Climate Change Vulnerability Assessment for Natural Resources Management: Toolbox of Methods with Case Studies

Version 1.0

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1.0 Introduction

The toolbox of methods for climate change vulnerability assessment (CCVA) for natural resources—from individual species to habitats to places (e.g., protected areas, watersheds, landscapes)—continues to grow as new approaches are developed, tested, and applied. The purpose of this document is to provide a non-comprehensive survey of some of the principal CCVA methods being used today for: (1) species; (2) habitats; (3) places (protected areas, watersheds, landscapes); (4) ecosystem processes; (5) ecosystem services; (6) water resources; and (7) coastal resources. Case study examples are presented for as many of the methods as possible. Most of the text is taken directly from the abstract or methods section of the article/report cited.

This toolbox does not provide an evaluation of the pros and cons of methods, but simply provides a description of each method and case study to provide the reader with sufficient information so they can: (1) decide if further investigation of a tool or case study is warranted; and (2) find additional resources about that tool/case study.

Deciding which tool to use is not always simple or straightforward, and depends on factors including the management question being asked, the target natural resource or resources, the staff and financial resources available, the level of stakeholder participation desired, the desired level of confidence in the results, and other factors. Readers should consult the comprehensive publication *Scanning the Conservation Horizon* (Glick et al. 2011; http://www.habitat.noaa.gov/pdf/scanning_the_conservation_horizon.pdf), for an introduction to climate change vulnerability assessment and questions to ask in deciding which tool to use.

The goal is to regularly update the Toolbox as new methods and case studies are published. To be effective, this needs to be a living document. We welcome input from readers regarding different methods and case studies, as well as any published evaluations of methods.

Please send information on additional tools and case studies to Kurt A. Johnson (kurt_johnson@fws.gov).

2.0 Species Approaches

CCVAs at the species level are generally categorized into "coarse-filter" approaches that use indices to develop a qualitative categorization of vulnerability, and "fine-filter" approaches that use models, often spatially-explicit, to determine where and how species may be vulnerable to climate change. Each approach has strengths and limitations. Using the two in conjunction with one another may be a fruitful approach. In such an analysis, a coarse-filter approach would first be used to identify a suite of species generally vulnerable to climate change. Then a fine-filter approach can be used to identify species-specific responses in greater detail. One such approach is being used by Lawler and associates in the Pacific Northwest (http://www.climatevulnerability.org/). Of course, if there is a species or suite of species of interest, it may make more sense to proceed directly to one or more fine-filter approaches.

2.1 Coarse-filter Species Approaches -- Indices

At present, three coarse-filter approaches to assessing species vulnerability to climate change are being used to varying degrees in the U.S.: (1) NatureServe's Climate Change Vulnerability Index; (2) US Forest Service System for Assessing Vulnerability of Species (SAVS); and (3) the US Environmental Protection Agency Framework for Categorizing the Relative Vulnerability of Threatened &Endangered Species to Climate Change. A brief synopsis and case studies of each approach follow.

2.1.1 Climate Change Vulnerability Index, CCVI (NatureServe)

The Climate Change Vulnerability Index (CCVI) uses a scoring system that integrates a species' projected exposure to climate change in an assessment area with three factors associated with climate change sensitivity: (1) indirect exposure to climate change; (2) species-specific factors (including dispersal ability, temperature and precipitation sensitivity, etc.); and (3) documented response to climate change. The CCVI is intended for use with terrestrial and aquatic (but not Marine) animals and plant species. According to NatureServe: "Assessing species with this Index facilitates grouping taxa by their relative risk to climate change, and by sensitivity factors, which we expect will help users to identify adaptation options that could benefit multiple

species." Interpretation of the results involves using the outcomes in conjunction with the NatureServe status ranks since CCVI does not consider some key factors that influence vulnerability.
Developer: NatureServe
http://www.natureserve.org/prodServices/climatechange/pdfs/Guidelines_NatureServeClimateChangeVulnerabilityIndex_r2.1_Apr2011.pdf

CCVI Case Studies:

- **Vulnerability of At-risk Species to Climate Change in New York (Schlesinger et al. 2011)**
  The New York Natural Heritage Program calculated the relative vulnerability of 119 of New York's Species of Greatest Conservation Need using the CCVI. They selected species spanning taxonomic groups that were thought (1) might be susceptible to climate change; (2) would be good indicators of vulnerability of species in similar habitats; and (3)would have sufficient data to allow conducting the assessment.
  http://www.natureserve.org/prodServices/climatechange/pdfs/ccvi_report_ny.pdf

- **Integrating Climate Change Vulnerability Assessments into Adaptation Planning: A Case Study for Species in Florida (Dubois et al. 2011)**
  Defenders of Wildlife assessed 21 species that reflected diverse ecological and management attributes of interest using the NatureServe CCVI, for potential use in the Florida State Wildlife Action Plan. Defenders writes: "By using a facilitated process with species experts, we were able to use the CCVI as a framework to (1) identify factors contributing to vulnerability, (2) elucidate hypothesized relationships among these factors and the potential impacts on species and their habitats, and (3) differentiate among sources of uncertainty."
  http://www.defenders.org/publications/integrating_climate_change_vulnerability_into_adaption_planning.pdf

- **Assessing Species and Area Vulnerability to Climate Change for the Oregon Conservation Strategy: Willamette Valley Ecoregion (Steel et al. no date)**
  The Conservation Management Program at the University of California, Davis, used the CCVI to conduct a vulnerability assessment of 46 focal species across seven broad taxonomic groups within the Willamette Valley Ecoregion of Oregon.
  http://www.defenders.org/publications/assessing_species_and_area_vulnerability_to_climate_change_for_the_oregon_conservation_strategy_willamette_valley_ecoregion.pdf

- **Climate Change Vulnerability Assessment of Species of Concern in West Virginia (Byers and Norris 2011)**
  The West Virginia Division of Natural Resources used the CCVI to assess and rank the relative climate change vulnerability of 185 animal and plant species in West Virginia. Most species were selected based on their status as Species of Greatest Conservation Need within the West Virginia Wildlife Conservation Action Plan.
  http://wvdnr.gov/publications/PDFFiles/ClimateChangeVulnerability.pdf

- **Adapting Conservation to a Changing Climate: An Update to the Illinois Wildlife Action Plan**
  The Illinois Chapter of The Nature Conservancy used the CCVI to assess the climate change vulnerability of 162 Species in Greatest Need of Conservation for use in Illinois Wildlife Action Plan.
  http://conserveonline.org/library/adapting-conservation-to-a-changing-climate-an/view.html

- **Identifying Species in Pennsylvania Potentially Vulnerable to Climate Change (Furedi et al. 2011)**
  The Pennsylvania Natural Heritage Program completed climate change vulnerability assessments for 85 priority species from Pennsylvania's State Wildlife Action Plan using the CCVI.
  http://www.naturalheritage.state.pa.us/ccvi/ccvi_final_report.pdf

- **Climate Change Vulnerability Assessment of Rare Plants in California (Anacker and Leidholm 2012)**
  The California Department of Fish and Game, Biogeographic Data Branch used the CCVI to assess the 'vulnerability' of roughly 10% of California's rare plant species (156 of 1625 total rare plants) representing a range of species characteristics. Due to the large number of rare plants in California, authors sought to determine whether the level of climate change vulnerability could be inferred for certain groups of rare plants based on characteristics such as level of rarity, habitat specificity, or other life history traits.
  http://climate.calcommons.org/sites/default/files/final_report_oct_29_2012%281%29.pdf

- **Assessing Climate Change Vulnerability of Breeding Birds in Arctic Alaska (Liebezeit et al. 2012)**
  The Wildlife Conservation Society assessed the climate change vulnerability of 54 Arctic Alaskan breeding bird species using the CCVI. In addition, the assessment was intended to: (1) evaluate the relative contribution of specific sensitivity and exposure factors to individual species rankings; (2) consider how this assessment may be integrated with other approaches; and (3) appraise the effectiveness of the CCVI tool.
  http://www.wcsnorthamerica.org/WildPlaces/ArcticAlaska.aspx

- **Use of a Climate Change Vulnerability Index for Assessing Species at Risk on Military Lands (Sperry and Hayden 2011)**
  The Construction Engineering Research Laboratory of the U.S. Army Engineer Research and Development Center evaluated the CCVI as a tool for military land managers by applying it to three high priority Species at Risk: (1) the Mohave ground squirrel (*Spermophilus mohavensis*) on Fort Irwin, CA; (2) the Columbia Basin distinct population segment of the greater sage-grouse (*Centrocercus urophasianus*) on the Yakima Training Center, WA; and (3) the gopher tortoise (*Gopherus polyphemis*) on Fort Stewart, GA.
  http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA559189

- **Climate change planning for the Great Plains: Wildlife vulnerability assessment & recommendations for land and grazing management (Zack et al. 2010)**
  The Wildlife Conservation Society used the CCVI tool to conduct an assessment for a set of 30 grassland species, focusing primarily on the species of concern listed in the wildlife action plans of the states within the Great Plains LCC.
  http://www.southernclimate.org/documents/resources/Climate_Change_Planning_for_Great_Plains_Wildlife_Conservation_Society.pdf

- **Assessing Species and Area Vulnerability to Climate Change for the Oregon Conservation Strategy: Willamette Valley Ecoregion (Steel et al. no date)**
  The Conservation Management Program at the University of California, Davis, used the CCVI to conduct a vulnerability assessment of 46 focal species across seven broad taxonomic groups within the Willamette Valley Ecoregion of Oregon.
  http://www.defenders.org/publications/assessing_species_and_area_vulnerability_to_climate_change_for_the_oregon_conservation_strategy_willamette_valley_ecoregion.pdf

2.1.2 A System for Assessing Vulnerability of Species to Climate Change, SAVS (US Forest Service)

The System for Assessing Vulnerability of Species (SAVS) identifies the relative vulnerability of terrestrial vertebrate species to climate change. Designed for managers, the SAVS tool uses a questionnaire of 22 predictive criteria to create vulnerability scores. The user scores species' attributes relating to potential vulnerability or resilience associated with projections for their region. Six scores are produced: an overall score denoting level of vulnerability or resilience, four categorical scores (habitat, physiology, phenology, and biotic interactions) indicating source of vulnerability, and an uncertainty score, which reflects user confidence in the predicted response.
Developer: US Forest Service, Rocky Mountain Research Station
http://www.fs.fed.us/rm/grassland-shrubland-desert/products/species-vulnerability/

SAVS Case Studies:

- **Species Vulnerability in Coronado National Forest (Coe et al. 2012; Davison et al. 2012)**
  US Forest Staff, led by Rocky Mountain Research Station, assessed the vulnerability of a selection of terrestrial vertebrates in the "Sky Islands" of Coronado National Forest (NF), AZ using SAVS. Two publications resulted, a Forest Service General Technical Report and a paper in the peer-reviewed literature. In this second paper, authors evaluated 15 animal species that had been scored with SAVS, and applied the SAVS vulnerability scores to each species' respective potential habitat model (spatially-explicit) in order to visualize the spatial patterns of cross-species vulnerability across the biologically diverse Coronado NF, and to identify the considerations of spatially referencing such indices.
  http://www.fs.fed.us/rm/pubs_other/rmrs_2012_davison_j001.pdf
  http://www.fs.fed.us/rm/pubs/rmrs_gtr273.pdf

- **Vulnerability of Species to Climate Change in the Southwest: Threatened, Endangered, and At-Risk Species at the Barry M. Goldwater Range, Arizona (Bagne and Finch 2012)**
  This Forest Service conducted assessment of 15 vertebrates and 1 plant species uses SAVS to rank individual species of interest within the eastern portion of the Barry M. Goldwater Range, Arizona, according to predicted climate change responses and associated population declines balanced with responses expected to incur resilience or population increases.
  http://www.fs.fed.us/rm/pubs/rmrs_gtr284.pdf

- **An Assessment of Vulnerability of Threatened, Endangered and At-Risk Species to Climate Change at Fort Huachuca, Arizona (Bagne and Finch 2010)**
  This Forest Service conducted assessment of 21 vertebrates and 2 plant species uses SAVS to rank individual species of interest within Fort Huachuca, Arizona, according to predicted climate change responses and associated population declines balanced with responses expected to incur resilience or population increases.
  http://www.denix.osd.mil/nr/upload/09-433-Fort-Huachuca-Full-Assessment.pdf

2.1.3 Framework for categorizing the relative vulnerability of threatened & endangered species to climate change (US Environmental Protection Agency)

The EPA Framework is composed of four modules. Module 1 categorizes baseline vulnerability to extinction or major population reduction. Module 2 scores the likely vulnerability of a species to future climate change, including the species' potential physiological, behavioral, demographic, and ecological response to climate change. Module 3 combines the results of Modules 1 and 2 into a matrix to produce an overall score of the species' vulnerability to climate change. Module 4 is a qualitative determination of uncertainty of overall vulnerability based on evaluations of uncertainty done in each of the first 3 modules.
Developer: Environmental Protection Agency (prepared by Galbraith and Price under contract)
http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=203743

EPA Framework Case Study:

