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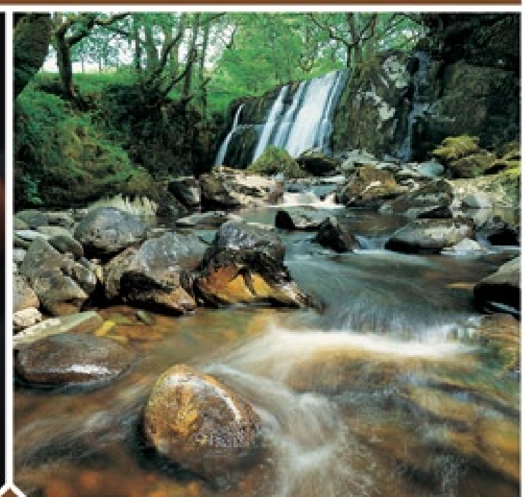

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National Center for Environmental Research

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Effects of Sea Level Rise and Climate Variability on Ecosystem Services of Tidal Marshes, South Atlantic Coast

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The investigators employed field and laboratory measurements, geographic information systems (GIS), and simulation modeling to investigate how tidal marsh area and delivery of ecosystem services will be affected by accelerated sea level rise (SLR) along the South Atlantic (GA-SC) coast. Different habitats of tidal marshes provide different quantities of ecosystem services. For example, aboveground biomass was 40 to 70 percent greater in tidal freshwater and brackish marshes than in salt marshes. Tidal freshwater and brackish marshes also provided greater waste treatment per unit area than did salt marshes. These marshes sequestered three times more N in soil and supported two to three times greater potential denitrification than salt marshes.

Model simulations using the IPCC mean (52 cm) and maximum (82 cm) estimates of SLR by 2100 for the Georgia coast suggest that salt marshes will decline in area by 20 percent and 45 percent, respectively. Tidal freshwater marshes will increase by 2 percent under the IPCC mean scenario but will decline by 39 percent under the maximum scenario. Delivery of ecosystem services associated with productivity (macrophyte biomass) and waste treatment (N accumulation in soil, potential denitrification) also will decline. These findings suggest that tidal marshes at the lower and upper salinity ranges and their attendant delivery of ecosystem services will be the most affected by accelerated SLR unless geomorphic conditions (i.e., gradual increase in elevation) enable tidal freshwater marshes to migrate inland, or vertical accretion of salt marshes increases to compensate for accelerated SLR.

The effects of climate variability were evaluated by analysis of climate (rainfall, temperature, salinity, freshwater discharge) and selected ecosystem services data collected from 2000 to 2006 from permanent plots of 10 marshes of the Georgia Coastal Ecosystems Long Term Ecological Research (LTER) study domain. The data revealed that river discharge was the most strongly correlated with the measured ecological variables. Discharge was positively correlated with *Spartina alterniflora* aboveground biomass and sediment deposition. *S. alterniflora* on the marsh plain also was positively correlated with precipitation. Salinity was inversely correlated with freshwater discharge. Increasing salinity was associated with reduced *S. alterniflora* aboveground biomass and greater numbers of fiddler crabs. There was no association between temperature and the measured ecological variables.

This work provides a basis to: (1) understand how ecosystem services vary among salt-, brackish-, and tidal freshwater marshes; (2) determine how sea level rise will alter marsh area and delivery of ecosystem services; and (3) elucidate how climate variability affects temporal patterns of macrophytes, epifauna, and sediment deposition.

Reference:

Craft C, Clough J, Ehman J, Joye S, Park D, Pennings S, Guo H and Machmuller M. Forecasting the effects of accelerated sea level rise on tidal marsh ecosystem services. *Frontiers in Ecology and the Environment* 2009;7:73-78.

EPA Grant Number: 832220

Climate-Linked Alteration of Ecosystem Services in Tidal Salt Marshes of Georgia and Louisiana

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The investigators' objective is to elucidate the effects of climate change on tidal marsh ecosystem services in tidal salt marshes of Georgia and Louisiana. The goal of this research is to better understand how the ecosystem services of eutrophication control, carbon sequestration, sustainable habitat, and faunal support are influenced by climate change, specifically increased drought severity, in salt marshes with tidal amplitudes ranging from mesotidal (Georgia) to microtidal (Louisiana).

This research project takes advantage of a unique and timely opportunity afforded by recent, multi-year, severe drought events in the tidal salt marshes of both Louisiana and Georgia that resulted in large areas of sudden salt marsh dieback. Within each state, six large study areas will be identified in which permanent plots will be established in habitats that represent a range of salt marsh response to drought from relatively unimpacted, reference (high vegetation cover) to severely impacted (complete dieback and loss of vegetation cover). Additionally, *Spartina alterniflora*, the dominant salt marsh grass, will be artificially established at low and high stem densities within areas of complete dieback (bare) marsh as a mechanism of controlling plant density independently from the drought-induced dieback. Alteration to the ecosystem services mentioned above will be evaluated at several scales over two growing seasons.

The proposed research will greatly increase the understanding of how climate change and severe drought events impact crucial salt marsh ecosystem services. By conducting this research in a natural laboratory that brackets a range of hydrogeomorphic conditions (deltaic plain/microtidal to coastal plain/mesotidal), the data generated on the effects of climate change on tidal salt marsh ecosystem services will have widespread applicability and value to coastal managers.

EPA Grant Number: R832221

Linking Impacts of Climate Change to Carbon and Phosphorus Dynamics Along a Salinity Gradient in Tidal Marshes

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Tidal freshwater marshes are often located in areas experiencing intense urbanization pressure, yet they provide valuable services to coastal ecosystems by acting as water quality filters (removing nutrients and sediments), sequestering carbon [C] and phosphorus [P], serving as nursery habitat for fishes, and buffering storm and flood waters. A climate change stressor that is unique to tidal freshwater systems is the intrusion of salt water into environments that have historically been dominated by freshwater flows. The investigators especially are interested in how the increase in SO_4^{2-} concentration associated with salt water intrusion will affect the biogeochemical interactions that govern the cycling of C and P in tidal freshwater marshes and how it will affect the flux of elements between marshes, tidal waters, and the atmosphere.

The investigators will implement a novel, three-phase approach to determine changes in tidal marsh metabolism (e.g., CO_2 and CH_4 gas fluxes and SO_4^{2-} reduction), C and P sequestration (sediment deposition and burial), sediment P speciation, and porewater chemistry at sites along a low-salinity transitional gradient in the Delaware Estuary. Phase 1 consists of field observations (as a space-for-time substitute) to assess current ecosystem services provided by tidal freshwater and low salinity marshes, and allow the investigators to predict how these services may change as a result of salt water intrusion. Phases 2 and 3 provide a more detailed look at specific biogeochemical processes that impact cycling of C, P, and S. In Phase 2, laboratory experiments using marsh cores exposed to low salinity levels (< 5 psu) will be conducted to study the short-term (weeks to months) impact of increased salinity on marsh sediment C and P biogeochemistry. Phase 3 involves large-scale manipulations in the field (reciprocal transplanting of cores between tidal freshwater, oligohaline, and mesohaline marshes) to examine longer term (~1-2 yr) ecosystem-level responses of marshes to elevated salinity.

This research will improve the assessment of how ecosystem services provided by tidal freshwater marshes are likely to respond to predicted changes in climate-induced sea level rise and salinity. It is expected that a small increase in salinity in tidal freshwater wetland sediments will increase rates of decomposition (but decrease rates of C burial and emissions of the greenhouse gas CH_4), and cause a release of sediment-bound P from the soils. The results from this project can be used to improve existing climate change forecast models and will allow appropriate management to moderate the impacts of future climate change in low salinity tidal marshes.

EPA Grant Number: R832222

Connectivity in Marine Seascapes: Predicting Ecological and Socioeconomic Costs of Climate Change on Coral Reef Ecosystems

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This research project seeks to integrate theory and data from ecology, biology, and the social sciences to address major questions about the potential consequences of climate change on coral reef ecosystems. The researchers will establish a general framework starting at the habitat scale that is linked with population biology and socioeconomic models. This structure will allow systematic exploration of several core questions, including: (1) How do local impacts, including overfishing and mangrove deforestation, affect the vulnerability of Caribbean coral reefs to climate change? (2) When do socioeconomic responses to changes in the ecosystem triggered by climate change stressors exacerbate the vulnerability of coral-reef ecosystems to future stressors? and (3) What are the critical ecological and/or socioeconomic uncertainties for predicting climate change impacts on ecosystem services that will yield the greatest returns from investigation? In all questions, ecosystem services will be measured through the effects on fisheries, biodiversity, and social/cultural systems.

The investigators will develop an integrated ecological-socioeconomic model that will be representative of Caribbean ecosystems and be formulated in discrete time and space. Data for estimating ecological and socioeconomic response functions are already being collected by this team in an ongoing National Science Foundation-funded biocomplexity project. This unique data set will allow the investigators to highlight and measure the effects of local processes that are typically averaged out in more aggregate climate change models. The model will include explicit spatial processes, such as larval and adult/juvenile dispersal and movements of fishers, along with dynamic adjustment responses to predict the vulnerability of coral-mangrove ecosystems to climate change stressors. Given the large uncertainties in both the nature of the relationships and measurement, the researchers will perform a value of information analysis to learn about the impacts of reducing uncertainties on various ecological and socioeconomic criteria.

Taking advantage of ongoing model development and data collection analysis of Caribbean coral-reef ecosystems, the goals in this study are to develop a new understanding of changes in ecological services due to climate stressors, provide a framework for evaluating different management scenarios on ecosystem services, and highlight mechanisms where climate stressors can cascade through the ecological and socioeconomic systems triggering responses that increase the vulnerability of the ecosystem.

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Effects of Climate Change on Ecosystem Services Provided by Hawaiian Coral Reefs

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A robust, modular model of reef and ecosystem services responses to both the long-term mean and the short-term extreme event components of climate change will be developed from the wealth of ecological and physiological data available for the coral and reef communities of Hawaii. Its output will be the input for the socioeconomic models, which will translate the climate change scenarios into a comprehensive picture of possible futures of the ecosystem services and socioeconomic sectors, activities, and costs for the region. The model (as well as the environmental data used and a comprehensive inventory of Hawaiian corals) will be available for both online use and download from a Web site (www.kgs.ku.edu/Hexacoral), providing for community involvement through hands-on testing and feedback.

This research project will integrate and extend existing models to develop a comprehensive, scenario-based analysis of the range of possible effects of global climate change on ecosystem services provided by the coral reefs of the Hawaiian archipelago, and on the economic valuation of predicted changes. It will build on an extensive base of coral, reef, environmental, and economic data and analyses already assembled for the region, using targeted surveys and experiments to characterize five diverse case study sites that will sample the region. Cross-scale (reef to Global Circulation Model [GCM] cell dimensions) and cross-domain (biological, environmental, economic) analyses will be carried out and integrated using domain-based typologies to classify sites and services, and to scale and integrate the impacts on services and values. A Geographic Information System (GIS) will be used extensively for visualization, analysis, integration, and communication of results.

In addition to systematic identification and valuation of potential changes in ecosystem services, broken down by service, environmental type, and socioeconomic sector, the project will emphasize the unique suitability of Hawaii and its indigenous culture for advancing methods of valuing both unused resources (the Northwest Hawaiian Islands) and the cultural and spiritual, as well as aesthetic, services provided by coral reefs. In addition to elucidating the interactions among climate change stressors and their relative effects on multiple ecosystem services, the project will develop and disseminate a suite of new and useful technical, methodological, and conceptual tools that will be broadly applicable to other systems.

EPA Grant Number: R832224

Hydrologic Forecasting for Characterization of Nonlinear Response of Freshwater Wetlands to Climatic and Land Use Change in the Susquehanna River Basin

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The objectives of this research project are to characterize nonlinear responses to global climate change in linked aquatic and terrestrial ecosystems through: (1) selection of a linked terrestrial-aquatic ecosystem that provides critical ecosystem services and ecological functions; (2) characterization of various global change scenarios, incorporating both climate and land cover, and a method of assessing their effect on the identified ecosystem through the primary forcing factor of hydrology (both alone and in conjunction with other human-associated stressors); (3) identification of potential nonlinear ecological responses (sensu Scheffer et al., 2002) in the selected ecosystem as a result of these changes; and (4) estimation of the resultant change in ecosystem services on a watershed and Basin-wide scale in the Susquehanna River Basin (SRB).

The general approach to investigating the response of freshwater wetlands to climatic and land use change is based on the tools and products of four previous U.S. Environmental Protection Agency Science To Achieve Results (EPA STAR) grants, and involves the following series of activities:

1. Develop scenarios of climate and land cover change, operating on a scale of decades, relevant to the SRB.
2. Using these scenarios, in conjunction with a coupled surface-ground water model, develop a number of predictive hydrologic scenarios for a collection of 11-digit HUC watersheds representing a range of human-associated land uses in the SRB.
3. Characterize the relationships between hydrologic and landcover parameters and ecosystem characteristics and services in wetlands of various types in the SRB, focusing on those with preliminary evidence of non-linearity and/or thresholds.
4. Utilize the predicted hydrologic scenarios to forecast changes in ecosystem services across the entire SRB, clearly identifying where and when non-linearities and/or thresholds in response occur, utilizing a series of unique statistical tools to develop a probability surface.

The investigators will develop a unique analytical method for prediction of climate and land cover change impacts, incorporating the forecasting of hydrologic conditions, which can be used to identify thresholds and non-linearities in the functional performance of freshwater wetlands. Any set of hydrologic/land cover change conditions can then be placed on the probability surface, allowing the statistical model to be used in a predictive fashion. The method could be applied to a wide variety of aquatic ecosystems for which state changes occur over either a spatial or temporal extent, or both.

EPA Grant Number: R833013

Sustainable Coastal Habitat Restoration in the Pacific Northwest: Modeling and Managing the Effects, Feedbacks, and Risks Associated With Climate Change

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The overall objective of this research project is to develop a predictive landscape simulation model, incorporating non-linear feedbacks, of the ecological and geomorphological consequences of climate-induced sea level rise and river flow alteration in two of the most ecologically significant estuarine systems in Puget Sound, Padilla Bay, and Skagit Bay. The investigators will use the model to guide the course of restoration and management efforts, given climate change, as they relate to salmon habitat in Puget Sound.

The investigators will develop and link a spatially explicit hydrodynamic and sediment transport model of Padilla Bay and Skagit Bay to a mechanistic wetland elevation dynamics and vegetation unit model and models of tidal channel geomorphology and juvenile salmon abundance and distribution. The linked models will be initialized, calibrated, and validated using extensive site-specific data sets that the investigators have already developed and the data that they have collected. The model will be run under various sea level rise and river flow scenarios.

Effective and sustainable habitat restoration needs to anticipate future environmental conditions to ensure that restoration efforts will be robust and capable of surviving anticipated climate change. The investigators will use this model to examine how recovery goals (e.g., hectares to be restored) should be adjusted depending on how much marsh progradation or erosion occurs over the next century, and will characterize regions in the estuary that would be high- or low-risk restoration sites depending on their likely vulnerability or resilience to climate change. It is precisely this “vulnerability/resilience” response to climate change that is nonlinear. The investigators anticipate immediately incorporating this model into planning and management processes used by local tribes, local restoration planning organizations (e.g., the Skagit Watershed Council), and regional restoration planning organizations (e.g., the Northwest Indian Fisheries Commission, Washington Shared Strategy, and the Puget Sound Nearshore Restoration Program, among others).

EPA Grant Number: R833014

Nonlinear Response of Pacific Northwest Estuaries to Changing Hydroclimatic Conditions: Flood Frequency, Recovery Time, and Resilience

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Pacific Northwest (PNW) estuarine soft-sediment habitats are productive systems that play an important role in the biodiversity and functioning of coastal ecosystems and provide economically important biotic resources and diverse ecosystem services. Rainfall intensity is on the rise, and the sediment yield from PNW basins has increased. Consequently, sediment input to estuaries has increased in magnitude and intensity, and the input rate of fine-grained sediment from the surrounding drainage basin is likely to have important effects on estuarine ecosystem services. It also may interact nonlinearly to impact the structure and function of intertidal benthic communities and facilitate colonization by non-indigenous species (NIS).

The investigators conducted a manipulative field study simulating different frequencies of flood sedimentation events (zero, one, or two events in a single rain season) and tracked the initial mortality and recovery of the benthic community from these events using a combination of high resolution benthic sampling and univariate and multivariate analyses of benthic community metrics. Particular emphasis has been placed on identifying changes in functional biodiversity, documenting recovery times and potential hysteresis effects of having two sedimentation events in a rain season, tracking mortality and recovery of important functional groups, and changes to the populations of NIS. Parallel sediment samples were collected and analyzed to track changes in important sediment properties that have direct or indirect effects on survival or habitat suitability to the benthic community.

This study will develop an empirical and theoretical framework for predicting the effects of flood sedimentation events on tideflat macrobenthic communities in PNW estuaries and how these changes affect ecologically and economically important biotic resources and ecosystem services. This research will be used to quantify the resilience of intertidal benthic communities and identify important structural changes that may indicate a threshold or catastrophic shift in the benthic ecosystem in response to sedimentation events. Because neither sufficient data nor models currently exist to conduct risk analyses, these datasets will significantly improve our ability to perform ecorisk assessments in PNW estuaries, which can be used by resource managers to make better informed decisions regarding actions to minimize or eliminate the risks to these systems.

EPA Grant Number: R833015

Nonlinear Response of Prairie Pothole Landscapes to Climate Change and Land Management

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This research project involves a multi-disciplinary, multi-institutional project that examines the possibility that the response of prairie wetland ecosystems to climate change may be nonlinear or threshold in nature.

Wetland ecosystems of the Prairie Pothole Region (PPR) in the northern Great Plains are extremely vulnerable to climate change. While aspects of this vulnerability have been examined in previous research, strongly suspected threshold responses of these wetlands to environmental drivers remain largely unstudied. The objective of this research project is to identify possible future climatic and land use conditions that could sharply reduce biodiversity in wetlands across the PPR.

A multi-step, integrated research framework will examine nonlinear responses through the use of a tested mathematical model (WETLANDSCAPE) that links upland and wetland processes at the landscape scale. Simulations will focus on critical environmental thresholds that control key ecosystem processes upon which most wetland biodiversity depends. Terrestrial (upland) conditions and their management will be incorporated explicitly as they influence the environment of wetlands down slope. The potential to use land management to mitigate for possible negative consequences of climate change on prairie wetland biodiversity will be examined using a land use decision model that embeds economic variables. This will allow quantification of the economic costs of land use alterations to achieve ecosystem goals.

A primary outcome of this research will be to inform the scientific and management community, and ultimately the public, of the existence of critical thresholds in the hydrologic environment of prairie wetlands which, if exceeded by future climate forcings, could produce major negative consequences for biodiversity. The possibility that amphibian and waterfowl numbers will greatly diminish in North America because of climate change in the PPR is of great concern among public and natural resource management agencies. This research will provide new understanding of the complex relationships among climate, wetland environment, and the habitat base for these and other elements of biodiversity. The research also will suggest the degree to which human adjustments (beyond reductions in greenhouse gases) such as land use changes can lessen the severity of impacts of climate change on natural ecosystems in the PPR. Finally, this study will provide preliminary information on the economic feasibility of alternative land use options and indicate the magnitude of required societal costs to achieve such outcomes.

EPA Grant Number: R833016

Innovative Management Options To Prevent Loss of Ecosystem Services Provided by Chinook Salmon in California: Overcoming the Effects of Climate Change

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In this research project, investigators are using an integrated water resources management model (WEAP21) to simulate potential changes in flow and temperature in the salmon spawning reaches of Butte Creek, California, in response to climate change. The resulting data are being used to drive a fish population model (SALMOD) that simulates response to changing environmental conditions, including threshold effects on survival. Literature reviews, field surveys, and an expert panel are being used to develop a conceptual model of the impacts of changes in the salmon marine-derived nutrient subsidy to terrestrial wildlife.

The basic objective of the research is to determine the flow and temperature thresholds that lead to long-term losses or reductions in spring-run Chinook salmon in Butte Creek. **Hypothesis 1:** Climate induced changes in flow and temperatures in Butte Creek will lead to critical reductions in the available habitat of spring-run Chinook salmon. **Hypothesis 2:** The loss/reduction of Chinook salmon will reduce the diversity and abundance of birds and mammals in the riparian corridor. The final objective is to evaluate management options to ameliorate these impacts.

The approach to assessing non-linear and threshold responses to gradual climate change on spring-run Chinook and the dependent terrestrial ecosystem services will be both analytical and expert-panel based. The primary, linked analytical models are WEAP21—an integrated watershed hydrology, water and irrigation management, and water quality model, and SALMOD—a population dynamics model that predicts the growth, survival, and movement (habitat choice) of salmon in freshwater systems from spawning to the egg, juvenile, and smolt life stages, based on water quantity and quality conditions. Model results, along with the knowledge base of the study team, will provide information for expert panels in Years 2 and 3 of the project. These experts will help assist in the evaluation of potential impacts of climate change and management policies to address these impacts.

Expected results include greater insight into the sustainability of spring-run Chinook salmon and their role in defining the terrestrial biodiversity of the riparian corridor. Bringing climate change to bear on the issues will determine environmental thresholds that also will be decision-making thresholds. The investigators will provide various stakeholder and management groups with a set of tools and new information to help determine: (1) if salmon are in increased danger from climate change; (2) if there are strategies to save the fish and fish-dependent wildlife species from climate change effects; and (3) when and how these strategies can be implemented. The analytical process and expert panel opinion will lead to: (1) possible water management strategies to counter climate change impacts on stream ecosystems and the services they provide; and (2) an improved understanding of the potential tradeoffs between services provided by water diversion versus services provided by water left in the stream.

Analytical tools developed will be made available to the research and water management communities. Dr. Lisa Thompson (Co-PI), who has an appointment in the University of California Cooperative Extension (UCCE), will extend academic information about California inland fisheries to stakeholders such as private landowners and government officials. David Purkey has worked with the U.S. EPA Office of Research and Development to extend the WEAP21 modeling framework to incorporate climate change, and it was used in the recent California Governors Report on Climate Change (http://www.climatechange.ca.gov/). Thus, the results of this work will be relevant for water management decision makers far beyond the Butte Creek basin.

EPA Grant Number: R833017

Hydrologic Thresholds for Biodiversity in Semiarid Riparian Ecosystems: Importance of Climate Change and Variability

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Riparian ecosystems of the arid and semiarid Southwest are linear corridors of high productivity and diversity. These ecosystems are sensitive to even small changes in the riparian water balance, with sharp changes in vegetation as streams become intermittent and as groundwater declines below survivorship thresholds. As a result, riparian vegetation has declined on many rivers due to water abstraction or has been altered due to the hydrologic impacts of climate variability. Despite much disciplinary work on individual rivers, a regionally comprehensive and integrated understanding of how aquatic-terrestrial ecotones respond to hydrologic change, including those imposed by climate change, awaits development.

The investigators will determine region-wide sensitivity of riparian vegetation to climate change. Project hypotheses include: (1) decadal scale climate change and variability alter riparian aquifer recharge through mechanisms that depend on the magnitude, frequency, and seasonality of flooding, and exert the greatest change in reaches that receive minimal groundwater inflow from the regional aquifer; (2) riparian vegetation structure responds non-linearly as riparian aquifers are dewatered and as key hydrologic thresholds for survivorship of plant species are exceeded; and (3) decadal scale climate variability and change alters riparian ecosystem water budgets that in turn changes vegetation structure and function and the ecosystem services provided to society.

For **hypothesis 1**, the investigators will: isotopically quantify riparian aquifer recharge along a regional precipitation gradient. On one river, the San Pedro, a model that links storm flow and aquifer recharge, calibrated with isotopic data, to estimate steam base flows and seasonal aquifer conditions will be developed. For **hypothesis 2**, the investigators will: further evaluate established connections between vegetation condition and hydrologic conditions of flood flows, groundwater depth, and stream flow permanence. For **hypothesis 3**, the investigators will: develop five alternative scenarios of climate change and use a scenario driven model to estimate the climate impacts on vegetation along the San Pedro River. For the other rivers, climate scenarios and hydrologic and vegetation data will be used to develop a climate change sensitivity matrix. Biodiversity and water quality ecosystem services of riparian systems will be quantified for each scenario.

This research project will produce three useful products for resource managers in the Southwest. First, the research will improve understanding of the linkages between climate (precipitation timing and amount), hydrologic variability (stream flow and aquifer conditions), vegetation structure, and ecosystem services in riparian ecosystems, and of the regional variability in these relationships. Second, a transferable coupled model of hydrologic-vegetation processes in riparian ecosystems that will allow for modeling of non-linear responses to hydrologic change resulting from climate change or other causes will be produced. Third, the climate sensitivity matrix that is developed will be useful for projecting regional impacts of climate change and anthropogenic impacts on riparian water budgets and ecosystem change.

EPA Grant Number: R833025

Nonlinear and Threshold Responses to Environmental Stressors in Land-River Networks at Regional to Continental Scales

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Ecosystems of the United States are subject to a variety of human-caused stressors, including changes in: climate, the chemistry of the atmosphere, the chemistry of precipitation, and land cover and land use. These stressors can act singly or together to elicit nonlinear and threshold responses in freshwater ecosystems and alter their capacity to deliver ecosystem services such as sufficient quantities of clean water. In this research project, the investigators will explore how a set of environmental stressors acts to affect the physical, chemical, and biological integrity of linked land-river networks using a coupled terrestrial-aquatic ecosystem model that is process-based and is applied in a georeferenced context within drainage basins across the United States. The research project will have two parts: building the linked land-river network model, and using the model in both retrospective and prospective studies. Use of the model will be guided by two hypotheses: (1) nonlinear and threshold responses in the coupled land-water systems are key to defining the observed variations in water quality across the United States during the last 100 years, transforming and intensifying local and in some cases regional-scale problems to fully continental-scale syndromes; and (2) future policy interventions can slow and sometimes reverse these problems and syndromes, but the interventions will be complicated by the reality of new stable states and the heritage of existing threshold responses requiring many years to reverse. The research plan includes two workshops involving the science team, resource managers, and policy makers. At the first workshop, the investigators will develop a set of “what if” scenarios that include specific policy interventions and use them in simulations. At the second workshop, the investigators will analyze how these interventions affect nonlinear and threshold behaviors in the freshwater ecosystems within drainage basins, and what the consequences will be for ecosystem services. This research will contribute significantly to the development of a theoretical basis for effectively protecting and managing ecological systems that exhibit nonlinear and threshold responses to environmental stressors. The successful development of research and management tools, such as the ones we are proposing, will help scientists to predict ecological thresholds before they are observed. These research tools also will help resource managers and policy makers select among alternative courses of action as they work to maintain, and in some cases enhance, the services provided to us by ecosystems.

Integrated Bioclimatic-Dynamic Modeling of Climate Change Impacts on Agricultural and Invasive Plant Distributions in the United States

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Biological invasions of nonindigenous plants and pests are serious threats to U.S. natural and managed ecosystems, causing more than $120 billion per year of major environmental damages and losses. In agriculture alone, $27 billion per year is estimated for the crop production lost from alien invasive weeds and herbicide application expense. It is well established that climate is the dominant determinant of the geographic distribution of plant species, native or alien. This distribution is confined by the prevailing bioclimatic limits in the regional resources of light, heat, water, and nutrients. Given the rapid growth in worldwide trade or globalization, long-range transport of non-native plant species across national boundaries becomes increasingly important, exacerbating U.S. invasive species problems. Although humans facilitate the initial establishment, the invasion, spread, and subsequent distribution of nonindigenous species may be controlled largely by local environmental factors. Recent climate change, such as general warming, earlier spring, longer growing season, decreasing winter frost period, and altered hydrologic cycle has already caused unequivocal shifts in the distributions and abundances of species, and even pushed certain native species to extinction.

The objective of this study is to quantify and understand the impacts and uncertainties of regional climate changes from the present to 2050 on the U.S. agricultural and invasive plant species distributions, emphasizing crop production, and to account for both adaptation of alternative crops and invasion of non-native species to enable decision makers to design effective management and control strategies for a sustainable future agroecosystem. The original contribution of this research will derive from the application of a state-of-the-art bioclimatic-dynamic ensemble forecast system that integrates a species environmental matching or niche modeling component (SEM) with a high-resolution dynamic regional climate-ecosystem predictive component (CEP) over North America. Both components incorporate multiple alternative models representing the likely range of climate sensitivity and ecological response under the conceivable anthropogenic emissions scenarios to rigorously assess the resulting uncertainty to improve risk analysis. This study will account for both adaptation of alternative crops and invasion of non-native species in response to projected climate changes. Historical simulations of the observed climate and crop production first will be conducted using the CEP to provide the best proxy of the actual soil and bioclimatic conditions fundamental to the plant survival and reproduction. This module can generate a high-resolution (10-30 km in this study), physically consistent and most complete list of climate variables.

The high-resolution CEP-integrated bioclimatic predictors, including total plant productivity as input, will be used to establish the SEM functional relationships of species distributions with these environmental envelopes. The optimized ensemble of multiple CEP and SEM component models driven by four combinations of regional climate models/global climate models (RCM/GCMs) and emissions scenarios will be used to represent the most plausible range and uncertainty of future projections of U.S. agricultural and invasive plant species distributions in the 2050s. The coupled CEP will be used to study climate-crop interactions, focusing on how they affect U.S. agricultural productivity at the present and in the future. The representative GCM projected and RCM downscaled climate changes will be used in this study. The recent RCM incorporates the most comprehensive surface boundary conditions and advanced physics schemes that improve surface-atmosphere and convection-cloud-radiation interactions. More importantly, it has been coupled with comprehensive crop growth models to realistically simulate U.S. crop yields. The coupled RCM-crop modeling system will serve as the key CEP to predict the climate and crop production conditions needed for the development and application of the ensemble SEM system. These conditions will be used as input to develop a robust SEM to best capture the observed agricultural and invasive plant species distribution. Future projections for the potential niche distributions of alternative crops adaptable to the likely range of climate changes in the 2050s will subsequently be made using the CEP. These CEP simulations of the future soil and bioclimatic conditions will be integrated by the SEM to project the geographic distribution and abundance of U.S. agricultural weeds and invasive plant species in the 2050s.

Through the proposed application of this unique ensemble forecast system, the investigators will make major contributions to the key goal of the U.S. Department of Agriculture Cooperative State Research, Education, and Extension Service (USDA CSREES) to enhance protection and safety of the Nation's agriculture and food supply. The advanced state of the system components will result in a more in-depth understanding of complex interactions among regional climate and land use, focusing on agricultural crop production and invasive plant species across a full range of spatial and temporal scales. The investigators expect to model the risks associated with several high-profile, costly agricultural weeds in the United States. By using a conceivable range of climate scenarios, we will evaluate, with a credible estimate of associated uncertainties, how these weeds may change in future distribution across a wide suite of crop types and environmental envelopes. This will lead to better targeting of harmful invasive species in response to climate change. It is expected that that the results will greatly surpass the capability of existing studies for climate change impacts on future U.S. agricultural productivity.

Global Change and the Cryptic Invasion by Transgenes of Native and Weedy Species

Cynthia L. Sagers and Peter K. Van de Water
Department of Biological Sciences, University of Arkansas, Fayetteville, AR

According to the U.S. Department of Agriculture (USDA): "The sustainability of agriculture, forest and rangelands depends on understanding the factors that influence climate change, the mechanisms that may enhance or mitigate this change, and its effects on food and fiber production and natural resources." (USDA: http://www.csrees.usda.gov/). A global issue in agriculture is the increasing incidence of herbicide resistant weeds. Weeds may become resistant to herbicides by mutation or by gene flow from sexually compatible crop species genetically modified for herbicide resistance. The adventitious presence of transgenes in the environment represents a potential threat to U.S. agriculture, and is an understudied aspect of global change. The investigators have adopted commercially available canola genetically modified for herbicide resistance as a model system. Canola is sexually compatible with a number of weeds in the United States; this project will focus on field mustard (*Brassica rapa L.*) and black mustard (*Sinapis arvensis*). The investigators will travel to sites in the midwestern United States to collect weeds and their seed progeny to: (1) evaluate the incidence of gene flow from crop to weed, and (2) to assess population variability in the likelihood of hybridization. The population measures, including flowering phenology and sexual compatibility, will be mapped and merged with predictive models of climate change in the United States. The result will be an understanding of regional variation in the likelihood of transgene flow, a predictive model of how these risks will change in the advent of climate change, and a heightened awareness of the impact of global change on agriculture and food supply in the United States.

The primary goal of this research project is to develop a predictive model of how populations of plant agricultural pests may expand or contract in the face of climate change. The study system is genetically modified canola (*Brassica napus L.* [*Brassicacea]*) and native and weedy plant species that are sexually compatible with canola. To this end, the investigators will conduct plant surveys of the upper midwestern United States where canola is currently an important crop system, greenhouse experiments to evaluate population variability in compatibility, and GIS modeling efforts that incorporate these data with accepted models of predicted climate change. This collaborative work will involve scientists from the University of Arkansas, California State University (CSU), Fresno, and the U.S. Environmental Protection Agency's National Health and Environmental Effects Laboratory, Western Ecology Division. It is anticipated that one postdoctoral fellow and two graduate students will be recruited to the project. The results of the work will be published in a series of peer-reviewed publications (at least three), one review article, four papers presented at national or international meetings, and a symposium arranged by the collaborators to be held in the last year of the project.

This research approach adopts methods from plant population biology and rapidly evolving geospatial technologies. The investigators visit sites in the upper midwest (Montana, North Dakota, Minnesota, and Wisconsin); midwest (Iowa, Illinois); and southeast (Arkansas, Oklahoma) to collect seeds of weed pests that are sexually compatible with canola (primarily *B. rapa* and *S. arvensis*). These seeds will be used to address a number of questions that include estimating the rate of gene flow from GM herbicide resistant canola, and determining population variability in sexual compatibility with canola. Greenhouse studies will be completed at the University of Arkansas, Fayetteville. Spatially explicit information regarding rates of gene flow, sexual compatibility, and environmental data will be incorporated into a GIS layer, which in turn will be incorporated into an emerging predictive model of climate change. The majority of the geospatial modeling will be completed at CSU, Fresno. This work constitutes a novel approach to assessing the risks of transgene escape in the face of climate change. This project is unique in melding traditional plant population biology with emerging spatial technologies.

A Multi-Scale Approach to the Forecast of Potential Distributions of Invasive Plant Species

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Controlling and preventing the spread of invasive plant species are common goals among ecologists and natural resource managers. Because these goals often are most successful when initiated early in the invasion process, the ability to predict where invasives will spread is crucial. The objective of this research project is to explain the distribution and abundance of invasive plants across the northeast United States as a function of climate and land use, and then forecast their future spread across the region to mid-21st century. To achieve reliable predictions on invasive species spread, the investigators propose a comprehensive approach that will take into consideration the major variables that will shape plant invasions in the next few decades (i.e., climate change, land use change, and the effects of elevated atmospheric CO_2).

The investigators will integrate experiments with predictive modeling to study plant invasions by focusing on the factors affecting their establishment and spread at four spatio-temporal scales: (1) regional-level, in which distributional ranges, based on the response to climate, will indicate the broad tolerance limits of each species; (2) landscape-level, in which incorporating the structure and composition of the landscape will inform predictions on the land use attributes that promote the spread and population growth of invasive species; (3) local-level, in which local site attributes (e.g., habitats, microclimates, soils, biotic interactions, etc.) will inform of establishment thresholds for these species; and (4) individual-level, in which changes in drought and shade tolerance will be examined under elevated atmospheric CO_2. The focus is to identify where specific species could establish and increase in abundance as successful invaders now and in the future.

An integral component of this project is to incorporate education and outreach for the public at large, professionals, and scientists. The investigators will use as a model the outreach and networking tools that they have implemented through the IPANE project (Invasive Plant Atlas of New England). The IPANE project has developed extensive educational and outreach materials on invasive species through its Web site, IPANE.org. Output from this project will be incorporated on model-prediction Web sites. The investigators plan to present the results of this research at regional, national, and international meetings of relevant scientific societies (e.g., the Ecological Society of America) each year during the course of the project. It is anticipated that the results of the research will be published in peer reviewed journals that focus on ecology, climate change, invasive species, and related issues (e.g., Ecological Applications, Biological Invasions, Global Change Biology, etc.). The investigators also will consider submitting articles, when appropriate, to high-profile general science journals.

Using the IPANE data set (species presence/absence, canopy closure, habitat type, etc.) with climate and land use and land cover (LULC), hierarchical Bayesian (HB) models will be constructed to predict potential distribution of selected invasive species. This approach provides for the specification of uncertainty in model components, as well as the predictions, and accepts prior knowledge and data from multiple sources. Regional predictions of future climates, focusing on projected changes in temperature and soil moisture, then will be incorporated. The climate models will be identified with co-PI Wang after examining the temperature and soil moisture changes projected by each of more than 20 global climate models (IPCC AR4). Climate projections from the North American Regional Climate Change Assessment Program (NARCCAP) also will be examined using forecasts for the middle of the 21st Century. The investigators will develop predictive LULC-change models, using LULC-change data from co-PI Civco. Co-PI Gelfand will develop and implement the LULC change models for the region. To evaluate the process of successful establishment of invasive species, in the context of new climates, varying establishment factors, and new biotic environments, the investigators will conduct a large-scale transplant study of invasive plant species across the region; this includes planting sites from southern Connecticut to northern Vermont. Demographic variables will be estimated as functions of environmental covariates using R and OpenBUGS software. Co-PI Reid will implement a CO_2 enrichment experiment with representative invasive and native species, grown under ambient and elevated (mid-21st Century) CO_2, under an array of watering and light levels; this allows quantification of the potential demographic advantage that projected elevated CO_2 levels may bring to some species.

The major objective of this project is to provide potential distribution maps and site information on potential establishment and abundance of invasive plant species across the region now and in the future. Predictions based on experimental data will reflect realistic plant responses to environmental conditions. This model approach will provide measurements of the uncertainty in predictions, one of the advantages of using statistical hierarchical Bayesian models. These models will be evaluated in part using Deviance Information Criterion and cross validation analyses. Data documentation, data files, and model descriptions will be made available through the IPANE Web Site. Periodic self-evaluation will be conducted by the project PIs. Independent evaluation of the project will come from peer reviews of manuscripts submitted for publication.

Predicting Relative Risk of Invasion by the Eurasian Saltcedar and New Zealand Mud Snail in River Networks Under Different Scenarios of Climate Change and Dam Operations in the Western United States

N. LeRoy Poff[1], Gregor T. Auble[2], Brian P. Bledsoe[1], Denis Dean[1], Jonathan Friedman[2], David Lytle[3], David M. Merritt[4], David Purkey[5], David A. Raff[6], and Patrick B. Shafroth[2]
[1]Colorado State University, Fort Collins, CO; [2]U.S. Geological Survey, Fort Collins, CO; [3]Oregon State University, Corvallis, OR; [4]U.S. Forest Service, Washington, DC; [5]Stockholm Environmental Institute, Davis, CA; [6]U.S. Bureau of Reclamation, Denver, CO

Predicting the spread and establishment of invasive species in river ecosystems under climate change requires developing models that mechanistically link species population success to climate-sensitive environmental drivers. The goal of this research project is to build a general and mechanistic framework with which to predict the future potential distribution of two invasive species expected to expand their ranges under a warming climate in streams and rivers of the western United States. The investigators hypothesize that local site invasibility will be regulated by climate-sensitive thresholds of hydrogeomorphic disturbance, which will vary throughout river networks in response to reach-scale channel geomorphology, future precipitation regimes, and operation of dams, which modify natural flow regimes.

In a geographic region predicted to support saltcedar snails in the near future, the investigators will downscale projected scenarios of temperature and precipitation as inputs to the Water Evaluation and Planning (WEAP) model framework, allowing generation of streamflow regimes at ca. 50 km^2 sub-basins based on precipitation and water management operations (including dams). An artificial neural network (ANN) model will be used to spatially distribute the WEAP hydrologic predictions throughout river networks at the reach scale (100s of meters). These reach-scale flow regime predictions, in conjunction with GIS-derived measures of channel and valley bottom geomorphology, will allow application of the biological model to assess the most likely locations in river networks for successful saltcedar and mud snail invasion given the flow-mediated disturbance regimes of any of several future climate scenarios. Further, using the coupled WEAP-ANN model, the investigators will explore how a range of water management operations might influence the likelihood of invasive establishment in these climate contexts. Finally, innovative stochastic population models will be used to evaluate the probability of long-term success of the invasive species across a range of habitat vulnerability.

This synthetic, multi-scale approach will generate a sequence of spatially explicit maps that will provide science guidance to support strategic decision-making regarding the spatially distributed risk of, and possible adaptation to, the spread of invasive species at local to regional scales in the western United States. The model will be general enough that it can be applied to other riverine species and resources, including non-invasive species.

Grant Number: R833833

Integrating Future Climate Change and Riparian Land Use To Forecast the Effects of Stream Warming on Species Invasions and Their Impacts on Native Salmonids

Julian D. Olden[1], Timothy Beechie[2], Joshua J. Lawler[1], and Christian E. Torgersen[1]
[1]University of Washington, Seattle, WA; [2]National Oceanic and Atmospheric Administration (NOAA), Seattle, WA

This project develops and applies an analytical framework that quantifies how future climate change and riparian land use influences the direct and indirect effects of invasive species on the survival of Pacific salmon in the John Day River in Oregon. Climate change, increasing agricultural land use, and invasive species threaten the functioning of freshwater ecosystems in the Pacific Northwest. Elevated stream temperature is one of the most pervasive water quality issues in this region, and projected climate change and riparian vegetation loss are predicted to exacerbate this problem. Rising temperatures have direct implications for coldwater native salmon, but they also will alter the composition of aquatic biota by facilitating range expansion and altering the impacts of warmwater invasive species.

The investigators will integrate climate-change projections, geomorphic sensitivity, riparian land use, stream thermodynamics, and ecological niche modeling to quantify the potential range expansion and temperature-mediated impacts of invasive smallmouth bass (*Micropterus dolomieu*) and northern pikeminnow (*Ptychocheilus oregonensis*) in critical habitats that support endangered Chinook salmon (*Oncorhynchus tshawytscha*). The proposed work will: (1) predict spatiotemporal patterns of riverine thermal regimes in response to future climate change, geomorphic sensitivity, and riparian land-use; (2) forecast species-specific responses to projected future thermal regimes; and (3) evaluate alternative scenarios of climate change to identify critical opportunities for riparian habitat restoration and protection to mediate future climate-induced warming of streams and species invasions.

This project provides both the science and decision-support tools required to forecast with certainty how the interactive effects of climate change, land use change, and invasive species will affect native salmon in the future. Model results provide spatially explicit predictions of the vulnerability of adult and juvenile Chinook salmon to the direct effects of stream warming associated with climate and land use change, and the indirect, temperature-mediated effects of smallmouth bass and northern pikeminnow range expansion. Model outputs improve the scientific capabilities for guiding management strategies and policies aimed at minimizing the future range expansion of invasive species through protection and restoration of riparian vegetation that creates and maintains a coolwater habitat. More broadly, this project and the analytical framework it developed is readily applicable to other species of concern and relevant in other river systems of the Pacific Northwest, where the range expansion of warmwater fishes in response to climate change and riparian-habitat loss is ongoing and of imminent threat to native fishes.

EPA Grant Number: R833834

Understanding the Role of Climate Change and Land Use Modifications in Facilitating Pathogen Invasions and Declines of Ectotherms

Jason R. Rohr[1], Andrew Blaustein[2], and Thomas R. Raffel[1]
[1]University of South Florida, Tampa, FL; [2]Oregon State University, Corvallis, OR

Invasive parasites of humans and wildlife are arising at an unprecedented rate and are debilitating our ecosystems. For instance, pathogens have been implicated in many amphibian declines that are triggering state changes and impairing ecosystem functions. Climate change and land use modifications might elicit disease emergence, but few generalizations have materialized for how these factors facilitate parasite invasions. The investigators recently documented immunosuppression in amphibians associated with agrochemical exposure and temporal climatic variability, stimulating the agrochemical spread and climatic variability hypotheses. These hypotheses predict that proximity to agriculture (a global land-use modification) and elevated temporal variability in temperature (due to climate change), respectively, compromise host immunity and facilitate parasite invasions. In preliminary work, both temperature increases and decreases caused suboptimal immunity, but drastic seasonal drops in temperature caused the longest periods of suboptimal immunity, stimulating the hypothesis that cold-tolerant parasites will benefit most from elevated climatic variability driven by global climate change. The investigators propose to test these hypotheses on multiple parasites and ectothermic taxa, but intentionally focus on the invasive *Batrachochytrium dendrobatidis* and amphibians because this emerging chytrid fungus is cold-tolerant and implicated in many of the global amphibian declines.

The investigators will test these hypotheses by: (1) examining whether the timing of apparently disease-induced amphibian extinctions in Central and South America are related to climatic variability, proximity to agriculture, or alternative factors; (2) testing whether the distribution of extinct and threatened ectothermic species worldwide is positively associated with the spatial pattern of climatic variability and agriculture across the globe; and (3) conducting a series of manipulative experiments in which numerous ectothermic hosts and cold- and warm-tolerant parasites will be exposed to constant and variable temperatures (across a temperature range) and quantify subsequent host immunity and parasite infections.

This research project is expected to reveal general mechanisms by which climate change and specific land use modifications facilitate parasite invasions. This will enhance risk assessment and management by allowing decision makers to prioritize regions, localities, and species that are at risk for potentially debilitating parasite invasions.

EPA Grant Number: R833835

Beach Grass Invasions and Coastal Flood Protection: Forecasting the Effects of Climate Change on Coastal Vulnerability

Eric Seabloom, Sally Hacker, and Peter Ruggiero
Oregon State University, Corvallis, OR

Increased storm severity and sea-level rise resulting from climate change have greatly elevated the risk of catastrophic flooding and storm damage to coastal communities. These risks have been exacerbated by alterations to coastal ecosystems and the introduction of exotic species. In the Pacific Northwest, coastal dunes protect approximately one-half of the coastline, and our initial results suggest that climate change-induced sea level rise could double the frequency with which waves overtop dunes. Intentional planting of exotic grasses may have initially increased coastal protection from flooding by building tall foredunes parallel to the shoreline. However, an unintentional second invasion appears to be decreasing foredune height by 50 percent, thereby increasing risk exposure. In addition, many agencies are removing exotic beach grasses to restore habitat for imperiled species listed in the Endangered Species Act. The effects of these conservation actions on flooding risk are unknown. The objectives of this research are to determine: (1) the effects of climate change on exotic beach grass invasion; (2) the effects of exotic beach grass invasion on coastal vulnerability; and (3) if conservation management alters coastal vulnerability to flooding under a range of climate change, invasion, and management scenarios.

The investigators will use published climate change scenarios, remotely sensed beach topography data (LIDAR), and field experimentation to parameterize coastal process and vulnerability models. These empirically parameterized models will be used to forecast the risk of flooding in coastal communities under a range of climate change and invasion scenarios.

This research will yield an increased general understanding of interactions among the alteration of coastal ecosystems, species invasions, climate change, and human risk in coastal environments. In addition, the researchers will conduct a quantitative vulnerability assessment of a specific coastal community in Washington. This case study will serve as a template for other applications of our models and data in coastal dune systems worldwide.

EPA Grant Number: R833836

Elevated Temperature and Land Use Flood Frequency Alteration Effects on Rates of Invasive and Native Species Interaction in Freshwater Floodplain Wetlands

Curtis J. Richardson, Neal Flanagan, and Song S. Qian
Duke University, Nicholas School of the Environment and Earth Sciences, Durham, NC

The primary objective of this research project is to assess how predicted climate and land use driven changes in hydrologic flux and temperature regimes of floodplain ecosystems affect plant communities in terms of their vulnerability to the establishment and spread of invasive species and, in turn, ecosystem functions and services. Future climate scenarios for the southeastern United States predict that surface water temperatures will increase (in concert with air temperature) and that stream flows will likely decrease, with a greater proportion of annual watershed hydrologic yield occurring during major storm events. Land use changes (urban vs. forested, etc.) have been shown to raise water temperature and increase pulsed water releases during storms. This research project focuses on the relationships between native species composition, diversity, productivity, and invasibility of floodplain ecosystems affected by alterations of water temperature and annual hydrographs driven by climate and land use changes. The investigators will use a combination of varying scale experimental studies and one novel large-scale regional study to verify the experimental and threshold modeling results.

There are four study levels: (1) A field-based warming experiment will allow the investigators to directly evaluate and model treatment effects of temperature and hydrology on species invasions, community composition, and ecosystem services of an experimental (restored) floodplain ecosystem. (2) There are 99 diversity plots on a floodplain that will be used to test how species richness affects species invasions. (3) There are 102 permanent vegetation plots that will be distributed over three hydrogeomorphic zones in the floodplain (stream bank, low terrace, and high terrace) to assess species invasions affected by pulsed waters. (4) Regional studies on wetlands downstream of surface and bottom-releasing dams will be used to assess pulsed water and temperature effects on invasive species as compared to control rivers. At each experimental level the investigators will assess how feedbacks from invasive species alter ecosystems services such as flood control, sediment retention, and maintenance of water quality. A unified Bayesian hierarchical model will be developed as a decision support tool to predict temperature and hydrology thresholds for invasive species response to alterations in floodplain ecosystems.

Experimental results will be used to estimate the effects of predicted temperature increases and increased storm flow events on the ability of existing floodplain communities to resist invasive species. Proposed Bayesian modeling methods can address nonlinear responses and provide a risk assessment probability analysis to predict ecosystem threshold shifts.

EPA Grant Number: R833837

Ecological Impacts From the Interactions of Climate Change, Land Use Change, and Invasive Species

Robert B. Whitlatch[1] and Richard W. Osman[2]
[1]University of Connecticut, Groton, CT; [2]Smithsonian Environmental Research Center, Edgewater, MD

The five objectives of this research project are to: (1) work with environmental managers and stakeholders to explore different scenarios for land use planning, development of coastal areas, habitat restoration, or other management issues in the context of climate change and invasive species; (2) conduct mesocosm experiments testing links between climate change and land use in altering the ability of invasive species to affect native communities; (3) conduct field experiments to assess temporal and/or spatial scales of potential efforts needed to effectively manage invasive species; (4) conduct field experiments examining the survival of key predators of invasive species in areas of different land use; and (5) develop predictive models to assess alternative management strategies. Focus will be placed on integrating management needs with ecological predictions that allow managers to evaluate multiple stressors at different temporal and spatial scales in different types of coastal systems.

Workshops with managers and stakeholders will discuss multi-stressor management needs and establish the most useful management scenarios for coastal zone planning in a context of climate change and invasive species and information dissemination methods. Mesocosm experiments will simulate predicted temperature changes, and the population and community responses of native and recently introduced species will be compared. Field experiments will determine the spatial and temporal scales for the effective management of invasive species in the context of differences in coastal land use and climate change. An existing population/community model will be modified to present easily understood scenarios to managers and planners.

This study will directly examine climate change on shallow-water marine communities that are most likely to suffer from the poleward spread of species as coastal waters warm. The adaptation of an existing model will couple climate and land use changes to assess their combined effects on the susceptibility of habitats to species invasion and subsequent ecosystem changes in a manner that can be used by managers and planners. Because the invaders are easily recognized and their damage to native communities can be readily quantified, they can be used by managers as highly visible indicators of stress, as well as to assess the success of various types of implemented management plans.

