CLIMATE CHANGE VULNERABILITY ASSESSMENT TOOL FOR COASTAL HABITATS

CCVATCH

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Guidance Documentation

Jennifer Plunket, North Inlet-Winyah Bay NERR

Kiersten (Madden) Stanzel, Mission Aransas NERR

Robin Weber, Narragansett Bay NERR

Scott Lerberg, Chesapeake Bay-Virginia NERR

National Estuarine Research Reserve System

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CLIMATE CHANGE VULNERABILITY ASSESSMENT TOOL FOR COASTAL HABITATS

GUIDANCE DOCUMENTATION

ABSTRACT:

The National Estuarine Research Reserve System uses its living laboratories to find solutions to crucial issues facing America's coasts, including climate change and resilience. The input of land managers, decision-makers, and researchers across agencies was sought to ensure that the Climate Change Vulnerability Assessment Tool for Coastal Habitats (CCVATCH) would provide results that could be directly applied to current management and conservation decisions. Changes in climate have direct effects on ecosystems and also interact with current stressors to impact vital coastal habitats. Adaptive capacity, either natural traits of the system or potential management actions, can lessen the impacts of climate change. The CCVATCH utilizes a facilitated expert elicitation process to assign numerical scores for the potential impact of climate change (e.g. change in CO2, temperature, precipitation, sea level, and extreme climate events) and environmental stressors (e.g. invasive and pest species, nutrients, sedimentation/erosion, and environmental contaminants) on the habitat and adaptive capacity potential into a spreadsheet-based decision support tool. Tool design and facilitation process was tested on multiple habitats at each of two pilot sites (e.g. Chesapeake Bay Virginia and North Inlet-Winyah Bay South Carolina NERRs). The pilot project helped the development team to refine the CCVATCH so that it can be used nationally by coastal resource managers as a tool for completing vulnerability assessments.

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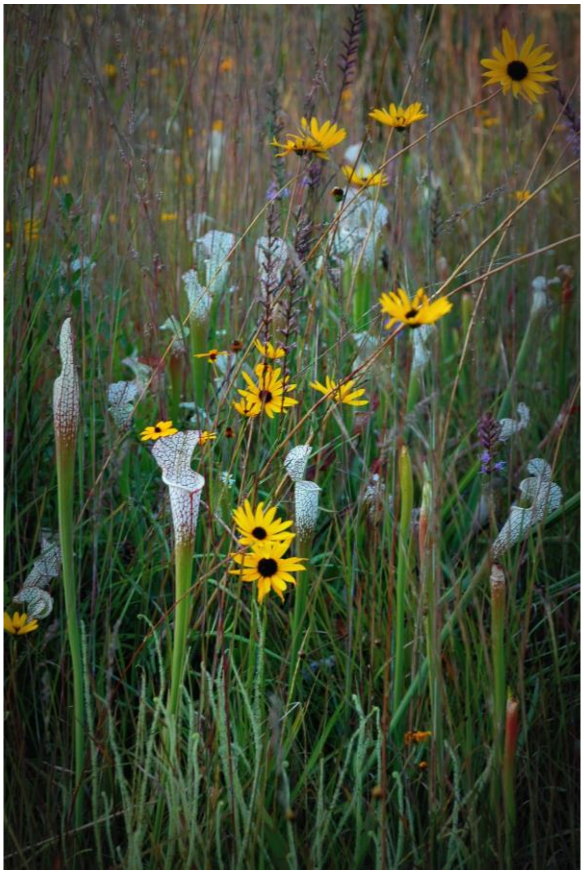

Pitcher Plant Bog, Weeks Bay NERR, Alabama
Primary Stressor: Fire suppression, invasive species
(*photo credit: Eric Brunden*)

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OVERVIEW

The CCVATCH is a spreadsheet-based decision support tool which guides users through a series of questions to calculate numerical climate vulnerability scores for ***ecological habitats***. The questions are designed to assess the potential interactions of climate change exposure (i.e., air/water temperature increase, precipitation change, relative sea level rise, and change in frequency/severity of storm events) with non-climate stressors (i.e., invasive species, nutrients, sediment supply, and contamination exposure/toxicity) to affect the ability of a habitat to persist. The direct sensitivity of the habitat to climate change, the current condition of the habitat, and natural and anthropogenic conditions that affect adaptive capacity are also calculated into the final numerical vulnerability score, which can be used to rank the *relative vulnerability of assessed habitats within a defined area*.

The CCVATCH functions as an integration framework that incorporates local data and knowledge with climate change research/predictions and assessment tools to

(1) provide an evaluation of the degree to which a habitat may be vulnerable to climate change

(2) determine how existing stressors are likely to be exacerbated (or mitigated) by climate change

For both the direct effects and each climate exposure by non-climate stressor interaction, guidance is provided in this document for assigning an exposure-sensitivity score to each habitat. This guidance documentation summarizes available research findings, provides information resources, and outlines how other tools may be used to assess the potential climate exposure by non-climate stressor interaction. This information is meant to be incorporated with knowledge from topical and local experts in a collaborative process to derive the overall vulnerability score for each habitat across a specified range, or alternatively, applied to habitats within individual management units of concern. The ability of the habitat to adjust to changes in climate and stressors (i.e., its adaptive capacity) is also scored by evaluating the degree to which factors that tend to increase a habitats' resiliency apply to the habitat being assessed.

The tool developers acknowledge that the current state of knowledge (i.e., existing climate prediction models, documented impacts of a changing climate on coastal habitats, interactive response of climate change exposures with non-climate stressors, and the degree to which conditions influence adaptive capacity) is in many instances unknown or uncertain. However, they believe it will be possible for local experts to anticipate habitat response based on the available knowledge to a degree that application of the tool is possible and will provide a useful product for managers of coastal habitats. To address gaps in knowledge that arise when determining the vulnerability scores, a certainty score for each vulnerability score is also supplied by users to clarify the degree of confidence in individual vulnerability score derivations.

It is important to note that this tool is designed to require the collaborative input of local knowledge experts and habitat managers to assess the likely sources of vulnerability to climate change impacts for habitats of ecological, economic, and management concern. This tool does not internally generate scores or produce management recommendations. It is intended to provide a framework for incorporating local data and knowledge into the climate adaptation planning process by identifying habitats with the greatest relative vulnerability and by indicating the most likely sources of vulnerability. Understanding which climate-stressor interactions are most likely to contribute to the loss (or gain) of a particular habitat will help habitat managers and local decision-makers to select the most appropriate strategies to either eliminate or reduce the stressor, or alternatively, to improve the processes and conditions that support the resiliency of the habitat.

APPLICATIONS

Information resulting from the CCVATCH process can be used to inform all stages of the vulnerability assessment process. In general CCVATCH results inform management decisions by determining the main sources of vulnerability, potential adaptive capacity components, and comparative vulnerabilities across geographic locations. Potential applications identified by participants from the South Carolina and Virginia pilot projects include:

USE IN MANAGEMENT PLANNING

- Incorporate information derived from CCVATCH into Integrated Natural Resources Management Plans to adjust funding requests to better align with achievable goals and objectives.
- Use vulnerability rankings in the development of agency Wildlife Management Area Plans currently under development.
- Apply CCVATCH as a tool for state park and natural area preserve management.
    - "We hope that our resource managers will use it to influence state park facility development planning. We work facilitating statewide and regional conservation plan creations and revisions. A major role is to bring together experts, stakeholders, partners, and the general public in an effort to make the most comprehensive documents and databases possible." Virginia Dept. of Conservation and Recreation staff
- Value in combining with established decision support tools such as the VEVA (Virginia Ecological Value Assessment) tool for Coastal Virginia.
    - For example, use VEVA to assess the current ecological value of habitats in a targeted area and then determine which you would want to rank in terms of vulnerability (helps in prioritization of projects) .
    - Goal would be to differentiate between high priority versus low priority actions (i.e. high priority habitats might be those with high ecological value as well as being highly vulnerable).
    - Use of a suite of tools in a complementary way (more holistic thinking and planning).
        - Goes beyond ranking individual site habitat vulnerability, if we lose a particular site, how does that impact more comprehensive restoration/green infrastructure planning efforts.
- Use CCVATCH to reverse engineer on-going restoration projects; specifically to identify design elements for climate change adaptation.
    - For example, using CCVATCH to modify the design of living shorelines (based on vulnerability).
    - Use in Natural Resource Consulting; specifically, to evaluate whether projects can reduce habitat vulnerability.

PRIORITIZE RESTORATION PLANNING EFFORTS AND ACQUISITION AREAS

- Rank potential mitigation banks or wetland restoration opportunities across counties/localities.
    - For example, counties may have existing watershed restoration plans but does not yet have a prioritized list of mitigation banks for tidal wetland restoration activities.
- Set protection and restoration priorities and for land conservation opportunities.

Developed to assess the vulnerability of coastal habitats, the use of CCVATCH is not limited to habitats located within the coastal environment; all ecological habitats can be assessed.

  - For example, designing living shorelines and watershed restoration activities to help meet the requirements of TMDL strategies.
  - Elizabeth River Project – undergoes comprehensive ecological planning and can use information on how to design restoration projects to be the least vulnerable.
- CCVATCH can be used to inform recovery decisions for critical habitats and federally/state listed coastal species.

EDUCATION AND OUTREACH

- Public health and safety education
  - "Living and working in the Hampton Roads area makes me very aware of the consequences of rising sea level. I will use this tool while working on the beaches of Ocean View, sampling beach water and executing sanitary surveys, keeping in mind what factors play into the health of the beaches." Virginia Dept. of Health *staff*
- Land trust support: Use CCVATCH to rank vulnerability of current and potential acquisition properties through this tool and use this as an educational and teaching tool for conservation groups.

GUIDANCE FOR POLICY AND FUNDING DECISIONS

- CCVATCH implementation process, certainty scoring, and data resource identification help identify data gaps and potential research avenues and funding opportunities.
- As restoration resources are limited, use CCVATCH to identify best use of funding to promote resiliency where there is the greatest chance of success.
- Use CCVATCH to inform coastal resiliency planning efforts.

IDENTIFY ADDITIONAL DATA AND MONITORING NEEDS

- Greatest value comes in identify data unknowns to be resolved which is critical before you take the next step of management efforts.
- A possible benefit of the certainty scoring in CCVATCH is to identify aspects of climate change that are likely to have a big impact but are also poorly understood.
  - *"As a researcher, the "unchecked boxes" interest me and I hope that researchers (such as those at the NERRS) can work together to fill them in and identify any missing information."*
- CCVATCH helps to fill a gap between science and management.

> *"Going through this process as an exercise is a great example of how discussion amongst knowledgeable peers can find the weaknesses in habitats to climate related stressors."*

Defining Habitat

During the pilot test of the fresh marsh impoundments in South Carolina, there was a discussion about whether the small 'hammocks', islands of bald cypress occurring throughout the marsh, should be considered as separate habitats and not considered in the evaluation of the impounded marsh, or if they were an integral component of the overall marsh habitat. Because one of the main intents in the development of this tool was for it to be used to assist in making management decisions, we recommend that one way of defining the habitat is to consider an area that is under one management regime. In the example above, the cypress stands are imbedded within the impounded marsh, and are managed as a part of the marsh, so should be considered as a part of the habitat for the purposes of this analysis. The goals of the vulnerability assessment should help to determine how the habitats of interest should be delineated.

DEFINITIONS

The following definitions are largely adopted from accepted documents (IPCC 2007, Glick et al. 2011), but they have been adapted to express the specific intent of their use in this documentation.

Adaptive capacity: conditions present in a habitat that may ameliorate the sensitivity or exposure of the habitat or increase its resiliency

Climate exposure: the change in climate attributes that will affect habitat (i.e., air/water temperature increase, precipitation change, relative sea level rise, and change in frequency/severity of storm events)

Exposure: the degree of climate stress upon the habitat, which may be either from long-term changes in climate conditions, or changes in variability, including the magnitude and frequency of extreme events

Foundation species: a species that plays a major role in creating or maintaining a habitat, the loss of which would cause the loss of the habitat. Keystone species should also be included in considerations of stressor effects.

Habitat: a place where multiple species occur together under similar environmental conditions and function as an ecological system

Habitat manager: A person responsible for making or implementing management decisions that ultimately affect a habitat's ability to respond to climate change

Non-climate stressor: Conditions that have been shown to impact the function or integrity of ecological habitats (i.e., invasive species, nutrients, sediment supply, biological and chemical contamination, and disturbance)

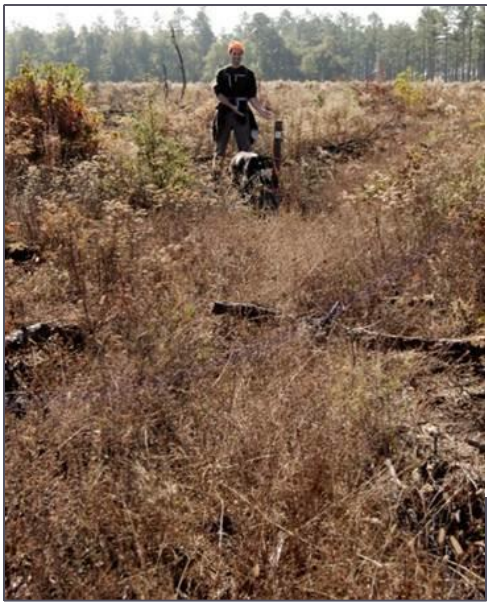
Sensitivity: a measure of whether and how a species or system is likely to be affected by a given change in climate (Glick et al. 2011)

Vulnerability: a function of the sensitivity of a particular system to climate changes, its exposure to those changes, and its capacity to adapt to those changes (IPCC 2007)

Fresh Marsh Impoundment

Restored, fully functional longleaf pine forest

Moderately impaired habitat with limited functionality for target species



Habitat is severely impaired; does not meet any target species requirements

What is meant by 'Impaired' Habitat

Another definition challenge is in the meaning of the word 'impaired' and how to determine the degree of impairment. This could be thought of as a percent area lost, or as a degree of function lost. Determining loss of function can be very difficult to quantify. Although we would like to manage our lands holistically, it is often true that we are managing a habitat for a particular function that can be measured, such as habitat for an endangered species. For example, longleaf pine forests are often managed for red cockaded woodpecker, a species that has fairly specific habitat requirements. A range of functional conditions is possible across habitat areas, from the ideal for this particular species, to a habitat that is possibly undergoing restoration and may provide at least marginal habitat, to one that does not meet any of the species requirements. This can provide a relative scale for determining the degree of impairment a habitat may face due to climate-stressor interactions.

GENERAL GUIDANCE ON SCORING

User assigned scores for current habitat condition, non-climate stressor interactions with climate change exposure, adaptive capacity and certainty related to these scores are entered into the scoring worksheet. Users should apply scores in as many cells as possible. Cells for which a score is not input will be counted as 'null'. In instances when multiple climate change stressors function interactively to effect a non-climate stressor (e.g. a change in temperature results in seasonal changes in precipitation), users should determine whether to assign a single 'best' response in one category (i.e. that of the presumed causative agent influencing habitat change) or provide scores in each related CC stressor column. Applying this user determined response criteria consistently is necessary to generate relative sensitivity-exposure scores between habitats. Additional details on final score computation and worksheet format are available in Appendix A.

CURRENT CONDITION (*green cells of Sensitivity-Exposure worksheet*)
The current condition score is intended to capture the relative health of a habitat prior to the influence of additional stress from a changing climate at some future date. How individual habitat units respond to this future state will depend to some degree on whether the habitat is already compromised from non-climate stressors or, in the case of the direct climate effects, the degree to which climate change has already influenced the habitat (i.e. observed changes in phenology, reduced reproductive success, etc.).

SENSITIVITY-EXPOSURE (*blue cells of Sensitivity-Exposure worksheet*)
The direct effects of climate change on the habitat and the anticipated interactions of climate change with the non-climate stressors are scored in this section of the worksheet. For each habitat, assign a score for each possible interaction of the six sensitivity categories (e.g. direct climate effects, invasive species, nutrients, sedimentation, erosion, environmental contamination) and five climate change exposure categories (e.g. CO_2, temperature, precipitation, sea level rise, extreme climate events).

ADAPTIVE CAPACITY (*pink cells of the Adaptive Capacity worksheet*)
Inherent traits or external factors that allow a habitat to adjust to a changing climate are assessed in the adaptive capacity section of the scoring sheet. For each habitat, assign a score as appropriate to each of the seven adaptive capacity components (e.g. degree of fragmentation, barriers to migration, recovery/regeneration, diversity of functional groups, management actions, and institutional/human response).

CERTAINTY (*pale yellow cells of the Sensitivity-Exposure and Adaptive Capacity worksheets*)
The basis and level of agreement among tool users for selected current condition, sensitivity-exposure and adaptive capacity scores is recorded in the certainty score. When assigning certainty scores for current condition, expert opinion and direct evidence are likely to be the most frequent scores assigned.

The scoring worksheet is designed to accommodate scores for each of five defined habitats. To apply the CCVATCH for more than five habitats simply open and save one or more additional scoring worksheets to record your scores.

Table 1: Scoring Levels

CURRENT CONDITION	**0**	Habitat is not impacted by non-climate stressor
	2	Habitat is currently impacted by non-climate stressor but to a limited degree (i.e. over a modest portion of its' extent or no significant influence on habitat structure/function)
	5	Habitat is currently moderately impacted by non-climate stressor (i.e. evidence of stressor impact over a majority portion of its' extent or clear degradation of habitat structure/function)
	10	Habitat is severely impacted by non-climate stressor
SENSITIVITY-EXPOSURE	**-2**	Habitat may benefit; non-climate stressor impact is alleviated by a change in climate condition
	0	No anticipated change in habitat structure, function or extent
	2	Habitat will likely be impaired to a limited degree (i.e. over a modest portion of its' extent or no significant influence on habitat structure/function)
	5	Habitat persistence will be limited (i.e. degradation of habitat structure/function sufficient to modify reproductive potential, reduced habitat extent)
	10	Habitat will be lost
ADAPTIVE CAPACITY	**0**	Severe impediments to habitat persistence or dispersal (e.g. barriers, fragmentation exist *or* innate community characteristics of the habitat are not sufficient to compensate for CC stressors *or* policy or management actions to offset CC stressors are not possible or are likely to be implemented
	2	Modest impediments to habitat persistence or dispersal (e.g. barriers, fragmentation) exist *or* innate community characteristics of the habitat are sufficient to partially overcome CC stressors *or* appropriate policy or management actions may be taken to partially offset CC stressors
	5	No impediment to habitat persistence or dispersal (e.g. barriers, fragmentation) exists *or* innate community characteristics of the habitat are sufficient to overcome CC stressors *or* appropriate policy or management actions may be taken to fully offset CC stressors
CERTAINTY	**0**	No direct or anecdotal evidence is available to support the score, topic needs further investigation
	1	Low: Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts, score base on anecdotal observations
	2	Medium: Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought, score based mostly on expert opinion
	3	High: Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus, general information can be applied to local habitats
	4	Very High: Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus, information for local habitats

CONSIDERATIONS WHEN SCORING

PROCESS

Once the habitats to be scored are selected, CCVATCH users may elect to work through a single habitat, applying a score for each cell in the automated scoring matrix as appropriate before proceeding to evaluate another habitat or, alternatively, they may choose to sequentially evaluate the individual effects of exposure-sensitivity interactions and adaptive capacity components across all habitats. Tool users may wish to determine, in advance, how to best handle disagreement in responses derived from multiple sources (e.g. expert opinion, peer-reviewed literature). Options may include consensus, highest proposed score as default, average response, etc. The degree to which the assigned score reflects generally accepted opinion is captured using the associated certainty score.