- This method apparently has not been widely used, as we could find no published papers specifically applying the method to one or more taxa. However, the publication describing the method, cited above, includes a case study of six vertebrate, ESA-listed taxa. In addition, the Mexican Spotted Owl (Strix occidentalis lucida) Recovery Plan explored the vulnerability of Mexican spotted owls to climate change using current knowledge of Mexican spotted owl ecology and three tools designed to allow assessment of effects of climate change on species of interest, including the EPA framework.
  http://ecos.fws.gov/docs/recovery_plan/MSO_Recovery_Plan_First_Revision_Dec2012.pdf

2.1.4 Framework for Assessing Climate Change Vulnerability of California's At-risk Birds

Point Reyes Bird Observatory and Cal Fish and Game developed a modified vulnerability index, based in part on the CCVI and EPA approaches, but tailored for California bird populations (Gardali et al. 2012). They developed four sensitivity and three exposure criteria (with assessed confidence levels for each) and used these to develop a climate vulnerability index. They then developed a matrix that integrates the California Bird Species of Special Concern ranks with the climate vulnerability rankings to generate three levels of priority for conservation action. Using this index, they ranked 358 bird taxa, and classified 128 as vulnerable to climate change.
http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0029507

2.1.5 Assessing the Vulnerability of Biodiversity to Climate Change Using Landscape-scale Indicators

Klausmeyer et al. (2011) present a "rapid and cost-effective method to estimate the vulnerability of biodiversity to climate change impacts across broad areas using landscape-scale indicators." This coarse-scale approach does not replace species-specific vulnerability assessments, but allows managers to focus analysis on the species likely to be most vulnerable to climate change and identify the categories of conservation strategies for implementation to reduce vulnerability. They applied this method to California, USA to map the portions of the state where biodiversity managers should focus on minimizing current threats to biodiversity, and reducing constraints to adaptation, reducing exposure to climatic changes.
http://www.esajournals.org/doi/abs/10.1890/ES11-00044.1

2.1.6 Framework for Assessing Climate Change Vulnerability of California's Native and Alien Freshwater Fishes

Moyle et al. (2013) developed a systematic assessment approach that incorporates expert knowledge to determine status and future vulnerability to climate change of native and alien freshwater fishes in California, USA. The method uses expert knowledge, supported by literature reviews of status and biology of the fishes, to score ten metrics for both (1) current status of each species (baseline vulnerability to extinction) and (2) likely future impacts of climate change (vulnerability to extinction). Baseline and climate change vulnerability scores were derived for 121 native and 43 alien fish species.
http://www.plosone.org/article/fetchObject.action?uri=info%3Adoi%2F10.1371%2Fjournal.pone.0063883&representation=PDF

2.1.7 Novel predictive framework of species extinction vulnerability for coral reef fishes

Authors developed a predictive bivariate approach to assess species vulnerability to extinction through climate change associated coral reef disturbance. With this framework, a species' vulnerability to population declines following a climatic disturbance event (termed "climate vulnerability") is plotted against the intrinsic extinction risk of that species (termed "extinction risk"). Based on scientific theory and published empirical assessments, four variables were included in the climate vulnerability index that are known to relate to population declines following benthic disturbances; diet specialization, habitat specialization, recruitment specialization for live coral and body size.
http://onlinelibrary.wiley.com/doi/10.1111/j.1461-0248.2011.01592.x/pdf

2.2 Fine-filter Species Approaches -- Modeling

A number of modeling approaches are used to look at the vulnerability of species to future climate change, including mechanistic approaches and correlative approaches. "Mechanistic models aim to incorporate physiologically limiting mechanisms in a species' tolerance to environmental conditions. Such mechanistic models require detailed understanding of the physiological response of species to environmental factors and are therefore difficult to develop for all but the most well understood species. Correlative models aim to estimate the environmental conditions that are suitable for a species by associating known species' occurrence records with suites of environmental variables that can reasonably be expected to affect the species' physiology and probability of persistence. The central premise of this approach is that the observed distribution of a species provides useful information as to the environmental requirements of that species" (Pearson 2007). "Potential impacts of projected climate change on biodiversity are often assessed using single-species bioclimatic 'envelope' models. Such models are a special case of species distribution models in which the current geographical distribution of species is related to climatic variables so to enable projections of distributions under future climate change scenarios" (Heikinnen et al. 2006). There is a rich and growing literature on SDM and bioclimate envelope models, including assessments of the pros and cons of the approach (Araújo and Peterson 2012).

Species Modeling Case Studies:

- **Greater Glider (*Petauroides volans*) in Australia (Kearney et al. 2010)**
  Kearney et al. (2010) applied both mechanistic (Niche Mapper) and correlative (Maxent, Bioclim) SDMs to predict current and future distributions and fertility of the greater glider, an Australian gliding possum. They found that the approaches make congruent, accurate predictions of current distribution and similar predictions about the impact of a warming scenario, thus supporting previous predictions for similar species using only correlative approaches. The authors argue that convergent lines of independent evidence provide a robust basis for predicting and managing extinctions risks under climate change.
  http://www.environmentportal.in/files/Correlative%20and%20mechanistic%20models%20of%20species%20distribution.pdf

- **Polar Bears in the Southern Beaufort Sea (Hunter et al. 2010) (Regehr et al. 2010) (Rode et al. 2010)**
  Hunter et al. (2010) evaluated the impacts of climate change on polar bears in the southern Beaufort Sea of Alaska and Canada by means of a demographic analysis, combining deterministic, stochastic, environment dependent matrix population models with forecasts of future sea ice conditions from IPCC general circulation models (GCMs).
  https://darchive.mblwhoilibrary.org/bitstream/handle/1912/4685/09-1641.1.pdf?sequence=1

  Regehr et al. (2010) evaluated the effects of sea ice conditions on vital rates (survival and breeding probabilities) for polar bears in the southern Beaufort Sea. They estimated vital rates using multistate capture–recapture models that classified individuals by sex, age and reproductive category. They used multimodel inference to evaluate a range of statistical models, all of which were structurally based on the polar bear life cycle. We estimated parameters by model averaging, and developed a parametric bootstrap procedure to quantify parameter uncertainty.
  http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2656.2009.01603.x/abstract

  Rode et al. (201) tested whether patterns in body size, condition, and cub recruitment of polar bears in the southern Beaufort Sea of Alaska were related to the availability of preferred sea ice habitats and whether these measures and habitat availability exhibited trends over time, between 1982 and 2006. Specifically, they addressed the following four questions: (1) Is reproductive output, quantified as litter mass, associated with maternal condition? If so, what measures of female stature/condition (condition indices, body mass, skull size) are most closely related to reproductive output? (2) Did body mass, skull size, or condition relate to interannual variation in available ice habitat? (3) Did body mass, skull size, or condition of polar bears exhibit a trend between 1982 and 2006? (4) Did reproductive output (litter mass and cubs per female) exhibit a trend between 1982 and 2006? Was it related to interannual variation in available ice habitat?
  http://www.esajournals.org/doi/pdf/10.1890/08-1036.1

- **American Pika in Western United States (Calkins et al. 2012)**
  Authors modeled current and future distribution of suitable habitat for the talus-obligate l *Ochotona princeps* (American pika) across the western USA under increases in temperature associated with climate change, to: (a) compare forecasts using only climate variables vs using those plus habitat considerations; (b) identify possible patterns of range collapse; and (c) compare conservation and management implications of changes at two taxonomic resolutions, and using binned- vs binary-probability maps. They used MaxEnt to analyze relationships between occurrence records and climatic variables to develop a bioclimatic-envelope model, which was refined by masking with a deductive appropriate-habitat filter based on suitable land-cover types. They used this final species-distribution model to predict distribution of suitable habitat under range-wide temperature increases from 1 to 7°C, in 1°C increments.
  http://onlinelibrary.wiley.com/doi/10.1111/j.1600-0587.2011.07227.x/abstract;jsessionid=0A1FFF42B6698DEEC24C46D6FA75446D.d01

t01?systemMessage=Wiley+Online+Library+will+be+disrupted+on+18+May+from+10%3A00-12%3A00+BST+%2805%3A00-07%3A00+EDT%29+for+essential+maintenance&userIsAuthenticated=false&deniedAccessCustomisedMessage=

- **Wolverine Circumboreal Distribution (Copeland et al. 2010)**
  Authors hypothesized that the occurrence of wolverines is constrained by their obligate association with persistent spring snow cover for successful reproductive denning and by an upper limit of thermoneutrality. To investigate this hypothesis, they developed a composite of MODIS classified satellite images representing persistent snow cover from 24 April to 15 May, which encompasses the end of the wolverine's reproductive denning period. To investigate the wolverine's spatial relationship with average maximum August temperatures, they used interpolated temperature maps. They then compared and correlated these climatic factors with spatially referenced data on wolverine den sites and telemetry locations from North America and Fennoscandia, and our contemporary understanding of the wolverine's circumboreal range.
  http://www.fs.fed.us/rm/pubs_other/rmrs_2010_copeland_j001.pdf

- **Montane Mammals in Cascadia (Johnston et al. 2012)**
  Johnston et al. (2012) examined potential impacts of climate change over the next century on eight mammal species of conservation concern in western Washington State, under four warming scenarios. They used two species distribution models, including a logistic regression-based model and the "maximum entropy" (MaxEnt) model, to project the location and extent of the potential current and future range of each species based on a suite of environmental and geographical variables.
  http://www.esajournals.org/doi/abs/10.1890/ES12-00077.1

- **European Mammals (Levinsky et al. 2007)**
  Using the "fuzzy climatic envelope model," Levinsky et al. (2007) evaluated the potential impact of climate change on the distributions and species richness of 120 native terrestrial nonvolant European mammals under two of IPCC's future climatic scenarios. Assuming unlimited and no migration, respectively, the model predicted that 1% or 5–9% of European mammals risk extinction, while 32–46% or 70–78% may be severely threatened (lose > 30% of their current distribution) under the two scenarios.
  http://192.38.112.111/pdf-reprints/Levinsky2007.pdf

- **Snow Leopards in the Himalaya (Forrest et al. 2012)**
  Authors developed a hybrid approach to climate-adaptive conservation landscape planning for snow leopards in the Himalayan Mountains. First they mapped current snow leopard habitat using a mechanistic approach that incorporated field-based data, and then combined it with a climate impact model using a correlative approach. For the latter, they used statistical methods to test hypotheses about climatic drivers of treeline in the Himalaya and its potential response to climate change under three IPCC GHG emissions scenarios. Second, they assessed how change in treeline might affect the distribution of snow leopard habitat.

http://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Biol.Cons.2012_Vulnerability_of_Snow_Leopard_Habitat_to_Treeline_Shift__1_.pdf

- **Giant Panda in China (Songer et al. 2012)**
  Authors used Maxent to relate current giant panda distribution to environmental variables and to project future giant panda habitat within China.
  http://www.hindawi.com/journals/ijeco/2012/108752/

- **Koala in Australia (Adams-Hosking et al. 2011)**
  Authors aimed to predict the likely shifts in the climate envelope of the koala throughout its natural distribution under various climate change scenarios and identify potential future climate refugia. To predict possible future koala climate envelopes, they developed bioclimatic models using Maxent, based on a substantial database of locality records and several climate change scenarios.
  http://www.publish.csiro.au/?paper=WR10156

- **Tidal Marsh Birds in the San Francisco Estuary (Nur et al. 2012)**
  Nur et al. (2012) developed population-dynamic models to assess and better understand the long-term population viability of four key, tidal marsh-dependent species, under a variety of environmental conditions, including climate change impacts, in the San Francisco Estuary. Species are: California Black Rail (*Laterallus jamaicensis coturniculus*), California Clapper Rail (*Rallus longirostris obsoletus*), Saltmarsh Common Yellowthroat (*Geothlypis trichas sinuosa*), and three tidal marsh subspecies of Song Sparrow: Alameda (*Melospiza melodia pusillula*), Samuel's (*M. m. samuelis*), and Suisun (*M. m. maxillaris*).
  http://data.prbo.org/apps/sfbslr/LCC%20PRBO%20SFBay%20TidalMarsh%20Demogr%20ClimateChange_2012.pdf

- **Sichuan Jay in West-central China (Lu et al. 2012)**
  Authors used MaxEnt software to construct models and make predictions for the rare Sichuan Jay (*Perisoreus internigrans*), which is known only from isolated fragments of high-elevation coniferous forest on the Qinghai–Tibet plateau of west-central China.
  http://www.jstor.org/stable/full/10.1525/cond.2012.110030

- **Lizard Diversity in Mexico (Sinervo et al. 2010)**
  Sinervo et al. (2010) compared recent and historical surveys for 48 Mexican lizard species at 200 sites. Since 1975, 12% of local populations have gone extinct. Authors verified physiological models of extinction risk with observed local extinctions and extended projections worldwide. Since 1975, authors estimate that 4% of local populations have gone extinct worldwide, but by 2080 local extinctions are projected to reach 39% worldwide, and species extinctions may reach 20%.
  http://bio.research.ucsc.edu/~barrylab/classes/climate_change/SinervoSci2010.pdf

- **Salamander Biodiversity in Appalachia (Milanovich et al. 2010)**
  Milanovich et al. (2010) used Maxent to model the suitable climatic habitat of 41 plethodontid salamander species inhabiting the Appalachian Highlands region (33 individual species and eight species included within two species complexes). They evaluated the relative change in suitable climatic habitat for these species in the Appalachian Highlands from the current climate to the years 2020, 2050, and 2080, using two models and two emissions scenarios and using two-model thresholds levels (relative suitability thresholds for determining suitable/unsuitable range).
  http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0012189