EPA Grant Number: R833838

Appendices

U.S. Environmental Protection Agency (EPA)
The Plight of Ecosystems in a Changing Climate: Impacts on Services, Interactions, and Responses Workshop

May 27 - 28, 2009

Plymouth Church
1217 Sixth Avenue
Seattle, WA

AGENDA

Webinar Information
http://hawkeye.epa.gov/imtapp/app/sch_mtg_details.uix?mID=410300
Conference ID: 410300
Conference Key: 2546283

Call-in Information:
Toll-free dial-in number (US and Canada): (866) 299-3188
International dial-in number: (706) 758-1822
Conference code: 2023439850

Day One, Wednesday, May 27, 2009

8:00 a.m. – 8:30 a.m.	**Registration**
8:30 a.m. – 9:00 a.m.	**Introductory Remarks** *Roseanne Lorenzana*, EPA, Region 10 Science Liaison *Brandon Jones*, Project Officer, EPA, ORD, NCER

Tier I – Effects of Climate Change on Ecosystem Services Provided by Coral Reefs and Tidal Wetlands

9:00 a.m. – 9:20 a.m.	**Effect of Sea Level Rise and Climate Variability on Ecosystem Services of Tidal Marshes** *Chris Craft, Indiana University, Bloomington*
9:20 a.m. – 9:40 a.m.	**Climate-Linked Alteration of Ecosystem Services in Tidal Salt Marshes of Georgia and Louisiana** *Mark Hester, University of Louisiana at Lafayette*
9:40 a.m. – 10:00 a.m.	**Linking Impacts of Climate Change to Carbon and Phosphorus Dynamics Along a Salinity Gradient in Tidal Marshes** *Melanie Vile, Villanova University*
10:00 a.m. – 10:20 a.m.	**Break**

*** USDA Grantees**

10:20 a.m. – 10:40 a.m.	**Connectivity in Marine Seascapes: Predicting Ecological and Socioeconomic Costs of Climate Change on Coral Reef Ecosystems** *Julie Kellner, Resources for the Future*
10:40 a.m. – 11:00 a.m.	**Effects of Climate Change on Ecosystem Services Provided by Hawaiian Coral Reefs** *Paul Jokiel, University of Hawaii at Honolulu*
11:00 a.m. – 12:00 p.m.	**Tier I Discussion**
12:00 p.m. – 1:00 p.m.	**Lunch** (on your own)

Tier II – Nonlinear Responses to Global Change in Linked Aquatic and Terrestrial Ecosystems

1:00 p.m. – 1:20 p.m.	**Hydrologic Forecasting for Characterization of Nonlinear Response of Freshwater Wetlands to Climatic and Land Use Change in the Susquehanna River Basin** *Denice Wardrop, Pennsylvania State University*
1:20 p.m. – 1:40 p.m.	**Sustainable Coastal Habitat Restoration in the Pacific Northwest: Modeling and Managing the Effects, Feedbacks, and Risks Associated With Climate Change** *John Rybczyk, Western Washington University*
1:40 p.m. – 2:00 p.m.	**Nonlinear Response of Pacific Northwest Estuaries to Changing Hydroclimatic Conditions: Flood Frequency, Recovery Time, and Resilience** *Rob Wheatcroft, Oregon State University*
2:00 p.m. – 2:20 p.m.	**Nonlinear Response of Prairie Pothole Landscapes to Climate Change and Land Management** *Carter Johnson, South Dakota State University*
2:20 p.m. – 2:40 p.m.	**Innovative Management Options To Prevent Loss of Ecosystem Services Provided by Chinook Salmon in California: Overcoming the Effects of Climate Change** *Lisa Thompson and David Purkey, University of California at Davis*
2:40 p.m. – 3:00 p.m.	**Break**
3:00 p.m. – 3:20 p.m.	**Hydrologic Thresholds for Biodiversity in Semi-Arid Riparian Ecosystems: Importance of Climate Change and Variability** *Thomas Meixner, University of Arizona*
3:20 p.m. – 3:40 p.m.	**Nonlinear and Threshold Response to Environmental Stresses in Land-River Networks** *Jerry Melilo, Woods Hole Oceanographic Institution*

Day One, Wednesday, May 27, 2009 (continued)

3:40 p.m. – 4:40 p.m.	**Tier II Discussion**
4:40 p.m.	**Adjournment** (continued discussion and dinner on your own)

Day Two, Thursday, May 28, 2009

7:30 a.m. – 8:00 a.m.	**Registration**

Tier III – Ecological Impacts From the Interactions of Climate Change, Land Use Change, and Invasive Species

8:00 a.m. – 8:20 a.m.	**Integrated Bioclimatic-Dynamic Modeling of Climate Change Impacts on Agricultural and Invasive Plant Distributions in the United States** *****_Wei Gao, Colorado State University_
8:20 a.m. – 8:40 a.m.	**Global Change and the Cryptic Invasion by Transgenes of Native and Weedy Species** *****_Cynthia Sagers, University of Arkansas_
8:40 a.m. – 9:00 a.m.	**A Multi-Scale Approach to the Forecast of Potential Distributions of Invasive Plant Species** *****_John Silander, University of Connecticut_
9:00 a.m. – 9:20 a.m.	**Predicting Risk Invasion by Salt Cedar and Mud Snails** _Leroy Poff, Colorado State University_
9:20 a.m. – 9:40 a.m.	**Integrating Future Climate Change and Riparian Land Use To Forecast the Effects of Stream Warming on Species Invasions and Their Impacts on Native Salmonids** _Julian Olden, University of Washington_
9:40 a.m. – 10:00 a.m.	**Break**
10:00 a.m. – 10:20 a.m.	**Climate Change: Pathogens and Decline of Ectotherms** _Jason Rohr, University of South Florida_
10:20 a.m. – 10:40 a.m.	**Beach Grass Invasions and Coastal Flood Protection: Forecasting the Effects of Climate Change on Coastal Vulnerability** _Eric Seabloom, Oregon State University_
10:40 a.m. – 11:00 a.m.	**Elevated Temperature and Land Use Flood Frequency Alteration Effects on Rates of Invasive and Native Species Interactions in Freshwater Floodplain Wetlands** _Curtis Richardson, Duke University_

Day Two, Thursday, May 28, 2009

11:00 a.m. – 11:20 a.m.	**Ecological Impacts From the Interactions of Climate Change, Land Use Change, and Invasive Species** *Robert Whitlatch, University of Connecticut*
11:20 a.m. – 12:20 p.m.	**Tier III Discussion**
12:20 p.m. – 12:30 p.m.	**Closing Remarks**
12:30 p.m.	**Adjournment**

U.S. Environmental Protection Agency (EPA)
The Plight of Ecosystems in a Changing Climate: Impacts on Services, Interactions, and Responses Workshop

May 27 - 28, 2009

Plymouth Church
1217 Sixth Avenue
Seattle, WA

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Swinomish Indian Tribal Community

Nathaniel Weston
Villanova University

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Oregon State University

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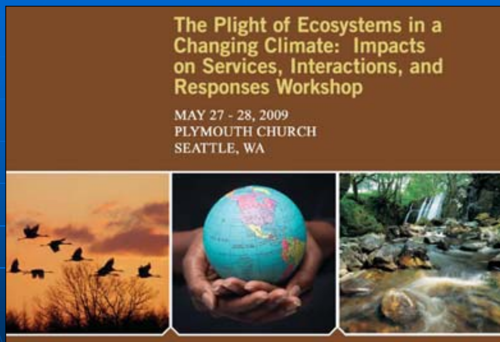

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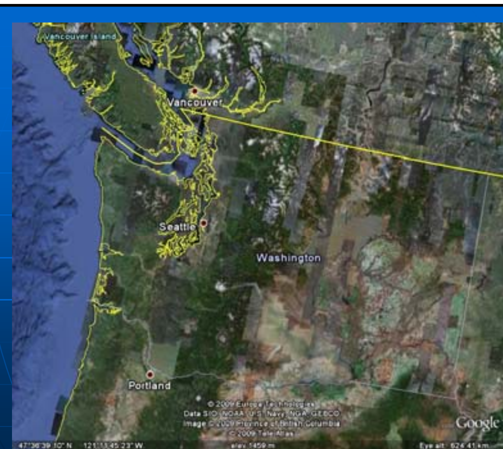
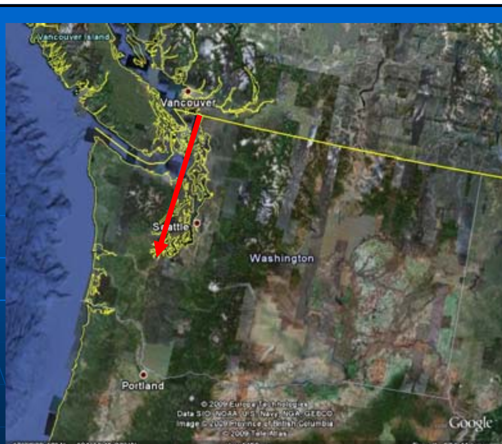
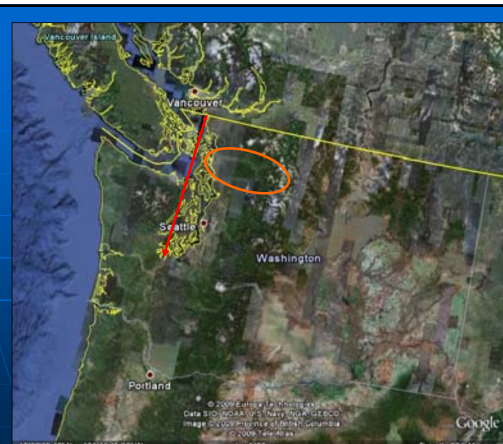






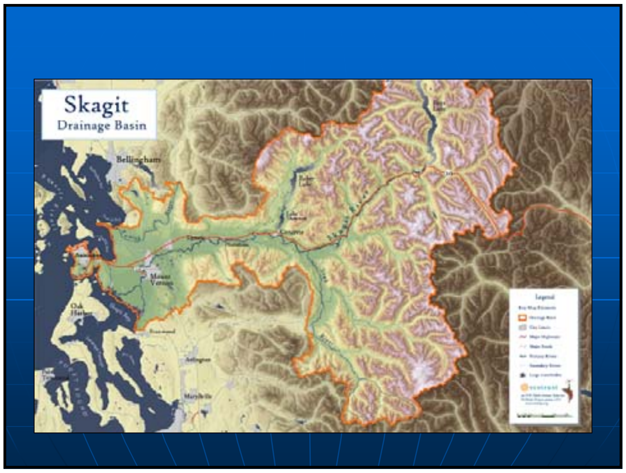
Skagit Watershed, Puget Sound, WA

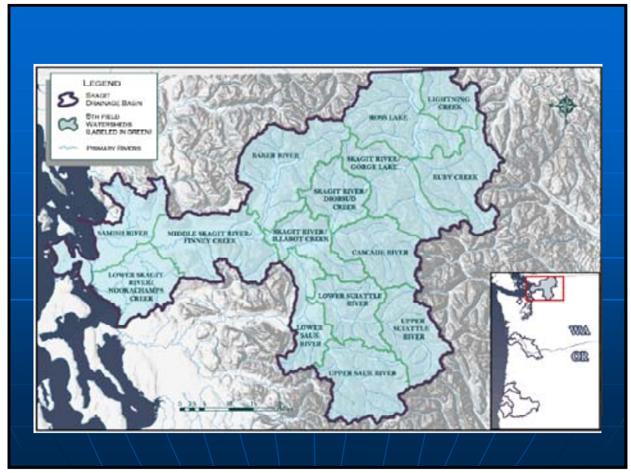
- Largest river system and watershed in Puget Sound
- Four native Indian Tribes
- ~30% of freshwater draining into Puget Sound
- 394 glaciers
- Precipitation: 50” at mouth; > 140” ridge tops
- Parts designated wild and scenic
- All 5 species of Pacific Salmon (largest producer of wild salmon in Puget Sound ; it produces 60% of wild Chinook salmon in the Sound and is the largest run of Chum in the lower 48 states)
- Bald eagles, waterfowl, shorebirds, raptors
- Intertidal/delta critical for salmon, ESA, agriculture
- Most upland private timber, US Forest Service
- Lowland highly developed for urban and agriculture

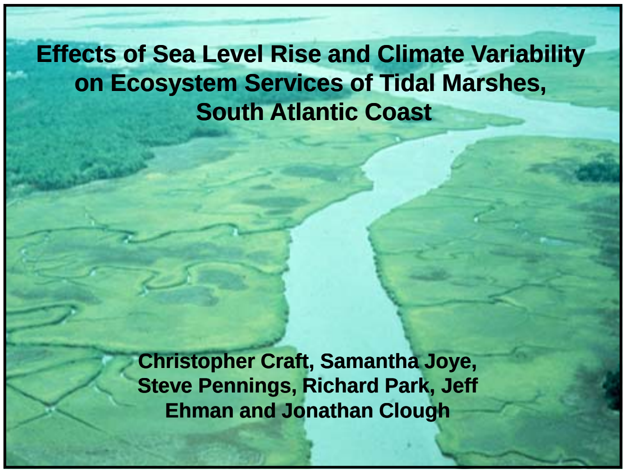
Slide Credit: Univ of Washington, Seattle City Light and others

Current EPA climate related grants

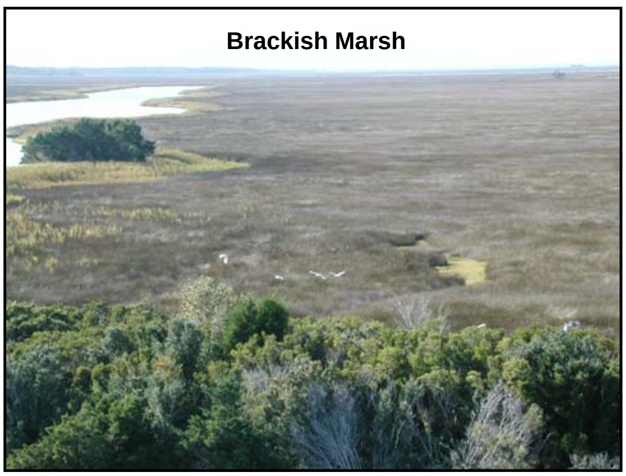
- **3 EPA grants: @ $2,300,000**
- **Other grants, investments: $800,000+**
- **In-kind and matching**
- **Total current investments**


Skagit
Drainage Basin
Bellingham
Mount Vernon
Oak Harbor
Arlington
Marysville
Legend

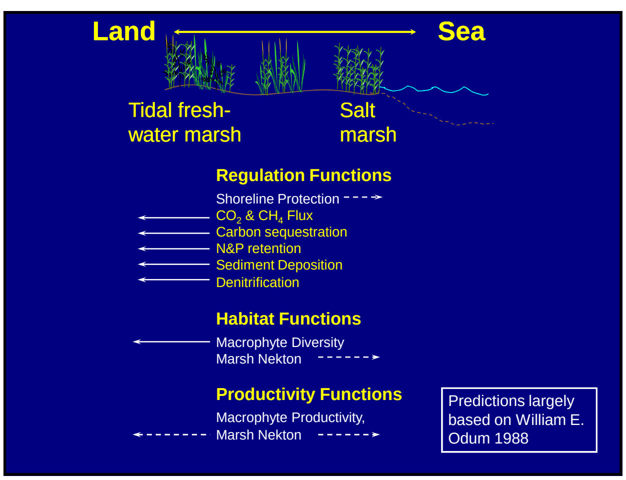

LEGEND
SKAGIT DRAINAGE BASIN
5TH FIELD WATERSHEDS (LABELED IN GREEN)
PRIMARY RIVERS
LIGHTNING CREEK
ROSS LAKE
BAKER RIVER
SKAGIT RIVER/ GORGE LAKE
RUBY CREEK
SKAGIT RIVER/ DIOBSUD CREEK
SAMISH RIVER
MIDDLE SKAGIT RIVER/ FINNEY CREEK
SKAGIT RIVER/ ILLABOT CREEK
CASCADE RIVER
LOWER SKAGIT RIVER/ NOOKACHAMPS CREEK
LOWER SUIATTLE RIVER
LOWER SAUK RIVER
UPPER SUIATTLE RIVER
UPPER SAUK RIVER
WA
OR


Effects of Sea Level Rise and Climate Variability on Ecosystem Services of Tidal Marshes, South Atlantic Coast
Christopher Craft, Samantha Joye, Steve Pennings, Richard Park, Jeff Ehman and Jonathan Clough


Salt Marsh


Brackish Marsh


Tidal Freshwater Marsh


Land
Sea
Tidal fresh-water marsh
Salt marsh
Regulation Functions
Shoreline Protection
CO_2 & CH_4 Flux
Carbon sequestration
N&P retention
Sediment Deposition
Denitrification
Habitat Functions
Macrophyte Diversity
Marsh Nekton
Productivity Functions
Macrophyte Productivity,
Marsh Nekton
Predictions largely based on William E. Odum 1988


Climate Change = Rising Sea Level

Project Goal

Develop a conceptual model that describes how tidal marsh ecosystem services vary along the salinity gradient and a simulation model of how sea level rise and climate variability will affect the delivery of ecosystem services.

Hypotheses

- Rising sea level (RSL) leads to inundation and loss of tidal marshes, especially tidal freshwater marshes and their ecosystem services.
- Diking protects freshwater marshes against RSL. But, when marshes are diked, ecosystem services associated with connectivity are lost.
- Greater inter-annual variability of climate leads to greater frequency of drought and reduction in ecosystem services in drought years. Greater variability in rainfall leads to increased delivery of ecosystem services in wet years.

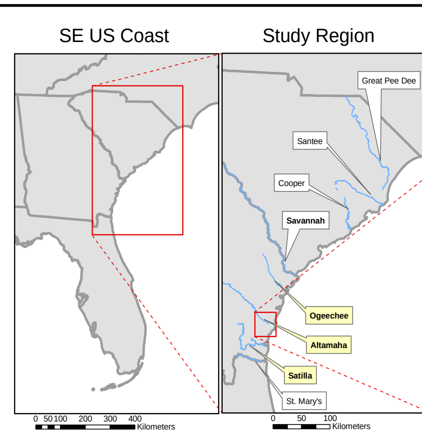
How will accelerated sea level rise (SLR) affect the area and spatial distribution of tidal marshes AND their delivery of ecosystem services?

Wetland Habitat

- Reduced salt and brackish marsh habitat
- Near complete loss of tidal freshwater marsh
- Increased submerged land

Ecosystem Services

- Reduced regulation functions (shoreline protection, carbon sequestration, *N&P retention*, *denitrification*, sediment deposition, greater CH_4 & CO_2)
- Reduced habitat functions (plant diversity, migratory songbird habitat)
- Reduced production functions (*plant productivity*, marsh nekton, commercial shrimp yield)



Measurement of Ecosystem Services

Three estuaries:

- Altamaha
- Ogeechee
- Satilla

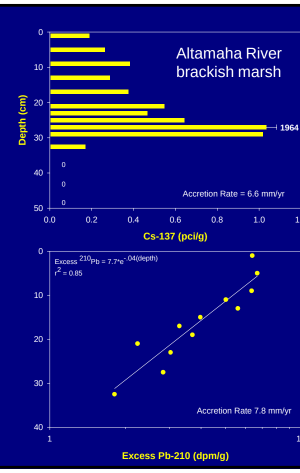
Three marsh types:

- Tidal fresh
- Tidal brackish
- Tidal salt

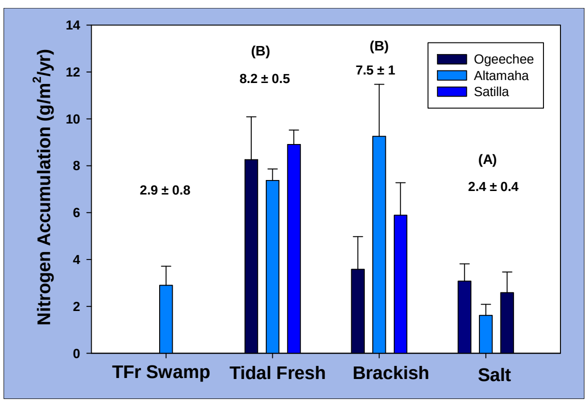
3 estuaries / 3 marsh types / 2 sites, n=18 sites

Measurement of Ecosystem Services:

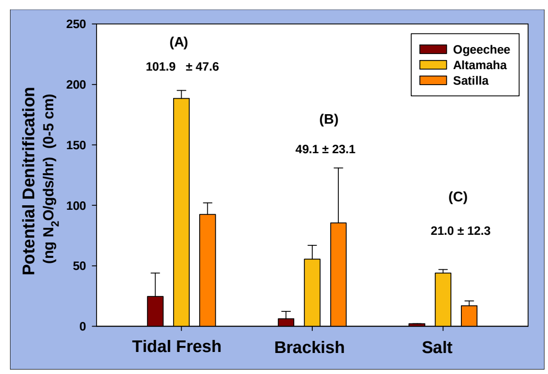
Nitrogen Accumulation in Soil as an Example



Nitrogen Accumulation in Soil



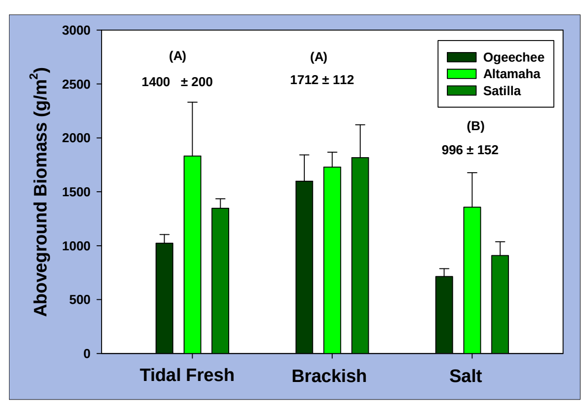
Potential Denitrification



Potential Denitrification (g N/m^2/yr)

Tidal fresh marsh	**6.6 ± 2.7**
Brackish marsh	**4.6 ±2.3**
Salt marsh	**1.7 ± 1.1**

Aboveground Biomass

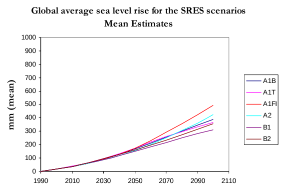


SLAMM Version 5 (beta)
(Sea Level Affects Marshes Model)

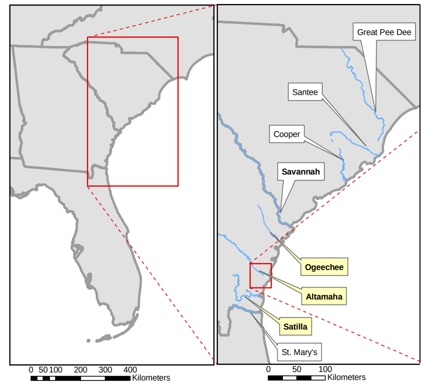
SLAMM uses elevation, NWI, tide range, historic sea level rise and site-specific accretion rate data to parameterize the model.

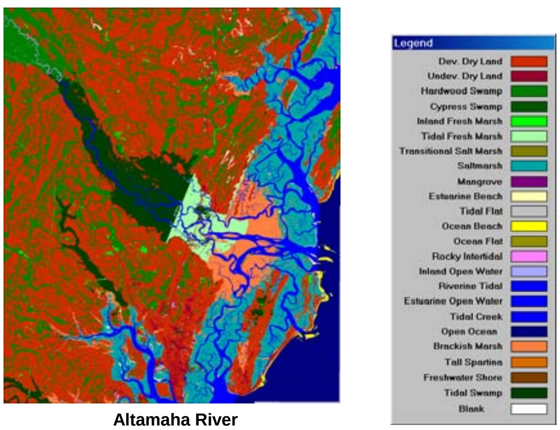
A salinity algorithm is used to simulate saltwater intrusion into river-dominated estuaries as sea level rises.

The simulation is run using A1B SRES (mean, max) scenario.

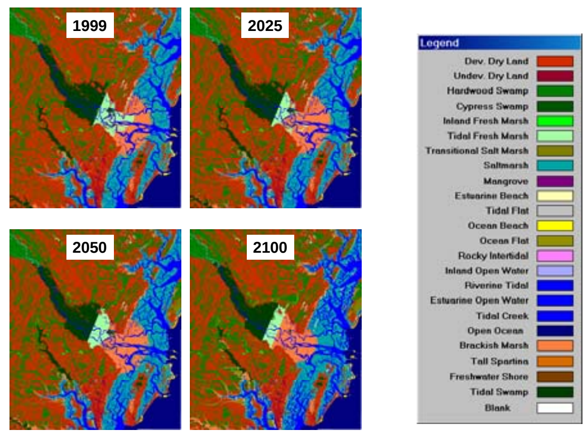


The Altamaha River Estuary (Georgia) as an Example

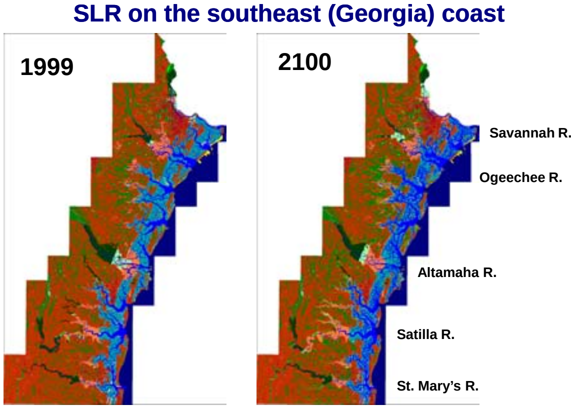




Altamaha River
(1999)



SLAMM simulation of the effects of accelerated SLR on the southeast (Georgia) coast



SLAMM simulation of the effects of accelerated SLR (A1B mean = 52 cm) on (wet)land cover types the Georgia coast

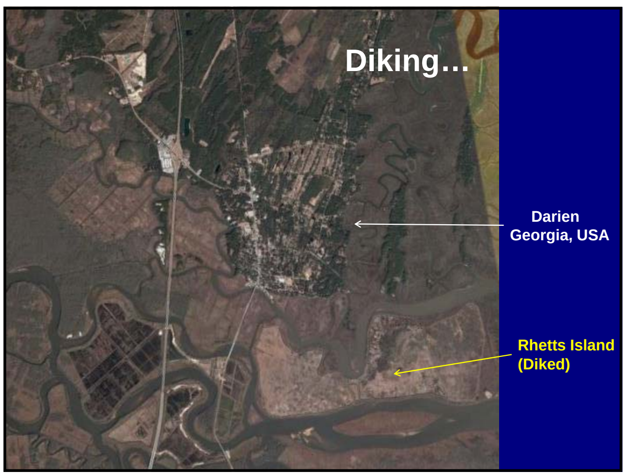
	Initial Condition (km^2)	Year 2100 (km^2)	Loss (%)
Dry land	5008	4385	12
Non-tidal swamp	1838	2089	(+14)
Inland fresh marsh	64	65	(+2)
Tidal fresh swamp	413	316	24
Tidal fresh marsh	79	80	(+2)
Brackish marsh	417	458	(+10)
Salt marsh	1116	890	20
Transitional salt marsh	32	254	(+680)
Tidal flat	11	26	(+150)
Estuarine open water	742	1091	(+47)

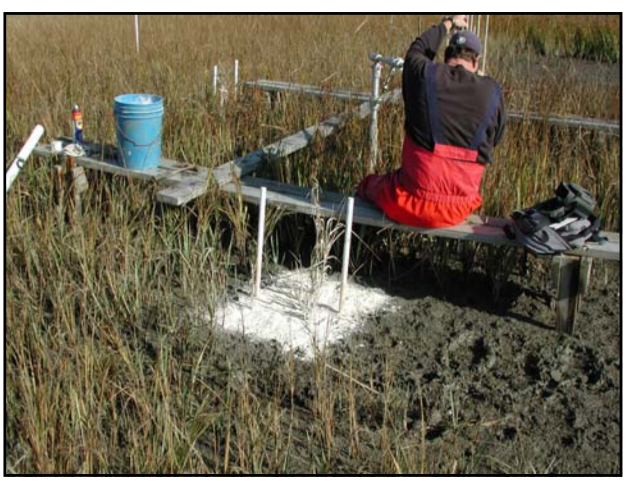
Landscape-scale (Georgia coast) N Accumulation in Soil and Denitrification (A1B mean = 52 cm)

	Wetland Change (km^2)	N MT/yr	Denitrification MT/yr
Tidal fresh	+1	+ 8	+7
Brackish	+41	+307	+184
Salt marsh	-226	-542	-384
Cumulative	-184	-227	-193
	-12%	-4%	-4%

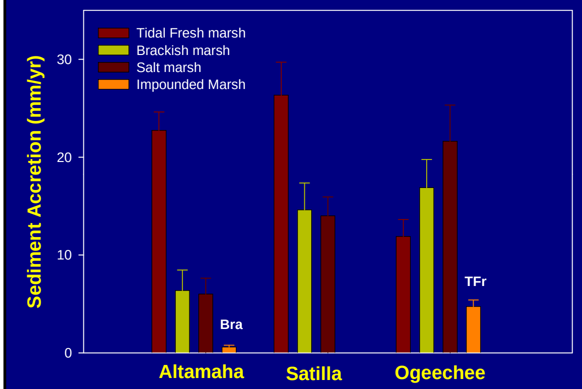
Landscape-scale (Georgia coast) N Accumulation in Soil and Denitrification (A1B max = 82 cm)

	Wetland Change (km^2)	N MT/yr	Denitrification MT/yr
Tidal fresh	-32	-262	-211
Brackish	-4	-30	-18
Salt marsh	-496	-1188	-843
Cumulative	-532	-1482	-1072
	33%	23%	25%





Sediment Accretion Atop Feldspar Marker Layers



Correlations of *Spartina alterniflora* aboveground biomass with temperature, precipitation, discharge, and salinity (2000-2006).

	Location	Temperature (prior 6 mo.)	Precipitation (prior 6 mo.)	Discharge (prior 6 mo.)	Salinity (prior 6 mo.)
Spartina alterniflora aboveground biomass	Plain	- r = - 0.032 p = 0.453	+ 0.158 0.002	+ 0.190 < 0.0005	- - 0.356 < 0.0005
	Levee	- -0.145 0.002	+ 0.032 0.424	+ 0.395 <0.0005	- -0.176 0.002
	All	- - 0.095 0.005	+ 0.055 0.138	+ 0.276 <0.0005	- - 0.251 <0.0005

Correlations of crab hole density with temperature, precipitation, discharge, and salinity (2001-2005).

	Location	Temperature (prior 6 mo.)	Precipitation (prior 6 mo.)	Discharge (prior 6 mo.)	Salinity (prior 6 mo.)
Crab hole density	Plain	- r = - 0.084 p = 0.117	- - 0.071 0.176	+ 0.077 0.148	+ 0.130 0.035
	Levee	+ 0.110 0.040	+ 0.141 0.008	- - 0.179 0.001	+ 0.336 ≤ 0.0005
	All	+ 0.0 0.780	+ 0.0316 0.399	- - 0.0447 0.202	+ 0.239 ≤ 0.0005

Correlations of sediment deposition with temperature, precipitation, discharge, and salinity (2001-2006).

	Location	Temperature (prior 6 mo.)	Precipitation (prior 6 mo.)	Discharge (prior 6 mo.)	Salinity (prior 6 mo.)
Sediment deposition (Feldspar markers)	All	- r= - 0.202 p= 0.250	+ 0.230 0.189	+ 0.366 0.033	+ 0.045 0.796

Lessons Learned

- Different types of tidal marshes provide different levels of ecosystem services.
- Tidal fresh- and brackish-marshes have greater aboveground biomass, N retention in soil and denitrification than salt marshes.

Lessons Learned (continued)

- Climate change (sea level rise - SLR) will promote salt water intrusion and submergence, leading to habitat conversion and loss of tidal marshes, especially those at either end of the salinity gradient.
- Wetland loss may not be a great as predicted because spatial models lack positive feedback mechanisms that enable marshes increase surface elevation.

Lessons Learned (continued)

- Dikes, while protecting tidal marshes, leads to loss of connectivity to estuarine waters and the ecosystem services that depend on connectivity.
- Tidal marsh ecosystem services are more strongly correlated with variation in salinity, driven by river discharge, than by variation in temperature and precipitation.

Challenges

- Difficulty in evaluating ecosystem services of fauna/wildlife (fishes, birds).
- Difficulty working with subcontractors (esp. consultants).

Interaction with Clients

- **The Nature Conservancy**

  (Sea level rise (SLR) modeling of the Altamaha River Bio-reserve and elsewhere in coastal Georgia)

- **US Fish & Wildlife Service**

  (SLR modeling of National Wildlife Refuges in Georgia and South Carolina)

Outcomes

- SLAMMView (Sea Level Affects Marshes Model)
  - An interactive web-based tool to visualize sea level rise.
  - Spatial domains include Georgia-South Carolina, parts of the Chesapeake Bay, Florida, & Puget Sound, Washington.
  - Used by US Fish & Wildlife Service refuges, The Nature Conservancy and National Wildlife Federation.
  - Developed by Image Matters LLC.
  - www.spea.indiana.edu/wetlandsandclimatechange; www.slammview.org
- New Projects
  - NOAA National Estuarine Research Reserve System
  - DOE National Institute for Climate Change Research
  - GCE LTER (Phase II)

Outcomes

- Three publications in 2009 including…

  Craft, C., J. Clough, J. Ehman, S. Joye, D. Park, S. Pennings, H.Guo and M. Machmuller. 2009. Forecasting the effects of climate change on tidal marsh ecosystem services. *Frontiers in Ecology and the Environment 7:73-78.*

- Three "in review"
- Three planned including…

  Summary paper in *Global Change Biology*.


Questions?

Climate-Linked Alteration of Ecosystem Services in Tidal Salt Marshes of Georgia and Louisiana

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Coastal Plant Ecology Laboratory
University of Louisiana at Lafayette

Irving A. Mendelssohn
Department of Oceanography and Coastal Sciences
Louisiana State University

Merryl Alber
Samantha B. Joye
Department of Marine Sciences
University of Georgia

Funding provided by US EPA STAR

Outline

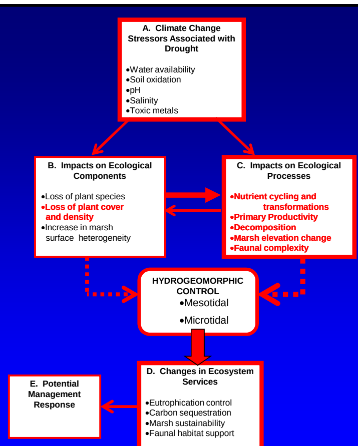
- Introduction
- Project Goals*
- Approach
- Lessons Learned/Challenges*
- Results
- Key Findings
- Interactions with Clients*
- Outcomes*

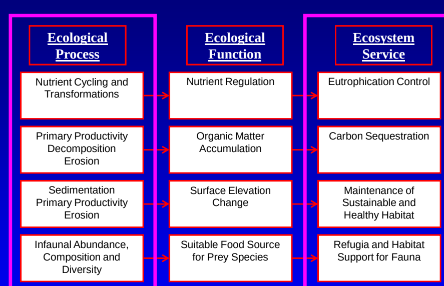
Introduction

- Drought-induced sudden salt marsh dieback of *Spartina alterniflora* tidal salt marshes
  - Louisiana (2000-2001)
  - Georgia (2001)
  - Reported in several other coastal states since
- Potential for drastic alteration of ecosystem services
  - Driven by decrease in *S. alterniflora* living stem density
  - Directly linked to degree loss of ecosystem processes

Project Goals*

- Elucidate the effects of climate change (increased drought severity) on tidal salt marsh ecosystem services
  - Eutrophication control
  - Carbon sequestration
  - Sustainable habitat
  - Faunal support
- Two hydrogeomorphic settings
  - Louisiana (microtidal)
  - Georgia (mesotidal)
- Develop exploratory Structural Equation Model (SEM)
  - Causal relationships
    - Between *S. alterniflora* stem density
    - Measurable Ecosystem Processes
  - Ecosystem Service latent variables (Ecosystem Processes)





Relationships between tidal marsh ecological processes, ecological functions, and ecological services
(Definitions according to de Groot et al. 2000)

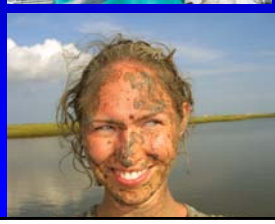
Experimental Approach

- Manipulative field experiment of *Spartina alterniflora* plant density in micro- and mesotidal salt marsh ecosystems (Main Plots)
  - Louisiana (Caminada-Moreau Headland)
  - Georgia (Sapelo Island)
- Identify 6 dieback areas (Blocks) within each state for establishment of large research plots
  - 24 plots per state
  - Each plot 8.0-m x 7.5-m
  - 4 vegetated conditions
    - Bare
    - Low *Spartina alterniflora* stem density
    - High *Spartina alterniflora* stem density
    - Reference (unimpacted) marsh
- Series of specific a-priori, process-driven hypothesis testing (univariate and multivariate)
- SEM (Structural Equation Modeling) to reveal relationships between stem density, ecosystem processes, and ecosystem services

Lessons Learned/Challenges*

It seemed so easy on paper . . .



Challenges:

Hurricane Katrina
August 29, 2005

Hurricane Gustav
August 31, 2008

Challenges:

Hurricane Katrina
August 29, 2005

Hurricane Gustav
August 31, 2008

Louisiana Study Sites

Challenges:

Prolonged Drought in Georgia

Lessons Learned/Challenges*

- Hurricane Katrina
  - Damage to UNO, resultant resignation
  - Contract novation to UL
    - Long delays in re-establishment of prime and subcontracts
    - ~18 months without contract
    - Issues with team morale
- Prolonged drought in Georgia
  - Affected achieving target plant densities (covariable)
  - Scientific benefit of additional sudden salt marsh dieback in 3rd year (2008) in established plots
- Improved communication of rigors of large manipulative experiments
  - With co-PIs prior to committing to proposal
  - During budgeting, setup, and adaptive responses
- Personnel changes at LSU and UGA; UNO to ULL
  - Required continued effort in management and continuity
  - Maintaining (managing?) enthusiasm during adversity
- Adaptive management is a necessary (and expected) component
- Climate variability

Louisiana EPA Climate-Change Sites

Planting in Louisiana

Louisiana EPA Climate-Change Sites May 2007

Low-Density Planting

High-Density Planting

Louisiana Summer 2008

Louisiana December 2008

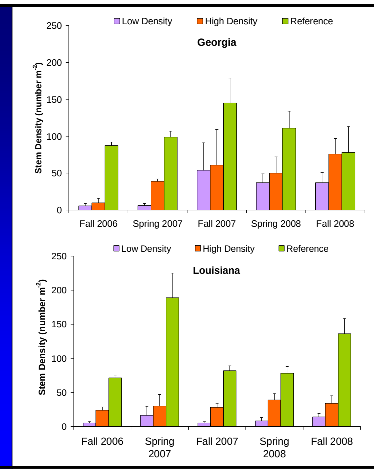
Louisiana December 2008

Results

Aboveground Primary Productivity and Carbon Assimilation

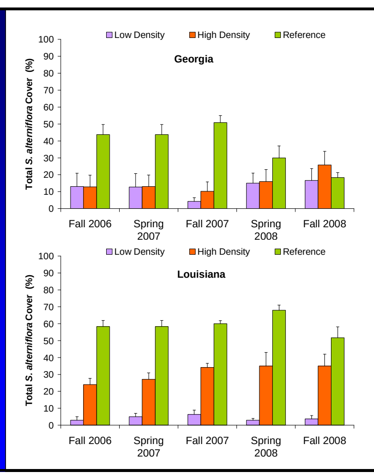
Spartina alterniflora Stem Densities

- Gradient of stem density treatments established in each state by 2007



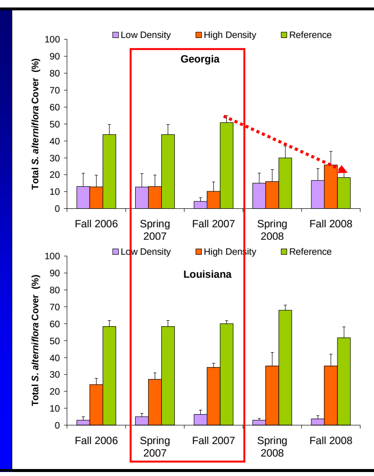
Spartina alterniflora Cover

- Cover reflected stem densities
- Desired gradient in Louisiana



Spartina alterniflora Cover

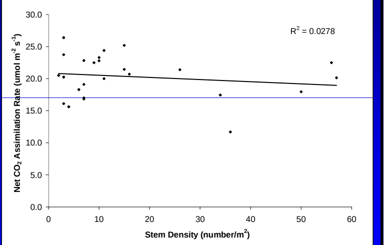
- Cover reflected stem densities
- Desired gradient in Louisiana
- New dieback occurred in 2008 in 3 Georgia Reference plots



Additional Experiment

- Natural variation in stem density
- In (dynamic) equilibrium with resource supply
- Overall non-significant differences in C assimilation rates

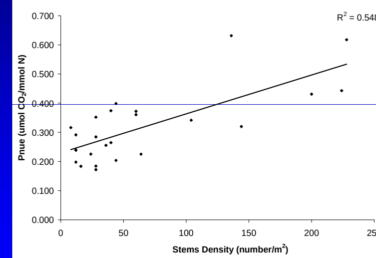
Non-significant effect of stem density on net CO_2 assimilation



Additional Experiment:

- Higher density *Spartina* more efficient utilization of leaf N for C assimilation

Highly significant effect of stem density on PNUE



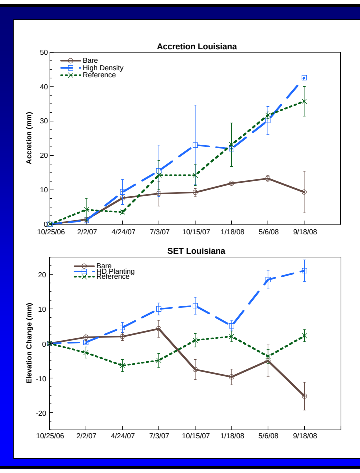
Sediment Accretion & Net Marsh Surface Elevation Change

Louisiana Accretion & Net Elevation Change

High Density plots had equivalent accretion rates to Reference plots

High Density plantings increased surface elevation

Bare plots had lower accretion rates and lost elevation



Georgia Accretion & Net Elevation Change

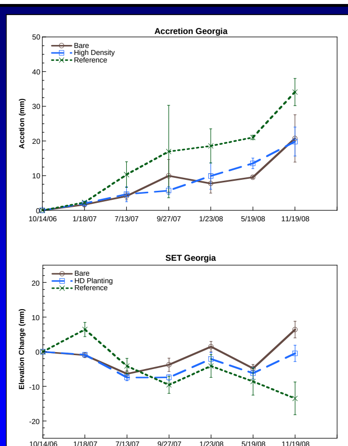
Reference plots had greatest accretion rates

High Density & Bare plots had lower but equivalent accretion rates

Reference plots are losing elevation over time

accelerated loss following 2008 new dieback(?)

feedbacks on marsh surface elevation (?)



Belowground Productivity & Decomposition

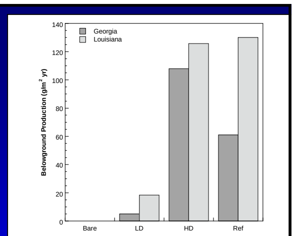
Belowground Productivity & Decomposition

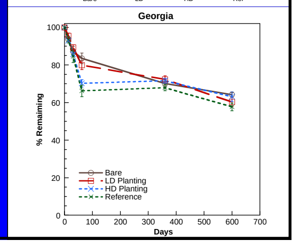
High Density and Reference Plots had equivalent belowground productivity rates

Litterbag decomposition

Reference and High Density initially higher decomposition rates

No significant differences after >400 days





Biogeochemistry

Cyanobacteria mats

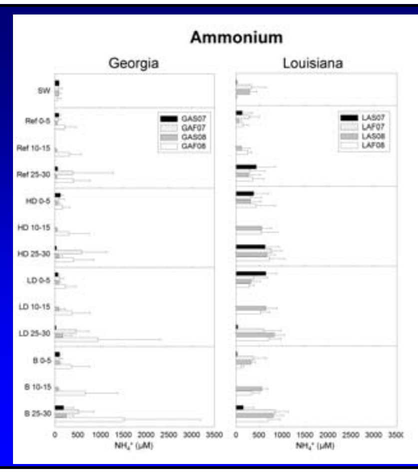
In Louisiana plots (Diatoms only in Georgia)

Most abundant in low density and bare plots

Potential for shift from detrital to grazing food web

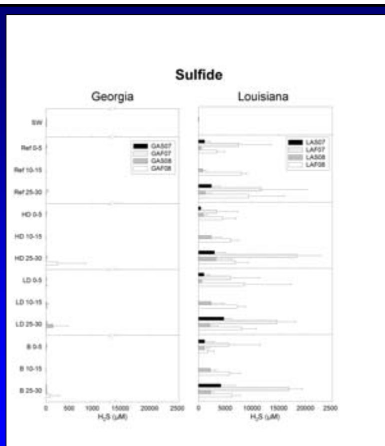
Interstitial Ammonium

- Much greater ammonium in Louisiana
- However, no consistent pattern with stem density



Interstitial Sulfides

- Much greater in Louisiana
- Often below detection in Georgia
- Sulfides can inhibit plant uptake of NH4
- May be less tight coupling of plant C & N relations in Louisiana

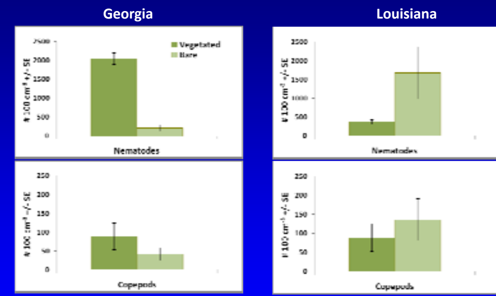


Secondary Productivity

Meiofauna species

Taxa		GA	LA
Nematoda	**Nematodes**	+	+
Annelids			
	Oligochaeta	+	+
	Polychaeta (Sabellidae)	-	+
Crustacea			
	Copepoda	+	+
	Ostracoda	+	+
	Arthropod nauplii	+	+
	Crab zoea	+	-
Molluscs			
	Geukensia	+	-
	Hydrobiidae	+	-
Insects			
	Ceratopogonidae	+	+
	Collembola	-	+
	Acari	-	+
Other			
	Kinorhyncha	+	-
	Foraminifera	-	+

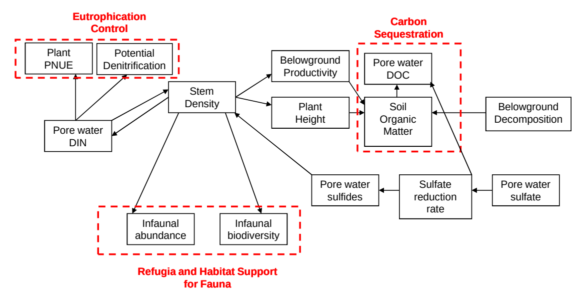
Meiofauna Abundance



- In Georgia, increase in vegetated areas.
- In Louisiana, increase in bare areas.
- Nematodes larger in vegetated treatments in GA; no difference in nematode size in LA or copepod size in either state

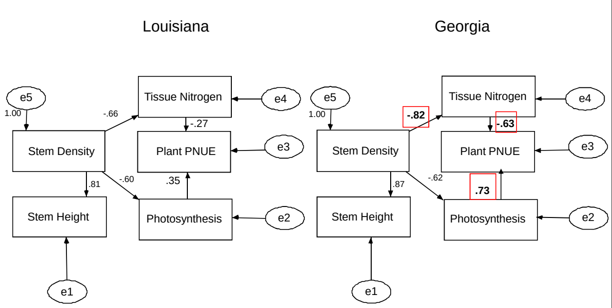
Exploratory Structural Equation Model

Exploratory SEM of *Spartina alterniflora* Stem Density on Ecosystem Processes & Services



Will be a 2-Group Model: LA and GA

Differences between Louisiana and Georgia in Relative Strength of Relationships Determining Photosynthetic N-Use Efficiency



Key Findings

- Climate change (severe drought) can affect a suite of ecosystem services
- Density of *Spartina alterniflora* important driver of many ecosystem services across hydrogeomorphic setting
- Hydrogeomorphic setting important modulator of ecosystem processes and services
  - Altered patterns of carbon sequestration, eutrophication control
    - carbon assimilation
    - N-use, N cycling
    - S transformations
  - Sustainable habitat and faunal support
    - Sediment accretion
    - Net elevation change
    - Feedbacks on marsh surface elevation

Interactions with Clients*

- Louisiana
  - LUMCON (Louisiana Universities Marine Consortium)
  - Burlington Land
    - Permission to establish plots and infrastructure
  - Louisiana Department of Natural Resources
- Georgia
  - Georgia Department of Natural Resources
  - University of Georgia Marine Institute

Interactions with Clients*

7 Presentations Directly Resulting from this Project

- Hester, M. W., I. A. Mendelssohn, M. Alber, and M. Joye. Influence of *Spartina alterniflora* stem density on salt marsh ecosystem services. Coastal and Estuarine Research Federation 20th Biennial Conference. Invited session: Tipping Points in Wetlands. Portland, Oregon. (*Upcoming: November 1– 5, 2009*).
- Hester, M. W., I. A. Mendelssohn, M. Alber, and M. Joye. Climate-linked alteration of ecosystem services in meso- and micro-tidal salt marshes of the southeastern United States. 10th International Congress of Ecology. *Upcoming: August 16-21, 2009*. Brisbane, Australia.
- Baustian, J., I. A. Mendelssohn, and M. W. Hester. Remediating the effects of sudden marsh dieback through vegetative plantings: impacts on elevation change and belowground processes. Society of Wetland Scientists 30th Annual Meeting. *Upcoming: June 21-26, 2009.* Madison, Wisconsin.
- Hester, M. W., I. A. Mendelssohn, M. Alber, and M. Joye. Climate-linked alteration of ecosystem services in tidal salt marshes of Georgia and Louisiana: preliminary findings. Estuarine Research Federation 19th Biennial Conference. Invited session: Climate Effects on Tidal Wetlands. Providence, Rhode Island. November 4 – 8, 2007.
- Hester, M. W., I. A. Mendelssohn, M. Alber, and M. Joye. 2007. Climate-linked alteration of ecosystem services in tidal salt marshes of Georgia and Louisiana: preliminary findings. Estuarine Research Federation 19th Biennial Conference. November 4-8, 2007. Providence, R.I.
- McFarlin, C., B. Kennemer, M. Alber, M. W. Hester, and D. Bishop. 2007. A comparison of dieback effects on salt marsh invertebrates in Georgia and Louisiana. Estuarine Research Federation 19th Biennial Conference November 4-8, 2007. Providence, R.I.
- Joye, S. B., K. S. Hunter, M. Bernier, I. A. Mendelssohn, M. Alber, and M. W. Hester. 2007. Climate-linked alteration of ecosystem services in tidal salt marshes of Georgia and Louisiana. Poster presented at 10th International Symposium on Wetlands Biogeochemistry. April 1-4, 2007. Annapolis, Maryland.

Interactions with Clients*

Synergistic Activities Related to this Project

Publications Related to this Project

- Alber, M., E.M. Swenson, S.C. Adamowicz, and I.A. Mendelssohn. 2008. Salt marsh dieback: an overview of recent events in the US. Estuarine Coastal and Shelf Science 80 (1): 1-11.

Media Coverage Related to this Project

- "*Georgia salt marshes healthy for now*" The Darien News. December 2007.
- "*Salt marsh still drought sensitive*." The Savannah Morning News. November 2007.
- *"Drought, what drought?*" The Savannah Morning News. October 2007.
- "*Cause sought as marshes turn into barren flats*" Boston Globe. July 2006.

Interactions with Clients*

Another 7 Presentations Related to this Project

- Hester, M. W. A question of balance: Management insights from plant C and N allocations. Society of Wetland Scientists 30th Annual Meeting. Symposium: Physiological Ecology of Wetlands: Translating Process-based Studies into Important Management Insights. Madison, Wisconsin. (*Upcoming: June 21 – 26, 2009*).
- Alber, M., J. MacKinnon, D. Hurley, and M.C. Curran. 2007. Salt marsh dieback in Georgia. Estuarine Research Federation 19th Biennial Conference. November 4-8, 2007. Providence, R.I.
- Mendelssohn, I. A., M. Alber, E. Swenson, and S. Adamowicz. 2007. Sudden salt marsh dieback: a synthesis. Estuarine Research Federation 19th Biennial Conference. November 4-8, 2007. Providence, R.I.
- Alber, M. 2006. Salt marsh dieback in Georgia. Sudden wetland dieback meeting. May 2006. Wellfleet, MA.
- Alber, M. 2006. Losses of foundation species and the consequences for ecosystem structure and function. Working group at the LTER All Scientists Meeting. September 2006. Estes Park, CO.
- Alber, M. 2006. CSI Ecology: Salt marsh dieback in Georgia. September 2006. Univ. of Georgia Dept. of Geology.
- Kenemer, B., C. McFarlin, and M. Alber. 2006. Fiddler crabs dig it: A study of burrow dynamics in a salt marsh. Poster presented at the Southeastern Estuarine Research Society. October 2006. Savannah, GA.

Outcomes*

- Data in process of final integration
- Structural Equation Model
  - Valuable management tool
  - Key differences in strength of relationships
    - *Spartina alterniflora* density
    - Hydrogeomorphic setting
- Improved insights into climate variability
  - Future management and planning
    - Value of salt marsh habitat
    - Alteration of ecosystem services
  - State agencies (Louisiana & Georgia DNR)
  - Federal agencies (EPA, DOE, NOAA)
- Continued research opportunities
  - DOE NICCR
    - SEM confirmatory model of salt marsh ecosystem services
    - Expansion of SEM ecosystem services approach upslope
- Website: http//www.coastalplantecologylab.com

Acknowledgments

Irv Mendelssohn (LSU)
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Jane Buck (LSU)
Caroline McFarlin (UGA)
Ellery Mayence (UNO)
Jessica Hawke (UNO)
Sean Graham (LSU)
Theryn Henkel (UNO/Tulane)
Daniel Saucedo (UGA)
Jacob Shalack (UGA)
Bill Porubsky (UGA)
Megan 1 & 2 (UGA)
Jodie Noel (ULL)
Mike Dupuis (ULL)
Lauren Alleman (ULL)
Christine Pickens (ULL)

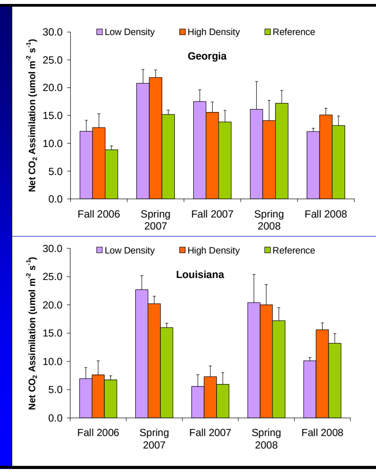
LUMCON
UGAMI

EPA STAR (especially Brandon Jones!)

‘Mais dat climate must be changin’ down here, Boudreaux! No joke, dem mangroves are ev’rywhere now, um humm . . .

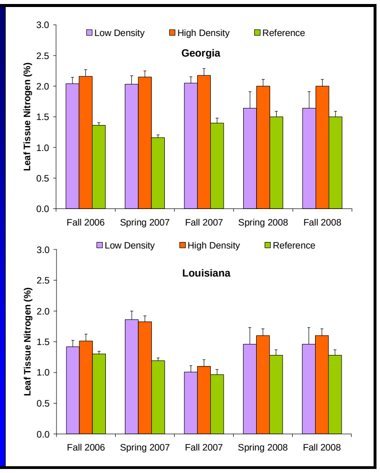
Spartina alterniflora Net CO_2 Assimilation

- Trend towards greater C assimilation rates in Low and High Density plots

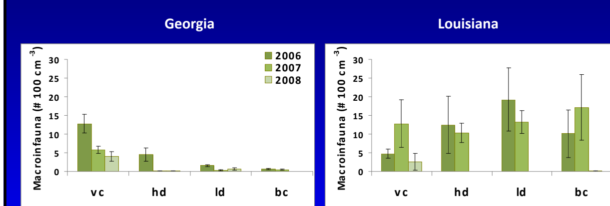


Spartina alterniflora Leaf N

- Often higher in Low and High Density plots
- Does not appear due to previous dieback
- What is the relationship between stem density, leaf N, and PNUE?



Macroinfauna Abundance



- In Georgia, increased macroinfauna in vegetated areas.
- In Louisiana, no clear trend with treatment.
- Some evidence for decreases over time
  - (GA – drought?: LA – Hurricane Gustav?)

