences for which there was agreement on both type and degree of influence. There were seven influences for which there was agreement on type but not degree. There was no agreement for three influences. Relative to the rest of the diagram, the influences from the top row variables, which represent management options, have less agreement.

Under Climate Scenario A, there were 17 influences for which there was agreement on both type and degree, which includes all of the same influences as under current conditions plus one additional influence, the feedback from the endpoint to Inundation Regime. There were five relationships for which there was agreement on type but not degree and four relationships had no agreement. The influences for which there was no agreement include two of the same ones as current and two for which there previously was agreement on type but not degree.

Under Climate Scenario B, there were 15 influences for which there was agreement on both type and degree. There were six relationships for which there was agreement on type but not degree and five relationships had no agreement. Most of the changes in Climate Scenario B are influences losing agreement on degree or ones that had already changed in Climate Scenario A. Inundation Regime to Wind/Waves settled into agreement on direct disproportional, strong response.

Thresholds

Relationship N (Relative Sea Level on Inundation Regime) and relationship Z (Wind/Waves on Sediment Flux) were identified to be threshold relationships under the climate scenarios. The threshold of relationship N is related to the marsh response to sea level rise, and is tied to the rate of sea level rise. At the point in the inundation regime where the marsh is no longer able to keep up with sea level rise, the marsh elevation will drop, thereafter experiencing a different inundation regime. The threshold of relationship Z occurs where wind-driven waves change from a source of sediment, adding to net vertical accretion, to a net negative impact through erosion of the marsh edge. This occurs because, as water depth increases due to sea level rise, the effect of wave energy on re-suspension of bottom sediment will decrease while its effect on marsh edge erosion will increase. In both of these cases the type or sensitivity of the influence did not change across the scenarios (direct influence with intermediate sensitivity for both), but the influences were indicated by participants to be important threshold relationships through the discussion. One possible reason why these thresholds identified in the discussion did not show up in the coding as changes in sensitivity is because participants did not know where the threshold would occur, so they did not want to attach that estimate to a particular climate scenario. Alternatively, it may be that there is a threshold that represents a state change that falls within the range of natural variability, so this method was not sensitive enough to identify the threshold. Relative sea level and wind and waves are both closely tied to climate drivers, making relationships driven by them sensitive to climate change.

2.3.1.3. *Influence Sensitivity*

Figure 2-3 shows the sensitivity results using the influence diagram, indicating where there is agreement under current conditions. The typology described in Section 2.2.2.5 was used to code sensitivity, with an additional differentiation within the "no agreement" category. In all "no agreement" cases, there was a mixture of codes for intermediate sensitivity along with low and/or high sensitivity; if at least four participants provided judgments, and there were more high sensitivity judgments than low sensitivity judgments, then the dashed arrow was colored orange to indicate intermediate-to-high sensitivity. Under current conditions, 19 influences for which there was agreement were categorized as intermediate sensitivity. Three influences were categorized as low sensitivity, two of which originate from the variable Channelization. There were no instances of agreement on influences with high sensitivity. There was no agreement on sensitivity for four influences.

Figure 2-3. Sediment Retention group summary influence diagram of sensitivities under current conditions.

Figure 2-4 compares the sensitivities as in Figure 2-3, across the three scenarios. There were no influences for which the sensitivity category changed between scenarios; the only changes were between no agreement and a type of sensitivity. Under Climate Scenario A, all of the same influences as those under current conditions were again categorized as intermediate sensitivity, with the exception of both Freshwater Inflow and Inundation Regime on Net Organic Accumulation, for which there no longer was agreement. However, Inundation Regime on Net Organic Accumulation showed a trend toward increasing sensitivity (orange arrow), as did Inundation Regime on Wind/Waves. The same three influences as under current conditions were categorized as low sensitivity for both Climate Scenario A and Climate Scenario B.

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

Under Climate Scenario B, one influence which previously had no agreement (but did show an orange trend), Inundation Regime to Wind/Waves, increased in agreement, which resulted in a categorization of high sensitivity. Three additional intermediate sensitivity influences dropped below the standard of agreement: Wind/Waves on Sediment Size, Sediment Size on Net Mineral Accumulation and the feedback from Net Erosion/Accretion on Inundation Regime, such that the number of influences with no agreement on sensitivity increased to eight. The disagreement shows a trend of some participants estimating increasing sensitivity, with several of the influences characterized as a mix of intermediate and high sensitivity (orange arrows) where there had once been agreement on intermediate sensitivity.

One reason for lack of agreement on changes in sensitivity across scenarios, as well as lack of agreement within scenarios, may have been the degree of variability among participants in their judgements. Overall, there was more variability among participants than across scenarios for any given participant. There were no patterns across participants, such as characterizing only increasing sensitivity. Further description, as well as figures depicting variability in judgments across participants, can be found in Appendix B.

2.3.1.4. *Relative Impact*

Figure 2-5Figures 2-5 and 2-6 present the characterizations of relative impact between current and future climate scenarios (the group's discussion did not differentiate between the two future climate scenarios). Six influences were identified as having high relative impact under current conditions. None of these are connected to the management options level within the diagram. We have assumed that these same relationships are still of high impact under the climate scenarios unless otherwise noted in the group discussion on climate change impacts. The influences of Net Organic Accumulation on Net Erosion/Accretion and of Wind/Waves on Sediment Flux were identified as having increasing impacts under the climate scenarios. Two new influences, both on Freshwater Inflow and driven by variables in the management options level, were identified as having high relative impact under the climate scenarios: Reservoir Management and Channelization.

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

Figure 2-6. Sediment Retention group influences indicated as having high *relative impact* under climate scenarios.

2.3.1.5. *Confidence*

The confidence results shown in Table 2-7 are provided for the Sediment Retention influences for which there was agreement on type. The lack of agreement on confidence for almost half of the judgments is a significant gap, limiting our ability to prioritize around confidence judgments. Eight of the 11 influences for which there was agreement on confidence across all three scenarios were scored as high evidence and high agreement (HH). The influences of Reservoir Management on Sediment Flux and Sediment Size, which were both categorized as HH under current conditions, showed declining confidence under the climate scenarios, with scores of low evidence/high agreement (LH) under Climate Scenarios A and B. Relative Sea Level on Tides, scored as HH under current conditions, also showed declining confidence under the climate scenarios, with a score of low evidence/low agreement (LL) under Climate Scenario A and Climate Scenario B.

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

The confidence results shown in Figure 2-7 total all judgments across all participants. The total number of HH and HL judgments decreased under the climate scenarios compared to current conditions, and the total number of LH and LL judgments increased under the climate scenarios compared to current conditions. The decrease in the total number of HH judgments from current conditions to the climate scenarios and the corresponding increase in the total number of LL judgments show that influences are less well-understood, probably due to less information being available about future climate conditions.

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

2.3.1.6. *Interacting Influences*

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

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

Under current conditions, there were five interactive influences for which there was agreement among participants in the Sediment Retention group. For each of these interactive influences, Synergy was the type of influence chosen. Among these, there is a cluster of multiple interactions between Inundation Regime, Sediment Flux and Sediment Size on Net Mineral Accumulation. The other two interacting influences identified act on Inundation Regime and Sediment Flux, so they are highly interconnected. There was only agreement on the confidence for two of these interactive influences, both of which were scored as high evidence and high agreement (HH).

Under both Climate Scenario A and Climate Scenario B, there was agreement on three of the previous five synergistic interactive influences, with synergy again chosen as the type of interactive influence. Again the same cluster of influences on Net Mineral Accumulation was identified. There was no agreement on confidence for these interactive influences under either of the future climate scenarios.

This lack of agreement on interacting influences was primarily due to not having many influences with enough participants characterizing the same interacting influences. Of the 48 combinations of influences with interactions characterized by participants, only 10 could be considered for agreement with at least three participants making a judgment; half of those had three participants in agreement.

2.3.2. Community Interactions

2.3.2.1. *Group Influence Diagram*

Figure 2-8 shows the group diagram developed by the Community Interactions group. Variable definitions that were developed by the participants during the construction of the diagram are found in Table 2-9. Figure 2-8 shows a high degree of interconnectivity between variables, especially among those directly influencing the endpoint. These variables are Extent of Mudflat (and, therefore, extent of feeding habitat), Predators and Disturbance, Bed Sediment Characteristics and Quality, Shorebird Prey Community and Landscape Mosaic (i.e., where mudflats sit relative to other foraging and roosting habitats such as salt ponds). Many of the variables encompass complex processes, which combine more than one key variable. Defining a metric specific to such broad variables, including whether they are increasing or decreasing, proved to be challenging. The possibility of differing assumptions about definitions among participants complicates interpretation of the results. The variables indirectly affecting the endpoint are primarily physical ones: Mudflat Bathymetry, Tides and Hydrodynamics, Sediment Resuspension and Deposition, Wind/Waves, Water Quality, Freshwater Inflow and Sediment Supply. The management and stressor variables are broad categories: Water Management, Restoration and Land Use Change.

Figure 2-8. Community Interactions group influence diagram.

Table 2-9. Community Interactions variable definitions clarified during group discussion

2.3.2.2. *Influence Types and Degrees*

Agreement

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

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

The participants agreed on the type and degree of influence for a smaller fraction of the total number of influences than the Sediment Retention group did. Under current conditions, there were 18 influences for which there was agreement on both type and degree. These are spread throughout the diagram, but it is of note that there was agreement on type for all of influences going into the endpoint and of those, there was also agreement on degree for all but Bed Sediment Characteristics and Quality. There were five influences where there was agreement on type but not degree of influence. There was no agreement for 13 relationships.

Under Climate Scenario A, the number of influences for which there was agreement on both type and degree dropped to 12; for those that changed, they split between changing to agreement on type but not degree and to no agreement. The influence of Tides and Hydrodynamics on Extent of Mudflat went from no agreement to agreement on inverse disproportional, strong response. There were nine relationships for which there was agreement on type but not degree. There were 15 relationships for which there was no agreement.

Under Climate Scenario B, there were 11 influences for which there was agreement on both type and degree. There were nine relationships for which there was agreement on type but not degree. There were 16 relationships for which there was no agreement, which includes all of the same influences under Climate Scenario A along with the influence of Mudflat Bathymetry on Extent of Mudflat.

Agreement for the type and degree of influence remained consistent across the scenarios for eight relationships. Agreement on type but not degree of influence remained consistent across the scenarios for three relationships. There were 11 relationships for which there was no agreement on type or degree of influence across the scenarios.

The larger number of influences for which there was no agreement under all scenarios leaves a gap which makes it difficult to understand the type or degree of influence for these relationships. This is partially due to a higher occurrence of no response given for the Community Interactions group. It is not possible to differentiate between lack of response due to insufficient time and disinclination to answer due to lack of knowledge about the influence.

Thresholds

Four relationships were identified as threshold relationships under the climate scenarios, based on the notes and discussions. These were: Freshwater Inflow on Tides and Hydrodynamics (Relationship K); Water Quality on Shorebird Prey Community (Relationship S); Bed Sediment Characteristics and Quality on Shorebird Prey Community (Relationship BB); and Extent of Mudflat on Shorebirds (Relationship DD). Relationship K was characterized as a direct influence of uncertain degree; coding for degree was a mixture of weak, proportional and strong influences with a slight trend toward increasingly strong influences through time. Some participants indicated that winter increases in freshwater flow will be very important as mudflats reach a threshold of becoming subtidal; this would be especially true during high tides, where flows could push a system above a threshold and create a large impact on inundation height.

Relationship S was characterized as direct proportional across the three scenarios. The water quality aspect emphasized by the participants as a threshold was dissolved oxygen (DO). They noted that small decreases in DO could have a large negative effect on mudflat prey populations as a threshold is reached.

Relationship BB was direct proportional under current conditions, but there was no agreement on degree under the climate scenarios. One participant indicated a change to a disproportionately strong response through coding, but other participants did not change their coding or left some blank cells, such that there was no majority agreement on degree under the climate scenarios. However, participants' notes indicated that as habitat becomes more limited, even small areas of poor habitat will have large effects on shorebirds. For this example as well as the previous two threshold influences above, the participants chose to indicate the thresholds through notes (rather than through coding) because they were not sure when (i.e., under which climate scenario) the threshold was most likely to be reached.

Relationship DD was unique in being the only threshold influence that was identified clearly through the coding exercise. Under current conditions the relationship was considered direct proportional. Under Climate Scenario A there was agreement that it was still a direct relationship, but there was no agreement on degree because there was a mixture of proportionate and disproportionately strong codes. Under Climate Scenario B the conversion to agreement on a direct disproportionately strong relationship was complete. This reflects the opinion of the participants that as access to foraging habitat on mudflats becomes limiting due to sea level rise and other factors, the effect on shorebird populations will become more extreme.

2.3.2.3. *Influence Sensitivity*

Figure 2-9 shows the sensitivity results using the influence diagram, indicating where there is agreement under current conditions. The typology described in Section 2.2.2.5 was used to code sensitivity, with an additional differentiation within the “no agreement” category. In all “no agreement” cases, there was a mixture of codes for intermediate sensitivity along with low and/or high sensitivity; if at least four participants provided judgments, and there were more high sensitivity judgments than low sensitivity judgments, then the dashed arrow was colored orange to indicate intermediate-to-high sensitivity. Under current conditions, 19 influences for which there was agreement were categorized as intermediate sensitivity. Five influences were categorized as high sensitivity: both the influence of Restoration and of Land Use Change on Landscape Mosaic, Landscape Mosaic on the endpoint, and both the influence of Tides and Hydrodynamics and of Mudflat Bathymetry on Extent of Mudflat. There was no agreement on sensitivity for 12 influences. There were no instances of agreement on influences with low sensitivity.

Figure 2-9. Community Interactions group summary influence diagram of sensitivities under current conditions.

Figure 2-10 compares the sensitivities as in Figure 2-9, across the three scenarios. Under Climate Scenario A, 10 influences for which there was agreement were categorized as intermediate sensitivity. Five influences were categorized as high sensitivity: four of the same as under current conditions, with a change the influence of Land Use Change on Landscape Mosaic to no agreement and new agreement for the influence of Predators and Disturbance on the endpoint. The number of influences with no agreement increased substantially to 21. Seven of those are in disagreement because there is a combination of intermediate and high sensitivity (orange arrows). This decrease in agreement reflects a trend of increasing sensitivity for some participants, but not enough to shift to a new category. It could be indicative of either disagreement about at what point such a shift would occur or differing assumptions about what falls outside the current range of variability, which was left up to each participant to decide based on their own knowledge and intuition.