- **Cutthroat Trout (*Oncorhynchus clarkii*) (Wenger et al. 2011)**
  Wenger et al. (2011) assessed the effects of temperature, flow regime, biotic interactions, topographic variables and land-use variables on distribution of four trout species in the western United States, then used downscaled outputs from general circulation models coupled with a hydrologic model to forecast species suitable habitat under climate change Projections under the 2080s A1B emissions scenario project that native cutthroat trout, already excluded from much of its potential range by nonnative species, will lose a further 58% of habitat due to an increase in temperatures beyond the species' physiological optima and continued negative biotic interactions.
  http://www.pnas.org/content/early/2011/08/09/1103097108.full.pdf

- **Gila Trout (*Oncorhynchus gilae*) in New Mexico (Kennedy et al. 2009)**
  This study uses a regional climate change simulation (Leung et al., Clim Change 62:75–113, 2004) to determine changes in the climate envelope for Gila trout, which is sensitive to maximum temperature, associated with a plausible scenario for greenhouse gas increases. These regional climate changes are downscaled to derive surface temperature lapse rates using regression models.
  http://epswww.unm.edu/facstaff/gutzler/manuscripts/ClimChange_09.pdf

- **Joshua Tree (*Yucca brevifolia*) Cole et al. (2011)**
  Cole et al. (2011) combined paleoecological records, current observations and climate envelope modeling to identify future possible ranges of Joshua trees under several climate change scenarios. They developed a model of climate suitability for Joshua tree based on its 20th century range and climates, and applied it to future climates modeled through GCMs downscaled to accommodate the complex topography within Joshua tree range. All of the models projected elimination of the Joshua tree from most of the southern portion of its current range. And several models projected expansion of suitable climate space beyond the current range.
  http://www.esajournals.org/doi/abs/10.1890/09-1800.1?journalCode=ecap

- **North American Trees (McKenney et al. 2011)**
  McKenney et al. (2011) reanalyzed their previous work on shifts in tree climate envelopes (CEs) using the newer-generation AOGCM projections. Based on the updated AOGCMs, by the 2071–2100 period, tree CEs shifted up to 2.4 degrees further north or 2.6 degrees further south (depending on the AOGCM) and were about 10% larger in size.

http://climateknowledge.org/figures/Rood_Climate_Change_AOSS480_Documents/McKenney_Rood_Forest_Envelopes_GlobChanBio_2011.pdf

- **Native Plants in Australia (Summers et al. 2012)**
  Summers et al. (2012) conducted a large-scale modeling effort to assess the vulnerability of "584 native plant species under three climate change scenarios in an 11.9 million hectare fragmented agricultural region in southern Australia." The authors represented: (1) exposure as species' geographical range under each climate change scenario as quantified using species distribution models; (2) sensitivity as a function of the impact of climate change on species' geographical ranges; and (3) adaptive capacity as species' ability to migrate to new geographical ranges under each climate change scenario.
  http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2012.02700.x/abstract

- **Climate Change and Vulnerability Analysis for Four Species in Three Southwestern Utah National Parks/Monuments (Shovic and Thoma 2011)**
  Shovic and Thoma (2011) conducted a modeling exercise to assess the climate vulnerability of four taxa: American pika (*Ochotona princeps*), Desert tortoise (*Xerobates* [*Gopherus*] *agassizii*), Shivwits Milk-vetch (*Astragalus ampullarioides*), and Great Basin bristlecone pine (*Pinus longaeva*). Three levels of models were developed; first to estimate the degree of climate change, then to create a local physical proxy for that change, and finally to predict the effects of modifying that proxy for each species/habitat response model.
  http://www.cfc.umt.edu/CESU/Reports/NPS/MSU/2010/10Roberts_Shovic_ZION_cc_scenario%20planning_Final.pdf

- **Tree and bird species in the eastern United States (Iverson et al. 2011)**
  Iverson et al. (2011) took an empirical-statistical modeling approach, using randomForest, with species abundance data from national inventories combined with soil, climate, and landscape variables, to build abundance-based habitat models for 134 tree and 147 bird species. They developed a framework, ModFacs, in which they used the literature to assign default modification factor scores for species characteristics that cannot be readily assessed in such models, including 12 disturbance factors, nine biological factors, and assessment scores of novel climates, long-distance extrapolations, and output variability by climate model and emission scenario. They also used a spatially explicit cellular model, SHIFT, to calculate colonization potentials for some species, based on their abundance, historic dispersal distances, and the fragmented nature of the landscape. By combining results from the three efforts, they created projections of potential climate change impacts over the next 100 years or so.
  http://www.nrs.fs.fed.us/pubs/jrnl/2011/nrs_2011_iverson_001.pdf

2.3 Migratory Species

- **A blind spot in climate change vulnerability assessments (Small-Lorenz et al. 2013)**
  Small-Lorenz et al. (2013) "reviewed how five multi-species frameworks used to assess climate change vulnerability in North America treat migratory species, and found their

approaches to be varied and incomplete." They outlined three areas for improving species-level CCVAs to "make them more robust in accounting for migratory species": (1) examine the full annual cycle; (2) consider key life-history traits; and (3) incorporate conservation status.
http://www.parcc-web.org/parcc-project/documents/2013/02/a-blind-spot-in-climate-change-vulnerability-assessments.pdf

- **Migratory connectivity magnifies the consequences of habitat loss from sea-level rise for shorebird populations (Iwamura et al. 2013)**
  Iwamura et al (2013) developed a novel graph-theoretic approach to measure the vulnerability of a migratory network to the impact of habitat loss from SLR based on population flow through the network. We show that reductions in population flow far exceed the proportion of habitat lost for 10 long-distance migrant shorebirds using the East Asian–Australasian Flyway.
  http://rspb.royalsocietypublishing.org/content/280/1761/20130325.short

- **Travelling through a warming world: climate change and migratory species (Robinson et al. 2009)**
  Robinson et al., (2009) assesses the risks and opportunities from climate change faced by migrant species because they (1) occur in specific types of habitat, (2) undertake often hazardous migrations, and (3) must time their arrival at breeding and non-breeding grounds in relation to resource availability there. We then go on to address the key knowledge gaps and the types of measures required for conserving migratory species, which include some of the most iconic species of the earth's fauna.
  http://www.int-res.com/articles/esr2009/7/n007p087.pdf

2.4 Other

- **Vulnerability Assessment Methodologies: An Annotated Bibliography for Climate Change and the Fisheries and Aquaculture Sector (Barsley et al. 2013)**
  This circular contains a comprehensive annotated bibliography of vulnerability methodologies specific to climate change and the fisheries and aquaculture sector. The circular was prepared between 2012 and 2013 and commissioned by FAO as a supporting background document for an international expert workshop in Namibia on climate change vulnerability methodologies, funded under the project "Fisheries management and marine conservation within a changing ecosystem context". The annotated bibliography presents a range of the most contemporary and seminal vulnerability methodologies from over the past decade, providing a reference for workshop participants and also practitioners, policy-makers, non-governmental organizations and governmental organizations conducting vulnerability assessments.
  http://www.fao.org/docrep/018/i3315e/i3315e.pdf

3.0 Habitat Approaches

CCVAs at the habitat level can also be categorized into "coarse-filter" approaches that use indices to develop a qualitative categorization of vulnerability, and "fine-filter" approaches that use models, often spatially-explicit, to determine where and how species may be vulnerable to climate change. AS with species indices, each of these approaches has strengths and limitations.

3.1 Coarse-filter Habitat Approaches – Indices

3.1.1 Climate Change and Massachusetts Fish and Wildlife: Volume 2, Habitat and Species Vulnerability (Manomet)

One of the earliest habitat-based vulnerability assessments was conducted for a 3-volume report on "Climate Change and Massachusetts Fish and Wildlife" by Manomet Center for Conservation Science and Massachusetts Division of Fisheries and Wildlife. It was intended to provide supplementary climate change related materials to the existing SWAP. The assessment was conducted using an expert panel approach and a simple "habitat vulnerability scoring system." Twenty habitat types were selected for evaluation.
Developer: Hector Galbraith of Manomet
http://www.mass.gov/dfwele/dfw/habitat/cwcs/pdf/climate_change_habitat_vulnerability.pdf

3.1.2 Northeast Association of Fish and Wildlife Agencies Regional Habitat Vulnerability Model (Manomet)

The NEAFWA model, based on an Excel spreadsheet platform, comprises four connected modules: Module 1 (Attachment 1) consists of 9 variables and scores the likely vulnerabilities of non-tidal habitats to future climate change (and the potential interaction between climate and non-climate stressors). Module 2, using 5 variables, categorizes the comparative vulnerabilities of habitats to existing, non-climate change stressors. Module 3 combines the results of Modules 1 and 2 to produce an overall evaluation and a score of the habitat's future vulnerability to climate change and to nonclimate stressors. Module 3 also groups these scores into five categories: critically vulnerable, highly vulnerable, vulnerable, less vulnerable, and least vulnerable. The primary aim of the narrative (Module 4) that accompanies each habitat

assessment is to make transparent the rationales and assumptions underlying the scores that were assigned to each variable.
Developer: Hector Galbraith of Manomet
http://static.rcngrants.org/sites/default/files/final_reports/RCN%202009-01%20Final%20Report%20-%20NEreport%202%20THE%20MODEL.pdf

NEAFWA Case Study:

- **The Vulnerabilities of Fish and Wildlife Habitats in the Northeast to Climate Change**
  In this report the authors: summarize our current scientific understanding about how the climate in the Northeast region is projected to change over the rest of this century (Chapter 2); how the NEAFWA Habitat Vulnerability Model was developed (Chapter 3); how habitats were selected for analysis; and the results of applying the model to major habitat types in the northeast (Chapters 4 and 5).
  http://static.rcngrants.org/sites/default/files/final_reports/RCN%202009-01%20Final%20Report%20-%20THE%20VULNERABILITIES%20OF%20FISH%20AND%20WILDLIFE%20HABITATS%20IN%20THE%20NORTHEAST%20TO%20CLIMATE%20CHANGE.pdf

3.1.3 Habitat Climate Change Vulnerability Index (HCCVI)(NatureServe)

The HCCVI aims to implement a series of measures addressing climate change sensitivity and ecological resilience for each community type for its distribution within a given ecoregion. Since quantitative estimates may not be feasible for all measures, both numerical index scores (normalized 0.0-1.0 scores) and qualitative expert categorizations may be used in the HCCVI. The combined relative scores for sensitivity and resilience determine the categorical estimate of climate change vulnerability by the year 2060 for a community type. Index measures are organized within categories of direct effects, indirect effects, and adaptive capacity. A series of 3-5 measures, each requiring a separate type of analysis, produces sub-scores that are then used to generate an overall score for sensitivity (from direct effects) vs. resilience (indirect effects + adaptive capacity). For the HCCVI, climate-change vulnerability is expressed in four categories: Very High, High, Moderate, and Low. Therefore, the index ratings are quite general, but this is because predictive uncertainty is often high, and the overall intent is a generalized indication of vulnerability.
Developer: NatureServe
http://www.fws.gov/refuges/whm/pdfs/NatureServe_HCCVI_Report.pdf

HCCVI Case Study:

- **Climate Change Vulnerability and Adaptation Strategies for Natural Communities: Piloting Methods in the Mojave and Sonoran Deserts**
  NatureServe piloted their NCCVI on an assessment of community type in the Sonoran and Mojave deserts. For the HCCVI, climate-change vulnerability is expressed in four categories, including This pilot analysis resulted in six type/ecoregion combinations

being categorized high for climate-change vulnerability. These included Mojave Mid-Elevation [Joshua tree-Black brush] Desert Scrub (Mojave Desert), North American Warm Desert Riparian Woodland and Stream (Mojave and Sonoran deserts), North American Warm Desert Mesquite Bosque (Mojave and Sonoran deserts), Sonora-Mojave Creosotebush-White Bursage Desert Scrub (Sonoran Desert). All other types were categorized as moderate for climate-change vulnerability. No types from this pilot analysis were categorized as either very high or low for climate-change vulnerability.
http://www.fws.gov/refuges/whm/pdfs/NatureServe_HCCVI_Report.pdf
http://www.fws.gov/refuges/whm/pdfs/NatureServe_HCCVI_Appendix%202.pdf

3.1.4 Climate Change Vulnerability Assessment for Shorebird Habitat (CC-VASH)

The CC-VASH is an Excel-based vulnerability assessment and decision-making tool developed by the Manomet Center for Conservation Science in partnership with the United States Fish and Wildlife Service Northeast Region Division of Refuges. The CC-VASH guides participants through a series of worksheets and exercises that enable them to assess the vulnerability of coastal shorebird habitats to climate change, using three categories: (1) Effects of sea-level rise; (2) Effects of other climate-change variables, such as predicted changes in temperature and precipitation; and (3) Effects of increased frequency and intensity of storms. Once the vulnerability is measured, the assessment outlines explicit strategies and adaptation options, and evaluates each option's chances for success.
Developer: Dorie Stolley, US Fish and Wildlife Service
http://www.whsrn.org/tools/climate-change-tool