Linking Impacts of Climate Change to Carbon and Phosphorus Dynamics Along a Salinity Gradient in Tidal Marshes

Nathaniel B. Weston[1], Melanie A. Vile[2], Scott Neubauer[3] & David Velinsky[4]

[1]Department of Geography and the Environment, Villanova University
[2]Department of Biology, Villanova University
[3]Baruch Marine Field Laboratory, University of South Carolina
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EPA – 24 May 2009

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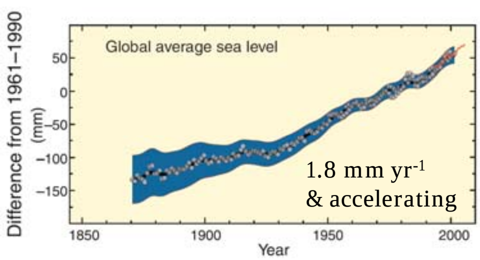
Environmental Protection Agency, STAR Program

Laboratory for Molecular and Systematic Ecology, Academy of Natural Sciences

Villanova Department of Biology

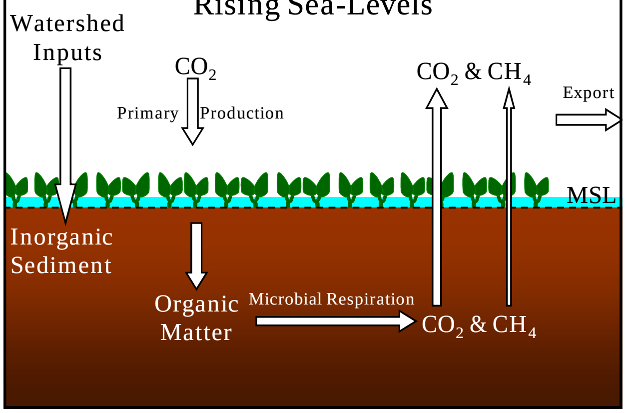
Sea Level Rise

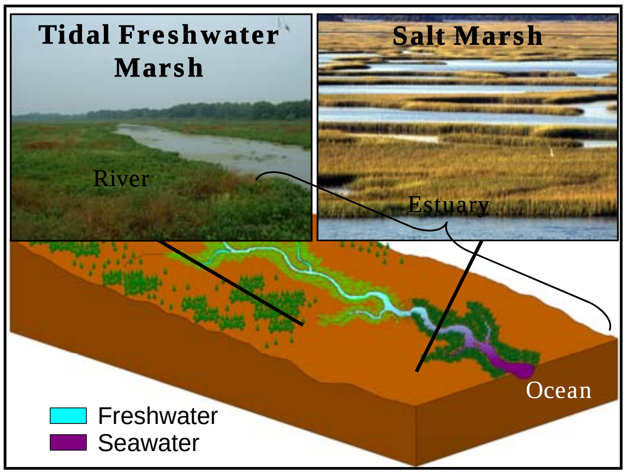


Intergovernmental Panel on Climate Change Fourth Assessment Report (2007)

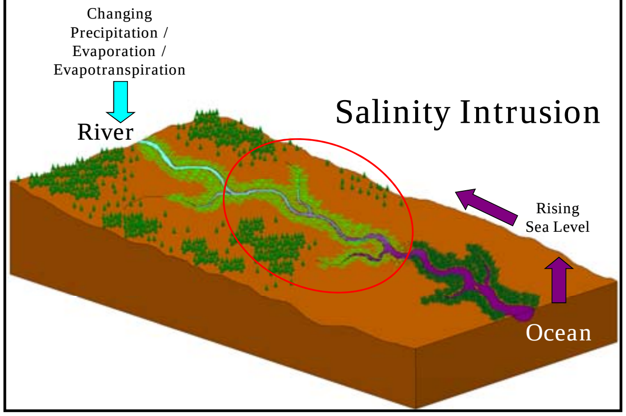
Coastal Tidal Marshes

Marshes Must Accrete to Keep Pace With Rising Sea-Levels





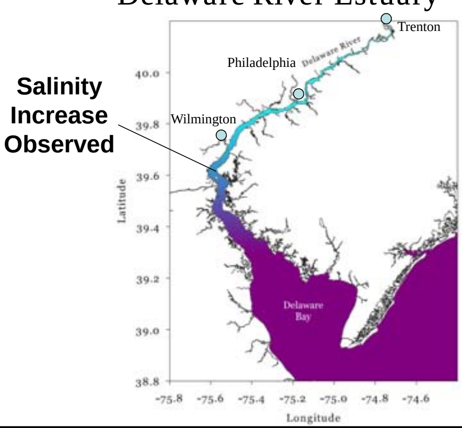
Estuarine / Marsh Coastal Ecosystem



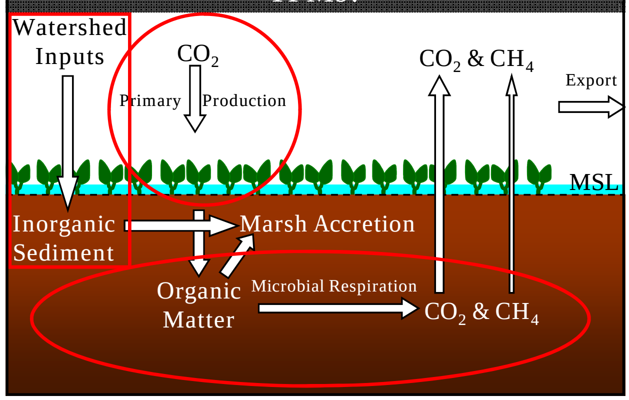
Project Goals

- Understand how salt water intrusion into TFMs will impact C, N and P cycling
  - Plant processes
  - Microbial processes
- Predict the response of TFMs and the ecosystem services they provide to scenarios of future climate change

Delaware River Estuary



What are the impacts of climate change on TFMs?



Microbial Respiration Processes

Freshwater Marshes:
Methanogenesis

$C_6H_{12}O_6 + 3\ H_2O \rightarrow 3\ CH_4 + 3\ HCO_3^- + 3\ H^+$

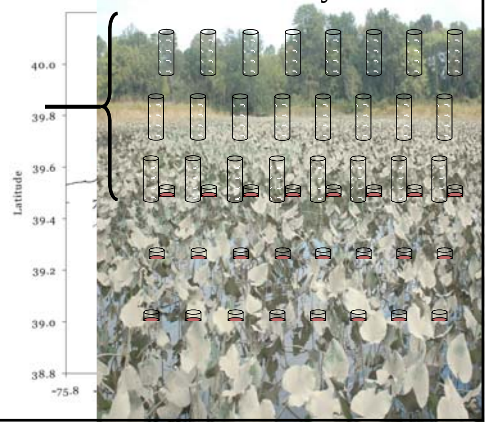
Microbial Respiration Processes

Salt Marshes:
Sulfate Reduction

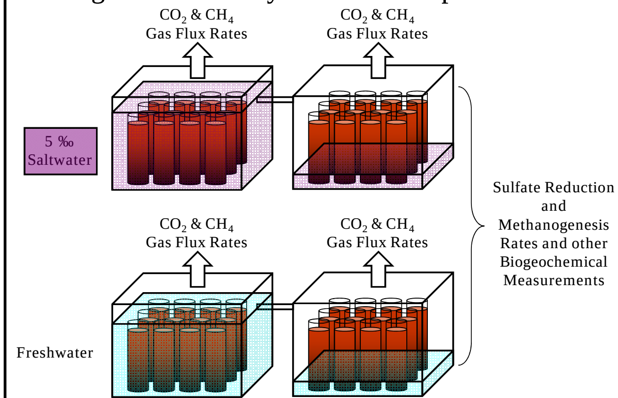
$C_6H_{12}O_6 + 3\ SO_4^{2-} \rightarrow 3\ HS^- + 6\ HCO_3^- + 3\ H^+$

Sulfate - Major constituent in seawater

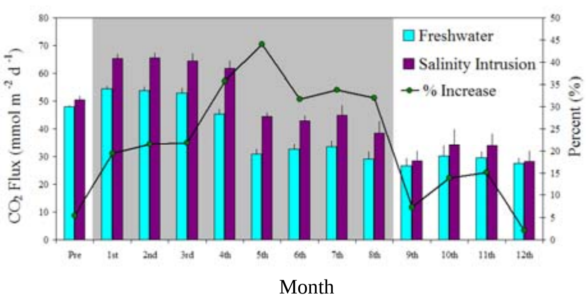
Delaware River Estuary



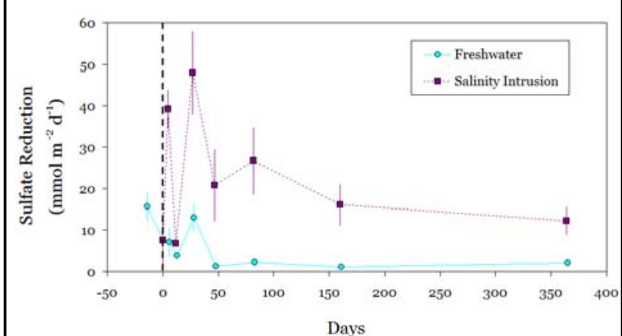
Long-Term Salinity Intrusion Experiment



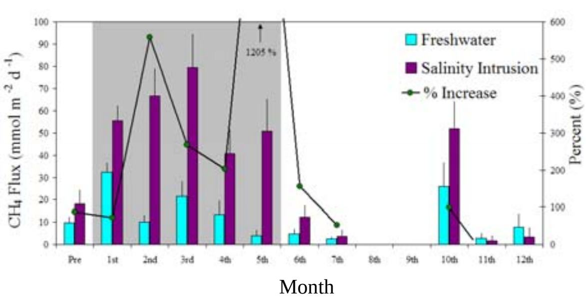
CO_2 Flux



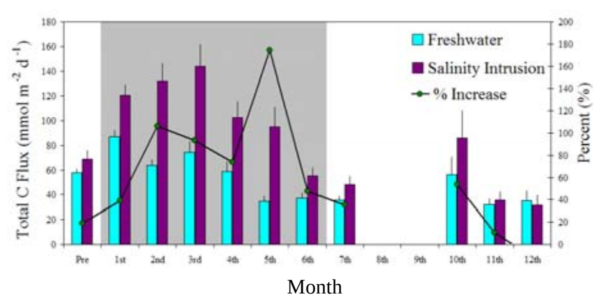
Sulfate Reduction Rates



CH_4 Flux

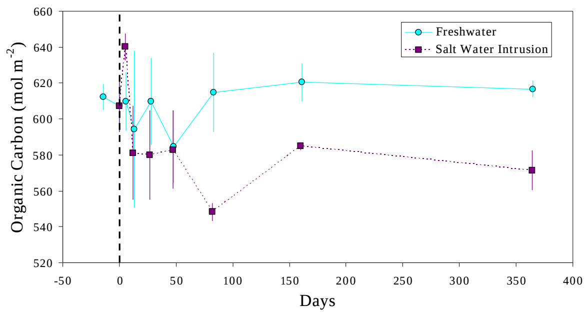


Total C Gas Flux

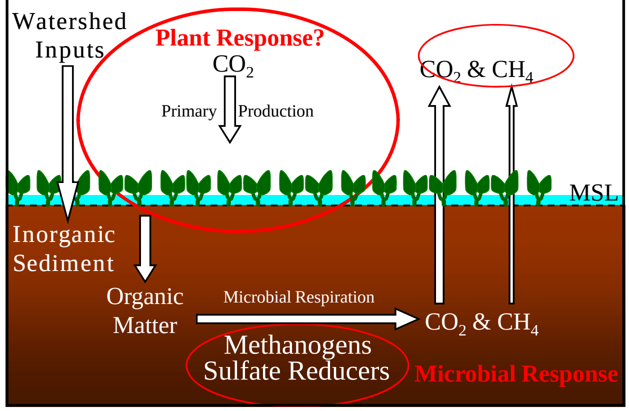


50% Higher C Flux over 1 Year

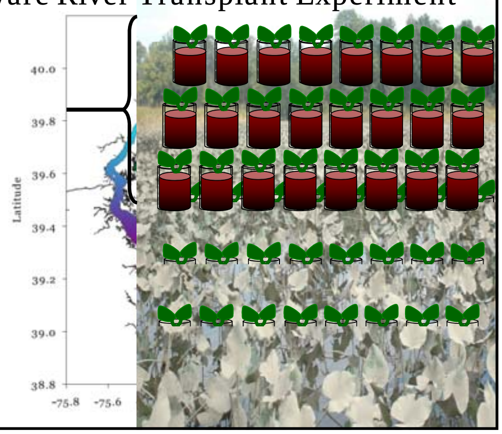
Soil Organic Carbon



Freshwater Marsh Undergoing Salinity Intrusion



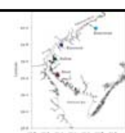
Delaware River Transplant Experiment

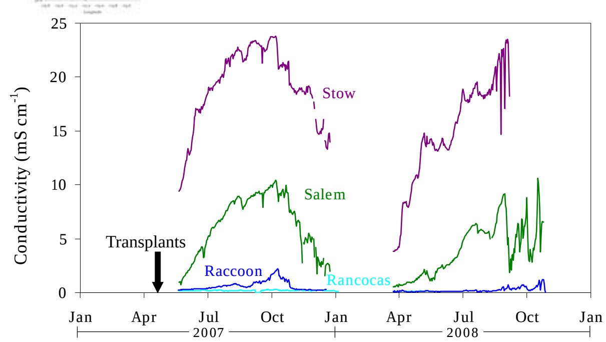


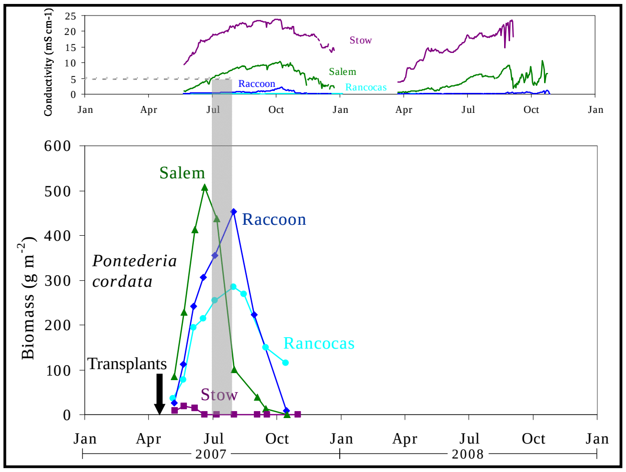
Delaware River Transplant Experiment

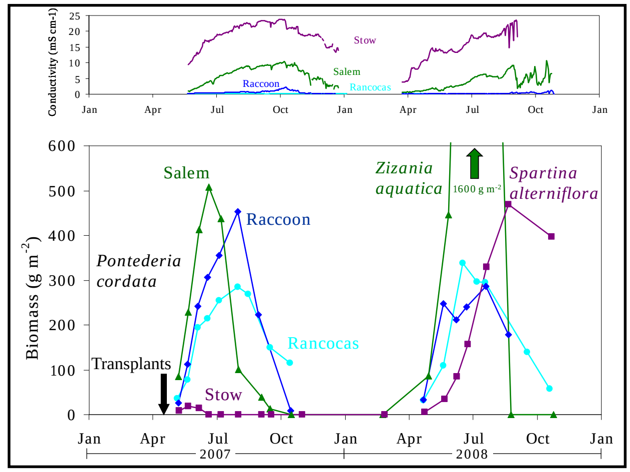
- Field Site Monitoring
- CO_2 and CH_4 flux
- Plant Biomass
- Microbial Rate Measurements
- Biogeochemistry
- Microbial Community Composition

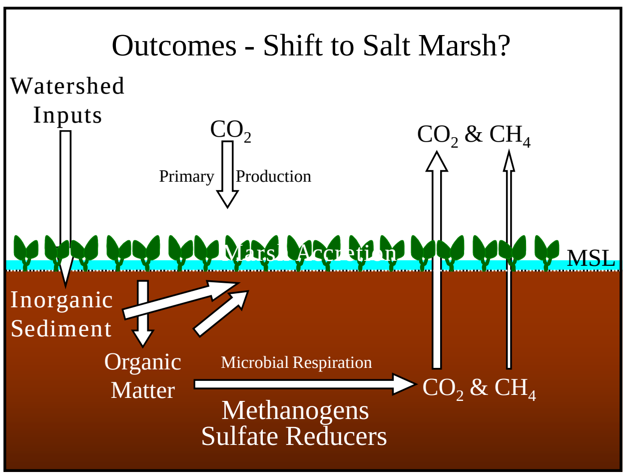
Delaware River Transplant Experiment - Conductivity







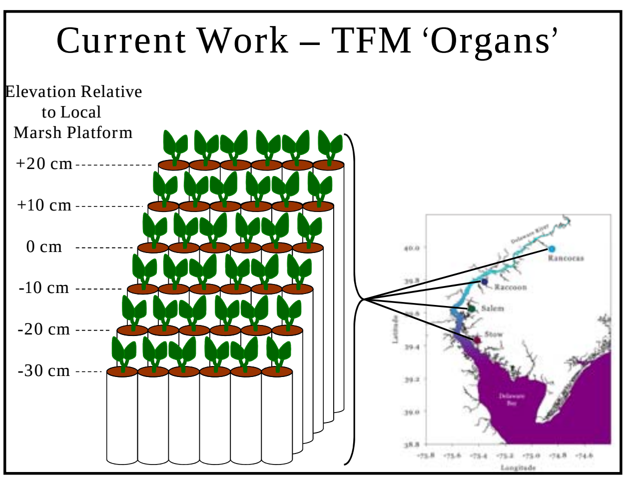


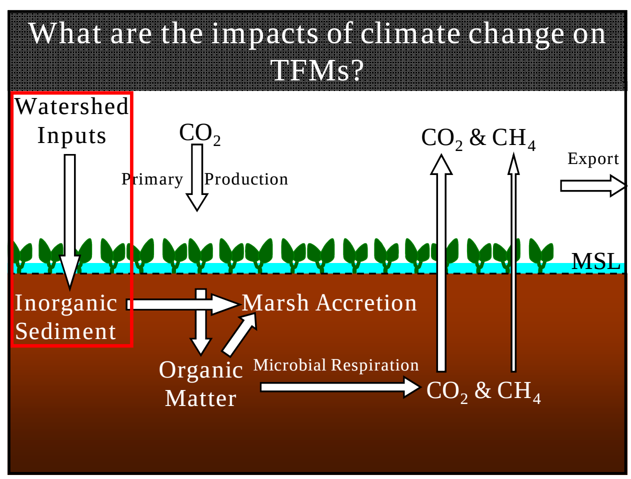


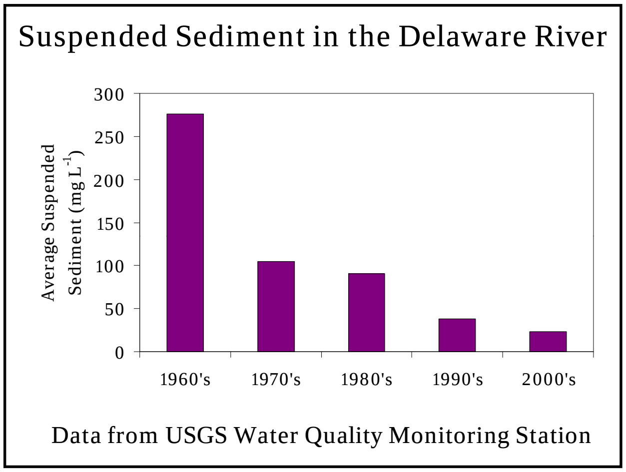
Response of Freshwater Marsh Plants to Salinity Intrusion and Inundation

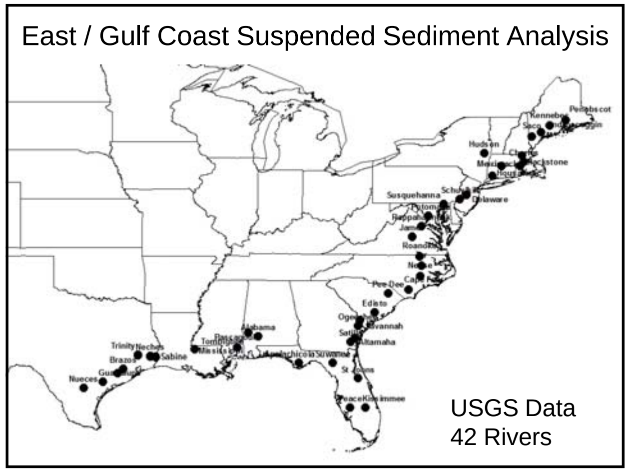
TFM Plant Biomass (g m^{-2}) =
– 10.8 [Conductivity (mS cm^{-1})]
+ 9.6 [Temperature (°C)]
– 1.4 [Inundation (cm)]
– 23.1

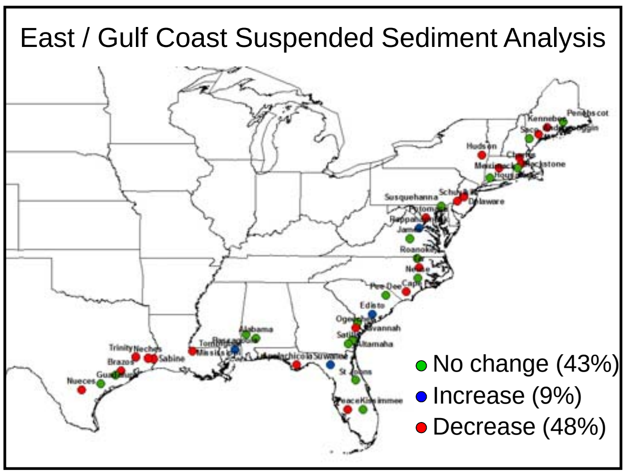
$R^2 = 0.37$; $p < 0.001$

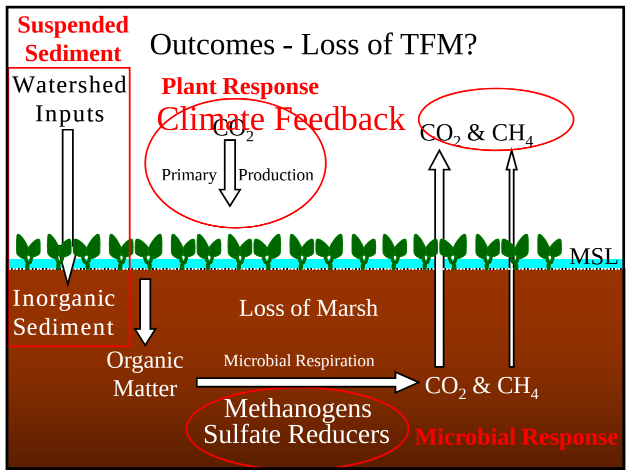












Challenges

- Controlling for marsh vertical elevation critical in field experiments
- Multiple TFM plant species (salt marshes are easy!)
- Understanding response of methanogens
- Complex, interconnected processes (plant, microbial, sedimentation, accretion)

Interaction with Clients

- Integration with ongoing work in other groups
  - Partnership for the Delaware Estuary
  - University of Delaware, Rutgers, DEP, EPA
- Communication with local stakeholders
  - Delaware Estuary Environmental Summit
  - Earth Day event
  - Field site interactions
- Communication at national meetings
  - Society of Wetlands Scientists
  - Estuarine Research Federation
  - American Society of Limnology and Oceanography


*Patrick Costello
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Oliva Gibb
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Paul Kiry
Chris McLaughlin
Avni Malhotra
*Justin Meschter
Stephen Mowbray
*Michael Patson
*Tatjana Prša
James Quinn
*Daniel Russo
*Mariozza Santini
Kimberli Scott
Roger Thomas
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(* - Undergraduate Student)
Environmental Protection Agency, STAR Program
Laboratory for Molecular and Systematic Ecology, Academy of Natural Sciences
Villanova Department of Biology

Connectivity in Marine Seascapes: Predicting ecological and socioeconomic costs of climate change on coral reef ecosystems

---

Climate change and coral reef ecosystems

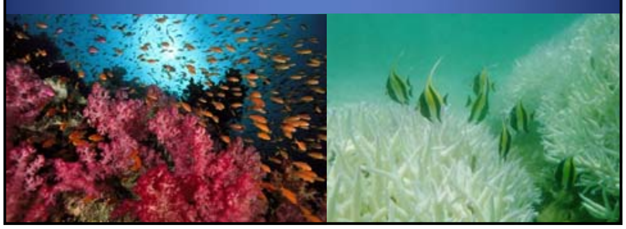
Team

- James N. Sanchirico (Resources for the Future)
  - Julie B. Kellner (post-doc)
- Kenneth Broad (University of Miami)
- Dan Brumbaugh (American Museum of Natural History)
- Alan Hastings (University of California, Davis)
- Fiorenza Micheli (Stanford University)
  - Steven Y. Litvin (post-doc)
- Peter J. Mumby (Exeter University)
  - Helen J. Edwards (post-doc)

<u>Project Information:</u>

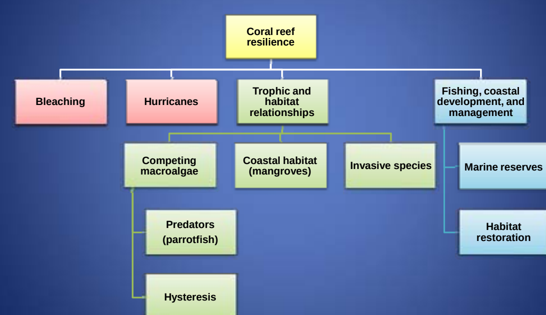
- Research Category and Sorting Code: Effects Of Climate Change On Ecosystem Services Provided By Coral Reefs and Tidal Marches, 2004-STAR-J1
- Project Period: March 1, 2005 – February 28, 2008

The deteriorating health of the World's coral reefs threatens global biodiversity, ecosystem function, and the livelihoods of millions of people living in tropical coastal regions.



Climate change and coral reef ecosystems

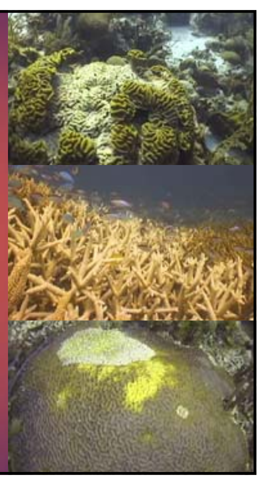
Team projects



Climate change and coral reef ecosystems

Project Goals

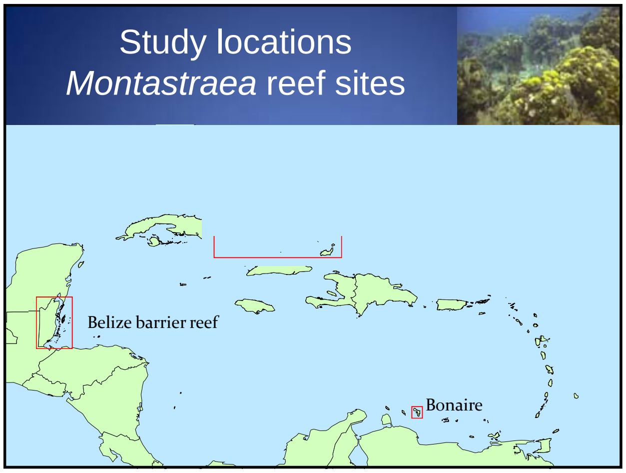
- Integrate theory and data from ecology, biology and the social sciences to address major questions about the potential consequences of climate change on coral reef ecosystems.
- Predict how fishing pressure, tourism development, and local economies will be affected by climate change stressors.
- Provide guidance for future management.

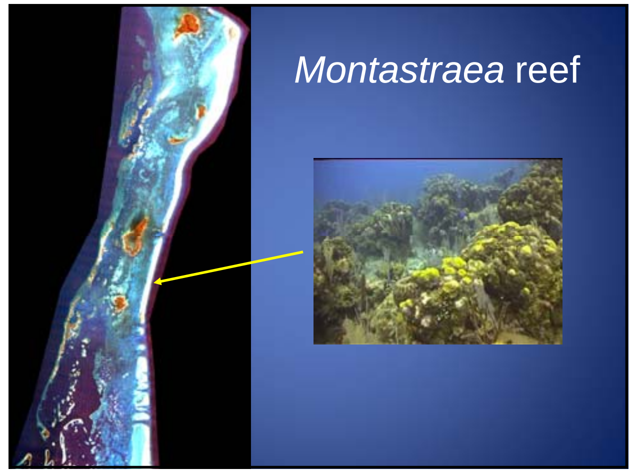


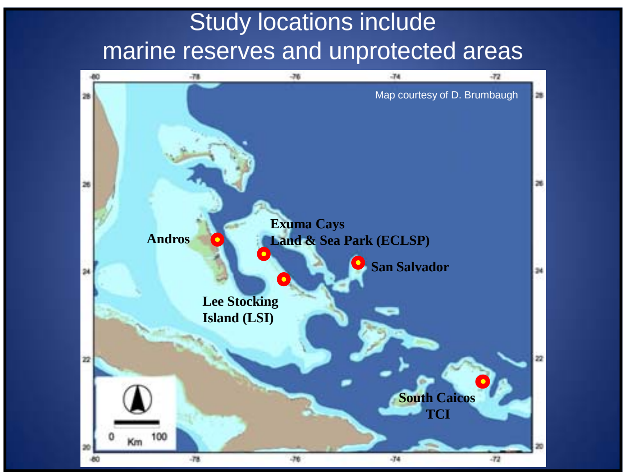
Climate change and coral reef ecosystems

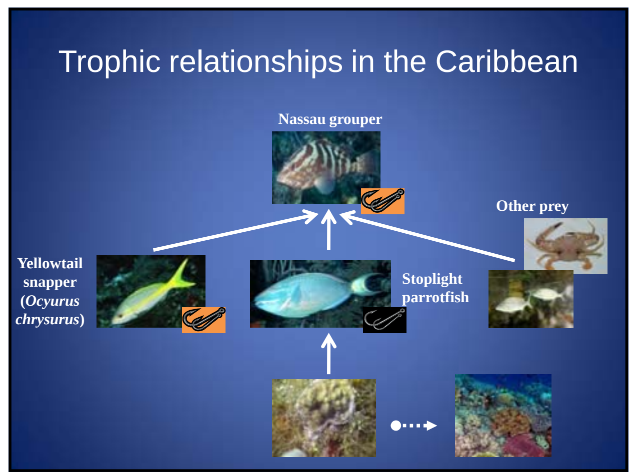
Research Questions

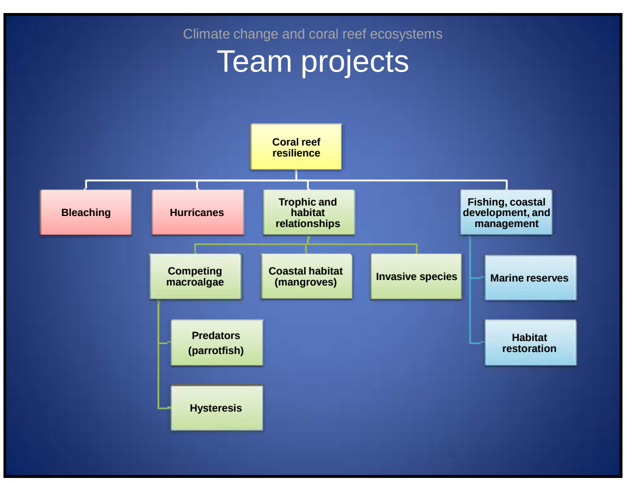
- How do environmental and anthropogenic impacts including overfishing and mangrove deforestation affect the vulnerability of Caribbean coral reefs to climate change?
- When do socioeconomic responses to changes in the ecosystem triggered by climate change stressors exacerbate the vulnerability of coral-reef ecosystems to future stressors?
- What are the critical ecological and/or socioeconomic uncertainties for predicting climate change impacts on ecosystem services that will yield the greatest returns from investigation?

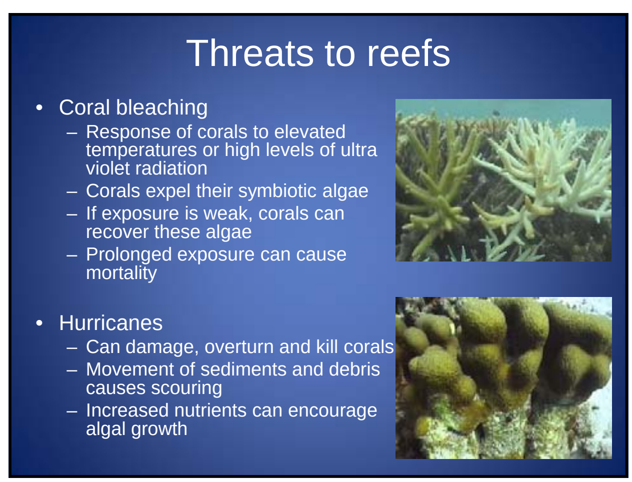

Study locations
Montastraea reef sites
Belize barrier reef
Bonaire


Montastraea reef


Study locations include
marine reserves and unprotected areas
Map courtesy of D. Brumbaugh
Andros
Exuma Cays
Land & Sea Park (ECLSP)
San Salvador
Lee Stocking
Island (LSI)
South Caicos
TCI
0 Km 100


Trophic relationships in the Caribbean
Nassau grouper
Other prey
Yellowtail
snapper
(Ocyurus
chrysurus)
Stoplight
parrotfish


Climate change and coral reef ecosystems
Team projects
Coral reef resilience
Bleaching
Hurricanes
Trophic and habitat relationships
Fishing, coastal development, and management
Competing macroalgae
Coastal habitat (mangroves)
Invasive species
Marine reserves
Predators (parrotfish)
Habitat restoration
Hysteresis


Threats to reefs
• Coral bleaching
– Response of corals to elevated temperatures or high levels of ultra violet radiation
– Corals expel their symbiotic algae
– If exposure is weak, corals can recover these algae
– Prolonged exposure can cause mortality
• Hurricanes
– Can damage, overturn and kill corals
– Movement of sediments and debris causes scouring
– Increased nutrients can encourage algal growth

Threats to reefs: coral bleaching

- Response of corals to elevated temperatures or high levels of ultra violet radiation
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Threats to reefs: hurricanes

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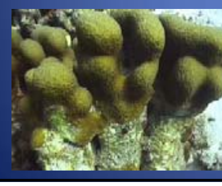
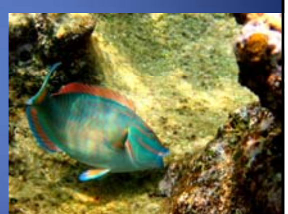


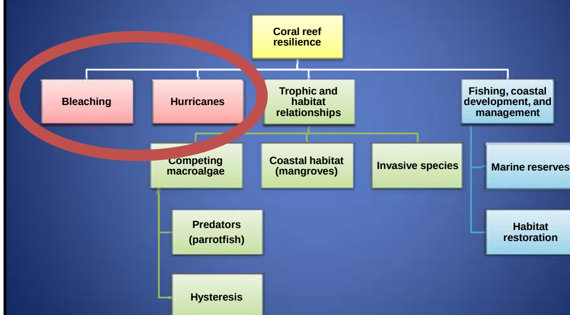
The importance of grazers

- Macroalgae compete with corals
- Reefs can switch from a healthy (coral-dominated) state to an unhealthy (algal-dominated) state
- Grazers influence replenishment rate, growth & fecundity of coral colonies
- Grazing underpins resilience of coral reefs to disturbance



Climate change and coral reef ecosystems

Team projects



Managing the resilience of coral reefs in the face of rising sea temperature

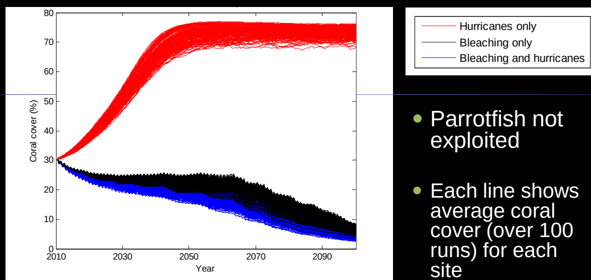
Helen J Edwards
University of Exeter

Both images © C. Vernon

Modelling the impacts of disturbances on corals

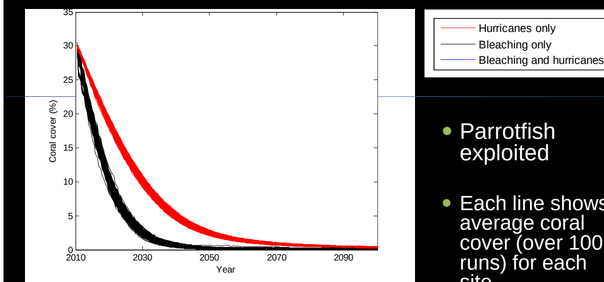
- Mortality caused by bleaching depends on
  - Magnitude & duration of thermal stress (calculated using degree heating months)
  - Each coral's 'thermal history'
- Mortality caused by hurricane depends on
  - Strength of hurricane at reef location (Saffir-Simpson category)
  - Colony size
- If a hurricane occurs, bleaching is prevented from occurring that year

Predicted health of Belize's reefs



- Parrotfish not exploited
- Each line shows average coral cover (over 100 runs) for each site

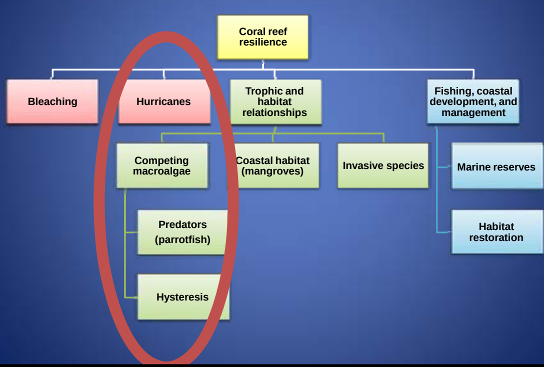
Impacts of exploiting grazers



- Parrotfish exploited
- Each line shows average coral cover (over 100 runs) for each site

Climate change and coral reef ecosystems

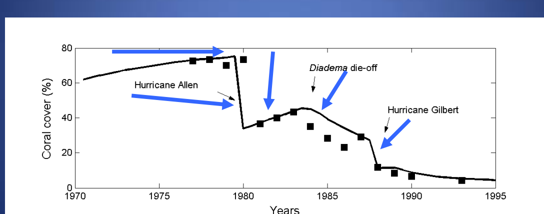
Team projects



Managing the resilience of coral reefs in the face of climate change

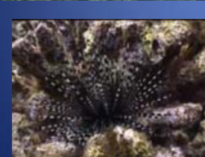
Peter J. Mumby
University of Exeter

Model vs. Hughes 1994



Urchins & Parrotfish

- Spatially limited (max 40% of reef per 6 mo)
- **Williams & Polunin** (2001) MEPS 222: 187-196
- **Mumby** (2006) Ecol. Apps. 16: 747-769

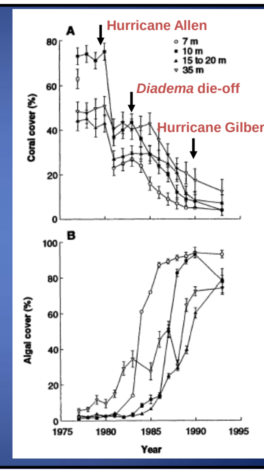


- Either zero or 40% of reef per 6 mo
- **Carpenter** (1984) Marine Biology 82: 101-108
- **Carpenter** (1988) PNAS 85: 511-514
- **Mumby** et al. (2006) Ecol. Model. 196: 131-148

What is resilience?

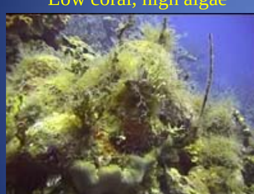

Coral cover and role of grazers

- Alteration of food-web structure and ecosystem functioning of coral reefs: Discovery Bay, Jamaica (Hughes 1994. *Science*)
- Does the loss of grazers reduce resilience?



Coral and algae cover

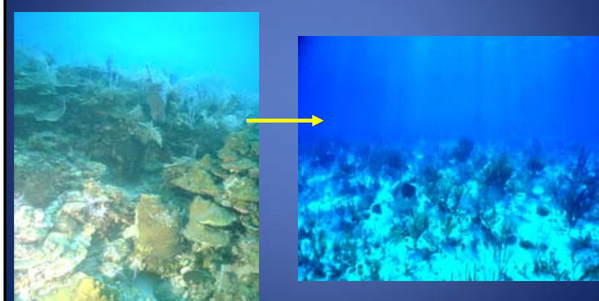
Low coral, high algae



High coral, low algae

Potential for two stable states in the system

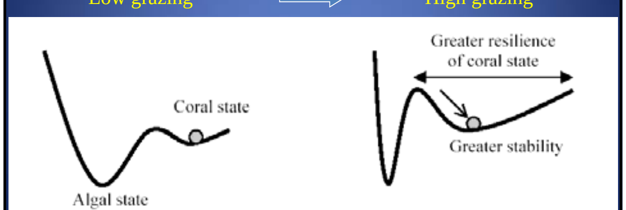
Adaptive capacity of system may change if left degraded

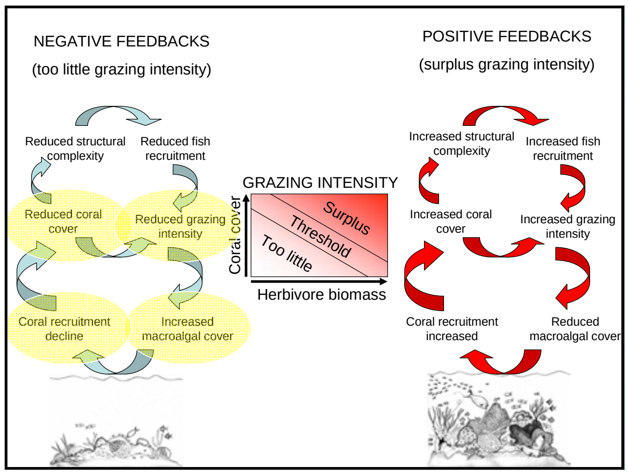


Resilience

Predictions of coral-reef grazer model (hysteresis)

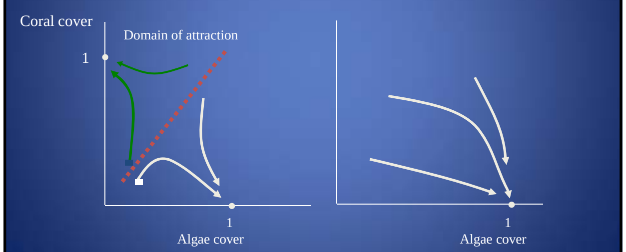
Low grazing ⇨ High grazing





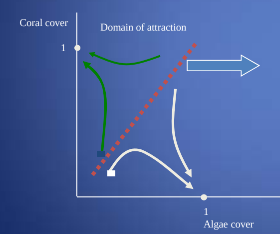
Predictions of coral-reef grazer model (hysteresis)

High grazing Low grazing



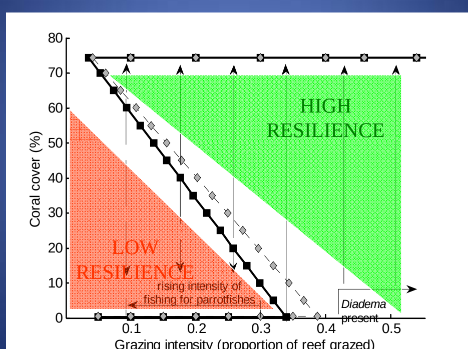
Predictions of coral-reef grazer model (hysteresis)

High grazing Low grazing



The location and nature of the threshold and the shift is a function of ecological, climate, and socioeconomic factors

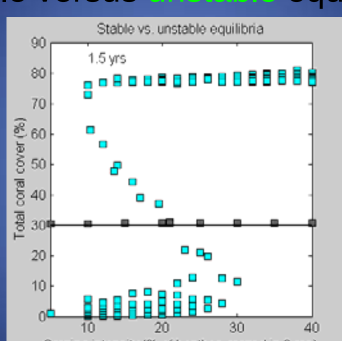
Managers challenge to keep reefs to right

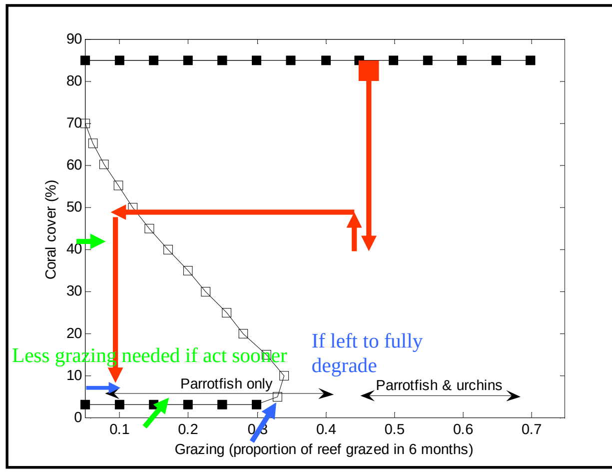


Resilience influenced by…

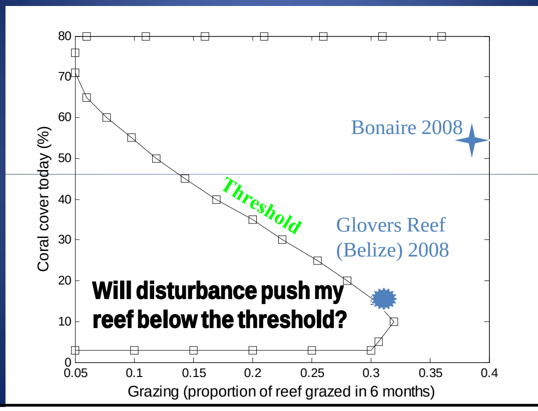
- **Shape (bifurcation points)**
  - Primary production (medium)
  - Recruitment rate (weak)
  - Coral growth rate (high)
- **Grazing Axis (X-axis)**
  - Disease of urchin *Diadema antillarum*
  - Fishing of grazing fishes
  - Seascape context (mangrove nurseries)
- **Coral axis (Y-axis)**
  - Bleaching
  - Hurricanes
  - Disease

Stable versus unstable equilibria

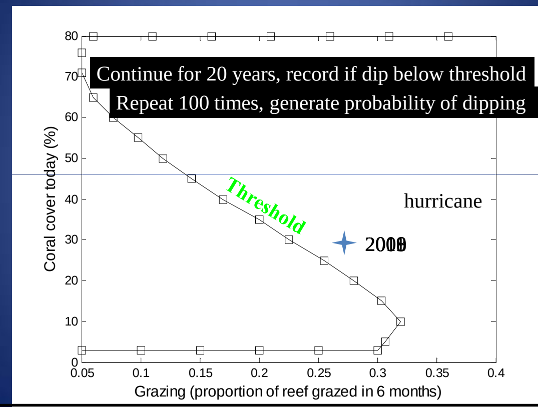




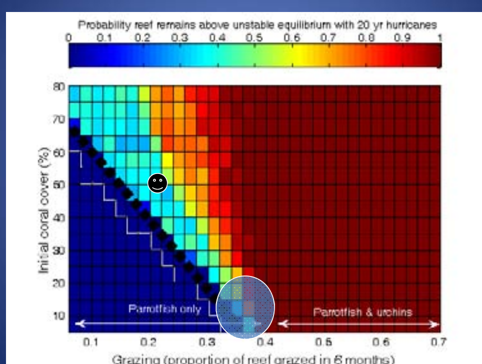
How resilient is my reef?



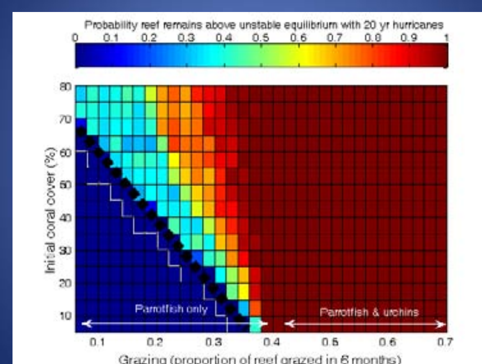
Quantify resilience



Resilience



Resilience

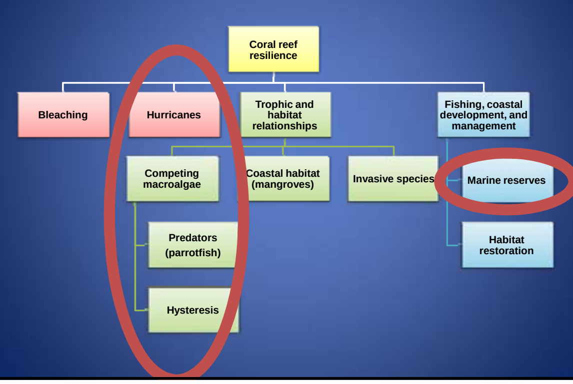


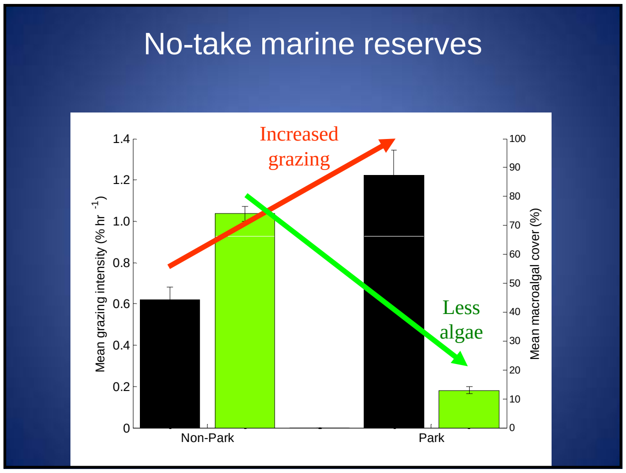
Uses of model for reef management

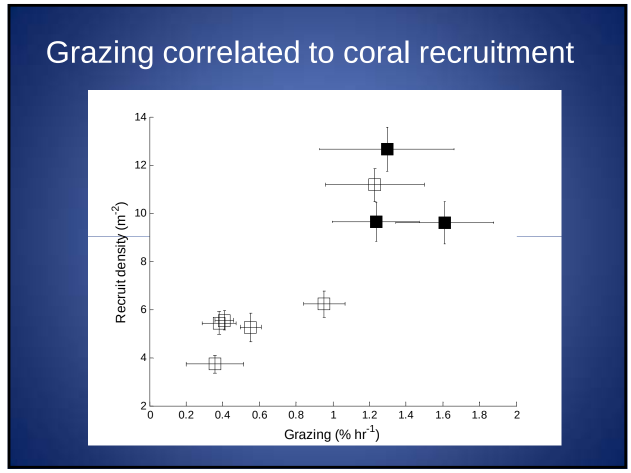
1) Managing grazers on reefs
2) Conservation of mangroves
3) Choose sites of naturally-lower productivity

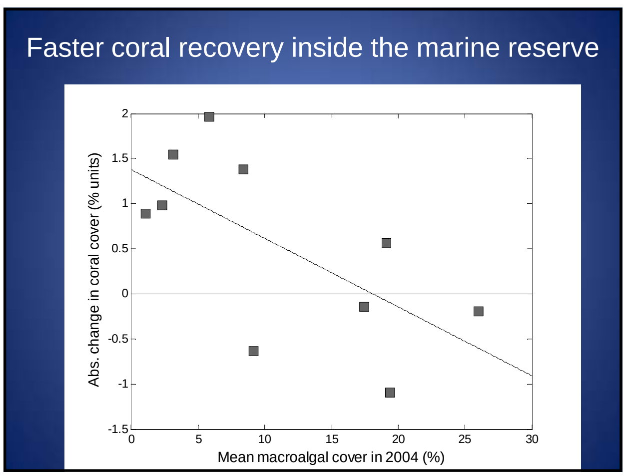
Climate change and coral reef ecosystems

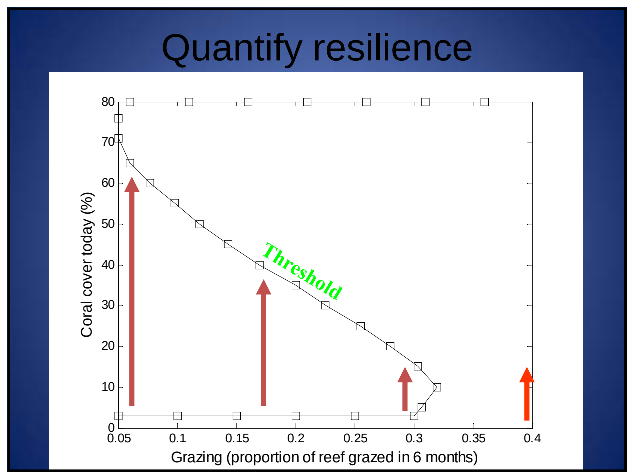
Team projects

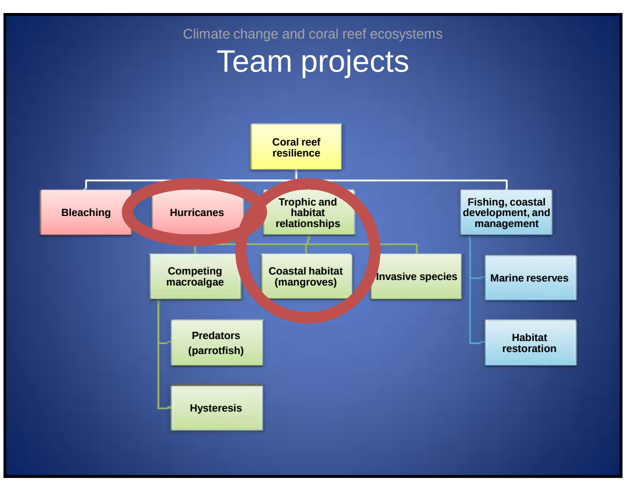



No-take marine reserves
Increased grazing
Less algae
Mean grazing intensity (% hr -1)
Mean macroalgal cover (%)
Non-Park
Park


Grazing correlated to coral recruitment
Recruit density (m-2)
Grazing (% hr-1)


Faster coral recovery inside the marine reserve
Abs. change in coral cover (% units)
Mean macroalgal cover in 2004 (%)


Quantify resilience
Threshold
Coral cover today (%)
Grazing (proportion of reef grazed in 6 months)


Climate change and coral reef ecosystems
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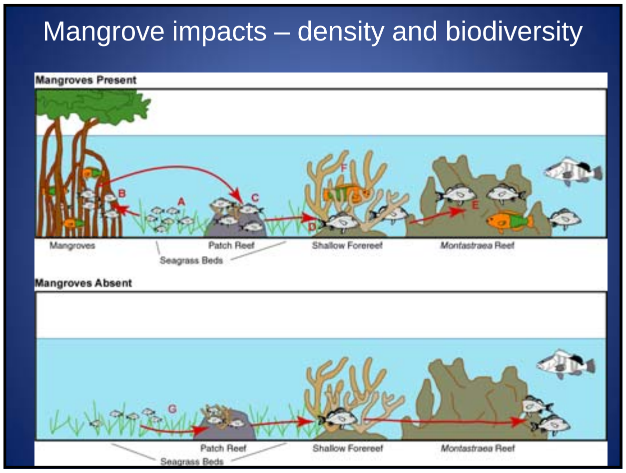
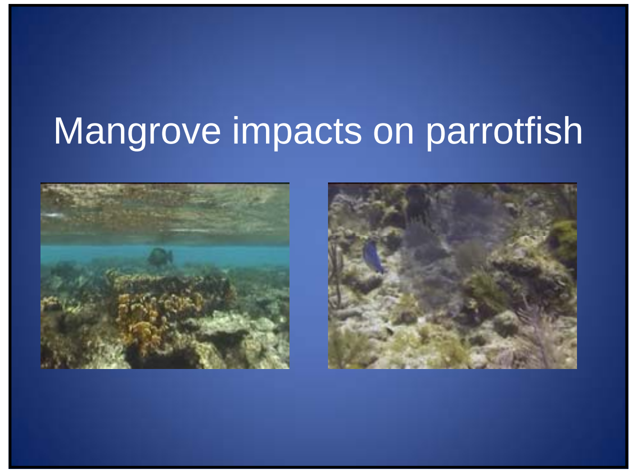
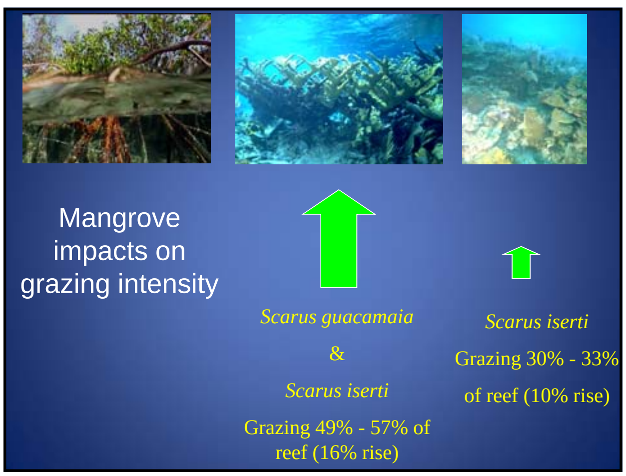
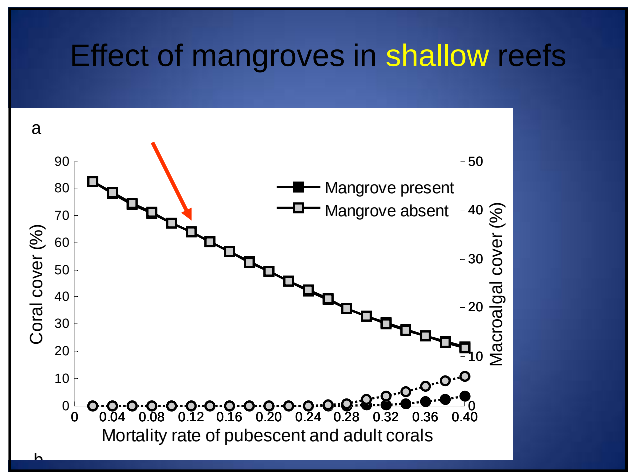
Coral reef resilience
Bleaching
Hurricanes
Trophic and habitat relationships
Fishing, coastal development, and management
Competing macroalgae
Coastal habitat (mangroves)
Invasive species
Marine reserves
Predators (parrotfish)
Habitat restoration
Hysteresis

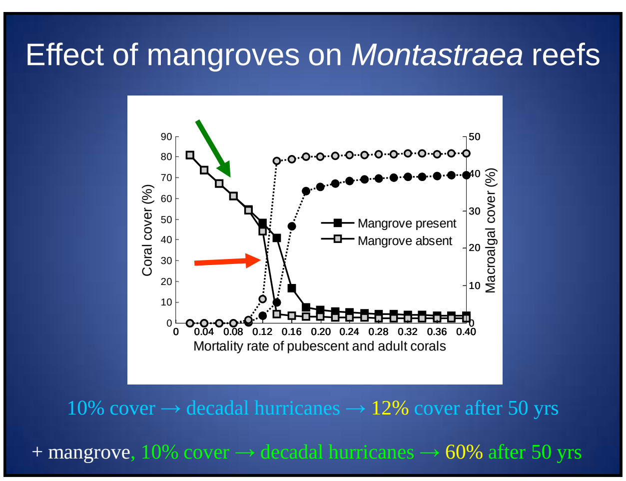

Mangrove – reef connectivity

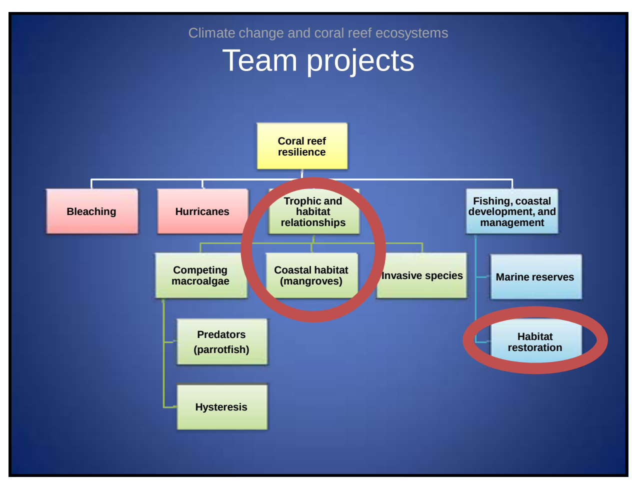

Mangrove impacts – density and biodiversity
Mangroves Present
Mangroves
Seagrass Beds
Patch Reef
Shallow Forereef
Montastraea Reef
Mangroves Absent
Patch Reef
Seagrass Beds
Shallow Forereef
Montastraea Reef


Mangrove impacts on parrotfish


Mangrove impacts on grazing intensity
Scarus guacamaia
&
Scarus iserti
Grazing 49% - 57% of reef (16% rise)
Scarus iserti
Grazing 30% - 33% of reef (10% rise)


Effect of mangroves in shallow reefs
a
Coral cover (%)
Macroalgal cover (%)
Mangrove present
Mangrove absent
Mortality rate of pubescent and adult corals


Effect of mangroves on Montastraea reefs
Coral cover (%)
Macroalgal cover (%)
Mangrove present
Mangrove absent
Mortality rate of pubescent and adult corals
10% cover → decadal hurricanes → 12% cover after 50 yrs
+ mangrove, 10% cover → decadal hurricanes → 60% after 50 yrs


Climate change and coral reef ecosystems
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Coastal habitat (mangroves)
Invasive species
Marine reserves
Predators (parrotfish)
Habitat restoration
Hysteresis

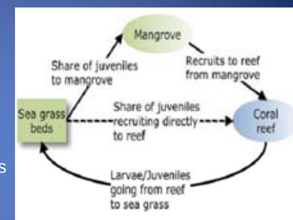
Habitat Conservation and Ecosystem Services

Research questions

- How does habitat (and loss thereof) affect the productivity of fisheries?
- What does this imply for the economic value of habitat?
- How do these values impact coastal land use decisions?