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

Under Climate Scenario B, seven influences for which there was agreement were categorized as intermediate sensitivity. Six influences were categorized as high sensitivity, with the addition of Extent of Mudflat on the endpoint, which had been intermediate under current conditions. This is another way to identify a threshold, when there is a change in sensitivity to a more sensitive category. The number of influences with no agreement increased again to 23; however, for six of these the lack of agreement was due to a mixture of intermediate and high sensitivity codes (orange arrows).

As with the Sediment Retention group, there was more variability in judgments among participants than across scenarios for any given participant. The majority of changes in sensitivity across the climate scenarios are of increasing sensitivity. Further description, as well as figures depicting variability in judgments across participants, can be found in Appendix B.

2.3.2.4. *Relative Impact*

Figure 2-11 and Figure 2-12 present the characterization of relative impact between current and future climate scenarios (the group's discussion did not differentiate between the two future climate scenarios). Relative impact was distinguished among the influences by indicating primary, secondary or tertiary levels of relative impact. For the Community Interactions group, the relative impacts of five influences were indicated as important under current conditions, based on the discussion. The influences of Landscape Mosaic and of Extent of Mudflat on the endpoint were both identified as having primary impacts. The influences of Predators and Disturbance and of Shorebird Prey Community on the endpoint were identified as having secondary impacts, and the influence of Bed Sediment Characteristics and Quality on the endpoint was identified as having tertiary impact.

Figure 2-11. Community Interactions influences indicated as having high *relative impact* under current conditions.

Figure 2-12. Community Interactions group influences indicated as having high *relative impact* under climate scenarios.

A total of 10 influences were indicated as having high relative impact under climate change conditions for the Community Interactions group (Figure 2-12). Three of the influences indicated as having high relative impact under current conditions increased in relative impact when considering future climate conditions: the influences of Landscape Mosaic, Predators and Disturbance, and of Shorebird Prey Community, each on the endpoint. The relative impact of Extent of Mudflat on the endpoint stayed equally important. Five additional influences were indicated as having high relative impact under the climate change scenarios. In addition, the influence of disease on the endpoint was identified as an influence of emerging impact. Disease was not an original key variable in the influence diagram, as variables were included based on importance under current conditions. This influence was not scored, but was considered to be important by the participants. The influence of Bed Sediment Characteristics on the endpoint was indicated as having high relative impact under current conditions but not under the climate scenarios. It is unclear whether this was intentional or was just not covered in the discussion of relative impact under future climate conditions.

2.3.2.5. *Confidence*

The confidence results shown in Table 2-11 are provided for the Community Interactions influences for which there was agreement on type. The lack of agreement on confidence for two-thirds of the judgments is a major gap, limiting our ability to prioritize around confidence judgments. Five of the six influences that for which there was agreement on confidence across all scenarios were scored as high evidence and high agreement (HH). The influence of Freshwater Inflow on Net Organic Accumulation was scored as low evidence high agreement (LH) across all scenarios. The HH type of confidence was the most used type of judgment. The dominant pattern on confidence across the climate scenarios was a decrease in the number of influences on which there was agreement.

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

The confidence results shown in Figure 2-13 total all judgments across all participants. In total, confidence decreased from current conditions to the climate scenarios, with a decrease in the total number of HH and an increase in LL. However, a larger increase was in the total number of no answer given, and the decreases in HL and LH are difficult to explain in total.

Figure 2-13. Community Interactions group confidence results for all influences; HH = High evidence, High agreement; HL = High evidence, Low agreement; LH = Low evidence, High agreement; LL = Low evidence, Low agreement.

2.3.2.6. *Interacting Influences*

Under current conditions, there were no interactive influences for which there was agreement among participants in the Community Interactions group. Likewise, under both climate scenarios there were no interactive influences for which there was agreement on the type of interactive influence. This lack of agreement was primarily due to not having many influences with enough participants characterizing the same interacting influences. Of the 24 combinations of influences with interactions characterized by participants, only four had at least three participants make any kind of judgment, which was the threshold for agreement, but those were not ever in agreement on a type of interaction.

2.4. DISCUSSION OF ADAPTATION STRATEGIES

With background on strategic priorities provided by SFEP, the workshop participants discussed the implications of the exercise results for management. Table 2-12 lists adaptation strategies that emerged during the group discussions. The experts discussed a variety of general adaptation strategies as well as some specific adaptation activities that would be responsive to key potential climate-related changes identified through their judgments. The strategies fall into several broad categories, including Restoration & Conservation, Sediment Management and Planning & Monitoring.

Table 2-12. Adaptation strategies and associated top pathways for management (see section 3.2 for pathways). SG=Sediment Retention Green pathway; SB=Sediment Retention Blue pathway; SP=Sediment Retention Purple pathway; CG=Community Interactions Green pathway; CB=Community Interactions Blue pathway; CP=Community Interactions Purple pathway.

2.4.1. Restoration & Conservation

Restoration was identified as a powerful management tool with a variety of specific planning and prioritization considerations. The experts emphasized the urgency of implementing restoration projects as an immediate priority, taking climate change impacts into consideration in planning. For marsh restoration, the key is getting started early enough so that marshes can be established before rates of sea level rise become too high. As a restored marsh matures, it is better able to keep pace vertically through vegetative production. Similarly for other types of restored habitats, they will be more resilient to changing climate conditions as they mature. The other temporal issue for restoration planning was the need to plan for ecological succession, building a dynamic landscape mosaic that includes habitats that will thrive under future climate conditions.

Similar and related considerations apply to conservation strategies. One consideration for conservation could be habitats that are well suited to future climate conditions. Though some habitats may not survive climate change (e.g., where there are not long term opportunities for migration), it may still be important to preserve and restore these habitats in the short and medium term as interim habitats until alternate habitats that serve similar ecosystem functions have been established.

Available space for habitat migration is a major consideration for both restoration and conservation. On the conservation side, adjacent transitional uplands should be maintained to allow for local habitat migration. Policy options may include regulation or incentives to encourage relocation and to discourage development on lands where there is potential for upslope habitat migration or restoration. The slope of the adjacent uplands is an important factor in such conservation priorities, and the need for improved vertical data as a mapping priority was highlighted in the workshop discussion. Such mapping would help to identify upland areas for restoration adjacent to current healthy marshes, where migration of marshes is possible. The experts especially emphasized the need to identify and prioritize wetland areas for restoration where the adjacent uplands currently include complementary habitats that would contribute to a complete landscape mosaic that could support valued species such as shorebirds that will be stressed by climate change. Another key part of developing and conserving such landscape mosaics is providing for connectivity between multiple habitats. Also underscored was the need to focus restoration efforts in the North Bay because the shoreline of the South Bay is so developed that it precludes the ability of marshes to migrate upland. Finally, many restoration efforts to date have involved fringing marshes. The focus of restoration could be expanded beyond fringing marshes to larger areas where there is available space for multiple habitats.

A major spatial planning consideration for restoration is the need to consider the impacts of each project on adjacent and downstream habitats and future restoration projects. In particular, any project that broaches levees in Suisun Marsh will impact downstream sediment budgets and adjacent hydrodynamics. Restoration projects could be coordinated so that projects can be planned and timed to maximize success. Deciding when and where (e.g., how far upstream) to focus restoration of different marsh types will also depend on changes in the salinity gradient; conditions that suit freshwater and brackish marshes will be moving upstream through time under climate change, unless maintaining marsh salinity becomes a priority for Delta freshwater storage policies.

2.4.2. Sediment Management

Sediment management is already a priority within the region and will continue to be an important focus for marsh management in the context of sea level rise and changing precipitation patterns. There is an expectation that sediment supply from the Sacramento Valley will continue to decline due to the cessation of hydraulic mining, but currently it remains elevated above levels prior to the 19^{th} century. It will become increasingly important to support movement of inorganic sediment into restoration sites in the near term, so that salt marshes can build to threshold elevations for vegetation establishment and begin contributing organic sediment to maintain themselves.

Changes in sediment supply will require local tributaries and Delta sources to be managed differently. On the tributary side, there are opportunities to reconnect streams to wetlands through flood control districts. An example of a specific option for increasing inorganic sediment loads from local tributaries would be to for regional water boards to consider adjusting sediment TMDLs (Total Maximum Daily Loads) to allow for increases in coarse sediment loads in streams that do not support salmonids. On the Delta side, Integrated Water Management will be increasingly important for maintaining sediment supply, and may prompt a switch in priority from storage to conservation. In the Bay, dredge sediment reuse is an opportunity to redistribute sediment to desired locations. Limiting factors on current use of this technique were discussed by the workshop participants, including the need for best management practices and funding.

While most of the discussion on sediment was about keeping pace vertically with sea level rise, horizontal impacts through marsh edge erosion were also discussed. There is a need to develop ways to reduce wave action on the front sides of marshes. Protecting adjacent mudflats, such as with berms, is one specific option.

2.4.3. Planning & Monitoring

The final category of adaptation strategies discussed at the workshop addressed planning and monitoring. Many of the above recommendations are based on planning, including prioritizing. The need to develop rapid response plans for catastrophes or contingency plans for when thresholds are passed was emphasized. Preparing the political and funding conditions necessary to implement such plans would be essential.

Monitoring will become increasingly important in order to detect when thresholds are being crossed. The scales at which monitoring is focused will have to be adapted to changes in restoration priorities. Monitoring at the landscape scale -- especially for birds and other mobile species that use multiple habitat types -- will be a necessity in order to track potential thresholds. This will likely require coordination among multiple agencies since many habitats and habitat mosaics span jurisdictional boundaries. The current condition and extent of these habitats needs to be monitored and understood now, as the current data are insufficient for a baseline at the landscape level. Examining habitats at a larger scale will also be important for facilitating species movements. It may become necessary to ensure that birds can move among ponds, tidal marshes, and mudflats as conditions change. Some species (e.g., clapper rail, salt marsh harvest mouse) may not be able to migrate from degrading areas on their own and may require intervention.

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

3. MAKING THE LINK TO MANAGEMENT

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

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

In the workshop exercise and group discussions, the experts generated three categories of information about the relationships in the influence diagrams: 1) the type and degree of each influence; 2) the sensitivity of each influence (including thresholds); and 3) the high relative impact of certain influences on the endpoints. All three categories of information should be considered in concert when interpreting management implications. This can be done by performing a "crosswalk" of all three categories of information in order to identify pathways of particular interest that connect each endpoint (Net Accretion/Erosion or Shorebirds) to stressors or drivers that can be addressed through particular management activities. The crosswalks as well as example pathways are presented below.

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

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

3.1.1.1. *Sediment Retention Crosswalk*

Table 3-1. Sediment Retention group crosswalk for comparison of influence type and degree, sensitivity and relative impact for current conditions and climate scenarios. NA = No agreement; Prop = Proportional; Disprop = Disproportional; L = Low sensitivity; I = Intermediate sensitivity; H = High sensitivity; H-trend = No agreement but trending toward high sensitivity; X = High relative impact; ↑ = Increasing relative impact from current; () = Number of respondents; Ranking column orders the influences according to completeness of information

For Sediment Retention (Table 3-1), there was agreement on both type and sensitivity for the majority of influences. Especially when coupled with the designation of high relative impact, certain influences emerge as being of special interest for management. These are influences for which we have a good understanding of the nature of the relationships, their sensitivity to changes now and in the future, and their high relative impact on the endpoint of Net Accretion/Erosion. Therefore these are the influences for which management interventions are most likely to have the intended effects. Influences ranked one through three in Table 3-1 fall into this category.

Even when not designated as highest relative impact, influences for which there was agreement on type as well as sensitivity are equally important to consider. While not necessarily of highest relative impact, they are well understood and sensitive to change, and may be linked with other influences for important cumulative effects on the endpoint. Influences of rank four and five, and also influence G, fall into this category (Table 3-1). Meanwhile, lack of agreement on one or more of the type and sensitivity categories indicates that more information is needed to understand the particular influence. It does not imply that the relationship is not potentially important, but rather that it is not well enough understood by this particular group of experts for managers to be confident about the response to either climate change or management interventions. The remaining nine influences fall into this group. Relationship E (Water Resource Management: Channelization on Freshwater Inflow) and Relationship T (Inundation Regime on Net Organic Accumulation) are interesting cases in that there was no agreement on influence type or sensitivity, but there was agreement on high relative impact. These influences were identified as having high or increasingly-high relative impact under the climate scenarios. This indicates that the influences are not well understood, yet are considered by the experts to have a high relative impact on the ecosystem process endpoint of Net Accretion/Erosion. In the case of these influences as well as the remaining influences in this group, priorities for further investigation (in the form of literature reviews to more deeply assess existing information, followed by new research where understanding is confirmed to be lacking) could be based in part on which of these influences are most critical to understand since they have a high relative impact or have links to other influences of special importance to the endpoint.

3.1.1.2. *Community Interactions Crosswalk*

Table 3-2. Community Interactions group crosswalk for comparison of influence type and degree, sensitivity and relative impact for current conditions and climate scenarios. NA = No agreement; Prop = Proportional; Disprop = Disproportional; L = Low sensitivity; I = Intermediate sensitivity; H = High sensitivity; H-trend = No agreement but trending toward high

sensitivity; ↑ = Increasing relative impact from current; () = Number of respondents; Ranking column orders the influences according to completeness of information

The Community Interactions crosswalk (Table 3-2) also has some influences for which there was agreement on both type and sensitivity. Especially when coupled with the designation of high (or increasing) relative impact across the scenarios, these influences emerge as being of special interest for management. These are influences for which we have a good understanding of the nature of the relationships, their sensitivity to changes now and in the future, and their high relative impact on the Shorebirds endpoint. Therefore these are the influences for which management interventions are most likely to have the intended effects. These influences include Relationships O, GG, Q, DD, EE, FF, and E.

Even when not designated as highest relative impact, influences for which there was agreement on type as well as sensitivity are equally important to consider. While not necessarily of highest relative impact, they are well understood and sensitive to change, and may be linked with other influences for important cumulative effects on the endpoint. Influences for which there was agreement on both type and degree across at least two of the three scenarios include Relationships S, U, Y, HH, I, X and JJ.