3.2 Fine-filter Habitat Approaches – Modeling

Habitat Modeling Case Studies:

- **Sagebrush (*Artemisia* spp.) ecosystems in the state of Nevada (Bradley 2010)**
  Bradley (2010) modeled sagebrush (*Artemisia* spp.) ecosystems in the state of Nevada, USA from climate change, land use/land cover change, and species invasion. Risk from climate change is based on an ensemble of 10 AOGCM projections applied to two bioclimatic envelope models (Mahalanobis distance and Maxent). Risk from land use is based on the distribution of roads, agriculture, and powerlines, and on the spatial relationships between land use and probability of cheatgrass *Bromus tectorum* invasion in Nevada. Risk from land cover change is based on probability and extent of pinyon-juniper (*Pinus monophylla*; *Juniperus* spp.) woodland expansion.
  http://people.umass.edu/bethanyb/Bradley,%20Ecography,%202010.pdf

- **Climate Change Vulnerability Assessment in the Appalachian Mountains: Bioclimatic Envelope Modeling of Major Ecosystem Types (Jantz et al. 2013)**
  In consultation with National Park Service (NPS) partners, Jantz et al. (2013) generated climate envelope models for a set of forest ecosystems in several NPS units spanning

elevational and latitudinal gradients in the Appalachian LCC. Ecosystem types considered include spruce-fir, cove hardwood, northern hardwood, and oak hickory forests. They used monthly climate projections from the IPCC 5th Assessment Report downscaled to 1 kilometer to forecast changes in suitable climate space for these ecosystems.
http://www.usiale.org/austin2013/abstracts/climate-change-vulnerability-assessment-appalachian-mountains-bioclimatic-envelope

Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change (Gonzalez et al. 2010)
Gonzalez et al. (2010) examined nine combinations of three sets of potential indicators of the vulnerability of ecosystems to biome change: (1) observed changes of 20thcentury climate, (2) projected 21st-century vegetation changes using the MC1 dynamic global vegetation model under three IPCC emissions scenarios, and (3) overlap of results from (1) and (2). Estimating probability density functions for climate observations and confidence levels for vegetation projections, we classified areas into vulnerability classes based on IPCC treatment of uncertainty.
http://site.xavier.edu/blairb/sustainable-agriculture-2/climate-change/gonzalez-2010.pdf

3.3 Specific Habitat Types

3.3.1 Freshwater and Riparian

Flowing Forward: Freshwater ecosystem adaptation to climate change in water resources management and biodiversity conservation (Le Quesne et al. 2010)
This review was prepared by World Wildlife Fund for the World Bank. Its purpose is to develop the guiding principles, processes, and methodologies for incorporating anthropogenic climate change within an analytical framework for evaluating water sector projects, with a particular emphasis on impacts on ecosystems. It is a contribution toward the development of a systematic approach to climate change adaptation in the Bank's water and environment sectors. One section of the report deals with vulnerability assessment. The report recommends that attempts to assess and respond to climate change should adopt a risk-based approach rather than focus on impact assessment: "The considerable uncertainty about ecosystem impacts of climate change means that attention should be focused on using scenario analysis to identify those ecosystems that are most sensitive to and at risk from change rather than relying only on the development of deterministic predictions of impacts."
http://assets.worldwildlife.org/publications/385/files/original/Flowing_Forward_Freshwater_ecosystem_adaptation_to_climate_change_in_water_resources_management_and_biodiversity_conservation.pdf?1345749323

Strengthening the link between climate, hydrological and species distribution modeling to assess the impacts of climate change on freshwater biodiversity (Tisseuil et al. 2012)
Tisseuil et al. (2012) develops a novel methodology that combines statistical downscaling and fish species distribution modeling, to enhance the understanding of how global climate changes (modeled by global climate models at coarse-resolution) may affect local riverine fish diversity.

The novelty of this work is the downscaling framework developed to provide suitable future projections of fish habitat descriptors, focusing particularly on the hydrology which has been rarely considered in previous studies.
http://gael.grenouillet.free.fr/grenouillet_publications_fichiers/Tisseuil_STE2012.pdf

Freshwater Case Studies:

- **Cutthroat Trout (*Oncorhynchus clarkii*) (Wenger et al. 2011)**
  Wenger et al. (2011) assessed the effects of temperature, flow regime, biotic interactions, topographic variables and land-use variables on distribution of four trout species in the western United States, then used downscaled outputs from general circulation models coupled with a hydrologic model to forecast species suitable habitat under climate change. Projections under the 2080s A1B emissions scenario project that native cutthroat trout, already excluded from much of its potential range by nonnative species, will lose a further 58% of habitat due to an increase in temperatures beyond the species' physiological optima and continued negative biotic interactions.
  http://www.pnas.org/content/early/2011/08/09/1103097108.full.pdf

- **Identifying species at risk from climate change: Traits predict the drought vulnerability of freshwater fishes (Chessman 2013)**
  Chessman (2013) used trait analysis -- data from a large-scale monitoring program to assess how 14 dietary, life-history and physiological-tolerance traits related to changes in occurrence and abundance of 39 freshwater fish species in Australia's Murray-Darling Basin. Rankings of drought vulnerability of fish species derived from correlations between population changes and traits showed good agreement with a previous assessment of inter-specific variation in resistance to drought, and were corroborated by independent observations of drought responses for some species. Trait analysis should have wide application to identifying species at risk from climate change, provided that sufficient traits are assessed and that adequate consideration is given to variation in trait-vulnerability relationships among different groups of organisms, geographic regions and types of ecosystems.
  http://www.parcc-web.org/parcc-project/documents/2013/02/identifying-species-at-risk-from-climate-change-traits-predict-the-drought-vulnerability-of-freshwater-fishes.pdf

- **Climate Change and Cold Water Fish Habitat in the Northeast: A Vulnerability Assessment (Manomet Center for Conservation Sciences and the National Wildlife Federation 2012)**
  Manomet Center for Conservation Sciences and the National Wildlife Federation (2012) attempted to estimate the likely vulnerability of riverine habitat for cold water fish to future climate change in the northeastern US, using a framework with components of sensitivity, adaptive capacity, exposure, and uncertainty analysis. The report begins with a description of the distribution of the habitat in the Northeast Region and its general and thermal ecology. Then it reviews previous attempts to model the vulnerability of this habitat and its fish in the Northeast to climate change. Following that, they describe how current exposures to climate variables are likely to change in the future, the extent to which the habitat and its fish may be resilient to and able to adapt to these climatic

changes, and the resulting vulnerabilities of this habitat to climate change. Throughout these analyses they identify and discuss the major uncertainties that affect vulnerability projections.
http://static.rcngrants.org/sites/default/files/final_reports/RCN%202009-01%20Final%20Report%20-%20CLIMATE%20CHANGE%20AND%20COLD%20WATER%20FISH%20HABITAT%20IN%20THE%20NORTHEAST-%20A%20VULNERABILITY%20ASSESSMENT.pdf

- **Climate Change Vulnerability Assessment for Aquatic Ecosystems in the Clay Belt Ecodistrict (3E-1) of Northeastern Ontario (Chu and Fischer 2012)**
  Chu and Fischer (2012) assessed the potential effects of climate change on the wetland, stream, and lake ecosystems of the Clay Belt, represented using five indicators: wetland vulnerability, a coldwater stream fish index, maximum lake surface water temperature, smallmouth bass (*Micropterus dolomieu*) thermal habitat availability, and walleye (*Sander vitreus*) productivity. Existing empirical models were used to relate the ecosystem indicators to climate. Present climate conditions were estimated using 1971 to 2000 Canadian climate averages. The Canadian Coupled Global Climate Model 3 was used to project future climate for the 2011-2040, 2041-2070, and 2071-2100 time periods for B1 and A2 emissions scenarios.
  http://www.mnr.gov.on.ca/stdprodconsume/groups/lr/@mnr/@climatechange/documents/document/stdprod_100953.pdf

- **Vulnerability of riparian ecosystems to elevated CO2 and climate change in arid and semiarid western North America (Perry et al. 2012)**
  In this literature review, Perry et al. (2012): (1) summarize expected changes in [CO2], climate, hydrology, and water management in dryland western North America, (2) consider likely effects of those changes on riparian ecosystems, and (3) identify critical knowledge gaps.
  http://www.fort.usgs.gov/Products/Publications/23228/23228.pdf

3.3.2 Wetlands

A Framework for assessing the vulnerability of wetlands to climate change (RAMSAR)

RAMSAR technical consultants brought together a variety of methods and approaches to develop a general framework for assessing the vulnerability of wetlands to climate change. The framework has the following elements: (1) establishing present status and recent trends (description of the wetland (biophysical and social)), the present and recent pressures that exist, and the present condition); (2) determining the wetland's sensitivity and adaptive capacity to multiple pressures (description of the pressures on the wetland and the development of plausible future changes in order to assess the sensitivity and adaptive capacity of the wetland to multiple pressures); (3) developing responses (determining the likely impacts of these changes on the wetland and the desired outcomes for it, as well as the responses that must be developed and

implemented given its sensitivity and resilience); and (4) monitoring and adaptive management (determining the necessary steps to ensure the path to the desired outcomes).
Developer: RAMSAR
http://www.ramsar.org/pdf/lib/lib_rtr05.pdf

Wetland Case Studies:

- **A geospatial assessment on the distribution, condition, and vulnerability of Wyoming's wetlands (Copeland et al. 2010)**
  Copeland et al. (2010) presents a landscape-scale geospatial assessment of wetlands in Wyoming. Areas containing high densities of wetlands were identified and mapped, and wetland complexes were quantified as a function of their biological diversity, protection status, susceptibility to climate change, and proximity to sources of impairment. To estimate climate vulnerability, we followed the methods in Enquist et al. (2008) and Enquist et al. (under review) and compiled climate data of monthly temperature and precipitation, and identified wetland complexes already impacted by drying trends in a basic water balance metric called the 'water balance deficit'.
  http://www.sciencedirect.com/science/article/pii/S1470160X1000021X

- **The Vulnerability of Wetlands to Climate Change: A Hydrologic Landscape Perspective (Winter 2007)**
  Winter (2007) discussed the vulnerability of wetlands to changes in climate. He found that vulnerability depends on the position of the wetland within hydrologic landscapes. Hydrologic landscapes are defined by the flow characteristics of ground water and surface water and by the interaction of atmospheric water, surface water, and ground water for any given locality or region. Six general hydrologic landscapes are defined; mountainous, plateau and high plain, broad basins of interior drainage, riverine, flat coastal, and hummocky glacial and dune. Assessment of these landscapes indicate that the vulnerability of all wetlands to climate change fall between two extremes: those dependent primarily on precipitation for their water supply are highly vulnerable, and those dependent primarily on discharge from regional ground water flow systems are the least vulnerable, because of the great buffering capacity of large ground water flow systems to climate change.
  http://onlinelibrary.wiley.com/doi/10.1111/j.1752-1688.2000.tb04269.x/abstract

- **Vulnerability of Northern Prairie Wetlands to Climate Change (Johnson et al. 2005)**
  Johnson et al. (2005) explored the broad spatial and temporal patterns across the Prairie Pothole Region of the USA and Canada between climate and wetland water levels and vegetation by applying a wetland simulation model (WETSIM) to 18 stations with 95-year weather records. WETSIM is a process-oriented, deterministic model that simulates watershed and wetland surface processes, watershed groundwater, and wetland vegetation dynamics. The model uses daily precipitation and mean daily temperature to estimate wetland water balance, wetland stage, and wetland vegetation dynamics.
  http://www.bioone.org/doi/pdf/10.1641/0006-3568(2005)055%5B0863:VONPWT%5D2.0.CO%3B2

- **Prairie Wetland Complexes as Landscape Functional Units in a Changing Climate (Johnson et al. 2010)**
  Johnson et al. (2010) conducted climate warming simulations using the new model WETLANDSCAPE (WLS) project major reductions in water volume, shortening of hydroperiods, and less-dynamic vegetation for prairie wetland complexes across the Prairie Pothole Region of the USA and Canada. WETLANDSCAPE (WLS) is a climate driven, process-based, deterministic simulation model. Its predecessor, WETSIM, was the backbone of the group's previous climate-change research (e.g., Johnson et al. 2005), but it modeled only semipermanent wetlands. The development of WLS allowed for a more comprehensive analysis of the climate-change issue across the northern prairies because it simultaneously simulates wetland surface water, groundwater, and vegetation dynamics of the wetland complex, including multiple wetland basins of semipermanent, seasonal, and temporary permanence types, in addition to overflows between basins.
  http://www.fws.gov/home/feature/2010/pdf/PrairiePotholesBioScience.pdf

- **Great Lakes Coastal Wetland Communities: Vulnerabilities to Climate Change and Response to Adaptation Strategies (Mortsch et al. 2006)**
  Mortsch et al. (2006) developed vulnerability indices to assess the current sensitivity of Great Lakes coastal wetland vegetation and wetland-dependent breeding birds to hydrologic changes, and fishes to hydrologic and thermal changes. Scores for vulnerability factors were used to categorize species into low, moderate, and high risk groups.
  http://environment.uwaterloo.ca/research/aird/aird_pub/Great_Lakes_Coastal_Wetlands_Report_2006.pdf