SCORING LEVELS

Following each climate stressor description, a table provides some examples of how considerations about climate-stressor interactions may be used to determine a numerical score level. These examples will not apply to all habitats, but are intended to provide general guidance on how the assessment questions and other information can be used to determine the potential level of response of the habitat.

Although discrete scoring levels are provided for current condition, non-climate stressor interactions with climate change exposure, adaptive capacity, and certainty, tool users are encouraged to assign intermediate scores when scoring levels as described do not fit the presumed habitat response or mitigation potential of the habitat or, alternatively, when tool users cannot agree on the score to be applied. Scoring levels are provided to indicate the relative difference in anticipated change in habitat condition only. Tool users may apply any integer or fractional score provided they do not input values outside the range of scores indicated for the particularly scoring component (e.g., current condition, sensitivity-exposure interaction).

ZERO VS. BLANK

A zero score is not equivalent to a ‘blank’ or ‘null’ score. A zero suggests no change and a blank suggests there is no known potential influence of the stressor on the habitat. Unlike blank scores, zeros are used in computing the total number of responses provided for a given habitat (although they are obviously not reflected in the sum of score tallies) and therefore influence the degree of weighting applied for non-response.

Timeframe for Evaluating Change and Response

Application of the tool requires that the timeframe for evaluating change be agreed upon before beginning the process. Anticipated habitat response will be based on the selected climate projection scenarios for the matching timeframe. The time frame over which adaptive capacity elements are considered is also important. It will need to be determined if predicted changes over the assessment period (e.g. extent of surrounding development, changes in political climate, etc. over the agreed upon timeframe) should be considered or whether scoring within this section should assume the same or similar regulatory / management strategies as currently exist.

The following example is offered to illustrate the appropriate use of zeros vs. blanks in scoring. Habitat 1 is known to be exposed infrequently to chemical contamination and the chemical contaminants are known to have greater toxicity at higher temperatures. The anticipated change in temperature in the selected assessment period (i.e. 25, 50, 100 years from present) is insufficient to cause a measurable change in toxicity. The score assigned should reflect no change (e.g. zero). Habitat 2 typically occupies exposed stream banks or flood plains that occur as the result of significant flooding events. While an anticipated change in temperature can, in certain regions, influence sediment transport associated with snowmelt, the region in which the habitat being assessed is located is not exposed to this annual pulse of stream flow and periodic flooding. No score should be assigned for the interaction of temperature and sediment supply as there is no presumed influence on the habitat.

THE BASIS OF CERTAINTY

Researchers and managers often have a very good understand of the basic ecosystem processes that affect the functioning of their managed habitats, and there is a growing body of research and literature to help assess the possible impacts of climate change on these processes. However, it became evident in all pilots that there are cases where there is missing information about ecosystem processes that was believed to be important, but how or to what degree was unknown. This was either because the particular people in the room doing the assessment did not have enough of a background in the subject or, in many cases, because studies have not been done on the subject. There was also concern over other input and controlling factors that may be entirely unknown at this time. In cases where the assessment team comes to a sticking point due to a lack of information during the assessment process, they can opt to use the certainty score as a flag. By assigning a certainty of 0 to the score, this will represent a topic area that the team may want to revisit after the assessment process.

Included in the guidance is a resource list of literature, websites, and other tools that may be useful in answering some of the unknowns. When assigning a certainty score, information from peer reviewed literature, grey literature (e.g. internal documents, management plans, etc.) and expert consensus should all weigh into assigning the overall certainty for each score. For example, if research found in peer reviewed literature on a subject is sparse or absent, but all of the habitat experts participating in the assessment project have a high degree of agreement based on experience, then a higher certainty score may still be assigned. Another approach to determining certainty may be to decide how comfortable habitat managers would be making management decisions based on the information they have available.

Importance of Note Taking

A good note taker is vital to the process. Key points the note taker should capture include the detailed basis of the score selection for current habitat condition and stressor interactions as well as any information sources used. For example, if invasive species are present in or adjacent to the habitat, a listing of those species should be included in the notes. Good notes will make it possible to review / revisit tool results if new information becomes available and make it possible for individuals / agencies who did not participate in the process to understand the rationale for score selection and, by extension, the primary sources of vulnerability. Recording the information sources will help clarify the assigned certainty scoring and aid in follow-up if the team plans to seek out additional expert opinion to increase certainty. In addition, it can be useful to tally the scores of each person in the room (as well as the final score for the workshop) to assist as a record of how that score was derived (either by some group averaging or consensus driven).

POSITIVE VS. NEGATIVE EFFECTS

When considering any single CC and non-CC interaction the assignment of an 'average' score would not necessarily be appropriate as the directionality and degree to which climate stressors interact with non-climate stressors is not consistently positive or negative nor are relative effects necessarily comparable. For example, a given habitat has multiple invasive species and a change in seasonal precipitation is anticipated to reduce the influence of one invasive species, have no effect on another invasive species, and increase the effect of yet a third invasive species. An 'average' of the anticipated response would suggest a neutral score when in reality the replacement of one invasive whose influence on the habitat is reduced by altered precipitation by another invasive species which is anticipated to have greater effect would result in an overall change in habitat structure and function. The most appropriate score should reflect the 'worst case' anticipated change.

INDEPENDENCE OF SCORES

In some instances, a particular CC and non-CC interaction is anticipated to have a devastating effect on a specific habitat to the extent that habitat persistence is unlikely. Although it may seem unnecessary to continue scoring additional interactions for that habitat, scoring responses should be considered independent of one another to reliably capture the cumulative effect of all contributing CC factors on non-CC stressors and appropriately derive relative measures of overall vulnerability. To illustrate the need for capturing the cumulative effect of all contributing CC factors on non-CC stressors, consider the following simple example. Assume that you have two management units with similar habitats that are sensitive to SLR to the extent that you feel confident that the habitat will be entirely lost at both sites. At one location you have the potential for severe degradation of habitat due to the presence of invasive species and at the other management unit no invasive species are present. As a habitat manager, you determine that it may be possible to mitigate the influence of SLR by the installation of a tide gate at both management units yet there are only sufficient resources to install one. Failing to capture the multiple potential impacts on habitats (e.g., by ignoring subsequent interactions once one has been identified that would lead to habitat loss) would suggest that the installation of a tide gate at either site would have comparable results which is not likely true. It is necessary to treat scoring responses independently of one another to derive relative measures of overall vulnerability in all habitats assessed to better inform management decisions.

FEEDBACK LOOPS

This tool asks the user to consider the impacts of each stressor on the habitat independently, although we do recognize that in reality feedback loops exist between stressors. For example, a predicted decrease in annual rainfall may increase salinity in coastal marshes due to increased salt water intrusion. This affect will likely by compounded by sea level rise, the rate of which could also be compounded by subsidence due to a decrease in primary production. For the purposes of this tool, the effects of the change in precipitation directly on the marsh through increasing salinity could be assessed as a precipitation-sediment interaction if the major potential effect is considered to be a decrease in sediment due to a decrease in growth of marsh grasses. The effects of sea level rise on the marsh surface would then be considered independently under the sea level-sediment interaction if the primary adverse effect is due to loss of production, or as a sea level-erosion interaction if the major adverse effect is the washing away of sediment due to more frequent flooding.

Table 2: Multiple stressor interactions and feedback loops

	↓Precipitation	**Sea Level**
Sediment	↑ Salinity= ↓ vegetation growth = ↓ sediment production	↑ Salinity (inundation frequency) = ↓ vegetation growth = ↓ sediment production
Erosion	↓ Erosion due to runoff	↑ inundation frequency, current velocity = ↑ edge erosion

DOUBLE COUNTING

In cases where a single climate-stressor effect on a habitat could be scored under multiple climate-stressor interactions, there is a potential for 'double counting' the effects of an interaction. For example, the effect of frequent storms on coastal erosion can be considered as both a direct climate effect, but also under the erosion stressor category. If it is believed that a change in storm frequency or intensity will cause erosion though direct removal of sand during the storm, then it is suggested that this would be scored under direct effects. If there is an erosion problem that is believed to be mainly the result of changes to the landscape that have altered the natural movement of sediments, such as up current groins, dredging, upriver dams, etc., then this would be scored as an erosion stressor. It is possible that both of these could be true for this habitat, so giving scores in both of these categories would not be double counting as they are accounting for two different sources of vulnerability. It is up to the knowledge experts to determine the level of scoring for each category and what the most likely or important sources of vulnerability are. The strength of this method is that it helps managers to break down the individual sources of vulnerability to determine where adaptive capacity can be increased.

Table 3: Multiple stressor interaction and double counting

	Current Condition	**Predicted ↑ Storms**
Direct Effects	Erosion due to storms occurs regularly	An increase in storm intensity will directly increase amount of erosion
Erosion	Erosion is occurring due to changes to system processes (e.g. groins)	Habitat will be more exposed to storm erosion due to changes to the natural processes of the system

Component Species Transitions

Species within a habitat might change, but this is not always detrimental. For example, salt marsh composition may change as salinity changes within a tidal marsh system, but this might not ultimately result in the habitat being more "vulnerable" (i.e. you might have a set of replacement species which could serve the same function as the species they replaced). During one workshop participants agreed that there would always be a 'shrub component' but that the species may vary; the climate change scenario will bring about changes in species composition but not in community structure – not good or bad – just different. It's humans who put a value on specific habitats/species/systems.

DIRECT CLIMATE EFFECTS

CURRENT CONDITION

Direct climate effects are the ecophysiological responses of organisms and ecosystems to changes of CO_2, temperature, precipitation, sea level and extreme climate events in the absence of ecological stressors. Changes in climate may directly affect development, survival, range and abundance of species as well as species interactions. For example, studies in Europe and North America have revealed phenological trends that very probably reflect responses to recent climate change (Walther et al. 2002). Common changes in the timing of spring activities include earlier breeding or first singing of birds, earlier arrival of migrant birds, earlier appearance of butterflies, earlier choruses and spawning in amphibians and earlier shooting and flowering of plants. Range shifts have also been documented across a wide range of taxonomic groups and geographic locations. Community composition may also be affected as changes in distribution are often asymmetrical with species invading faster from lower elevations or latitudes than resident species are receding upslope or pole-ward. The result is a (presumably transient) increase in species richness of the community in question as a consequence of the variability in rates at which species shift their ranges (Walther et al. 2002). Changes to recruitment success and trophic interactions may also be indicators that recent climate changes have altered habitat function.

Assessment Questions

- Have changes to the timing of breeding, hatching, flowering, or the arrival of migrants been documented in recent decades?
- Has there been a change in the species composition of the habitat that is associated with a range shift?
- Have changes to recruitment success been observed in the habitat?

DIRECT EFFECTS OF AN INCREASE IN CO_2

Elevated levels of atmospheric CO_2 are known to increase photosynthesis, plant biomass production, and transpiration rates (Rosenzweig and Hillel 1998). However, the effect of increased CO_2 can be disproportionate among species (e.g., C3 and C4 species) and under varied water stress conditions (Shutz and Fangmeier 2001) can result in a potential shift in plant community composition. More rapid fuel accumulation may occur in some forest types, and altered competitive relationships between various overstory and understory plants could also affect the distribution and characteristics of fuels. Such changes may increase fire frequency and severity in some ecosystems and diminish it in others (Keeley et al. 2009).

Ocean acidification is the on-going decrease in the pH of the Earth's oceans caused by the uptake of anthropogenic CO_2 from the atmosphere. Decreases in pH predicted for the next century are expected to affect several marine taxa (Fabry et al. 2008). Calcifying invertebrates can be affected by the direct effects of carbonate chemistry on calcification rate and shell integrity, as well as through CO_2 induced disturbances that lead to metabolic disturbances and ultimately impact growth and calcification rates (Thomsen et al. 2010).

Assessment Questions

- Is the habitat composed of species which are likely to respond differently to elevated levels of CO2 resulting in altered community composition?
- Is fuel loading within this habitat anticipated to change as a result of elevated CO2 potentially resulting in more frequent or severe wildfire?
- Are calcifying invertebrates a keystone species in the structure of the habitat?

DIRECT EFFECTS OF AN INCREASE IN TEMPERATURE

Annual or seasonal increases in temperature can influence competitive interactions among species resulting in range expansions or species dominance shifts. For example, increased temperature increases evapotranspiration and causes forb species to be outcompeted and displaced by high marsh grasses which will potentially drive rare forb assemblages to local extinction in southern New England (Gedan & Bertness 2009), and a reduction in freeze frequency has resulted in the displacement of salt marsh through the more widespread establishment of mangroves in the northern Gulf coast (Day et al. 2005). An increase in temperature may increase winter survival rates of a species, and this change may adversely impact the habitat if the population of a keystone species increases beyond the carrying capacity. Heat stress in foundation species can affect habitats directly through increased mortality or through increased susceptibility to disturbances such as fire, pests, and pathogens. Population structures can also be impacted by seasonal changes to temperature, for example increased temperature can change sex ratios of offspring.

Assessment Questions

- Is the predicted temperature expected to meet or exceed a foundational species tolerance?
- Is heat stress likely to affect foundational species and increase direct or indirect mortality rates?
- Would a change in growing season length cause phenological shifts in foundational species and life-cycles of pollinators?
- Is an increase in frost free days predicted to exceed the tolerance of a frost-dependent foundational species?
- Would an increase in heat stress make the habitat become more susceptible to disturbances such as pathogens, pests and fire?

DIRECT EFFECTS OF A CHANGE IN PRECIPITATION

Projected regional changes in total precipitation and the seasonal timing of precipitation events alters flow regimes which may influence salinity levels in coastal areas, nutrient availability, sediment supply, channel stabilization rates, hydrologic connectivity, available water supply and residence time. Alteration in annual precipitation amounts and shifts in seasonality of precipitation can result in more severe dry seasons which contribute to direct and indirect mortality (i.e. increased susceptibility to disease). Drought stress is typically greater in vegetation occurring in shallow sandy soils than vegetation growing in deeper, heavier soils (Hanson and Weltzin 2000). Longer wet seasons could lead to waterlogging and reduce germination and changes to understory vegetation. Predicted change in precipitation patterns and increased temperatures may lead to prolonged fire seasons and encourage more frequent and intense fires (Westerling et al. 2002; Gillett et al. 2004).

Salt Marsh, Great Bay NERR, New Hampshire
Primary Stressor: Sea level rise
(*photo credit: Rachel Stevens*)

Assessment Questions

- Will the predicted change in timing of precipitation events change seasonal water availability to the extent that it would influence a species' reproductive success or shift competitive interactions among species?
- Is a predicted change in annual precipitation amounts sufficient to induce drought stress and/or mortality of foundational species?
- Will predicted changes to precipitation alter salinity regimes to a degree that exceeds the physiological tolerance of a foundational species?
- Will predicted changes to precipitation alter salinity to a degree that will affect species competition and alter the composition of the habitat?
- Is drought stress likely to contribute to increased direct or indirect mortality (e.g. fire frequency and intensity) through changes in severe disturbance effects?
- Is a predicted shift in precipitation timing and amount likely to expose this habitat to an altered flooding or fire regime?

DIRECT EFFECTS OF SEA LEVEL CHANGE

Sea level rise can influence species distributions through both direct inundation and by salinity intrusion into coastal and groundwater aquifers. Coastal habitats experiencing higher salinity levels in surface and groundwater will shift to more salt tolerant species resulting in altered habitat structure and fuel loading as coastal communities, particularly coastal forests, suffer increased mortality (Poulter et al. 2009).

Assessment Questions

- Is this habitat likely to be directly lost due to inundation?
- Is projected sea level rise likely to influence salinity levels of this habitat's available surface or sub-surface water beyond foundational species' tolerance?
- Is relative sea level rise sufficient to cause physiological stress or mortality in the coastal community and increase opportunities for disturbance dependent habitats to colonize?

DIRECT EFFECTS OF EXTREME CLIMATE EVENTS

Extreme climate events include weather events such as hurricanes and northeasters, as well as fires, major floods, and snow and ice events that can cause sudden, large-scale disturbance to habitats. Local, regional, and global changes in temperature and precipitation can influence the occurrence, timing, frequency, duration, extent, and intensity of disturbances (Dale et al. 2001). The direct effect is a potential change in community composition as the result of open canopy gaps and the indirect effect is the potential for more frequent or extreme disturbance events. For example, both wildfire and storm surge have the potential to directly create extensive and catastrophic habitat disturbance, while an increase in fuel loading from downed trees after a storm can indirectly increase the severity, frequency and duration of wildfire. Disturbance from storm events can also directly affect habitats if the disturbance serves as a catalyst for increases in insect populations resulting in additional feeding and predation stresses on tree hosts (Woods et al. 2010), which in turn may increase fire mortality rates. More frequent disturbances from extreme events will favor species assemblages that readily occupy newly available space or benefit from altered light intensity or water availability and is detrimental to habitats with species which do not reach sexual maturity or complete their life cycles within the disturbance interval.

Assessment Questions

- Is the anticipated frequency and intensity of storms predicted to be at an interval that would prohibit regeneration in foundational species and compromise habitat persistence?
- Has the habitat been susceptible in the past to secondary effects such as fire or insect herbivory following major disturbance events?

Human-induced disturbance (e.g., prescribed fire regimes, mechanical clearing, flood control), while also capable of altering ecosystem structure and habitat persistence, are considered management actions which are incorporated in the adaptive capacity section and are not addressed here.