Meanwhile, lack of agreement on one or more of the type and sensitivity categories indicates that more information is needed on the particular influence. Again, it does not imply that the relationship is not potentially important, but rather that it is not well enough understood by this particular group of experts such that more information is needed. The remaining influences all lacked agreement in type and/or sensitivity for at least two of the three scenarios. Relationship K (Freshwater Inflow on Tides and Hydrodynamics) and Relationship AA (Extent of Mudflat on Predators and Disturbance) are cases for which there was no agreement on sensitivity across the climate scenarios, but there was agreement on high relative impact. These influences were identified as having increasingly-high relative impact under the climate scenarios (with Relationship K being designated a threshold response). This indicates that although the influences are not fully understood, they are considered by the experts to have a high relative impact on the Shorebirds endpoint. In the case of influences in this group, priorities for further investigation (through literature reviews and further research where needed) could be based in part on which of these influences are most critical to understand since they have a high relative impact or have links to other influences of special importance to the endpoint.

It is notable that the community interactions influence diagram had a larger proportion of influences that were not well understood compared to the sediment retention group. There were eight influences for which there was no agreement on any of the three categories of information, for any of the three scenarios. The larger number of influences in the Community Interactions diagram (36 compared to 26 for Sediment Retention) reflects the complexity of modeling both physical (e.g., sediment supply) and biological (e.g., shorebirds and their prey) components of the community interactions process, and may have contributed to less agreement among the participants, especially across scenarios.

3.1.1.3. *Information Gaps*

Crosswalks

Patterns of information gaps in the crosswalk tables varied for Sediment Retention (Table 3-1) compared to Community Interactions (Table 3-2). Influences for Sediment Retention were relatively well understood across type and degree and sensitivity categories of information. However, in quite a few cases, even though there was agreement on type there was not agreement on degree. Where there was agreement under current conditions, the agreement tended to carry across the climate scenarios as well. For Community Interactions, there was far less agreement overall about the nature of the influences, with a greater number of gaps in influence type, degree and sensitivity. Also, compared to Sediment Retention there were more cases where agreement that was present under current conditions was lost under the climate scenarios, indicating a greater uncertainty about how the influences might behave in the future.

Such information gaps – especially involving influences in otherwise well-understood pathways that link to rich opportunities for management – could be used to prioritize targeted literature reviews and/or scientific research that focuses on key process components of interest. Another method for sorting through and prioritizing "non-agreement" influences for further study might be to start from the perspective of management opportunities. Managers could look at their most tractable and effective management levers currently available, and trace pathways from those down to the endpoint of interest, as a means of identifying and selecting priority influences for research. Examples of promising pathways are presented below.

Confidence

Confidence estimates were not included in the crosswalk tables because of extensive information gaps in the form of missing estimates. It is possible that this was partly due to time limitations as participants prioritized characterizing the influences before marking confidence.

However, another problem that may have led to gaps was that the confidence exercise did not take into account specialty areas of participant knowledge. Due to the complex and interdisciplinary nature of the influence diagrams and the individual specialties of the participants, some participants may have been asked to make judgments on influences for which they felt they had insufficient expertise. In some cases they may have elected to leave those cells blank.

Even where confidence estimates were entered, there is cause for caution in interpreting the information. Discussions during and after the exercise revealed some confusion about the definitions of evidence and agreement (as per the confidence handout in Appendix D). In particular, there may have been a misunderstanding related to equating agreement alone (even where there was minimal evidence) with full confidence; that is, a large amount of agreement, even where little information (data) was available, may have been misconstrued as highest (HH) confidence in some cases.

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

3.1.2. Identifying Key Pathways for Management

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

3.1.2.1. *Sediment Retention Example*

The pathway of Reservoir Management to Freshwater Inflow (Relationship B) to Net Organic Accumulation (Relationship O) to the endpoint (Relationship U) is a relatively direct route to the endpoint of Net Accretion/Erosion (Figure 3-1). For type and degree of influence, Relationship B was characterized as being an inverse proportional influence under all scenarios. For sensitivity, Relationship B was characterized as having intermediate sensitivity under all scenarios. In terms of relative impact, Relationship B was indicated as an influence with increasing impact under the climate change scenarios.

Figure 3-1. Sediment Retention Example Pathway. Future = Climate Scenario B.

Relationship O had less agreement. For type and degree of influence, Relationship O was characterized as being a direct influence under Climate Scenario A (not shown in Figure 3-1), but there was no agreement on type and degree under current conditions or Climate Scenario B. For sensitivity, Relationship O was characterized as having intermediate sensitivity under current conditions, but there was no agreement under the climate scenarios. In terms of relative impact, Relationship O was indicated as having high impact under both current and future scenarios. An area for further investigation would be the source of disagreement on the influence type for current conditions versus Climate Scenario B. Is there a potential for a threshold since multiple participants changed their characterization of type between each scenario? Or was the disagreement based on differences in definitions between participants, as the influence could act differently based on considering a change in timing or volume of flow? In order to use Reservoir Management to impact Net Accretion, it will be necessary to understand the nature of the influence of Freshwater Inflow.

Relationship U was characterized as a direct proportional influence under all scenarios. It has intermediate sensitivity under all scenarios. In terms of relative impact, it was identified as having high impact under current conditions and increasing impact under the climate scenarios.

When examined using all three categories of information, this is a relatively well understood pathway for which there was agreement on type for two of the three influences. Where there is agreement on sensitivity along this pathway, the influences are characterized as intermediate sensitivity, which indicates that they would be responsive to management actions. Each influence has high relative impact, with both Relationships B and U having increased impact under the climate change scenarios. To manage along this pathway, an increased understanding of Relationship O would be important. Understanding the specifics of how the timing or volume of freshwater inflow influences the aboveground and belowground organic processes that lead to net accumulation would complete the pathway so managers can utilize reservoir management to increase net accretion.

3.1.2.2. *Community Interactions Example*

The pathway of Restoration on Landscape Mosaic (Relationship E) to the Shorebirds endpoint (Relationship O) is well understood and highly sensitive, and its relative impact will increase in the future (Figure 3-2). The management lever of Restoration is a broad category that constitutes a number of management options. Relationship E was characterized as a direct influence under all scenarios, but there was no agreement on degree of influence. Relationship E was characterized as having high sensitivity under all scenarios. In terms of relative impact, Relationship E was indicated as an influence with increasing relative impact under the climate change scenarios.

Figure 3-2. Community Interactions Example Pathway. Future = Climate Scenario B.

Relationship O was characterized as a direct, disproportional strong influence under all scenarios. For sensitivity, Relationship O was characterized as having high sensitivity under all scenarios. The relative impact of Relationship O was indicated as primary under current conditions, with increasing relative impact under the climate change scenarios.

When examined using all three categories of information, the Restoring the Landscape Mosaic pathway stands out as well understood and likely to be responsive to management options when planning for climate change. Restoration and Landscape Mosaic are broad variables, so a wide variety of accompanying management options fall within this pathway. One management option could be to restore salt marshes adjacent to a mudflat of concern, which would provide a sediment source for the mudflat as well as secondary habitat for the shorebirds.

3.2. TOP PATHWAYS AND IMPLICATIONS FOR ADAPTATION PLANNING

Sections 3.1.2.1 and 3.1.2.2 above have used examples to demonstrate how the results of the expert elicitation exercise can be used to help identify key pathways for management. This method of identifying well-understood pathways that can be traced from endpoints of concern to management levers is a useful way to explore the implications of the workshop results for adaptation planning. In some cases it may be possible to identify management actions for immediate implementation, i.e., where there is sufficient understanding of the relationships among the variables as well as their sensitivities to act with relative confidence in the effects of management interventions. Additional pathways of interest can be identified through further examination of the crosswalk tables (Tables 3-1 and 3-2), using amount of information for which there was agreement (to identify current best-understood influences) as well instances of climate thresholds (indicating potential climate-induced shifts) to identify “top pathways” of interest for management. This section describes three top pathways for the Sediment Retention and Community Interactions processes, as well potential adaptation responses. This is followed by a brief review of SFEP planning documents and discussion of where adaptation activities relating to the top pathways could be 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 under 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 Net Accretion/Erosion endpoint. Blue, green and purple colors are used to distinguish different pathways. Red boxes highlight changes under future climate conditions. * indicates high relative impact under current conditions. ^ indicates increasing relative impact under future 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.

Figure 3-4. Top pathways for management of the Shorebirds endpoint. Blue, green and purple colors are used to distinguish different pathways. Red boxes highlight changes under future climate conditions. 1° and 2° indicate primary and secondary relative impact under current conditions, respectively. ^ indicates increasing relative impact under future conditions. A direct to strong direct threshold occurs where there is a direct effect under current conditions that may shift to a very strong direct effect under future climate conditions. Dashed lines indicate inconsistent agreement across scenarios.

3.2.1.1. *Sediment Retention Top Pathways*

Green pathway

The Sediment Retention example pathway described in section 3.1.2.1 above is elaborated upon here as the Green top pathway (Figure 3-3). Starting with the Net Accretion/Erosion endpoint and working "up" the diagram, a major determinant of the net balance between accretion and erosion is the contribution of organic accumulation by way of below ground biomass production. Organic accumulation has a higher relative impact on the endpoint than mineral accumulation, and this relative impact is expected to increase under climate change. This is because as marshes are challenged to adjust to sea level rise, vegetative processes can respond by increasing below ground biomass productivity, and this may become increasingly important in the context of historical (and continuing) decreases in mineral sediment supplies.

At the next level up the pathway, net organic accumulation is directly affected by freshwater inflow due to salinity effects. As freshwater flows decrease, salinity increases, favoring more salt tolerant, but less productive plants in the community. Agreement on the nature of this relationship was not consistent across the climate scenarios, with some participants indicating the potential for an inverse relationship depending on whether or not they were considering changes in species composition. If invasive *Spartina alterniflora*, which is favored and has higher productivity than native species under higher salinity regimes, is allowed to become established, then the influence of freshwater inflow could be an inverse relationship in which increased salinity favored vegetative production. However, for the purposes of this discussion we are assuming that the goal is to preserve the native salt marsh habitat; hence we are considering management of the direct relationship.

Finally, freshwater inflow is acutely affected by reservoir management (see top level of pathway). Here, reservoir management refers to the practice of storing and diverting freshwater supplies for flood control, agriculture and other human uses. Thus, an increase in reservoir management typically results in an overall decrease in availability of freshwater flows to salt marshes. This inverse effect on the volume, speed and seasonal availability of freshwater flows is expected to be of increasingly high relative impact under climate change as freshwater supplies become increasingly variable in a context of increasing human demand.

The management implications for adaptation given the relationships within this pathway are that managing reservoirs for downstream salinity regulation in favor of native marsh vegetative productivity will require more steady, lower-volume releases. The strategy for such releases relative to the growing season requires further investigation of the effects of timing versus volume of freshwater inflow on net organic accumulation, on a site-specific basis. Given the high relative impact of net organic accumulation compared to net mineral accumulation, a priority could be placed on releases designed for salinity maintenance compared to high volume pulses to support mineral sediment transport (discussed in the Purple pathway below). In addition, since increased salinity regimes favor invasive Spartina, if the goal is to preserve native salt marsh, another important management consideration will be the need to continue or even "step up" invasive species eradication programs.

Purple pathway

Starting with the Net Accretion/Erosion endpoint and working up the Purple pathway (Figure 3-3), a second major determinant of the balance between accretion and erosion is the contribution of mineral accumulation. Net mineral accumulation has a direct effect – in conjunction with organic accumulation – on net accretion.

The next level up the Purple pathway represents the effect on mineral accumulation of sediment size. This is another direct relationship, with larger grain sizes favoring mineral accumulation, since larger grains deposit more readily, are harder to re-suspend and provide larger building blocks for accretion. An important effect of future climate change may be an increasing sensitivity of net mineral accumulation to sediment size. This increase is partly because sediment flux, the other determinant of net mineral accumulation, is expected to continue to decrease, not only because of continuing processes responsible for historical declines from peak sediment inputs in the past, but also because of potential changes in wave driven erosive processes (see Blue pathway description below).

At the top level of the diagram, the Purple pathway links sediment size to two management levers: impervious cover and reservoir management. It is likely that changes in impervious cover will have important effects on sediment size, but our understanding of these effects is incomplete. The influence of impervious surfaces on runoff, and resulting impacts on sediment size, is highly dependent on the location of impervious surface relative to other land cover, topography and proximity to water bodies. Workshop participants noted that the effect of impervious surfaces on runoff is much greater than the expected effect of climate driven changes in precipitation and resulting runoff patterns. Meanwhile, the effect of reservoir management on sediment size is better understood. As flow volumes and speeds are reduced, there is a negative impact on transport of large grains.

Management implications for adaptation based on this pathway vary. In the case of the impervious cover management lever, further investigation of the effects of impervious cover on sediment size is greatly needed in order to identify appropriate management strategies. Basic information on how changes in land cover (including changes from impervious to permeable pavement systems) may affect sediment size will be critical as land use change and development continue to increase into the future.

With regard to reservoir management, high volume releases will increase transport of larger grain sediments to marshes. However, there is a trade-off to consider between high volume pulses to enable large grain sediment transport and water availability for steady, lower-volume releases to favor vegetative production as discussed for the Green pathway (see above).

Other options for addressing sediment size through management could include adjusting policies that prevent coarse sediment from entering the Bay. This could include a change in TMDL (Total Maximum Daily Load) requirements for streams that do not support salmonids, to allow an increase in sediment loads. Engaging with flood control districts is another possible avenue for re-coupling stream sediments to wetlands. Current flood control priorities may not take into account the future benefits of downstream wetlands as climate change and associated sea level rise begin to increase the occurrence of flooding due to changes in upstream tidal pulses. Also there is an opportunity to take advantage of strategies that maximize sediment transport to wetlands, with the additional benefit to flood control districts of decreasing their dredging needs.

Blue pathway

Like the Purple pathway, the Blue pathway (Figure 3-3) starts with the direct effect on net accretion of net mineral accumulation, but from there it diverges. The next step up this pathway concerns the direct relationship of net mineral accumulation to sediment flux, which is an expression of the rate of sediment supply. All else being equal, increases in sediment flux result in increased net mineral accumulation.

An important driver of sediment flux is wind driven wave action, and the nature of this relationship will potentially change under future climate conditions. Under current conditions, wave action has a net positive effect on sediment flux onto salt marshes, as greater wave energy can mobilize and increase rates of sediment transport from bays and adjacent mudflats deep into marsh systems. However, under future climate conditions a threshold may be crossed whereby the role of waves as a sediment source will decrease and the erosive effect of waves will increase, leading to a shift from a direct to an inverse relationship. This threshold is caused by a potential change in wave character as water depth increases due to sea level rise. In deeper water waves behave differently, with less wave energy available for re-suspension of bottom sediments and more energy delivered to the marsh edge, leading to increased erosion.