- **Assessing Climate Change Impacts on Vernal Pool Ecosystems and Endemic Branchiopods (Pyke 2005)**
  Pyke (2005) evaluated the hydrologic sensitivity of vernal pool ecosystems in the Central Valley of California to climatic changes projected for 2100. A vernal pool water-balance model was used to evaluate rain-fed vernal pools at four locations under future conditions projected by two contrasting global climate models. The potential for change in the duration of continuous inundation, frequency of reproductively suitable inundation events, and the seasonal distribution of inundation was quantified.
  http://link.springer.com/content/pdf/10.1007%2Fs10021-004-0086-y.pdf

3.3.3 Coastal Habitats

3.3.3.1 Indices

Coastal Vulnerability Index (CVI) (USGS)

The USGS CVI ranks the following in terms of their physical contribution to sea-level rise-related coastal change: geomorphology, regional coastal slope, rate of relative sea-level rise, historical shoreline change rate, mean tidal range, and mean significant wave height. The rankings for each variable are combined and an index value is calculated for 1-kilometer grid

cells along the coast. The CVI highlights those regions where the physical effects of sea-level rise might be the greatest.
Developer: USGS

CVI Case Studies:

- **Coastal Vulnerability Assessment of the Northern Gulf of Mexico to Sea-Level Rise and Coastal Change (Pendleton et al. 2010)**
  The CVI assessment presented in Pendleton et al. (2010) builds on an earlier assessment conducted for the Gulf of Mexico. Recent higher resolution shoreline change, land loss, elevation, and subsidence data provide the foundation for a better assessment for the Northern Gulf of Mexico. The areas along the Northern Gulf of Mexico that are likely to be most vulnerable to sea-level rise are parts of the Louisiana Chenier Plain, Teche-Vermillion Basin, and the Mississippi barrier islands, as well as most of the Terrebonne and Barataria Bay region and the Chandeleur Islands. These very high vulnerability areas have the highest rates of relative sea-level rise and the highest rates of shoreline change or land area loss. The information provided by coastal vulnerability assessments can be used in long-term coastal management and policy decision making.
  http://pubs.usgs.gov/of/2010/1146/pdf/ofr2010-1146.pdf

  Importance of Coastal Change Variables in Determining Vulnerability to Sea- and Lake-Level Change (Pendleton et al. 2010)
  In 2001, the U.S. Geological Survey began conducting scientific assessments of coastal vulnerability to potential future sea- and lake-level changes in 22 National Park Service sea- and lakeshore units. In this paper, Pendleton et al. (2010) analyze the results of coastal vulnerability assessments (CVIs) for 22 coastal national park units. Index-based assessments quantify the likelihood that physical changes may occur based on analysis of the following variables: tidal range, ice cover, wave height, coastal slope, historical shoreline change rate, geomorphology, and historical rate of relative sea- or lake-level change. This approach seeks to combine a coastal system's susceptibility to change with its natural ability to adapt to changing environmental conditions, and it provides a measure of the system's potential vulnerability to the effects of sea- or lake-level change. Assessments for 22 park units are combined to evaluate relationships among the variables used to derive the index.
  http://www.jcronline.org/doi/pdf/10.2112/08-1102.1

3.3.3.2 Modeling

Sea Level Rise Affecting Marshes Model Version 6 (SLAMM 6.0) (Warren Pinnacle)

SLAMM simulates the dominant processes in wetland conversion and shoreline modifications during long-term sea level rise (SLR). SLAMM accounts for inundation, subsidence, soil saturation, erosion, accretion, and barrier island overwash to project future wetland changes. It can be applied to a range of landscape scales (<1 km2 to 100,000 km2) at high resolution and

identifies potential changes in both extent and composition of different wetland types. Feedback mechanisms between SLR and marsh accretion rates can be accounted for in SLAMM 6 predictions. However, other complex factors affecting regional marsh system response to SLR are not, such as localized geomorphology, hydrodynamic effects, higher average temperatures, and more-intense hurricanes. SLAMM 6 integrates a stochastic uncertainty analysis module to provide best/worst case scenarios, and likelihood and confidence statistics given uncertainty in future SLR, future erosion rates, and feedbacks between marsh vertical-accretion rates and SLR. Developer: Warren Pinnacle Consulting, Inc. (warrenpinnacle.com/prof/SLAMM/)
http://www.warrenpinnacle.com/prof/SLAMM/

SLAMM Case Studies:

- **Retrospective and prospective model simulations of sea level rise impacts on Gulf of Mexico coastal marshes and forests in Waccasassa Bay, Florida (Geselbracht et al. 2011)**
  Geselbracht et al. (2011) used SLAMM simulation to improve understanding of the magnitude and location of these changes for 58,000 ha of the Waccasassa Bay region of Florida's central Gulf of Mexico coast. To assess how well SLAMM portrays changes in coastal wetland systems resulting from sea level rise, the authors conducted a hindcast in which they compared model results to 30 years of field plot data. Overall, the model showed the same pattern of coastal forest loss as observed.
  http://research.fit.edu/sealevelriselibrary/documents/doc_mgr/447/Big_Bend_SLAMM_Simulations_of_SLR_%20Impacts_-_Geselbracht_et_al._2011.pdf

- **Application of the Sea Level Rise Affecting Marsh Model (SLAMM) Using High Resolution Data At Prime Hook National Wildlife Refuge (Scarborough 2009)**
  Scarborough (2009) used SLAMM 5 to assess the potential impacts of sea-level rise on Prime Hook National Wildlife Refuge, Delaware for use in the Refuge's Comprehensive Conservation Plan (CCP) development.
  http://www.dnrec.delaware.gov/coastal/Documents/PHNWR%20SLAMM.pdf

- **Impacts of Sea-Level Rise on National Wildlife Refuges (Liu and Delach, no date)**
  Liu and Delach (no date) used SLAMM 6.0 to model sea-level rise in eight national wildlife refuges: Blackwater, Great White Heron, Laguna Atascosa & Lower Rio Grande Valley, Lower Suwannee, Cape Romain, St. Mark, and Savannah. The goal was to provide information relevant for deciding on land protection priorities in these coastal refuges.
  http://www.defenders.org/publications/impacts-of-sea-level-rise-on-refuge-land-protection-priorities.pdf

- **Sea Level Rise Modeling for the SAMBI Designing Sustainable Landscapes Project (Rubino, no date)**
  The Biodiversity and Spatial Information Center is modeling landscape scale changes to avian habitats based on various climate change scenarios within the South Atlantic Migratory Bird Initiative (SAMBI) geographic planning region. In coastal areas, the Sea

Level Affecting Marshes Model (SLAMM) is being utilized to incorporate marsh migration dynamics due to longterm sea level rise.
http://www.basic.ncsu.edu/dsl/downloads/DSL-SAMBI_Sealevel_Rise_Modeling.pdf

- **The Vulnerabilities of Northeastern Fish and Wildlife Habitats to Sea Level Rise Manomet Center for Conservation Sciences and the National Wildlife Federation (2012)**
  This report reviewed SLAMM modeling conducted at 28 national wildlife refuges in the northeastern US, funded by the U.S. Fish and Wildlife Service. Both SLAMM 5 and SLAMM 6 were used.
  http://static.rcngrants.org/sites/default/files/final_reports/RCN%202009-01%20Final%20Report%20-THE%20VULNERABILITIES%20OF%20NORTHEASTERN%20FISH%20AND%20WILDLIFE%20HABITATS%20TO%20SEA%20LEVEL%20RISE.pdf

Other Modeling Approaches and Tools

Tools

- **Sea Level Rise and Coastal Flooding Impacts Viewer (NOAA)**
  Being able to visualize potential impacts from sea level rise is a powerful teaching and planning tool, and the Sea Level Rise Viewer brings this capability to coastal communities. A slider bar is used to show how various levels of sea level rise will impact coastal communities. Additional coastal counties will be added in the near future. Maps are not available for Alaska due to elevation data accuracy and vertical datum transformation gaps.
  http://www.csc.noaa.gov/digitalcoast/tools/slrviewer

- **Coastal Resilience (The Nature Conservancy and partners)**
  Coastal Resilience is an approach that supports decisions to reduce the ecological and socio-economic risks of coastal hazards. The Nature Conservancy and partners are advancing this approach by creating a global network for Coastal Resilience to support adaptation planning and post-storm redevelopment decisions. The approach includes 4 critical elements: (1) **Assess Risk and Vulnerability** to coastal hazards including alternative scenarios for current and future storms and sea level rise with community input: (2) **Identify Solutions** for reducing vulnerability focusing on joint solutions across social, economic and ecological systems; (3) **Take Action** to help communities develop and implement solutions; and (4) **Measure Effectiveness** to ensure that efforts to reduce disaster risk and apply ecosystem-based adaptation are successful. Page includes case studies.
  http://www.coastalresilience.org/

Other Modeling Approach Case Studies:

- **Evaluating Tidal Marsh Sustainability in the Face of Sea-Level Rise: A Hybrid Modeling Approach Applied to San Francisco Bay (Stralberg et al. 2011)**
  Stralberg et al. (2011) built upon established models to develop a hybrid approach that involves a mechanistic treatment of marsh accretion dynamics and incorporates spatial variation at a scale relevant for conservation and restoration decision-making. They applied this model to San Francisco Bay, using best-available elevation data and estimates of sediment supply and organic matter accumulation developed for 15 Bay subregions. Accretion models were run over 100 years for 70 combinations of starting elevation, mineral sediment, organic matter, and SLR assumptions. Results were applied spatially to evaluate eight Bay-wide climate change scenarios.
  http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0027388

- **Modeling of Coastal Inundation, Storm Surge, and Relative Sea-Level Rise at Naval Station Norfolk, Norfolk, Virginia, U.S.A. (Li et al. 2012)**
  Li et al. (2012) examined the potential risk and effects of storm-surge damage caused by the combination of hurricane-force waves, tides, and relative sea-level-rise (RSLR) scenarios at the U.S. Naval Station, Norfolk, Virginia. A hydrodynamic and sediment transport modeling system validated with measured water levels from Hurricane Isabel was used to simulate two synthesized storms representing 50-year and 100-year return-period hurricanes, a northeaster, and five future RSLR scenarios to evaluate the combined impacts of inundation on this military installation in the lower Chesapeake Bay.
  http://cirp.usace.army.mil/Downloads/PDF/JCR_2012_Li-Lin.pdf

- **Preparing for Tomorrow's High Tide: Sea Level Rise Vulnerability Assessment for the State of Delaware (Delaware Coastal Programs of the Department of Natural Resources and Environmental Control 2012)**
  Authors used high resolution elevation data to create a bathtub model of Delaware. The bathtub model floods all land below a certain elevation, unless there is a structure that would block tidal flow (like dikes and dams). Based upon this model, a series of maps was developed to show what the recommended sea level rise scenarios would look like on the ground at mean higher-high water. The Vulnerability Assessment was developed in five stages: (1) Identification of Resources of Concern; (2) Data Collection; (3) Exposure Assessment; (4) Impact Assessment; and (5) Risk Assessment.
  http://www.dnrec.delaware.gov/coastal/Documents/SeaLevelRise/AssesmentForWeb.pdf

- **Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States (Strauss et al. 2012)**
  Strauss et al. (2012) employed a recent high-resolution edition of the National Elevation Dataset and using VDatum, a newly available tidal model covering the contiguous US, together with data from the 2010 Census, to quantify low-lying coastal land, housing and population relative to local mean high tide levels, which range from ~0 to 3 m in elevation (North American Vertical Datum of 1988). Previous work at regional to national scales has sometimes equated elevation with the amount of sea level rise, leading

to underestimated risk anywhere where the mean high tide elevation exceeds 0 m, and compromising comparisons across regions with different tidal levels.
http://iopscience.iop.org/1748-9326/7/1/014033/article

- **Vulnerability of Shallow Tidal Water Habitats in Virginia to Climate Change (Bilkovic et al. 2009)**
  The principal objective of this study was to develop a characterization of current shallow-water habitat components in Virginia tidal waters and predict climate driven changes to these habitats. To project broad-scale climate change effects on the abundance and distribution of coastal habitats, an inundation model based on anticipated relative sea-level rise, temperature and salinity projections, and coastal development were integrated into a GIS modeling framework. Using this framework, simple models were constructed that forecast the distribution of key coastal habitat parameters within the next 50 to 100 years including: shallow-water areas, tidal wetlands, submerged aquatic vegetation and estuarine beaches.
  http://ccrm.vims.edu/research/climate_change/COASTALHABITATS_FinalReport.pdf

3.3.4 Mangroves

Climate Change Vulnerability Assessment and Adaptation Planning for Mangrove Systems (World Wildlife Fund)

This manual draws on on-the-ground experience and scientific knowledge to help conservation practitioners assess the vulnerability of mangrove ecosystems to climate change and assist them in planning adaptation activities. Eight methods are discussed in the VA, including field-based techniques to assess forest condition and health and more sophisticated approaches for understanding past and present change. Each method includes a case study from a WWF project that clearly describes how the method was carried out and how the results were analyzed. Guidance is given on how to combine the results from each method to form a composite understanding of vulnerability for a given mangrove area, and how to select and prioritize adaptation strategies for reducing that area's vulnerability to climate change.
Developer: World Wildlife Fund
http://worldwildlife.org/publications/climate-change-vulnerability-assessment-and-adaptation-planning-for-mangrove-systems