Flatwoods, Weeks Bay NERR, Alabama
Primary Stressors: Temperature, precipitation, sea level rise, extreme climate events, invasive species, environmental contaminants
(*photo credit: Eric Brunden*)

Table 4: Scoring Examples for Direct Climate Effects

These examples will not apply to all habitats, but are intended to provide general guidance on how the assessment questions and other information can be used to determine the potential level of response of the habitat.

	-2	0	2	5	10
Current Conditions		No changes to phenology, species composition, or recruitment success that are attributed to climate change have been observed	A shift in phenology or species composition attributed to recent climate change has occurred, but has not caused significant loss of habitat function	There has been a disconnect between a host-plant and pollinator, or significant change to a tropic interaction due to recent climate change	A phenologic disconnect, change to tropic interactions or change to recruitment has resulted in the loss of function of the habitat
Increase in CO_2	Habitat will benefit from elevated CO_2 through more rigorous growth and/or changes in the fire regime due to shifts in fuel load	An increase in CO_2 will not affect growth and/or the fire regime	Community composition is likely to be altered by changes in growth and/or fire regime which will have some effect on habitat structure or function	Changes in community composition due to changes in growth and/or fire regime are likely to severely alter habitat structure or function	Foundation species will be displaced due to changes in competitive growth rates *or* habitat will be completely lost by changes in disturbance regime
Increase in Temperature	Habitat will benefit from increase in growing season length, decrease in frost days	Habitat is not affected by the predicted change in temperature or predicted change is not great enough to affect the habitat	Changes in temperature (e.g., growing season length, number of frost days) will reduce growth / vigor or reproduction of foundation species	Change in temp (e.g., growing season length, number of frost days) will cause phenological shifts that will alter habitat function *or* interactions between temperature and disturbance will increase mortality or decrease habitat function	Change in temperature (e.g., growing season length, number of frost days) will exceed foundation species tolerance *or* habitat will not persist under altered disturbance frequency and/or severity

Table 4: Scoring Examples for Direct Climate Effects (cont.)

	-2	0	2	5	10
💧 Change in Precipitation	Habitat is comprised of generalist species which are likely to benefit (i.e. by competitively displacing habitats with a narrow tolerance for hydrologic conditions)	This habitat will not be affected by the predicted change in precipitation	Change in amount or seasonality of water will reduce growth/vigor or reproduction of foundation species or alter competitive interactions (e.g. drought tolerant species become dominant) to a limited degree	Reduced growth/vigor or reproduction of foundation species and change in competitive interactions (e.g. drought tolerant species become dominant) resulting in habitat conversion over some portion of the current extent	Habitat structure will be altered by loss of foundation species, or direct conversion (i.e. permanent flooding or drying up)
🌊 Change in Sea Level	Habitat will benefit (e.g. increased area due to inundation)	Change in sea level will not affect this habitat	Change in salinity levels will affect available surface or subsurface fresh water causing moderate stress to foundational species resulting in limited change in community structure / function	Frequency of inundation will cause stress for foundation species to the extent that it is likely to alter species composition or alter critical species interactions	Habitat will be inundated or exposed (direct conversion)
⛈ Increase in Extreme Climate Events	Habitat is dominated by pioneer species that benefit from increased disturbance	Habitat is not affected by storm disturbance	Foundation species is slow to regenerate after disturbance or will be stressed by increased frequency of disturbance (e.g. salt spray)	Critical species interactions will be affected by an increase in disturbance events resulting in a partial displacement within current habitat range	Habitat is not likely to recover from major disturbance (e.g. isolated habitat with no source of recolonizers) or disturbance frequency prohibits regeneration of foundational species

INVASIVE / NUISANCE SPECIES

CURRENT CONDITION

Invasive species are animals or plants whose introduction causes environmental, ecological, or economic damage. Both native species and exotic species not indigenous to the area can be considered invasive or nuisance species if they threaten local biodiversity. Nuisance species may also be species that cause periodic disruptions to the habitat if those disruptions are greater than the normal range of conditions. For example, beaver ponding may be a regular feature of a habitat area, but an increase in beaver population may create unfavorable conditions. Pest species, such as plant parasites, should also be considered within this stressor category.

Assessment Questions

- Is there an invasive species that is currently under management or requires management in the habitat?
- Is there an invasive species present in the area surrounding the habitat that is likely to invade?
- Is there a known nuisance species (e.g. parasite, insect, or habitat altering animal such as beaver) that is at least periodically affecting the function of the habitat?

INCREASE IN CO_2 EFFECTS ON INVASIVE / NUISANCE SPECIES

Plant pests and invasive species may become more difficult to manage due to the effects of elevated CO_2. Studies have demonstrated that an increase in atmospheric CO_2 can increase plant herbivore consumption (Stiling and Cornelissen 2007) and has the potential to increase plant pathogen aggressiveness (Lake and Wade, 2007). There is some evidence in terrestrial invasive species that increasing carbon dioxide concentrations may enhance their tolerance to certain herbicides, undermining the effectiveness of chemical treatments (Ziska et al. 1999, 2004).

Assessment Questions

- Are plant stress or mortality rates associated with herbivore or pathogen interactions likely to increase with an increase in CO_2?

INCREASE IN TEMPERATURE EFFECTS ON INVASIVE / NUISANCE SPECIES

Increasing winter minimum temperatures and reductions in the frequency and severity of freezing conditions will most likely produce a northward shift in the range of subtropical species (Mulholland et al. 1997). Some currently unsuccessful, non-native species will be able to colonize if conditions become more like the species' native range. The higher optimum temperature for photosynthesis found in C4 species may provide an advantage over C3 plants in a warmer environment (Ehleringer et al. 1997). Milder winters also create longer growing seasons, potentially increasing reproductive output of invasive species. Because climate change is expected to shift native species out of the conditions to which they are adapted, competitive resistance from native species may lessen (Byers 2002).

Oyster Reef, Apalachacola NERR, Florida
Primary Stressors: Pathogens, change in precipitation/temperature (reduced water availability)
(*photo credit: Lakeland Ledger*)

Greater overwintering success of pathogens will likely increase disease severity in terrestrial and marine biota (Harvell et al. 2002). An increase in frost free days may reduce pathogen latency periods which alone, or in combination with heat stress in host plants, can effect habitats directly through increased mortality or indirectly (e.g. by increasing fire mortality).

Assessment Questions

- Is the spread/extent/vigor of an invasive species currently limited by temperature extremes (e.g. frost) that are predicted to change to be within the tolerance limits of the species?
- Is the distribution of an invasive currently limited by a natural control (e.g. herbivory) that will be affected by a change in temperature?
- Is an increase in frost-free days liable to alter host-pathogen or host-pest interactions and cause increased host plant stress or mortality?

CHANGE IN PRECIPITATION EFFECTS ON INVASIVE / NUISANCE SPECIES

Changes in precipitation during specific seasons appear to be a particularly important predictor of plant invasion. Large rainfall events have been shown to increase germination and growth of invasive trees in arid savannah. In regions where precipitation increases, ornamental species that had been restricted to gardens by water limitation could become more problematic. An increase in floods may increase the dispersal of terrestrial plant species with floating seeds. Under some conditions, climate change could alter the relative impact of an invasive species. For example, species that tend to uptake water may have a greater impact on the ecosystem under drought conditions.

Assessment Questions

- Is the distribution of an invasive species limited by flooding timing/duration? Will changes to precipitation patterns change this threshold?
- If there is a predicted increase in drought frequency/severity, is an invasive species more drought tolerant than the natives?

- Would an increase in floods increase the dispersal of an aquatic invasive species with planktonic larvae and terrestrial plant species with floating seeds?

SEA LEVEL CHANGE EFFECTS ON INVASIVE / NUISANCE SPECIES

Increased inundation time and salinity as a result of sea level rise can reduce the competitive ability of native species and increase the distribution of invasive species. Salinity-intolerant species incur an increased physiological cost to maintain osmotic balance as salinity increases, and they grow more slowly than salinity-tolerant species. Thus, climate-induced increases in salinity may favor invasive aquatic species if they are more salinity tolerant than native species (Rahel and Olden 2008).

Assessment Questions

- Will the potential colonization area of the invasive species be increased by increased tidal inundation or exchange?
- Is the dominant native species already at the upper limit of its salinity or inundation tolerance, effectively restricting its competitive capacity?

EXTREME CLIMATE EVENTS EFFECTS ON INVASIVE / NUISANCE SPECIES

Extreme climate events may facilitate invasions by creating disturbed sites for invasive species to become established and by dispersing these species to the sites. Major floods or storm surge may disperse marine invasive species with planktonic larvae and terrestrial plant species with floating seeds into new habitats. Wind storms and fires may open up the canopy in forest habitats, allowing invasive plants to colonize.

Assessment Questions

- Is there an invasive or nuisance species that will rapidly colonize the habitat after a major disturbance?

Atlantic Coastal Pine Barrens, Narragansett Bay NERR, Rhode Island
Primary Stressors: Temperature, precipitation, extreme climate events, invasive/nuisance species, fire suppression
(*photo credit: Robin Weber*)

Harmful Algal Blooms (HABs) are the result of a change in condition favoring the rapid growth of native algal species beyond normal population levels. As byproducts of HABs may include the buildup of toxins as well as high turbidity and low oxygen events resulting in increased mortality across a variety of habitats, HABs are included in the Environmental Contaminants section.

Table 5: Scoring Examples for Invasive / Nuisance Species

These examples will not apply to all habitats, but are intended to provide general guidance on how the assessment questions and other information can be used to determine the potential level of response of the habitat.

	-2	0	2	5	10
Current Conditions		No invasive species are present or currently pose a threat to the habitat	An invasive species is present in the habitat, but currently does not require management or is not expected to significantly alter habitat function	An invasive species requires management and has or is expected to alter habitat function	An invasive species has replace most of the native species and habitat function has been lost
Increase in CO_2	The habitat would benefit from increase growth, vigor, or reproductive output with an increase in CO_2	There is no anticipated interaction between CO_2 and a current or potential invasive species	A plant herbivore or pathogen is present that may benefit from an increase in CO_2, or an invasive is expected to have a competitive advantage under increased CO_2	An herbicide currently used to control an invasive has been shown to be less effective under increased CO_2 conditions, or an invasive has been shown to be more vigorous with increased CO_2	There is an interaction between CO_2 and an invasive that is predicted to cause the loss of habitat function
Increase in Temperature	Predicted change will limit the growth/spread of a current invasive species	Predicted changes in temperature will not increase the invasive species threat	At least one invasive species is predicted to become more invasive due to increased growth/vigor due to change in temperature	At least one invasive species is predicted to become more invasive and a foundation species is predicted to become more susceptible or less competitive resulting in moderate changes in habitat structure or function	An invasive that will completely alter the habitat structure is predicted to become more invasive due to increased vigor, loss of temperature control, or loss of competitive native species

Table 5: Scoring Examples for Invasive / Nuisance Species (cont.)

	-2	0	2	5	10
Change in Precipitation	Predicted change will limit the growth/spread of a current invasive species	Predicted changes in precipitation will not increase an invasive species threat	At least one invasive species is predicted to become more invasive due to increased growth/vigor due to change in precipitation	The spread of at least one invasive is predicted to be enhanced (e.g. through flooding) and/or an invasive species is more adapted to the predicted precipitation patterns than foundation species (e.g. drought tolerant) resulting in a change in community composition across some portion of the current habitat extent	At least one invasive that will benefit from the predicted precipitation change has the potential to alter the habitat structure (e.g. increased water uptake) effectively causing complete loss of habitat
Change in Sea Level	Predicted change will limit the growth/spread of a current invasive species	Predicted changes in SL will not increase invasive species threat	An invasive species will be introduced by a change in SL or invasive species will have a moderately greater competitive advantage	An invasive species will be introduced and a foundation species will be less competitive resulting in a significant shift in community composition over a portion of the habitats' current extent	At least one invasive that will benefit from change in SL has the potential to alter the habitat structure to the extent that it effectively causes complete loss of habitat
Increase in Extreme Climate Events	An increase in disturbance from storm events would limit the growth/spread of a current invasive	Storm disturbance will have no effect on invasives	Invasive that is quick to colonize disturbed areas is present	Invasive that is quick to colonize disturbed areas is present and disturbance exposure will stress foundation species (e.g. wind driven salt exposure) resulting in a major shift in community composition over a portion of the original habitat extent	Invasive that is quick to colonize disturbed areas is present and disturbance exposure will exceed tolerance of foundation species (e.g. wind driven salt exposure) resulting in complete habitat loss

NUTRIENTS (DEFICIENCY OR EXCESS)

CURRENT CONDITION

The availability of nutrients affects plant growth, community composition, and habitat structure. In coastal systems such as salt marshes, nitrogen is typically the limiting nutrient, while freshwater wetlands are typically phosphorus-limited or limited by both phosphorus and nitrogen. If nutrient availability changes significantly, shifts in species composition may occur. In most cases, excess nutrients cause loss of habitat function, although for some habitats a lack of nutrient input could be an ecological stressor. Changes to the landscape surrounding the habitat, for example increased impervious surface area, will affect the nutrient inputs, so the condition of areas adjacent to the habitat that is being assessed should be considered when scoring this stressor.

Recent studies in New England, United States, salt marshes indicate that nutrients may strongly mediate plant community composition by increasing the competitive ability of stress-tolerant species that are normally displaced by competition to recently-disturbed or low-intertidal habitats. For example, fertilization always increased the biomass of the low-marsh dominant *Spartina alterniflora* and usually led to it increasing in dominance at the expense of high-marsh species. Fertilization also led to increased community dominance by *Distichlis*, but only in a mixture where it was already common (Pennings et al. 2002). Literature reviews (DiTomasso and Aarssen 1989) and meta-analyses (Gough et al. 2000) have found relatively similar responses of community biomass and species richness to nutrient additions, with biomass increasing and richness decreasing. Excess nutrients may also decrease live plant root biomass because the efficacy of root foraging for nutrients increases, causing a much diminished matrix to bind marsh soils together and a lower rate of vertical accretion (Darby and Turner 2008).

Assessment Questions

- Is eutrophication currently an issue for this habitat?
- Is habitat function limited due to a lack of nutrient input?

INCREASE IN CO_2 EFFECTS ON NUTRIENTS

Forested Wetland, Narragansett Bay NERR, Rhode Island
Primary Stressors: Temperature, precipitation, extreme climate events, invasive species
(*photo credit: Robin Weber*)

Some of the expected changes in biogeochemical processes (in both soil and water) from the expected increases in atmospheric carbon associated with climate change include increased rates of the following: primary production, organic matter accumulation, nutrient storage in above and below ground biomass, nutrient release from soils and methane emissions (Reddy et al. 2010).

At low fertility sites, such as bog and some lake shorelines, nutrient enrichment favors weedy, strongly competitive species that can outcompete the native dominant species as well as those that are rare and endangered. In these situations, CO_2 enrichment may contribute to a reduction in local plant diversity. Mozdzer and Megonigal examined two different strains of *Phragmites*, the introduced invasive strain from Europe and the native North American strain, exposed to one of four treatments: elevated CO_2, elevated nitrogen, elevated CO_2 and nitrogen combined, and a control treatment within a Smithsonian Environmental Research Center (SERC) greenhouse (Mozdzer and Megonigal 2012). The invasive *Phragmites* gained roughly 40 percent more biomass under higher CO_2 and almost 300% with CO_2 and nitrogen combined. The critical factor was in the flexibility of the invasive species, or its ability to adapt to the changing environment (while the native strain showed little to no variation with changing environmental conditions). For example, when CO_2 levels increased, the leaves of the invasive *Phragmites* thickened, allowing them to grow more with less water. When nitrogen levels in the soil rose, invasive *Phragmites* responded by growing fewer roots and more shoots. When nitrogen was limited, the invader changed its metabolism to maintain high growth.

High marsh/forest ecotone, Chesapeake Bay NERR, Virginia
Primary Stressors: Sea level/salinity, invasive species
(*photo credit: Scott Lerberg*)

Carbon dioxide enrichment itself has the potential to alter species composition in some wetland types, independently of hydrologic or temperature changes. For example, higher CO_2 concentrations favored C-3 species in comparison with C4 counterparts in marshes on the Chesapeake Bay. This resulted in an actual decrease in biomass of the C-4 component with four years of high CO_2 exposure (Marsh 1999). Responses of plants to CO_2 enrichment are further masked by enrichment of nitrogen and phosphorus in wetlands and contributing aquatic ecosystems and biochemical theory predicts that the availability of soil nitrogen may limit natural ecosystem response to elevated CO_2 concentration, diminishing the CO_2 fertilization effect on terrestrial plant productivity in unmanaged systems (Langley and Megonigal 2010). In a study conducted at the SERC in Maryland, researchers manipulated atmospheric CO_2 concentration and soil nitrogen availability in a herbaceous brackish wetland dominated by a C3 sedge and C4 grasses. They found that N addition strongly promotes the encroachment of C4 plant species that respond less strongly to elevated CO_2 concentrations. In this case, the results point to a novel finding that N-driven changes in species composition limited the whole ecosystem response to elevated CO_2 (Langley and Megonigal 2010). However, in general, elevated CO_2 studies have reported no consistent CO_2 effects on estimates of soil N availability, either owing to great error in estimates or because CO_2-stimulated plant activity could liberate additional soil N to compensate (Langley and Megonigal 2010).

Understanding whether and how climate change affects cycling of nutrients such as phosphorus, sulfur, nitrogen, and potassium would likely alter current predictions about the carbon cycle responses within coastal ecosystems (Mozdzer and Megonigal 2012).

Assessment Questions

- Will changes in the community composition of the habitat anticipated by increased levels of atmospheric carbon be impacted by concurrent increases in nutrients with the system?
- Is the habitat sensitive to any of the expected increases in biogeochemical processes or increased rates of nutrient storage expected with an increase in carbon dioxide levels in the atmosphere?
- Are there non-native species which might be able to take advantage of the nutrient limited (or nutrient enriched) environments under future increases in atmospheric carbon dioxide?

- Are foundation species susceptible to small changes in sediment nutrient levels or organic matter accumulation?
- Does the habitat have a current nutrient enrichment problem that would be worsened or benefited by an increase in atmospheric carbon?

INCREASE IN TEMPERATURE EFFECTS ON NUTRIENTS

An overall increase in air and ground temperatures may increase nutrient availability to systems through several mechanisms. Increased temperature may increase decomposition rates, increasing nutrient availability. Higher temperatures also reduce saturation levels. Ammonium concentration increases over time as higher temperatures increase soil mineralization.