Bringing ecology into habitat valuation

- Develop a model that allows for obligate and/or facultative associations
- Develop a model with multiple habitat types
- Develop a model that links recent finding on ecology to tools of economic valuation



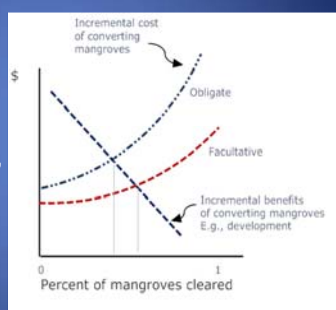
Mangrove present

Mangrove absent

Mumby et al. (2004) *Nature*

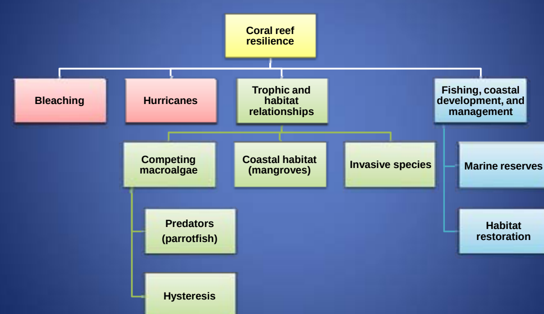
Species habitat use and coastal land–use decisions

- Obligate relationship between species and habitat results in less clearing than if the behavior is facultative, everything else being equal



Climate change and coral reef ecosystems

Team projects



Lessons learned (1)

- Caribbean coral reefs appear to exhibit alternate stable states
- Threshold levels of coral cover, grazing, nutrients etc
- Restoring reef health becomes disproportionately more difficult as health declines
- Act sooner rather later

Lessons learned (2)

- Hysteresis plot = trajectory of reef between disturbance events & location of thresholds
- Resilience = probability that reef does NOT become entrained in shift towards stable algal state
- Derive by combining hysteresis plot with stochastic simulations of disturbance

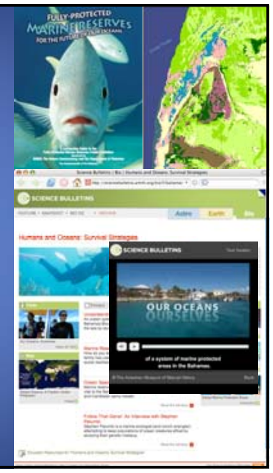
Outreach - Interaction with clients

- Examples of activities of the group
  - Chair of Remote Sensing Working Group of the World Bank/GEF Coral Reef Targeted Research Project (www.gefcoral.org).
    - The ecological models developed under the EPA project have been extended through collaborators on this World Bank project so that a parameterization for coral disease was added.
  - Intermittent Expert Hire of the U.S. EPA to help them design their coral reef valuation work
  - Bahamas National Trust board member
- Examples of the work being included in policy decisions
  - The modeling we did on parrotfish exploitation was presented to the Fisheries Administration, 170 fishermen, and stakeholders in Belize (March 2005, 2008 and 2009). In partial response to this, the Minister of Fisheries has just signed new legislation to ban parrotfish harvesting in the country.
    - A similar story is also true for Bonaire where they are currently drafting regulations to ban fish traps.

Outreach

Public

- Website: http://bbp.amnh.org
- Booklet: *Fully-protected Marine Reserves for the Future of our Oceans*
- Posters: Habitat maps for 4 sites
- Multimedia: *Humans and Oceans: Survival Strategies*
- Videos: *Our Oceans, Ourselves* Andros video



Outreach (cont.)

Educators

- G3-6 teaching resources: *Treasures in the Sea*
- College-level exercise: *Marine Reserves & Local Fisheries*

Practitioners

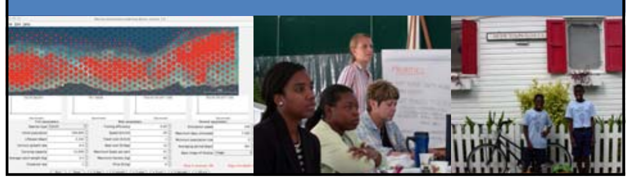
- Newsletter: *BBP in Brief*
- Project meetings
- Presentations

Decision makers

- Project meetings & office visits
- BNT Council representation

Outreach: next steps & investments

- Interactive simulations
- Decision-support tools
- Workshops for practitioners
- Public forum for decision makers & the media
- Edited academic press book on BBP as a case study



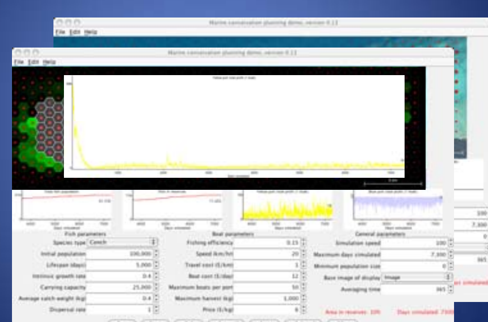
Output - Outcomes

- Integrative models useful and used for management and education
- Examples of peer-reviewed publication outlets
  - Nature, Conservation Letters, Theoretical Ecology, Science, Ocean and Coastal Management, Conservation Biology, Coral Reefs, PNAS, Marine Biology, Ecological Applications, and Journal of Ecology
- Examples of presentations
  - International Coral Reef Symposium, Ecological Society of America, International Marine Conservation Congress, American Fisheries Society, NOAA, WWF, TNC, etc.

Integrative models

An interactive exercise for marine conservation education

Prototype for dynamic model development for planning



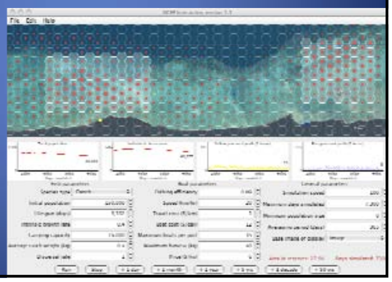
Center for Biodiversity and Conservation
AMERICAN MUSEUM & NATURAL HISTORY

Bahamas Biocomplexity Project

Network of Conservation Educators & Practitioners

Marine Reserves and Local Fisheries

An Interactive Simulation for Education & Outreach



Katherine Holmes & Daniel R. Brumbaugh

Uses & Users

Visualization, exploration, & experimentation with various factors that influence fish population viability and fishery sustainability.

Lab exercises in undergrad & graduate courses in the US, UK, NZ, and The Bahamas

Stakeholder meetings in The Bahamas & Ecuador

Features

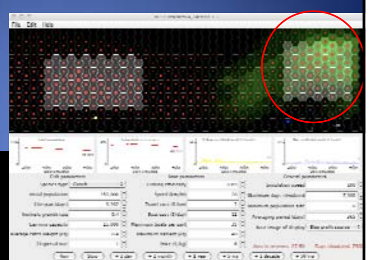
Realistic seascapes

- satellite imagery
- habitat classification
- habitat suitability

Interactive population parameters

Interactive fisheries parameters

Interactive marine reserves



Suite of save-able, graphic outputs, including catch, effort, profits, & the origin of profit (e.g., spillover effect)

Additional details

- Java-based, cross-platform program (*developed by Steven Phillips, AT&T*)
- Agent-based model, with spatial complexity, probabilistic & economically rational fishing behavior, and simple logistic population growth
- Exercise & solutions (draft)
- More info and open-access downloads via http://bbp.amnh.org/website/curricula.html

RESOURCES FOR THE FUTURE

Ongoing work

- Multiple regression analysis to understand the factors that explain key proxies for ability to adapt to climate change
- Development of a supplemental survey to better understand how people have adapted to and respond to hurricanes
  - Use this information to better understand how households in the Caribbean would likely adapt to increased storm intensity
- Mapping our fishermen income and effort levels to the trophic model and reef resilience modeling

Discussion and ongoing work

- Reef resilience exhibits hysteresis as a function of grazing intensity
  - Modeling endogenous thresholds
- Model of grazers that takes into account
  - Habitat dependencies (mangroves, sea grasses)
  - Predator interactions (Grouper)
  - Direct and indirect fishing pressure
- Model of households that predicts changes in fishing pressure via changes in labor market and fishing returns

Thank You!

We also want to acknowledge the NSF biocomplexity team members.
(Bahamas Biocomplexity Project information can be found at http://bbp.amnh.org/)

Dan Brumbaugh, AMNH
Kenny Broad, Univ. Miami, RSMAS
Steve Cantrell, Univ. Miami
Jackie Chisholm, College of The Bahamas
Chris Cosner, Univ. Miami
Bob Cowen, Univ. Miami, RSMAS
Craig Dahlgren, Perry Inst. Marine Science
Rob DeSalle, AMNH
Meg Domroese, AMNH
Christine Engels, AMNH
Nonong Gayanilo, Univ. Miami, RSMAS
Alastair Harborne, Univ. Exeter
Alan Hastings, UC Davis
Kate Holmes, AMNH
Carrie Kappel, NCEAS

Julie Kellner, UC Davis
Phil Kramer, The Nature Conservancy
Steve Litvin, Stanford University
John McManus, Univ. Miami, RSMAS
Fiorenza Micheli, Stanford University
Jessica Minnis, College of The Bahamas
Peter Mumby, Univ. Exeter
Don Olson, Univ. Miami, RSMAS
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Claire Paris-Limouzy, Univ. Miami, RSMAS
Jim Sanchirico, Resources for the Future
Rich Stoffle, Univ. Arizona
Liana Talaue-McManus, Univ. Miami, RSMAS
Eric Treml, Duke University
Maria Villanueva, Univ. Miami, RSMAS

Thank you.

Peer-Reviewed Publications

Published and in press publications related to the EPA Star grant:

- Peter J. Mumby, Alastair R. Harborne, Jodene Williams, Carrie V. Kappel, Daniel R. Brumbaugh, Fiorenza Micheli, Katherine E. Holmes, Craig P. Dahlgren, Claire B. Paris, and Paul G. Blackwell. 2007. Trophic cascade facilitates coral recruitment in a marine reserve. PNAS, 104:8362-8367.
- Harborne, A. R., P.J. Mumby, F. Micheli, C. T. Perry, C.P. Dahlgren, D. Brumbaugh, and P. Kramer. In press. The functional value of Caribbean reef habitats to ecosystem processes. Advances in Marine Biology.
- Mumby, P. J., F. Micheli, C. P. Dahgren, S. Y. Litvin, A. B. Gill, D. R. Brumbaugh, K. Broad, J. N. Sanchirico, C. V. Kappel, A. R. Harborne, K. E. Holmes. 2006. Marine Parks Need Sharks? – response. Science 312: 527.
- Mumby, P.J., C. P. Dahlgren, A. R. Harborne, C. V. Kappel, F. Micheli, D. R. Brumbaugh, K. E. Holmes, J. M. Mendes, K. Broad, J. N. Sanchirico, K. Buch, S. Box, R.W. Stoffle, A. B. Gill. 2006. Fishing, trophic cascades, and the process of grazing on coral reefs. Science 311: 98-101.
- Mumby, Peter J., Hedley, John D., Zychaluk, Kamila, Harborne, Alastair R. & Blackwell, Paul G. (2006) Revisiting the catastrophic die-off of the urchin Diadema antillarum on Caribbean coral reefs: Fresh insights on resilience from a simulation

Presentations

- Smith, M., J.N. Sanchirico, J. Wilen. The Economics of Spatial-Dynamic Processes: An Application to Renewable Resources. Presented at the Frontiers in Environmental Economics Conference, Washington DC, Feb. 2007
- Peter Mumby, Keynote speech, 12th National Symposium on the Natural History of the Bahamas, San Salvador Bahamas, June 2007.
- Peter Mumby Caribbean & Gulf Caribbean Fisheries Institute, 59th Annual meeting, Belize 2006
- Peter Mumby, Keynote speech, International Society for Reef Studies, Bremen 2006
- Litvin S., J. Kellner, A. Hastings, H. Edwards, F. Micheli. Multiple factors influencing species interactions in a coral reef ecosystem: implications for the dominant grazer, Sparisoma viride. Annual Meeting of the Ecological Society of America, San Jose, CA, August 2007.
- Micheli, F., C. Kappel, R. Martone, and A. Rosenberg. Marine ecosystem-based management: theory and practice. CalCOFI conference, Pacific Grove, CA, 4-6 December 2006.

Institutional partners on the BBP are:

END

Models of coral community structure, environmental variation and connectivity

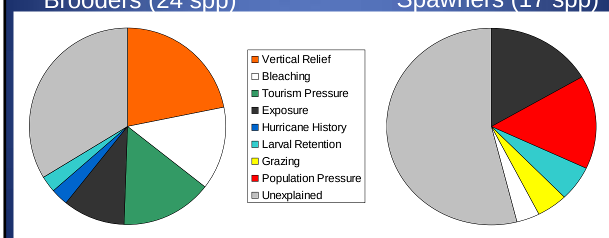
Carrie Kappel
National Center for Ecological Analysis & Synthesis

Dan Brumbaugh, Craig Dahlgren,
Alastair Harborne, Katherine Holmes,
Fiorenza Micheli, Peter Mumby, Claire Paris

- What environmental factors are important to coral abundance and community structure at the seascape scale?
- What role does connectivity play?

Relating coral abundances and community structure to environmental variation

Brooders (24 spp) Spawners (17 spp)



66% of variance explained 46% of variance explained

* Vertical relief not included in spawners' analysis

Significant predictor variables of coral abundance and community structure

- Exposure is consistently a strong predictor of coral abundance and community patterns.
- Larval retention and to some degree larval subsidies showed weak, but significant effects at species and community scales.
- The signal of past disturbances from bleaching and hurricanes is detectable at the community level and for some species.
- Grazing by herbivorous fishes is important to the assemblage of spawning corals and to certain species at the seascape scale.

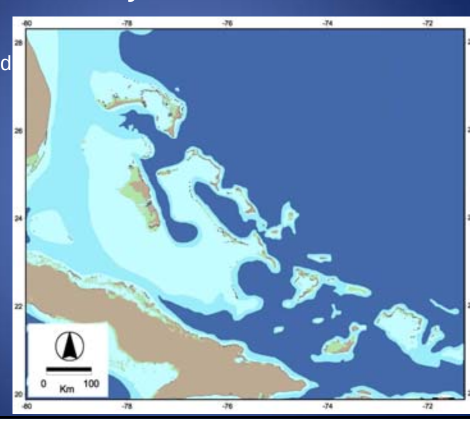
Relating coral abundances and community structure to environmental variation

Predictor Variables:

- Water depth
- Vertical relief
- Wave exposure
- Temperature history
- Hurricane history
- Grazing by parrotfish
  - Human population density
  - Tourism intensity
- Larval subsidies
- Larval retention

Study locations

We conducted habitat mapping, fish and benthic surveys across the Bahamas archipelago



Map courtesy of D. Brumbaugh

Connectivity among islands estimated from simulations of larval dispersal

"Typical" brooding coral:
- 1 day pre-competent period
- 42 day max competency
- Year round planulae release (Apr-Dec here)

"Typical" spawning coral:
- 5 day pre-competent period
- 30 day max competency
- Spawning in Aug & Sept

Both images © C. Vernon

Effects of Climate Change on Ecosystem Services Provided by Hawaiian Coral Reefs

P. L. Jokiel, PI
R. W. Buddemeier
P. van Beukering

W. Haider, Z. Hausfather, D. Fautin, K. Rodgers, S. Saving, Y. Liu, K. Zimmerman, K. Shapiro, S. Garcia, A. Andersson, I. Kuffner, F. Cox, F. MacKenzie

1. Project Goals

Integrate and extend existing models to develop a comprehensive, scenario-based analysis of the range of possible effects of global climate change on ecosystem services provided by the coral reefs of the Hawaiian archipelago, and on the economic valuation of predicted changes.

Features and emphasis

Cross-scale (reef to GCM cell)
Cross-domain (biological, environmental, socio-economic)
Responses to long-term means and short-term events
Valuation of lightly used or unused resources
Aesthetic, cultural, and spiritual values
Development and dissemination of tools as well as results
l

Model available for both on-line use and
download from a website (www.kgs.ku.edu/Hexacoral), providing for community involvement through hands-on testing and feedback.

2. Lessons learned/Challenges

Challenge of Model Building at 3 levels

•Climate Change Modeling
•Biological Response Modeling
•Ecosystem Services Modeling

Lessons Learned

Unexpected: Ocean acidification, corals, crustose coralline algae, calcification
(coral growth and mortality central to all our work)

Timing: Economic downturn at time of valuation survey.

3. Interaction with clients

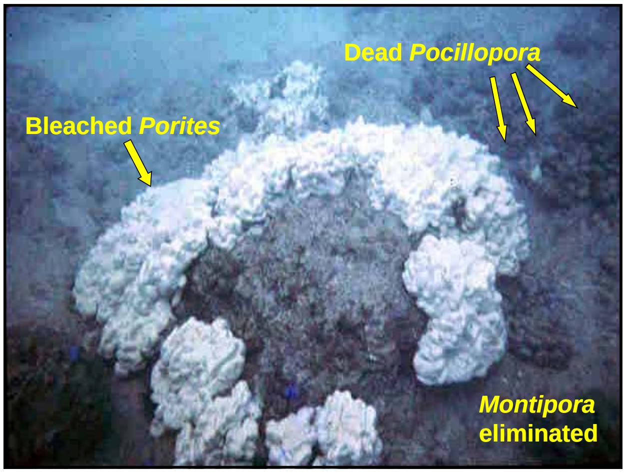
3 Sept 2008 "**Identifying Bleaching Thresholds**" Paul Jokiel.
NOAA Climate Workshop, HIMB
3 Sept 2008 "**Techniques for Bleaching Assessments**"
Paul Jokiel and Ku'ulei Rodgers NOAA Climate Workshop, HIMB
4 Sept 2008 "**Reef Restoration**". NOAA Climate Workshop, HIMB
5 Sept 2008 "**Indigenous Practices and Climate Change**" by Paul L. Jokiel.
NOAA Climate Workshop, HIMB
12 Oct 2008 "**Impact of Ocean Acidification on Hawaiian Coral Reefs**"
The Nature Conservancy Workshop on Ocean Acidification,
St. Stephens Diocesan Center, Kāne'ohe, Hawai'i.
April 5-7, 2009. Climate Change Symposium. Local and global panel member and moderator. Exploratorium. San Francisco, CA.
"**Impacts of Climate Change in the Hawaiian Islands**"
and "**Impacts of Climate Change on Coral Reefs in America**" Ku'ulei Rodgers
March 2-6, 2009 Pacific Science Inter-Congress in Tahiti French Polynesia
Climate Change Symposium "**Impact of ocean acidification on Hawaiian coral reefs in the 21st century**" Presenter and moderator Paul Jokiel

Also- Upcoming Bleaching response team (managers), Local Action Strategy Committee On Climate Change, Hawaii Conservation Conference
Training Graduate Students, Undergraduates, Interns, Docents

4. Outcomes

ENVIRONMENTAL PROTECTION AGENCY (15 April 2009)
[EPA–HQ–OW–2009–0224; FRL–8892–5]
Ocean Acidification and Marine pH Water Quality Criteria
AGENCY: Environmental Protection
Agency (EPA). ACTION: Notice of data availability (NODA)
http://www.epa.gov/fedrgstr/EPA-WATER/2009/April/Day-15/w8638.pdf

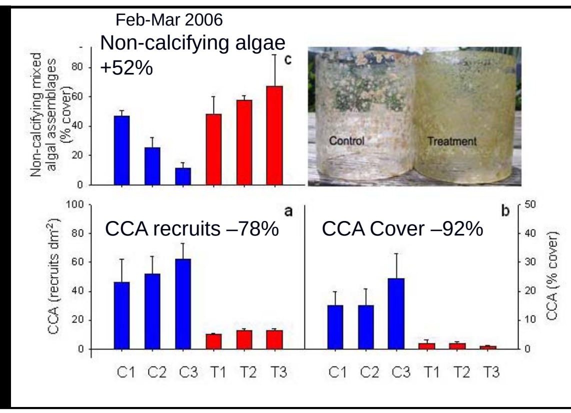
Four of our recent EPA funded papers were cited in the Federal Register announcement (**Jokiel et al. 2008, Kuffner et al. 2008, Andersson et al.2009, Buddemeier et al. 2008**). The NODA notes that "EPA has supported the development of the **Coral Mortality and Bleaching Output (COMBO)** model to project the effects of climate change on coral reefs by calculating impacts from changing sea surface temperature and CO2 concentration, …".
The notice also mentions the **EPA biocriteria initiative**. This NODA is an important step related to possible future EPA action related to controlling ocean acidification and climate change.



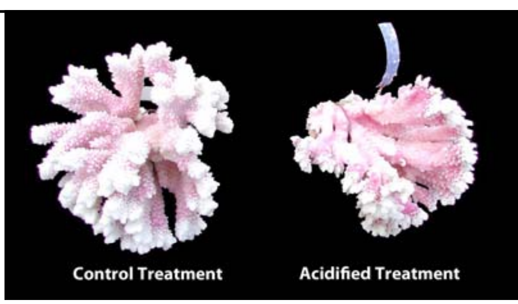
Response of Hawaiian corals to increased temperature.

Hawaii Institute of Marine Biology
Coconut Island, Kaneohe Bay, HI

•Experiments are conducted in continuous flow outdoor mesocosms that simulate the reef environment.
•Treatments: acidified to produce carbonate saturation states predicted for year 2100, plus controls (3x replication).



Kuffner IB, Andersson AJ, Jokiel PL, Rodgers KS, Mackenzie FT (2008)
Decreased abundance of crustose coralline algae due to ocean acidification.
Nature Geoscience 1:114-117

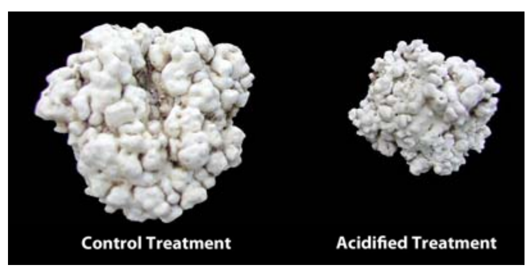


No mortality Coral calcification rate reduced 15-20%

Skeletal density decreased, branches thinner

No evidence of acclimation

The calculated decrease in $CaCO_3$, production, estimated using the scenarios considered by the International Panel on Climate Change (IPCC), is 10% between 1880 and 1990, and 9-30% (mid estimate: 22%) from 1990 to 2100. (Gattuso et al. 1999).



Recruitment	Control mean±1 s.e.	Acidification mean ±1 s.e.	Percent Difference	Two-sample t-test
Rhodolith accretion (g buoyant weight yr^{-1})	+ 0.6±0.3	- 0.9±0.3	-250	P<0.0001

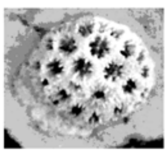
Maro Reef - Crustose Coralline Reef Formation

Photo by Paul Jokiel

Mesocosm Wall Settlements

Recruitment	Control mean±1 s.e.	Acidification mean ±1 s.e.	Percent Difference	Two-sample t-test
Crustose coralline algae (% cover on walls)	**25±4.0**	**3.6±0.9**	-84	p = 0.03
Turf algae (% cover on walls)	16.6±4.0	14.5±2.6	-13	p = 0.69
Vermetid tubes (no. per m^2) *Serpulorbis* sp.	78.4±35.1	7.7±3.1	-90	p = 0.18
Oyster % cover *Dendrostrea sandwichensis*	5.7±1.9	4.4±0.8	-23	p = 0.56
Barnacles (no. per m^2) *Balanus* sp.	8.3±3.5	4.5±1.6	-46	p = 0.37
Barnacle size (mm) *Balanus* sp.	5.1±0.6	6.0±0.2	+18	p = 0.25
Bare Substratum (% cover on walls)	**53.2±2.1**	**77.5±1.1**	+46	p=0.0006

Jokiel et al. 2008



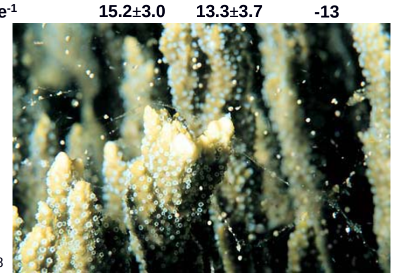
Settlements of reef coral *Pocillopora damicornis*

	Control Mean ±1 s.e.	Acidification Mean ±1 s.e.	Percent Change	Two-sample t-test
Settlements per m^2	55±14	49±18	-11	p = 0.81
Diam. (mm)	2.5±0.2	2.8±0.1	+12	p = 0.44
no. of polyps per settlement	4.4±0.9	5.3±0.6	+20	p = 0.47

Jokiel et al. 2008

Consistent with: Albright, Mason and Langdon (2008)

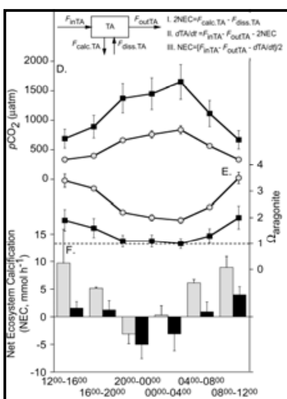
Measured Variable	Control ±s.e.	Acidified ±s.e.	Percent Difference	Statistical Significance
bundles g^{-1} coral	**5.2±5.4**	**7.2±10.1**	**+38**	**p = 0.47**
eggs $bundle^{-1}$	**15.2±3.0**	**13.3±3.7**	**-13**	**p = 0.06**



Jokiel et al. 2008

Photo: Waikiki Aquarium

Consistent with Fine and Tchernov (2007)



June 21-22, 2006

Net Ecosystem Calcification (NEC = $CaCO_3$ production - dissolution)

+4.5 mmol $CaCO_3$ h^{-1}
At present seawater pCO_2

–0.1 mmol $CaCO_3$ h^{-1}
At twice present pCO_2

CORALS WILL STILL BE GROWING WHILE REEFS ARE DISSOLVING!

Andersson, Andreas J., Ilsa B. Kuffner, Fred T. Mackenzie, Paul L. Jokiel, and Ku'ulei S. Rodgers. Adrian Tan (2009) Net loss of CaCO3 from coral reef communities due to human induced seawater acidification. Biogeosciences Discuss., 6, 1–20, 2009.

Climate-response modeling (The COMBO Model)*

Buddemeier, R. W., P.L. Jokiel, K.M. Zimmerman, D.R. Lane, J. M. Carey, G.C. Bohling, J.A. Martinich. (2008) A modeling tool to evaluate regional coral reef responses to changes in climate and ocean chemistry Limnol Oceanogr. Meth. 6:395–411

Excel-based model of coral cover incorporating steady-state temperature and CO2 effects on coral growth and mortality, plus a probabilistic treatment of high temperature stress (bleaching mortality).

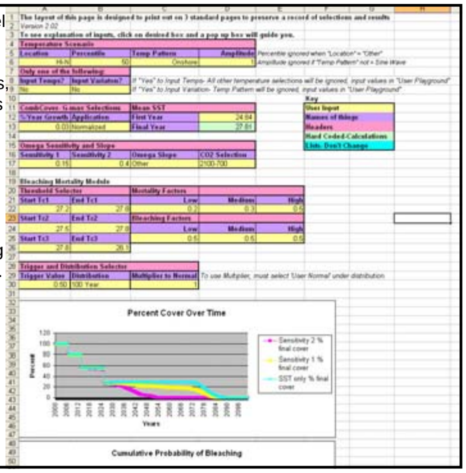
Key features:
-User has control of all factors (sensitivities, probabilities, environmental inputs).
-Regionally appropriate default values are provided (versions for other areas have also been developed).
-The effects of quasi-steady-state temperature, CO_2 concentration, and temperature variation are assessed independently and accumulated into net change in cover.

Much of the initial development and testing was funded by the EPA Climate Change Program (Dr. Jane Leggett) through a contract with Stratus Consulting. That support has contributed to strong synergy and mutual advantage for the two projects.

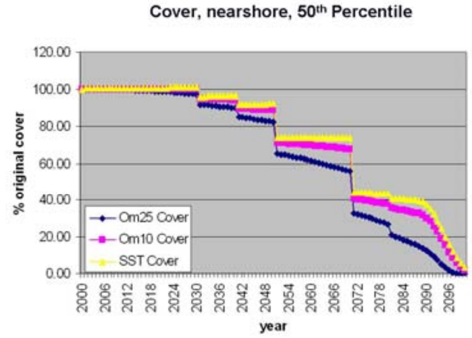
The response model user interface offers drop-down menus, explanatory pop-ups, and fill-in-the-blanks value selections.

Calculations are performed in linked, user accessible worksheets, with options for replacing the built-in datasets.

As input values are changed, output plots and tables (% original cover vs. time) update immediately.



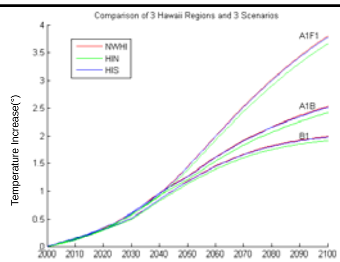
Predicted Changes in Coral Cover, Hawaii

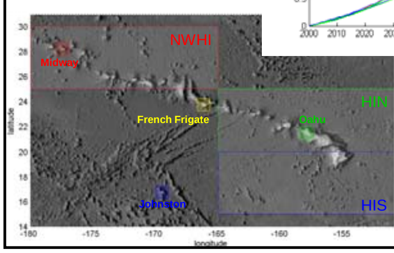


Buddemeier, R. W., P.L. Jokiel, K.M. Zimmerman, D.R. Lane, J. M. Carey, G.C. Bohling, J.A. Martinich. (2008) A modeling tool to evaluate regional coral reef responses to changes in climate and ocean chemistry Limnol Oceanogr. Meth. 6:395–411

Initial COMBO temperature predictions in the Hawaiian Islands are older IPCC (AR3) data and are limited to three 5° latitude x 15° longitude 'boxes', or regions.

These locations were updated to 1°x1° boxes centered on Johnston Atoll, Oahu, French Frigate Shoals, and Midway

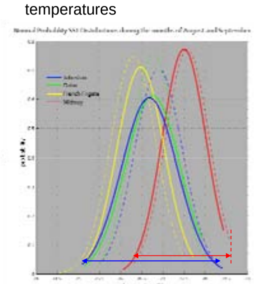




The data itself was updated to reflect the latest model ensembles for current IPCC predictions (AR4).

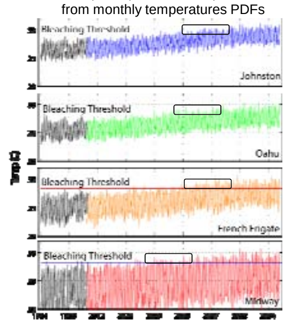
Historical temperature analysis (e.g. Satellite SST) was used to "train" the variability in these predictions.

From SST datasets – calculation of probability density functions (PDFs) of summertime temperatures



Midway has a the largest deviation – much larger than Johnston, e.g. the 'tails' are much longer. Extreme thermal anomalies happen most often here.

Example of predicted temperatures from monthly temperatures PDFs

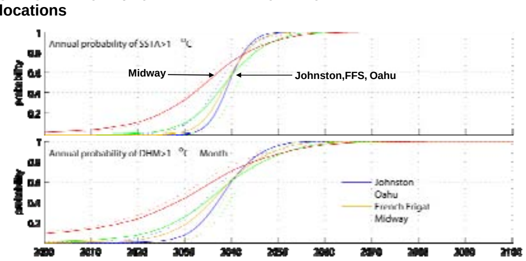


'bleaching threshold' = Maximum Monthly Climatology Value + 1°C

….and the predicted onset of 'regular' mass coral bleaching temperatures is a decade or two earlier

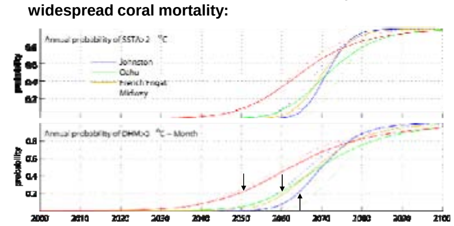
Run this prediction many times ……..

Results in a 50% probability of some coral bleaching occurring each year (every other year) by ~2030 at Midway, ~10 years later at the other locations



But coral mortality is often linked to heat exposure, the time duration of extreme water temperatures, eg 'Degree Heating Weeks' (DHW) or 'Degree Heating Months' (DHM)

Probabilities of 2 DHM, from literature, likely to result in widespread coral mortality:



20% (once every five years) at Midway by ~2050
French Frigate and Oahu ~2060
Johnston by ~2065

Temperature and predictions were derived from the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project phase three (CMIP3) multi-model dataset, constrained and downscaled with historical data.

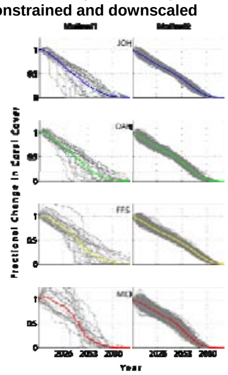
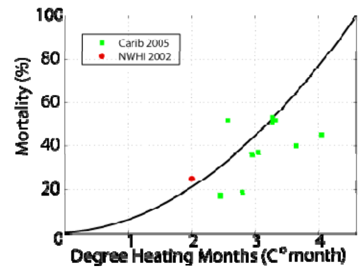


Figure-10: Model results for fractional change in coral cover: episodic mortality with no assumed ability of corals to adapt; Ω_a sensitivity = 0.2. Representations are the same as for Figure 6.



Validation observations

Extremely unlikely that viable coral populations will persist in the shallow waters of the Hawaiian archipelago in 2100; precipitous declines will likely start in the northern region sometime between 2030 and 2050 with steady decline over the entire century throughout the region.
Hoeke et al. (manuscript)

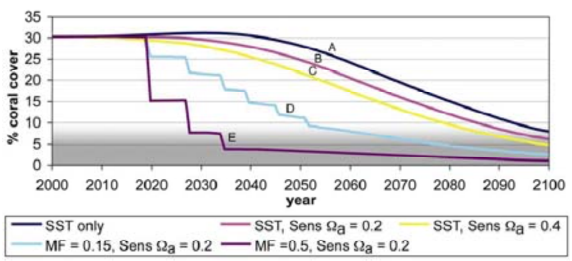


Figure 2. The effects of various mortality and growth scenarios on a coral community with an initial 30% cover. The initial dose is 12.3 DHW, and subsequent thresholds are progressively 2.6 DHW higher; other than this threshold increase, no adaptation is assumed. The A1B climate scenario and the temperature datasets identified in the text are used. A: projected effects on growth of gradual SST increase (no bleaching events) and no Ω effect. B: SST effects, with moderate Ω sensitivity (0.2). C: SST effects, with high Ω sensitivity (0.4). D: 15% mortality per event with moderate Ω sensitivity (0.2). E: as in D, but with 50% mortality per event.

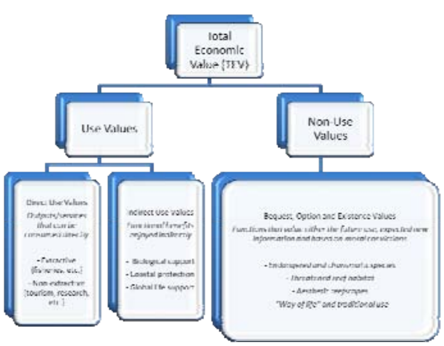
Modeling Regional Coral Reef Responses to Global Warming and Changes in Ocean Chemistry: Caribbean Case Study
R.W. Buddemeier, D.R. Lane, J.A. Martinich (submitted to Climatic Change

Socioeconomic modeling --

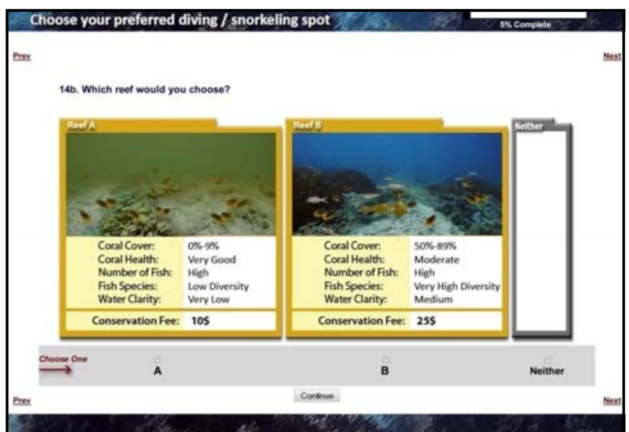
Adapted a STELLA dynamic model previously created (Cesar et al. 2005) to determine changes in reef-related Total Economic Value (TEV) over time. Modifications include adding climate change factors to anthropogenic degradation; TEV factors are tourism, diving/snorkeling, amenity, biodiversity, coastal protection, fish catch, and cultural and traditional values.

TEV, especially for the non-use values, are assessed through a series of surveys that will determine "willingness-to-pay" based on stated choice analysis.

GIS and geographic similarity analysis (typology) was used to apportion vales and probable changes from the case study areas to the archipelago as a whole.



TEV As adapted from Cesar & Van Beukering (2004)

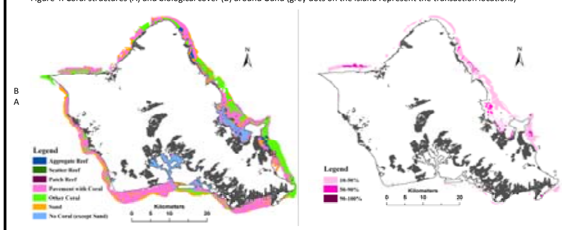


Conservation Fee Choice Task

Discrete Choice Experiments

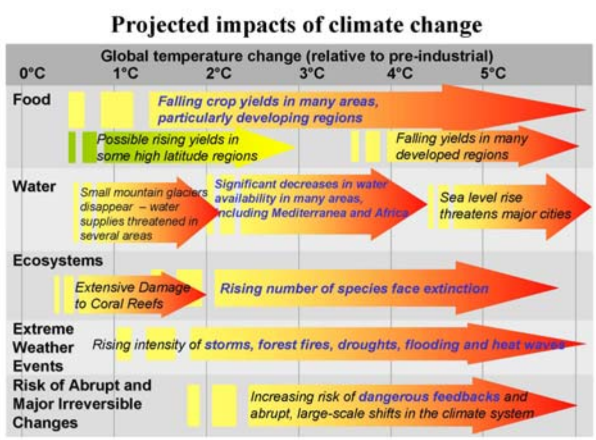
- an alternative to revealed preference analysis
- avoid the problem of multi-colinearity
- multi-attribute trade-off analysis
- evaluation of non-existing alternatives
- decision support systems
- specify models on any appropriate scale (somewhat bound by behavioral relevance to respondent)
- Web-based surveys supplemented by targeted interviews are an efficient and versatile means of collecting responses

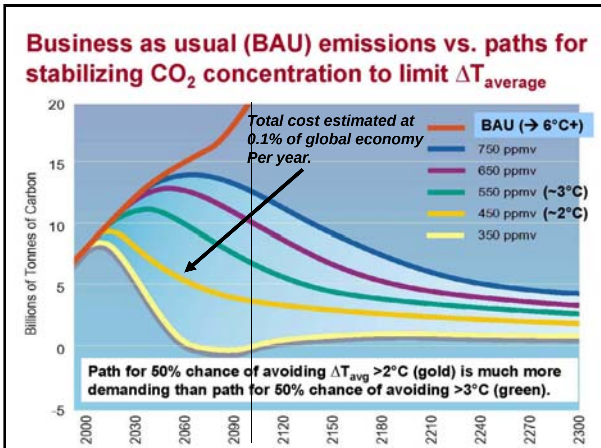
Figure 4: Coral structures (A) and biological cover (B) around Oahu (grey dots on the island represent the transaction locations)

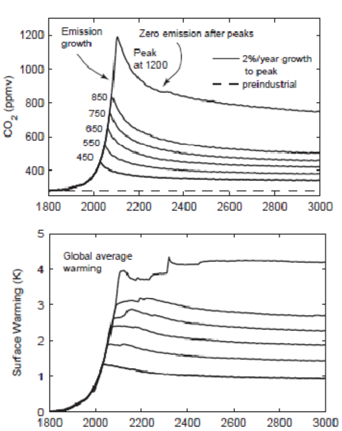


Hedonic Pricing (estimated real estate damage)
Adding the coral reef variables results in a significant improvement of the hedonic price model's fit. a relatively small, but statistically significant improvement of the model's explanatory power, suggesting that **coral reef has a significant impact on house prices, both in terms of presence and quality**.

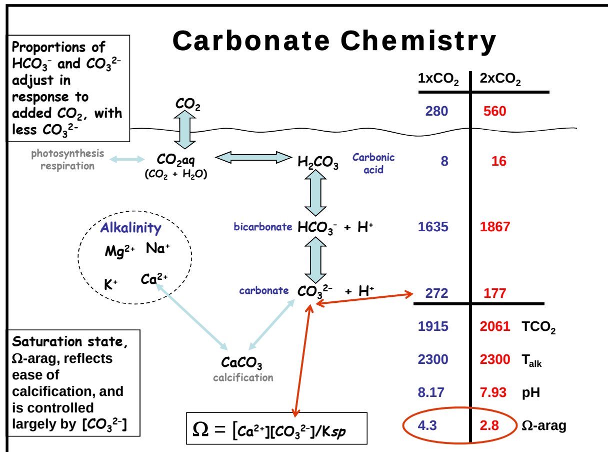
Roy Brouwer, Sebastiaan Hess, Pieter van Beukering, Yi Liu, and Sonia S. Garcia (manuscript)
A Hedonic Price Model of Coral Reef Quality in Hawaii

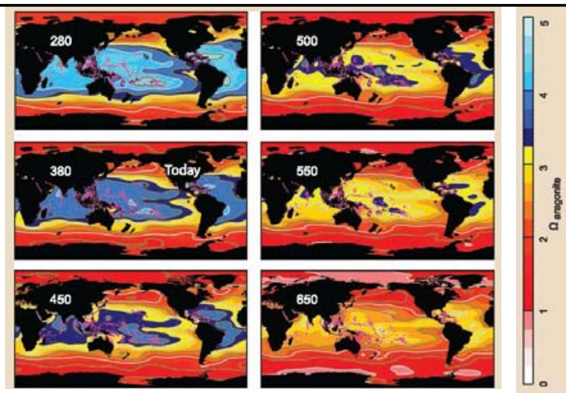






Solomon et al. 2008.
Irreversible climate change due to carbon dioxide emissions.
PNAS 106:11704-1709.





Changes in aragonite saturation predicted to occur as atmospheric CO_2 concentrations (ppm) increase.

Hoegh-Guldberg et al. (2007). Science 318:1737-1742

SFU

Wolfgang Haider

School of Resource and Environmental Management

WTP for mitigation of climate change effects to Hawaiian coral reefs:
A contingent choice study

Research Goal

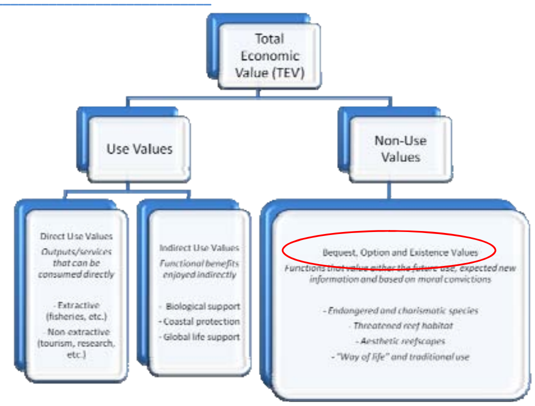
To estimate the willingness to pay (WTP) for mitigating the effects of climate change on coral reefs in Hawaii

Challenges

- To separate use values from non-use values
- To control for key components of the reef ecosystem
- To design a payment vehicle that is applicable from the present, but leads to uncertain outcomes in the future

Method: Contingent Choice Survey

Environmental Valuation



Discrete Choice Experiment

Attribute	Levels							
Coral Cover	0%-9%		10%-49%		50%-89%		90%-100%	
Coral Health	Poor		Moderate		Good		Very Good	
Fish #	Few		Moderate		High		Very High	
Species Diversity	Low Diversity		Moderate Diversity		High Diversity		Very High Diversity	
Water Clarity	Low		Moderate		High		Very High	
Mitigation Fee	$10	$20	$40	$60	$80	$100	$150	$200
Turtle	No Turtle				Turtle			
Relief	Low			Medium			High	

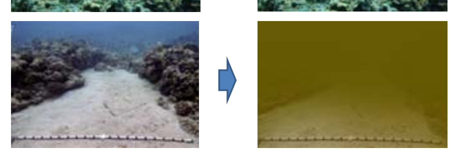
Ideal for visualization

Discrete Choice Experiment -Visualization

Coral Cover

Fish Numbers

Water Clarity



Discrete Choice Experiment – Visualization of Turbidity

Option 1: Effluent/Run-off. Used the same brown/green colour for each level and adjusted opacity as turbidity increased.

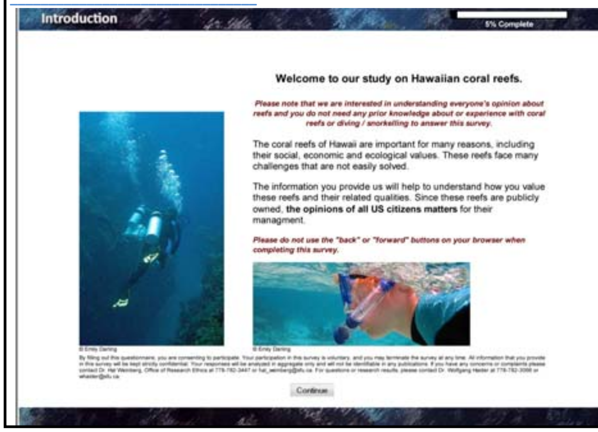
Option 2: Algae. Blue/green colour darkens and opacity adjusted as turbidity increased.

Original image with adjusted colour, contrast, levels.

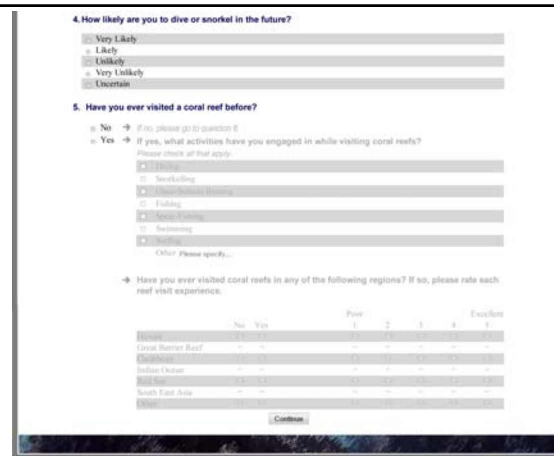
Original image

Option 3: Black filter used throughout. Opacity adjusted as turbidity increased.