***A methodology for assessing the vulnerability of mangroves and fisherfolk to climate change* (Faraco et al. 2010)**
Faraco et al. (2010) propose a research methodology for assessing the vulnerability to climate change of the social-ecological system mangroves - fisherfolk, by analyzing exposure to sea-level rise, sensitivity and adaptive capacity, and the impacts of conservation policies on these elements, particularly the effects of coastal protected areas in southern Brazil. An integrated social-ecological diagnosis may lead to more flexible policies, elaborated with stakeholders' participation, more adequate to local realities and more inclusive of strategies for mitigation and adaptation to climate change.
http://www.panamjas.org/pdf_artigos/PANAMJAS_5(2)_205-223.pdf

3.3.5 Islands and Marine

***Vulnerability of terrestrial island vertebrates to projected sea-level rise* (Wetzel et al. 2013)**
Wetzel et al. (2013) quantified area loss for over 12,900 islands and over 3,000 terrestrial vertebrates in the Pacific and Southeast Asia under three different SLR scenarios (1 m, 3 m and 6 m). They used very fine-grained elevation information, which offered >100 times greater spatial detail than previous analyses and allowed them to evaluate thousands of hitherto not assessed small islands.
http://jetzlab.yale.edu/sites/default/files/gcb12185.pdf

***Using expert judgment to estimate marine ecosystem vulnerability in the California Current* (Teck et al. 2010)**
Drawing on methods from decision science, Teck et al. (2010) offer a method for eliciting expert judgment to (1) quantitatively estimate the relative vulnerability of ecosystems to stressors, (2) help prioritize the management of stressors across multiple ecosystems, (3) evaluate how experts give weight to different criteria to characterize vulnerability of ecosystems to anthropogenic stressors, and (4) identify key knowledge gaps.
http://www.esajournals.org/doi/pdf/10.1890/09-1173.1

4.0 Place-Based Approaches

Place-based approaches typically use a combination of methods to look at species, habitats, landscapes, water resources, cultural resources, infrastructure and other resources.

Badlands National Park: Climate Change Vulnerability Assessment
This report assesses the vulnerability of natural, paleontological, and cultural resources in Badlands National Park, South Dakota, to climate change. It characterizes the projected regional downscaled climate changes and the best estimates of resource vulnerabilities based on available literature and professional judgment. Natural resources evaluated include plant communities and individual wildlife species (or groups of species, such as grasslands birds), as well as three ecological processes that shape the Badlands landscape (fire, grazing, and erosion). The Park's significant paleontological resources are also addressed, as are the Park's cultural resources (e.g., historic roads, archeological sites, ethnographic resources).
Conducted by: National Park Service and Saint Mary's University of Minnesota
Citation: Amberg et al. (2012)
http://www.nature.nps.gov/publications/nrpm/nrr.cfm

Climate Change and Forest Biodiversity: A Vulnerability Assessment and Action Plan for National Forests in Western Washington
The specific objectives of this assessment were to: (1) Assess the potential impacts of projected changes in climate on both forest trees and selected vulnerable habitats (alpine and subalpine habitats, dry grasslands, and wetlands); (2) Evaluate tools that have been developed to assess vulnerability and mitigate the expected stress of a warming climate; (3) Recommend actions that will improve understanding of changes taking place with forest tree species and vulnerable habitats, maintain and increase biodiversity and increase resilience, and prepare for an uncertain future; and (4) Collaborate in the implementation of these actions with the National Park Service and the Washington State Department of Natural Resources.
Conducted by: US Forest Service
http://ecoshare.info/wp-content/uploads/2011/05/CCFB.pdf

Adapting to Climate Change at Olympic National Forest and Olympic National Park
A vulnerability assessment was conducted to facilitate development of adaptation strategies and actions for Olympic National Forest (ONF) and Olympic National Park (ONP). The authors first

reviewed available climate model projections to determine likely levels of exposure to climate change on the Olympic Peninsula. The second step involved working with regional scientists and resource specialists to review relevant literature on the effects of climate change and on available projections to identify likely climate change sensitivities in each of four focus areas on the Olympic Peninsula (hydrology and roads, fish, vegetation, and wildlife). The final step was a review of current management activities at ONF and ONP and identification of management constraints in order to evaluate some aspects of institutional capacity to implement adaptation actions.
Conducted by: US Forest Service
Citation: Halofsky et al. (2011)
http://www.fs.fed.us/pnw/pubs/pnw_gtr844.pdf

Ecosystem Vulnerability Assessment and Synthesis: A Report from the Climate Change Response Framework Project in Northern Wisconsin
This effort assessed the climate change vulnerability of northern Wisconsin forests. The report begins by describing the contemporary landscape and major existing climate trends using state climatological data, and then proceeds to discuss potential future climate trends for northern Wisconsin using downscaled data from general circulation models. Potential vulnerabilities are identified by incorporating the future climate projections into species distribution and ecosystem process models and assessing potential changes to northern Wisconsin forests.
Conducted by: US Forest Service
Citation: Swantson et al. (2011)
http://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs82.pdf

Climate Change Response Framework Vulnerability Assessments for Forest Ecosystems
Vulnerability assessments are being developed for three forest regions in the eastern US by the US Forest Service. Each vulnerability assessment is tailored to meet the needs of a particular region while maintaining a consistent approach and format across assessments. The vulnerability assessments: (1) focus on forest ecosystems within a region defined by a combination of ecoregional and political boundaries; (2) address vulnerabilities of individual tree species and forest or natural community types within each region; (3) use gridded historical and modeled climate change information as well as two different approaches to modeling impacts on tree species; and (4) rely on a panel of scientists and managers with local expertise to put scientific results in context.
http://forestadaptation.org/sites/default/files/Vulnerability%20Assessments%20Brief_Aug2012.pdf

Climate Change on the Shoshone National Forest, Wyoming: A Synthesis of Past Climate, Climate Projections, and Ecosystem Implications
This report synthesizes the current understanding of the paleo- and historical climate of the Shoshone National Forest in Wyoming, US as a reference point, determine what future climates may look like, and what the effects of future climate may be on natural resources. Authors synthesize current resource conditions and the latest scientific information about how future climate change may affect natural resources on the Shoshone and GYE, and synthesize the studies related to resources and natural or human influenced processes that may be vulnerable to

climate change—specifically, water, vegetation, fish and wildlife, fire or insect disturbance, biochemical cycling, economic activities, and land use.
http://www.fs.fed.us/rm/pubs/rmrs_gtr264.pdf

Vulnerability Assessment and Strategies for the Sheldon National Wildlife Refuge and Hart Mountain National Antelope Refuge Complex
Nature Serve conducted a vulnerability assessment of a complex of two national wildlife refuges in southeastern Oregon. The condition of priority resources on the Refuge complex was assessed using NatureServe's Vista software. Vista is a free decision-support system that helps users integrate conservation with land use and resource planning of all types. Vegetation resources were assessed using the Vegetation Dynamic Development Tool (VDDT). VDDT was developed to facilitate improved understanding of vegetation change through the use of successional pathway modeling. The processes modeled could include succession, harvest, disease, insects, and fire.
Conducted by: NatureServe (Crist et al. 2011)
http://www.fws.gov/refuges/whm/pdfs/SheldonHartNWR_RVA_Report.pdf
Following the methodology of Crist et al. (2012):
http://www.fws.gov/refuges/whm/pdfs/RefugeVulnerabilityAssessmentTechnicalGuide_FINAL.pdf

National Wildlife Refuge System-Wide Vulnerability Assessment
Magness et al. (2011) used a GIS analysis to assess the vulnerability of 501 reserve units in the National Wildlife Refuge System as a basis for a nationally coordinated response to climate change adaptation. They used measures of climate change exposure (historic rate of temperature change), sensitivity (biome edge and critical habitat for threatened and endangered species), and adaptive capacity (elevation range, latitude range, watershed road density, and watershed protection) to evaluate refuge vulnerability.
Conducted by: Magness et al. (2011)
http://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/8348/ES11-00200.pdf?sequence=1

Gunnison Basin Climate Change Vulnerability Assessment
This report summarizes the results of a landscape-scale climate change vulnerability assessment of the Upper Gunnison Basin in Colorado to determine the relative vulnerability of 24 ecosystems using methods developed by Manomet Center for Conservation Science and 73 species of conservation concern using the CCVI of NatureServe. The report also summarizes the results of a social vulnerability and resilience assessment of ranching and recreation sectors in the Basin, which consisted of a document review and interviews with ranchers, recreation business representatives and one water expert.
Citation: Neely et al. (2011)
http://www.cnhp.colostate.edu/download/documents/2011/Gunnison-CC-Vulnerability-Assessment_and_Appendices-FULL_REPORT-Jan_9_2012.pdf

Swinomish Climate Change Initiative: Impact Assessment Technical Report
The report describes the scientific data and potential climate change scenarios, assesses possible local impacts, and identifies specific areas of potential risk and vulnerability to climate change

effects on the Swinomish Indian Reservation community, lands, and resources in Washington State.
http://www.swinomish-nsn.gov/climate_change/Docs/SITC_CC_ImpactAssessmentTechnicalReport_complete.pdf

A Vulnerability-Based Strategy for Incorporating the Climate Threat in Conservation Planning: A Case Study from the British Columbia Central Interior
Authors present a framework to handle uncertainty in the incorporation of climate change in regional conservation planning. The framework uses expert opinion to: (1) formulate qualitative scenarios of climatic and ecological change based on expected as well as less probable but plausible futures not tied to specific model projections; (2) synthesize established knowledge of the climate vulnerability of species and ecosystems of concern; and (3) specify no-regrets climate adaptation strategies to reduce these vulnerabilities in conservation site selection. This framework was implemented in an ecoregional assessment of the British Columbia Central Interior selecting terrestrial and freshwater high-priority conservation sites. Including climate vulnerability based adaptation strategies in the regional site-selection process had a substantial effect on both freshwater and terrestrial assessments.
http://jem.forrex.org/index.php/jem/article/view/89

The value of a multi-faceted climate change vulnerability assessment to managing protected lands: Lessons from a case study in Point Reyes National Seashore
Based on existing climate change vulnerability assessment frameworks in the literature, the authors developed a multifaceted climate change vulnerability assessment at the biological community level comprised of: a) expert judgment, b) predictive vegetation mapping, c) predictive geophysical mapping, and d) species-specific evaluations. Authors wrote a climate change vulnerability assessment for Point Reyes National Seashore and evaluated the usefulness of each facet, alone and in concert. They found that the facets were complementary and that each one was useful to inform some management goals; they also found that expert judgment was the most widely applicable and flexible assessment method. They believe that this multifaceted framework can be employed in other protected areas to facilitate management decisions under a changing and uncertain future climate.
http://www.parcc-web.org/parcc-project/documents/2013/04/hameed-s-o-et-al-2013-the-value-of-a-multi-faceted-climate-change-vulnerability-assessment-to-managing-protected-lands-lessons-from-a-case-study-in-point-reyes-national-seashore.pdf

Assessment of the vulnerability of terrestrial and coastal habitats and species in Europe to climate change
The aim of this research was to develop a transferable methodology for identifying areas in Europe vulnerable to climate change and to identify the possibilities for adaptation, within the context of spatial planning. This was achieved through assessing the potential impacts of climate change on terrestrial and coastal biodiversity and on coastal environments at the European and NW Europe scale. The objectives were: (1) To collate data and information on habitats and species vulnerability to climate change; (2) To model changes in the climate space for a selection of these habitats and species, at the European scale and to calculate their vulnerability at both the European, NW Europe and country level; (3) To identify ecological networks that may gain or lose species as a consequence of climate change, including extreme events; (4) To review current

coastal vulnerability to sea-level rise; (5) To define and map a NW Europe coastal biodiversity vulnerability index, with a major focus on sea-level rise; and (6) To define strategies for adaptation for specified habitats and species, arising from the spatial implications of climate change and to feed into other parts of the BRANCH project.
http://webdocs.alterra.wur.nl/internet/landschap/BRANCH/Annex2_1BerryEtAl.pdf

Climate Change Vulnerability Assessment for the North Coast Integrated Regional Water Management Plan

The assessment process used borrows from the ICLEI (2007) Climate Change Guide for Local Governments to provide managers with a clearer understanding of the combined relative sensitivity and adaptability North Coast sectors to potential future climate impacts. Detail and precision of this assessment is designed to match the information available as well as the likely resources available for these types of assessments (ICLEI 2007). Vulnerability is determined by considering a set of qualitative questions for which both quantitative and qualitative information may be available (sensitivity and adaptive capacity sections below). The questions considered incorporate current conditions and stressors as well as likely extent and magnitude of impacts in the region and closely reflect the concepts proposed for consideration in IRWM checklist (DWR 2011).
http://www.2ndnaturellc.com/wp-content/uploads/2010/09/Final-NC-Climate-Change-Vulnerabilty-Assessment.pdf