While managing wind driven waves may not immediately appear straightforward as a management lever, given the importance of this potential threshold it is necessary to think broadly about adaptation options for this pathway. It would be valuable to monitor wind, waves and sediment fluxes in marshes in order to detect the threshold shift when it occurs. Ideally a response plan would be prepared in advance of such a shift, with the necessary public and management backing and resources in place to implement the plan when needed. Current tools for reducing wave action on the front sides of marshes are limited; such tools need to be further developed and tested in areas where waves are currently having an inverse influence on sediment flux. Existing tools include building berms or restoring oyster reefs as protective barriers against wave energy. Depending on the depth of adjacent water, such barriers could either be designed to reduce wave energy on mudflats or on the marshes themselves. Another adaptation option might be to strategically locate sites to deposit dredge materials with a goal of enhancing sediment concentrations on mudflats adjacent to marshes. This could serve the dual purpose of both increasing sediment fluxes and compensating for changes in water depth above mudflats.

3.2.1.2. *Community Interactions Top Pathways*

Green pathway

The Community Interactions example pathway described in section 3.1.2.2 above is elaborated upon here as the Green top pathway (Figure 3-4). Starting with the Shorebirds endpoint and working “up” the diagram, shorebirds are best able to effectively use mudflat foraging habitats only if landscape mosaics – which are defined as a mixture of habitats for secondary foraging, roosting, and cover from predators -- are available in close proximity. Therefore, the presence of such mosaics, including ponds, diked wetlands, seasonal wetlands, and muted tidal wetlands, has a strong positive effect and a high relative impact on shorebird populations. The high relative impact of this influence is likely to increase even further under climate change as mudflat habitats become scarcer and smaller in extent.

At the next level up the pathway, landscape mosaic is directly affected by restoration. Workshop participants noted that small changes in restoration can have the potential for large positive effects on landscape mosaic. The relative impact of restoration on landscape mosaic is likely to increase under climate change as temperatures increase, precipitation patterns change, and water diversions continue to escalate.   These effects also will be exacerbated by ongoing and increasing land use changes (especially development), further raising the importance of restoration as a mitigating force.

Management options for adaptation given the relationships in this pathway center on restoration as a key and increasingly critical management activity. Workshop participants noted that there is little monitoring of landscape mosaics currently underway, so there is almost no information on the current status of, or rates of change in, mosaic habitats.   Assessment and mapping is needed to detect changes and manage at the landscape scale for shorebirds and other mobile species that use multiple habitats.

Given the implications under the climate change scenarios, managers might place a priority on "stepping up" management of landscape mosaics through spatial planning designed to prioritize where and how to restore which habitats. The goal would be to create a continuum of wetland and upland ecosystems, across a range of salinity regimes, which could migrate inland as sea level rises. Workshop participants noted that managers might also include "threshold landscapes" (those that are about to change from one set of dominant processes to another, or from one state to another) in consideration of good landscapes for restoration. As part of spatial planning, restoration should be focused on where there are good opportunities for restoration, where there can be flexibility in management, and where migration inland is possible. Decision makers could even be urged to consider legislation or incentives that encourage moving back or blocking of development on lands where there is restoration potential now or in the future.

Blue pathway

Starting with the Shorebirds endpoint and working up the Blue pathway (Figure 3-4), another key factor affecting shorebird populations is the extent of mudflat available for foraging (i.e., the acre-hours that mudflats are exposed and therefore accessible).   Extent of mudlflat has a direct effect of high relative impact on shorebird populations. This direct effect will become increasingly strong, and is considered a threshold effect, under climate change as extent of mudflat may become limiting as sea level rises, with available foraging habitat becoming too limited to support shorebird populations.

Continuing to work up the pathway, a major determinant of extent of mudflat is mudflat bathymetry, which has a strong direct effect on the extent of mudflat exposed at low tide.

Mudflat bathymetry is itself directly affected by sediment resuspension and deposition processes, which are turn directly affected by sediment supply. A key source of sediment supply is the direct effect of freshwater inflows.

An important management lever appears in the form of the sensitivity of freshwater inflow to water management. Workshop participants noted that water management practices (specifically, reservoir management and upstream operations) have an important direct effect on freshwater inflows. This effect will become increasingly strong under climate change. This is because the sensitivity of freshwater inflow to water management may increase in the future as freshwater flows from alternate sources such as precipitation and tributaries become more variable and/or scarce, and as the entire watershed becomes even more highly managed.

Implications for adaptation based on this pathway currently center around management of water releases and sediment supply. Reservoir management of water releases in order to mobilize and transport sediments (e.g., through the use of sediment maintenance flushing flows) could become an increasingly important option; in light of this, continuing to improve upstream operations in order to ensure greater availability of water (to allow more frequent and/or more intense pulse releases) is warranted. Participants noted that an increasingly important technique will be integrated water resources management, with an emphasis on shifting from storage more toward conservation uses.

Attention to management options for directly enhancing sediment supply is also needed. This is especially the case since sediment supply will become increasingly sensitive to restoration as well as water management, with participants noting in their discussions a potential synergistic interaction between the two. Methods for moving sediment (especially coarse sediments) into the bay need to be developed. Adaptation options might include strategically locating dredge spoil sites to enhance sediment supplies to mudflats.

Purple pathway

Starting with the Shorebirds endpoint, the Purple pathway (Figure 3-4) begins with a link to the shorebird prey community. Shorebird communities rely on abundant mudflat prey populations, which therefore have a positive effect -- of high relative impact -- on shorebird populations. The abundance of prey per unit area will become increasingly important (of increasing relative impact) under climate change as spatial extent of mudflats shrink with sea level rise. This effect will be magnified if secondary feeding habitats in the landscape mosaic (see Green pathway) continue to be lost due to development and other pressures.

Working up the next step of the pathway, shorebird communities are strongly affected by water quality. Specifically, sufficient levels of dissolved oxygen (DO) have a direct positive effect on prey communities. Since this is a direct relationship, this means that as decreases in DO occur with climate change due to increased temperatures and/or eutrophication, prey communities may flag. A threshold may occur in the future if DO reaches low enough levels to cause prey populations to crash.

With regard to management implications, the Purple pathway provides further justification for continued prioritization of water quality management. Water quality is already a major concern in the watershed; and for shorebirds, a water quality aspect of special concern may be DO. Oxygen depletion usually results from high rates of microbial and/or algal respiration that exceed the capacity of the water body to replenish oxygen through phytoplankton photosynthesis and diffusion from the air. Excessive inputs of organic material and nutrients, for example from poorly treated sewage discharges or from agricultural activities, can accelerate respiration rates and trigger localized and regional oxygen depletion. Protection and improvement of water quality will be critical through integrated water resources management, which could include stormwater management and rainwater-harvesting (which benefits water conservation as well).

Other improvements to water quality could occur through land use decisions (e.g., use of permeable surfaces to reduce runoff) and restoration decisions (e.g., restoration of riparian zones as natural filters). The importance of land use decisions was emphasized by the participants, who discussed a synergistic effect of freshwater inflow on water quality that is dependent on land use change. In summary, water quality is an existing concern for which there are already a variety of management options available; and because the affects of water quality on mudflat prey populations are known and expected to increase with climate change, this is further confirmation of the importance of implementing such options, in conjunction with public education and outreach to explain and justify support for their use.

3.2.1.3. *Top Pathway Caveats*

Above we have described three pathways that scored as especially promising for successful management application in light of the information provided by the particular group of experts at this workshop. Given the complexity of these systems and instances of uneven agreement among participants, actions based on these pathways should be considered with care. A different set of pathways could be chosen based on additional meaningful criteria that are site-specific and specific to individual managers' expertise. Based on their own knowledge of their sites and/or input from different experts, managers are encouraged to examine the potential for additional top pathways for their own particular systems by examining the crosswalk tables and applying their unique knowledge.

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

A final consideration is that these diagrams were developed considering the current condition of each system. At this workshop there was a variable (disease for the Community Interactions group) that arose as critical to the system under future conditions, even though it had not been included in the diagram under current conditions. Individual managers should identify -- and consider management options for -- any other such variables that may be specific to their system or site.

3.2.2. Adaptation Planning

There are multiple ways to go about climate change adaptation planning, including integrating adaptation into existing plans, or developing a stand-alone adaptation plan. This report focuses on the planning options for SFEP, which as an NEP has several key management plans. The SFEP management plans discussed here are used to demonstrate the type of adaptation planning that can be done to address these particular issues. Other organizations can use their particular planning documents to apply the same approach.

SFEP's planning documents include a Comprehensive Conservation and Management Plan (CCMP), which articulates long range goals and objectives, a Strategic Plan for mid-term objectives, and an annual Work Plan that lays out short-term actions to implement the goals and objectives. Each of these plans addresses climate change on some level, so it makes sense to use the results of this study to continue integrating climate change into each of these planning scales. In this section we provide some links between SFEP's plans and the top pathways and management options discussed above; this set of examples is not comprehensive, but rather is meant to illustrate how the results of this study can be used to inform adaptation planning.

One management strategy outlined in the 1993 CCMP that pertains to the Green Sediment Retention pathway (Figure 3-3) is Action AR-4.1: "Adopt water quality and flow standards and operational requirements designed to halt and reverse the decline of indigenous and desirable non-indigenous estuarine biota" (SFEP, 1993). The relevance of the Green Sediment Retention pathway to this action is that reservoir management activities and their effects on freshwater inflow are considered key to sustaining net organic accumulation through this pathway. While animal species have been the primary focus of this action, it also applies to managing for salt tolerance of plant species with resulting effects on plant productivity and net organic accumulation.

Another relevant action, from the revised 2007 CCMP, is Action DW-1.1: "Conduct studies, research, modeling, and analysis of sediment processes and trends to more thoroughly understand sediment transport in San Francisco Bay, particularly in light of sea level rise and changing sediment inputs from the Delta and major tributaries" (SFEP, 2007). This mandate will be important for informing management along both the Blue and Purple Sediment Retention pathways (Figure 3-3) as well as the Blue Community Interactions pathway (Figure 3-4). For the Blue Sediment Retention pathway, the priority research would be monitoring of the potential threshold effect of waves on sediment flux. For the Purple Sediment Retention pathway, information is needed to understand the relationship between impervious cover and sediment. Such understanding could inform where and how to manage impervious cover. In addition, further investigation is needed into reservoir management options that provide pulse events which can increase the supply of large grain sediment. Very similar questions on how water management methods affect sediment supply come up for the Blue Community Interactions pathway,

A strategy from the revised 2007 CCMP that relates to the Green Community Interactions pathway (Figure 3-4) is Action WT-4.1: "Identify, convert, or restore non-wetlands to wetlands or riparian" (SFEP, 2007). While mudflats may not have been the wetlands originally intended for this action, considering mudflats within the landscape mosaic is advisable while implementing strategies of where to restore non-wetlands to wetlands (see also Table 2-12).

In the 2010-2012 Strategic Plan (SFEP, 2010), one of the four key objectives for focusing the implementation of the CCMP is Objective 2: "Support Estuary resilience in the face of climate change". Under Sub-objective 2.3 is "Promote climate adaptation strategies and policies that encourage protection and restoration of Estuary health and reduce damage to the ecosystem". The workshop results of this study can be used to provide specific areas of focus for that objective and for mainstreaming adaptation into applicable actions under the other objectives.

Meanwhile, under Objective 1: "Promote integrated watershed stewardship," there is Sub-objective 1.2: "Assist development of regional goals projects and management plans (i.e., Habitat Goals, Subtidal Habitat Goals, Upland Habitat Goals, regional sediment plans)". The abovementioned Goals projects enumerating Baylands Ecosystem Habitat Goals (Monroe et al., 1999), Upland Habitat Goals (Weiss et al., 2007; 2008; 2010), and Subtidal Habitat Goals (BCDC, 2010) are highly relevant to the Green Community Interactions pathway (Figure 3-4). Developing projects that coordinate across goals to connect habitat types could serve as a strategy for rebuilding landscape mosaics through restoration projects. The original Baylands Goals report did not take climate change into consideration, but the two newer projects consider climate change as a factor.

Many of the current projects in the 2010-2011 Annual Work Plan are examples of management options that potentially could be informed by the results of this study. For instance, sediment reduction is an objective or component of 14 of the projects. For both the Blue

Community Interactions pathway (Figure 3-4) and the Purple Sediment Retention pathway (Figure 3-3), one management option cited in Table 2-12 is to adjust policies that keep coarse sediment from reaching the Bay. Many of the current projects are based on meeting TMDL restrictions for salmonid streams, which is a competing goal with developing methods to increase sediment supplies into the Bay. Some current projects focus on reducing fine sediment; management practices that target fine sediment only (while allowing coarse sediment) could be developed or expanded to other projects where appropriate. Tools such as those in the "Watershed Scale Mapping of Project Results: Linking On-the-Ground Results to Measurable Regional Outcomes" designed to assist in stopping downstream sediment migration could be adapted to prioritize salmonid streams while allowing increased sediment transport in other streams. Such a tool would distinguish where recommended practices should target fine sediment while maintaining a supply of coarse sediment, versus those streams where it is important to reduce all sediment sizes. Another current project, "Innovative Wetland Adaptation Techniques in Lower Corte Madera Creek Watershed", will provide results that can be used for one of the recommended actions in Table 2-12: "Develop methods to reduce wind/wave action on the front side of marshes". The project includes measurements for wind-wave propagation and attenuation in the marsh as well as developing best practices for flood control.

Within each plan are a variety of additional opportunities for incorporating the workshop results. The examples offered here are intended to demonstrate the links, but are not comprehensive. In addition to the adaptation of current management projects and strategies, this study has identified sensitivities that may require the development of entirely new management options. Planning for future projects should identify opportunities to fills those needs and test new methods. Conflicting goals due to trade-offs -- such as the simultaneous need to reduce sediments in salmonid habitats, but increase coarse sediment transport to the Bay – will become increasingly problematic with climate change. Indeed, in some cases such trade-offs may necessitate re-evaluation of habitat goals, and even the application of a "triage" approach to prioritize certain habitats over others in the system.

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

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 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 more time they would have distinguished between delta and local tributary sediment and freshwater inputs, but were forced to lump these due to the 15-variable constraint and time limitations. Nevertheless, they were able to agree on an acceptable influence diagram for the exercise, with a tractable number of unidirectional influence arrows and a few large feedback loops to handle important bidirectional influences.