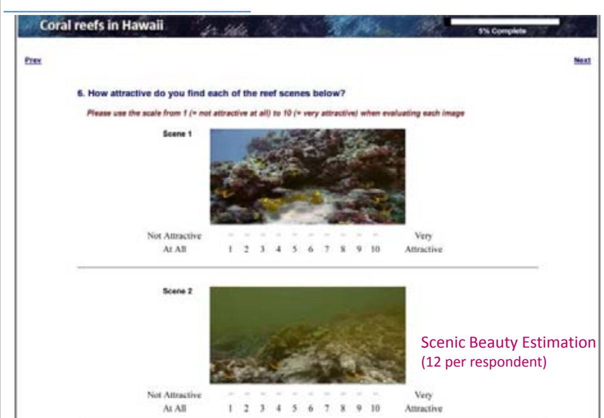
The Survey Instrument



Survey – Introductory Questions

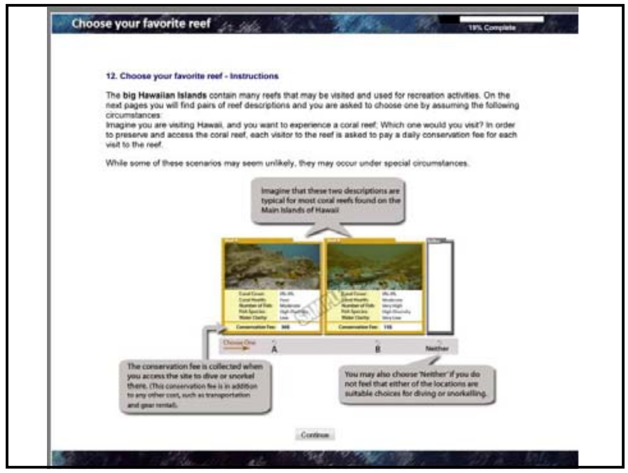


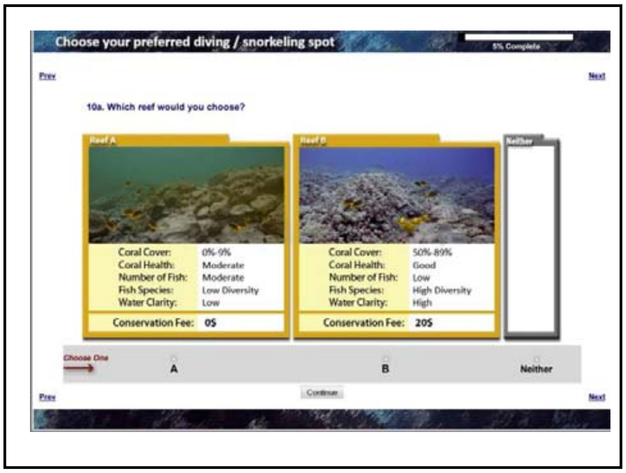
Survey - Introduction of Coral Reefs

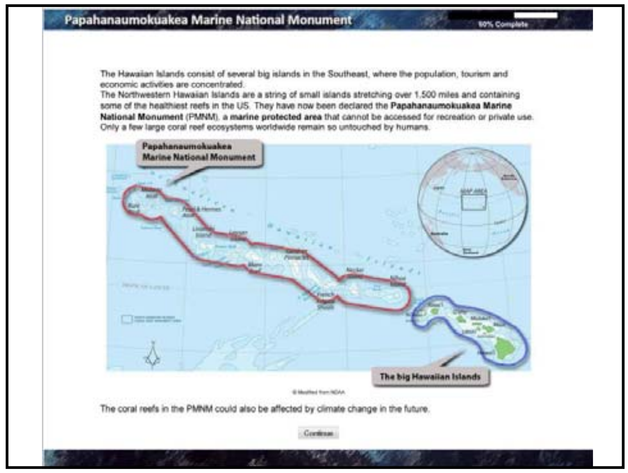


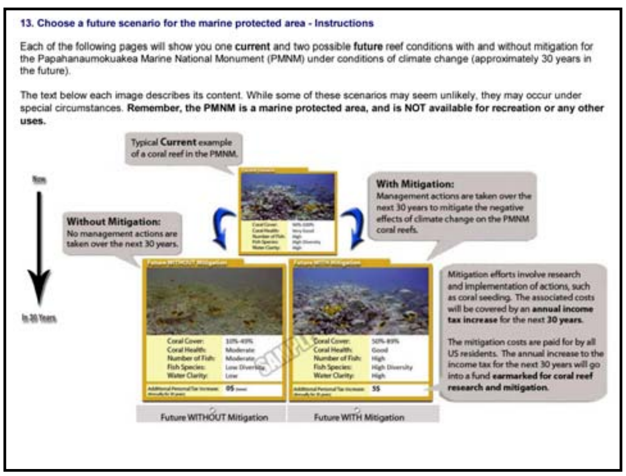
Scenic Beauty Estimation
(12 per respondent)


Coral reefs and climate change
15% Complete
Scientists now agree that climate change will lead to environmental changes worldwide. Coral reefs will be affected by rising ocean temperatures. They might bleach, and eventually the numbers of corals and their associated marine life will decline.
Bleached Coral
The Hawaiian coral reefs will also be affected by climate change. The only way to prevent this is to develop and use local mitigation measures. No such measures are in place at the moment, but could be developed in the future. Possible measures include the cultivation and planting of corals and the establishment of marine protected areas.
Coral Seeding
11. Should humans take actions to reduce climate change?
No
Yes
If yes, who should lead and coordinate these actions?
Please specify...
Continue


Choose your favorite reef
19% Complete
12. Choose your favorite reef - Instructions
The big Hawaiian Islands contain many reefs that may be visited and used for recreation activities. On the next pages you will find pairs of reef descriptions and you are asked to choose one by assuming the following circumstances:
Imagine you are visiting Hawaii, and you want to experience a coral reef: Which one would you visit? In order to preserve and access the coral reef, each visitor to the reef is asked to pay a daily conservation fee for each visit to the reef.
While some of these scenarios may seem unlikely, they may occur under special circumstances.
Imagine that these two descriptions are typical for most coral reefs found on the Main Islands of Hawaii
Choose One
A
B
Neither
The conservation fee is collected when you access the site to dive or snorkel there. (This conservation fee is in addition to any other cost, such as transportation and gear rental).
You may also choose 'Neither' if you do not feel that either of the locations are suitable choices for diving or snorkelling.
Continue


Choose your preferred diving / snorkeling spot
5% Complete
Prev
Next
10a. Which reef would you choose?
Reef A
Coral Cover: 0%-9%
Coral Health: Moderate
Number of Fish: Moderate
Fish Species: Low Diversity
Water Clarity: Low
Conservation Fee: 0$
Reef B
Coral Cover: 50%-89%
Coral Health: Good
Number of Fish: Low
Fish Species: High Diversity
Water Clarity: High
Conservation Fee: 20$
Neither
Choose One
A
B
Neither
Continue


Papahanaumokuakea Marine National Monument
50% Complete
The Hawaiian Islands consist of several big islands in the Southeast, where the population, tourism and economic activities are concentrated.
The Northwestern Hawaiian Islands are a string of small islands stretching over 1,500 miles and containing some of the healthiest reefs in the US. They have now been declared the Papahanaumokuakea Marine National Monument (PMNM), a marine protected area that cannot be accessed for recreation or private use. Only a few large coral reef ecosystems worldwide remain so untouched by humans.
Papahanaumokuakea Marine National Monument
The big Hawaiian Islands
The coral reefs in the PMNM could also be affected by climate change in the future.
Continue


13. Choose a future scenario for the marine protected area - Instructions
Each of the following pages will show you one current and two possible future reef conditions with and without mitigation for the Papahanaumokuakea Marine National Monument (PMNM) under conditions of climate change (approximately 30 years in the future).
The text below each image describes its content. While some of these scenarios may seem unlikely, they may occur under special circumstances. Remember, the PMNM is a marine protected area, and is NOT available for recreation or any other uses.
Typical Current example of a coral reef in the PMNM.
Now
In 30 Years
Without Mitigation:
No management actions are taken over the next 30 years.
With Mitigation:
Management actions are taken over the next 30 years to mitigate the negative effects of climate change on the PMNM coral reefs.
Coral Cover: 10%-49%
Coral Health: Moderate
Number of Fish: Moderate
Fish Species: Low Diversity
Water Clarity: Low
0$
Coral Cover: 50%-89%
Coral Health: Good
Number of Fish: High
Fish Species: High Diversity
Water Clarity: High
5$
Mitigation efforts involve research and implementation of actions, such as coral seeding. The associated costs will be covered by an annual income tax increase for the next 30 years.
The mitigation costs are paid for by all US residents. The annual increase to the income tax for the next 30 years will go into a fund earmarked for coral reef research and mitigation.
Future WITHOUT Mitigation
Future WITH Mitigation

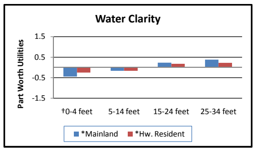

Choose a future reef scenario
5% Complete
Prev
Next
13b. Given the current situation, which future scenario would you select for the marine protected area (PMNM)?
Current Scenario
Future WITHOUT Mitigation
Coral Cover: 0%-9%
Coral Health: Moderate
Number of Fish: High
Fish Species: Low Diversity
Water Clarity: Very Low
Additional Personal Tax Increase: 0$
Future WITH Mitigation
Coral Cover: 50%-89%
Coral Health: Moderate
Number of Fish: High
Fish Species: Very High Diversity
Water Clarity: Medium
Additional Personal Tax Increase: 20$
Future WITHOUT Mitigation
Future WITH Mitigation
Continue

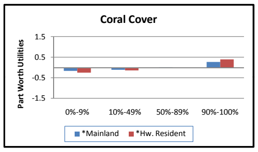
Results - Part Worth Utility

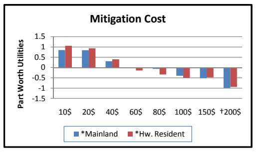
Water Clarity
- Linear Coded
- Main: (z= 7.5854)
- Hw: (z= 4.1891)

Coral Cover
- Linear Coded
- Main: (z= 5.2785)
- Hw: (z= 3.5037)

Mitigation Cost
- Linear Coded
- Main: (z= -16.588)
- Hw: (z= -11.2983)





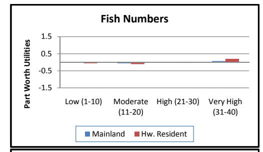


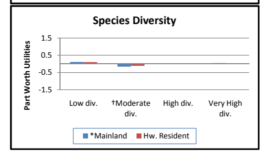
Results - Part Worth Utility

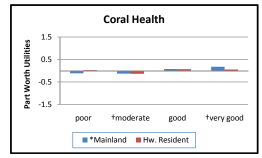
Fish Numbers
- Linear Coded
- Hw: (z= 3.1383)

Species Diversity
- Effects Coded
- Main: Moderate Div. (z= -2.6745)

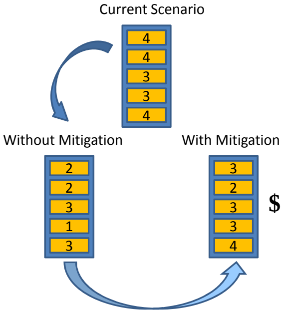
Coral Health
- Effects Coded
- Main: Moderate Health (z= -3.1115)
- Main: Very Good Health (z= 2.6669)
- Hw: Moderate Health (z = -2.2689)

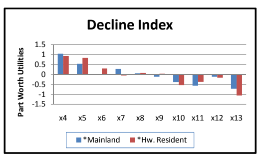






Results - Decline Index





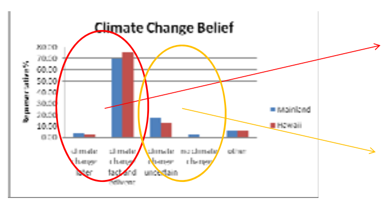
Decline Index = 7

(Improvement Index = 4)

Explaining Heterogeneity

Which of the following statements best reflects your opinion about climate change?

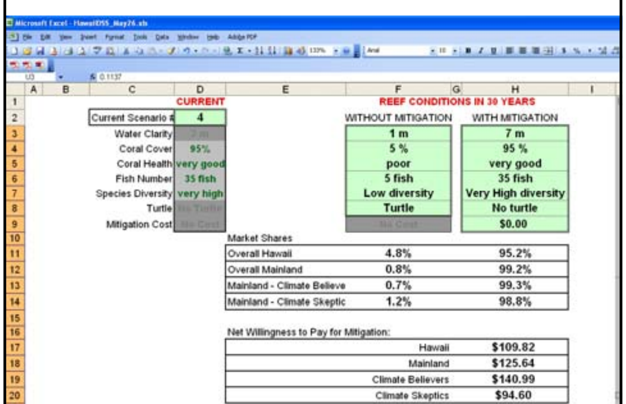
- There will be climate change, but the implications will only be noticeable later
- Climate change is a fact and the first indications are evident already
- Evidence about climate change is still too uncertain; it is too early to know what will happen
- I do not believe in climate change
- Other (please specify…)



Climate Change Believers

Climate Change Skeptics

Decision Support Tool



Decision Support Tool - Scenarios

Attribute	**Best-case scenario**			**Worst case scenario**			**Maximum Difference**		
	Current	Without Mitigation	With Mitigation	Current	Without Mitigation	With Mitigation	Current	Without Mitigation	With Mitigation
Water Clarity	7m	7m	7m	7m	1m	1m	7m	1m	7m
Coral Health	70%	95%	95%	95%	5	5	95%	5	95%
Coral Cover	Good	Very Good	Very Good	Very Good	Poor	Poor	Very Good	Poor	Very Good
Fish Number	25 fish	35 fish	35 fish	35 fish	5 fish	5 fish	35 fish	5 fish	35 fish
Species Diversity	High	Very High	Very High	Very High	Low	Low	Very High	Low	Very High
Turtle	No Turtle	No Turtle	No Turtle	No Turtle	Turtle	Turtle	No Turtle	Turtle	No Turtle
Mitigation Cost	0$	No Cost	0$	0$	No Cost	200$	0$	No Cost	0$
Market Share *Hawaii*		72.8%	27.2%		97.1%	2.9%		4.8%	95.2%
Mainland		56.9%	43.1%		64.1%	35.9%		3.0%	97.0%
Net WTP *Hawaii*			**($36.25)**			**($129.04)**			**$109.82**
Mainland			**($32.69)**			**($68.42)**			**$125.64**

No gain, no pain

(residual for branding)

guilt

Thanks to:

Mike Taylor

Ben Beardmore

(REM, SFU)

Pieter van Beukering

Roy Brouwer

(Cesar Consulting, NL)

The rest of the Team

Explaining Heterogeneity

Mainland	3 Class		
	Class 1 (n=669)	Class 2 (n=234)	Class 3 (n=81)
Water Clarity*	0.3391 *(0.0573)* •	0.2538 *(0.0571)* •	-0.433 *(0.3148)*
Coral Cover*	0.1416 *(0.0365)* •	0.1424 *(0.0287)* •	-0.0278 *(0.0831)*
Coral Health†	-0.9416 *(0.3268)* •	0.045 *(0.1738)*	-0.2255 *(0.5416)*
	-0.339 *(0.1294)* •	-0.1768 *(0.111)*	0.1735 *(0.2904)*
	0.3236 *(0.1526)* •	0.1827 *(0.1116)*	-0.2556 *(0.3583)*
	0.957 *(0.2474)* •	-0.051 *(0.1626)*	0.3075 *(0.49)*
Fish #*	0.0846 *(0.0668)*	0.031 *(0.0489)*	-0.0631 *(0.137)*
Spec. Diversity†	-0.2558 *(0.2283)*	-0.0621 *(0.1884)*	0.2936 *(0.492)*
	-0.4842 *(0.1142)* •	-0.0807 *(0.1057)*	-0.0367 *(0.3267)*
	0.0302 *(0.1424)*	0.2282 *(0.1177)*	-0.0909 *(0.3323)*
	0.7099 *(0.2197)* •	-0.0853 *(0.1616)*	-0.1659 *(0.4194)*
Turtle†	0.2529 *(0.1258)* •	-0.1158 *(0.1321)*	0.4314 *(0.3967)*
	-0.2529 *(0.1258)* •	0.1158 *(0.1321)*	-0.4314 *(0.3967)*
Mitigation Fee*	-0.2348 *(0.0573)* •	-0.7369 *(0.0622)* •	-0.963 *(0.2305)* •
Climate Belief	0.7883 *(0.1247)* •	-0.2983 *(0.1484)* •	1.0866 *(0.194)* •
Intercept	2.1391 *(0.2112)* •	0.5307 *(0.2419)* •	-2.669 *(0.3528)* •

*attributes that were linear coded
†attributes that were effects coded
( ) Standard Error
• represents significance at the 10% level

Class 1=
Pro-Mitigation Climate Believers

Class 2=
Anti-Mitigation Climate Believers

Class 3=
Anti-Mitigation Climate Skeptics

Hydrologic Forecasting for Characterization of Non-Linear Responses of Freshwater Wetlands to Climatic and Land Use Change in the Susquehanna River Basin, USA

Denice Wardrop[1]; Christopher Duffy[3]; Kevin Dressler[2]; Raymond Najjar[4];Richard Ready[5];Kristen Hychka[1]; Susan Yetter[1]; and Mary M. Easterling[1]

Penn State University
[1] Cooperative Wetlands Center, Department of Geography
[2] Penn State Institutes of Energy and Environment,
[3] Department of Civil Engineering
[4] Department of Meteorology
[5] Department of Agricultural Economics and Rural Sociology

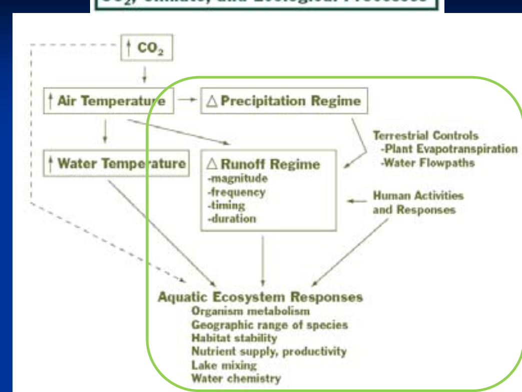
This research is funded by U.S. EPA - Science To Achieve Results (STAR) Program Grant # 83301301

EPA Project Officer Brandon Jones


Wetlands in the Basin

- Comprise 2-4% landscape
- Small (<10 acres)
- 73% of wetland area associated with headwater streams (0-3rd order)
- Predominantly forested
- Unmapped forested wetlands ~50% of resource
- Support > 75% threatened and endangered plant species

CO_2, Climate, and Ecological Processes



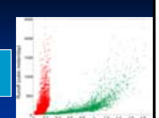
Poff et al 2005

Characterizing non-linear responses through:

- Selection of a linked terrestrial-aquatic ecosystem that provides critical ecosystem services and ecological functions,
- Characterization of various global change scenarios, incorporating both climate and land cover, and a method of assessing their effect on the identified ecosystem through the primary forcing factor of hydrology (both alone and in conjunction with other human-associated stressors),
- Identification of potential nonlinear ecological responses (sensu Scheffer et al., 2002) in the selected ecosystem as a result of these changes, and
- Estimation of the resultant change in ecosystem services on a watershed and Basin-wide scale.

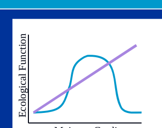
Scenarios of Climate Change → Predictive Hydrologic Scenarios

Scenarios of Land Cover Change → Predictive Hydrologic Scenarios



Predictive Hydrologic Scenarios → Functional Loss Estimates + Plants and Macroinvertebrates

Hydrology/Ecological Function Models → Functional Loss Estimates + Plants and Macroinvertebrates



Functional Loss Estimates + Plants and Macroinvertebrates → Valuation of Changes in Ecosystem Services

Functional Loss Estimates + Plants and Macroinvertebrates → Identification of Non-Linearities

Specification of Scale

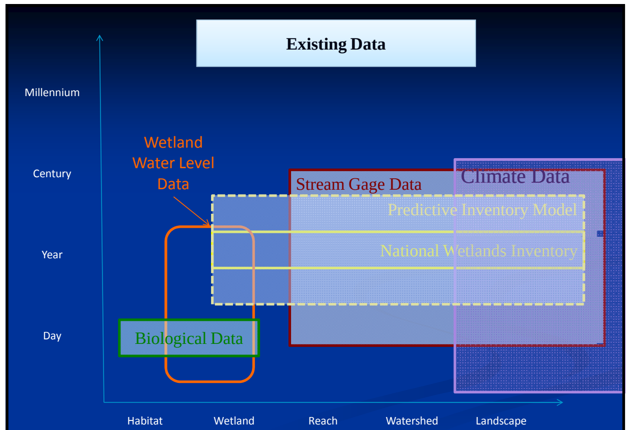
Or, does size matter?

Scaling Issues

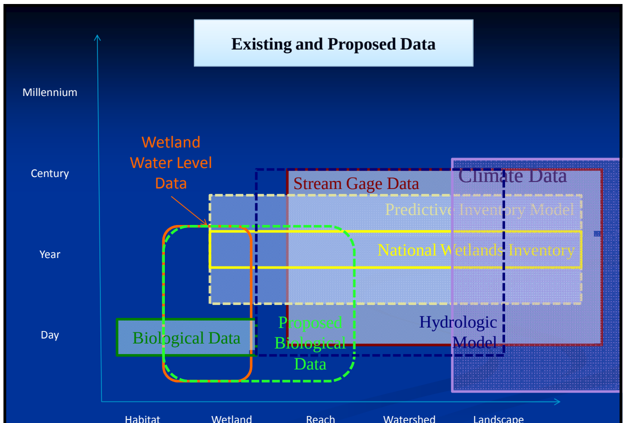
- What is our assessment unit?
- How do we stratify the study area for the purpose of sampling, modeling, and subsequent "scaling up"?
- At what scale do we express final results?
- How do we resolve differences in scale (both extent and resolution) of different disciplinary components of the project?

Assessment unit that:

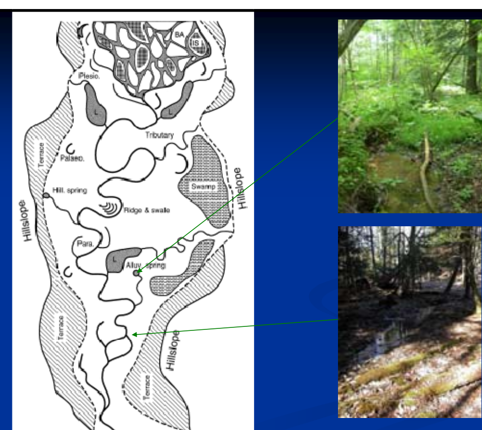
- Integrates freshwater wetlands with important contextual landscape
- Spatial and temporal scale that matches ecosystem services
- Scale capable of being modeled
- Representative of the range of conditions in the SRB



Interpreted from Benda et al. 2002



Interpreted from Benda et al. 2002



Ward, J. V., K. Tockner, D. B. Arscott, and C. Claret. 2002. Riverine landscape diversity. Freshwater Biology 47:517-539.

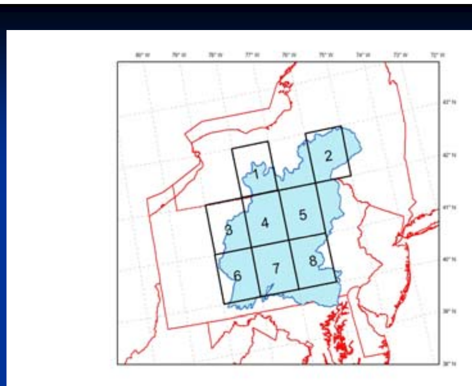
Climate Scenarios

Or, the weather's fine, wish you were here

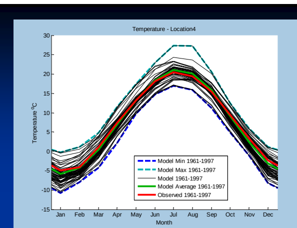
Climate models

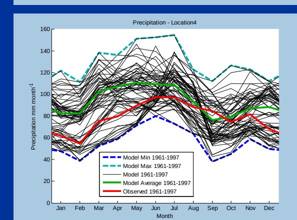
- World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project Phase 3 (CMIP3) multi-model dataset
- Daily & monthly averages of 2-m temperature and precipitation
- 21 models from 12 countries
- Some models: multiple realizations
- Horizontal resolution: ~1.5° to 4.5°
- 20th century: observed forcing
- 21st century: A2 scenario

GCM output and observational data were placed on a one degree grid within the SRB



Mean annual cycle of monthly means of temperature (top) and precipitation (bottom) at grid cell 4 in the SRB for the models and the observations. Each thin black line is a realization.





Computation of Performance Index
[approach of Reichler and Kim (2008)]

1) Compute an overall squared error computed for each variable (*v*, one of the 10 metrics) and for each model (*m*) where,
   - *n* spans all 12 calendar months and 8 grid points within the SRB;
   - *svmn* represents the simulated metric for each model, month, and grid point;
   - *ovn* is the corresponding observed metric;
   - and *svn* is the observed interannual variance.

$$e^2_{vm} = \sum_{n=1}^{96} \frac{\left(s_{vmn} - o_{vn}\right)^2}{\sigma^2_{vn}}$$

2) Normalize e^2_{vm} by its average over all of the models:

$$I^2_{vm} = \frac{e^2_{vm}}{\overline{e^2_{vm}}^{m}}$$

3) Finally, compute the overall performance index by averaging over all of the metrics:

$$I^2_{v} = \overline{I^2_{vm}}^{v}$$

Metrics for Model Selection

- Annual cycle of mean temperature
- Annual cycle of mean precipitation
- Annual cycle of interannual temperature variability (standard deviation)
- Annual cycle of interannual precipitation variability (standard deviation)
- Mean annual cycle of intramonthly temperature variability (std. dev.)
- Mean annual cycle of intramonthly precipitation variability (std. dev.)
- Mean annual cycle of the maximum number of consecutive dry days within a month
- Mean annual cycle of the maximum 5-day precipitation total within a month
- Mean annual cycle of precipitation intensity (total monthly precipitation divided by the number of wet days*)
- Mean annual cycle of the number of days with precipitation exceeding 10 mm

*A wet day is considered to be a day in which precipitation exceeds 1 mm.

Model Performance

Overall model performance index for the 21 models and the multi-model average. This index was computed using the mean annual cycles in monthly means, interannual variability, and intramonthly variability in temperature and precipitation.

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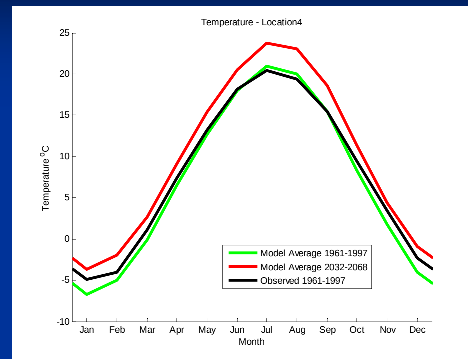
Projections



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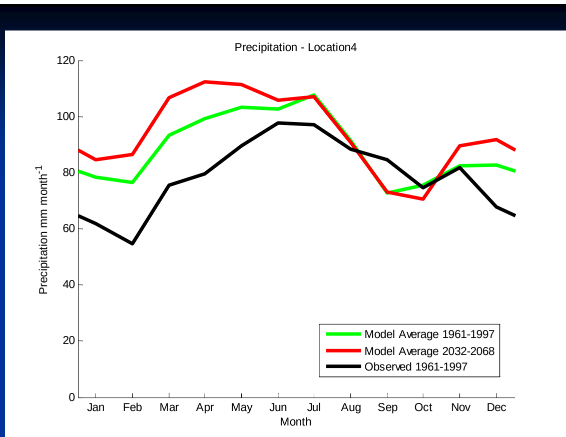

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Climate Considerations

- Models differ dramatically in their ability to predict the climate of SRB
- Evaluation process for model selection
- Model mean is superior to any individual model (according to 10 metrics), is specific to region
- What are the relevant metrics for model evaluation
- Raw model output is not as bad as thought (precip is so local, would think model would be awful; e.g., # of extreme wet days)

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Hydro model runs

- Daily output from model 1960-1990 (baseline)
- Same thing, but 2035-2065
  - Effect of climate change
- What's the impact of the change in mean climate versus change in variability
  - Repeat first run , modify by change in mean annual cycle (#1-#2)

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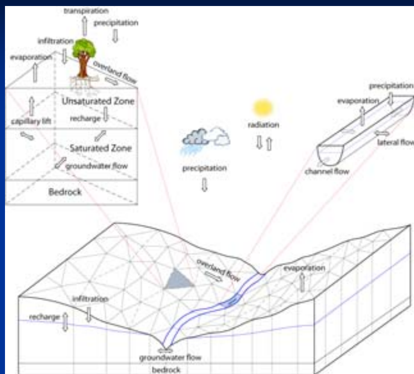
Hydrology model

Or, water flowing underground….

Penn State Integrated Hydrologic Model (PIHM)

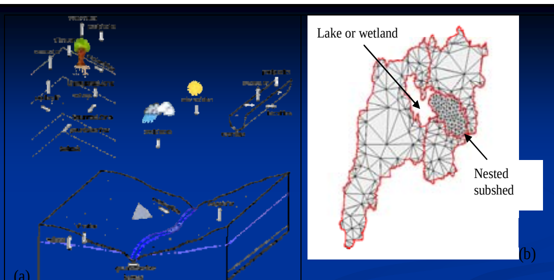


Estimates recharge, bank storage, ephemeral stream losses, climate and landuse effects across river basins

Qu and Duffy 2007

PIHM: Fully-Coupled Finite Volume Theory

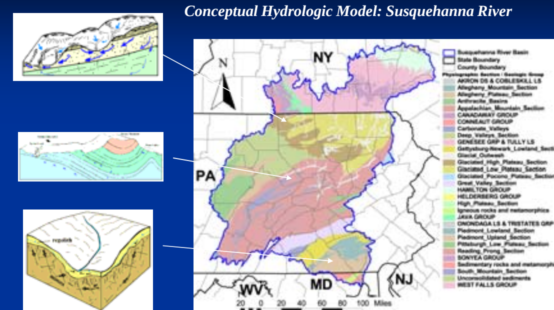
Process	Governing equation/model	Original governing equations	Semi-discrete form
Channel Flow	St. Venant Equation	$\frac{\partial h}{\partial t}+\frac{\partial(uh)}{\partial x}=q$	$\left(\frac{d\zeta}{dt}=P_c-\sum Q_{gc}+\sum Q_{sc}+Q_{in}-Q_{out}-E_c\right)_i$ [1]
Overland Flow		$\frac{\partial h}{\partial t}+\frac{\partial(uh)}{\partial x}+\frac{\partial(vh)}{\partial y}=q$	$\left(\frac{\partial h}{\partial t}=P_n-I-E_o-Q_{sc}+\sum_{j=1}^{3}Q_s^j\right)_i$ [2]
Unsaturated Flow	Richard Equation	$C(\psi)\frac{\partial \psi}{\partial t}=\nabla\cdot(K(\psi)\nabla(\psi+Z))$	$\left(\frac{d\xi}{dt}=I-q^s-ET_s\right)_i$ [3]
Groundwater Flow		$C(\psi)\frac{\partial \psi}{\partial t}=\nabla\cdot(K(\psi)\nabla(\psi+Z))$	$\left(\frac{d\zeta}{dt}=q^s+\sum_{j=1}^{3}Q_g^j-Q_l+Q_{gc}\right)_i$ [3]
Interception	Bucket Model	$\frac{dS_I}{dt}=P-E_I-P_n$	$\left(\frac{dS_I}{dt}=P-E_I-P_n\right)_i$
Snowmelt	Temperature Index Model	$\frac{dS_{snow}}{dt}=P-E_{snow}-\Delta w$	$\left(\frac{dS_{snow}}{dt}=P-E_{snow}-\Delta w\right)_i$
Evapotranspiration	Penman-Monteith Method	$ET_0=\frac{\Delta(R_n-G)+\rho_a C_p\frac{(e_s-e_a)}{r_a}}{\Delta+\gamma(1+\frac{r_s}{r_a})}$	$\left(ET_0=\frac{\Delta(R_n-G)+\rho_a C_p\frac{(e_s-e_a)}{r_a}}{\Delta+\gamma(1+\frac{r_s}{r_a})}\right)_i$

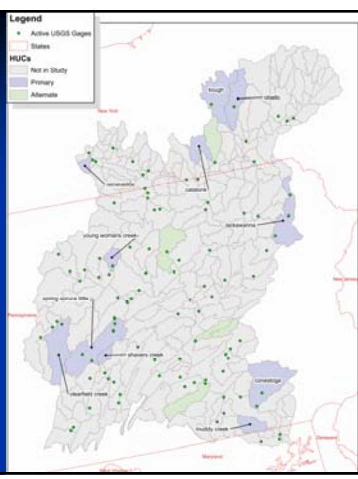


a) The finite volume approach uses a TIN (triangular irregular network) to decompose the watershed into elements and projects the TIN downward to form the Finite Volume for modeling. Note that all surface water bodies are represented along edges of the triangular grid allowing accurate representation of stream and lake boundaries while still minimizing the number of elements in the watershed.

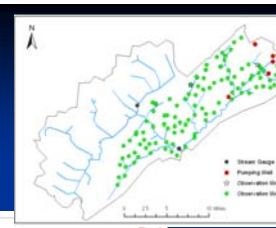
b) Example watershed decomposition into a TIN, shown for the case with a nested high resolution sub-watershed and a lake or wetland.

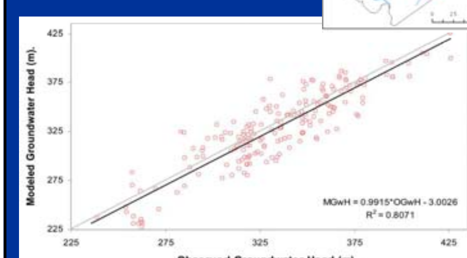
Conceptual Hydrologic Model: Susquehanna River

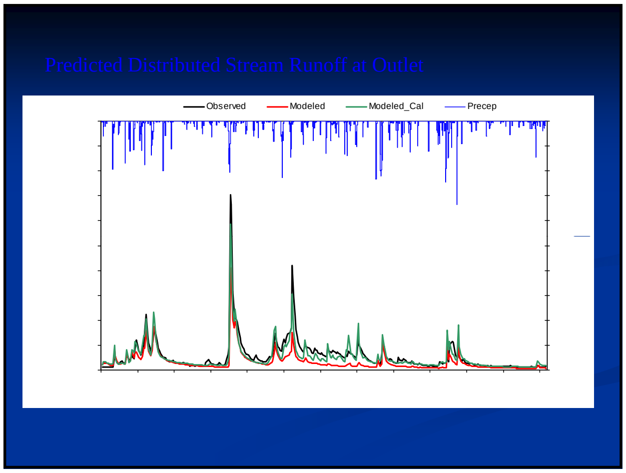


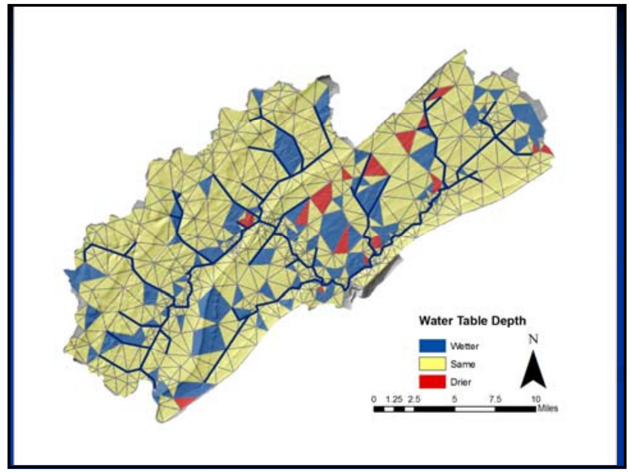


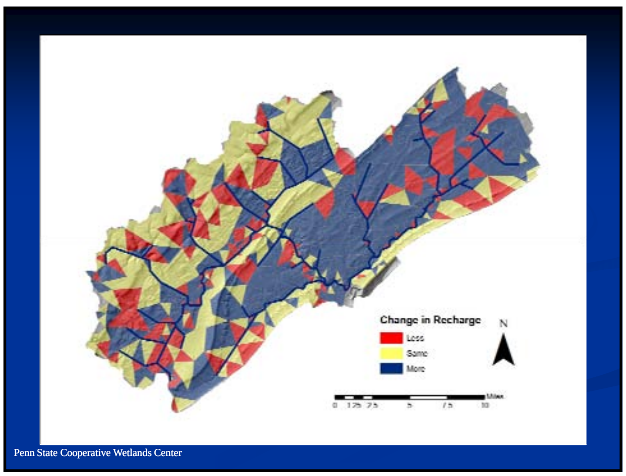
Predicted Groundwater






Predicted Distributed Stream Runoff at Outlet
Observed
Modeled
Modeled_Cal
Precep


Water Table Depth
Wetter
Same
Drier
N
0 1.25 2.5 5 7.5 10
Miles


Change in Recharge
Less
Same
More
N
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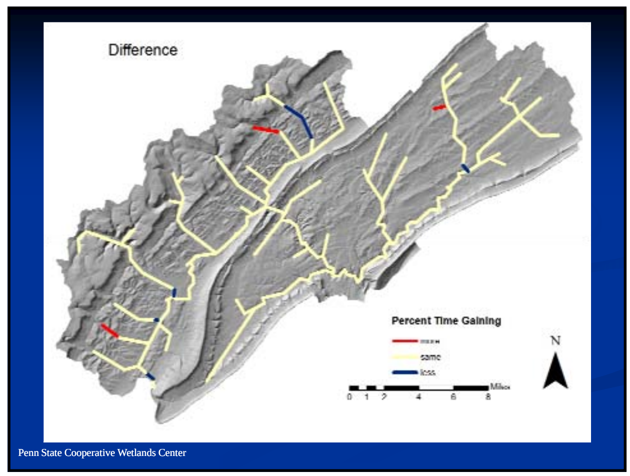
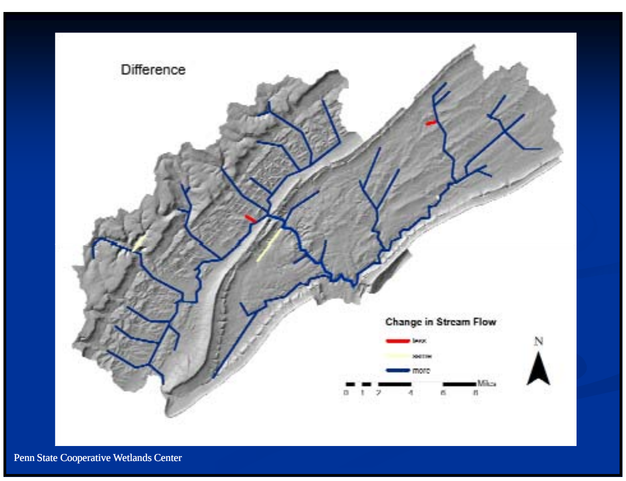
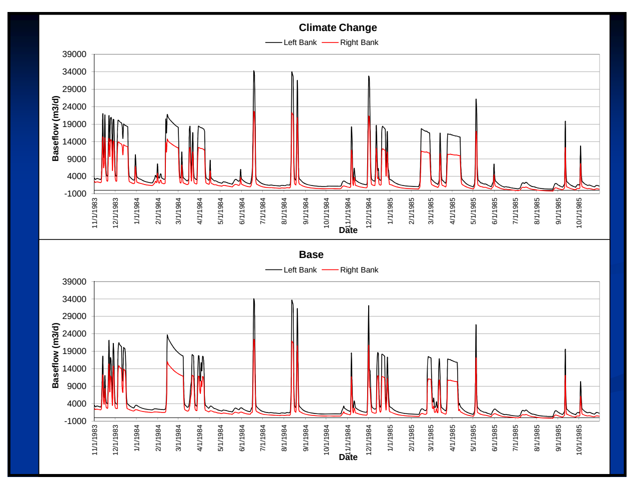
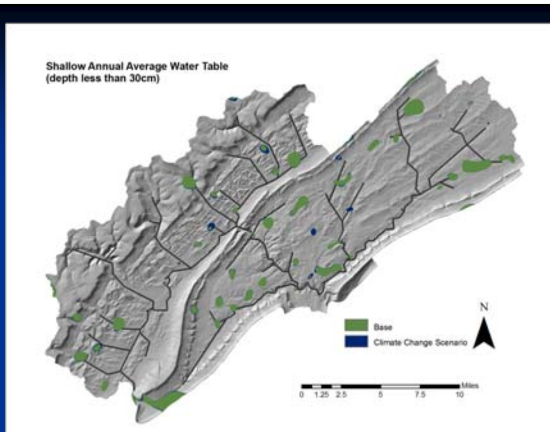

Difference
Percent Time Gaining
same
less
N
0 1 2 4 6 8
Penn State Cooperative Wetlands Center


Difference
Change in Stream Flow
N
Penn State Cooperative Wetlands Center


Climate Change
Left Bank
Right Bank
Baseflow (m3/d)
Date
Base
Left Bank
Right Bank
Baseflow (m3/d)
Date



Hydrological Modeling Considerations

- Scale-appropriate and ecologically-relevant hydrologic scenarios
- Ecologically-relevant and powerful metrics are difficult to identify
- Spatially heterogeneous response to a homogeneous forcing function
- Absolute values of predictions are difficult to utilize in a meaningful way

Ecological Response

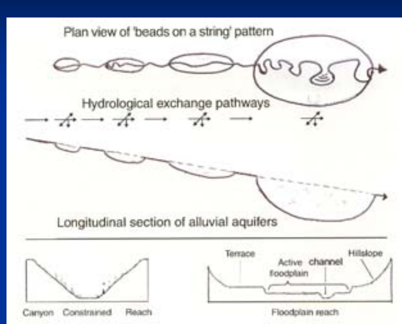
Or, it's all so complex

Ecological Non-linearities

- Could changes in the hydrologic regime result in:
  - The loss of wetland area?
  - The loss of function through physical changes and the loss of functional process zones?

REACH CLASSIFICATION

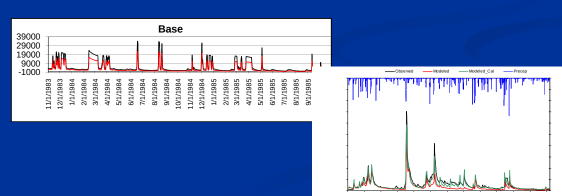
Unconfined river reaches occur in areas of 3-dimensional hydrologic exchange and are characterized by high spatial and temporal heterogeneity

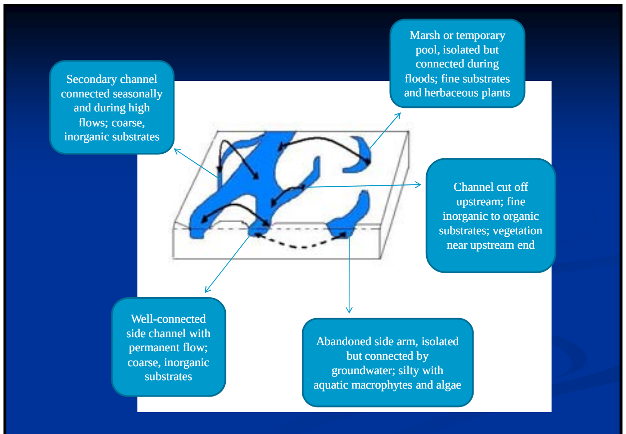


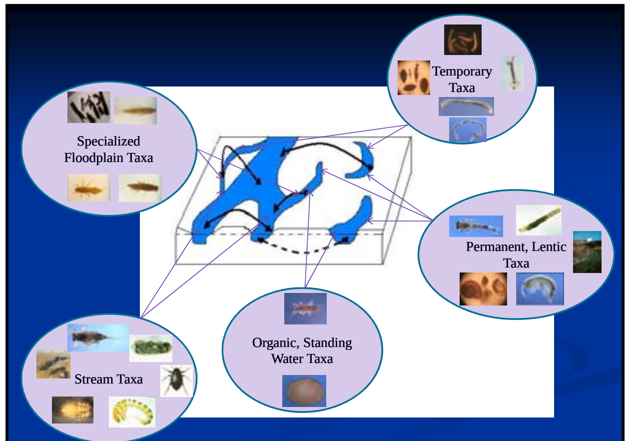
Ward et al. 2002

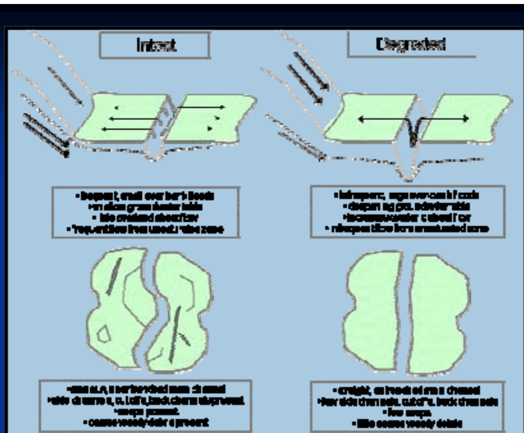
"Super Sites"

Reach Type/Disturbance	Floodplain (<5 sq. miles)	Mixed (5-10 sq. miles)	Wetland (>10 sq miles)
Low			
Moderate			
High			









"Super Sites"

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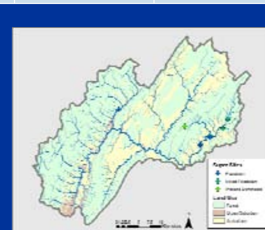

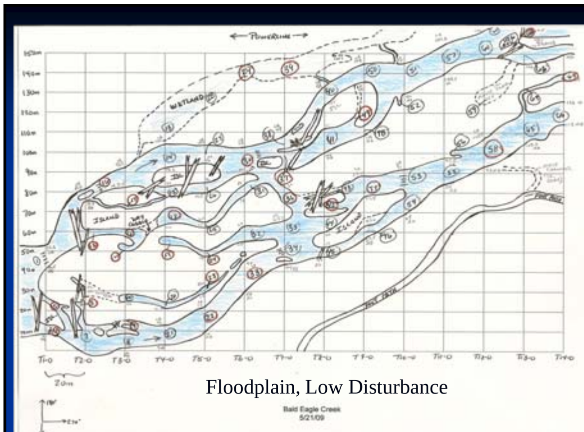

Floodplain, Low Disturbance

BALD EAGLE CREEK

Plot 11

Plot 22

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Plot 23

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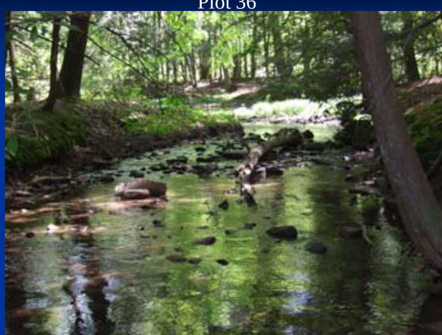
Plot 36



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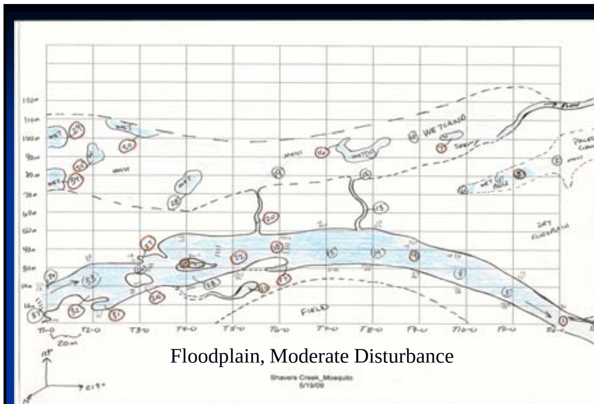

Floodplain, Moderate Disturbance

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SHAVERS CREEK _ MOSQUITO

PLOT 34

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PLOT 24

Penn State Cooperative Wetlands Center

PLOT 22

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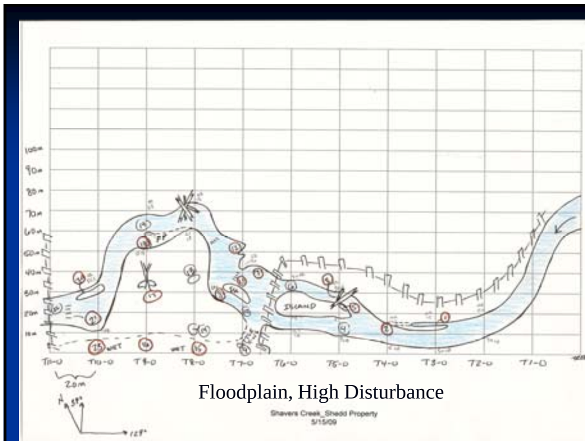

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PLOT 23

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PLOT 11

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PLOT 3

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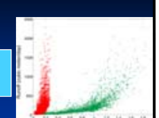
Scenarios of Climate Change

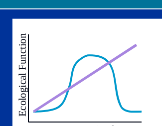
Scenarios of Land Cover Change

Predictive Hydrologic Scenarios



Hydrology/Ecological Function Models

Functional Loss Estimates + Plants and Macroinvertebrates



Valuation of Changes in Ecosystem Services

Identification of Non-Linearities

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Interactions with Clients

- Pennsylvania Climate Change Impacts Assessment (PA Climate Change Advisory Panel)
- Chesapeake Bay Climate Impacts Assessment (CBP STAC)
- Integrated Riparian Assessment Unit for Pennsylvania DEP
- Climate change impacts for wetlands, Mid-Atlantic Wetland Workgroup

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Lessons Learned

- Scale, scale, scale
- Choosing climate models for ecological applications
- The good and bad news of, “which hydrology metric would you like?”
- Use data visualization tools whenever possible

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Continued Studies

- Hydrologic modeling
  - Difficult to truly parse groundwater component of water regime for site data alone; investigating hydrologic complexity at site scale
  - Hydrologic modeling can trace water source (McKillop et al. 1999, Cloke et al. 2006)
- Continuing to characterize and validate physical and functional reach characterizations across physiographic provinces
- Run the hydrologic models with a range of land use scenarios
- Define distributions of hydrologic parameters for each reach type/disturbance cell, and extrapolate results Basin-wide

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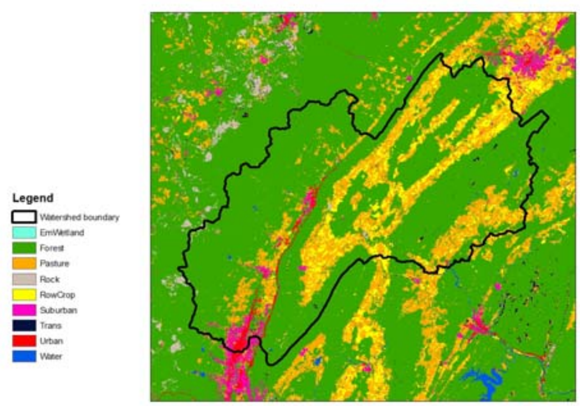
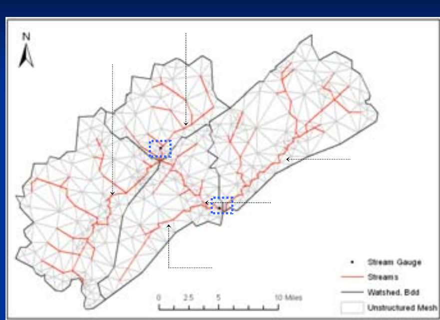


Domain Decomposition



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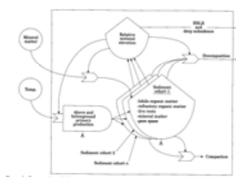
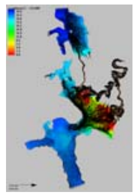
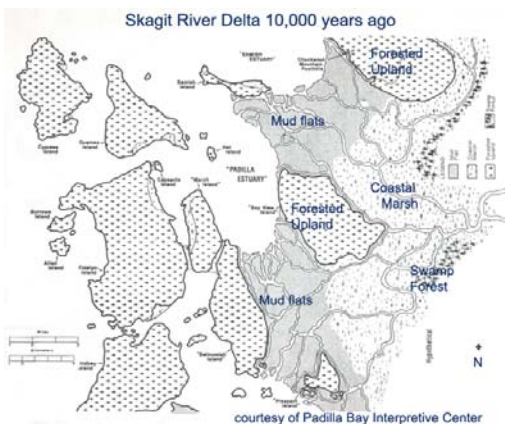
Sustainable Coastal Habitat Restoration
In the Pacific Northwest

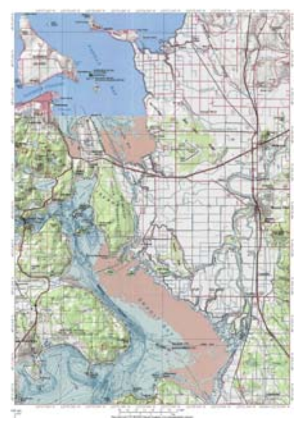
Greg Hood, Tarang Kangaonkar,
John Rybczyk, Zhaoqing Yang



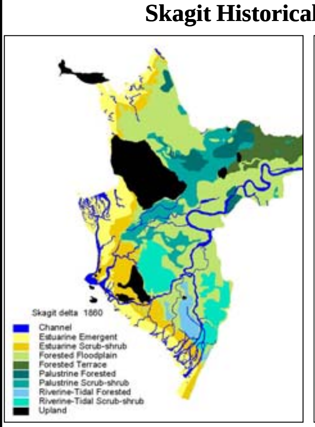
Modeling and Managing the Effects, Feedbacks and Risks Associated with Climate Change

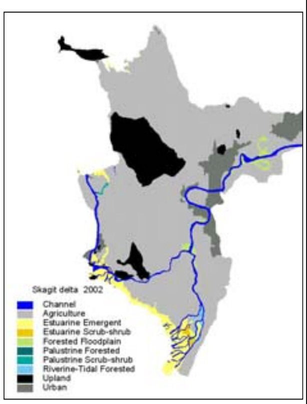




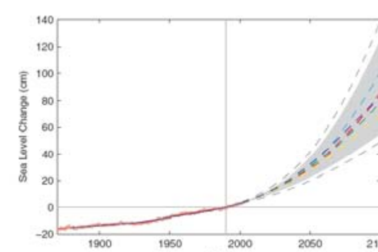


Skagit Historical and Current Deltas

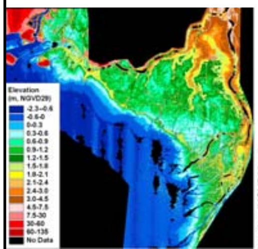




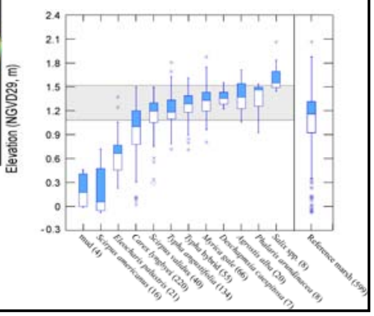
B. Collins 2001 (University of Washington) **W. G. Hood, unpublished (Skagit System Cooperative)**

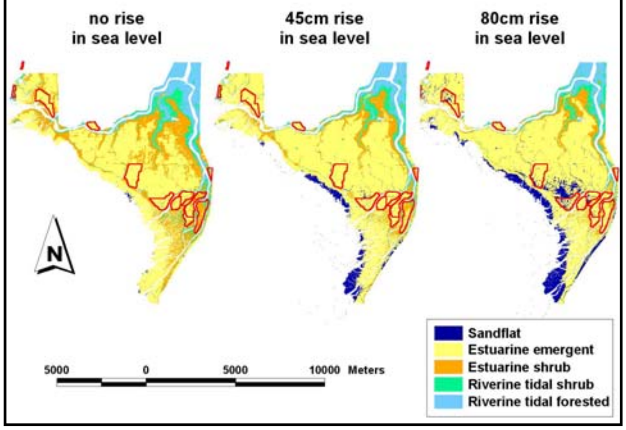


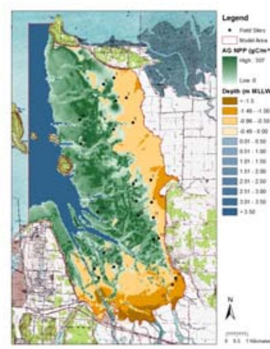
Rahmstorf S. 2007. A semi-empirical approach to projecting future sea-level rise. *Science* 315: 368-370.