Increased temperature may enhance eutrophic conditions by stimulating macrophyte growth. A 2002 study found that a 2–3°C temperature increase could cause a 300–500% increase in shoot biomass of the aquatic macrophyte *Elodea canadensis* (Kankaala et al. 2002). Because macrophytes take up the phosphorus sequestered in the sediment, the amount of phosphorus immediately available for other primary producers may decline and the increased oxygen demand during the bacterial and fungal decomposition of these macrophytes can lead to depressed levels of dissolved oxygen, raising the likelihood of chronically stressful hypoxic conditions (Ficke et al. 2007).

Assessment Questions

- Is the habitat currently nutrient limited so that an increase in decomposition rates or soil mineralization due to higher temperatures would change structural composition of the habitat?
- Would a current nutrient enrichment problem be worsened by a lengthening in the growing season?
- Is the habitat sensitive to small changes in nutrient input or decomposition rates?

CHANGE IN PRECIPITATION EFFECTS ON NUTRIENTS

Larger and more intense precipitation events mobilize nutrients on land and increase nutrient enrichment of receiving waters (Paerl et al. 2006; King et al. 2007). Freshwater discharge to downstream waters would also increase, which in the short-term may prevent blooms by flushing. However, as the discharge subsides and water residence time increases, its nutrient load will be captured and cycled by receiving water bodies, eventually promoting bloom potentials. This scenario will most likely occur if elevated winter-spring rainfall and flushing events are followed by protracted periods of drought (Paerl and Paul 2012). During low-flow periods, nutrients will become concentrated and flush out of systems more slowly. Lower minimum flows imply less volume for dilution and higher concentrations downstream of point discharges such as wastewater treatment works. Under reduced flows in summer, phosphorus levels may increase, whereas ammonia levels would fall due to higher nitrification rates. This gives rise to increased nitrate concentrations as ammonia decays to nitrate, causing enhanced growth of algal blooms in rivers and reservoirs which could affect dissolved oxygen levels (Whitehead et al. 2009). Higher rates of primary production have been observed in the Hudson River estuary (USA) during dry summers when freshwater discharges are lower and residence times, stratification and depth of the photic zone increase (Howarth et al. 2000).

Assessment Questions

- Is the habitat dependent upon nutrient inputs that will be altered by the predicted change in precipitation (e.g. lack of runoff due to drought)?
- Will the predicted change in precipitation cause excess nutrients to enter the habitat?
- Is the habitat susceptible to an increase or decrease in nutrient concentrations or ratios that would occur with increased or decreased flow into the habitat?

SEA LEVEL CHANGE EFFECTS ON NUTRIENTS

An increase in sea level will have direct consequences on the benthic primary producers of coastal environments due to the increase in depth, the reduction of light reaching the bottom, the changes of salinity and the alteration of the hydrodynamics of the areas.

In salt marshes, nitrogen limitation restricts plants' ability to synthesize osmolytes and deal with salts (Cavalieri and Huang, 1981).

Assessment Questions

- Would the nutrient dynamics of the habitat be altered by a change in water level (e.g. decrease in light attenuation)?
- Would the nutrient dynamics of the habitat be altered by a change in salinity?

EXTREME CLIMATE EVENTS EFFECTS ON NUTRIENTS

With increased storm events, especially in summer, there could be more frequent incidences of combined sewer overflows discharging highly polluted waters into receiving water bodies, although there could be benefits in that storms will also flush away algal blooms. (Whitehead et al 2009).

Assessment Questions

- Is the habitat at risk from an influx of nutrients associated with overflow from waste water treatment plants during storm events?

Table 6: Scoring Examples for Nutrients

These examples will not apply to all habitats, but are intended to provide general guidance on how the assessment questions and other information can be used to determine the potential level of response of the habitat.

	-2	0	2	5	10
Current Conditions		There is no nutrient enrichment or deficiency affecting this habitat	There is an excess or deficiency of nutrients that is moderately impacting the function of the habitat	Nutrients are a significant management concern in the habitat or changes to the surrounding habitat have created a nutrient stressor that is impacting the function of the habitat	Habitat function has been lost due to a nutrient stress
Increase in CO_2	The removal of nutrients from system through organic matter accumulation, storage in plant biomass, or release from soils would benefit the habitat	Increase in CO_2 would have no effect on nutrient cycling processes or differential impacts to nutrient cycling would balance out (both beneficial and negative response among species)	Alter the composition of the habitat to a limited extent by increasing nutrient availability	Alter the composition of the habitat to a significant extent by increasing nutrient availability	A small change to nutrient availability through increased levels of atmospheric carbon dioxide would eliminate the habitat
Increase in Temperature	Predicted change in temperature will increase nutrient availability from decomposition which will benefit the habitat	Have no effect on the decomposition rates or O_2 saturation levels	Alter the composition of the habitat to a limited extent by increasing nutrient availability or decreasing O_2	Alter the composition and structure of the habitat over a portion of the original habitat extent	A small change to decomposition rates or nutrient availability would eliminate the habitat

Table 6: Scoring Examples for Nutrients (cont.)

	-2	0	2	5	10
Change in Precipitation	Benefit the habitat by increasing or decreasing input or flushing from discharge	Will not affect nutrient input or cycling	Create a nutrient enrichment or depletion problem causing some degree of habitat stress	Worsen an existing enrichment or depletion problem resulting in a change in habitat composition or structure over some portion of its' current extent	Habitat is extremely sensitive to small changes in nutrient input and is likely to be completely lost
Change in Sea Level	Habitat will benefit from a change in nutrient availability associated with an increase in salinity or SL through increased productivity or range expansion	Will not affect nutrient dynamics in the habitat	A change in nutrient dynamics associated with an increase in salinity will cause stress in foundational species	A change in nutrient dynamics associated with an increase in SL will result in displacement of foundational species over some portion of the habitats' current extent	A change in nutrient dynamics due to increase SL is likely to cause a complete loss of habitat
Increase in Extreme Climate Events	An increase in extreme events may benefit the habitat by flushing out excess or brining in needed nutrients	Extreme events have no impact on nutrient flows or cycling in this habitat	Extreme events may cause a temporary change in nutrient dynamic s that will impact habitat function, but the habitat is likely to recover	Extreme events will cause long term changes in nutrient dynamics from which the habitat may not recover fully	The habitat is highly sensitive to changes in nutrient dynamics such that a sudden change due to an extreme event would cause the collapse of ecosystem processes

SEDIMENTATION

Eelgrass Meadow, Padilla Bay NERR, Washington
Primary Stressors: Sediment supply, precipitation, sea level change, invasive/nuisance species
(*photo credit: Richard Gwozdz*)

CURRENT CONDITION

A major controlling factor of habitat type and health is sediment type and composition (quality), which is dependent upon sediment balance at the landscape scale and the dynamic processes that control sediment quantity, transport and location (Wall 2004). Natural, climate, and human-induced changes to bathymetry; the timing and magnitude of river flows; inshore and offshore currents; and storm tracks, intensity, and duration are likely to produce significant changes in sediment depositional patterns. The loading of terrestrial sediment to aquatic environments is increasingly recognized as a threat to coastal and estuarine ecosystems. For example, average sedimentation rates in the Chesapeake Bay have increased by an order of magnitude since 1760, when land clearing activities were first initiated (Cooper and Brush 1993). Excessive sediments can be directly detrimental to aquatic organisms (clogging gills or smothering individuals) and indirectly detrimental to habitats and food chains by limiting light production (Wall 2004). Sediment loading is also an important factor in vulnerability for coral reefs as well as on rocky coasts (Thrush 2004).

Sediment starvation may be considered a separate process from erosion. Dams, alterations in tidal flow patterns, and navigation and flood control works can reduce natural sediment loads to a habitat, and can greatly affect the ability of a habitat to cope with other physical impacts of climatic change (Nichols 2007). For example, exceeding critical sea-level thresholds in sediment starved systems can initiate an irreversible process of drowning, and other geomorphological and ecological responses (Burkett et al. 2005)

Assessment Questions

- Is there currently an excess of sediment entering the system from an external source that is having an adverse impact on the function of the habitat?
- Are sedimentation rates considered to be insufficient to maintain the habitat?
- Has the habitats capacity to trap sediment been diminished?

INCREASE IN CO_2 EFFECTS ON SEDIMENTATION

Elevated CO_2 may accelerate the decay of soil organic matter, the net effect of which may be to increase soil mass, subsurface expansion, and elevation gain which can all occur without an increase in mineral sediment deposition (Kirwan and Megonigal 2013).

Assessment Questions

- Would even a small change to elevation through increased soil formation impact the function of the habitat?

INCREASE IN TEMPERATURE EFFECTS ON SEDIMENTATION

Temperature changes may impact biomass production levels and ground cover, which in turn will affect sediment transport. However, this process is very complex (Nearing et al. 2004). For example, biomass production may increase with increasing temperature, particularly if the growing season is extended, but it may start to decrease if temperature becomes too high (Rosenzweig and Hillel, 1998). Increases in soil and air temperature (and moisture) will also likely cause faster rates of residue decomposition due to an increase in microbial activity potentially influencing biomass production rates.

Assessment Questions

- Are biomass production rates critical to maintain the function of the habitat (e.g. sediments are only generated internally; there is no external input of sediment)?
- Would an increase in the production/extent of biomass and ground cover in the habitat or its watershed due to an increase in growing season result in changes in sediment transport that would adversely affect the habitat?

CHANGE IN PRECIPITATION EFFECTS ON SEDIMENTATION

A significant potential impact of climate change on sediment generation is associated with the change from snowfall to rainfall, particularly in northern climates. Warmer winter temperatures would bring an increasing amount of winter precipitation as rain instead of snow, and therefore, erosion by storm runoff would increase (IPCC 2007). Bouraoui et al. (2004) showed, for southern Finland, that the observed increase in temperature and precipitation was responsible for a decrease in snow cover and increase in winter runoff, which resulted in an increase in modeled suspended sediment loads. Seasonal changes in precipitation may also affect vegetation growth along channels, which will impact erosion and sediment trapping, as well as channel flow rates and sediment suspension.

Assessment Questions

- Will an increase in precipitation frequency or intensity result in higher rates of sediment transport in the habitat or watershed that would adversely affect the habitat?
- Will a change in precipitation impact biomass and ground cover and result in a change in sediment transport that will adversely impact the habitat?
- Would a shift from winter snowfall to winter rainfall alter the amount of sediment transport?

Tidal salt marsh and mud flats, North Carolina NERR, North Carolina
Primary Stressors: Temperature, precipitation, sea level, extreme climate events, invasive species, nutrients, environmental contaminants
(*photo credit: Hope Sutton*)

SEA LEVEL CHANGE EFFECTS ON SEDIMENTATION

Sea level will affect sediment transport in complex ways and abrupt, non-linear changes may occur as thresholds are crossed (Alley et al. 2003). The balance between sediment supply and morphological adjustment can be maintained if a salt marsh accretes or a lagoon infills at the same rate as sea level rise. However, acceleration in the rate of sea-level rise may mean that morphology cannot keep up, particularly where the supply of sediment is limited. Exceeding the critical sea-level thresholds can initiate an irreversible process of drowning, and other geomorphological and ecological responses follow abrupt changes of inundation and salinity (Williams et al. 1999; Doyle et al. 2003; Burkett et al. 2005).

An increase in flooding duration can increase sedimentation rates due to an increase in time for sediment deposition to occur when vegetation slows down the movement of water on the marsh's surface, allowing suspended sediment in the overlying water to settle (Moller et al. 1999; Morris 2007; Yang 1999; Leonard and Croft 2006). Also, greater flooding depth allows for greater sediment volume and higher sedimentation (Harter and Mitsch 2003). Increasing below-ground production causes accretion directly by subsurface addition of organic material (bioaccumulation), while higher above-ground macrophyte biomass leads to greater baffling of tidal water flows, thereby inducing greater sedimentation. The enhancement of macrophyte production as water levels rise could be a compensatory feedback process that could allow the marsh surface accretion to equilibrate with rising sea level (Morris et al. 2002). For example, relatively short-term observations, over periods of a few years, documented positive correlations between relative sea-level rise and mangrove sediment accretion which contributes to mangroves keeping pace with regional relative sea-level rise (Cahoon and Hensel 2006).

Assessment Questions

- Is the predicted rate of SLR greater than the rate of sediment transport into the habitat that would be needed to maintain elevation (e.g. has sediment transport been limited by erosion control structures)?
- Has a decrease in vegetative growth affecting sedimentation rates already been documented due to SLR?

EXTREME CLIMATE EVENTS EFFECTS ON SEDIMENTATION

Climate change is expected to affect the frequency, intensity, timing, and distribution of hurricanes and tropical storms which can alter coastal wetland hydrology and geomorphology, and therefore sediment transport. Storms can cause subtidal and intertidal sediment scouring, locally increasing depth, but resuspended materials may then be deposited elsewhere, increasing elevation, causing progradation or transgression, and reducing depth in other habitat areas (Day et al. 2008). Higher energy waves associated with storms can increase sediment input to coastal habitats in some circumstances. For example, Leonard et al. (1995) found that sediment concentrations at a creek mouth increase by as much as two orders of magnitude during strong wind events due to the presence of waves. Waves initially mobilized sediments in the adjacent embayment but increased tidal prisms, and the associated higher velocities, were necessary for transport of this material further into the creek. In the northern Gulf, high wave energy conditions associated with cold fronts play an integral role in the evolution and maintenance of barrier islands, however these events were found to be more effective in reworking sediment after the occurrence of extreme events such as hurricanes (Stone et al. 2004). Storms may also have a greater effect on sediment supply and movement on micro- and meso-tidal marshes, and less influence on macro-tidal marshes (Stumpf 1983).

Abrupt transitions from dry periods to heavy precipitation caused by clustered or more intense storms can also affect sediment loading. For example, the abrupt transition from dry climate to wet climate in 1969 brought a suspended sediment flux of 100 million tons to the ocean edge of the Santa Barbara Channel from the rivers of the Transverse Range, an amount greater than their total flux during the preceding 25-yr dry period (Inman and Jenkins 1999).

Assessment Questions

- Is the habitat susceptible to storm deposition to a degree that an increase in the frequency and/or intensity of storms (i.e., hurricanes, tropical storms, nor'easters) would adversely impact the habitat?

Freshwater Stream, Old Woman Creek, Ohio
Primary Stressors: Temperature, precipitation, invasive species, nutrients, environmental contaminants
(*photo credit: Ohio Department of Natural Resources*)

Table 7: Scoring Examples for Sedimentation

These examples will not apply to all habitats, but are intended to provide general guidance on how the assessment questions and other information can be used to determine the potential level of response of the habitat.

	-2	0	2	5	10
Current Conditions		There are no sedimentation issues	The system has shown changes in sedimentation rates from historic rates that may be adversely impacting the current function of the system	Habitat function has been altered by an excess or deficiency of sediment or the capacity of the system to trap sediment has been lost	The habitat cannot persist at current sedimentation rates
Increase in CO_2	Increased vegetative growth or soil mass as the result of elevated CO_2 would benefit of the habitat	An increase in vegetative growth or changes in decomposition would have no impact on sediment supply	Habitat function will be altered by changes in sedimentation rates due to changes in ground cover or decomposition rates associated with elevated levels of CO_2	Significant function or extent of the habitat will be lost due to changes in sedimentation from increased ground cover or decomposition rates associated with elevated levels of CO_2	Habitat is dependent on sedimentation processes and changes to ground cover or decomposition of soil associated with increased CO_2 would result in complete loss of the habitat
Increase in Temperature	Habitat will benefit from decreased sedimentation rates due to increased ground cover or increased decomposition rates	Sedimentation will not be affected by predicted change in temperature	Habitat function will be altered by changes in sedimentation rates due to changes in ground cover or decomposition rates associated with an increase in temperature	Significant function or extent of the habitat will be lost due to changes in sedimentation from increased ground cover or decomposition rates associated with an increase in temperature	Habitat is dependent on sedimentation processes and changes to ground cover or decomposition of soil associated with increased temperature would result in complete loss of the habitat

Table 7: Scoring Examples for Sedimentation (cont.)

	-2	0	2	5	10
Change in Precipitation	Habitat will benefit from needed sediment input due to increased runoff or vegetative sediment trapping ability	Changes in precipitation will not affect sediment dynamics of the habitat	Habitat function will be altered by changes in sedimentation rates due to changes in runoff, changes in runoff, channel flow, or vegetative sediment trapping ability	Significant function or extent of the habitat will be lost as the result of changes in sedimentation due to changes in amount or intensity of rainfall	Habitat is dependent on current sedimentation processes such that any change in input due to a change in rainfall would result in complete loss of habitat
Change in Sea Level	Changes in sedimentation due to sea level change will benefit the habitat	This habitat will not be affected by sea level rise, or the habitat will be able to compensate at the predicted rate of SLR	The rate of SLR will gradually outpace the ability of the habitat to compensate through increased vegetative growth and sediment trapping	The rate of SLR will rapidly outpace the ability of the habitat to compensate through increased vegetative growth and sediment trapping	Habitat is dependent on current sedimentation processes such that any change in sea level would result in complete loss of habitat
Increase in Extreme Climate Events	Habitat will benefit from the altered sediment supply associated with extreme climate events	Habitat is not anticipated to experience a change in sediment supply associated with extreme climate events	Anticipated increases in sediment deposition will affect the habitat to a limited degree (e.g. over a modest portion of its extent)	Significant function or extent of the habitat will be altered due to changes in sedimentation as the result of an increase in extreme climate events	Habitat is sensitive to changes in sediment supply and will not persist due to an increase in extreme climate events

EROSION

CURRENT CONDITION

In coastal habitats, erosion involves the wearing away of land due to processes such as wave action, tidal currents, and runoff. The vulnerability of a particular coastal habitat to erosion may depend on factors such as the type of rock or sediment, the slope of the land, degree of exposure to wind and waves, and anthropogenic influences such as agriculture or urban development.

Assessment Questions

- Is the habitat area currently being lost to erosion?
- Are shoreline stabilization or erosion control measures currently necessary to maintain the habitat?

Dune, Mission-Aransas NERR, Texas
Primary Stressors: Precipitation, extreme climate events, invasive species
(*photo credit: Anne Evans*)

INCREASE IN CO_2 EFFECTS ON EROSION

Increases in plant production and changes to community composition due to increased CO_2 can potentially affect soil surface cover (Nearing et al. 2004) which can reduce soil erosion rates (Pruski and Nearing 2002).