The Community Interactions group was also successful in agreeing on an acceptable influence diagram for the exercise. However, their diagram was more complex, with a greater mixture of both physical sediment processes (which maintain mudflats) and biological processes (which affect shorebirds and their prey). In fact, a set of variables similar to the Sediment Retention group's diagram was nested within the Community Interactions diagram; but then the Community Interactions diagram was expanded further to also include a set of variables representing the three biological communities (shorebirds, prey, and predators). Due to this greater complexity, the Community Interactions group was forced to use two more boxes, a larger number of influence arrows, and four bidirectional arrows, resulting in nine more influence arrows than the Sediment Retention group. The complexity also led to less time for defining the management levers specifically, making it more difficult to judge their effects. These factors – combined with varying expertise in the specialty areas of sediment processes versus ecological processes in this interdisciplinary group – may have contributed to the greater numbers of gaps in agreement in the subsequent exercise.

While the two groups had different experiences and challenges in building their influence diagrams, both groups were effective in generating a useful representation of their ecosystem process for the sensitivity exercise. Participants reported that the highly constrained diagram-building procedure challenged them to focus on the most key elements of the system while still maintaining a sufficiently realistic model for sensitivity analysis. Designing the diagrams while considering current conditions, then applying climate scenarios to the same diagrams during the sensitivity exercise, worked smoothly. The one exception was a disease variable in the Community Interactions diagram that was not in the original diagram, but which emerged as critical to the Community Interactions process under the climate scenarios. This and other complications could be avoided in future workshops by providing the participants with an opportunity for one more revision of the diagrams after being briefed on the climate change scenarios. This would allow them to account for how future climate might raise additional variables for priority consideration in the diagrams.

4.1.2. Characterization of Influences

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

Participant notes and discussions revealed that for both processes, while there are many intermediate (and some high) sensitivity relationships among variables that are useful to be aware of for management, it was difficult to detect changes in sensitivities across the scenarios based on this method. Under the climate scenarios, one influence for the Sediment Retention group became highly sensitive and four others showed a trend (but no majority agreement) toward greater sensitivity, but most of the sensitivities remained intermediate. For the Community Interactions group, under the climate change scenarios there were seven influences that trended toward increasing sensitivity, but without majority agreement, while the majority of influences remained intermediate in sensitivity, or lost agreement. It was noted that natural variation in most of the variables is large enough that changes generated by the climate scenarios would not be enough to move the variables outside their current range of variation. In other words, a response in variable "Y" would need to be outside the normal range of variation in order to clearly detect a sensitivity threshold change by way of the coding scheme that was used. Only one threshold (Relationship DD, Table 2-10) was indicated through coding in the Community Interactions group.

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

Another way of identifying relationships of particular interest for management is to examine the relative impact of certain influences in the context of the whole process. For both processes, under current conditions the influences identified as having primary impact tended to include variables closer to the endpoints (Figure 2-5 and Figure 2-11) compared to relationships that emerged as high or increasingly-high impact under future climate (Figure 2-6 and Figure 2-

12). This implies that variables related to management levers may become increasingly important as climate changes.

Finally, characterization of interactions and confidence were also included in the sensitivity exercise, with mixed results. Trying to consider interactive effects of multiple variables moves the exercise to a much greater level of complexity. The number of possible pair-wise interactions in the influence diagrams was very large, and the challenge of understanding combinations of effects could become very complicated. Thus the participants were not asked to attempt every possible pair-wise combination, but rather were asked to indicate which interactions "leapt out" as well understood and important. Of course, even looking at all pair-wise interactions would be a vast oversimplification because variables interact in greater multiples than just pairs. Nevertheless, while there were only a few pair-wise interactions identified by enough participants to stand out, at least these relationships are sufficiently well understood to merit consideration in management planning. With regard to confidence, the exercise made a good start of acknowledging the need to gauge confidence in the judgments and providing a systematic way for doing so; however, the large number data gaps indicate that there were difficulties with this part of the methodology. Potential reasons for these difficulties, as well as potential improvements, have been discussed in section 3.1.1.3. Both interactions and confidence are concepts that need further refinement and better estimation methods before they can be effectively interpreted for management planning.

4.2. APPLICATION OF WORKSHOP RESULTS

4.2.1. Top Pathways for Management

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

The climate-related changes of interest in the top pathways are of three main types: 1) changes in relative impact under climate change; 2) changes in sensitivity under climate change; and 3) threshold shifts under climate change. In the case of the influences for which relative impact is likely to increase under one or both future climate scenarios, and especially where relative impact is already high under current conditions, action could be taken immediately. These are influences for which there is sufficient understanding and opportunity to connect to management options that favor desirable outcomes, with increasing relative impact on the process as a whole as climate change continues. In the case of influences for which an increase in sensitivity is expected under climate change, there is still time to further study and anticipate the degree and timing of the sensitivity and to prepare best management responses. An expectation of increasing sensitivity could be considered a notification to monitor and plan for when and how management practices can be adjusted to account for the impending change. Finally, in the case of thresholds, there is often a strong expectation that a threshold shift is likely, but usually a great deal of uncertainty as to exactly when the threshold will be crossed. Monitoring of threshold variables is needed so that managers will be alerted immediately to the shift when it occurs. In the meantime, actions can be taken to attempt to prevent the shift by keeping the system "below" the threshold as long as possible, while preparing a plan for what to do if an unavoidable shift occurs. After a shift occurs, managers should have a plan as to how they will manage the system differently in its new state, or whether they will take no action and instead shift their priorities to other goals.

It is important to note at this point that each pathway also sits in the context of other influences with which there could be key interactions, so there may be opportunities for management options beyond those most directly evident from the main pathways. Also, in the case of other management pathways for which there are currently information gaps based on the workshop results, it is vital to remember that lack of agreement does not mean zero understanding of influences or zero degree of sensitivity. Closer inspection can show that the agreement may be split between intermediate and high sensitivity, so the understanding that the sensitivity of the influence is important may be obscured by the distinctions between categories. It is of note that for influences for which there was agreement, the variation among participants was greater than that between scenarios. This could be due to a number of reasons: a limited range between the two mid-century climate scenarios; the number of assumptions each participant was required to make individually for each judgment; and the interdisciplinary and complex nature of the questions. This is an indication that these types of questions do not lend themselves to consulting a single expert, but rather require the combined judgments of a group of experts to complete the full picture. This also highlights the need for caution against relying solely on combined (agreement) information: the nature of the variation across participants is also important to consider. Equally important is the application of local expertise when further examining the results of this study; the local manager is the best expert on his or her unique system and should thus apply an appropriate filter when making final interpretations and decisions based on these results.

4.2.2. Mainstreaming Adaptation into Planning

The vulnerability assessment results for the two ecosystem processes presented here are a big first step in the climate change adaptation planning process. We have given examples of ways to tie the vulnerability assessment results to potential management options as a starting point, but incorporating adaptation fully into management planning will require a more systematic and comprehensive process. Planning is an iterative process, especially for climate change adaptation, which is still a nascent field. Due to this iterative nature, the planning recommendations presented here are based on mainstreaming (continuously integrating) planning into existing planning mechanisms and documents, rather than developing a comprehensive, stand-alone adaptation plan. For SFEP, nearer-term planning includes a multi-year Strategic Plan and an Annual Work Plan, both of which provide ways to insert specific management options into projects that are currently underway. In future plans, new projects that specifically incorporate climate adaptation priorities can be added. Repeating vulnerability assessments (once management options have been tested through project implementation) should be part of the iterative process. Finally, this study only covered two ecosystem processes and did not attempt to evaluate relative vulnerability or resilience across different ecosystem processes. The vulnerabilities of additional ecosystems, processes and goals will need to be assessed, taking into account what was most useful in the results of this study for adaptation.

Thresholds remain a major unknown, and while much can be done to improve our understanding of factors affecting thresholds, some may only be revealed after they have been crossed. Thus it would be advisable for monitoring plans to be put into place to track indicators of state changes. Contingency plans for management actions once a system has changed states could be developed, as well as contingency planning for ways to respond to catastrophic events such as levee failures or earthquakes. Successful implementation of contingency responses will require that the political and scientific base be put into place now for responding properly following catastrophes or threshold changes. In the meantime, when prioritizing implementation of adaptation actions, it is advisable to start with win-win options that contribute to current management goals and efforts while also responding to current and future climate change. For example, working now to proactively move highways and railroads that are barriers to marsh migration where there is otherwise space for migration is not only advantageous for marshes, but will also prevent damage and disruption to human transportation and infrastructure as inundation from sea level rise continues. Likewise, the practice of working with authorities in flood control districts to re-couple streams to wetlands will not only benefit wetlands but will also improve natural flood control services.

Looking beyond the win-win options, many other actions will force managers to confront trade-offs that will require difficult policy decisions. One example highlighted in sections 2.4.2

and 3.2.2.1 is the trade-off between increasing coarse sediment supply from tributaries, which comes into conflict with current sediment reduction efforts for salmonid streams. While a first step is to set up different best practices for salmonid and non-salmonid streams, beyond that there may come a decision point when it is no longer possible to meet both goals, so a choice between the two conflicting goals will be necessary. As climate change progresses, there are likely to be more trade-offs, often between short and long term goals. Mainstreaming adaptation planning will provide a better chance of foreseeing conflicts between long and short term goals and identifying opportunities to build support for hard decisions and creative solutions.

4.3. GENERAL CONCLUSIONS

4.3.1. Transferability of Results and Method

The results of this study were developed for two specific ecosystem processes within two ecosystems. Therefore the question arises as to how transferable the results may be. The sensitivities examined in this study are specific to sediment retention in salt marshes and community interactions of shorebirds in mudflats, so the characterizations of influence type, sensitivity and relative impact cannot be transferred directly to other ecosystems and do not apply to different processes within these ecosystems. However, an example site was used as a way to focus the exercise and was chosen as a representative example of intact ecosystems, thus the results could be transferable to other North Bay locations in which the same ecosystem processes are present. The variables that ended up in the group influence diagrams are general enough that most of the results may transfer to the entire Bay, with only a few specific enough to only apply to the North Bay. In addition, it is likely that the influence diagrams could also be transferred for use with like ecosystems in other estuaries, with minor revisions for place-specific stressors or other process variables. The characterizations of influence type, sensitivity and relative impact would have to be revisited, particular to that location.

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

4.3.2. Utility of Method for Rapid Vulnerability Assessments

Given that the method is transferable, the question of utility arises: in what cases is this method advantageous? This method could be repeated elsewhere as a "rapid" vulnerability assessment, with opportunity for some of the improvements that have been suggested for some of the limitations. By rapid, we mean assessments that can be carried out within six months to a year, as opposed to assessments based on detailed quantitative modeling that can take many years. Another advantage is that this method is able to capture more recent knowledge than would be available from a literature review. It is also better able to capture more knowledge of the type that is closely related to management, which is less frequently published than scientific studies. Finally, the information is more integrated across disciplines and scales and is designed to better match the scale of adaptation decisions. In some cases new insights about management effectiveness may arise while in other cases existing understanding may be validated. Having a well supported study to substantiate new and existing ideas can position managers to justify the most appropriate management options and priorities. It also can validate research priorities by highlighting known research gaps.

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

Nevertheless, the expert elicitation method developed for this study was well suited for achieving the purpose and goals of the assessment. In addition to achieving the workshop goals, several unexpected benefits emerged from the workshop. Participants reported that the combination of the development of the influence diagrams with systematic judgments facilitated thinking about the system and questions of climate change vulnerability in a different way than they had previously. Several expressed an intention to explore adapting the method for use in other workshop or classroom settings. Many participants found that the multidisciplinary interactions with colleagues were a valuable, personal learning experience and that the group together generated new insights about the system and links to management that may not have been seen by individuals. In short, the method demonstrated in this project 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 management options in the face of insufficient data and deep uncertainty about future climate.

REFERENCES

BCDC (San Francisco Bay Conservation and Development Commission). (2010) San Francisco Bay Subtidal Habitats Goals Project, Draft Report. San Francisco Bay Conservation and Development Commission, the California Coastal Conservancy, National Oceanic and Atmospheric Administration, and the San Francisco Estuary Partnership. Available online at http://www.bcdc.ca.gov/planning/shg/subtidal_habitat.shtml.

Cayan, D; Bromirski, P; Hayhoe, K; et al. (2008a) Climate change projections of sea level extremes along the California coast. *Clim Change* 87(0): 57–73. DOI: 10.1007/s10584-007-9376-7.

Cayan, DR; Maurer, EP; Dettinger, MD; et al. (2008b) Climate change scenarios for the California region. *Clim Change* 87(Suppl. 1): S21–S42.

Cayan, D; Tyree, M; Dettinger, M; et al. (2009) Climate change scenarios and sea level rise estimates for the California 2008 Climate Change Scenarios Assessment. California Climate Change Center. CEC-500-2009-014-D.

CCSP (Climate Change Science Program). (2008a) Preliminary review of adaptation options for climate-sensitive ecosystems and resources. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Julius, S.H., J.M. West (eds.), J.S. Baron, B. Griffith, L.A. Joyce, P. Kareiva, B.D. Keller, M.A. Palmer, C.H. Peterson, and J.M. Scott (Authors)]. U.S. Environmental Protection Agency, Washington, DC, USA, 873 pp.

CCSP (Climate Change Science Program). (2008b) *Weather and climate extremes in a changing climate*. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Thomas R. Karl, Gerald A. Meehl, Christopher D. Miller, Susan J. Hassol, Anne M. Waple, and William L. Murray (eds.)]. Department of Commerce, NOAA's National Climatic Data Center, Washington, D.C., USA, 164 pp.

CEC (California Energy Commission). (2006) Our changing climate: assessing the risks to California. A Summary Report from the California Climate Change Center.

CEC (California Energy Commission). (2008) The future is now: An update on climate change science, impacts, and response options for California. A report from the California Climate Change Center California Energy Commission's Public Interest Energy Research Program.

Delta Risk Management Study. (2007) Technical memorandum: Delta Risk Management Study (DRMS) Phase 1.

Dracup, J; Vicuna, S. (2005) An overview of hydrology and water resources studies on climate change: the California experience. The Environmental & Water Resources Institute Congress, Proceedings, American Society of Civil Engineers, May 2005.