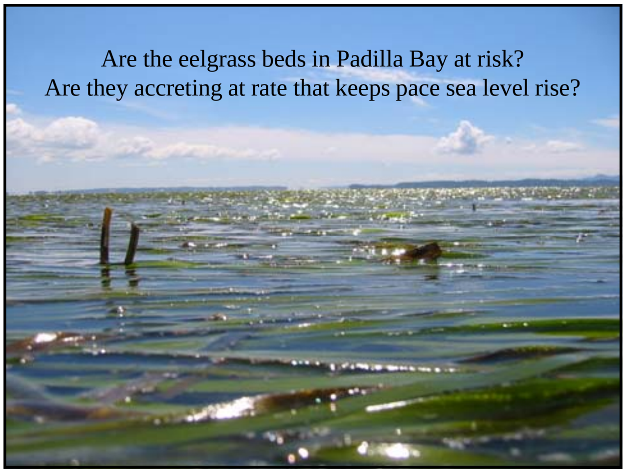
Approach: Link sea level rise predictions to LIDAR data and to known elevation distributions of vegetation in the tidal marshes of the Skagit delta.

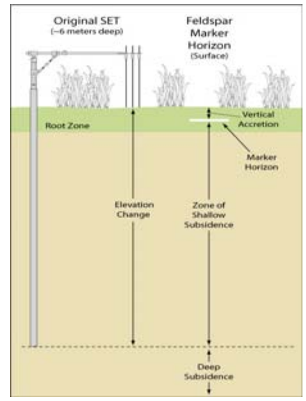


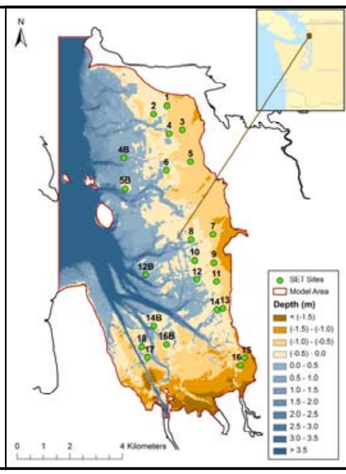


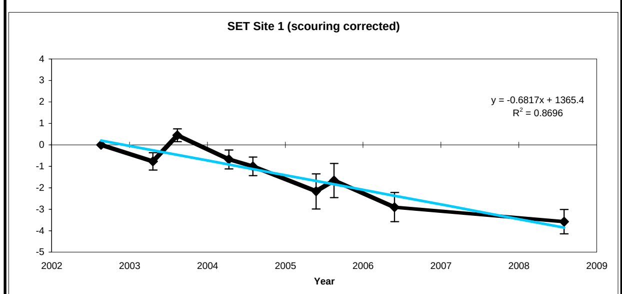


1) Cutoff from historical sources of sediment
2) No opportunity for upslope migration
3) An increasing rate of sea level rise







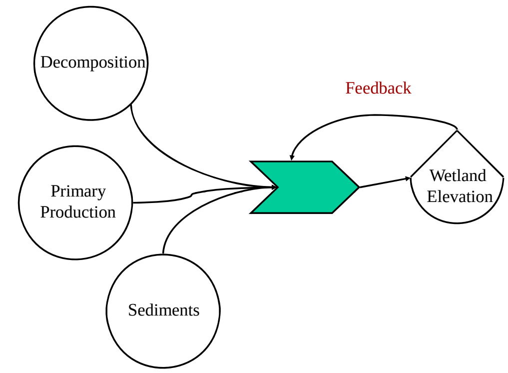


Padilla Bay
(2002 - 2008)

- Geologic Uplift............. 0.02 cm/year
- Eustatic Sea Level Rise....... 0.34 cm/year
- SET Elevation Change........ 0.25 ± 0.13 cm/yr

Elevation Deficit = 0.57 cm/year

These types of analyses ignore climate change induced changes in salinity, tidal regime, river flow, and sedimentation, for example, and they imply linearity.



Project Goals

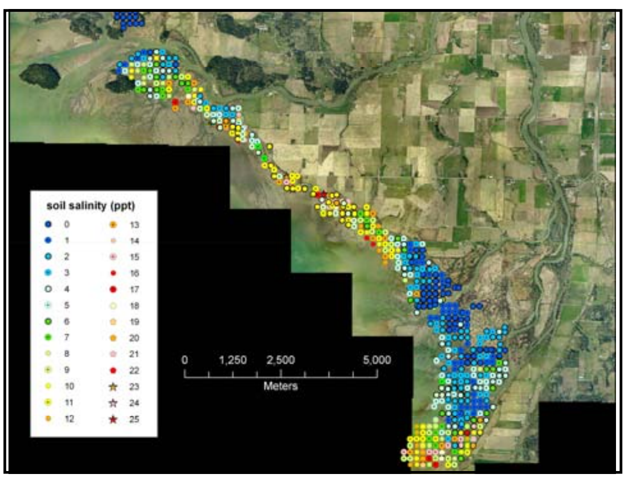
- Develop a predictive simulation model, incorporating non-linear elevation feedbacks, of the ecological and geo-morphological consequences of sea level rise and river flow alterations in Padilla and Skagit Bays.

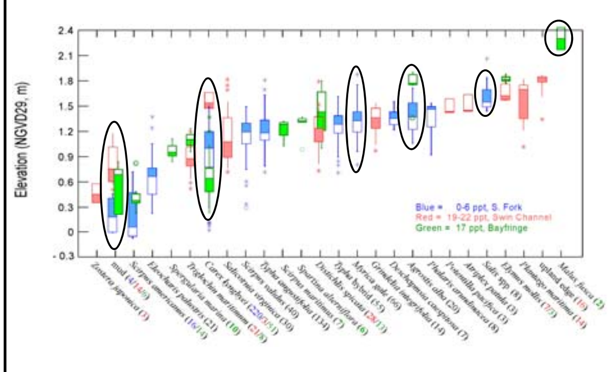
- Use the model to guide the course of restoration efforts, given climate change, in the Skagit River estuary.

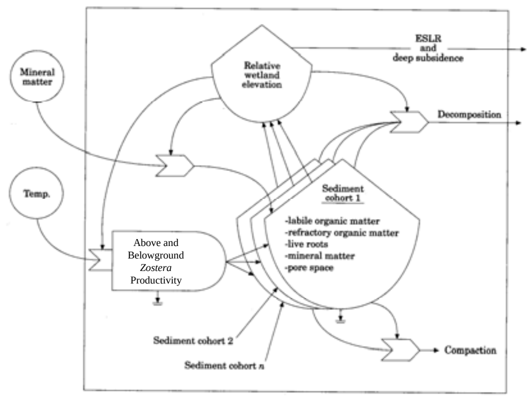
- Specifically:

  - Link a spatially explicit hydrodynamic/sediment model to a mechanistic wetland elevation dynamics and vegetation model.

  - Model will be initialized and calibrated using extensive, site specific data collected as part of this proposal.

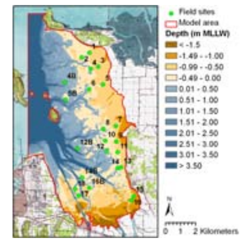


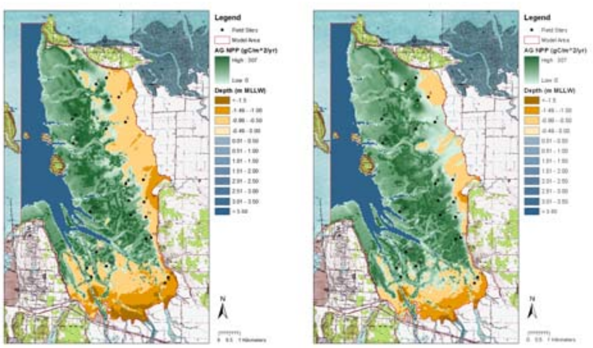




Spatial Extension

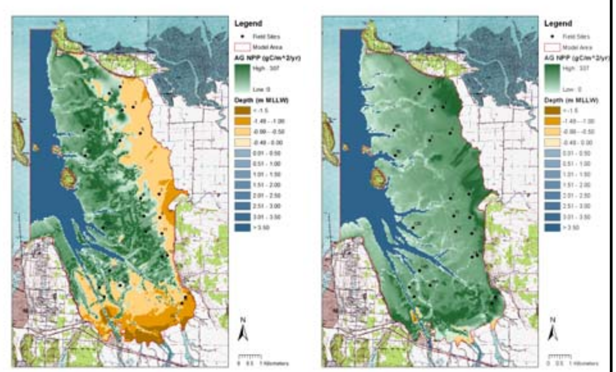
- Extended the REM to model a 3D surface instead of a single point
- Model input/output is in the form of map grids covering the spatial area of interest (AOI)
- Grid cell size: 50 m x 50 m
- Elevation/vegetation change for each cell is modeled individually
- AOI can be divided into independently calibrated regions





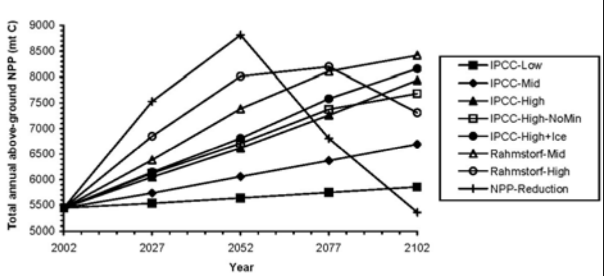
2002 2102

0.56 meter increase in 100 years

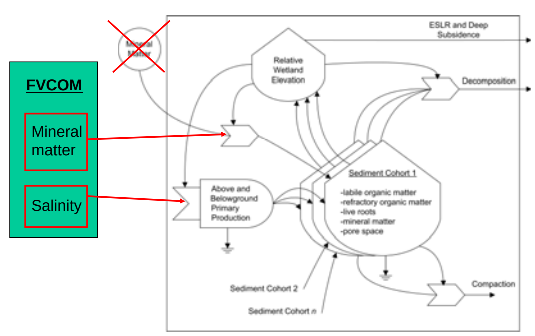


2002 2102

1.27 meter increase in 100 years (Rahmstorf 2007)

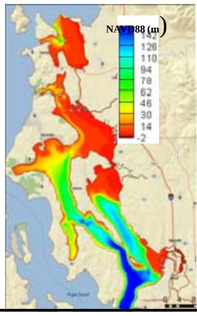


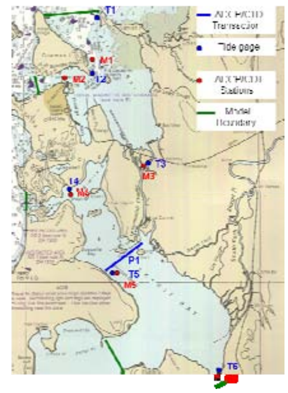
Next Step: Integration with FVCOM

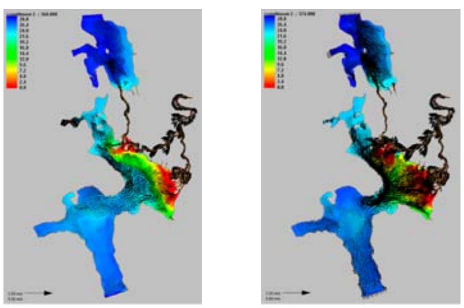


Finite Volume Coastal Ocean Model (FVCOM)
Model Setup- Bathymetry and Grid

- Elements: 43810
- Nodes: 25070
- Layers: 10

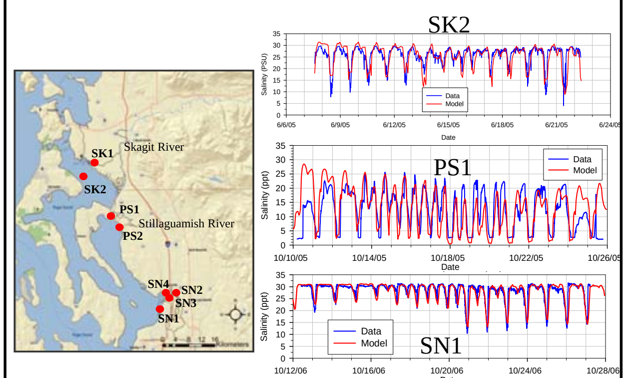




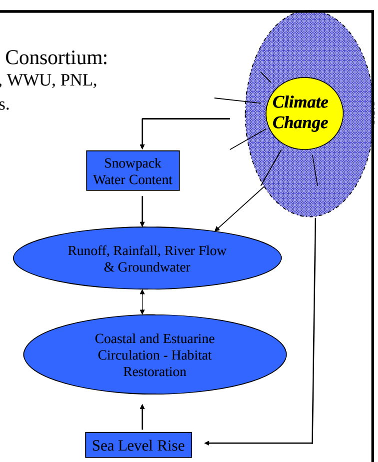


Simulated surface salinity and velocity during flood and ebb tides.

Model Calibration- Salinity



Skagit Climate Science Consortium:
SRSC, NOAA, USGS, UW, WWU, PNL,
Seattle City Light and others.



Sensitivity to Sea Level Rise and Climate Change

- What is the Effect of climate change and sea level rise on nearshore habitat?
  - Estuarine rearing habitat for juvenile salmon
    - Availability of brackish environment
    - Stability of marshes and mudflats
  - Effective and sustainable habitat restoration
    - Need to anticipate future climate change and sea level rise conditions

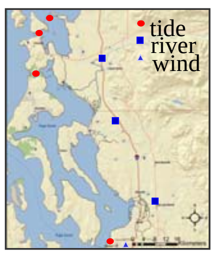
Recommendations

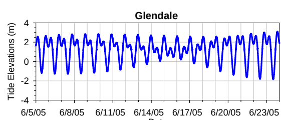
Reconsider our habitat restoration goals for salmon recovery.

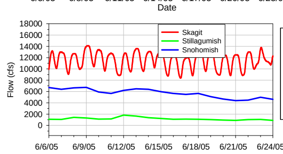
We need to run faster just to stay in place. We may have seriously underestimated the amount of tidal habitat restoration necessary to recover Chinook salmon, because we have not accounted for the restoration (dike and levee setbacks) that will likely be necessary to compensate for sea level rise. The uncertainty involved with climate change also argues for ecologically conservative estimates of future fish needs.

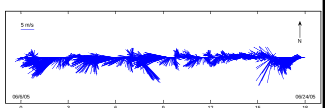
Model Boundary Conditions

- Tide Elevation- NOAA Xtide
- River Inflow– USGS gage
- Wind- Pain field

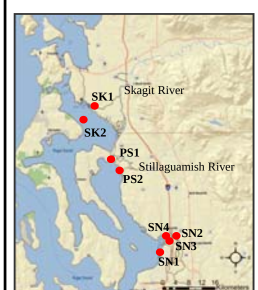


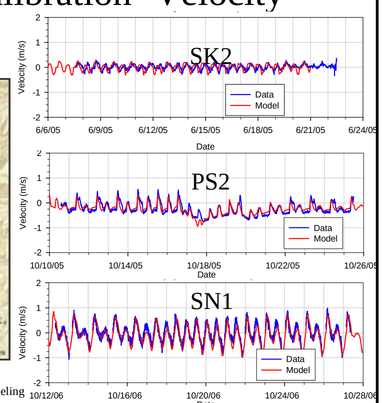






Model Calibration- Velocity





Yang and Khangaonkar (2008). Ecological Modeling (in review)

Nonlinear response of Pacific Northwest estuaries to changing hydroclimatic conditions: flood frequency, recovery time, and resilience

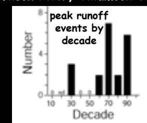
Anthony F. D'Andrea [1,2], Robert A. Wheatcroft[2], Rhea Sanders[2]

[1] MacLean Marine Science Center, University of the Virgin Islands, St Thomas, VI
[2] College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR

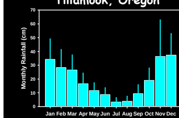
This research is funded by U.S. EPA-Science To Achieve Results (STAR) Program Grant # RD-83301501

Floods are increasing…as is sediment delivered

Wilson River, Tillamook County, OR



100 year rainfall patterns Tillamook, Oregon



- climate models predict increase in total ppt especially the frequency of extreme (high rain) events
- river flow and flooding to PNW increasing and amplified by seasonal rainfall patterns
- combination of watershed (timber, roads) and estuarine changes (diking, channelization) have decreased buffering capacity for water and has led to increased sediment flux for given precipitation amount

With potentially important (but unknown) effects…

or

- rapid sedimentation during floods can lead to abrupt changes in benthic intertidal communities
- last 30 years in Pacific estuaries
  - deposition up to 12cm thick
  - reduction in benthic abundance/diversity
  - alteration of tideflat habitat
  - rapid growth of NIS populations
- However most studies anecdotal or focused on only one or several species
- Need: Community-level studies of flood sedimentation impacts on estuarine benthic communities

APPROACH: manipulative field study simulating the effects of the frequency of floods (none, one, two) on PNW benthic intertidal communities

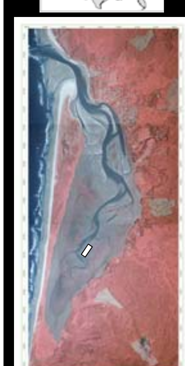
Key research questions:

1. What are the rates and timescales of recovery (i.e., resilience)?
2. What is the impact of flood sedimentation on the functional composition of the benthic community?
3. Does the within year frequency of floods alter the response, composition, or recovery times of the community?
4. Do flood events increase the susceptibility of community to colonization by non-indigenous species?

Project Goals

1) Design and implement a manipulative field study to determine the ecological effects of flood sedimentation on intertidal benthic macroinvertebrate communities
2) Use a combination of high resolution benthic sampling and multivariate analyses of benthic community metrics to track the initial mortality, recovery, and resilience of the benthic community.
3) Collect and analyze sediment samples parallel to the benthic community samples to track changes in important sediment properties that have direct or indirect effects on survival or habitat suitability of sediments to the benthic invertebrate community.
4) Synthesize the datasets from this study to develop an empirical and theoretical framework for predicting the effects of flood sedimentation events on tideflat macrobenthic communities in PNW estuaries and how these changes impact ecologically and economically important biotic resources and ecosystem services.

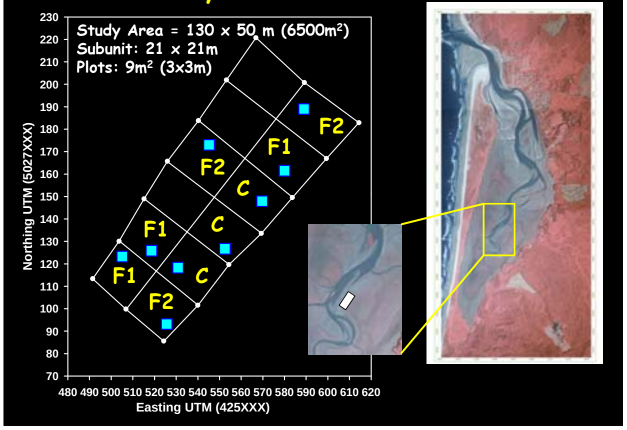
Why Netarts Bay?



- 6th largest estuary in OR
- large intertidal area (65%)

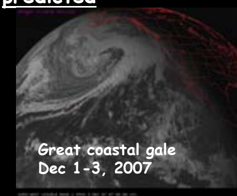
1. small watershed with no river so no previous flood events
2. conservation estuary: historic loss <1% (1900-1990)
3. relatively pristine – no port, industry, shoreline alterations
4. marine dominated minimizing physical/chemical variability
5. small size = accessibility

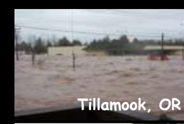
Study Plots

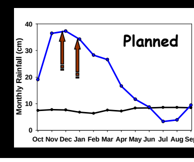


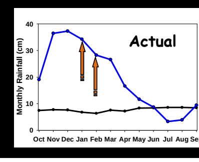
Challenges and Lessons Learned I

Ironic weather cannot be predicted









Challenges and Lessons Learned II

Multiple uses complicate field work

- trade-offs necessary in long-term field studies
- Netarts Bay has a number of uses by stakeholders including recreational clamming and oyster aquaculture
- limited potential field site locations but did initiate interaction with local users of system

Repeated sampling-minimal disturbance

Pilot study

Main Field Experiment

accessibility and minimal disturbance

Floods Happen (without helicopters)!

Collection of watershed sediments – 2 metric tons!

Creating our mud slurries

>100 buckets!

Floods Happen (without helicopters)!

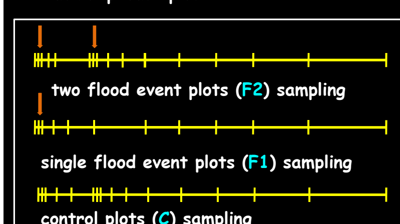
Simulated flood events in field

3-5 cm thick

Sampling Approach

- Experiment initiated in Jan 2008
- 12-16 time points over 500 days
- high frequency post-flood
- less frequent to track recovery

At each time point:
8 randomly sampled cores – 5 infauna, 2 physical properties, 1 biogeochemistry in each replicate plot



Part 1. Flood Layer and Physical Properties

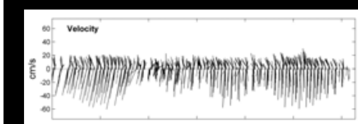
Temporal change in field plots
- photodocumentation
- Benthic tripod
  - -ADV, CT sensor, OBS

Sediment Physical Properties
- total organic carbon
- sediment phytopigments
- porosity
- grain size

Sediment Geochemistry
- O_2 microprofiles
- O_2 core incubations
- Benthic photosynthesis and O_2 production rates

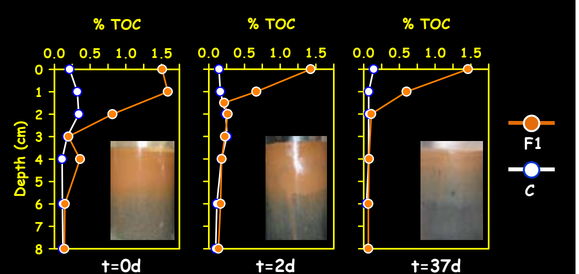
Temporal change in field plots

- key observations: persistence and potential long-term impacts despite high current speeds at site



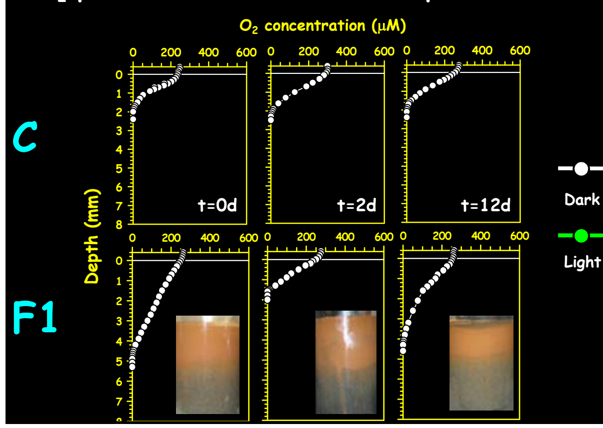
measured current speeds over study site during first 48 days of experiment. Highest current velocities are ebb-oriented

TOC patterns in flood layers

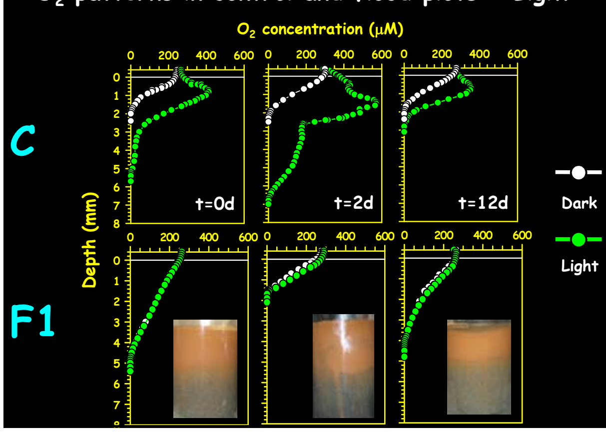


- control plots consistently low TOC (<0.4%)
- 7-fold increase in TOC in flood plots relative to controls
- some initial compaction of layer
- persistent feature through at least first 150 days

O_2 patterns in control and flood plots - Dark



O_2 patterns in control and flood plots - Light



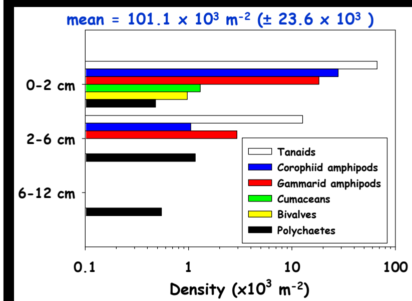
Part 2. Benthic Community Measurements

Changes in Community Structure and Diversity
- species composition
- abundances
- depth and seasonal patterns
- recovery times

Functional Changes
- feeding types, mobility
- deep vs. shallow dwelling
- native, non-indigenous, cryptogenic

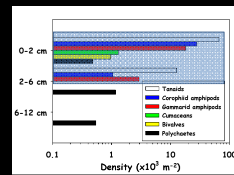
Univariate and Multivariate Analyses
- identify key community metrics
- track community changes in control and flood plots
- indicator species for sediment-stressed communities

Community Composition at Study Site



- 43 taxonomically verified species to date (~10% NIS)
- high abundance, deposit-feeding fauna
- numerically dominated by tanaids
- biomass dominated by corophiid amphipods in summer and fall
- two components: a surface- and deep-dwelling community

Surface Community - top 6 cm



tanaids (59%)
- 1 species

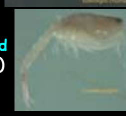
Leptochelia dubia

corophiids (22%)
- 5 species

bivalves (<1%)
- 9 species

gammarids (16%)
- 6 species

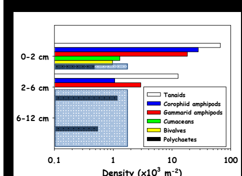
spionid and paraonid polychaetes (<1%)
- 6 species



cumaceans (1%)
- 1 species

Cumella vulgaris

Deep Community – 6-12 cm



capitellid polychaetes (>80%)
- 3 species

Mediomastus californiensis

opheliid polychaetes
- 1 species

Armandia brevis

other polychaetes
- 6 species

less mobile than surface community

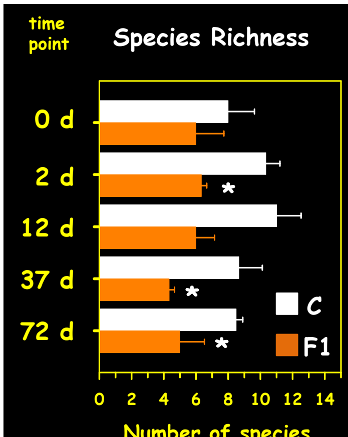
Infaunal Response to Flood Sedimentation

Behavioral Response

- many mobile species immediately left flood plots
- primarily corophiid and other gammarid amphipods

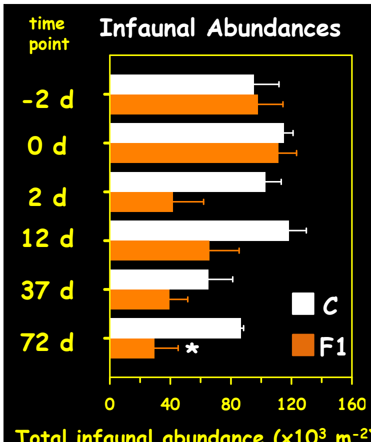
- observed immediate burrowing response in large bivalves present in plots

Species Richness

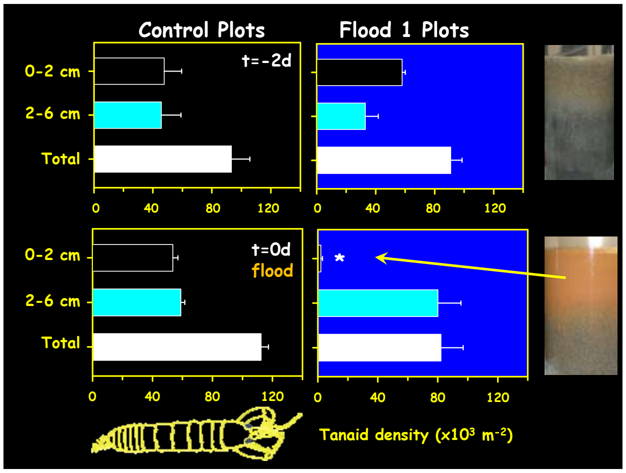


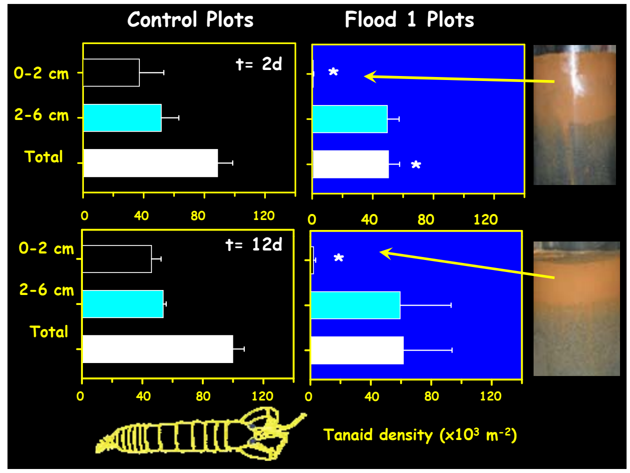
- Significant reduction in species richness for at least first 72 days post flood sedimentation
- approximately 50% decrease in number of species in flood plots relative to controls
- changes in functional diversity have not yet been assessed (planned for 2009-2010)

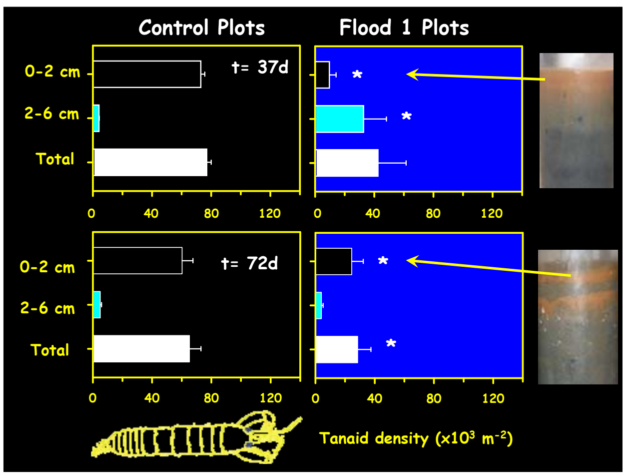
Infaunal Abundances



- Impacts observed by 2d
- Mean abundances in flood plots consistently lower than controls since day 2
- Effect of disturbance measurable and significant > 2.5 months after initial flood deposit with a >50% depression of abundances
- Driven in large part by changes in density of the tanaid *L. dubia*





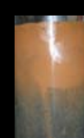


Outcomes

Flood sedimentation alters benthic intertidal habitat…

- The deposited flood layer persisted for >1 year with little physical or biological mixing
- properties of flood sediments were distinct from ambient intertidal sediments (TOC, grain size, O_2, benthic 1°)
- remaining benthos in flood plots may be food limited as indicated by combination of high TOC, deep oxygen penetration, and slow recovery of benthic microalgae






Outcomes

…with measurable impacts on the benthos

- amphipods immediately left plots in response to disturbance
- significant decrease in abundance and species richness – combination of organism behavior and smothering stress
- depressed abundances last for first 70+ days
- flood layer not readily recolonized, even by mobile species

species traits (e.g. behavior) may be important in determining community response and resilience to rapid sedimentation disturbance events

Interaction with Clients

Local Area Residents, Users, and Stakeholders

- communicated by direct discussions and press releases
- includes residents, recreational users, commercial oyster growers
- locally well-received by Netarts Bay residents and stakeholders

Oregon Resource Agencies

- Oregon Department of Fisheries and Wildlife
- Oregon Department of State Lands
- Oregon Department of Agriculture
- Oregon Department of Land Conservation

Future Interactions…

- Project is ongoing so much of interaction both with resource managers and residents will be done in future (Goal 4)
- empirical and theoretical framework for assessing risk to estuarine benthic resources by river flood sedimentation events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Field crew
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• Tina Schnell
• Susan Weeks
Planning
• ODA
• ODFW
• Oregon DSL
• Brett Dumbauld, USDA
• Netarts oyster growers
This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # RD-83301501

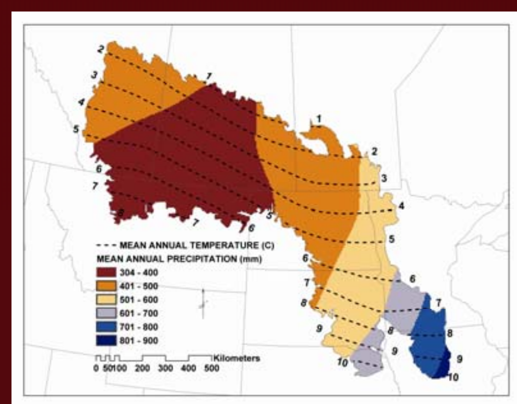
Prairie Pothole Landscapes, Climate Change, and Land Management

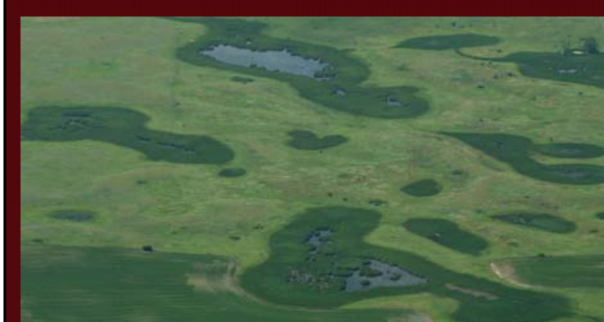
W. Carter Johnson
Bruce V. Millett ☼ *Glenn Guntenspergen*
Richard Voldseth ☼ *Ben Rashford*
Brett Werner ☼ *Richard Adams*
Mirela Tulbure ☼ *Jennifer Olker*
David Naugle ☼ *Phil Fay*

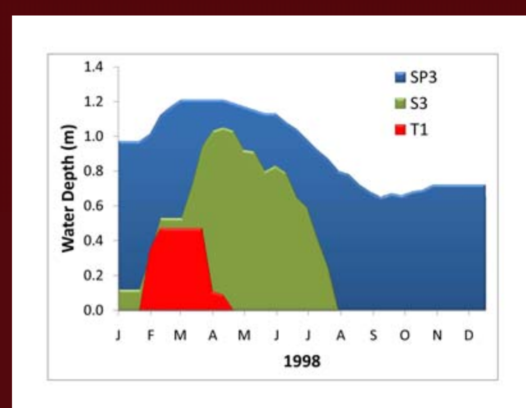
Website: http://wetlandscape.sdstate.org/

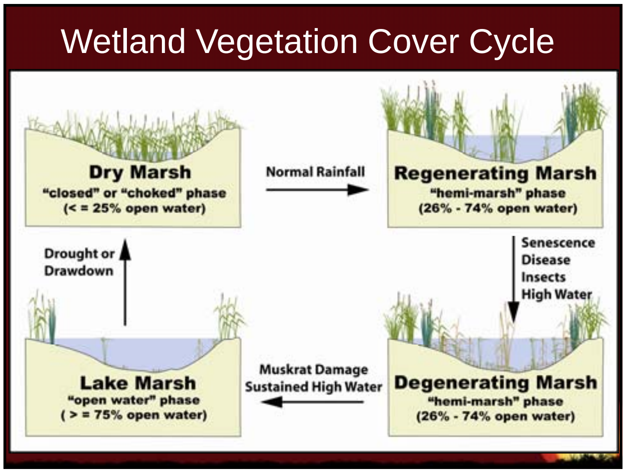
Overarching Goal

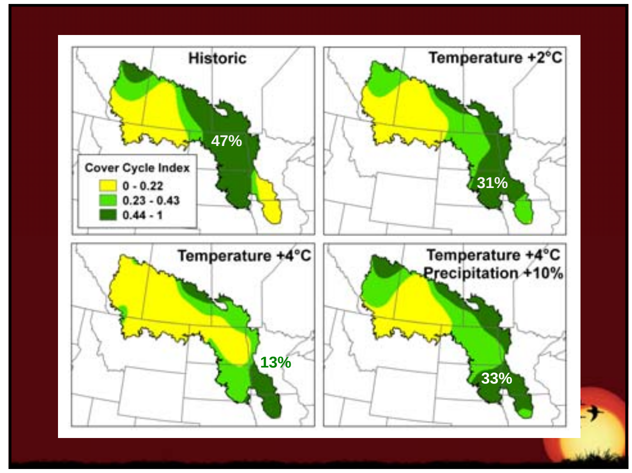
- Complete and test new simulation model (WETLANDSCAPE) to examine non-linear or threshold effects caused by climate change and land management on complexes of glaciated prairie wetlands

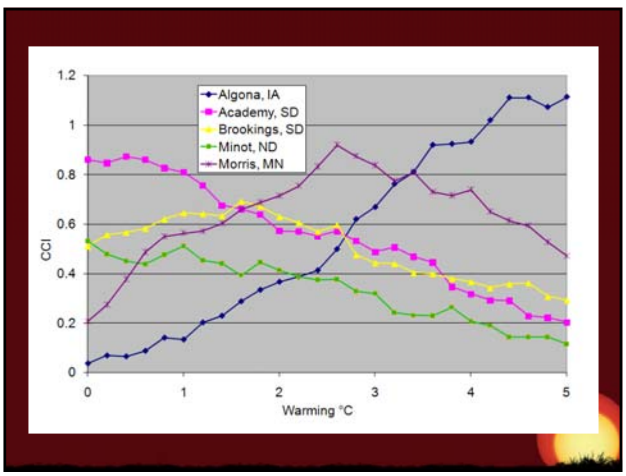


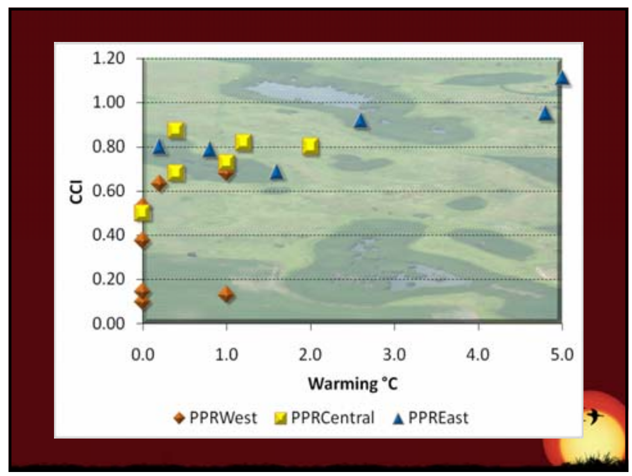


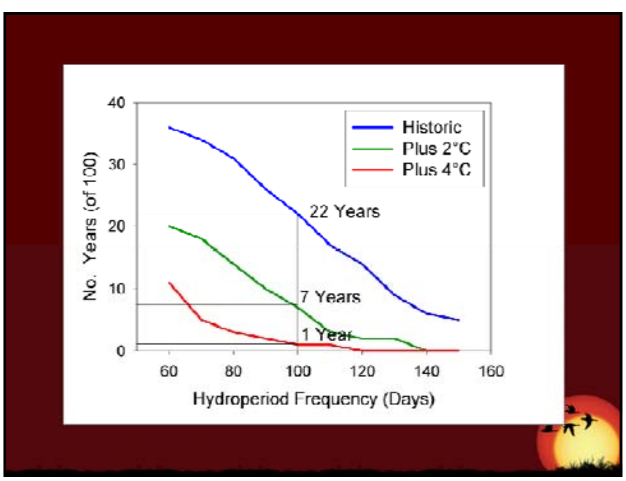


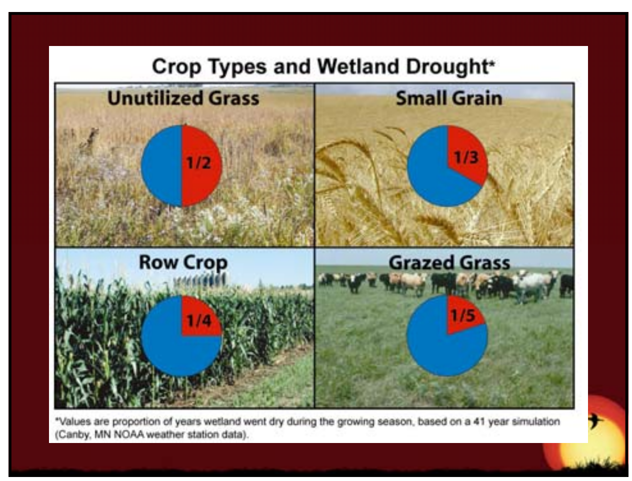

Wetland Vegetation Cover Cycle
Dry Marsh
"closed" or "choked" phase
(< = 25% open water)
Normal Rainfall
Regenerating Marsh
"hemi-marsh" phase
(26% - 74% open water)
Senescence
Disease
Insects
High Water
Drought or
Drawdown
Lake Marsh
"open water" phase
(> = 75% open water)
Muskrat Damage
Sustained High Water
Degenerating Marsh
"hemi-marsh" phase
(26% - 74% open water)

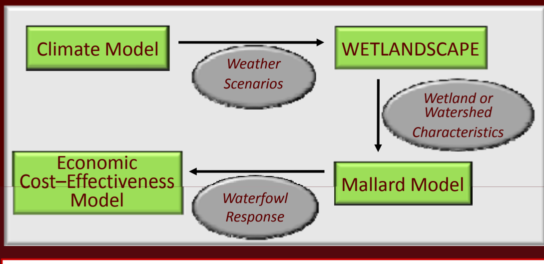

Historic
Temperature +2°C
47%
31%
Cover Cycle Index
0 - 0.22
0.23 - 0.43
0.44 - 1
Temperature +4°C
Temperature +4°C
Precipitation +10%
13%
33%


Algona, IA
Academy, SD
Brookings, SD
Minot, ND
Morris, MN
CCI
Warming °C


CCI
Warming °C
PPRWest
PPRCentral
PPREast


Historic
Plus 2°C
Plus 4°C
22 Years
7 Years
1 Year
No. Years (of 100)
Hydroperiod Frequency (Days)


Crop Types and Wetland Drought*
Unutilized Grass
1/2
Small Grain
1/3
Row Crop
1/4
Grazed Grass
1/5
*Values are proportion of years wetland went dry during the growing season, based on a 41 year simulation (Canby, MN NOAA weather station data).



Conceptual map of the modeling process to determine cost-effective mitigation of climate impacts on waterfowl productivity

Challenges

- Expected, but surmountable challenges in fine-tuning and calibrating a new simulation model

Interactions with Clientele

Professional

--U. S. Forest Service: new project proposed to adapt our wetland models to forested wetlands of the northeastern U.S.

--U. S. Fish and Wildlife Service: collaboration with Wildlife Refuge System on wetland monitoring and climate change detection

--Research findings reprinted in two new textbooks (**Wetlands** by Mitsch and Gosselink; **Biology of Freshwater Wetlands** by van der Valk)

Interactions with Clientele

Public

- Associated Press article carried in 60 U. S. newspapers including NY Times, LA Times, USA Today, Washington Post
- Frequent radio interviews: 10 commercial stations plus public and Earth Watch Radio-Madison, WI
- Frequent television interviews and press conferences: Sioux Falls and Minneapolis

Outcomes

- Wildlife conservation community (federal, state, private) using our research findings to develop long-range plans to mitigate for climate change effects on waterfowl.
- Participation in national workshop to write white paper on waterfowl and climate change policy at Ducks Unlimited Headquarters.

EPA Grant Number: R833017

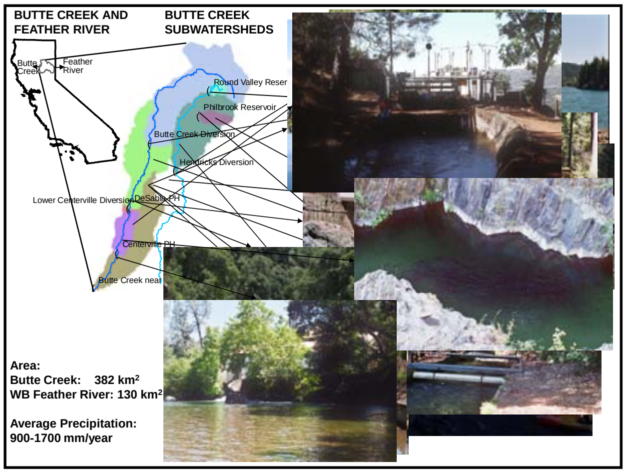
Innovative Management Options to Prevent Loss of Ecosystem Services Provided by Chinook Salmon in California:

Overcoming the Effects of Climate Change

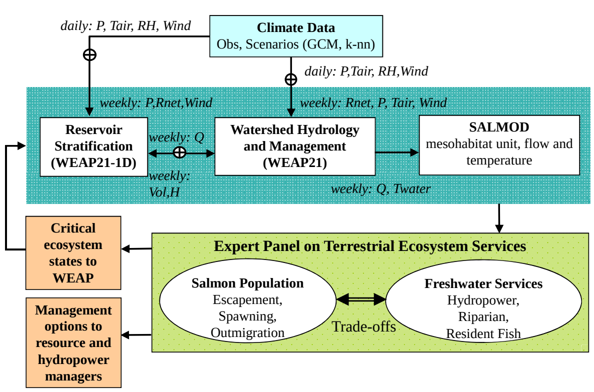
Dr. Peter Moyle, Dr. Lisa Thompson, Dr. David Purkey, Mr. Andrew Engilis, Jr., Dr. Marisa Escobar, Mr. Christopher Mosser, Dr. Melanie Truan

Project Goals / Objectives

- Long Term Goals
  - Investigate how climate change and land use practices change temperature and flow regimes within California watersheds
  - Determine if these changes will lead to a reduction in salmon habitat and thus a reduction in salmon abundance
  - Determine how a reduction in salmon abundance will affect local biodiversity through food web interactions
- Year 1 Goals
  - Develop watershed model
  - Parameterize baseline salmon population dynamics model
  - Develop site specific food web conceptual model



Input Data, Models and Outputs

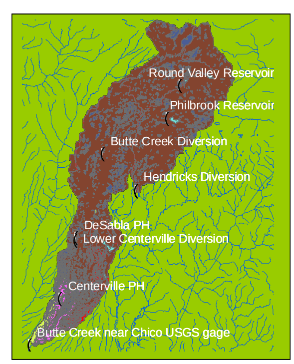


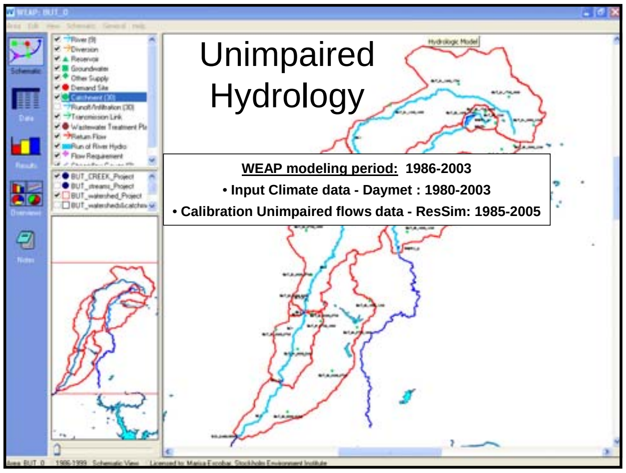
Elevation Bands, Soils, Land Use

Legend
watershed_elevationband_inte2
<all other values>
NAME
5075 Round Valley
5120 Philbrook
5200 Hendricks
90000 Butte near Chico
9720 Butte Diversion Dam
9750 De Sabla PH
9775 Centerville PH
9780 Lower Centerville Diversion

Legend
Soil_union_all_Clip3_Dissolv1
<all other values>
SoilDept_1
D
S

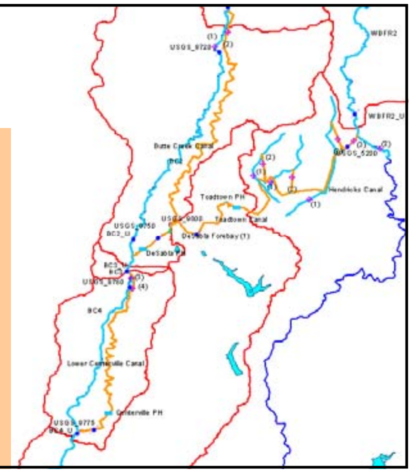
Legend
Land_cover_reclass_Dissolve
<all other values>
Reclass
BARREN
FOREST, DECIDIOUS
FOREST, EVERGREEN
GRASSLAND
SHRUB
URBAN
WATER

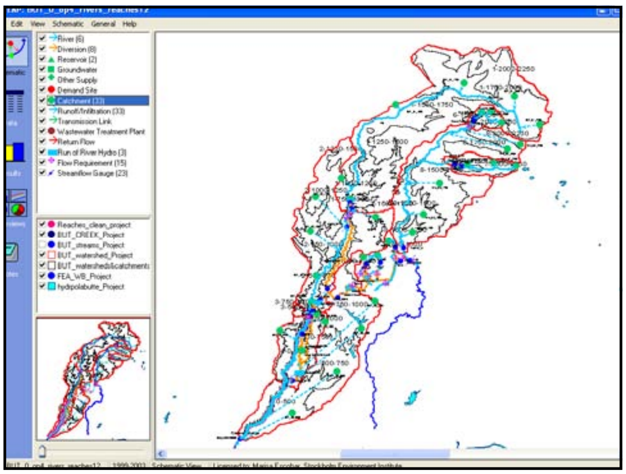




Operations

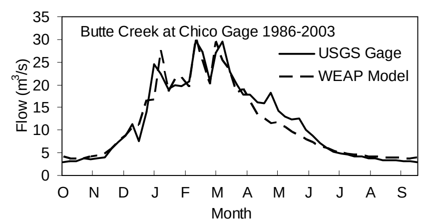
- Infrastructure
  - Diversions
  - Reservoirs
  - Powerhouses
- Operations
  - Flow Requirements
  - Operation Rules





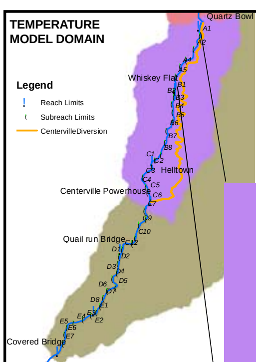
Calibration Point Statistics with Operations – Butte Creek

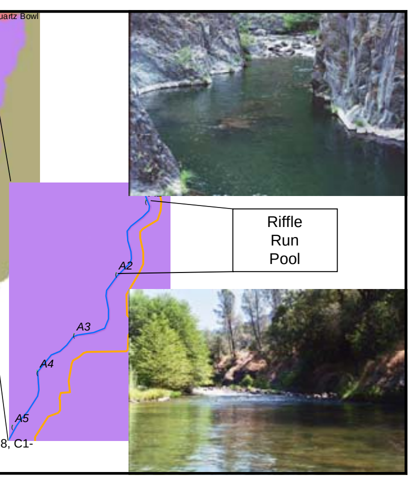
Note:
Model period = 1986-2003
USGS Gage = Butte Creek near Chico 11390000
1 m^3/s = 35 cfs



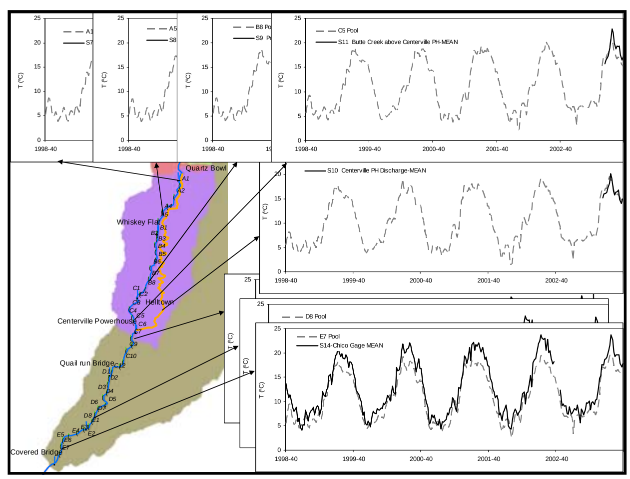
Location	Qave - observed m^3/year	Qave - model m^3/year	RMSE	BIAS	Nash-Ef
Butte Creek at Chico Gage 1986-2003	7.01E+06	6.80E+06	20%	-3%	0.93

TEMPERATURE MODEL DOMAIN

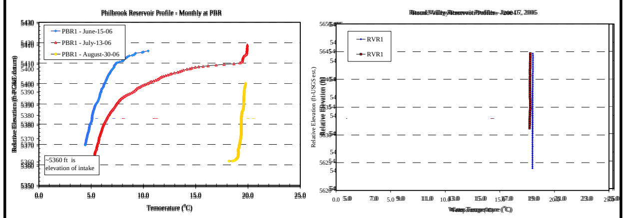




- Spawning reach: Aprox. 17 km
- Divided into:
  - 5 reaches (A-E)
  - 40 subreaches (A1-A5, B1-B8, C1-C12, D1-D8, E1-E7)



Potential Management Options

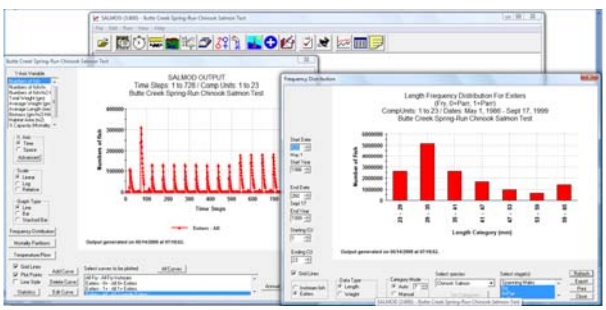


- Philbrook and Round Valley Reservoir stratification data for summer 2004, 2005, 2006

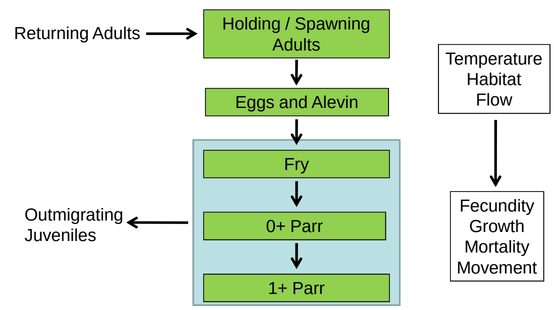
Lessons Learned / Challenges WEAP

- **Input Climate Dataset:**
  - **Daymet: 1980-2003**
  - **Mauer dataset: to 2005**
- **Temperature calibration:**
  - **Short period for calibration: summer 2001, 2002, 2003**
  - **Some sites with less data**
- **Reservoir Temperature Routine:**
  - **Reservoir stratification data: 2004, 2005, 2006**
  - **Link with Matlab existent 1D routine**

SALMOD



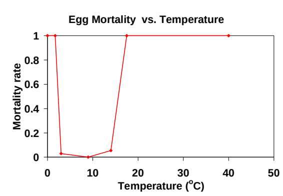
SALMOD Structure

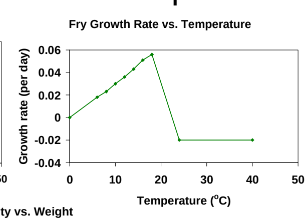


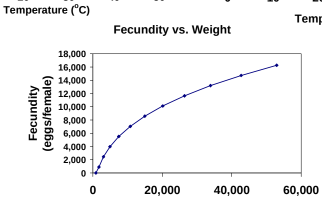
SALMOD Data Sources

- Government Reports
  - California Department of Fish and Game – Butte Creek Chinook Life History Investigations (1995 – present)
  - EPA – Water temperature effects
  - USFWS – Survival, Flow – Habitat Relationships
- Peer Reviewed Publications
  - Crisp 1981
  - Berman and Quinn 1991
  - Clarke and Shellbourne 1985
- Books
  - Pacific Salmon Life Histories (Groot and Margolis)
  - Behavior and Ecology of Pacific Salmon and Trout (Quinn)

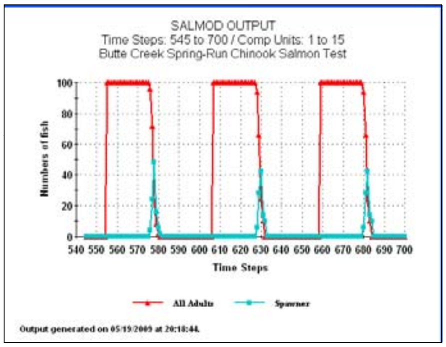
SALMOD Relationships





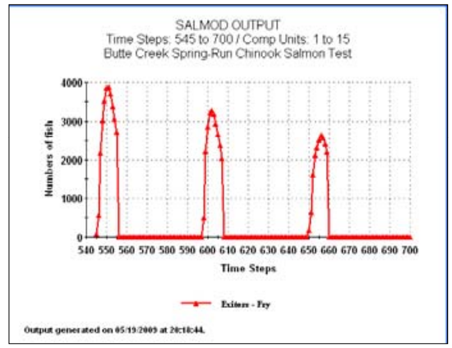


Adult Summer Survival and Spawning



- Input returning adults in spring
- Baseline model captures shift from holding to spawning and mortality
- Calibrate with summer mortality and spawner survey data

Juvenile Outmigration



- Integrates watershed effects on all life-stages
- Baseline model generates reasonable juvenile abundance
- Calibrate with CDFG outmigrant trap data?