Changes in plant biomass associated with CO_2 stimulates fine root growth and root secretions in soils (Pendall et al. 2004) which generates belowground carbon that can increase root respiration rates and soil microbes (Schlessinger and Andrews 2000). Faster residue decomposition from increased soil microbial activity can increase erosion rates (Nearing et al. 2005).

Assessment Questions

- Are erosion rates mediated by plant cover of a species that may have decreased growth or vigor under increased CO_2, or is likely to be outcompeted by another species that does not perform the same erosion control function?

INCREASE IN TEMPERATURE EFFECTS ON EROSION

Reduced sea-ice cover due to temperature increase could mean greater erosion in coastal areas that will be more exposed in the future to higher amounts of wave generation (Johannessen et al. 2002; Forbes 2005; Kont et al. 2007). Degradation and melting of permafrost due to climate warming are also contributing to the rapid retreat of Arctic coastlines in many regions (Forbes 2005). Higher temperatures also translate to higher evaporation rates, which will affect erosion rates through changes in soil moisture availability and surface roughness, sealing, and crusting (Nearing et al. 2004).

Assessment Questions

- Will warmer temperatures reduce sea ice extent and alter the direct exposure of the habitat to erosion from wave energy?

CHANGE IN PRECIPITATION EFFECTS ON EROSION

The most direct impact of climate change on erosion results from changes in precipitation and the erosive power of rainfall (Nearing et al. 2004; Pruski and Nearing 2002 a,b). To date, all studies on erosion and climate change indicate that increased rainfall amounts (and intensities) will lead to greater rates of erosion. Where rainfall amounts increase, erosion and runoff will increase at an even greater rate: the ratio of erosion increase to annual rainfall increase is on the order of 1:7. Even in cases where annual rainfall would decrease, system feedbacks related to decreased biomass production (e.g., soil moisture, soil decomposition rates) could still lead to greater susceptibility of the soil to erode (Nearing et al. 2004; Pruski and Nearing 2002a).

Changes in rainfall which occur due to changes in storm intensity can be expected to have a greater impact on erosion rates than those due to changes in the number of rain days alone (Pruski and Nearing 2002b). Results suggest that in studying erosional changes, changes in precipitation under climate change must be reflected as a combination of both factors. If only the number of days of precipitation is modified to account for precipitation changes, erosional changes will be underestimated. If only intensity changes are used to reflect precipitation changes, erosional changes will be overstated. The overall results of that study suggested that, other factors being equal (e.g., temperature, CO_2 levels, and solar radiation), each 1% change in precipitation can effect a 2% change in runoff and an approximate 1.7% change in erosion. Of course, other factors do not remain constant, and the interactions which result may be very complex (Pruski and Nearing 2002b).

Assessment Questions

- Is the soil type of the habitat susceptible to erosion due to rainfall and runoff?
- Does the geomorphology of the habitat make it more susceptible to runoff erosion (e.g. steep slopes)?

CHANGE IN SEA LEVEL EFFECTS ON EROSION

Sea level rise does not directly erode beaches and coastal areas, however rising sea levels act as a swelling tide that allows waves to act further up the beach profile and permits larger waves to reach the coast (Zhang et al. 2004). Beach erosion is intensified in areas affected by inlets or where the construction of groins and breakwaters disrupts long-shore drift (Gornitz et al. 2002).

Assessment Questions

- Is the habitat susceptible to coastal wave erosion that will be increased by sea level rise?

EXTREME CLIMATE EVENTS EFFECTS ON EROSION

Changes in the frequency and/or intensity of storms in coastal areas will have major impacts on the processes that drive coastal erosion. Severe storms, such as hurricanes, tropical storms, and northeasters, play a key role in the erosion of coastal areas. These storms generate a combination of high winds, currents, and large waves that can move large quantities of sediment and result in major coastal erosion. In fact, hurricanes have been directly responsible for major changes in the coastal landscape, such as the morphology of barrier islands and the configuration of inlets. In addition, changes in storm tracks as a result of climate change may alter wind patterns, such that waves hit the beach with more force or from new directions, resulting in new patterns of erosion.

Assessment Questions

- Do large storm events tend to result in significant erosion to the habitat?

Mangrove, Jobos Bay NERR, Puerto Rico
Primary Stressors: Temperature, sea level rise, extreme climate events, invasive species, erosion
(*photo credit: Angel Dieppa*)

Table 8: Scoring Examples for Erosion

These examples will not apply to all habitats, but are intended to provide general guidance on how the assessment questions and other information can be used to determine the potential level of response of the habitat.

	-2	0	2	5	10
Current Conditions		Erosion does not adversely affect the habitat	Erosion is an occasional problem following storm events, or affects a small portion of the habitat	Significant erosion is an ongoing problem, or erosion control measures are necessary for the persistence of the habitat	Habitat functionality has already been lost due to erosion
Increase in CO_2	Erosion rates are expected to be reduced as the result of enhanced ground cover associated with increased levels of CO_2, habitat will benefit	Habitat will not be adversely affected by a change in erosion rates as a result of an increase in CO_2	Habitat function will be altered to some extent by changes in erosion due to changes in ground cover or exposure resulting from elevated CO_2	Elevated levels of CO_2 are expected to increase erosion rates as the result of increased soil microbe activity; significant change in habitat structure, function, or extent	The extent to which soil microbe activity will be altered by an increase in CO_2, and the resulting increase in erosion will create major changes in structure and function; habitat will be lost
Increase in Temperature	Habitat will benefit from decreased erosion rates due to increased ground cover	Erosion will not be affected by predicted change in temperature	Habitat function will be altered by changes in erosion due to changes in ground cover or exposure due to loss of ice or permafrost	Significant function or extent of the habitat will be lost due to changes in erosion	The habitat requires winter ice cover or permafrost to persist which are predicted to no longer occur

Table 8: Scoring Examples for Erosion (cont.)

	-2	0	2	5	10
Change in Precipitation	Vegetation cover will increase and decrease erosion to the benefit of the habitat	Habitat is not susceptible to erosion from runoff	Habitat contains soil types or has a geography that would be susceptible to erosion from a change in the amount or intensity of rainfall	Significant function or extent of the habitat will be lost due to changes in erosion from changes in amount or intensity of rainfall	Habitat is highly susceptible to erosion from runoff and will likely be lost under predicted precipitation changes
Change in Sea Level	Habitat may benefit as erosion associated with wave-energy is reduced by an increase in sea level	Erosion rates on this habitat will not be affected by sea level rise	Habitat may be affected by increased erosion from wave action	Habitat is highly susceptible to erosion which would be significantly worsened by a change in sea level	Habitat will not persist due to the increase in erosion rates associated with a change in sea level
Increase in Extreme Climate Events	Erosion occurring at increased intervals and/or intensity benefits the habitat; foundational species become established and thrive with reduced vegetative competition	No anticipated change in erosion rates associated with an increase in extreme climate events	Some limited alteration of habitat structure, function or extent as the result of erosion due to an increase in extreme climate events	Significant function or extent of the habitat will be lost due to changes in erosion from changes in frequency or intensity of extreme climate events	Destructive erosion associated with an increase in extreme climate events occurs at a frequency that is too rapid for the habitat to recover; habitat will be lost

ENVIRONMENTAL CONTAMINANTS

CURRENT CONDITION

A contaminant as defined by DFO (2009) is any element or natural substance (e.g., metal or organic compound) whose concentration locally exceeds the background concentration, or any substance that does not naturally occur within the environment (e.g., synthetic chemicals such as DDT). Natural sources of contaminants include weathering of soils and bedrock as well as forest fires. Human sources of contaminants are potentially far more prevalent and varied. Human sources of contaminants are generally associated with industry, transportation, aquaculture, or agriculture and examples include metals, petroleum hydrocarbons, antibiotics, and pesticides. The introduction of contaminants to the coastal environment occurs through multiple pathways (e.g., surface runoff, effluent and sewage outfalls, surface spills, and atmospheric deposition). Additionally, the release of toxins from harmful algal blooms (HABs) can cause illness or death in organisms or form such large blooms that the death and subsequent decay of the algae leads to hypoxia. Hypoxia and anoxia may act as co-varying stressors with contaminants, causing more dramatic damage to organisms than the effects of any one of these stressors by itself (Schiedek et al. 2007).

Marine organisms can be affected by (1) chronic exposure to contaminants; (2) toxic effects of contaminants on prey species; and (3) direct contaminant exposure (e.g., oil spills) (Ross et al. 2007). Some contaminants may not cause adverse effects until they reach higher concentrations in an organism through bioaccumulation as the result of uptake of food and water over time or biomagnifications with increases associated with successive trophic levels (Harding and Burbridge 2013). In addition, a variety of chemical stressors are well documented to result in demographic alterations in populations, structural changes in communities, and functional response of ecosystems (Newman and Clements 2008).

Climate change is likely to affect the inputs of a range of contaminants to the natural environment as well as the rates of formation of natural toxins (Boxall 2014). A review of global climate change effects on the occurrence, fate, and distribution of chemical contaminants in Stahl et al. (2013) suggests that mechanisms of change in exposure include the potential for increased global transport of dust and pollution (Garrison et al. 2003; Zhang et al. 2008), increased erosion of soil and mobilization of legacy contaminants, alterations in the deposition and volatilization of chemicals, and altered flood and drought frequency and magnitude (Parry et al. 2007). Additionally, stress associated with altered climatic conditions may also reduce the potential for tolerance to and recovery from exposure to toxicants. Stahl et al. (2013) suggests that long-term exposure to a toxicant may result in species being able to acquire tolerance to this stressor at the population or community level but an associated "cost of tolerance" may be a reduced ability to tolerate subsequent climatic stress (or vice versa). Although some species may benefit from climatic changes such as increased temperature or greater hydrologic variability, the overall effect on communities will likely be the elimination of sensitive species, lower diversity, and loss of functional redundancy (Moe et al. 2013). Moreover, the remaining species in affected communities may be pushed to the limits of their distribution range or experience less optimal conditions. These communities are likely to show lower resistance to additional disturbances such as contaminant exposure and slower recovery after contaminant exposure (i.e., lower resilience) (Moe et al. 2013).

Assessment Questions

- Do contaminant exposure levels within the habitat remain fairly constant (implying a degree of tolerance) or do frequency and/or duration of contaminant exposure vary?
- Does periodic contaminant exposure exceed foundation species tolerance levels resulting in a change in habitat structure or function?

INCREASE IN CO_2 EFFECTS ON ENVIRONMENTAL CONTAMINANTS

Trace metal cycling in terrestrial ecosystems is controlled by plant and soil processes. Increased atmospheric carbon dioxide, by influencing plant growth and function, affects the biological storage and fate of trace metals and, presumably, may mediate toxicity levels through growth dilution effects (Natali et al. 2009). Metal solubility and availability to organisms is also strongly influenced by soil properties which are influenced by elevated CO_2 such as soil organic matter and, to a lesser degree, soil acidity (Natali et al. 2009). A study conducted by Duval et al. (2011) demonstrated that contaminant accumulation in plant biomass in soils with low organic matter corresponds to declines in contaminant levels in surface soils with results varying by soil horizon and contaminant element measured. The demonstrated mobilization of elements such as cadmium and lead, which are toxic to organisms that contribute to decomposition and nitrogen mineralization (Giller et al. 2009), suggests that elevated CO_2 can alter key ecosystem processes by altering contaminant mobility (Duval et al. 2011).

Assessment Questions

- Are contaminants located in surface soils where they are more likely to be mobilized into plants?
- Will soil processes and/or properties be impacted by elevated CO_2 thereby altering contaminant mobility within the habitat?

Spoil Islands, Mission-Aransas NERR, Texas
Primary Stressors: Environmental contaminants, extreme climate events
(*photo credit: Anne Evans*)

INCREASE IN TEMPERATURE EFFECTS ON ENVIRONMENTAL CONTAMINANTS

Increasing temperatures will generally both increase the uptake and excretion of toxicants and enhance contaminant toxicity (Noyes et al. 2009). Tolerance of species and populations to elevated temperatures may be impaired with toxicant co-exposure by affecting physiological processes and the ability of wildlife, particularly ectotherms, to maintain homeostasis (Broomhall 2004).

While global warming may result in reduced soil and aquatic concentrations of pesticides due to a combination of increased volatilization and degradation (Bailey 2004; Benitez et al. 2006; Van den Berg et al. 1999), the frequency and amount of pesticides used will likely change as agriculture shifts in response to a changing climate (Chen and McCarl 2001; Reilly et al. 2001, 2003). Climate change is likely to affect agriculture by shifting the location and type of crops grown and the range and magnitude of crop pests. Pesticide use will shift in response to these altered cropping patterns and crop pest distributions (Noyes et al. 2009).

The effects of higher temperature on the formation of HABs may be exacerbated by the presence of toxicants such as pesticides, resulting in an interactive effect of climate change impacts and toxicants on aquatic communities. (Moe et al. 2013). Historical evidence from long term phytoplankton monitoring data and fossil records suggests that future climate warming could impact HABs through the alteration of their geographic range and shifts toward relatively more and earlier blooms.

Assessment Questions

- For a known chemical contaminant in the habitat, would an increase in temperature cause the contaminant to become more toxic or, conversely, the habitat to become more sensitive?
- For a known chemical contaminant in the habitat, would an increase in temperature cause the chemical to become more volatile and disburse away from the habitat, resulting in lower concentrations available for uptake?
- Would proximity to lands in agriculture change with an increase in temperature thereby making exposure to pesticides more likely?
- Would an increase in aquatic temperature likely result in prolonged algal bloom formation that would adversely impact the habitat?

CHANGE IN PRECIPITATION EFFECTS ON ENVIRONMENTAL CONTAMINANTS

Increases in the intensity and frequency of rain and storm events will promote the wet deposition of pesticides to terrestrial and aquatic systems (Noyes et al. 2009) and runoff is a significant source of microbial pathogens, nutrients and toxic chemicals to coastal waters (Jones 2011). Increased precipitation and the resulting elevated soil moistures may enhance the degradation of pesticides to differentially toxic and environmentally mobile degradates; conversely, regions experiencing reduced precipitation and soil moisture levels will have reduced hydrolytic degradation of these chemicals (Bailey 2004; Van den Berg et al. 1999). An analysis of field and laboratory studies indicates that decreased salinity results in increased metal toxicity but reduced toxicity of organophosphates and, more generally, that organisms living under environmental conditions near their tolerance limits appear to be more vulnerable to additional chemical stress (Schiedek et al. 2007). Periods of drought also indirectly threatens water quality by the concentration of non-volatile chemicals and toxic metals.

Assessment Questions

- Would there be increased concentrations of contaminants in runoff during a rain event due to land use practices in the area and increased severity of rain events?
- Would increased precipitation and soil moisture enhance degradation of contaminants to more toxic and/or environmentally mobile degradates?
- Would decreased salinity associated with extreme precipitation events increase metal toxicity beyond the foundation species' tolerance?
- Would changes in precipitation patterns alter the frequency and amount of pesticides used as agriculture shifts in response?
- Would periods of drought concentrate contaminants to levels that increase vulnerability of the foundation species?

SEA LEVEL CHANGE EFFECTS ON ENVIRONMENTAL CONTAMINANTS

Organic compounds are generally less soluble and more bioavailable in saltwater than in freshwater due to the “salting out” effect whereby water molecules are strongly bound by salts making them unavailable for dissolution of organic chemicals (Schwarzenbach et al. 2003). Thus, increased contaminant bioavailability and toxicity is possible in subtropical latitudes experiencing increased salinity, as well as in estuaries and coastal freshwater ecosystems subject to increased saltwater intrusion or droughts (Noyes et al. 2009). Increased toxicity observed at elevated salinity is attributed to higher physiological costs to maintain osmoregulation resulting in decreased fitness and an elevated sensitivity to contaminant exposures (Heugens et al. 2001). In addition, a rise in sea level may threaten fuel storage facilities, pipelines, landfills and coastal contaminated sites (Rohr et al. 2013) thereby increasing the risk of contaminant exposure to coastal habitats.

Assessment Questions

- Would known contaminants become more bioavailable and toxic to foundation species as the result of sea level rise?
- Are areas that are susceptible to inundation due to sea level rise repositories for industrial or agricultural chemicals, etc which would become more readily distributed to the habitat?

EXTREME CLIMATE EVENTS EFFECTS ON ENVIRONMENTAL CONTAMINANTS

Increased storm intensity and frequency associated with climate change could lead to episodes of high contaminant exposures due to runoff (Noyes et al. 2009) and the increased risk of coastal flooding has implications for the inundation of contaminated land. This may cause a greater risk of contaminants being remobilised in floodwater and of contaminated sediment and water reaching the freshwater and marine environment (Schiedek et al. 2007). Additionally, with an increase in the frequency and intensity of extreme weather events, there will be an increase in the likelihood of spills and the release of hazardous substances from storage facilities (Rohr et al. 2013).

Assessment Questions

- Is the habitat at risk for contaminant exposure associated with coastal inundation of contaminated lands during storm events?
- Would the habitat be at risk for high levels of contaminant exposure if industrial infrastructure in the area was compromised as a result of the destructive force associated with more intense storms?

Tidal Salt Marsh, Chesapeake Bay NERR, Maryland
Primary Stressors: Temperature, sea level rise, nutrients, erosion, environmental contaminants
(photo credit: Correen Weilminster)

Table 9: Scoring Examples for Environmental Contaminants

These examples will not apply to all habitats, but are intended to provide general guidance on how the assessment questions and other information can be used to determine the potential level of response of the habitat.

	-2	0	2	5	10
Current Conditions		Contaminants are not present or occur at levels within tolerance limits of foundational species (i.e. stress from contaminants has not been indicated)	Contaminant exposure levels approach foundation species tolerance levels; causing some stress to the habitat	Contaminant exposure and/or mobility is sufficient to alter plant and/or soil processes resulting in alteration of habitat structure or function over some portion of the current extent	Contaminant exposure and/or mobility has altered plant and/or soil processes to a degree that habitat conversion is evident; habitat will not persist
Increase in CO_2	Predicted change in CO_2will reduce contaminant availability and/or sensitivity through growth dilution	Elevated CO_2 will not influence contaminant availability and/or sensitivity of habitats to contaminants	Elevated CO_2 may alter soil processes and/or properties and increase contaminant availability; causing stress in foundational species	Elevated CO_2 will alter soil processes and/or properties and increase contaminant availability and/or toxicity to foundation species resulting in alteration of habitat structure or function over some portion of the current extent	Predicted change in CO_2 will affect contaminant mobility and interrupt key ecosystem processes; habitat will not persist
Increase in Temperature	Predicted change in temperature will change adjacent land use patterns and reduce contaminant exposure	Predicted change in temperature will not influence exposure and/or sensitivity to contaminants	Increased temperature will enhance toxicity or availability of at least one contaminant causing stress in foundational species	Change in temperature will result in greater toxicity of known contaminants to foundation species thereby altering habitat structure or function over some portion of the current extent	Elevated temperature and contaminant co-exposure will exceed foundation species tolerance; habitat will not persist

Table 9: Scoring Examples for Environmental Contaminants (cont.)