Galbraith H; Jones, R; Park, R; et al. (2005) Global climate change and sea level rise: potential losses of intertidal habitat for shorebirds. USDA Forest Service Gen. Tech. Rep. PSW-GTR-191. Available online at http://www.fs.fed.us/psw/publications/documents/psw_gtr191/psw_gtr191_1119-1122_galbraith.pdf.

Gershunov, A; Douville, H. (2008) Extensive summer hot and cold extremes under current and possible future climatic conditions: Europe and North America. In: Diaz, H; Murnane, R; eds. Climate Extremes and Society. Cambridge, UK: Cambridge University Press; pp 74–98.

Groffman, P.M., Baron, J.S., Blett, T., Gold, A.J., Goodman, I., Gunderson, L.H., Levinson, B.M., Palmer, M.A., Paerl, H.W., Peterson, G.D., Poff, N.L., Rejeski, D.W., Reynolds, J.F., Turner, M.G., Weathers, K.C., and J. Wiens. 2006. Ecological thresholds: The key to successful environmental management or an important concept with no practical application? Ecosystems 9 (1): 1-13, DOI: 10.1007/s10021-003-0142-z

Hayhoe, K; Cayan, D; Field, CB; et al. (2004) Emissions pathways, climate change, and impacts on California. PNAS 101(34): 12422–12427.

Healey, MC; Dettinger, MD; Norgaard, RB, eds. (2008) The state of Bay-Delta science. Sacramento, CA: CALFED Science Program.

IPCC (Intergovernmental Panel on Climate Change). (2007) Climate change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S; Qin, D; Manning, M; et al. (eds.)]. Cambridge, UK: Cambridge University Press; pp. 1–996.
Jaffe, BE; Smith, RE; Torresan, LZ. (1998) Sedimentation and bathymetric change in San Pablo Bay: 1856–1983. OPEN-FILE REPORT 98-759. Version 1.0. Available online at http://geopubs.wr.usgs.gov/open-file/of98-759/of98-759.pdf.

Kneib, R; Simenstad, C; Nobriga, M; et al. (2008) Tidal marsh conceptual model. Sacramento (CA): Delta Regional Ecosystem Restoration Implementation Plan.

Knowles, N. (2009) Potential inundation due to rising sea levels in the San Francisco Bay region. PIER Research Report, CEC-500-2009-023-D, Sacramento, CA: California Energy Commission.

Knowles, N; Cayan, D. (2004) Elevational dependence of projected hydrologic changes in the San Francisco estuary and watershed. *Clim Change* 62: 319–336.

Krone, RB. (1979) Sedimentation in the San Francisco Bay system. In: Conomos, TJ; ed. San Francisco Bay: the urbanized estuary. San Francisco, CA: American Association for the Advancement of Science; pp 85–96.

Lund, J; Hanak, E; Fleenor, W; et al. (2007) Envisioning futures for the Sacramento–San Joaquin Delta. San Francisco, CA: Public Policy Institute of California.

Miller, NL; Hayhoe, K; Jin, J; et al. (2008) Climate, extreme heat, and electricity demand in California. *J Appl Meteorol Climatol* 47: 1834–1844.

Monroe, M; Olofson, PR; Collins, JN; et al. (1999) Baylands ecosystem habitat goals. A report of habitat recommendations prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. Oakland, CA: San Francisco Bay Regional Water Quality Control Board. Available online at http://www.sfei.org/node/2123.

Orr, M; Crooks, S; Williams, PB. (2003) Will restored tidal marshes be sustainable? *San Francisco Estuary and Watershed Science* 1: Article 1. Available online at http://www.escholarship.org/uc/item/8hj3d20t.

Page, GW; Whitacre, DF. (1975) Raptor predation on wintering shorebirds. *Condor* 77: 73–78. Available online at http://elibrary.unm.edu/sora/Condor/files/issues/v077n01/p0073-p0083.pdf.

Ralston, DK; Stacey, MT. (2007) Tidal and meteorological forcing of sediment transport in tributary mudflat channels (San Francisco Bay, CA). *Continental Shelf Research* 27: 1510–1527.

Reed, DJ. (1995) The response of coastal marshes to sea-level rise: survival or submergence? *Earth Surface Processes and Landforms* 20(1): 39–48.

Ruhl, CA; Schoellhamer, DH. (2004) Spatial and temporal variability of suspended-sediment concentrations in a shallow estuarine environment. *San Francisco Estuary and Watershed Science* 2: Article 1. Available online at http://repositories.cdlib.org/jmie/sfews/vol2/iss2/art1.

San Francisco Estuary Indicators Team. (2008) Assessment framework as a tool for integrating and communication watershed health indicators for the San Francisco estuary. Technical Report #1.

Schoellhamer, D; Wright, S; Drexler; J; et al. (2007) Sedimentation conceptual model. Sacramento, (CA): Delta Regional Ecosystem Restoration Implementation Plan.

SFEP (San Francisco Estuary Partnership). (1993) Comprehensive Conservation and Management Plan.

SFEP (San Francisco Estuary Partnership). (2007) Comprehensive Conservation and Management Plan.

SFEP (San Francisco Estuary Partnership). (2010) Strategic Plan for 2010-2012. Available online at http://www.sfestuary.org/userfiles/file/SFEPstratplan.pdf.

Stenzel, LE; Hickey, CM; Kjelmyr, JE; et al. (2002) Abundance and distribution of shorebirds in the San Francisco Bay area. *Western Birds* 33:69–98.

Takekawa, JY; Miles, AK; Schoellhamer, DH; et al. (2006a) Trophic structure and avian communities across a salinity gradient in evaporation ponds of the San Francisco Bay estuary. *Hydrobiologia* 567: 307–327.

Takekawa, JY; Woo, I; Spautz, H; et al. (2006b) Environmental threats to tidal-marsh vertebrates of the San Francisco Bay estuary. *Stud Avian Biol* 32: 176 197. Available online at http://www.sfei.org/bioinvasions/Reports/No489_06_BI_WT_EnviroThreatstoVertebrates.pdf.

U.S. EPA (Environmental Protection Agency). (1997) Terms of environment: glossary, abbreviations and acronyms. 175-B-001. Available online at http://www.epa.gov/OCEPAterms/.

U.S. EPA (Environmental Protection Agency). (2007) Indicator development for estuaries. EPA842-B-07-004

Weiss, SB; Schaefer, N; Branciforte, R. (2007) Study design and methodology for review by the Peer Review Panel. A project of the Bay Area Open Space Council. Available online at http://www.uplandhabitatgoals.org/upload/files/20100517114132_Study%20Design%20and%20Methodology%20for%20Peer%20Review,%20May%202007.pdf.

Weiss, SB; Schaefer, N; Branciforte, R. (2008) Methodology and Vegetation Representation Analysis. A project of the Bay Area Open Space Council. Available online at http://www.uplandhabitatgoals.org/upload/files/20100909121856_Methodology%20and%20Veg%20Rep%20Analysis%20v2.pdf.

Weiss, SB; Schaefer, N; Branciforte, R. (2010) Riparian/Fish Focus Team Report. A project of the Bay Area Open Space Council. Available online at http://www.uplandhabitatgoals.org/upload/files/20100908211440_Draft%20RFFT%20Report%20090110doc.pdf.

Wright, SA; Schoellhamer, DH. (2004) Trends in the sediment yield of the Sacramento River, California, 1957–2001. *San Francisco Estuary and Watershed Science* 2:2. Available online at http://repositories.cdlib.org/jmie/sfews/vol2/iss2/art2.

Ydenberg, RC; Butler, RW; Lank, DB; et al. (2004) Western sandpipers have altered migration tactics as peregrine falcon populations have recovered. *Proc Biol Sci* 271(1545): 1263–1269.

APPENDIX A. DEVELOPMENTAL PROCESS FOR CLIMATE READY ESTUARIES VULNERABILITY ASSESSMENT

A.1. SELECT KEY GOALS, ECOSYSTEMS, AND ECOSYSTEM PROCESSES

The SFEP partners participated in several discussions and meetings to outline management priorities, key resources to consult, and other considerations for selecting key goals for the assessment. As a starting point, SFEP's Comprehensive Conservation and Management Plan (CCMP) (SFEP, 1993; SFEP, 2007) was examined and discussed to select four to six key management goals as a focus of the assessment. These goals would help to further refine the analysis to specific ecosystems, ecosystem processes, stressors of concern, and indicators for measuring changes in the ecosystem. Selected management goals included:

- Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources;
- Stem and reverse the decline of estuarine plants, fish and wildlife and the habitats on which they depend;
- Ensure the survival and recovery of listed and candidate threatened and endangered species, as well as special status species;
- Protect and manage existing wetlands; and
- Restore and enhance the ecological productivity and habitat values of wetlands.

Following an October 2008 kickoff meeting with over 30 local experts to share information on climate change impacts and adaptation work in the region, salt marshes and mudflats were selected as two wetland habitats of focus for the project. These systems were identified by the local experts as highly relevant to SFEP's management goals due to their ecological productivity and their habitat values for threatened and endangered species, and are deemed highly sensitive to changes in climate-related variables such as sea level rise and altered hydrology. In order to explore the linkages among such climate-related variables, their interactions with non-climate stressors of concern, and the key ecosystem processes that maintain the systems, a conceptual model was developed for each ecosystem type.

A.2. CONCEPTUAL MODELS

The conceptual models were intended to serve as a framework for further analysis in the vulnerability assessment. The models depicted likely pathways by which climate drivers may directly or indirectly affect interacting stressors that impact ecosystem processes. The process is intended as iterative, as we learn from exploring the first two ecosystem processes, next steps can involve focusing on additional ecosystem processes, or for repeating a similar analysis for additional habitats. The development of the conceptual model has also served to help with the scoping process; we began with a comprehensive list of ecosystem processes and indicators and then chose those more important to and best representing healthy salt marsh functioning. The total number of possible ecosystem processes was narrowed down to five or six key ones for the ecosystem. The models also included a similar number of variables that may serve as indicators for the status of these endpoints. Ecosystem processes and indicators were identified in discussions among SFEP, BCDC, and EPA ORD, as well as through examination of the Delta Regional Ecosystem Restoration Implementation Plan's conceptual models developed by the CALFED Bay-Delta Program (Schoellhamer et al., 2007; Kneib et al., 2008). To ensure consistency with current research, these indicators were cross-walked with indicators developed for the Watershed Assessment Framework, which were being incorporated into a revision of SFEP's CCMP (San Francisco Estuary Indicators Team, 2008).

Stressor interactions are stressors that work together to affect ecosystem functioning. These included both non-climate and climate-related influences that stress salt marsh and mudflat ecosystems. Pre-existing stressors and stressor interactions were identified during the development of salt marsh and mudflat conceptual models, and impacts of these stressors of concern were identified using the SFEP Comprehensive Conservation and Management Plan.

Climate drivers are climate variables that may impact ecosystem processes directly (e.g., raise water temperature) or indirectly (e.g., cause changes in nutrient inputs). The climate drivers relevant to salt marshes and mudflats were identified by first examining climate drivers for estuarine systems outlined in Synthesis and Assessment Product 4.4: *Preliminary review of adaptation options for climate-sensitive ecosystems and resources* (CCSP, 2008a), followed by extensive discussions among the SFEP partners. The climate drivers were then mapped to the key processes of each ecosystem, either directly or through interactions with pre-existing stressors. These pathways provided the basis for the development of the conceptual models. The pathways included are intended as a heuristic, without distinguishing between the magnitudes between them. It is not possible to include all possible system components and connections between them. General models are first presented, and then additional detail for individual ecosystem processes is described in the two sub-models.

A.2.1. General Models

A.2.1.1. *Salt Marshes*

The general model for salt marshes in presented in Figure A-1. Climate drivers in the salt marsh conceptual model include: changes in air temperature, changes in precipitation, sea level rise, and changes in storm climatology and wind. Changes in air temperature refers to the variation from the climatological mean surface air temperature in a particular region. Changes in precipitation refers to variation from the climatological mean of the amount, intensity, frequency and type of rainfall, snowfall and other forms of frozen or liquid water falling from clouds in a particular region, changes refer to both the form and flow of precipitation. Sea level rise is defined as "relative sea-level rise," the change in sea level relative to the elevation of the adjacent land, which can also subside or rise due to natural and human induced factors. Relative sea-level changes include both global sea-level rise and changes in the vertical elevation of the land surface. Changes in storm climatology and wind refers to the variation from the climatological mean of the frequency, intensity and duration of extreme events (such as hurricanes, heavy precipitation events, drought, heat waves, etc.) and the changes in the direction and timing of the dominant seasonal winds.

Figure A-1. Salt Marsh Conceptual Model.

Stressor interactions within the salt marsh conceptual model include: changes in water temperature, changes in salinity, sedimentation and erosion, flooding, invasive species, other human uses, land use/land cover change, contaminants, and altered flows/water demand. Changes in water temperature refers to variation in the climatological mean surface water temperature in a particular region. Changes in salinity are measured by changes in the location along the estuary of different salinity zones (e.g., polyhaline, mesohaline, and oligohaline), or changes in vertical stratification based on salinity. Sedimentation and erosion includes the transport, deposition, and removal of soil and rock by weathering, mass wasting, and the action of streams, waves, winds and underground water. Flooding is defined as an excess of water that does not recharge ground water beyond time frames typical for watersheds due to high precipitation events, storm surge, or infrastructure damage. Invasive species are alien species (species not native to a particular ecosystem) whose introduction causes, or is likely to cause, economic or environmental harm or harm to human health. Other human uses is a catch all category based on the CCMP which includes the use of the marsh and surrounding area for activities such as fishing, shipping and ports, dredging, transportation projects, sand mining, recreational use, marinas, and industrial uses that may impact the marsh. Land use/land cover change is defined as the current use of marsh and human-induced changes to the marsh or surrounding land, including wetland alteration and expansion of the built environment. Contaminants include material that creates a hazard to the ecosystem by impairing water quality, poisoning or through the spread of disease (e.g., mercury, selenium, PCBs, DDT, chlordane, dieldrin, dioxin, trash and debris, and acid mine drainage). Altered flows/water demand includes upstream water diversions for agricultural, industrial, or urban uses that change the natural flow of freshwater and sediment into the marsh, including leveeing, diking, damming, filling, or channeling.