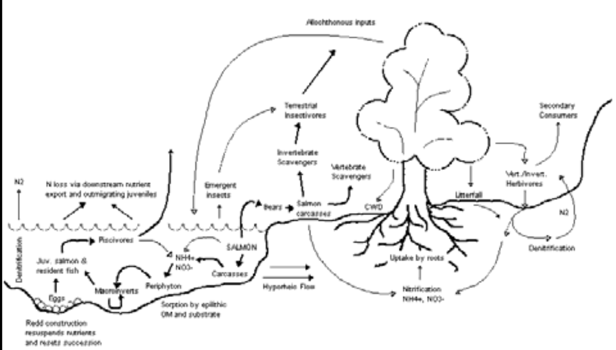
Lessons Learned / Challenges - SALMOD

- Program limitations
  - Weekly time step
    - Summer maximum temperatures
  - Temperature & Flow habitat unit restrictions
- Program calibration
  - Adult sampling method changes
  - Juvenile outmigrant estimation

Food Web Conceptual Model

- Role of spring-run Chinook salmon in delivering marine-derived nutrients (MDN) to the Butte Creek ecosystem
- Develop an integrated conceptual model
  - Fate of salmon-derived nutrients
  - Nutrient flowpaths
  - Aquatic-terrestrial trophic linkages
- Expert panel
  - Evaluate aquatic and terrestrial community structure and function under different climate and management scenarios

NITROGEN CYCLING IN A HYPOTHETICAL STREAM SYSTEM
SALMON SUBSIDY OF MARINE-DERIVED NUTRIENTS



Sources: Naiman et al. 2000; Helfield & Naiman 2006, 2001; Bartz 2002; Ben-David et al. 1998; Bilby et al. 1998, 1996; Johnston et al. 1997; Hilderbrand et al. 1996

Terrestrial Consumers of MDN

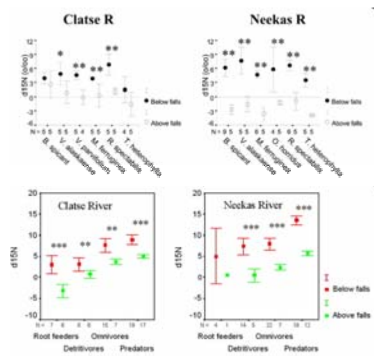
Use of Stable Isotopes in Tracking MDN

- **MDN (C, N and S) in adult salmon tissues are isotopically distinct from corresponding nutrients from freshwater and riparian ecosystems**
- **Isotopes accumulate at successively higher trophic levels due to food web dynamics and trophic relationships**
- **Compare isotope ratios in areas with and without salmon**
  - **Surrogate for loss of salmon due to climate change**

MDN above and below barriers to migration

Plants

Invertebrates



δ15N values in riparian vegetation and trophic groups of litter-based invertebrates collected immediately below and above waterfall barriers to salmon at Claste and Neekas Rivers, British Columbia, Canada. *t*-test results: *P < 0.05; **P < 0.01. (Mathewson et al. 2003; Hocking and Reimchen 2002).

Lessons Learned / Challenges MDN-Food Webs

- **Lack of data on components of the terrestrial ecosystem**
- **Broaden spatial and temporal extent**
  - **Deploy motion-sensor cameras across a broader spatial and temporal scale**
- **Need greater resolution of isotopic relationships**
  - **Preliminary results lack clear resolution between marine and freshwater derived nutrients in producers and consumers**
  - **Need better baseline samples (salmon tissue, aquatic and terrestrial invertebrates)**

Interactions with Clients

- Presentations
  - Spring-run Chinook Salmon Symposium (July 08)
  - California Department of Fish and Game (May 09)
  - Centerville Historical and Recreation Association (Sept 09)
- Other
  - Baltic Nest Institute, Stockholm Resilience Centre, Stockholm University (Thorsten Blenckner)
  - California Department of Fish and Game
  - California Sportfishing Protection Alliance (Chris Shutes)
  - Friends of Butte Creek (Allen Harthorn)
  - National Center for Atmospheric Research
  - Pacific Gas & Electric Co.

Outcomes

- Tasks on track
- Efficient and effective multidisciplinary research program
- Stakeholders and other parties interested in research outcomes
  - Resource managers
  - Watershed groups
  - Implications for restoration of spring-run Chinook in San Joaquin River

Hydrologic Thresholds for Biodiversity in Arid and Semiarid Riparian Ecosystems: Importance of Climate Change and Variability

Tom Meixner and James Hogan,
University of Arizona
Julie Stromberg,
Arizona State University

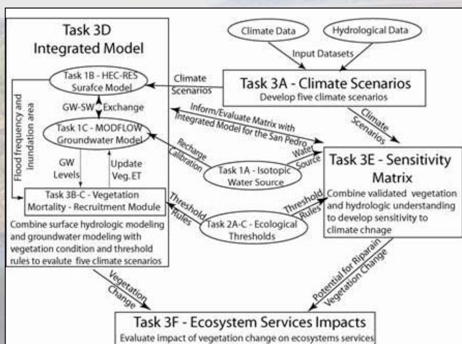
1

Project Goals - Hypotheses

- *1) Decadal scale climate change and variability alter riparian aquifer recharge through mechanisms that depend on the magnitude, frequency and seasonality of flooding, and exert the greatest change in reaches that receive minimal groundwater inflow from the regional aquifer.*
- *2) Riparian vegetation structure responds non-linearly as riparian aquifers are dewatered and as key hydrologic thresholds for survivorship of plant species are exceeded.*
- *3) Decadal scale climate variability and change alters riparian ecosystem water budgets that in turn change vegetation structure and function and the ecosystem services provided to society.*

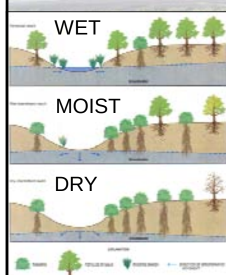
2

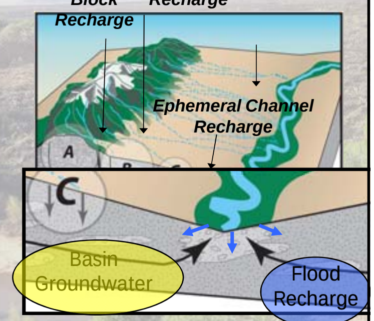
Project Overview



3

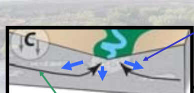
Statement of the problem:

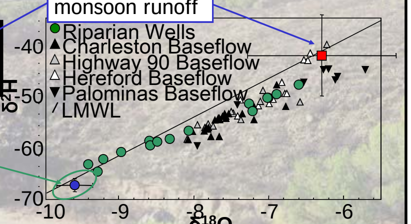




4

Riparian Water Sources



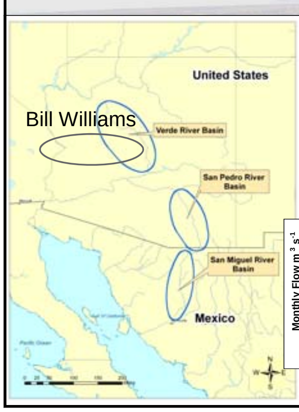


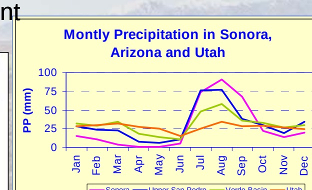
- Isotopes of water – natural tracer of source
- Riparian wells span range between end members
- Baseflow skewed toward monsoon runoff
- Quantify % using simple mixing model
- Uncertainty associated with runoff end member

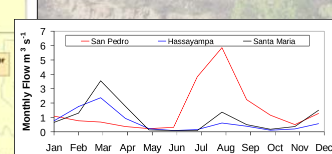
5

Baillie et al., 2007 JGR

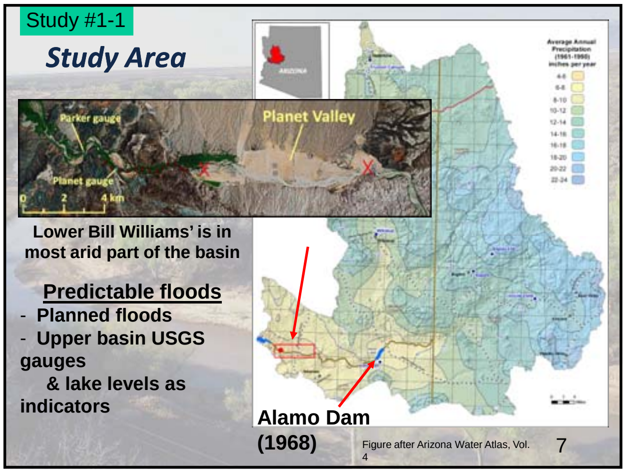
Regional Climate Gradient

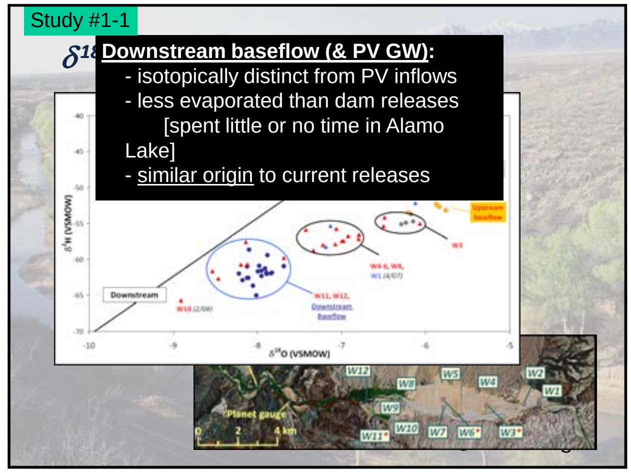


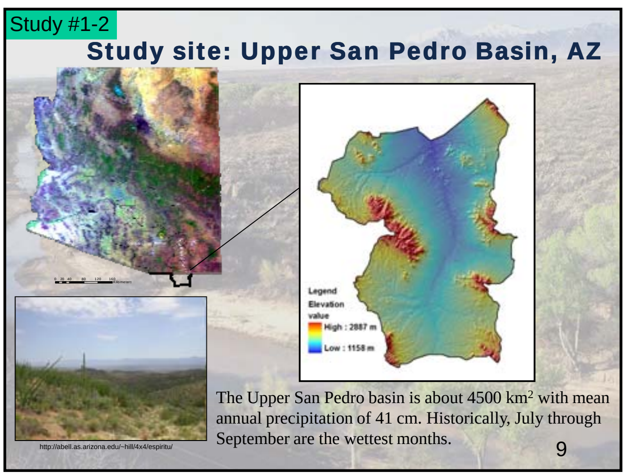


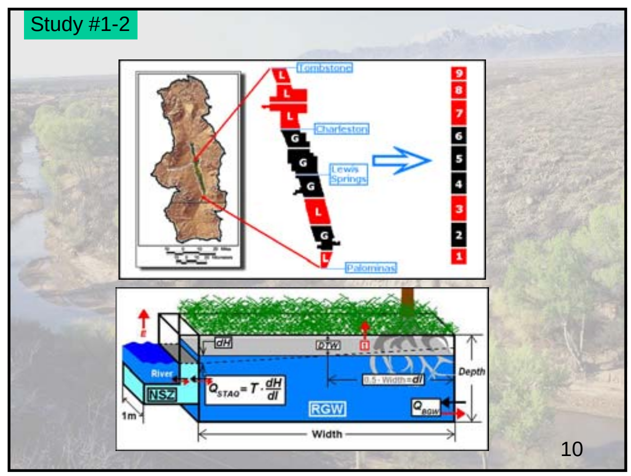


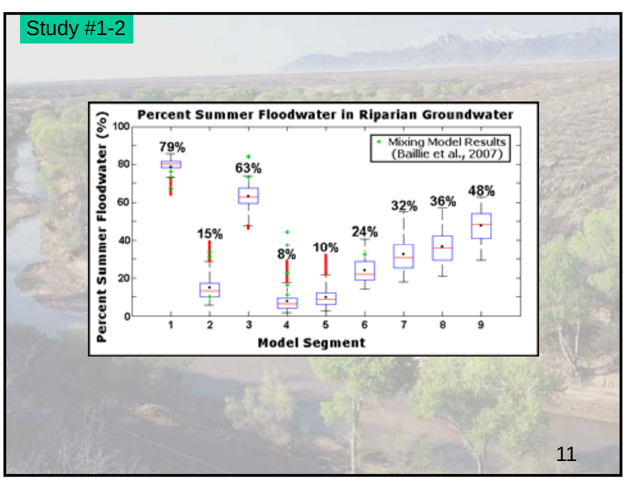
6

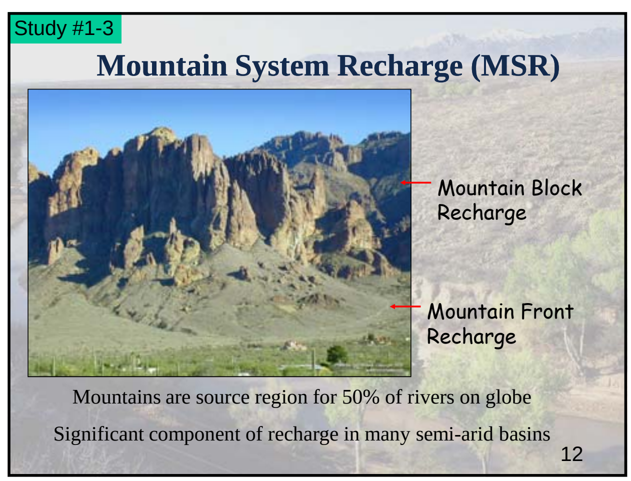

Study #1-1
Study Area
Parker gauge
Planet Valley
Planet gauge
0 2 4 km
Lower Bill Williams' is in most arid part of the basin
Predictable floods
- Planned floods
- Upper basin USGS gauges
& lake levels as indicators
Alamo Dam (1968)
Figure after Arizona Water Atlas, Vol. 4
7


Study #1-1
Downstream baseflow (& PV GW):
- isotopically distinct from PV inflows
- less evaporated than dam releases
[spent little or no time in Alamo Lake]
- similar origin to current releases
Downstream
W11, W12, Downstream baseflow
W4-6, W8, W1 (4/07)
W10 (2/08)
W3
Upstream baseflow
δ^{18}O (VSMOW)
δ^{2}H (VSMOW)
Planet gauge
0 2 4 km
W12 W8 W5 W4 W2 W1 W9 W10 W7 W6* W3* W11*


Study #1-2
Study site: Upper San Pedro Basin, AZ
Legend
Elevation value
High : 2887 m
Low : 1158 m
The Upper San Pedro basin is about 4500 km^2 with mean annual precipitation of 41 cm. Historically, July through September are the wettest months.
http://abell.as.arizona.edu/~hill/4x4/espiritu/
9


Study #1-2
Tombstone
Charleston
Lewis Springs
Palominas
L L L G G G L G L
9 8 7 6 5 4 3 2 1
dH
DTW
River
NSZ
$Q_{STAO} = T \cdot \frac{dH}{dl}$
RGW
Q_{RGW}
Depth
Width
1m
10


Study #1-2
Percent Summer Floodwater in Riparian Groundwater
Mixing Model Results (Baillie et al., 2007)
Percent Summer Floodwater (%)
Model Segment
79%
15%
63%
8%
10%
24%
32%
36%
48%
11


Study #1-3
Mountain System Recharge (MSR)
Mountain Block Recharge
Mountain Front Recharge
Mountains are source region for 50% of rivers on globe
Significant component of recharge in many semi-arid basins
12

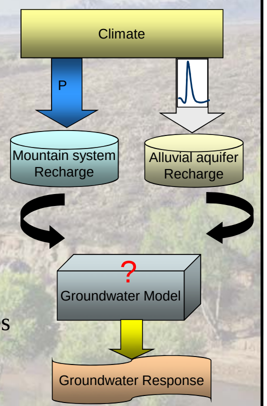
Study #1-3

Statement of the problem:

Most groundwater models apply temporally and spatially static recharge rates across a groundwater basin.

Empirical relationships
Model calibration

Limitations:
- Complexity of recharge processes
- Lack of observational data
- Lack of spatial analysis tools



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Empirical Models:
Temporal Discretization

Seasonal Isotopic Ratios
70% MSR winter and 30% summer
(Wahi et al (2008))

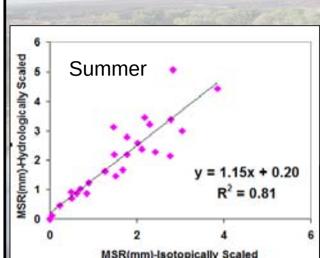
Seasonal MSR Ratios
(Hydrologic data)
P and ET values (NARR)

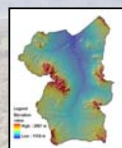
Normalized Seasonal Wetness Index: $NSWI = \frac{P_{winter}/ET_{win}}{TotalP/TotalE}$

Winter Ratio $= \frac{\left(\frac{P_{winter}}{ET_{winter}}\right)}{\left(\frac{P_{winter}}{ET_{winter}} + \frac{P_{summer}}{ET_{summer}}\right)}$

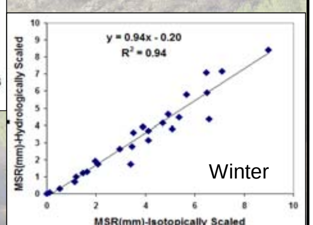
14

Comparison between hydrologically & isotopically scaled MSR





Upper San Pedro basin



Incorporating ET values enhanced MSR predictions especially for summer season.

Hypothesis 2

- *Threshold #1: Flow permanence and decline of hydric (obligate wetland) herbaceous plants*
- *Thresholds #2: Groundwater depth and decline of shallow-rooted and deep-rooted obligate riparian herbaceous plants.*
- *Threshold #3: Groundwater depth and decline of shallow-rooted and deep-rooted pioneer trees.*

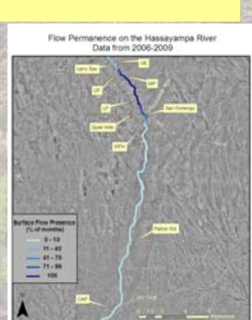
16

Study #2-1:
spatial patterns

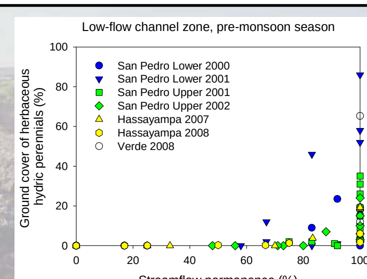
Threshold #1: Flow permanence and decline of hydric herbaceous plants

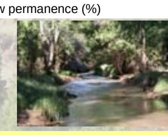
Problem statement: The regional uniformity of the response of riparian vegetation to declines in stream flow permanence is unknown.

Methods:
Surface flow monitored monthly for presence/absence at ephemeral to perennial sites at multiple rivers;
Vegetation sampled along active channel.



Results:
Wetland perennial herbaceous plants show consistent pattern of sharp decline in abundance as stream flow becomes non-perennial



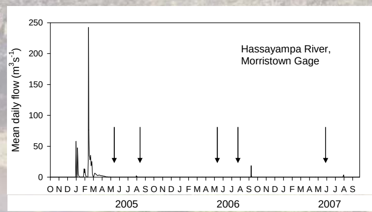


Conclusion: Abundance of a key stream community type (riverine marshland) will decline with increasing aridity

Study #2-2, Variance through time

Problem statement: Temporal and spatial response of streamside vegetation to fluctuations in stream flow poorly known.

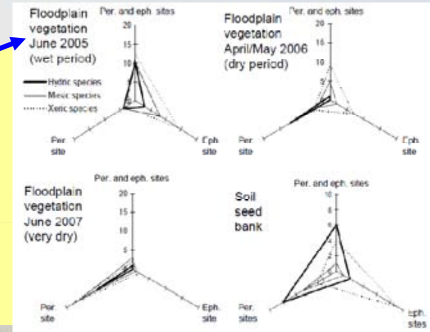
Methods: Multi-year field monitoring of vegetation (and soil seed banks) at ephemeral, intermittent, and perennial sites through wet-dry period.



Stromberg JC, AF Hazelton, MS White, JM White, RA Fischer. 2009 (expected). Ephemeral wetlands along a spatially intermittent river: Temporal patterns of vegetation development.

19

Results: In years with wet winters, flood runoff sustains flows at ephemeral sites, allowing for development of "ephemeral wetlands"

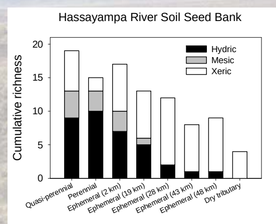


The "spider" charts show numbers of hydric, mesic, and xeric plant species present only at a perennial site, only at an ephemeral site, or at both hydrologic site types, during different years.

20

Soil seed banks provide resilience, allow distinct plant communities to develop in years with varying flow conditions.

Diversity of seed banks influenced by proximity to perennial reach.



Density and diversity of wetland species in soil seed banks of ephemeral reach decline with distance downstream from a perennial reach

Conclusion: Spatial distribution of wet and dry reaches influences vegetation response to stream flow changes.

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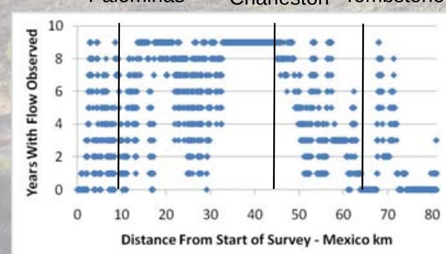
Citizen Wet Dry Mapping

Annual volunteer effort to Map Wet and Dry reaches of San Pedro

Simple but critical data

Citizen Science needed



Cooperative effort of Upper San Pedro Partnership and UA-Project NEMO

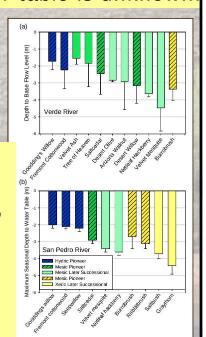
22

Study #2-3 *Thresholds #2: Groundwater depth and decline of woody riparian plants*

Problem statement: Regional uniformity of riparian vegetation response to declines in water table is unknown.

Methods: Monitoring wells monitored at multiple sites, multiple rivers; woody vegetation sampled for abundance and composition.

Preliminary results: Woody species, grouped by strategy type, show similar trends among rivers.



Hypothesis 3: Decadal scale climate variability and change can alter riparian ecosystem water budgets that in turn change vegetation structure and function as well as the services provided to society by these ecosystems.

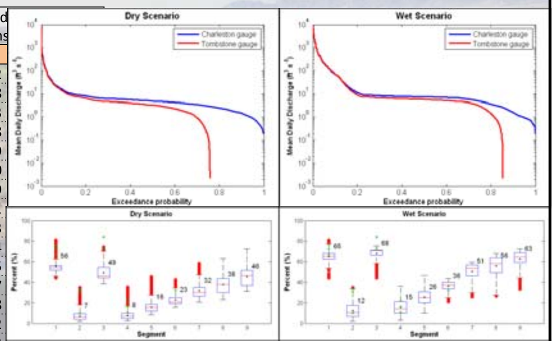
Floods, groundwater, recruitment and patch dynamics of hydromesic pioneer trees and shrubs.

24

Study #3-1 Scenarios

Wet Dry Scenarios

San Ped
Mons
Dry
1962
1968
1973
1978
1979
1980
1989
1991
1993
1994
1995
1997
1998
2002
2003



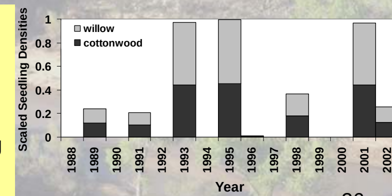
25

Study #3-2: Modeling

Problem statement: Recruitment response of riparian tree species to interactions between depth to water table and flood patterns not yet quantified.

Methods: Modeling approach being used to estimate potential seedling densities of riparian tree species (Mark Dixon, Univ. South Dakota).

Results: Modeled densities vary among San Pedro River sites with different stream hydrology and among years with different flow conditions.



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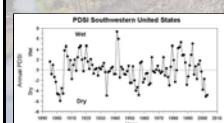
Study #3-3: Historic legacies

Problem statement: Legacies of past extreme flood events may be shaping current vegetation trajectories and response to climate change.

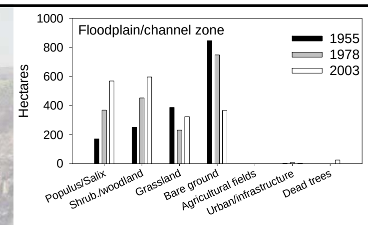
Climate extremes + land use extremes ⇨ Historic entrenchment of San Pedro River



"It was probably during the 1896 flood that a channel almost 244 m wide and 6 m deep developed…" (Hereford and Betancourt 2009).

Methods: Aerial photographs of the Upper San Pedro River from 1935, 1955, 1978 and 2003 analyzed to assess temporal and spatial trends in vegetation cover type abundance.

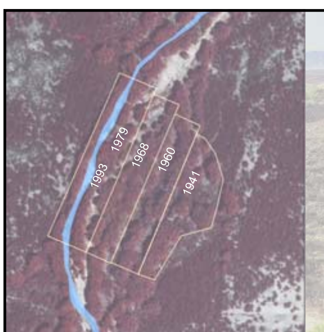
Results: As a legacy of past extreme disturbance, pioneer woody vegetation has been expanding over past ½ century.

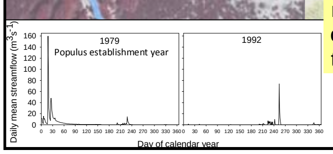


	Status in 2003				
	Populus Salix	Shrub./ wood.	Grass-land	Bare ground	Farm +urban
Status in 1955					
Populus/Salix	15%	3%	7%	9%	0%
Shrub./wood.	10%	46%	4%	23%	0%
Grassland	19%	22%	41%	18%	0%
Bare ground	56%	29%	48%	50%	0%
Farm + urban	0%	0%	0%	0%	0%
Sum	100%	100%	100%	100%	100%

Most *Populus/Salix* points mapped in 2003 arose from bare ground (as mapped in 1955)

28





Pioneer trees have sequentially established during years with suitable flood conditions.

As forest density increased, the sediments stabilized and flood intensity decreased.

Recruitment now shifting to a 'fringe replacement mode' with narrow bands of young trees stabilizing the channel.

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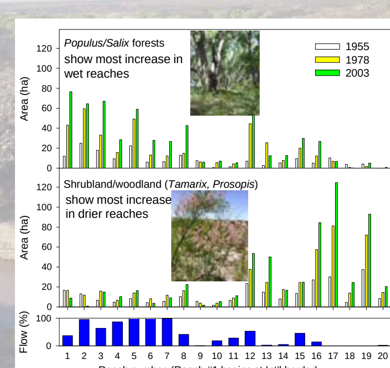
As the pioneer forests expanded in the post-entrenchment floodplain, water availability shaped species composition.

Conclusion:

Riparian forest patterns are a product of interactions between recent climatic cycles and land and water use and past extreme events that set in motion trajectories of change.



Flow % = percent of reach with perennial flow in 2007/2008, based on data from TNC

30

Future and ongoing work:

Greenhouse studies of plant rooting depth and response to water table decline underway.

Classification of riparian plants into strategy groups based on response to drought and flooding underway.

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Lessons Learned-Challenges

- One PI left science another moved institutions
  - Maintain flexibility
  - Fortunate to have redundancy of skill with a graduate student on team
- Shifted to simpler surface water model rather than HEC-RAS
  - Our questions do not need more complex model
  - Simplest model should be preferred

32

Interactions with clients/stakeholders

Stromberg J, M Tluczek, AF Hazelton. Long-term riparian forest change on the Upper San Pedro River. Upper San Pedro Partnership Technical Committee Meeting. May 20, 2009. Sierra Vista, AZ.

Meixner T, S. Simpson Flood Water Sources in Planet Valley Aquifer and the Bill Williams. Bill Williams River Steering Committee. September 16, 2008, Phoenix, AZ.

Continuing cooperation with Bill Williams Steering Committee, Upper San Pedro Partnership and TNC Hassayampa Preserve

33

Outcomes

- Flood recharge a critical process in all three systems
- More so in two farther north systems
  - Likely a geologic geographic control
  - rather than seasonality
- Vegetation response has significant lag times
- Perennial reach presence has significant downstream influence on vegetation

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Next Steps

- Build seasonal groundwater model of San Pedro
- Developing scenarios
- Greenhouse studies of plant rooting depth and response to water table decline underway.
- Classification of riparian plants into strategy groups based on response to drought and flooding underway.

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Acknowledgements

- Co-I's
- Andrea Hazelton, Meg White, Melanie Tluczek, Scott Simpson, Hoori Ajami
- Environmental Protection Agency (GAD-*R833025*, FP-*916987*)
- Project NEMO, Upper San Pedro Partnership
- City of Scottsdale & the Staffords
- Chris Eastoe (*UA-Geosciences*)
- Andrew Hautzinger (*USFWS*)
- Stan Culling (*USFWS*)

36

Integrated Bioclimatic-Dynamic Modeling of Climate Change Impacts on Agricultural and Invasive Plant Distributions in the United States

Wei Gao
USDA UV-B Monitoring and Research Program
Colorado State University

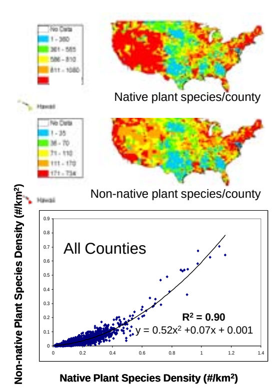
Xin-Zhong Liang, Shuyan Liu
University of Illinois

Thomas Stohlgren
USGS

Background and Rationale

- Biological invasions of nonindigenous species are serious threats to the U.S. natural and managed ecosystems ($120B/yr damage, $27B/yr crop loss)
- Rapid growth in trade worldwide or globalization exacerbates U.S. invasive species problems
- Climate is the dominant determinant of the geographic distribution of plant species, native or alien
- Climate change has already caused unequivocal shifts in distributions and abundances of species, and even pushed certain native species to extinction

Non-native Species Established in Species-Rich Counties



Invasive Species

The Rich Get Richer

Stohlgren, T.J., D. Barnett, C. Flather, J. Kartesz, and B. Peterjohn. 2005. Plant species invasions along the latitudinal gradient in the United States. Ecology 86: 2298-2309.

Stohlgren, T.J., D. Barnett, C. Flather, P. Fuller, B. Peterjohn, J. Kartesz, and L.L. Master. 2005. Species richness and patterns of invasion in plants, birds, and fishes in the United States. Biological Invasions 8: 427-457.

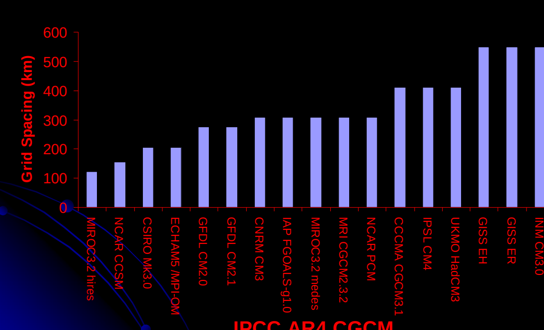
Overall Objective

- To better understand how global climate changes affect the U.S. agricultural and invasive plant species distributions focusing on crop production
- To account for both adaptation of alternative crops and invasion of non-native species to enable decision makers to design effective management and control strategies for a sustainable future agroecosystem

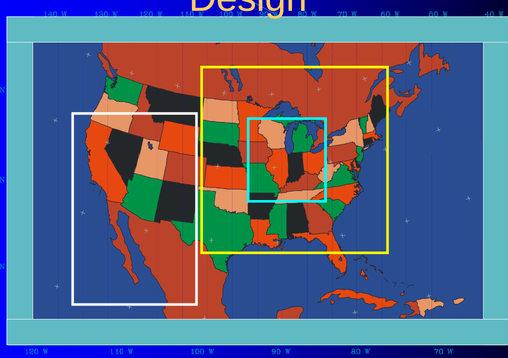
Proposed Research

- To develop a robust SEM (species environmental matching) to best capture the observed agricultural and invasive plant species distribution using the conditions from CEP (climate-ecosystem predictive).
- To make projections for the potential niche distributions of alternative crops adaptable to the likely range of climate changes in the future using CEP.
- To project the geographic distribution and abundance of U.S. agricultural weeds and invasive plant species by integrating newly-developed SEM and future soil and bioclimatic conditions simulated by CEP.

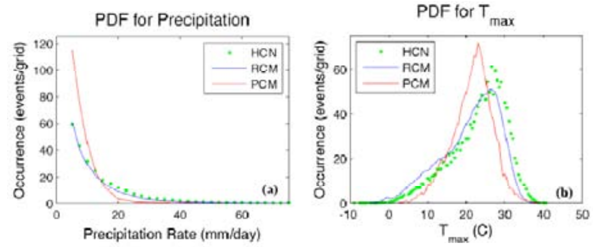
Current CGCMs for Climate Projection



Model Computation Domain Design

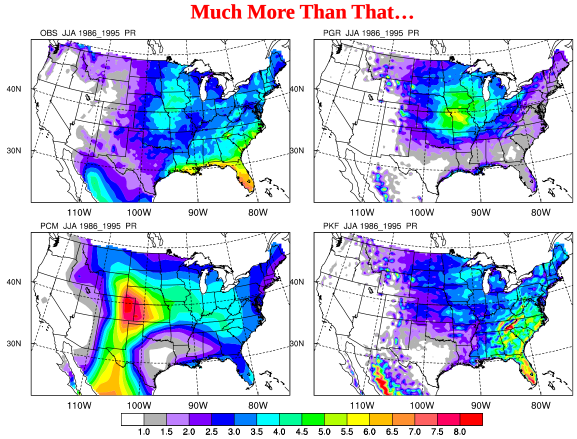


Northeast U.S. Assessment

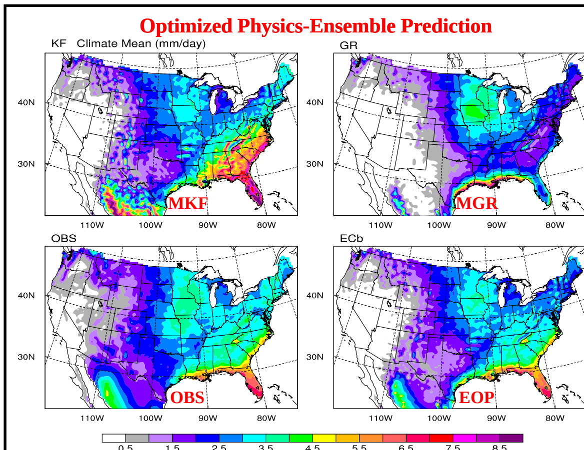


Anderson, B.T., K. Hayhoe, and X.-Z. Liang, 2009: Anthropogenic-induced changes in the 21st Century summertime hydroclimatology of the Northeastern US. *Climatic Change* (accept).

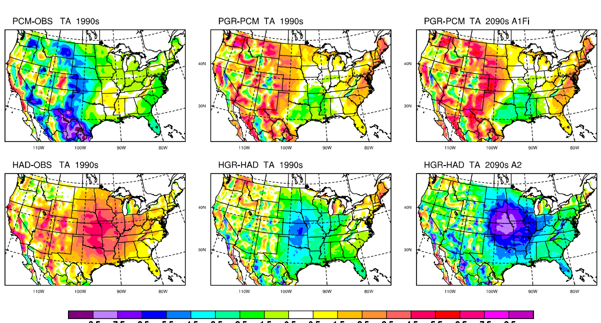
Much More Than That…



Optimized Physics-Ensemble Prediction

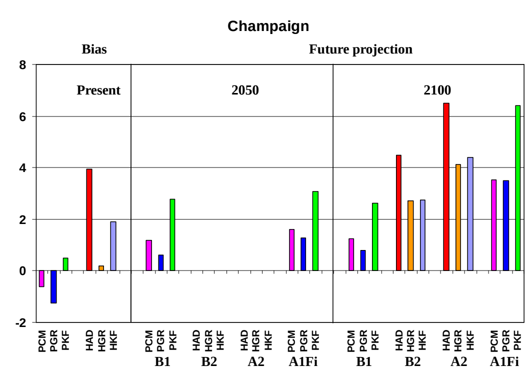


Propagation of GCM Present Climate Biases into Future Change Projections: Temperature



Liang, X.-Z., K.E. Kunkel, G.A. Meehl, R.G. Jones, and J.X.L. Wang, 2008: RCM downscaling analysis of GCM present climate biases propagation into future change projections. *Geophys. Res. Lett.*, **35**, L08709, doi:10.1029/2007GL032849.

Summer 2m Temperature (°C)



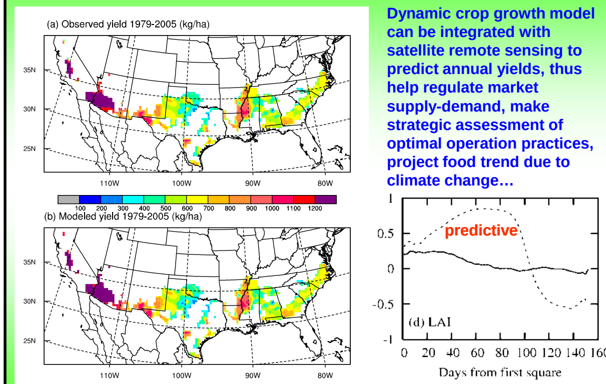
CWRF

Climate-Ecosystem Interaction

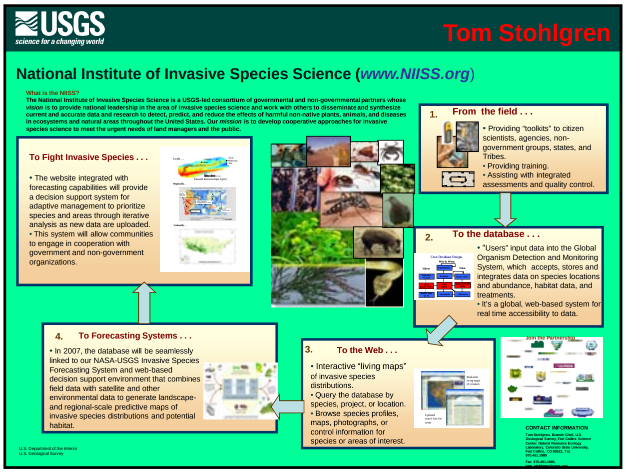
Mosaic Ecosystem Model

USDA
2003➔

U.S. Cotton Yield in 1979-2005



Dynamic crop growth model can be integrated with satellite remote sensing to predict annual yields, thus help regulate market supply-demand, make strategic assessment of optimal operation practices, project food trend due to climate change…



SEM method and assumption

- **Method:** relate observed species distributions to environmental envelopes
- **Assumption:** the fitted observational relationships to be an adequate representation of the realized niche of the species under a stable equilibrium or quasi-equilibrium constant

For this study

- **Model: MaxEnt**
- **Presence point data: cheatgrass**
- **Environmental layers: 10**

Cheatgrass or Drooping broom (*Bromus tectorum*)

Cheatgrass invasion

- Cheatgrass was brought in 1898 from Eurasia into Washington state by researchers looking for new grasses to make hay
- It is widely distributed throughout the U.S. except for Florida
- Its seeds can germinate after years of dormancy
- Wind can carry its seeds into areas that have been cleared
- No insects are yet available to control its spread
- Hand pulling cheatgrass is very hard work

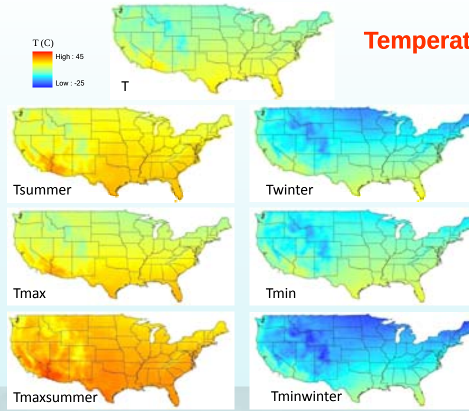
Precipitation

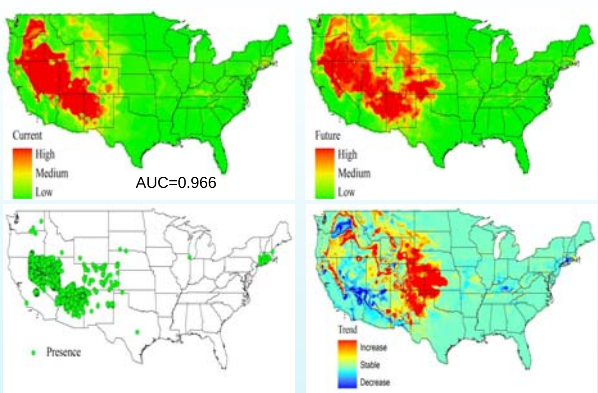
Annual mean
1982-2007

Summer mean
June-August
1982-2007

Grow season mean
April-September
1982-2007

Temperature





Crop suitability

(968 crops whose soil and climate requirements were identified from a literature search, Bowen and Hollinger, 2004)

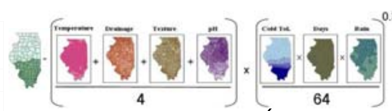
Climate:
Temperature
Precipitation
Growing season length
Minimum winter temperature

Current: observed
Future: RCM

Soil:
Drainage
Texture
pH

STATSGO: 1km

0	Unsuitable
1	Slightly suitable
2	Moderately suitable
3	Suitable
4	Highly suitable

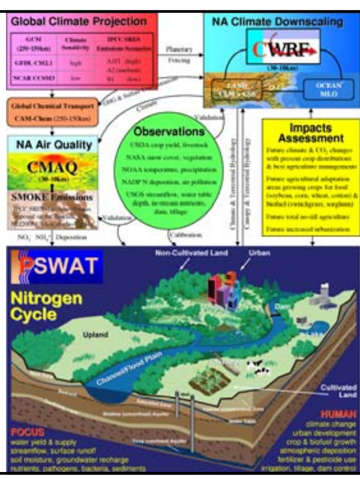


Follow the law of the minimum: if the suitability score for either of them is zero, the location is unsuitable for the crop

EPA STAR
2009-2012

Xin-Zhong Liang
R. Srinivasan
Pushpa Tuppad
Jeff Arnold
Donald Wuebbles

Award in process
August 2009

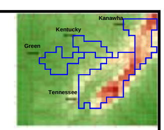


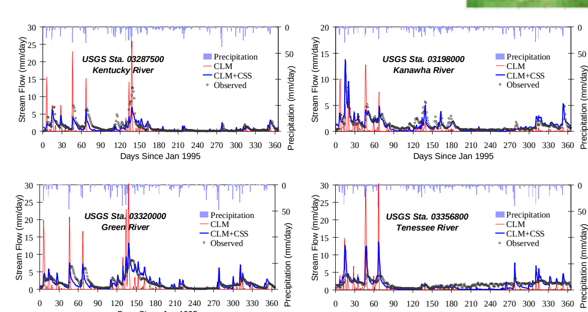
FOCUS
Nutrients
Pathogens
Bacteria
Sediments
Agriculture
Urban

ζ \ f	8		9		10	
	R	RMSE	R	RMSE	R	RMSE
500	0.610	2.957	0.677	1.462	0.734	1.235
1000	0.655	1.461	0.741	1.216	0.679	1.389
1500	0.707	1.258	0.733	1.226	0.654	1.486
2000	0.727	1.205	0.725	1.248	0.633	1.608

CLM+CSS

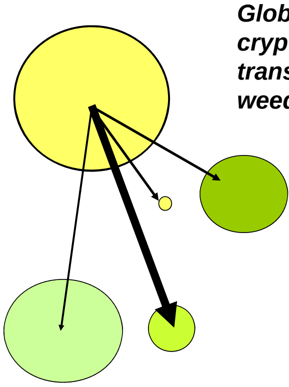
$f = 9$ & $\zeta = 1000$





Future Perspective

- **Expand the modeling system to predict most major crops**
- **Incorporate multi subgrids of land use/land cover**
- **Develop capability to simulate air pollution impacts on crop**
- **Develop capability to study agriculture water quality problems**
- **Develop capability to study the agroecosystem carbon cycle**



Global change and the cryptic invasion by transgenes of native and weedy species

Cynthia Sagers
Biological Sciences
University of Arkansas

Pete Van De Water
Geosciences
Cal State U. Fresno

Steven Travers
Biology
North Dakota State University

transgene – a gene from one species that has been introduced into the genome of another species through biotechnology

Herbert Baker (1971) *Human influence on plant evolution*. Bioscience 21:108

Evidence for crop-to-weed gene flow

Rank	Crop	Scientific name	Kilohectares	Evidence for hybridization
1	Wheat	*Triticum aestivum , T. turgidum*	228,131	+
2	Rice	*Oryza sativa, O. glaberrima*	149,555	+
3	Maize	*Zea mays mays*	143,633	+
4	Soybean	*Glycine max*	67,500	+
5	Barley	*Hordeum vulgare*	65,310	+?
6	Cotton	*Gossypium hirsutum, G. barbadense*	51,290	+
7	Sorghum	*Sorghum bicolor*	45,249	+
8	Millet	*Eleusine coracana*	38,077	m
9	Beans	*Phaseolus vulgaris*	28,671	+
10	Rapeseed	*Brassica napus, B. rapa*	24,044	+

Ellstrand et al. 1999

Evidence for crop-to-weed gene flow

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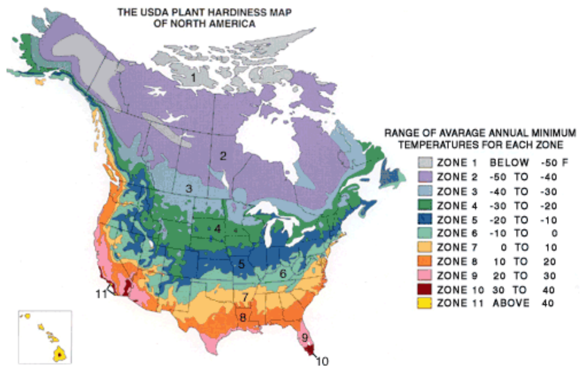
Ellstrand et al. 1999



Making canola:

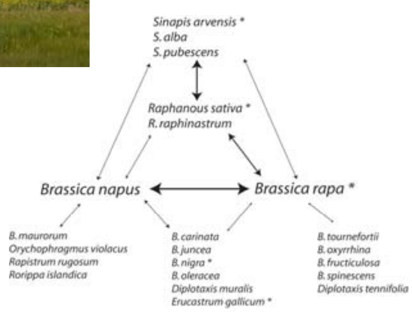
Brassica rapa
(AA, 2N = 20)

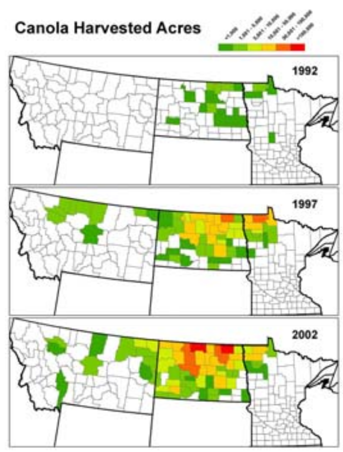
X

Brassica oleracea
(CC, 2N = 18)

Brassica napus
(AACC, 2n =38)

Canola is sexually compatible with least 44 brassicaceous species





Making hybrids:

Brassica rapa
(AA, 2N = 20)

X

Brassica napus
(AACC, 2N =38)

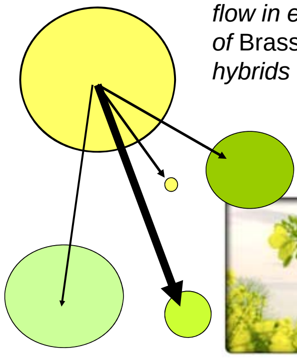
F_1 hybrid
2N = 20-29

What factors promote gene flow?

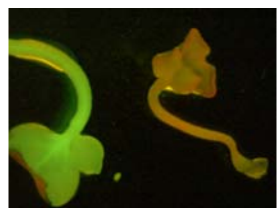
- Coexistence
- Sexual compatibility
- Hybrid vigor
- Selective benefit

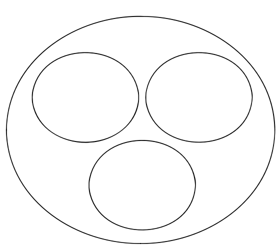
Herbivory, heterosis and gene flow in engineered populations of Brassica *and* Brassica-*hybrids*

US EPA, NRC



US EPA NHEERL WED, Corvallis, Oregon





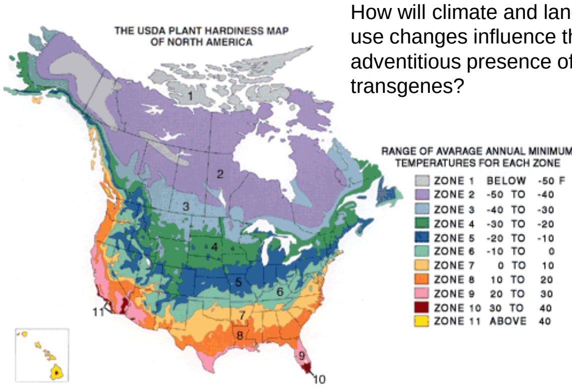
Parentals:
Canola
GM Canola
B. rapa

Hybrids:
B. rapa X canola
B. rapa X GM canola

Conclusions

Risk of transgene flow is a function of:

1) genetic background
2) competition
3) level of selection



How will climate and land use changes influence the adventitious presence of transgenes?

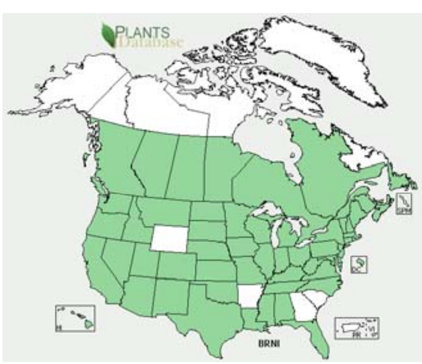
Objectives:
•Characterize variability among weedy populations in traits related to outcrossing

•Incorporate these parameters into existing climate change/land use change models to assess changing risk of transgene flow

What factors promote gene flow?