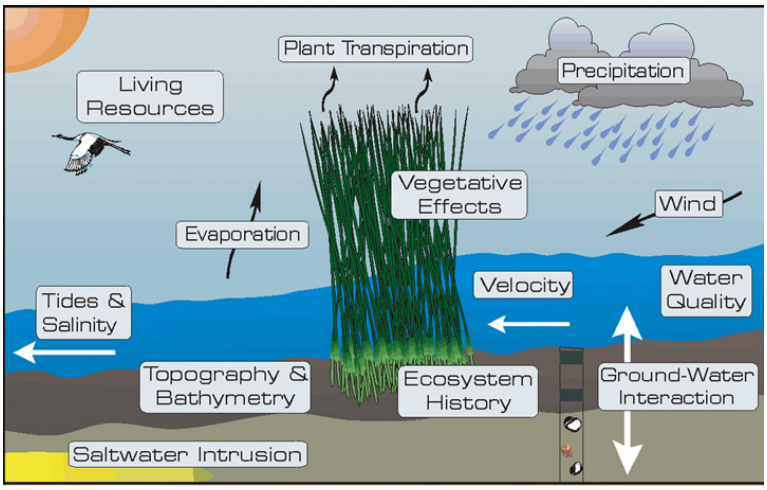
Montane Meadows in the Sierra Nevada: Changing Hydroclimatic Conditions and Concepts for Vulnerability Assessment

This technical report provides guidance for resource managers in considering conservation and restoration options for meadow ecosystems considering that the very foundation of meadow ecosystems—the dynamic interplay of surface and ground waters supporting unique vegetation—will likely change in time due to global atmospheric warming and resultant regional hydroclimatic alteration. This report begins by establishing a context for the nature, importance, and organization of montane meadows with a specific focus on a study region inclusive of the Sierra Nevada and portions of the southern Cascade Range. The report then proceeds with an overview of climate change and potential impact to meadows with specific discussion of general trends and projected outcomes, regional differences, and a comprehensive review of potential impacts on hydrological processes. This review is complemented by a discussion of how hydroclimatic alteration may impact meadow dependent species, and which indicator species are likely to be most beneficial for monitoring and management from a conservation standpoint.
https://watershed.ucdavis.edu/files/biblio/CWSMeadowsVulnerabilityWhitePaper_2013-1-1_FinalReport.pdf

Climate Change Vulnerability and Adaptation in the North Cascades Region, Washington (DRAFT May 2013)

The North Cascadia Adaptation Partnership (NCAP) is a science-management partnership consisting of M. Baker-Snoqualmie National Forest, Okanogan-Wenatchee National Forest, North Cascades National Park Complex, Mount Rainier National Park, the U.S. Forest Service Pacific Northwest Research Station, and the University of Washington Climate Impacts Group. These organizations worked with numerous stakeholders over two years to identify climate change issues relevant to resource management in the North Cascades and to find solutions that

will facilitate the transition of the diverse ecosystems of this region into a warmer climate. The NCAP provided education, conducted a climate change vulnerability assessment, and developed adaptation options for federal agencies that manage 2.4 million hectares in north-central Washington.
http://northcascadia.org/pdf/DRAFT_raymond_et_al_NCAP.pdf



5.0 Ecosystem Processes

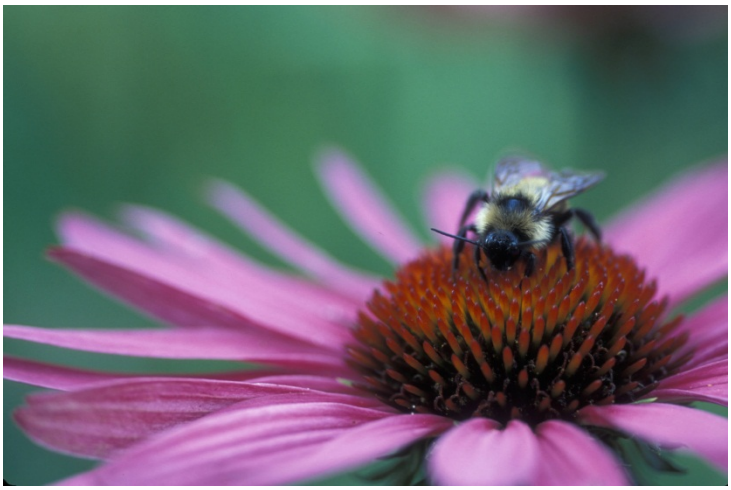
Vulnerability Assessments in Support of the Climate Ready Estuaries Program: A Novel Approach Using Expert Judgment Volume I Results for the San Francisco Estuary Partnership:

The San Francisco Estuary Partnership (SFEP), the San Francisco Bay Conservation and Development Commission, and the Environmental Protection Agency (EPA) collaborated on an ecological vulnerability assessment, using an expert elicitation-type exercise to systematically elicit judgments from experts in a workshop setting regarding climate change effects on two key ecosystem processes: sediment retention in salt marshes and community interactions in mudflats. For each process, an influence diagram was developed identifying key process variables and their interrelationships (influences). Using a coding scheme, each expert characterized the type and sensitivity of each influence under both current and future climate change scenarios. The experts also discussed the relative impact of certain influences on the endpoints.

Conducted by: EPA

Citation: U.S. EPA (2012)

http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=241556#Download



6.0 Ecosystem Services

Ecosystem services and livelihoods – vulnerability and adaptation to a changing climate:
This report summarizes the results of a Vulnerability Assessment of Ecosystem Services for Climate Change Impacts and Adaptation (VACCIA) for Finland. The assessment looked at the vulnerability of several key sectors of the Finnish society/economy, including watersheds and water bodies, urban areas, coastal areas, ex situ plant conservation, forestry, fisheries, and tourism. Sector-specific approaches were used in each assessment of vulnerability. They assessed the threats and challenges posed by climate change to ecosystem services and livelihoods, and suggested methods for adapting to changing conditions.
Conducted by: Finnish Environment Institute
Citation: Bergstrom et al. (2011)
http://www.ymparisto.fi/default.asp?contentid=404218&lan=en

Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services
Authors used field and laboratory measurements, geographic information systems, and simulation modeling to investigate the potential effects of accelerated sea-level rise on tidal marsh area and delivery of ecosystem services along the Georgia coast. They specifically looked at ecosystem services related to production (macrophyte biomass) and waste treatment (nitrogen [N] accumulation in soil, potential denitrification).
http://www.iu.edu/~spea/pubs/faculty/Frontiers_March_2009.pdf

The Impact of Climate Change on California's Ecosystem Services
This report projects the impact of future climate change on the natural provision of four key ecosystem services in California (carbon sequestration, forage production, water for instream flows for salmon, and snow recreation) and biodiversity, and the resulting change in market and non-market value of each service.
http://www.energy.ca.gov/2009publications/CEC-500-2009-025/CEC-500-2009-025-D.PDF

Potential Impacts of Climate Change on Biodiversity and Ecosystem Services in the San Francisco Bay Area
The objective of this paper is to summarize the current state of research on the potential impacts of anthropogenic climate change on SFBA biodiversity and ecosystem services. Studies addressing climate change include observational, experimental, and modeling approaches.

Variability of natural ecosystems across spatial gradients provides important insights into how natural ecosystems respond to climate, and may respond to climate change given enough time to equilibrate. Historical data can provide evidence of response to past climate change, though these changes have rarely if ever proceeded as rapidly as those forecast in the next 100 years. http://www.energy.ca.gov/2012publications/CEC-500-2012-037/CEC-500-2012-037.pdf

7.0 Watershed and Water Resources

National Forest Watershed Vulnerability Assessment Pilot Project
The US Forest Service recently completed a pilot project on national forests around the country to assess potential hydrologic change due to ongoing and expected climate warming. A pilot assessment approach was developed and implemented. Each National Forest identified water resources important in that area, assessed climate change exposure and watershed sensitivity, and evaluated the relative vulnerabilities of watersheds to climate change. The assessments provided management recommendations to anticipate and respond to projected climate-hydrologic changes.
http://www.fs.fed.us/ccrc/wva/PilotNFWatershedVulnerabilityReport.pdf

Climate Change Handbook for Regional Water Planning
This US EPA and CA Department of Water Resources document was developed by consulting firm CDM and presents an approach for assessing regional vulnerability of water resources to climate change and for measuring regional impacts. The vulnerability assessment approach includes: (1) characterizing a region; (2) identifying qualitative water-related climate change impacts; (3) identifying key indicators of potential vulnerability; and (4) prioritizing vulnerable water resources.
http://www.water.ca.gov/climatechange/CCHandbook.cfm

Climate Change Vulnerability Assessments: A Review of Water Utility Practices
The EPA reviewed the approaches used by eight municipal water utilities to assess their vulnerability to climate change. The eight utilities' climate change vulnerability analyses were studied in depth to identify tools and approaches used by those water utilities in their assessments. The report synthesizes the insights from the analysis of these eight utilities in the following sections: approaches to assessing climate change vulnerability, sources of climate information, modeling changes in water resources, summary, and recommendations for further study.
http://water.epa.gov/scitech/climatechange/upload/climate-change-vulnerability-assessments-sept-2010.pdf

Watershed Modeling to Assess the Sensitivity of Streamflow, Nutrient, and Sediment Loads to Potential Climate Change and Urban Development in 20 U.S. Watersheds (External Review Draft)

This report describes watershed modeling in 20 large, U.S. drainage basins (6,000-27,000 mi2) to characterize the sensitivity of U.S. streamflow, nutrient (N and P) loading, and sediment loading to a range of potential mid-21st century climate futures, to assess the potential interaction of climate change and urbanization in these basins, and to improve our understanding of methodological challenges associated with integrating existing tools (e.g., climate models, downscaling approaches, and watershed models) and datasets to address these scientific questions. Study areas were selected to represent a range of geographic, hydroclimatic, physiographic, and land use conditions together with practical considerations such as the availability of data to calibrate and validate watershed models. Climate change scenarios are based on mid-21st century climate model projections downscaled with regional climate models from the North American Regional Climate Change Assessment Program (NARCCAP) and the bias-corrected and spatially downscaled (BCSD) data set. Urban and residential development scenarios are based on EPA's national-scale Integrated Climate and Land Use Scenarios (ICLUS) project. Watershed modeling was conducted using the Hydrologic Simulation Program-FORTRAN (HSPF) and Soil and Water Assessment Tool (SWAT) watershed models.
http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=247495#Download

Vulnerability of U.S. Water Supply to Shortage: A Technical Document Supporting the Forest Service 2010 RPA Assessment

Comparison of supply and demand within a probabilistic framework yields an estimate of the probability of shortage and thus a measure of the vulnerability of the water supply system. This comparison was performed for current conditions and for several possible future conditions reflecting alternative socio-economic scenarios and climatic projections. Examining alternative futures provides a measure of the extent to which serious future risks of water shortage must be anticipated. Water supply was quantified by first estimating freshwater input as precipitation minus evapotranspiration for each point in a grid covering the study area. These water inputs were then allocated to major river basins and made available to meet basic in-stream flow requirements, satisfy off-stream demands including those from downstream basins or those reached by trans-basin diversions, and add to reservoir storage. Off-stream demands were estimated as threshold quantities of desired water use based on extending past trends in water use under the assumption that water supply would be no more constraining to future water withdrawals than in the recent past. Modeling water supply and demand in this way does not provide a forecast of future shortage levels. Rather, it provides a projection of the degree to which water shortages would occur in the absence of adaptation measures to either increase supply or decrease demand.
http://www.fs.fed.us/rm/pubs/rmrs_gtr295.pdf

Hydrologic Response and Watershed Sensitivity to Climate Warming in California's Sierra Nevada

Authors describe climate warming models for 15 west-slope Sierra Nevada watersheds in California under unimpaired conditions using WEAP21, a weekly one-dimensional rainfall-runoff model. Incremental climate warming alternatives increase air temperature uniformly by 2°, 4°, and 6°C, but leave other climatic variables unchanged from observed values. Results are

analyzed for changes in mean annual flow, peak runoff timing, and duration of low flow conditions to highlight which watersheds are most resilient to climate warming within a region, and how individual watersheds may be affected by changes to runoff quantity and timing. Results are compared with current water resources development and ecosystem services in each watershed to gain insight into how regional climate warming may affect water supply, hydropower generation, and montane ecosystems.
http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0009932

Stream Temperature Sensitivity to Climate Warming in California's Sierra Nevada: Impacts to Coldwater Habitat

This study assesses climate warming impacts on stream temperatures in California's west-slope Sierra Nevada watersheds, and explores stream temperature modeling at the mesoscale. We used natural flow hydrology to isolate climate induced changes from those of water operations and land use changes. A 21 year time series of weekly streamflow estimates from WEAP21, a spatially explicit rainfall-runoff model were passed to RTEMP, an equilibrium temperature model, to estimate stream temperatures. Air temperature was uniformly increased by 2°C, 4°C, and 6°C as a sensitivity analysis to bracket the range of likely outcomes for stream temperatures. Other meteorological conditions, including precipitation, were unchanged from historical values. Raising air temperature affects precipitation partitioning into snowpack, runoff, and snowmelt in WEAP21, which change runoff volume and timing as well as stream temperatures.
http://link.springer.com/article/10.1007%2Fs10584-012-0459-8