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

Indicators within the salt marsh conceptual model include: species population size, water quality standards, freshwater inflow, sediment quantity, extent of aquatic habitat, and biodiversity. Species population size is defined as the number of similar organisms residing in a defined place at a certain time, including threatened and endangered species, native species, and invasive species. Water quality standards are provisions of State or Federal law which consist of designated uses for waters of the United States, and water quality criteria for such waters based upon such uses. Criteria address the values for water quality indicators (e.g., water temperature, salinity, water contaminant exposure, biological thresholds for water contamination, nutrient concentrations, water toxicity) that are required to support designated uses. Freshwater inflow is the amount of freshwater inflow to the estuary from the watershed. Sediment quantity is defined as suspended sediment concentration. Extent of aquatic habitat is defined as the area of all contiguous, vegetated salt and brackish wetland, or mean width of marsh (may be divided into low or high marsh or by dominant species). Biodiversity is the presence and abundance of different species types (e.g., fish, birds, SAV).

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

A.2.1.2. *Mud Flats*

The general model for mudflats is presented in Figure A-2. Climate drivers in the mudflat conceptual model include: changes in air temperature, changes in precipitation, sea level rise, and changes in storm climatology and wind. Changes in air temperature refers to the variation from the climatological mean surface air temperature in a particular region. Changes in precipitation refers to variation from the climatological mean of the amount, intensity, frequency and type of rainfall, snowfall and other forms of frozen or liquid water falling from clouds in a particular region, changes refer to both the form and flow of precipitation. Sea level rise is defined as "relative sea-level rise," the change in sea level relative to the elevation of the adjacent land, which can also subside or rise due to natural and human induced factors. Relative sea-level changes include both global sea-level rise and changes in the vertical elevation of the land surface. Changes in storm climatology and wind refers to the variation from the climatological mean of the frequency, intensity and duration of extreme events (such as hurricanes, heavy precipitation events, drought, heat waves, etc.) and the changes in the direction and timing of the dominant seasonal winds.

Figure A-2. Mudflat Conceptual Model.

Stressor interactions within the mudflat conceptual model include: changes in water temperature, changes in salinity, sedimentation and erosion, flooding, invasive species, other human uses, and contaminants. Changes in water temperature refers to variation in the climatological mean surface water temperature in a particular region. Changes in salinity are measured by changes in the location along the estuary of different salinity zones (e.g., polyhaline, mesohaline, and oligohaline), or changes in vertical stratification based on salinity. Sedimentation and erosion includes the transport, deposition, and removal of soil and rock by weathering, mass wasting, and the action of streams, waves, winds and underground water. Flooding is defined as an excess of water that does not recharge ground water beyond time frames typical for watersheds due to high precipitation events, storm surge, or infrastructure damage. Invasive species are alien species (species not native to a particular ecosystem) whose introduction causes, or is likely to cause, economic or environmental harm or harm to human health. Other human uses includes the use of the marsh and surrounding area for activities such as fishing, shipping and ports, dredging, transportation projects, sand mining, recreational use, marinas, and industrial uses that may impact the marsh. Contaminants include material that creates a hazard to the ecosystem by impairing water quality, poisoning or through the spread of disease (e.g., mercury, selenium, PCBs, DDT, chlordane, dieldrin, dioxin, trash and debris, and acid mine drainage).

Ecosystem processes in the mudflat conceptual model include: community interactions, primary productivity, biomass, nutrient cycling, and key species. Community interactions is defined as the interrelations among species within the ecosystem. Primary productivity is the production of energy by plants and phytoplankton, within the entire system. Biomass is the total mass of biological material within the system or within a particular category or group. Nutrient cycling is the process of transfer of nutrients between organisms and the water. Key species are species which serve as a foundation for other species or fill a similar pivotal role for the rest of the ecosystem (e.g., ecosystem engineers). Indicators within the mudflat conceptual model include: species population size, water quality standards, extent of aquatic habitat, and biodiversity. Species population size is defined as the number of similar organisms residing in a defined place at a certain time, including threatened and endangered species, native species, and invasive species. Water quality standards are provisions of State or Federal law which consist of designated uses for waters of the United States, and water quality criteria for such waters based upon such uses. Criteria address the values for water quality indicators (e.g., water temperature, salinity, water contaminant exposure, biological thresholds for water contamination, nutrient concentrations, water toxicity) that are required to support designated uses. Extent of aquatic habitat is defined as the area of all contiguous, vegetated salt and brackish wetland, or mean width of marsh (may be divided into low or high marsh or by dominant species). Biodiversity is the presence and abundance of different species types (e.g., fish, birds, SAV).

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

A.2.2. Sub-models

Following the development of the general ecosystem models, one ecosystem process within each model was chosen to move to the specifics for an individual ecosystem process. The purpose was to select good processes for piloting the method, but the choice does not imply that these are necessarily the only important, or the most vulnerable, processes. Sediment retention was identified as a key salt marsh process because of the importance of sediment supply to allow for marsh development and growth. In the Bay, sediment supply has been declining due to changes in human activities and the use of the land and waterways (Jaffe et al., 1998; Wright and Schoellhamer, 2004). SFEP, BCDC, and other regional partners have done extensive work on examining changes in sediment and how these changes may be influenced by changes in climate. This provided the basis for the development of the sediment retention submodel.

Community Interactions was chosen as the second ecosystem process of focus. To select a specific well-constrained “storyline” of interactions between 2-4 species for this process, ICF and EPA consulted with SFEP, BCDC, and regional experts on key sensitivities for this process within the Bay system. The shorebird and mudflats interaction was selected for further study because of the priority status of key species and the climate sensitivities that structure the system. As mudflats may be one of the habitat types most vulnerable to climate changes (especially sea level rise) the interactions among wading shorebirds were identified as a key process for study. This provided the basis for the development of the community interactions submodel.

A.2.2.1. *Sediment Retention*

The sediment retention submodel is presented in Figure A-3. It focuses on the balance between the processes of removal and deposition of sediment onto a salt marsh and the resultant ability of the marsh to persist in the face of climate change. The accumulation of sediments and marsh vertical accretion result from interactions among tidal imports, vegetation dynamics, and depositional processes. Freshwater flow and coastal storms transport and deposit sediments onto the marsh surface, and the roots and stems of marsh vegetation retain sediment that would otherwise be carried away from the marsh by wind and waves. Over time, the accumulation of dead and dying organic matter produces peat, and the combination of peat accumulation and sediment deposition gradually builds up the marsh surface. Ultimately, it is the balance between marsh vertical accretion and sea level rise that determines whether a tidal marsh will persist in the face of rising seas or will convert to tidal flats or open water (Reed, 1995).

Figure A-3. Sediment Retention sub-model.

In the San Francisco Estuary, there is an annual cycle of sediment deposition and resuspension that begins when freshwater flow from the Delta in winter carries pulses of sediment to the bay. Most of this new sediment is deposited in shallow areas and where tidal velocities are lower. In spring and summer suspended sediment concentrations increase again as a result of wind-wave resuspension of bottom sediments (Ruhl and Schoellhamer, 2004). Sediment supply will play an increasingly critical role in this process. The supply of sediments is declining as the estuary completes the shift from a system with larger sediment loads as a result of past hydraulic mining to one that has a reduced sediment supply due to the cessation of mining and an increase in tributary dams that trap sediment upstream (Jaffe et al., 1998; Wright and Schoellhamer, 2004).

A number of key climate variables (air temperature, precipitation, storm climatology and wind, and sea level rise) and interacting human stressors (e.g., altered flows, dredging/dredge disposal, land use/land cover changes) may impact this process, either directly or indirectly. Increases in winter storms and in strong wind-driven waves may increase erosion of uplands, increasing sediment availability. The North Bay has become somewhat erosional because of an altered balance between riverine sediments and sediment transport. Storms and storm surges may also carry more sediment away from marshes or promote resuspension of bottom sediments, leading to increased suspended sediment concentrations. Sediment deposition and retention on the marsh surface will ultimately depend on marsh geomorphology and surface vegetation (Orr et al., 2003).

A.2.2.2.   *Community Interactions*

The community interactions submodel is presented in Figure A-4. This submodel focuses on community interactions between two species of mudflat wading birds, the Marbled Godwit and the Western Sandpiper, and their predators and prey. Inundation and sediment regimes influence not only mudflat extent, but also mudflat trophic dynamics (Takekawa et al., 2006a). The trophic structure of North Bay mudflats includes invertebrates within mudflat sediments, shorebirds that feed on mudflat infauna (Stenzel et al., 2002), and Peregrine Falcons and Merlins, which prey on shorebirds (Page and Whitacre, 1975; Ydenberg et al., 2004).

Figure A-4. Community Interactions sub-model.

A number of key climate variables and interacting human stressors (altered flows, dredging, land use/land cover changes) may impact these trophic interactions, directly or indirectly. Depending on sediment supply, increased inundation from sea level rise may drown mudflats, while an increase in winds and wave action from more frequent and intense storms may change sediment deposition patterns. Because suspended sediment concentrations are sensitive to the extent and elevation of mudflats, as mudflat elevations decrease, suspended sediment concentrations may decrease over time (Orr et al., 2003). If sediment deposition does not keep pace with sea level rise, mudflat invertebrates will become less available for shorebirds.

There is limited information on shorebird diets, making it difficult to group shorebirds by prey type, but shorebirds can be distinguished based on the depth at which they probe into the sediment for prey. Short-legged shorebirds that are shallow probers, represented by Western Sandpiper, forage in the top layer of sediments (< 3 cm) and will lose foraging habitat first. But eventually mudflat invertebrates will also become inaccessible to long-legged deep probers, represented by Marbled Godwit, which penetrate up to 8 cm into the substratum (Takekawa et al. 2006a).

A.3. CONCLUSIONS

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

APPENDIX B. EXPERT ELICIATION WORKSHOP PREPARATION AND IMPLEMENTATION

B.1. PRE-WORKSHOP

B.1.1. Selecting Workshop Participants

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

- Demonstrated understanding of the body of literature with regard to sediment retention OR community interactions (depending on which breakout group), as evidenced by academic training, research, and publications;
- Demonstrated ability to think of uncertainty in qualitative terms ;
- Knowledge of science behind estuary management, as evidenced by academic training, research, and publications;
- Knowledge of estuary management issues as evidenced by academic training, research, and publications;
- Past work in SFEP region; and
- Past work with salt marsh development/sediment retention processes (the balance of sediment supply versus loss) OR mudflat development/community interactions (interactions of shorebirds and their predators and prey), depending on the candidate's proposed breakout group.

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

Sediment Retention Breakout Group:

Dave Cacchione, U.S. Geological Survey

John Callaway, UC San Francisco

Chris Enright, CA Department of Water Resources

Bruce Jaffe, U.S. Geological Survey

Lester McKee, San Francisco Estuary Institute

Dave Schoellhamer, U.S. Geological Survey

Mark Stacey, UC Berkeley

Community Interactions Breakout Group:
Letitia Grenier, San Francisco Estuary Institute
Jessica (Jessie) Lacy, U.S. Geological Survey
Michelle Orr, Philip Williams & Associates
Diana Stralberg, PRBO Conservation Science
Stuart Siegel, Wetlands and Water Resources
Lynne Trulio, San Jose State University
Isa Woo, U.S. Geological Survey

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

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

Table B-2. Community Interactions breakout group participants, affiliations, and qualifications

B.1.2. "Straw Man" Influence Diagrams

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

Figure B-1. Sediment Retention "straw man" influence diagram.

Figure B-2. Community Interactions "straw man" influence diagram.

B.1.3. Pre-workshop Briefing and Homework Assignment

Participants participated in a pre-workshop briefing call and a homework assignment that would be used to develop consolidated influence diagrams to be used at the workshop. The pre-workshop briefing call was held on March 2, 2010. This call gave participants a briefing on the background of the project, work to date, the purpose of the workshop, and an overview of the homework assignment. Part of the background material presented was information on an example site for participants to consider when more spatial specificity would be useful during the workshop exercise. China Camp, a site on the southwest shore of San Pablo Bay, was chosen because it includes large wetland areas in a transitional salinity zone with intact adjacent habitats.

The homework assignment asked participants to review a number of items: (1) selected articles relevant to the ecosystem process breakout group to which they were assigned (for the Sediment Retention breakout group: Orr et al., 2003; Ruhl and Schoellhamer, 2004; and Wright and Schoellhamer, 2004; for the Community Interactions breakout group: Galbraith et al., 2005; Takekawa et al., 2006; Page and Whitacre, 1975; and Stenzel et al., 2002); (2) conceptual models of the ecosystem and ecosystem process to which they were assigned; and (3) the draft influence diagram for the ecosystem process to which they were assigned. Participants were asked to review the draft influence diagram and provide recommendations on what should be added or removed. Participants were asked to add or subtract variables or relationships until the preliminary influence diagram matched their understanding of the process. We asked participants to include no more than 10-15 variables in the diagram in order to keep it focused on the highest priority influences. We also asked participants to focus on current conditions (including current climate) when reviewing and commenting on the diagram.

Participants were asked to provide a quantitative definition for each variable, a metric for measuring the variable, and a range of values for the metric. Participants were also asked to assign values to the metrics they selected. This could include actual measured values (e.g., 35 km^3 of inflow) as well as a range of values (e.g., 5 to 50 km^3 of inflow).

B.1.4. Consolidated Influence Diagrams

The preliminary diagram for each breakout group was revised prior the workshop based on the participants' homework responses. The process involved examining the participants' responses and constructing a tally of the variables used and influences (arrows) included. Variables and influences that were most frequent across all responses were included in the consolidated influence diagrams. For the both the Sediment Retention and Community Interactions groups, all but one of the participants provided comments on the preliminary influence diagram. Based on the responses from the participants, consolidated influence diagrams were developed for the workshop.

B.2. WORKSHOP

B.2.1. Group Influence Diagrams

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

B.2.2. Introduction to Climate Scenarios and Confidence

The participants received two handouts designed to orient them to the climate scenarios and to the methodology for assessing confidence. The first handout contained a summary of Climate Scenarios A and B, which was used by the participants in assessing the sensitivity of salt marshes and mudflats across a range of plausible scenarios of climate change. It explained the development of two climate futures in a mid-century (2035-2064) time frame. Participants used these scenarios on Day 2 to make new judgments compared to their judgments under "current conditions" on Day 2. The full climate scenarios handout can be found in Appendix C.

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

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 Participant 3 were of only increasing sensitivity, Participant 1 only had one change to decreasing sensitivity, and Participants 2, 6 and 7 had both increases and decreases, sometimes across the scenarios for one influence. Partipants 4 and 5 made no changes in sensitivity across the climate scenarios.