	-2	0	2	5	10
Change in Precipitation	Predicted change in precipitation will change adjacent land use patterns and reduce contaminant exposure	Predicted change in precipitation will not influence exposure and/or sensitivity to contaminants	Altered precipitation patterns will enhance toxicity or availability of at least one contaminant causing stress in foundational species	Altered precipitation patterns will result in greater toxicity of known contaminants to foundation species thereby altering habitat structure or function over some portion of the current extent	Predicted change in precipitation will increase levels of contaminant exposure resulting in complete habitat loss
Change in Sea Level	Predicted change in sea level will alter salinity sufficiently to reduce toxicity of known metal contaminants	Predicted change in sea level will not influence exposure and/or sensitivity to contaminants	Higher sea levels will enhance toxicity or availability of at least one contaminant causing stress in foundational species	Rising sea levels will result in greater toxicity of known contaminants to foundation species thereby altering habitat structure or function over some portion of the current extent	Predicted change in sea levels will increase levels of contaminant exposure resulting in complete loss of habitat
Increase in Extreme Climate Events	Predicted change in extreme climate events will alter land use in the area and reduce exposure to contaminants	Predicted change in extreme climate events will not influence exposure and/or sensitivity to contaminants	Extreme climate events will increase likelihood of exposure to at least one contaminant causing stress in foundational species	Extreme climate events will result in greater exposure to known contaminants; habitat structure or function will be altered over some portion of the current extent	Extreme climate events will increase levels of contaminant exposure beyond foundation species tolerance resulting in complete loss of habitat

ADAPTIVE CAPACITY

Adaptive capacity is defined by the IPCC as “the potential, capability, or ability of a system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences” (IPCC 2007). For natural systems, adaptive capacity is often considered to be an intrinsic trait that may include evolutionary changes as well as “plastic” ecological, behavioral, or physiological responses (Williams et al. 2008). Intrinsic factors, however, are the not the only thing that must be considered when assessing the adaptive capacity of coastal habitats. There are likely to be a number of external factors (both natural and anthropogenic) that will influence the ability of a habitat to adjust to or cope with climate change (Glick et al. 2011). For the purposes of this tool, the following elements of adaptive capacity must be considered for each habitat:

- Degree of fragmentation
- Barriers to migration (natural and/or anthropogenic)
- Recovery / regeneration following disturbance
- Diversity of functional groups
- Management actions
- Institutional / Human response

DEGREE OF FRAGMENTATION

Habitat fragmentation refers to the loss of suitable habitat and the concurrent separation of individuals into a number of habitat patches, which are isolated from each other by unsuitable habitat types. Due to fragmentation, numerous populations of many plant species have decreased in size and have become more isolated. Fragmentation will affect a habitat’s vulnerability to climate change mainly due to two reasons. First, dispersal or movement (i.e., range shift) of habitats into areas with optimal climate conditions is compromised in a fragmented landscape (Sork et al. 1999; Sork and Smouse 2006; Honnay et al. 2002; Thuiller et al. 2008). Second, reduced genetic variation in fragmented populations is predicted to reduce the adaptive potential of species under climate change (Frankham et al. 2002). Although less understood, the impact of increased inbreeding, another major genetic consequence of fragmentation, may also influence the viability and extinction risk of habitats under climate change (Leimu et al. 2010).

Habitat fragmentation can lead to the disruption of biotic interactions such as plant–pollinator mutualisms (Aguilar et al. 2006; Olesen and Jain 1994; Rathcke and Jules 1993). Small fragmented plant populations may be less attractive to pollinators, and thus, more strongly pollinator- or pollen-limited, which results in reduced reproductive success (Kolb 2005; Waites and Agren 2004; Agren 1996). Habitat fragmentation may also alter the foraging behavior of pollinators and limit their movements (Lennartsson 2002; Jennersten 1988; Sih and Baltus 1987). Furthermore, fragmentation may disrupt interactions between plants and agents of seed dispersal. This may influence the population dynamics and fitness of populations of plants that rely on animals in their seed dispersal (Lennartsson 2002). Finally, habitat fragmentation may perturb antagonistic interactions, such as those between plants and herbivores, seed predators, or pathogens (Von Zeipel et al. 2006; Colling and Matthies 2004; Kéry et al. 2001).

Habitat fragmentation also causes changes in the physical environment. Small habitat fragments will have a different ratio of core to margin, which will change the biotic and abiotic quality of such fragments. As a result, fluxes of light, wind, water, and nutrients across the landscape are significantly altered. This, in turn, can have important consequences on the remnant individuals (Saunders et al. 1991). Therefore, the differences in habitat quality between the different fragments in which a population is subdivided (Arroyo-Rodríguez & Mandujano, 2006; Jules & Shahani, 2003) might have very different influences on within-fragment dynamics, including both positive and negative effects on life history processes and population viability.

Assessment Questions

- Does habitat fragmentation affect the ability of the species within the habitat to disperse and shift with climate change, including alterations in plant-pollinator relationships and interactions between plants and agents of seed dispersal?
- Does habitat fragmentation reduce genetic variation or lead to inbreeding within the habitat?
- Does the effect of habitat fragmentation lead to differences in the quality of habitat patches?

BARRIERS TO MIGRATION

The degree to which species, propagules, and processes can move through the landscape will affect the ability of habitats to adapt to the impacts of climate change. More permeable landscapes with fewer barriers to dispersal and migration will likely result in greater adaptive capacity for the species that compose a habitat. However, the degree to which a landscape is permeable depends on the process or organism that is being considered, and therefore, a permeable landscape for one species may not be permeable for another species (Glick et al. 2011).

The relative permeability of a landscape may depend on both natural and anthropogenic factors. Natural (e.g., rocky cliffs; soil type) or anthropogenic (e.g., seawalls, large areas of urban development or agriculture) barriers may limit a habitat's ability to shift its range in response to climate change. For the purposes of this tool, barriers are considered to be features or areas that completely or almost completely prevent movement or dispersal of the species that compose a habitat, both currently and for the foreseeable future. As climate envelopes shift due to climate change, species for which barriers would inhibit distributional shifts will be more vulnerable to climate change than are species whose movements are not affected by barriers. Barriers must be identified for each habitat, but often are the same for a group of closely located habitats.

The degree to which a barrier may affect a habitat's ability to shift its range in response to climate change depends in part on the distance of the barrier from the habitat's current distribution. Barriers that are separated from a habitat's range by a long distance of relatively flat topography can still affect range shifts because in gentle terrain relatively small changes in climate may result in large shifts in the location of a particular climate envelope. If a habitat in this type of topography changes its range in order to track a particular climate envelope, it might encounter barriers that were far from its original location. In contrast, landscapes where climatic conditions change rapidly over small horizontal distances (e.g., steep slopes, rocky cliffs) a habitat's distribution would have to shift a relatively small distance in order to track a particular climate envelope, so the species is less likely to encounter distant barriers.

Habitats that are composed of species that exhibit substantial dispersal capability, readily moving long distances as adults or immatures, or exhibit flexible movement patterns should be better able to track shifting climate envelopes than are species in which dispersal and movements are more limited or inflexible. For example, species with wind or water dispersed seed that can become established and persist to reproductive maturity under a wide range of environmental conditions effectively reduce the potential for barriers, if present, to prevent migration.

Assessment Questions

- To what extent do barriers (both natural and anthropogenic) impact the habitat's ability to migrate with changes in climate?
- Do the species within the habitat have the ability to disperse and move long distances in order to track shifting climate envelopes?

If appropriate, scoring of species whose dispersal capacity is not known can be based on characteristics of closely related species (or species of similar body size in the same major group).

RECOVERY / REGENERATION FOLLOWING DISTURBANCE

Disturbances provide conditions that favor the success of different species over pre-disturbance organisms. This can be attributed to physical changes in the abiotic conditions of an ecosystem in combination with reduced levels of competition. Climate change is expected to alter the frequency and intensity of disturbance events experienced by a habitat. How the species within a habitat respond to specific disturbance regimes (e.g., fires, floods, ice, severe winds, and pathogen outbreaks) will affect the habitat's ability to adapt to climate change.

Many plants and animals benefit from the conditions created by disturbances. Some species are particularly suited for exploiting recently disturbed sites. Species that are well adapted for exploiting disturbance sites are referred to as pioneers or early successional species. Vegetation with the potential for rapid growth can quickly take advantage of the lack of competition. Their fast growth is usually balanced by short life spans. Although these species dominate immediately following a disturbance, they are often unable to compete with later successional species and are replaced by these species.

There are four mechanisms by which populations become reestablished in a disturbed patch: (1) vegetative regrowth of survivors within the patch, (2) recruitment from propagules that survive the disturbance (e.g., seed banks), (3) lateral inward encroachment by juveniles or adults from the surrounding undisturbed assemblage, by vegetative spreading, active movement, or passive transport flow, or (4) recruitment from dispersing propagules including spores, larvae, or fragments capable of attaching to the substrate and growing (Bertness et al. 2001).

Assessment Questions

- Do the species within the habitat have the ability to respond quickly and reestablish themselves following disturbance events?

DIVERSITY OF FUNCTIONAL GROUPS

Within any community, there is a range of functional groups present. In ecological communities, this includes groups such as primary producers, herbivores, carnivores, and decomposers (Glick et al. 2011). In systems where each functional group is represented by multiple species and the response to any given environmental change varies significantly among the species that make up the functional group, system resilience to environmental change is likely to be higher (Nystrom et al. 2008; Naeem 1998; Petchey & Gaston 2009). In other words, if a particular species or primary producer responds negatively to a change in climate but others respond positively, primary production within the system may not be disrupted (Glick et al. 2011).

Assessment Questions

- Does the number of species within functional groups occurring within the habitat reduce the potential for a change in climate to impact the habitat's persistence?

MANAGEMENT ACTIONS

Implementation of various management strategies could affect the ability of a habitat to adapt to climate change, in both positive and negative ways. Management strategies that are either on-going or will occur with certainty in the future should be considered during the assessment. Examples of management activities that may affect climate change vulnerability include: implementation of water conservation and efficiency improvements, mitigation of hydrologic barriers, removal of barriers to migration, improvement of habitat connectivity, and increased frequency of prescribed burns.

Assessment Questions

- Do management actions that are on-going or will occur with certainty in the future have the potential to increase the habitat's ability to adapt to changes in climate?

INSTITUTIONAL / HUMAN RESPONSE

Institutional response refers to the ability of an organization/agency to respond to the potential impacts of climate change within a particular habitat. If an organization or agency has the ability to mobilize resources, change policies, or enforce new regulations within a particular habitat (i.e., there is a high institutional adaptive capacity) this could reduce the vulnerability of that habitat to climate change. Conversely, a habitat may be more vulnerable to climate change impacts if the institutional adaptive capacity is low. The particular components of institutional adaptive capacity will depend on the habitat being assessed and the agencies/organizations with regulatory authority over that habitat, but examples may include things like reducing impervious surface, encouraging low-impact development techniques, increasing the size of buffer zones around sensitive habitats, encouraging coordination among agencies to manage adjacent lands and ensure habitat connectivity, procuring resources for purchase of land or conservation easement, or altering existing regulations related to pollution, resource harvesting, agriculture, and water use.

Management Potential

In the original tool there were three adaptive capacity elements that dealt with the 'human component'. Management Actions accounts for management strategies that are either on-going or will occur with certainty in the future. Institutional adaptive capacity refers to the ability of an organization/agency to respond to the potential impacts of climate change within a particular habitat. If an organization or agency has the ability to mobilize resources, change policies, or enforce new regulations within a particular habitat (i.e., there is a high institutional adaptive capacity) this could reduce the vulnerability of that habitat to climate change. The human response of strategies designed to mitigate or adapt to climate change have the potential to affect very large areas of land, and the species that depend on these areas, in both positive and negative ways. The construction of seawall to mitigate sea level rise is a common example of a maladaptive response. However, there was some difficulty in distinguishing between these three components as they all involved human actions. We have responded to this issue by combining the institutional adaptive capacity and human response into a single category, and further defining management potential as the physical availability of management tools to affect ecosystem processes within the habitat. For example, impounded marsh habitat is already under regular management though tide gates, and there are multiple management options available depending upon the needs of the habitat, so this habitat would score high in adaptive capacity in this category. In contrast, and habitat such as a salt panne, has never been managed and it doesn't seem likely that any of our traditional management tools could be applied to this habitat.

By contrast, human response refers to the mechanisms by which private landowners would take advantage of current policy/regulations to respond to changing climate conditions. Strategies designed to mitigate or adapt to climate change have the potential to affect very large areas of land, and the species that depend on these areas, in both positive and negative ways.

Habitats that are likely to become more vulnerable as the result of human responses to a changing climate include those with foundational species having natural history/requirements known to be incompatible with mitigation-related land use changes that are likely to occur within its current and/or potential future range. Examples include: open habitats likely to become reforested to provide carbon offsets; habitats on suitable soils likely to be converted for biofuel production, in areas suitable for the placement of solar arrays/windfarms, or on river/stream reaches likely to be developed for hydropower; and, dynamic shoreline habitats (e.g., active dunes or salt marshes) likely to be destroyed by human fortifications against sea level rise.

Habitats that are likely to become less vulnerable as the result of human responses to a changing climate include those which will benefit from changes in long-held management policies/strategies. Examples include: habitats that would benefit from the removal of existing barriers (e.g., dams, impoundment systems); and, habitats on unprotected lands which may be protected and managed for conservation due to their carbon storage and/or sequestration ability.

Assessment Questions

- Has the agency responsible for making management decisions about the habitat previously taken into account climate change considerations? Has it shown flexibility in adapting management practices to changing conditions?
- Are other institutions that influence the habitat (e.g. local government) likely to support strategies to mitigate climate change impacts?
- Has the local community shown support for the habitat such that they would be likely to support climate mitigation strategies?

Riparian Zone, Apalachacola NERR, Florida
Primary Stressors: Temperature, precipitation, sea level change, extreme climate events, invasive/nuisance species, erosion, environmental contaminants
(*photo credit: Lakeland Ledger*)

Table10: Scoring Examples for Adaptive Capacity

	0	2	5
Fragmentation	Degree of fragmentation is sufficient to prevent habitat adaptation to CC across much of the habitats' original extent	Degree of fragmentation is not likely to influence more than a modest portion of the habitats' current extent (i.e. via reduced rate of seed dispersal)	Degree of fragmentation is not an impediment to habitat persistence
Barriers to Migration	Barriers border the current distribution to the extent that climate change-caused distributional shifts in the assessment area are likely to be greatly or completely impaired	Barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be somewhat, but not completely, impaired	Effective barriers to climate change caused distributional shifts do not exist for this habitat
Recovery / Regeneration	Foundational species of the habitat do not have characteristics that allow rapid recovery following disturbance	Foundational species of the habitat may exploit newly disturbed patches via lateral encroachment from immediately adjacent undisturbed areas resulting in a modest increase in habitat extent	Foundational species of the habitat have one or more characteristics that allow them to successfully exploit newly disturbed patches from proximate as well as distant undisturbed areas
Diversity of Functional Groups	There is limited species diversity within functional groups such that the climate change related loss of any species would result in a change in community structure or function	There is moderate species diversity within functional groups sufficient to compensate to some extent for the loss of a limited number of individual species to CC related stressors	The habitat has sufficient diversity to ensure that the loss of multiple species to CC related stressors is not likely to impair habitat structure or function
Management Actions	Anticipated level of resources are insufficient to alter the type or frequency of existing management actions or strategies	Anticipated level of resources is sufficient to alter type or frequency of management actions or strategies to offset CC impacts across a portion of the habitats' current extent	Anticipated level of resources is sufficient to apply management actions or strategies to offset most CC impacts across the habitats' current extent
Institutional / Human Response	Institutional response/capacity is low (i.e. multiple agency oversight has historically led to lack of consensus in implementing management actions) ; habitat is likely to be neutrally or negatively impacted by CC mitigation-related land use change	Institutional response/capacity is moderate (i.e. agency coordination is strong but adaptive strategies are only effective for a portion of the habitats' current extent)	Institutional adaptive capacity is high (i.e. demonstrated ability to implement policies to promote adaptation); revised management policies are likely to be effective over most of the habitats' range

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APPENDIX A: SCORING SPREADSHEET

The scoring spreadsheet contains multiple worksheets and is designed to assist tool users to capture scores for both current and anticipated future conditions as well as adaptive capacity scores for each habitat assessed. Only the Sensitivity-Exposure and Adaptive Capacity worksheets require tool user input. General guidance on scoring for these worksheets is provided in a separate section of this document and includes a description of the score categories to be applied within each section, basic scoring levels and considerations when scoring. Additional worksheets contain: basic instructions for scoring for quick reference; relationship tables used to automatically convert raw scores to appropriate scoring levels; and, a final score worksheet designed to automatically compute final scores.

FINAL SCORE COMPUTATION

The final score worksheet is automatically updated as scores are input into the Adaptive Capacity and Sensitivity-Exposure worksheets and are only finalized upon completion of the scoring process.

All formulas are locked to prevent them from being inadvertently over-written by tool users. Criteria for assigning numerical ranges to sensitivity-exposure and adaptive capacity levels (e.g. low, moderate, and high) have been estimated to reflect interpretation of final scores based on raw score input.

SENSITIVITY-EXPOSURE

Final scores for sensitivity-exposure reflect the sum of scores across each of the six sensitivity categories (e.g. direct climate effects, invasive/nuisance species, nutrients, sedimentation, erosion, environmental contamination) derived from a relationship table assumed to capture the relative contributions of both the current condition score and the sum of scores for sensitivity-exposure interactions within each sensitivity category for each habitat (Table A-1). The conversion of raw scores using the relationship table assumes that (1) the current condition of a habitat will influence its overall vulnerability (i.e. degraded habitats are potentially more vulnerable to the effects of climate change) and (2) the influence of multiple climate change stressors (e.g. CO_2, temperature, precipitation) on habitat sensitivity is cumulative (i.e. habitats that are sensitive to a single CC stressor (based on anticipated exposure levels) are likely to be less vulnerable than those which are sensitive to multiple CC stressors. The theoretical range of relationship table output scores across all six sensitivity categories is -12 to 210.