8.0 International

Climate Change and the Great Barrier Reef: A Vulnerability Assessment
This multi-chapter (24 chapters) vulnerability assessment of the entire Great Barrier Reef in Australia engaged expert scientists who integrated all current knowledge to assess the vulnerability of the different components of the ecosystem. The assessment of social vulnerability engaged with communities and industries that depend on the Great Barrier Reef, are regular users of the reef, or reside in the reef catchment. The chapters include an introduction, a species and species group section, a habitat section, and a conclusion.
http://www.gbrmpa.gov.au/resources-and-publications/publications/climate-change-and-the-great-barrier-reef-a-vulnerability-assessment

Climate Change Vulnerability Assessment of Wangchuck Centennial Park, Bhutan
This pilot study conducts a climate change vulnerability assessment in Wangchuck Centennial Park, Bhutan and focuses on three components: biodiversity, livelihood, and water. The study looks at the resource settings in and around the park, assesses the vulnerability of each resource to climate change, and recommends appropriate adaptation measures that seek to reduce these vulnerabilities.
http://awsassets.panda.org/downloads/wcp_ccva_report.pdf

Climate Change Vulnerability Assessment of the Galápagos Islands
This vulnerability assessment represents a collaboration among three organizations, with local stakeholder involvement. The process culminated in a vulnerability assessment expert workshop held in April 2009 in Puerto Ayora, Galápagos. At the workshop, local, national and international experts, scientists and decision makers reviewed the existing data, integrated data across disciplines and provided recommendations and priority actions for the next steps in ensuring Galápagos can adapt to the impacts of climate change. The objectives of the vulnerability assessment were: (1) To determine the potential impacts of climate change on the biodiversity and related human welfare of the Galápagos; (2) To provide recommendations for management that addresses these impacts; (3) To build in-country support for addressing the impacts of climate; and (4) To provide working examples ofadaptation for the Eastern Pacific.
http://awsassets.panda.org/downloads/integrated_report_final.pdf

Climate Vulnerability in the Barents Sea Ecoregion: A Multi-Stressor Approach
In this report, authors examine how climate change impacts may intersect and interact with other stressors in the Barents Sea Ecoregion. They investigated the vulnerability of the Barents Sea Ecoregion to both climate change and increased transport activity, particularly in relation to oil and gas transport from Western Russia, in order to develop a preliminary framework for assessing the effects of multiple stressors. Based on a survey of existing literature, some of the key processes and species that contribute to biodiversity in the Barents Sea Ecoregion are identified and current and future threats from maritime traffic discussed. They next discuss climate change impacts and vulnerability and present some future climate scenarios based on the results for 2050 from the Bergen Climate Model. Then they assess potential interactions between the two stressors and present an example of a structural analysis of multiple stressors for the Barents Sea Ecoregion.
http://www.cicero.uio.no/media/3024.pdf

Climate Change Vulnerability of Mountain Ecosystems in the Eastern Himalayas
The International Centre for Integrated Mountain Development (ICIMOD) undertook a series of research activities together with partners in the Eastern Himalayas from 2007 to 2008 to provide a preliminary assessment of the impacts and vulnerability of this region to climate change. Activities included rapid surveys at country level, thematic workshops, interaction with stakeholders at national and regional levels, and development of technical papers by individual experts in collaboration with institutions that synthesized the available information on the region. A summary of the findings of the rapid assessment was published in 2009, and is being followed with a series of publication comprising the main vulnerability synthesis report (this publication) and technical papers on the thematic topics climate change projections, biodiversity, wetlands, water resources, hazards, and human wellbeing
http://books.icimod.org/uploads/tmp/icimod-climate_change_vulnerability_of_mountain_ecosystems_in_the_eastern_himalayas.pdf

Biodiversity in the Eastern Himalayas: Status, Trends and Vulnerability to Climate Change
The International Centre for Integrated Mountain Development (ICIMOD) undertook a series of research activities together with partners in the Eastern Himalayas from 2007 to 2008 to provide a preliminary assessment of the impacts and vulnerability of this region to climate change. Activities included rapid surveys at country level, thematic workshops, interaction with stakeholders at national and regional levels, and development of technical papers by individual experts in collaboration with institutions that synthesized the available information on the region. A summary of the findings of the rapid assessment was published in 2009, and is being followed with a series of publication comprising the main vulnerability synthesis report and technical papers on the thematic topics climate change projections, biodiversity (this publication), wetlands, water resources, hazards, and human wellbeing
http://books.icimod.org/uploads/tmp/icimod-biodiversity_in_the_eastern_himalayas:_status,_trends_and_vulnerability_to_climate_change.pdf

Climate Change Vulnerability Mapping for Southeast Asia
This paper provides information on the sub-national areas (regions/districts/provinces) most vulnerable to climate change impacts in Southeast Asia. This assessment was carried out by

overlaying climate hazard maps, sensitivity maps, and adaptive capacity maps following the vulnerability assessment framework of the IPCC. The study used data on the spatial distribution of various climate-related hazards in 530 sub-national areas of Indonesia, Thailand, Vietnam, Lao PDR, Cambodia, Malaysia, and the Philippines. Based on this mapping assessment, all the regions of the Philippines; the Mekong River Delta in Vietnam; almost all the regions of Cambodia; North and East Lao PDR; the Bangkok region of Thailand; and West Sumatra, South Sumatra, West Java, and East Java of Indonesia are among the most vulnerable regions in Southeast Asia.
http://www.preventionweb.net/files/7865_12324196651MappingReport1.pdf

A holistic approach to climate change vulnerability and adaptation assessment: Pilot study in Thailand

This pilot vulnerability assessment uses a new holistic approach to assess the climate change vulnerability of multiple sectors in Thailand. The approach is premised on the notion that in order to provide an accurate view of the landscape in the long term, a vulnerability and adaptation assessment must take a holistic view, including socioeconomic factors as well as interactions among sectors. The process begins with assessments of individual sectors, but in a critical second step, it assembles the results of those individual assessments to create a storyline that looks at the whole landscape and its complex systems. The assessment process can be summarized as follows: (1) Identify key sectors in the landscape; (2) Analyze key climate concerns for each sector, including both the specific projected impacts, and their potential effects; (3) Analyze key socioeconomic factors that could affect each sector, and their potential impacts; (4) Consider plausible responses each of the different sectors to the combined impacts of climate change and socioeconomic factors; (5) Assemble the results of the sector-by-sector assessments to build one or more storylines or scenarios for the landscape as a whole, as the basis for landscape-wide adaptation planning; and (6) Looking at cross-sectoral impacts, identify adaptation pathways that minimize negative interactions.
http://static.weadapt.org/knowledge-base/files/1149/5140abc4d6369full-report-krabi.pdf

Freshwater Ecosystem Vulnerability Assessment The Indrawati Sub-Basin, Nepal

This report is part of a project of WWF Nepal and the Nepalese Water and Energy Commission Secretariat. It outlines the discussions and conclusions of three workshops held in Nepal to determine the vulnerability of the Indrawati sub-basin to the impacts of climate change and development within the context of climate change vulnerability at the national level. The workshops brought together a diverse group of more than 60 participants, including Nepali national experts, local bureaucrats, and most importantly, local water users and subsistence farmers with direct knowledge of resource management issues in the basin. Using a modified version of the ecosystem-based and water resource-focused vulnerability assessment methodology (Flowing Forward) developed by the World Wildlife Fund, workshop participants evaluated the combined impacts of climate change and development in the basin on both vulnerable ecosystems and local livelihoods. With this understanding, they outlined potential remedies, from macro-level policy reforms to on-farm technical capacity building. They then connected the outcomes of this process with some additional analysis of two key economic sectors (hydropower and agriculture) that are important in the Indrawati basin. The report briefly assesses the vulnerability of these sectors to climate change and identifies some potential adaptation options.

http://nicholasinstitute.duke.edu/sites/default/files/publications/freshwater-ecosystem-vulnerability-assessment-indrawati-sub-basin-nepal-paper.pdf

Climate Change Vulnerability Assessment for the Namakwa District Municipality
This report assesses vulnerability to climate change in the Namakwa District Municipality (NDM) of South Africa. It: (a) addresses climate change risks and impacts in the NDM; (b) profiles the structural conditions that contribute to socio-economic vulnerability in the NDM; (c) assesses institutional vulnerability and local government capacity; (d) identifies priority areas for Ecosystem-based Adaptation and conservation actions; and (e) makes recommendations for Ecosystem-based Adaptation actions. A vulnerability index complements the map, informing priority setting for resource allocation to Ecosystem-based Adaptation and for use as the metrics for measuring reduced vulnerability overtime as a result of government effort and the efforts of other stakeholders.
http://www.conservation.org/global/ci_south_africa/publications/Documents/Vulnerability%20Assessment%20Full%20Technical%20Report%20-%20NDM.pdf

A Preliminary Assessment of the Vulnerability of Australian Forests to the Impacts of Climate Change: Synthesis
This report is a synthesis of the Forest Vulnerability Assessment project undertaken by a consortium of research groups in Australia. The project was an initiative of the Natural Resource Management Ministerial Council and undertaken under the auspices of the National Climate Change Adaptation Research Facility, Griffith University. The project was established in 2009 to: (1) review current knowledge of the likely biophysical and socio-economic consequences of climate change on Australia's forests; (2) understand the vulnerabilities of Australia's forests; (3) identify current adaptation actions; and (4) identify information gaps to improve adaptive capacity. The assessment was carried out using a basic vulnerability assessment framework which considers sensitivity, exposure and adaptive capacity to determine the vulnerability of Australia's forests to climate change. Each of these factors was considered in turn using the general scientific literature. In addition interviews with stakeholders were used to identify key issues and current actions by forest managers and policy-makers. Four reports were developed and published as result of each of those projects. This synthesis report was developed based on those reports.
http://www.nccarf.edu.au/sites/default/files/attached_files_publications/Final%20FVA%20Synthesis_final.pdf

9.0 Other

***Putting vulnerability to climate change on the map: a review of approaches, benefits, and risks* (Preston et al. 2011)**
Authors review climate change vulnerability mapping in the context of four key questions that are fundamental to assessment design. First, what are the goals of the assessment? Second, how is the assessment of vulnerability framed? Third, what are the technical methods by which an assessment is conducted? Fourth, who participates in the assessment and how will it be used to facilitate change? Each of these questions is reviewed in turn by drawing on an illustrative set of 45 vulnerability mapping studies appearing in the literature. A number of pathways for placing vulnerability mapping on a more robust footing are also identified.
http://adaptation.arizona.edu/files/public/post%20conference%20uploads/SS-Vulnerability_mapping.pdf

***Social Vulnerability and Climate Change: Synthesis of Literature* (Lynn et al. 2011)**
This synthesis of literature illustrates information about the socioeconomic, political, health, and cultural effects of climate change on socially vulnerable populations in the United States, with some additional examples in Canada. Through this synthesis, social vulnerability, equity, and climate justice are defined and described, and key issues, themes, and considerations that pertain to the effects of climate change on socially vulnerable populations are identified. The synthesis reviews what available science says about social vulnerability and climate change, and documents the emergence of issues not currently addressed in academic literature. In so doing, the synthesis identifies knowledge gaps and questions for future research.
http://www.fs.fed.us/pnw/pubs/pnw_gtr838.pdf

***Climate change vulnerability assessments as catalysts for social learning: four case studies in south-eastern Australia* (Yuen et al. 2012)**
This paper explores the value of vulnerability/risk assessments in climate change adaptation planning processes as a catalyst for learning in four case studies in Southeastern Australia. Data were collected using qualitative interviews with stakeholders involved in the assessments and analyzed using a social learning framework. This analysis revealed that detailed and tangible strategies or actions often do not emerge directly from technical assessments. However, it also revealed that the assessments became important platforms for social learning. In providing these platforms, assessments present opportunities to question initial assumptions, explore multiple

framings of an issue, generate new information, and galvanise support for collective actions. This study highlights the need for more explicit recognition and understanding of the important role social learning plays in climate change vulnerability assessments and adaptation planning more broadly.
http://link.springer.com/article/10.1007%2Fs11027-012-9376-4

***Climate Change Vulnerability Assessments, Lessons Learned from Practical Experience: Practitioner's Responses to Frequently Asked Questions* (McCarthy et al. 2010)**
The Nature Conservancy's Global Climate Change Team, Southwest Climate Change Initiative and Colorado chapter organized a two-day workshop in April 2010 for internal and external climate adaptation experts engaged in assessing climate change vulnerability. Participants shared their methods, lessons learned and recommendations for climate change vulnerability assessments at regional, state and landscape scales. This document is a rapid summary of the methods and tools discussed at the workshop and is intended to provide a foundation for others embarking on development of adaptation planning and implementation.
http://conserveonline.org/workspaces/climateadaptation/documents/vulnerability-assessments/documents/climate-change-vulnerability-assessments-lessons/@@view.html

CRiSTALTool
CRiSTAL is a project planning tool that helps users design activities that support climate adaptation (i.e., adaptation to climate variability and change) at the community level. CRiSTAL stands for "Community-based Risk Screening Tool – Adaptation and Livelihoods." "Community-based" – CRiSTAL focuses on projects at the local community level. "Risk Screening" – CRiSTAL helps users to identify and prioritize climate risks that their projects might address. "Adaptation and Livelihoods" – CRiSTAL helps users to identify livelihood resources most important to climate adaptation (i.e., adaptation to climate variability and change) and uses these as a basis for designing adaptation strategies.
http://www.iisd.org/cristaltool/

10.0 Literature Cited

To be completed in Version 2.0……