Figure B-3. Sediment Retention influence diagrams of sensitivities: variance across participants.

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, 2 and 4 are of only increasing sensitivity; Participant 5 only had one change, to decreasing sensitivity; Participants 3, 6 and 7 had both increases and decreases, but more of the former.

Figure B-4. Community Interactions influence diagrams of sensitivities: variance across participants.

B.2.5. Exercise Discussions and Report-outs

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

Based on this group discussion, the facilitator helped the participants to identify some key points that emerged. These key points addressed issues such as key influences, important pathways, thresholds, significant changes associated with climate change, management implications, etc. One of the participants from each breakout group presented these key points to the larger group to summarize the discussion. Following the discussion, participants were given time to revisit their individual judgments.

B.2.6. Discussion of Management Implications

Following the breakout group discussions and exercise of making individual judgments, participants gathered in the larger group to discuss management implications. This discussion would help SFEP and BCDC to examine some of the key issues that emerged from the expert elicitation exercise and translating those issues into action. The facilitator led the discussion by asking participants to consider how climate stressors might impact the estuary across a range of management scenarios. The discussion also explored research and data needs, suggestions for water and sediment management, and fundamental shifts in management that may be necessary.

B.3. POST-WORKSHOP

B.3.1. Review of Workshop Report

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

B.3.2. Synthesis of Results

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

B.3.3. Review of Draft Report

The workshop report and preliminary results reports were used to develop this technical report to present the synthesis results and place them in the larger context of the implications for management and SFEP's capacity to respond. The draft report was revised based on an internal review by EPA scientists. The report is now under public and expert peer review. Following this review, a final report will be developed that responds to the public and peer-review comments. An additional report that focuses on lessons learned across the two assessments for SFEP and MBP will also be developed.

APPENDIX C. PARTICIPANT HANDOUT ON CLIMATE SCENARIOS

SFEP Workshop Climate Scenarios

This handout is intended to assist participants in assessing the sensitivity of salt marshes and mudflats across a range of plausible scenarios of climate change. It provides the details of two distinct but scientifically credible climate futures for a mid-century (2035-2064) time period.[2] Participants will use these scenarios in revisiting their assessments of influence completed on the first day.

Two Climate Change Scenarios: "Lower-Range" and "Higher-Range"[3]

Under both climate change scenarios, California will retain its Mediterranean climate (cool/wet winters and hot/dry summers) and continue to experience a high degree of variability in precipitation with rising sea levels. By mid-century, the "higher-range" scenario (including higher emissions and a more sensitive climate) is projected to experience a warmer and somewhat drier climate compared to the "lower-range" scenario (with lower emissions and a lesser impact on California's climate).

Development of the Climate Scenarios

The two bounding scenarios were developed from a collective group of studies in large part funded by the California Energy Commission (CEC) under the mandate of the Governor's Biennial Climate Change Report. A majority of the climate projections presented here were developed by Cayan et al. (2009), based on projections from 6 leading climate models.[4] These models were selected based on their reasonable representation of historical simulation of seasonal precipitation, seasonal temperature, the variability of annual precipitation, and El Nino/Southern Oscillation (ENSO). All models were run with both a lower emission scenario (B1 SRES) and a mid-high emission scenario (A2 SRES) to capture a range of plausible future emissions trajectories. The "lower-range" and "higher-range" temperature and precipitation scenarios for 2035-2064 compared to 1961-1990 baseline conditions are based on these climate model simulations, for the SRES B1 (lower) and SRES A2 (higher) scenarios, respectively. Regional projections were developed by statistical downscaling.[5]

For a given U.S. coastal location, relative sea level rise may differ from global estimates due to a number of factors such as changes in local ocean circulation, ocean density, vertical land motion,

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[2] These two futures are designed to capture a large part of the uncertainty inherent to future projections that is the result of two key factors: (1) the amount of future emissions of greenhouse gases from human activities that are driving global change, and (2) the ability of scientists to simulate the response of the Earth's climate system to those emissions.

[3] 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.

[4] U.S. NOAA's Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1; the National Center for Atmospheric Research (NCAR) Parallel Climate Model (PCM); the National Center for Atmospheric Research (NCAR) Community Climate System Model (CCSM); the Max Plank Institute ECHAM5/MPI-OM; the Center for Climate System Research of the University of Tokyo MIROC 3.2 medium-resolution model; and the French Centre National de Recherches Meteorologiques (CNRM) models.

[5] Statistical downscaling methodology includes constructed analogues, bias correction and spatial downscaling of the results from each of the 6 climate models.

erosion/sedimentation, gravitational effects, etc. Relative sea level rise in California has demonstrated similar rates of rise compared to global estimates (Cayan et al. 2008). Many California studies recommend using projections of global sea level rise estimates, which assumes relative sea levels continue to rise at the same rate as projected global sea level rise. The "lower-range" sea level rise estimate is provided as a mid-range of Rahmstorf (2007) and high-end of IPCC TAR. The "higher-range" sea level rise estimate is provided as the high estimate of Rahmstorf (2007).

Summary of Climate Scenarios: Averages for Mid-Century

		"Lower-Range" Scenario	**"Higher-Range" Scenario**
Temperature[6]	Annual Average[7]	**+2.8^{o}F (1.6^{o}C)**	**+3.5^{o}F (1.9 ^{o}C)**
	Average Increase of Winter Temperature[8]	**+2.5^{o}F (1.4 ^{o}C)**	**+2.7^{o}F (1.5 ^{o}C)**
	Average Increase of Summer Temperature[c]	**+4.0^{o}F (2.2 ^{o}C)**	**+4.5^{o}F (2.5 ^{o}C)**
	Extreme Heat Days[9]	**+10 days/year**	**+16 days/year**
Precipitation	Annual Change[10]	**-4.5%**	**-7%**
	Winter change	Reduced winter precipitation[11]	
	Heavy Events	Decline in frequency of precipitation events (exceeding 3mm/day) but not a clear signal in changes of precipitation intensity	

[6] Since the 1920s, minimum and maximum daily temperature have been observed to have increased in California with minimum temperature increasing at a greater rate accented by a small cooling trend in the summer (Cayan et al. 2009). These averages are for 2035-2064 projections relative to a 1961 to 1990 baseline for B1 and A2 emission scenarios.

[7] Approximate results using B1 and A2 emissions scenarios and three global climate models (PCM1, GFDL CM2.1, HadCM3) (CEC 2006).

[8] These results are for Sacramento, California. This warming is projected to be more moderate along the coastline (50 km from the coast) rising considerably inland (Cayan et al. 2009). These averages are for 2035-2064 projections relative to a1961 to 1990 baseline for B1 and A2 emissions scenarios.

[9] Extreme heat days are defined as when the daily maximum temperature exceeds the 95th percentile of temperature from the 1961-1990 historical averages of May-September days. 1961-1990 extreme heat days are approximately 8 days/year based on model runs. Results are provided by Cayan et al. (2009) using three climate models (CNRM CM3, GFDL CM2.1, MICRO 3.2; with bias corrected spatial downscaling) for B1 and A2 emissions scenarios. Mid-century projections suggest hot daytime and nighttime temperatures increase in frequency, magnitude, and duration (Cayan et al. 2009). Extreme warm temperatures in California, historically a July and August phenomenon, will increase in frequency and magnitude likely beginning in June and may continue into September (Hayhoe et al. 2004; Gershunov and Douville 008; Miller et al. 2008).

[10] Results are averaged across 6 GCMs using the grid point nearest to Sacramento (Cayan et al. 2009) for B1 and A2 emissions scenarios.

[11] These results are provided by CEC (2008).

		"Lower-Range" Scenario	"Higher-Range" Scenario
Sea Level	Total Increase for 2050[12]	**+30 cm**	**+45 cm[13]**
	Hourly Sea Level Exceedances[14]	**1343**	**1438**
Storms/Wind[15]	Tendency toward a decline in storms.[16] Projections suggest an increased tendency for heightened sea level events to persist for more hours. ENSO is not projected to increase in frequency or intensity.		

What else do these changes mean for our system?

Snow Pack Change	For the Sacramento-San Joaquin watershed, April watershed-total snow accumulation projected to drop by 64% by 2060.[17]
Spring Runoff	Spring runoff occurring earlier and reduced overall
Seasonal Changes in Amount of Freshwater Inflow to the Bay from the Delta in 2060[18]	October through February: inflow +20% March through September: inflow -20%

Where can I find additional information?

California Climate Change Research Center
http://www.climatechange.ca.gov/research/index.html

Union of Concerned Scientists
www.climatechoices.org/ca

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[12] Sea level rise relative to 2000 levels. This study applies Rahmstorf's methodology of estimating sea level rise as a function of rising temperatures. This study assumes sea level rise along the coast to be the same as global estimates given the observed rate of rise along the southern California coast has been about 17 to 20 cm per century similar to that of global sea level rise (assume no future changes in other factors that affect relative sea level rise such as changes in regional/local ocean circulation, ocean density, etc.) (Cayan et al. 2009). DMRS also provides recommended 2050 global sea level rise estimates relative to 1990 values: 11 cm (direct extrapolation of observed increased during the 20th century), 20 cm (low-end value of Rahmstorf and approx mid-range of IPCC TAR), 30 cm (approx mid-range of Rahmstorf and high-end of IPCC TAR); 41 cm (high end of Rahmstorf) (DMRS 2007).

[13] The total difference between mean range and spring range of 1.7 ft (50.3 cm) is slightly larger than the higher-range scenario rise of 45 cm, based on the Point San Pedro tide station. http://tidesandcurrents.noaa.gov/tides10/tab2wc1a.html#128

[14] The hourly sea level exceedance is defined as the maximum duration (hours) when San Francisco sea level exceeds the 99.99th % level (140 cm above mean sea level) based on the GFDL climate change (A2) simulation using the Rahmstorf sea level scheme averaged 2 to 4 hours increase for mid-century (Cayan et al. 2009).

[15] These results are provided by Cayan et al. (2009).

[16] Storm is defined as sea level pressure (SLP) equaling or falling below 1005 millibar (mb).

[17] Results provided by the Bay-Delta watershed model driven by temperature projections from a parallel climate model under a 'business-as-usual' scenario relative to 1995-2005 (precipitation is assumed to remain consistent with today's observations) (Knowles and Cayan 2004).

18 This study does account for reservoirs, in-stream valley diversions, and in-Delta withdrawals and assumes no future management adaptation or altered demand patterns (Knowles and Cayan 2004).

Works Cited

California Energy Commission (CEC). 2006. Our Changing Climate: Assessing the Risks to California. A Summary Report from the California Climate Change Center.

California Energy Commission (CEC). 2008. The Future is Now: An Update on Climate Change Science, Impacts, and Response Options for California. A report from the California Climate Change Center California Energy Commission's Public Interest Energy Research Program.

Cayan, D., P. Bromirski, K. Hayhoe, M. Tyree, M. Dettinger, & R. Flick. 2008. Climate change projections of sea level extremes along the California coast. *Climatic Change* 87(0), 57-73. DOI: 10.1007/s10584-007-9376-7.

Cayan, D., M. Tyree, M. Dettinger, H. Hidalgo, T. Das, E. Maurer, P. Bromirski, N. Graham, and R. Flick. 2009. Climate Change Scenarios and Sea Level Rise Estimates for the California 2008 Climate Change Scenarios Assessment. California Climate Change Center. CEC-500-2009-014-D.

Delta Risk Management Study (DRMS) 2007. Technical Memorandum: Delta Risk Management Study (DRMS) Phase 1.

Gershunov A., and H. Douville. 2008. Extensive summer hot and cold extremes under current and possible future climatic conditions: Europe and North America. In: H. Diaz, and R. Murnane (Eds.), *Climate Extremes and Society*. Cambridge University Press.

Hayhoe K., D. Cayan, C. B. Field, P. C. Frumhoff, E. P. Maurer, N. L. Miller, S. C. Moser, S. H. Schneider, K. N. Cahill, E. E. Cleland, L. Dale, R. Drapek, R. M. Hanemann, L. S. Kalkstein, J. Lenihan, C. K. Lunch, R. P. Neilson, S. C. Sheridan, and J. H. Verville. 2004. "Emissions pathways, climate change, and impacts on California." *PNAS* 101(34): 12422–12427. Aug. 24; Epub Aug. 16, 2004.

Knowles, N. and D. Cayan. 2004. Elevational Dependence of Projected Hydrologic changes in the San Francisco Estuary and Watershed. *Climate Chan*ge 62: 319-336.

Miller, N. L., K. Hayhoe, J. Jin, and M. Auffhammer. 2008. "Climate, Extreme Heat, and Electricity Demand in California." *Journal of Applied Meteorology and Climatology* 47:1834-1844.

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).

References

CCSP, 2008: Preliminary review of adaptation options for climate-sensitive ecosystems and resources. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Julius, S.H., J.M. West (eds.), J.S. Baron, B. Griffith, L.A. Joyce, P. Kareiva, B.D. Keller, M.A. Palmer, C.H. Peterson, and J.M. Scott (Authors)]. U.S. Environmental Protection Agency, Washington, DC, USA, 873 pp.

CCSP, 2009: Best practice approaches for characterizing, communicating and incorporating scientific uncertainty in climate decision making. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. [Morgan, M.G., H. Dowlatabadi, M. Henrion, D. Keith, R. Lempert, S. McBride, M. Small, and T. Wilbanks (Authors)]. Washington, DC, 156 pp.

IPCC, 2004: Workshop on Describing Scientific Uncertainties in Climate Change to Support Analysis of Risk and of Options. Working Group I Technical Support Unit, Boulder, Colorado [Manning, M., M. Petit, D. Easterling, J. Murphy, A. Patwardhan, H.-H. Rogner, R. Swart and G. Yohe (eds.)], May 11-13, 2004, National University of Ireland, Maynooth, Co. Kildare, Ireland, 146 pp. Available at: http://ipcc-wg1.ucar.edu/meeting/URW/product/URW_Report_v2.pdf.

IPCC, 2005: Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties, 4 pp. Available at: www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-uncertaintyguidancenote.pdf.

Moss, R. and S.H. Schneider, 2000: Uncertainties in the IPCC TAR: Recommendations to lead authors for more consistent assessment and reporting. In: Guidance Papers on the Cross Cutting Issues of the Third Assessment Report of the IPCC [Pachauri, R., T. Taniguchi, K. Tanaka (eds.)], World Meteorological Organisation, Geneva, Switzerland, 33-51.