Adjusted scores for sensitivity-exposure are simply the final scores weighted for non-response. Non-response adjustments for each habitat assessed is N/*n* where N equals thirty, the number of sensitivity-exposure cells for which a non-'null' response is likely, and *n* equals the actual number of non-'null' scores provided for that habitat. Note that although the number of sensitivity-exposure cells is actually equal to thirty-six, the direct influence of increased carbon dioxide levels on the habitat and the interaction with non-climate stressors may be impossible to predict given the current state of knowledge so N reflects likely number of scores as opposed to the full number of input scores possible. Final score computation also requires that scores have been assigned to a minimum of sixteen worksheet cells prior to final score computation to ensure that tool users are generating scores based on a fair understanding of the complexities of the effect of climate change on the habitat and not relying on a limited number of 'representative' scores to assess vulnerability. The theoretical range of non-response weights is 0.83 (if scores in all thirty-six cells are provided; else 1) to 1.875.

Assigned sensitivity-exposure levels reflect the same degree of habitat response as indicated by input scoring levels. Average scores for each of the six sensitivity categories less than three suggest modest habitat impairment, less than seven suggests habitat persistence will be limited, and greater than seven suggests the habitat will be severely impaired or lost. The sum of relationship table scores across all six sensitivity categories can therefore be used to assign sensitivity-exposure levels where: low is < 18, moderate is from 18 to 42, and high is ≥ 42.

Table A-1: Relationship Table of Output Scores for Combinations of Current Condition and Sensitivity-Exposure Scores

	Sum of Sensitivity-Exposure									
Current Condition	**<0**	**0 to .99**	**1 to 1.99**	**2 to 3.99**	**4 to 5.99**	**6 to 7.99**	**8 to 11.99**	**12 to 15.99**	**16 to 24.99**	**≥25**
≤0	-2	0.5	1.5	3	5	7	10	14	20	25
0.01 to 1	-1	1.5	2.5	4	6	8	11	15	21	26
1.01 to 2	0	2.5	3.5	5	7	9	12	16	22	27
2.01 to 3.5	1.5	4	5	6.5	8.5	10.5	13.5	17.5	23.5	28.5
3.51 to 5	3	5.5	6.5	8	10	12	15	19	25	30
5.01 to 7.5	5.5	8	9	10.5	12.5	14.5	17.5	21.5	27.5	32.5
7.51 to 10	8	10.5	11.5	13	15	17	20	24	30	35

ADAPTIVE CAPACITY

Final adaptive capacity scores are the simple of sum of scores assigned to each of the eight adaptive capacity components. The theoretical range of adaptive capacity scores is 0 to 30.

Adjusted scores for adaptive capacity are final scores adjusted for non-response using a weighting of N/*n* where N equals six and *n* is equal to the number of input scores contributing (i.e., non-'null' scores). A minimum of four adaptive capacity scores for a habitat must be provided for adaptive capacity final score computation to occur. The theoretical range of non-response weights for adaptive capacity is 1 to 1.5.

Assigned adaptive capacity levels reflect the same degree of climate change adaptation/mitigation potential as indicated by individual input scoring levels and are assigned based on the lower, middle, and upper components of the theoretical range of summed scores possible where: low is < 10, moderate is 10 to 20, and high is > 20.

CERTAINTY

Final certainty scores are the mean of user-input certainty scores in the SensitivityExposure and Adaptive Capacity worksheets. The theoretical range of certainty scores is 0 to 4.

The final certainty score provides a general indication of the basis and level of agreement among tool users for overall score assignment. Individually assigned certainty scores should be reviewed to identify information gaps and research needs.

The final certainty scores should be interpreted using the same scoring levels for certainty as described for individual certainty score assignment.

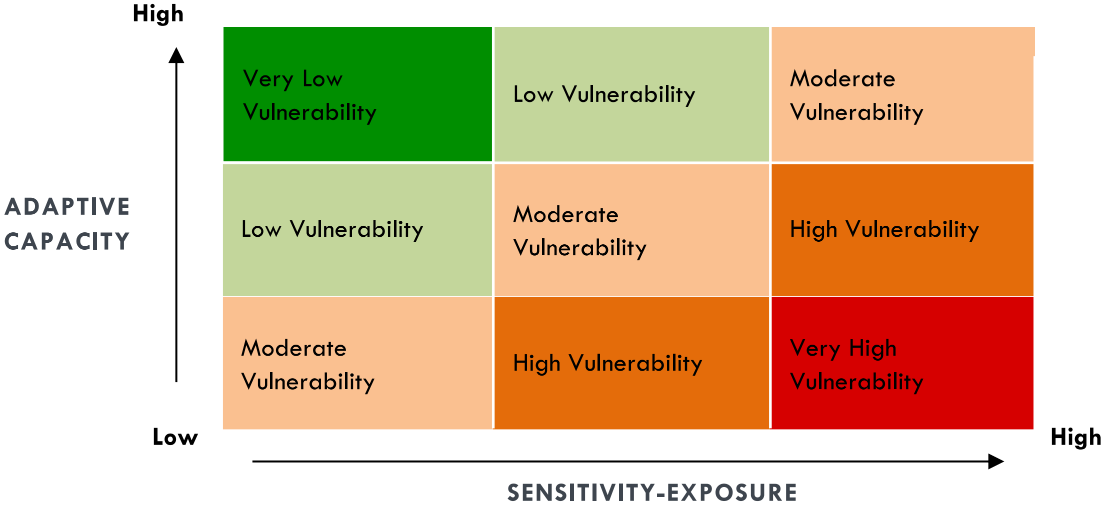
OVERALL VULNERABILITY

Overall vulnerability levels are based on levels assigned to sensitivity-exposure and adaptive capacity using the following relationship table (Table A-2). Overall vulnerability levels are based on the assumption that habitats having low sensitivity to predicted climate change exposure and high adaptive capacity will have less overall vulnerability and habitats that are highly sensitive to predicted climate change exposure and low adaptive capacity (i.e. no inherent traits or external factors that may offset climate change effects) will have the highest vulnerability to a changing climate.

HABITAT VULNERABILITY RANKING

While overall vulnerability levels for each habitat are indicated upon completion of scoring, tool users may elect to rank habitats based on final or adjusted scores to assess relative vulnerability of assessed habitats. Habitats with the greatest relative vulnerability should be reviewed to determine both the source of vulnerability and the potential for adopting strategies to reduce stressors or support habitat resiliency (using raw input scores) to better guide future management decisions.

Table A-2: Relationship Table of Vulnerability Levels for Combinations of Adaptive Capacity and Sensitivity-Exposure Levels



Very Low Vulnerability	Low Vulnerability	Moderate Vulnerability
Low Vulnerability	Moderate Vulnerability	High Vulnerability
Moderate Vulnerability	High Vulnerability	Very High Vulnerability

Scoring worksheets were designed to be printed directly from the Scoring Spreadsheet. They are included below for reference only.

Figure A-1: Instructions worksheet

Instructions for Scoring

1 Describe habitats being assessed:

1 ______________________________
2 ______________________________
3 ______________________________
4 ______________________________
5 ______________________________

2 Then, begin with Exposure X Sensitivity matrix and assign scores using the general scoring levels that follow as guidance:

General Scoring [*Refer to guidance document for specific examples of how this scoring should be applied]

a. Current Condition score (relative to non-climate stressor only)

0 Habitat is not impacted by non-climate stressor
2 Habitat is currently impacted by non-climate stressor but to a limited degree (i.e. over a modest portion of its extent or no significant influence on habitat structure / function)
5 Habitat is currently moderately impacted by non-climate stressor (i.e. evidence of stressor impact over a majority portion of its extent or clear degradation of habitat structure / function)
10 Habitat is severely impacted by non-climate stressor

b. Non-climate stressor interaction with CC stressors (i.e. with CO2, Temp, Precip, Sea Level, Storms)

-2 Habitat may benefit; non-climate stressor impact is alleviated by a change in climate condition
0 No anticipated change in habitat structure, function or extent
2 Habitat will likely be impaired to a limited degree (i.e. over a modest portion of its' extent or clear degradation of habitat structure/function)
5 Habitat persistence will be limited (i.e. degradation of habitat structure/function sufficient to modify reproductive potential, reduced habitat extent)
10 Habitat will be lost

***Note: The interaction of current condition and non-climate stressor interaction scores is captured in a relationship table [see Relationship Table worksheet]. Values in the relationship table are automatically extracted and contribute to the final score tally.**

3 For each cell in the Exposure-Sensitivity matrix, assign Certainty Scores as follows:

0 No direct or anecdotal evidence is available to support the score, topic needs further investigation
1 Low: Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts, score based on anecdotal observations
2 Medium: Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought, score based mostly on expert opinion
3 High: Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus, general information can be applied to local habitats
4 Very High: Strong evidence (established theory, multiple sources, consistent results, well documented and acceptable methods, etc.), high consensus, information for local habitats available

4 For each habitat, assign Adaptive Capacity scores using the following general scoring levels as appropriate:

General Scoring [*Refer to guidance document for specific examples of how this scoring should be applied]

0 Severe impediments to habitat persistence or dispersal (e.g. barriers, fragmentation) exist
or innate community characteristics of the habitat are not sufficient to compensate for CC stressors
or policy or management actions to offset CC stressors are not possible or are not likely to be implemented
2 Modest impediments to habitat persistence or dispersal (e.g. barriers, fragmentation) exist
or innate community characteristics of the habitat are sufficient to partially overcome CC stressors
or appropriate policy or management actions may be taken to partially offset CC stressors
5 No impediment to habitat persistence or dispersal (e.g. barriers, fragmentation) exists
or innate community characteristics of the habitat are sufficient to overcome CC stressors
or appropriate policy or management actions may be taken to fully offset CC stressors

Figure A-2: SensitivityExposure worksheet

EXPOSURE

SENSITIVITY

Habitat	**Current**	Cert.	**CO2**	Cert.	**Temp**	Cert.	**Precip**	Cert.	**Sea Level**	Cert.	**Extreme C**	Cert.
Direct Climate Effects (Ecophysiological & Community Response)												
1												
2												
3												
4												
5												
Invasive / Nuisance Species												
1												
2												
3												
4												
5												
Nutrients (deficiency or excess)												
1												
2												
3												
4												
5												
Sediment Supply												
Sedimentation												
1												
2												
3												
4												
5												
Erosion												
1												
2												
3												
4												
5												
Environmental Contamination												
1												
2												
3												
4												
5												

Figure A-3: Adaptive Capacity and Final Score worksheets

ADAPTIVE CAPACITY

Habitat	Degree of fragmentation	Certainty	Barriers to migration	Certainty	Recovery / regeneration following disturbance	Certainty	Diversity of functional groups	Certainty	Management actions	Certainty	Institutional / Human response	Certainty
1												
2												
3												
4												
5												

Final Scores

Habitat	Exposure-Sensitivity			Adaptive Capacity			Certainty	Overall Vulnerability Level
	Score	Adj. Score	Level	Score	Adj. Score	Level		
1	---	---	---	---	---	---	---	---
2	---	---	---	---	---	---	---	---
3	---	---	---	---	---	---	---	---
4	---	---	---	---	---	---	---	---
5	---	---	---	---	---	---	---	---

APPENDIX B: CASE STUDY SCORING EXAMPLE

The following provides an example of how the CCVATCH scoring was applied to evaluate a case study habitat. Brief statements about why each scoring level was chosen are given for each scoring category.

HABITAT DESCRIPTION

The habitat evaluated was composed of approximately 3,953 acres of deciduous forested wetlands that are managed by a National Wildlife Refuge in coastal South Carolina. These areas remain flooded or saturated throughout most years except during extreme drought periods. Water depth may periodically fluctuate as a result of tidal influences. Plant community composition is relatively homogeneous. Dominant species include swamp tupelo, bald cypress, green ash, water tupelo, and red maple. This habitat supports many species including rare bats, migratory birds, coastal black bears, and the highest density of nesting swallow-tailed kites in South Carolina and is the northernmost documented nesting site for this species. Additionally, forested wetlands play a critical role in filtering storm water runoff and supplying a primary drinking water resource for the greater region. This case study represents a relatively pristine habitat that may be susceptible to salt water intrusion and other climate change effects at the large parcel scale.

CLIMATE FORECAST

About a 2^{o}C annual increase in air temperature is expected by 2050 (RCP8.5 scenario). Precipitation predictions have a high degree of uncertainty; however an overall annual increase in precipitation is expected with more precipitation occurring as heavy rainfall events with longer periods of drought between events. With the increase in temperature, there is a modeled increase in the evaporative deficit by ~16 mm/month in the summer. Sea level has been rising locally at a rate of 3.2 mm/year, and is predicted to increase the tidal flood level in the area by approximately 17 cm by 2050. There is also a general prediction that the intensity of tropical storms will increase, but changes in frequency are uncertain.

	Current 1950-2005 Temp (^{0}C)		**Predicted 2050-2070 Temp (^{0}C)**		**Current Precip 1950-2005 (mm/day)**	**Predicted Precip 2050-2070 (mm/day)**	**Change in Evap. Deficit 2005-2074 (mm/mo)**	**Change in runoff 2005-2074 (mm/mo)**
	Min	Max	Min	Max				
Winter	1.4	14.4	3.9	16.9	3.0	3.2	0.1	-3.2
Spring	9.7	23.4	12.5	26.2	3.0	3.2	1.7	-1.1
Summer	20.0	31.4	23.1	34.6	4.8	5.1	16.3	-2.6
Fall	11.2	24.3	14.6	27.4	3.2	3.5	4.7	-3.3
Annual	10.6	23.4	13.5	26.3	3.5	3.8	5.7	-2.5

*Data from National Climate Change Viewer, USGS

The following scoring example does not consider CO_2 effects as that was a later addition to the CCVATCH tool.

DIRECT CLIMATE EFFECTS			
	Notes/Considerations	**Score**	**Certainty**
Current Conditions	• Unusual summer flooding in 2003 possibly climate related • Observed increase in poison ivy (CO2 effect?)	2	2
Increase in Temperature	• Longer growing season may benefit production • No frost dependent species; forest species are relatively heat tolerant	0	2
Change in Precipitation	• Dominant species are highly dependent on seasonality of precipitation for germination • Drought periods and heavy rainfall events will alter the understory • Changes in precipitation could stress trees which would make them more vulnerable to parasites	5	3
Change in Sea Level	• Salt intrusion is not expected by 2050, but the predicted increase in sea level will increase flooding depth and duration; understory structure will be altered • Changes in flooding amplitude could stress trees and make them more vulnerable to parasites	5	3
Increase in Extreme Climate Events	• Forest has historically recovered after storm events • Stronger storms may cause some salt water intrusion with SLR • Extreme drought would affect habitat structure	2	3

INVASIVE / NUISANCE SPECIES			
	Notes/Considerations	**Score**	**Certainty**
Current Conditions	• Privet and tallow on borders, *Phragmites australis* of concern • Red bay ambrosia beetle and forest tent caterpillar have done some damage • Presence and effects of aquatic invasives are unknown	2	3
Increase in Temperature	• Current species of concern would not be limited by temperature increase • longer growing season may benefit invasive plants • Water hyacinth overwintering may increase	3	2

Invasive/Nuisance Species (cont.)

Change in Precipitation	• Increased flooding could wash aquatic invasives in (e.g. hyacinth) • Tent caterpillars do better in drought years • At least one invasive will be positively affected	2	3
Change in Sea Level	• SL will not be high enough for intrusion to have an effect • Increased periodicity and amplitude of flooding could limit growth of invasive plants in the understory	-1	2
Increase in Extreme Climate Events	• Historically, inputs of tallow and *Phragmities* have followed storm events • Destabilization after storms could allow invasives to take hold	5	3

NUTRIENTS			
	Notes/Considerations	**Score**	**Certainty**
Current Conditions	• No evidence of current nutrient issues • Development (golf courses and housing) may be increasing nutrients in surrounding areas	0	2
Increase in Temperature	• Increased decomposition rates could benefit nutrient limited system • Net effect to changes in nutrient cycling is unknown	0	0
Change in Precipitation	• Increased flooding would bring in more nutrients • Effects of short-term drought on nutrient cycling are unclear	-2	2
Change in Sea Level	• SLR will not be great enough in 50 years to change soil salinity • Increase flooding amplitude would lead to more anaerobic processes making nutrients more available	0	2
Increase in Extreme Climate Events	• Increased storm debris could lead to increased decomposition, but effect is unclear	0	0

SEDIMENTATION

	Notes/Considerations	Score	Certainty
Current Conditions	• Surrounding agriculture practices are currently a minimal concern • Upstream dams have reduced historic sediment loads • Coring work shows higher sedimentation rates in the past than present • Forest clearing in the 1940's had long-term effect on sedimentation processes	1	3
Increase in Temperature	• Increased transpiration rates could dry soils, affecting sedimentation processes, but impact is uncertain	0	0
Change in Precipitation	• Increased drought periods and prolonged flooding would decrease decomposition and soil formation	2	2
Change in Sea Level	• Increase in tidal amplitude would carry more sediment into the system • Uncertainty over how rising sea level will affect the surrounding landscape	0	2
Increase in Extreme Climate Events	• Pulses of water from floods and storm surge tend to deposit sediments more than erode	-2	2

EROSION

	Notes/Considerations	Score	Certainty
Current Conditions	• There are no erosion issues currently	0	3
Increase in Temperature	• A longer growing season would increase the canopy and decrease the understory, allowing increased erosion during flood events	2	2

Erosion (cont.)

Change in Precipitation	• Increased flooding would create less understory, potential increased erosion during floods • More intense precipitation will increase erosion • Periodic drought may dry soils and make them more susceptible to erosion	2	3
Change in Sea Level	• Potential for increased ebb current velocities with increased amplitude may lead to more edge erosion, but this is unknown	0	0
Increase in Extreme Climate Events	• Historically, little erosion has occurred as a result of storms	0	3

ENVIRONMENTAL CONTAMINATION

	Notes/Considerations	Score	Certainty
Current Conditions	• Surrounding aging septic systems are of concern, but currently there is no evidence of contamination in habitat • An adjacent stretch of the river is 303d listed • Impacts of acid rain on forest health are unknown • Fish consumption advisory for methyl mercury may be an indicator of contamination, but has not impacted forest	0	1
Increase in Temperature	• Methyl mercury is more bioavailable at higher temps • Increased evaporation will concentrate contaminants • Little info on what contaminants are already present in soils	2	2
Change in Precipitation	• Increase precipitation will flush toxins out, but increased drought will concentrate • Increased precipitation may increase transport into the system • Increased use of herbicides in surrounding landscape	2	0
Change in Sea Level	• Potential for SLR to change chemical processes • No information on effects of amplitude and frequency of flooding on chemicals in soils • No score was given due to uncertainty	∅	∅

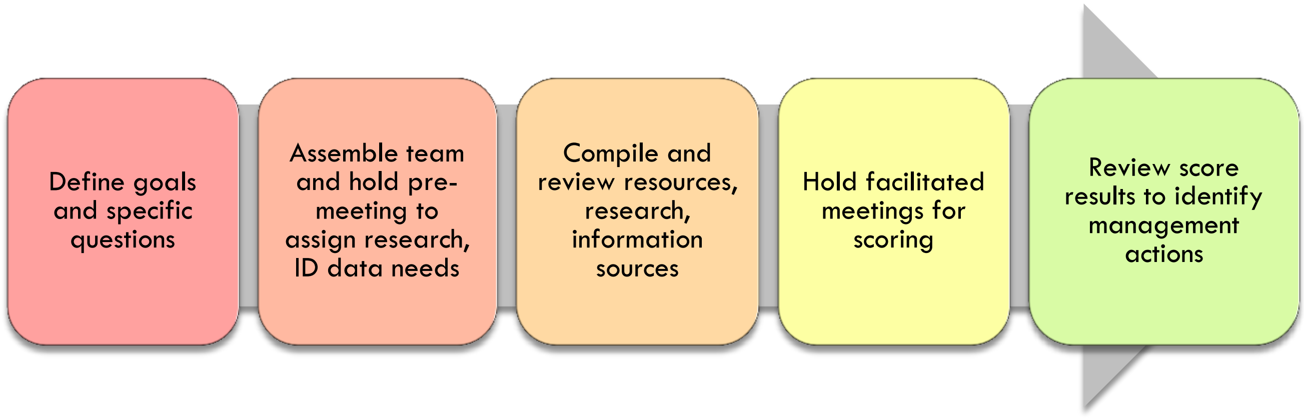
Environmental Contaminants (cont.)

Increase in Extreme Climate Events	• Chemicals captured in soil and vegetation may be released by extreme events • Plastic, trash, are pushed into system, may affect wildlife and have an impact to the habitat	2	1

ADAPTIVE CAPACITY

	Notes/Considerations	**Score**	**Certainty**
Fragmentation	• Area is not fragmented • Large area of surrounding habitat is protected	5	3
Barriers to Migration	• The study area is and island, but similar habitat exists all around the island • Depends on land use around it • Elevation may be barrier • Spread and germination of dominant tree species is highly dependent on correct timing of floods	1	3
Recovery / Regeneration	• Low potential for recovery if there is a significant salt event • Regeneration will depend on conditions following disturbance- has potential under just the right conditions	0	3
Diversity of Functional Groups	• Low diversity for tree species but high diversity for other functional groups, but difficult to predict the interrelatedness of groups	2	3
Management Actions	• It is unknown how management actions in other areas affect this habitat • Re-licensing for dams up the river may have downstream effects on the habitat, with the potential to offset salinity intrusion • Increased withdrawal up-river may compound SLR effects	1	3
Institutional / Human Response	• The management agency is adaptive, but adaptive response may be to not continue to manage this particular habitat area if it is not deemed strategic • The surrounding community has demonstrated a high degree of support in the past • Many diverse stakeholders using the water resources	5	2

APPENDIX C: GENERAL PROCESS



Using CCVATCH to assess the vulnerability of habitats will require some preparatory steps before the selected team of experts can begin scoring. The specific goals and questions that CCVATCH will be used to address should help to identify some core team members. During a pre-meeting and initial tool overview other experts may be identified as individuals that should be either invited to join the team or, if that is not possible, requested to contribute knowledge to the scoring process. Upon review of the tool and necessary input requirements it will become obvious that a great deal of resources will be necessary to complete the scoring. It is recommended that sufficient time be allotted between the pre-meeting and the planned facilitated meetings for resource review and data collection. The amount of time necessary to perform this task will be dependent on the collective knowledge of the experts on the team and the willingness of team members to take on that task. If little is known about the habitat to be assessed specifically, the effects of climate and non-climate stressors on the habitat, the relevant information will have to be collected [see Table C-1]. Tool users are encouraged to use the CCVATCH Guidance Document as a starting place for identifying relevant information needs and available resources. The specific types of information from a variety of sources that will need to be gathered and reviewed include:

- model output, particularly for climate projections, such as that available from the USGS National Climate Change Viewer;
- tools output to evaluate potential for change in site condition (many of which are available from NOAA's Digital Coast such as OpenNSPECT to determine sources of nonpoint source pollution and erosion potential);
- identified expert elicitation through requests for knowledge in the event these individuals are unavailable to serve on the assessment team;
- site visits when current conditions relative to stressors is not known; and,
- literature reviews to discover relevant information regarding the sensitivity of the habitats to various stressors.

Only after all of the material necessary for scoring has been identified, investigated and reviewed by team members, is it appropriate to begin holding facilitated meetings to assign scores on the scoring worksheet. When the scoring process is complete and the final scores have been derived coastal managers should consider both the final and raw scores as well as those for certainty to determine appropriate management strategies that make the best use of available resources.

Table C-1: Pre-Meeting Task Assignment for Resource Review/ Data Collection

Within each cell of the matrix indicate the degree of knowledge available to the group at the outset of the process and assign team members to review resources and/or collect necessary data in preparation for scoring.

Key: ✔ Sources of information known and readily available

✓ Sources of information are believed to be available but may require some effort to collect

? No known sources of information; will require investigation to identify appropriate resources for review

Sensitivity-Exposure

	Current Condition	CO_2	Temperature	Precipitation	Sea Level	Extreme Climate Events
Direct Effects						
Invasive / Nuisance Species						
Nutrients						
Sedimentation						
Erosion						
Environmental Contaminants						

Adaptive Capacity

	Fragmentation	Barriers	Recovery / Regeneration	Diversity of Funct. Groups	Management Actions	Inst. / Human Response
Background Information						

APPENDIX D: EXAMPLE FACILITATION PLANS AND WORKSHOP WORKSHEETS

This document offers guidance on facilitating the general process of implementing a CCVATCH working session for ranking the vulnerability of targeted coastal habitats based on the single workshop facilitation process used in the North Inlet-Winyah Bay Pilot Study, as well as suggestions for potential modifications that are available to the users.

EXAMPLE FACILITATION PLAN (SINGLE WORKSHOP)

The North Inlet-Winyah Bay National Estuarine Research Reserve pilot tested the process for using the CCVATCH tool starting in October 2013, with most of the pilot workshops in May of 2014. Participants from the kickoff workshop were instrumental in helping to identify four habitats in the South Carolina area on which to test the tool. Through a facilitated process, workshop participants selected *Spartina* salt marsh, Longleaf Pine forest, freshwater emergent marsh, and flooded forest. For each habitat, a working session was scheduled for which 4-6 local experts were identified to assist with implementing the CCVATCH process. Generally, each working session lasted approximately 4-5 hours. This time did include some familiarization with the tool and the scoring considerations as well (in future workshops, these steps should occur in a facilitated “pre-meeting workshop” prior to running the tool). Additionally, some of the participants in the pilot were not very familiar with the habitats in question, which should not be the case for the actual tool users.

SUPPLIES:

Computer & projector

Flip charts (6) & markers

Easels

Pre-made scoring criteria (as hand-outs or posted on wall)

Pre-made hand-outs or flipcharts with current conditions, stressor interactions, and adaptive capacity blank matrices for note-taking

PROCESS:

1) Introduce habitat –look at Google earth/maps of site on projector
2) Overview of climate projections
3) Introduce scoring levels for each scoring category (current condition, sensitivity-exposure, adaptive capacity, certainty)
4) Scoring for Current Conditions
    a) Option 1 – go through each of the non-climate stressors and record notes on current and potential impacts for each on pre-made blank matrix for current conditions. Then go back and record current condition scores for each stressor.
    b) Option 2 - go through each non-climate stressor individually and assign scores before proceeding to the next stressor.
    c) Comments:
        i) There is no required order of which stressor although it may be best to work through the stressors in the order in which they occur in the guidance document to prevent the need for shuffling back and forth between stressor sections.
        ii) There was a benefit to having all the stressors up on the wall/easels as flipcharts since group conversation may wander and the facilitator can better focus attention by moving chart to chart.

5) Break
6) Scoring for Sensitivity-Exposure (i.e. stressor interaction)
    a) Tear off current conditions flipchart sheet and post it below/nearby to the stressor interaction pre-made flipchart sheets
    b) Remove current conditions scoring and put up sensitivity-exposure scoring levels - review, and note that certainty scoring remains the same
    c) Go through stressor interactions – no definitive order, but may be useful to start wherever you did on current conditions
7) Break
8) Scoring for Adaptive Capacity
    a) Tear off stressor interactions sheet and put up pre-made flipchart sheets with adaptive capacity
    b) Remove stressor interaction scoring – replace with adaptive capacity scoring chart – explain scoring system, note that certainty remains the same
    c) Go through adaptive capacity scoring in order presented in guidance document
    d) Note: Having the scoring guide on the wall was least helpful in this category – it seemed that the participants referred to the example scoring in the guidance as opposed to the three different categories offered in the scoring criteria for this section

FACILITATION PLAN EXAMPLE (TWO WORKSHOPS)

WORKSHOP 1 - PREPARATION AND DATA GATHERING:

Before running the tool it is necessary to introduce your team to the tool, outline the general process, and assign necessary "tasks". At an initial pre-meeting, the group can review the habitats selected and decide what types of information and resources they will need. The team should gather data and information about the habitats, determine if there are key persons or information missing, and make process decisions, including setting ground rules. Additionally the group can decide if they need to obtain expert input for specific questions or habitats. This is where the group can decide on climate projections, including a timescale, sea-level models, atmospheric CO_2 projections (which emissions pathway to choose), precipitation change estimates, etc. To help the process proceed smoothly, the team should review the general scoring and understand the concepts behind the tool. The team should go through the assessment questions to record known data and make note of knowledge/data gaps. At this time they can assign pre-work or data assembly, especially for data gaps. By dividing up the data assembly the group can share the effort.

KEY PARTICIPANTS

- Land managers
- Scientists/researchers
- Representatives from resource management agencies (e.g. Coastal Management, Natural Resource Department, Environmental Health and Safety)
- CCVATCH Facilitators

POSSIBLE DATA SOURCES

- Site specific research
- Current and past land management documents
- Regulatory monitoring programs (e.g. shellfish bed advisories, water quality swimming advisories)

- Current management plan
- Topographic, soils & land cover maps
- High accuracy elevation data
- Current land use regulations
- Watershed delineations
- Local water quality data
- Historical events (e.g. oyster bed closures)
- Agency reports relevant to area or habitat
- Relevant model results (e.g. local SLAMM)

GROUND RULES FOR SCORING

Setting a few ground rules may help with the actual scoring process, and maintain consistency throughout the scoring of selected habitats. Below are several issues the group may consider when deciding on specific ground rules.

- How long do you want to work towards consensus?
- What to do if the group cannot initially agree.
    - Do you average the score?
    - Do you use majority rules?
- Can you go back and change the scoring as you move through the tool?

WORKSHOP 2 - FACILITATED WORKING SESSION

FACILITATION: (SEPARATE FROM THE GROUP)

When the facilitator has no stake in the scoring decision it is easier for them to appear as neutral and unbiased. The role of the facilitator is to guide the conversation to make a decision on scoring. Some challenges have been that the group will list many of the factors for the specific question but be hesitant to put an actual score on the question. The facilitator may use key phrases like: "what I'm hearing is" to repeat back some of the main points to the group and ask for hypothetical worse or better situations to try and get the group to decide where on the scale of no-impact to extreme impact they would fall. If necessary keep the group to a time limit.

FACILITATION: (WITHIN THE GROUP)

When the facilitator is a member of the decision-making team it is more challenging to appear that you are not driving the decision in the direction you want to go instead of hearing all of the ideas from the group. Possible suggestions would be to let everyone else talk before you add your input to not prime the group.

NOTETAKING:

This process uses flipcharts for visually recording comments from the decision making team, but a note taker is also vital to the process. The key points the note taker should focus on are the major points of the habitat condition or interaction (example: for invasive species listing the major invasive species potentially present in that habitat), the rationale for scoring and the information sources. With these three main pieces of information will help people who were not in the room understand the decisions made and thereby the vulnerability results. Additionally it will aid in follow up to the decision making meeting, if the team wants to revisit or review some of the decisions. Recording the information sources will help justify the certainty scoring and aid in follow-up if the team plans to seek out additional expert opinion to increase certainty. In addition, it can be useful to tally the scores of each person in the room (as well as the final score for the workshop) to assist as a record of how that score was derived (if either by some group averaging or consensus driven). Example scoring sheets are provided in the guidance document.

PROCESS

There are several options for facilitating the meeting and selection may depend on number of participants and in-person meeting potential.

SMALL GROUPS (6-8), IN PERSON:

There is no required order to start the discussion although in general the current conditions should go before the stressor interactions and it may run more smoothly if you consider stressors in the order in which they appear in the guidance document and score sheet. Adaptive capacity does not need to be scored last, but scoring levels are dissimilar to the other scored components of the tool and early discussions of the habitat as it relates to current condition and stressor interactions may make it easier to score if addressed last in the scoring process.

It may be easiest to begin the discussion by asking for the major stressors currently impacting the habitat. Begin with the most obvious issues of concern or where the most complete knowledge base exists. The facilitator can elicit a score and a certainty verbally. Benefits of this method: allows the group to converse about the decision at hand. Challenges: people who are less likely to speak up may not be heard. It is possible that one person in the group could be very vocal and control the conversation.

LARGE GROUPS (>8), IN PERSON:

The larger the group the harder it will be to come to consensus on the score to be assigned. More time may be required for conversation. A possible method to overcome larger group issues is using a polling method. Electronic keypad polling may aid in collecting and recording a large number of scores. Polling could be used as an initial survey to "take the temperature" of the room on the score, then the participants could discuss around those results, to provide rationale to the other participants, and then if there are initially divergent results the group can poll again to determine if there is more consistency in scoring. Benefits of this method: allows secret ballot and open discussion by the group about the decision at hand. Also provides an iterative decision making option, there is not necessarily a limit to the number of times the group votes (or, limit determined by ground rules). Challenges: It is still possible that one person in the group could be very vocal and control the conversation.

SMALL OR LARGE GROUPS, WORKING INDEPENDENTLY:

Each team member can fill out a scoring worksheet that includes their scores and a very brief statement of rationale (and associated certainty score). All of the results would then be compiled – if there is general agreement then the compiled results that would determine the assigned score. If there is

Team members working independently to derive scores may take much longer to implement the tool than in person meetings. However, if resource investigation summary materials were made available to team members in advance of the facilitated meeting, this exercise in independent scoring as a pre-meeting "homework" assignment may serve to make the actual in person workgroup session more productive.

disagreement, the facilitator would distribute the compiled scores back to the group, ask all the members to read each score and rational and then re-select their score based on their (presumed) greater level of understanding. The facilitator would look re-compile second tier scores and look for agreement. Hopefully this iterative method will bring the scores to agreement through the consideration of the responses of other group members. Benefits of this method: allows individuals to consider their position independently, provides a voice to group participants who are less vocal, and gives them time to think. Challenges: Getting the responses from the participants, and the time required for compilation. You may still need a rule for if the group is unable to come to consensus or a rule on how many rounds to go through.

SUPPLIES:

Computer & projector – to display maps, share information resources, display results, etc

Flip charts & markers

Easels

Pre-made scoring criteria as handouts or posted on wall

Pre-made flipcharts with current conditions, stressor interactions, and adaptive capacity blank matrices for note-taking

OPTIONAL SUPPLIES:

Internet Access – to use web tools like the NOAA Sea Level Rise Viewer

Powerpoint slides – with either Assessment Questions or Scoring Examples as it may help to have reminders up as you go along, also this reduces the need to flip through the guidance document, and keeps the group on the same page

It may be useful to project the captured “notes” on the screen while team members are discussing each stressor. A visual of the comments made could help facilitate a decision regarding a final score.

Facilitated scoring workshop held at Chesapeake Bay-Virginia NERR as part of the two site pilot project (Aug. 2014)

WORKSHOP WORKSHEETS

(see following pages)

Table D-1: Workshop Worksheet for Direct Effects

DIRECT CLIMATE EFFECTS

	Notes/Considerations	Score	Certainty
Current Conditions			
Increase in CO_2			
Increase in Temperature			
Change in Precipitation			
Change in Sea Level			
Increase in Extreme Climate Events			

Table D-2: Workshop Worksheet for Invasive / Nuisance Species

INVASIVE / NUISANCE SPECIES			
	Notes/Considerations	Score	Certainty
Current Conditions			
Increase in CO_2			
Increase in Temperature			
Change in Precipitation			
Change in Sea Level			
Increase in Extreme Climate Events			

Table D-3: Workshop Worksheet for Nutrients

NUTRIENTS			
	Notes/Considerations	Score	Certainty
Current Conditions			
Increase in CO_2			
Increase in Temperature			
Change in Precipitation			
Change in Sea Level			
Increase in Extreme Climate Events			

Table D-4: Workshop Worksheet for Sedimentation

SEDIMENTATION

	Notes/Considerations	Score	Certainty
Current Conditions			
Increase in CO_2			
Increase in Temperature			
Change in Precipitation			
Change in Sea Level			
Increase in Extreme Climate Events			

Table D-5: Workshop Worksheet for Erosion

EROSION			
	Notes/Considerations	**Score**	**Certainty**
Current Conditions			
Increase in CO_2			
Increase in Temperature			
Change in Precipitation			
Change in Sea Level			
Increase in Extreme Climate Events			

Table D-6: Workshop Worksheet for Environmental Contaminants

ENVIRONMENTAL CONTAMINANTS			
	Notes/Considerations	**Score**	**Certainty**
Current Conditions			
Increase in CO_2			
Increase in Temperature			
Change in Precipitation			
Change in Sea Level			
Increase in Extreme Climate Events			

Table D-7: Workshop Worksheet for Adaptive Capacity

ADAPTIVE CAPACITY

	Notes/Considerations	Score	Certainty
Fragmentation			
Barriers to Migration			
Recovery / Regeneration			
Diversity of Functional Groups			
Management Actions			
Institutional / Human Response			

NOTES