- Coexistence
- Sexual compatibility
- Hybrid vigor
- Selective benefit

B. rapa L.



B. nigra L.

Sinapis arvensis L.

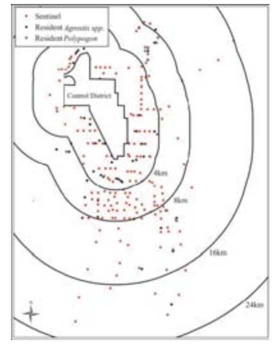
Weed surveys

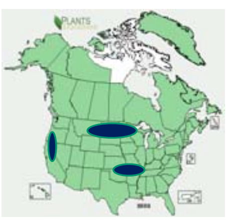
Objectives:
1) map local distributions
2) monitor transgene flow
3) model risk

Sentinel plant study

Objectives:
1) measure transgene flow
2) assess geographic variation
In gene flow rate

Long distance gene flow in *Agrostis stolonifera* (Watrud et al. 2002).



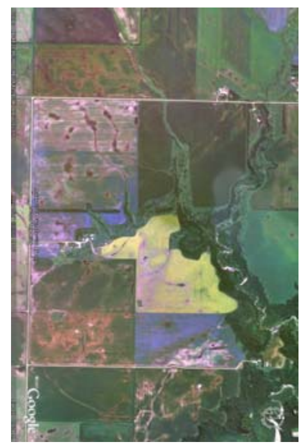


Greenhouse study

Objectives:
1) evaluate genetic variability of functional traits among *B. rapa* populations
2) measure pollinator preference in controlled environment

Modeling

Objectives:
1) develop phenological maps for sexually compatible relatives
2) create a probabilistic model of changing risks of transgene flow



"…seed crops hybridize with their ancestral races to produce weedy derivatives wherever wild and cultivated kinds are sympatric." DeWet and Harlan (1975)

August, Reuters: US rice farmers sue Bayer CropScience over GM rice
Rice farmers in Arkansas, Missouri, Mississippi, Louisiana, Texas and California have sued Bayer CropScience, alleging its genetically modified rice has contaminated the crop, attorneys for the farmers said on Monday. The lawsuit was filed on Monday in the U.S. District Court for the Eastern District of Arkansas in Little Rock, law firm Cohen, Milstein, Hausfeld & Toll said in a statement. The farmers alleged that the unit of Germany's Bayer AG <BAYG.DE> failed to prevent its genetically modified rice, which has not been approved for human consumption, from entering the food chain. As a result, they said, Japan and the European Union have placed strict limits on U.S. rice imports and U.S. rice prices have dropped dramatically. A Bayer representative could not be immediately reached for comment.

Acknowledgements

Collaborators

Robert Bacon (UA, Fayetteville)
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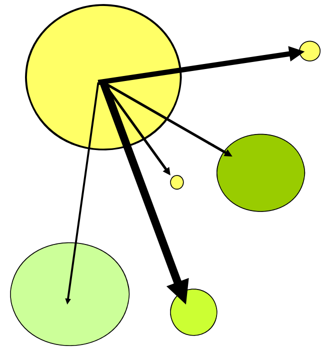
E. Henry Lee (US EPA)
Jason Londo (US EPA)
Tom Millican (UA, Fayetteville)
Sharon Morgan (UA, Fayetteville)
Chris Pires (Mizzou)
C. Neal Steward (U. Tennessee)
Lidia Watrud (US EPA)

Agency support

Dynamac Corp.
National Research Council
USDA NRI
US EPA

Escape from cultivation and the influence of crop plants on the evolution of native populations



Allele frequencies in sink populations are a function of initial frequencies, migration rate, and selection.

Question: what factors promote interspecific gene flow?
- hybrid vigor
- selective benefit of transgene
- sexual compatibility

Question: what factors promote interspecific gene flow?
- hybrid vigor
- selective benefit of transgene
- sexual compatibility

Predict:
- Heterosis (F1 > parentals)
- Performance GM > Performance non-GM
- Transgenic seeds in non-transgenic plants

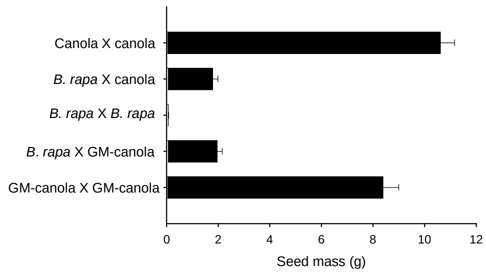
$$Risk = (probability\ of\ an\ accident) \times (losses\ per\ accident)$$

Outcrossing:

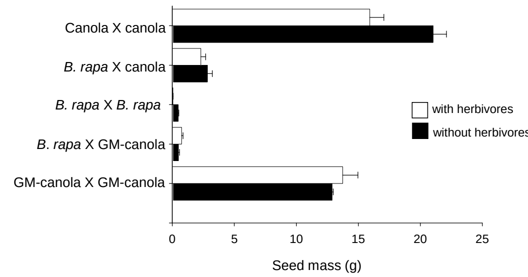
Brassica rapa (AA, 2N = 20) X *Brassica oleracea* (CC, 2N = 18)

Brassica napus (AACC, 2N = 38)

2006 Seed mass data – by mating type



2007 – Seed mass - herbivory by mating type interaction



Question: what factors promote interspecific gene flow?
- hybrid vigor
- selective benefit of transgene
- gene flow

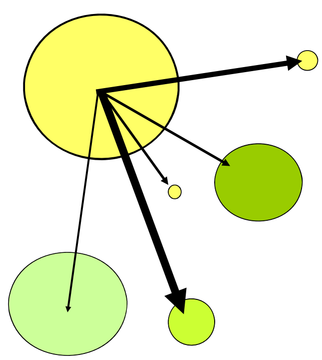
Found:
- √ Heterosis (F1 > parentals)
  (relative to the weedy parent, in nearly every case)
- √ Performance GM > Performance non-GM
- √ Transgenic seeds in non-transgenic plants

Question: what factors promote interspecific gene flow?
- hybrid vigor
- selective benefit of transgene
- sexual compatibility

Predict:
- Heterosis (F1 > parentals)
- Performance GM > Performance non-GM
- Transgenic seeds in non-transgenic plants

Allele frequencies in sink populations are a function of:

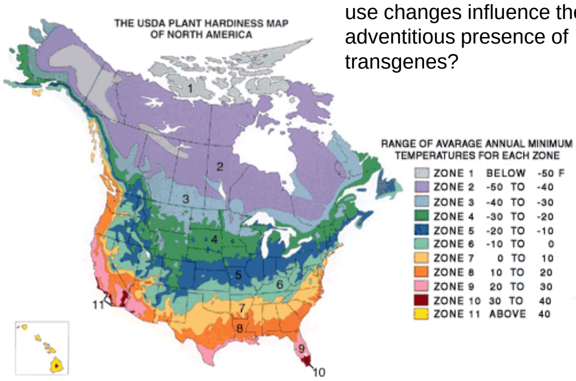
•*initial allele frequencies*
•*migration rate*
•*selection*



What factors promote gene flow?

- Hybrid vigor
- Sexual compatibility
- Benefit of transgene
- Ecological factors
  – Population size and density
  – Community structure
  – Physical environment

How will climate and land use changes influence the adventitious presence of transgenes?

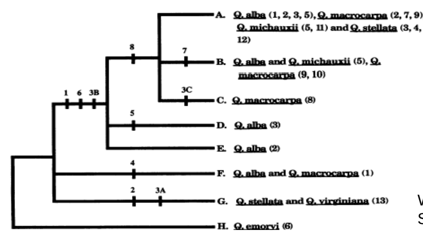


Modelling effort

"Breeders have found that, with rare exceptions, the crops do not successfully cross-breed with other plants in the environment, especially plants in crop-growing regions."

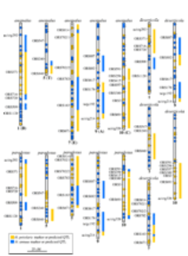
Martina McGloughlin, Director of Biotechnology at the University of California at Davis, Washington Post, 2000

Hybridization occurs in nature.

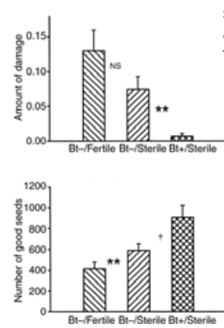


Whittenmore and Schaal 1991

Hybrids can be stable.



Reiseberg et al. 2003



Reduced herbivory and increased seed set in sunflower (*Helianthus annuus*) associated with the presence of *Bt* transgene.

Snow et al. 2003

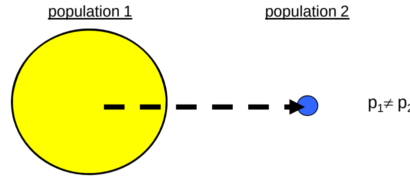
At the end of the day…

Population biologists are in an ideal position to address pressing questions of the effects of global change on natural/not-so natural populations.

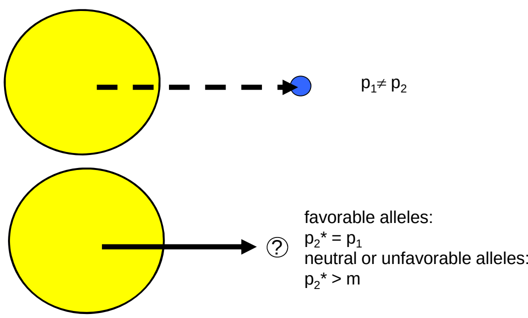
These projects operate at the juncture of policy, economics and biology.

These issues are an invitation for cooperation and collaboration across disciplines to provide recommendations and contributions to basic and applied sciences, to regulatory agencies, and to producers and developers in agricultural industries.

Island models of gene flow: equilibrium predictions



Island models of gene flow: equilibrium predictions

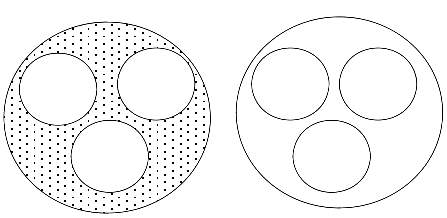


Project design

Brassica napus x *Brassica rapa* x GM-*B. napus*

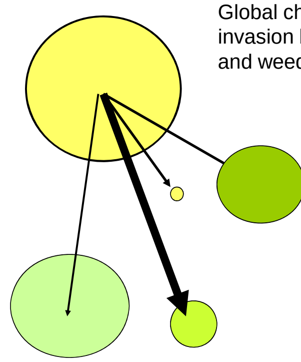
F_1 hybrid — GM – F_1 hybrid

Split plot design:
Two factors: mating type, herbivory



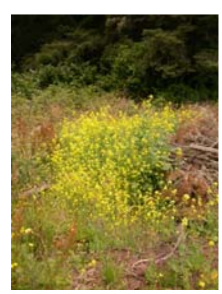
2006 – low herbivory
2007 – high herbivory

Response variables:
- biomass (g)
- seed mass (g)
- *seed counts*



Global change and the cryptic invasion by transgenes of native and weedy species

USDA CSREES NRI



Delzie Demaree
Malvern, Arkansas
1926

Herbert G. Baker,
UC Berkeley

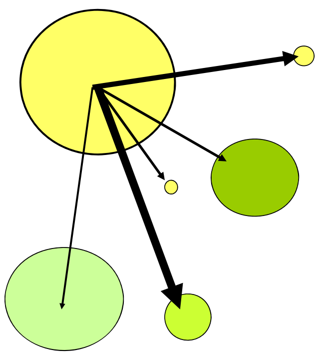
Victor Muehlenbach, St. Louis
Missouri 1969

Three general assumptions in risk assessment studies

- we understand the problem
- we know what to measure
- we can use available data to predict the behaviors of novel traits in nature

Gene flow, selection and perverse effects:

Influences of modern agriculture on the evolution of native species

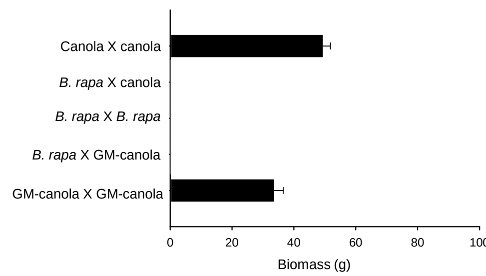


C.L. Sagers

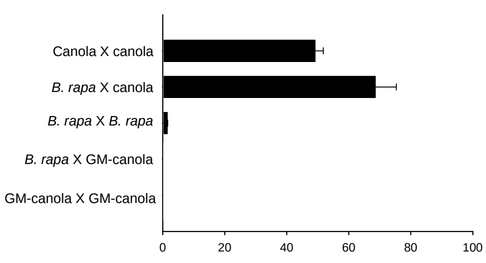
Biological Sciences

University of Arkansas

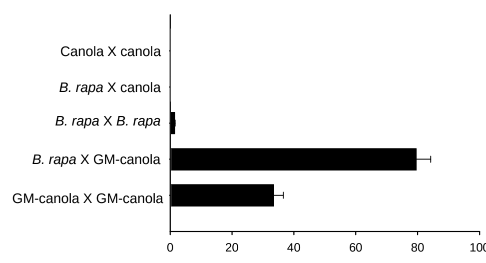
2006 Biomass – by mating type



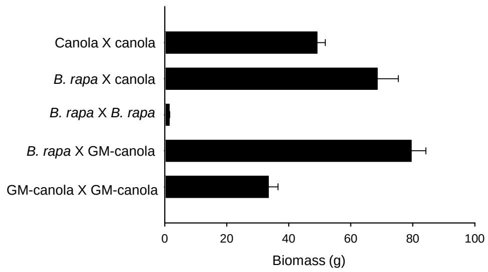
2006 Biomass – by mating type



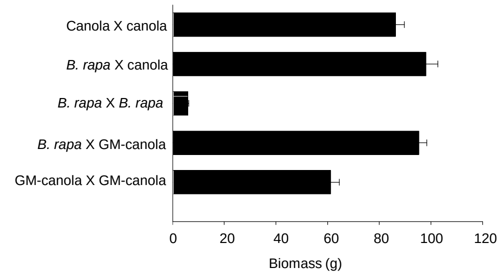
2006 Biomass – by mating type



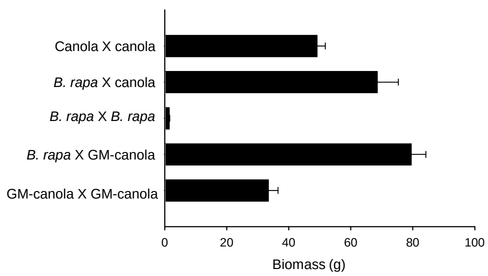
2006 biomass – by mating type



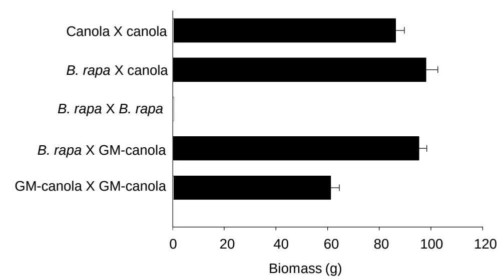
2007 Biomass – by mating type



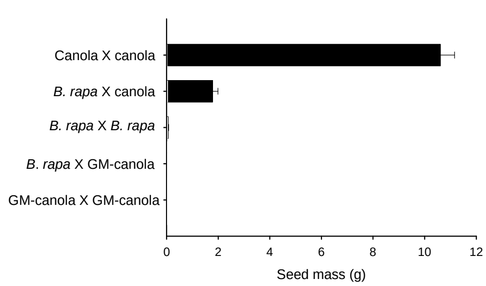
2006 Biomass – by mating type



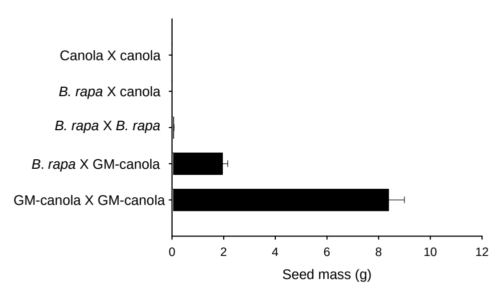
2007 Biomass – by mating type



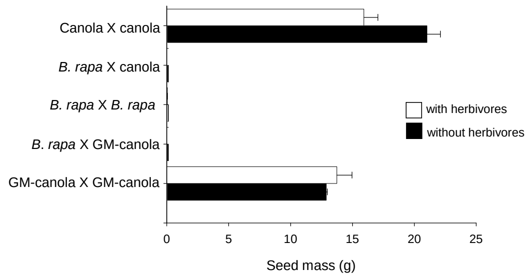
2006 Seed mass data – by mating type



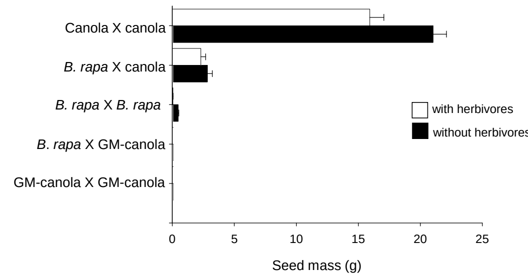
2006 Seed mass data – by mating type



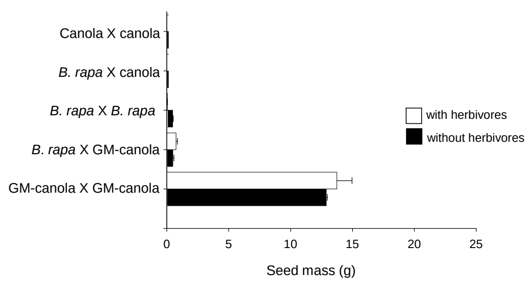
2007 – Seed mass - herbivory by mating type interaction



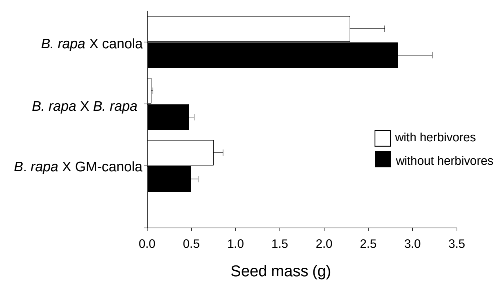
2007 – Seed mass - herbivory by mating type interaction



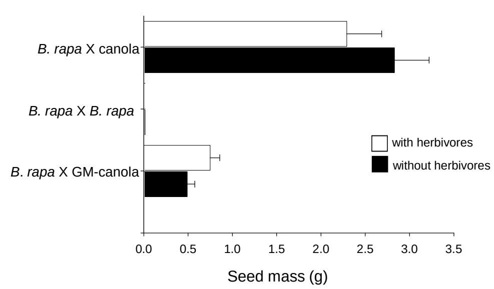
2007 – Seed mass - herbivory by mating type interaction



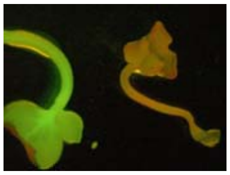
2007 Seed mass – herbivory by mating type interaction



2007 Seed mass – herbivory by mating type interaction



Question: what factors promote interspecific gene flow?
- hybrid vigor
- selective benefit of transgene
- sexual compatibility



A Multi-scale Approach to the Forecast of Potential Distributions of Invasive Plant Species

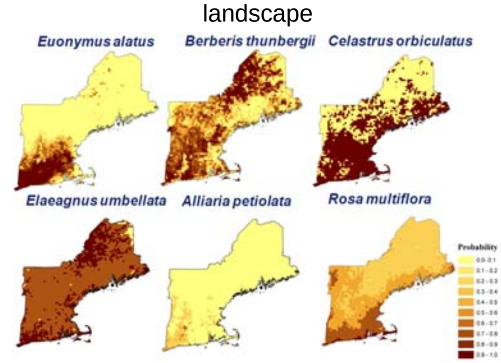
John Silander
University of Connecticut

Alien Invasive Species in New England

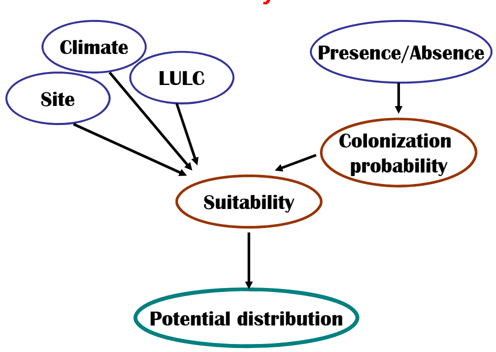
- 111 invasive plant species identified in New England: the vast majority (66%) are native to East Asia or Eurasia.
- Of these, the most pervasive are woody invasives that are native to East Asia.
- The majority (61%) of invasion sites are dominated by 18% of all invasive species that are fleshy-fruited and bird dispersed.

Data from:
www.IPANE.org

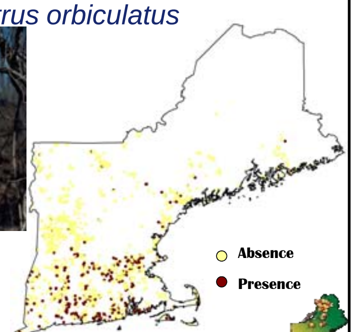
A primary objective has been to predict the where invasive species will potentially spread in the regional landscape



Our approach to modeling potential distribution is to use spatially explicit Hierarchical Bayesian models:



Response variable:
Presence/Absence data
Celastrus orbiculatus



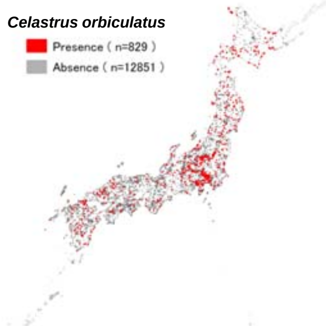
- native of East Asia
- woody Liana
- edge habitats

Data from:
www.IPANE.org

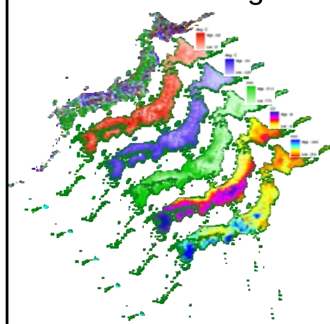
Incorporate native (Japanese) Presence/Absence data (relevés)

From the Japanese relevé plot dataset: presence/absence data from about 20,000 plots (PRDB database from N. Tanaka et al. 2005)

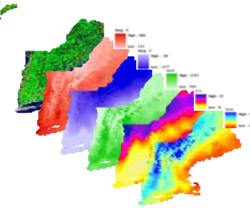
[Also used Nagano Flora database]



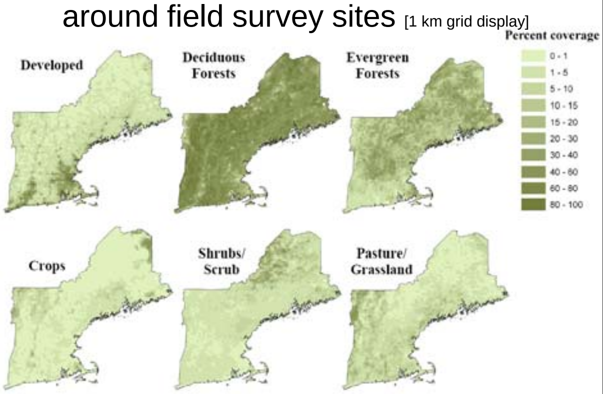
Climate data layers New England & Japan



- Max Temperature of Warmest Month
- Min Temperature of Coldest Month
- Annual Precipitation
- Precipitation Seasonality (Coefficient of Variation)
- Precipitation of Warmest Quarter



The collapsed LULC neighborhood around field survey sites [1 km grid display]



Local field survey site characteristics

- Habitat type (collapsed)
  - Edge
  - Deciduous forest
  - Evergreen forest
  - Open
  - Marine influence
  - Closed canopy wetland
  - Open canopy wetland
- Canopy closure (%)
  - An ordinal variable

Data from: www.IPANE.org

Potential distribution ~ *f*(Climate, Habitat, Canopy, LULC)

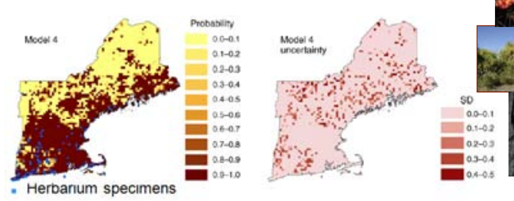
Celastrus orbiculatus

Models examined:

1. New England climate only
2. Japanese climate only
3. NE + J climates
4. NE+J climates + local habitats + LULC

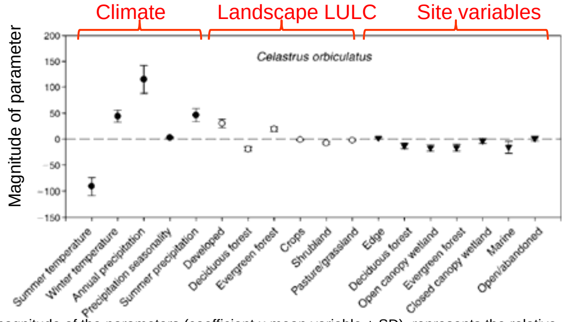
Prediction maps for New England: probability of species occurrence and uncertainty

Celastrus orbiculatus



Best model fits include: climate variables from New England & Japan, LULC, and local site characteristics; predictions validated by comparisons with independent herbarium records

Relative contribution of the explanatory variables to the estimation of the probability of establishment



magnitude of the parameters (coefficient x mean variable $\pm$ SD), represents the relative contribution of the variable to the estimation of the probability of establishment

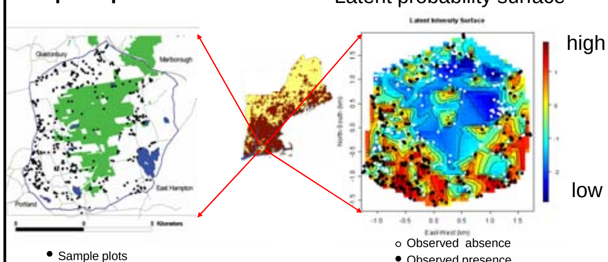
Factors across species that influence invasive species richness at a site

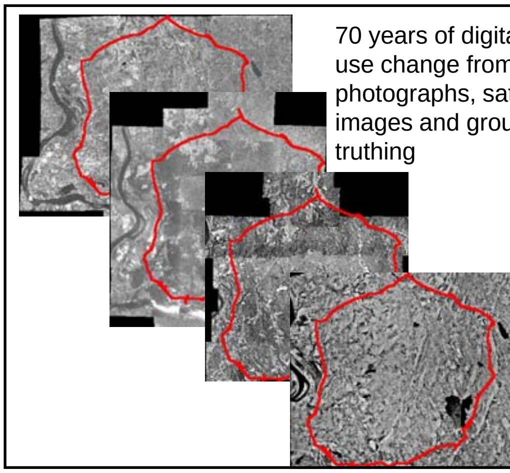
+ edges and open canopies
+ road density
+ deciduous forests
+ warmer summers
- conifer forests
- active agriculture

Predictions also at local landscape level with a focus on land-use change: *Celastrus orbiculatus*

Analysis is based on a **spatial point process model**

Latent probability surface





70 years of digital land-use change from aerial photographs, satellite images and ground truthing

Explanatory variables

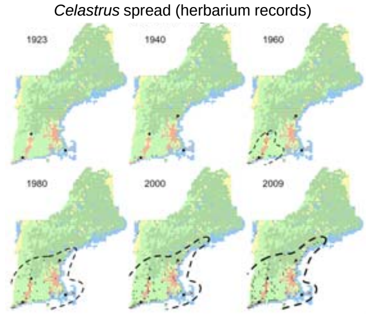
	Celastrus orbiculatus	
Variable	Posterior mean	Credible interval
Intercept	1.26	(0.63, 1.88)
Canopy closure	0.11	(-0.03, 0.26)
Heavily managed	-1.35	(-2.07, -0.7)
Distance to edge	-1.00	(-1.30, -0.73)
LULC: Δ to Residential	0.44	(0.10, 0.78)
LULC: Ag to forest	0.47	(0.10, 0.85)
LULC: Aband. field	0.78	(0.22, 1.31)

$\pm$

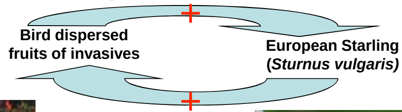
Land-use history is critical to predicting the distribution of invasive species in new England

But these are simply static models; how do invasive plant species spread across the landscape over time?

Celastrus spread (herbarium records)



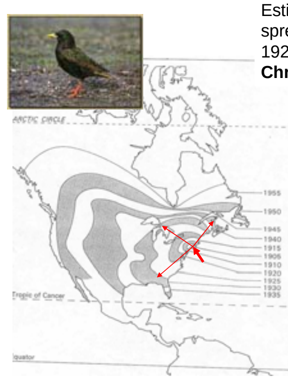
Bird dispersal mutualism?



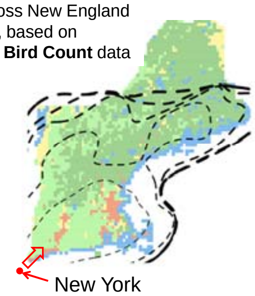
Invasive fruits that attract birds

Invasive bird introduced from Europe to New York 1896

Mutual spread across the region?

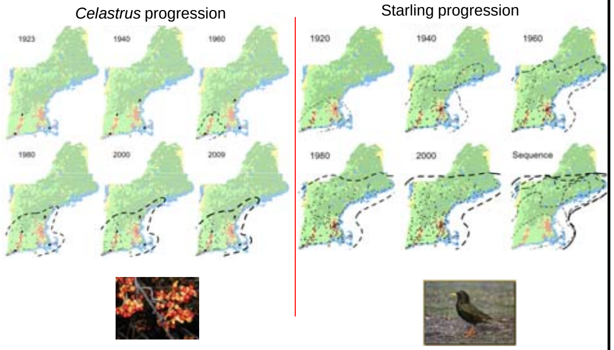


Estimate decadal starling spread across New England 1920-2009, based on **Christmas Bird Count** data



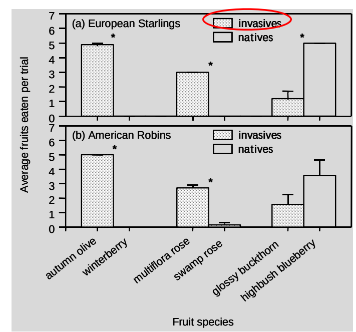
New York 1896

Joint spread of starlings & *Celastrus?*

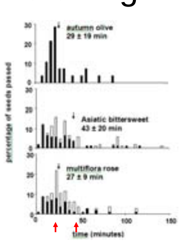


Feeding choice behavior

Starlings prefer invasive fruits



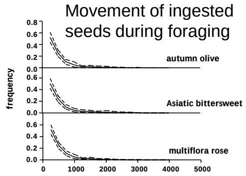
Starling movement of invasive fruits

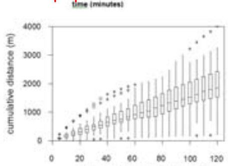


Ingested seed pass-through times

Local seed dispersal

Movement of ingested seeds during foraging



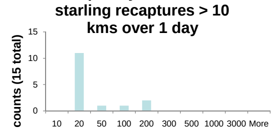


Cumulative distribution of flight movements

Long distance dispersal

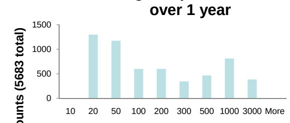
data on over 24,000 banded starling recaptures

Frequency distribution starling recaptures > 10 kms over 1 day



Up to 200+km/day

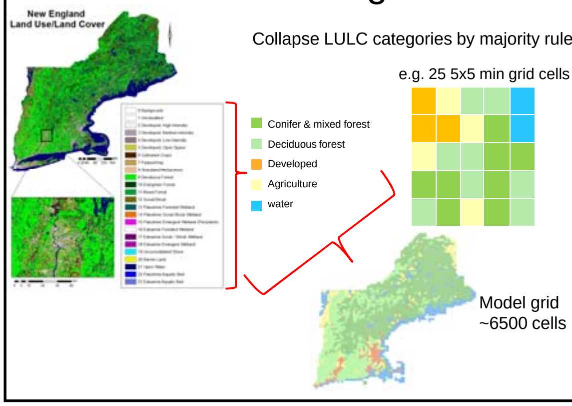
frequency distribution starling recaptures >10 kms over 1 year



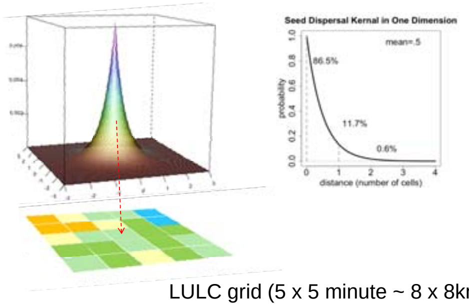
Develop a **Cellular Automaton model** of the dispersal and growth of *Celastrus* across the New England region

- Grid of cells = LULC across the region (5x5 min cells ~8x8kms) ~6500 cells.
- Set of population asymptotic growth (λ) rules for *Celastrus* based on LULC specific demographic responses.
- Local dispersal kernel for *Celastrus* linking cells on grid (based on starling data)
- Long distance dispersal rule

LULC CA grid



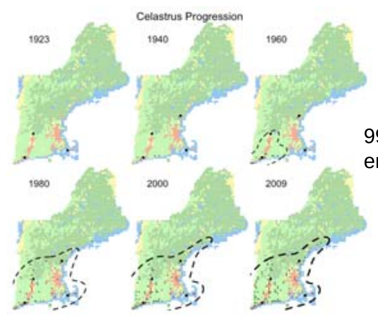
Dispersal kernel (local)



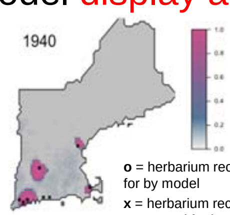
LULC grid (5 x 5 minute ~ 8 x 8km)

Spread Prediction Evaluations

Using independent data: herbarium specimens (& field data)



Model display and evaluation



o = herbarium record accounted for by model
x = herbarium record *not* accounted for by model

CA Model predictions for the spread of oriental bittersweet. summary of **200 replicate runs**:

- **proportion of model runs** predicting presence (0 – 1).
- if **80+%** model runs predict presence, then if herbarium record is present at that time, scored as correct prediction "o"; if <80%, scored as incorrect prediction "x"
- example here is 50% correct.

Seeding the model

LULC	Starling use*	Proportion of landscape	Growth rate (λ)
developed	30%	4%	1.5
agriculture	37%	7%	1.5
Deciduous forest	18%	27%	1.3
Conifer/mix forest	3%	51%	0.95
water	12%	11%	0

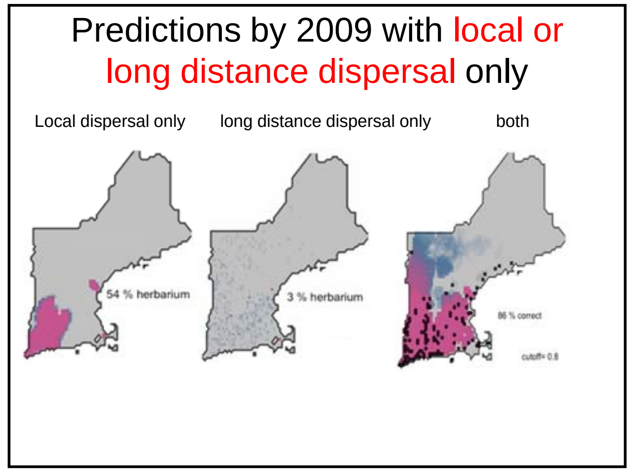
First sites in herbarium record:
New Haven, CT & Falmouth, MA;
a few years later, Durham, NH
These were used as **seed points** for the model runs

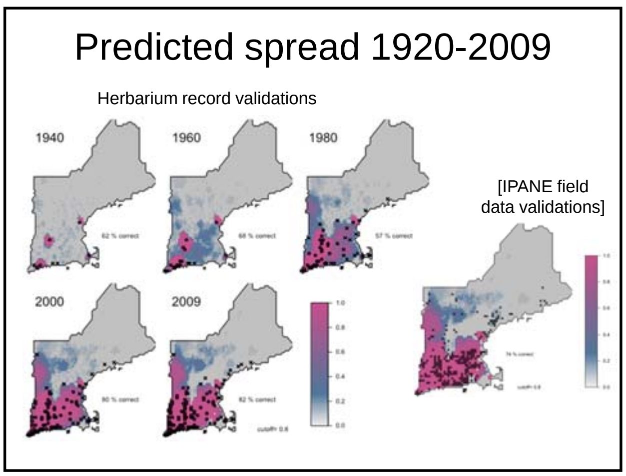
* Dispersal kernel is adjusted by starling behavioral use of the landscape.

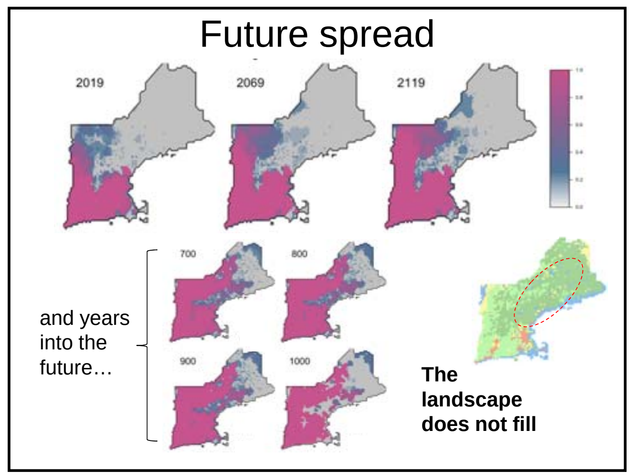
Exponential local dispersal kernel with mean = .5 (rate =2)

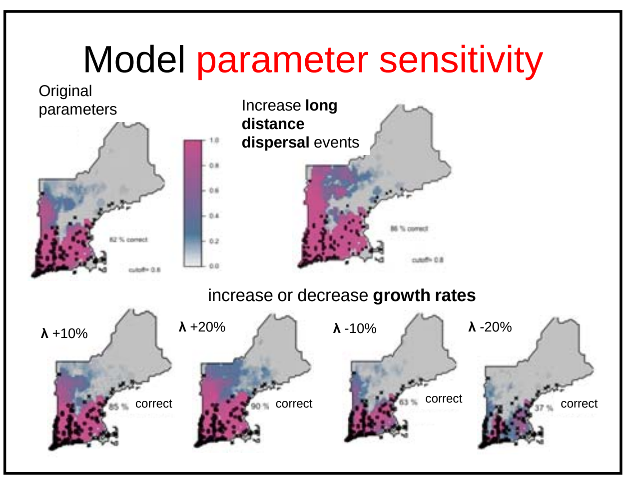
1 long distance dispersal per generation moving drawn from a uniform distribution on [3,20]

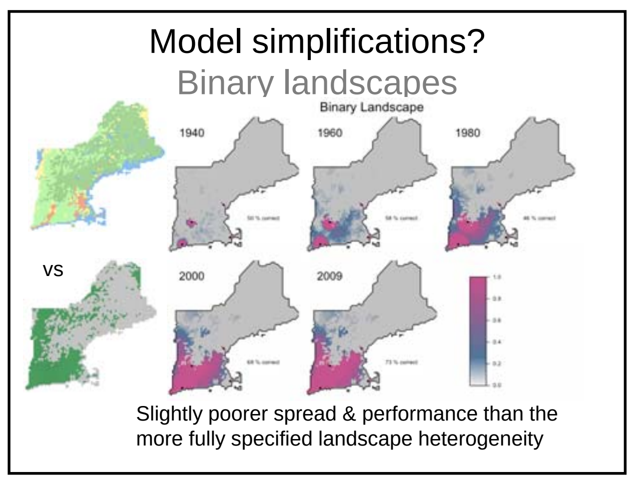

Light >
Low
Medium
High
Soil moisture
v
Low
Medium
High
Celastrus performance (growth, survival, reproduction) across transplant sites


Predictions by 2009 with local or long distance dispersal only
Local dispersal only
long distance dispersal only
both
54 % herbarium
3 % herbarium

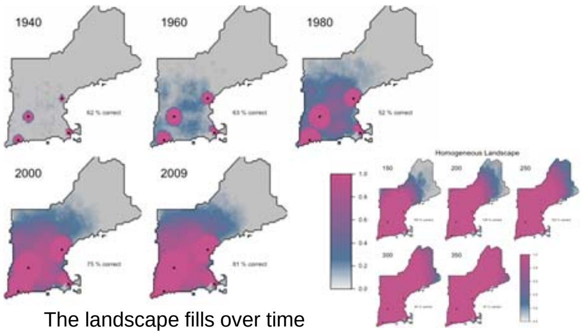

Predicted spread 1920-2009
Herbarium record validations
1940
1960
1980
2000
2009
[IPANE field data validations]


Future spread
2019
2069
2119
700
800
900
1000
and years into the future…
The landscape does not fill


Model parameter sensitivity
Original parameters
Increase long distance dispersal events
increase or decrease growth rates
λ +10%
λ +20%
λ -10%
λ -20%
85 % correct
90 % correct
63 % correct
37 % correct

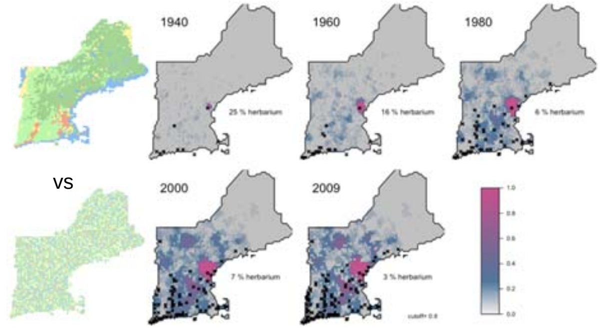

Model simplifications?
Binary landscapes
Binary Landscape
1940
1960
1980
VS
2000
2009
Slightly poorer spread & performance than the more fully specified landscape heterogeneity

Uniform landscapes?



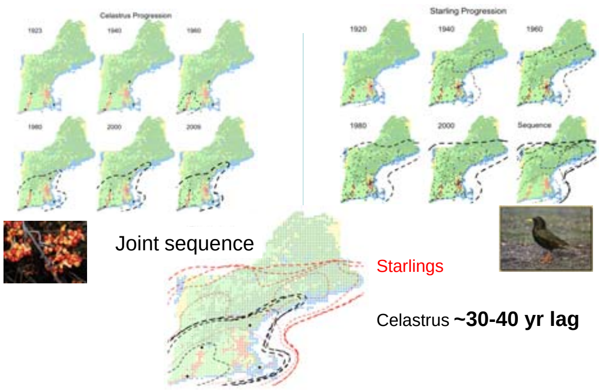
The landscape fills over time

Random landscapes?



Celastrus fails to spread in the landscape

Joint spread of starlings & *Celastrus?*



Summary

- The most pervasive invasive plant species in New England tend to be woody and with bird dispersed fruits.
- HB models provide accurate, static predictions of the potential distributions of species using climate, land-use, and local site traits as explanatory variables. Native range data together with invaded range data are critical to accurate predictions.
- CA models, calibrated from invasive plant demographic data (*Celastrus*) and starling movement, yield predictions that agree with the observed spread of invasives over space and time.
- Regional land-use patterns are critical to the patterns of spread of both invasive plants and starlings.

Predicting relative risk of invasion by saltcedar and mud snails in river networks under different scenarios of climate change and dam operations in the western United States

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Brian Bledsoe
Denis Dean
Colorado State University

Jonathan Friedman
Greg Auble
Pat Shafroth
USGS

David Merritt
David Raff
David Lytle
OSU
David Purkey
SEI Stockholm Environment Institute

This research is funded by U.S. EPA–Science To Achieve Results (STAR) Program Grant #

Climate change likely to enhance spread of invasives in river ecosystems … but how?

Eurasian saltcedar (*Tamarix*)

New Zealand mud snail
(*Potamopygus antipodarum*)

- Alter ecosystem structure and function
- Contribute to native species declines
- Economic damage

Climate Change Outcome: Range expansions within suitable thermal envelopes

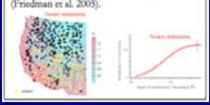


Figure 2. Occurrence of saltcedar in western US for 475 randomly-selected river reaches (left) and probability of saltcedar occurrence as a function of winter minimum temperature (Friedman et al. 2005).

Friedman, J.M., G.T. Auble, P.B. Shafroth, M.L. Scott, M.F. Merigliano, M.D. Freehling and E.R.Griffin. 2005. Dominance of non-native riparian trees in western USA. *Biological Invasions* 7:747-751.

Loo, S.E., R. Mac Nally, and P.S. Lake. 2007. Forecasting New Zealand mudsnail invasion range: model comparisons using native and invaded ranges. *Ecological Applications* 17:181-189.

Key point: *local* factors will determine invasion success - mechanisms?

Working Hypothesis

Within thermally suitable envelope …**local invasion success** will be dictated by habitat suitability and dynamics (hydrologic, geomorphic) and biotic factors, which can be modeled at the ecologically relevant scales.

Account for human responses to climate change, which will contribute to risk of invasion.

Scaling the problem:
GCM → Hydrologic Model (subcatchments)→ Ecological Response (reaches)

Framework: Hydrogeomorphic Template

Species population success is a function of magnitude, frequency, timing, and duration of flow events that limit establishment success or cause mortality.

Effectiveness of flow regime varies with geomorphic settings (e.g., canyon vs. alluvial river reaches).

Plan: Combine flow regime and geomorphic setting (= natural disturbance regime) to explain current distribution of salt cedar and mudsnail and to project future likelihood (risk) of invasion.

Generalize to disturbance-sensitive species that vary in flow-sensitive species traits.

Project Goals

(1) Develop a ecological response model to explain the current distribution and dominance of two invasive species across the interior West in terms of climatically-driven, local-scale environmental drivers.
(2) For a geographic region in the western US, use downscaled projections of regional climate change to describe possible future streamflow regimes, and incorporate the effect of water management on those future flow regimes.
(3) Disaggregate the subbasin-scale flow regime output from the WEAP model and construct a "reach scale" flow regimes for the drainage network in the entire region.
(4) Use the ecological response model to examine the "risk of invasion" for river reaches throughout the region for different combinations of climate change scenarios and modes of dam operations.in geomorphic context
(5) Model long-term invasion success for the two species under interannual flow regimes representing a range of hydrogeomorphic settings.

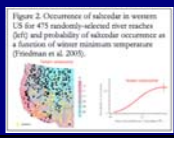
Goal 1

Develop empirical "mechanistic" ecological response models to explain the current distribution and dominance (probability of occurrence) of two invasive species across the interior West at the stream segment scale.

Hypotheses:

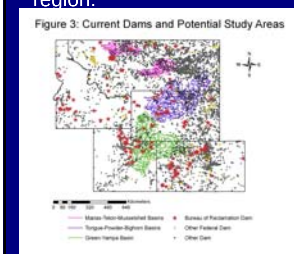
The current distribution and abundance of saltcedar and NZMS can be explained statistically in terms of site-scale hydrogeomorphic setting and dynamics.

Probability of species occurrence or dominance at a site will reflect a hydrogeomorphic threshold.



Study Region

Use GCM output to identify "thermal envelopes" where minimum winter temperatures will warm to > -30˚ C and thus promote salt cedar range expansion. Overlay with areas on edge of current salt cedar range to identify study region.



Region of conservation and management concern

Goal 2

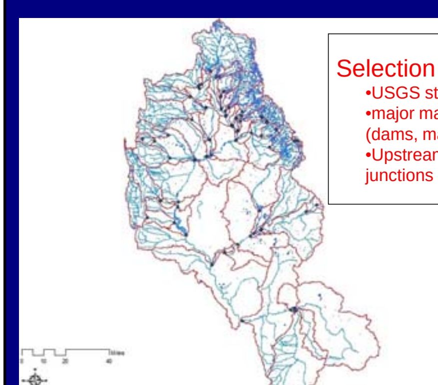
For a geographic region in the western US, use downscaled projections of regional climate change to predict future streamflow regimes, and incorporate the effect of water management on those future flow regimes.

Hypothesis: The WEAP modeling platform can be used to generate sub-basin scale, weekly flow regimes at a spatial grain of ca. 100s of km^2 and can be used to infer the effects of dam operations on natural flow regimes for subbasins in the region. [More below]

WEAP - Water Evaluation and Planning Program (http://weap21.org)

Rainfall-Runoff Model based on spatially distributed land use/land cover types and climatic inputs to catchment; operational rules of water management infrastructure are incorporated to generate hydrographs throughout network.

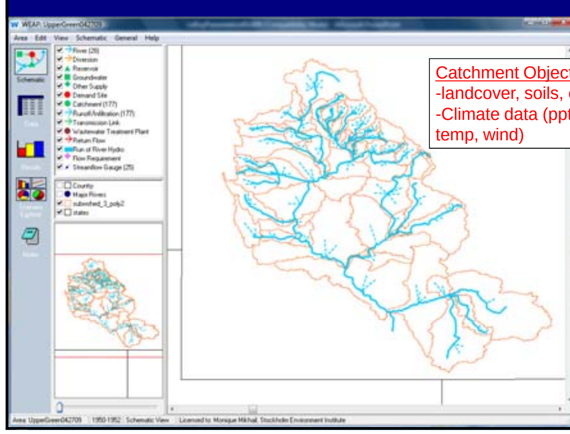
Green River Basin, WY



Selection of "pour points"

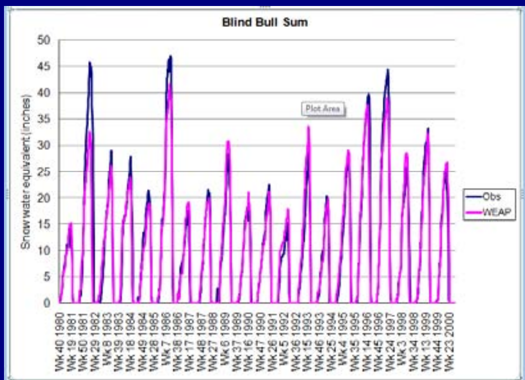
- USGS stream flow gauges
- major management points (dams, major ditch diversions)
- Upstream and downstream of junctions

Initial WEAP model for Green River basin

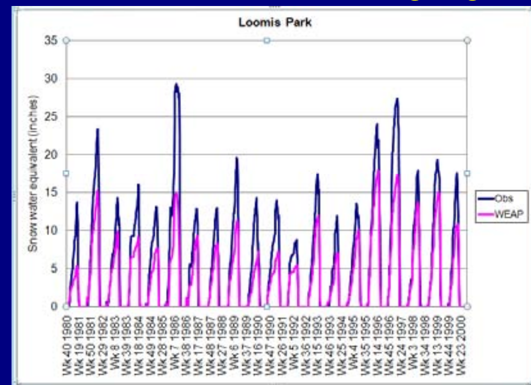


Catchment Objects:
-landcover, soils, etc.
-Climate data (ppt, temp, wind)

Calibration – snowmelt gauge



Calibration – snowmelt gauge



Goal 3

Disaggregate (as necessary) the subbasin-scale flow regime output from the WEAP model and construct a reach scale flow regimes for the drainage network in the entire region. Create geomorphic basemap (DEMs at reach scale) and overlay hydrology (natural plus management).

Hypothesis: An artificial neural net (ANN) model can be constructed to predict streamflow at the river reach scale based on subbasin-scale hydrologic output from the WEAP model, on GIS landscape variables, on projected climate data, and on river network structure.

Goal 4

Use the "mechanistic" ecological response model to examine the "risk of invasion" for river reaches throughout the region for different combinations of climate change scenarios and modes of dam operations.

(empirical models vs. process-based ecological models)

Hypothesis: A reach-scale geomorphic base map can be combined with projected reach-scale streamflow regimes to project relative risk (probability of occurrence or dominance) for the two species under various realizations of future runoff and streamflow.

Apply empirical ecological response model to develop "risk-based" predictions of invasion risk throughout region

geomorphic basemap X flow regime base map (including infrastructure) = invasion risk map

How does invasion risk change with
-- climate projection?
-- dam mangement?
-- propagule pressure?
-- dispersal pathways?

Goal 5

Model long-term invasion success for the two species under interannual flow regimes across a range of hydrogeomorphic settings.

Hypothesis: Stochastic population dynamics models can estimate year-to-year population sizes based on reach geomorphology and long-term (projected) flow regime (including dam operations) and thus assess long-term viability of non-natives.

Expected Outcomes

(what we're doing, what we're not, and what we might)

1. More mechanistic (dynamic) and appropriately scaled basis for projecting invasion risk.
2. Risk map - decision support system given high uncertainties in multiple, linked models. (Not precise point predictions)
3. Framework for thinking about the spatial distribution of threats and how to contemplate proactive management. (Not make precise predictions)
   - General application: Network scale model that enables questions of managing for ecological resilience or conservation planning in metapopulation context?
4. Future inclusion of social processes to examine cost-benefits of spatially-distributed water mangement?

II. Challenges / Lessons (being) learned

1. Projecting ecological response models for salt cedar and NZMS that can be applied to future (novel?) environmental conditions?
2. Scaling climate and hydrologic models to match ecological response/measurement scale.
   - Is weekly hydrograph good enough?
3. Representing "risk" in a robust way that allows for linked multi-model uncertainties.
   - Quantitative models … Qualitative interpretation

III. Interaction with Clients

- Discussions with BuRec (upper Colorado)
- Discussions with The Nature Conservancy (threats assessment of CRB)
- Planned discussions with Wyoming and Colorado state agencies

IV. Outcomes (to date)

- Developing a WEAP model for the upper Green River and Yampa River basins that can eventually be used to address a number of water management issues in the Green River and Yampa basins.
- Generating interest among NGOs, states, and feds.

Integrating future climate change and riparian land-use to forecast the effects of stream warming on species invasions and their impacts on native salmonids

Julian D. Olden

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Research Team

This research is funded by U.S. EPA - Science To Achieve Results (STAR) Program Grant # 833834010

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Challenge Synopsis

- The prospect of dramatic climate change over the next century underscores the need for innovative science and new decision-support tools for efficiently managing freshwater ecosystems
- Climate-induced changes in the geomorphic and physical processes that drive stream ecosystems in the PNW are imminent, including
  - warmer temperatures (2.3-2.9ºC)
  - lower accumulation of winter snowpack (-44%)
  - earlier onset of spring flows (4-6 weeks)
  - lower summer baseflows (-10-35%)
- Cumulative effects and complex interactions among multiple agents of environmental change may limit the success of current and future river management efforts

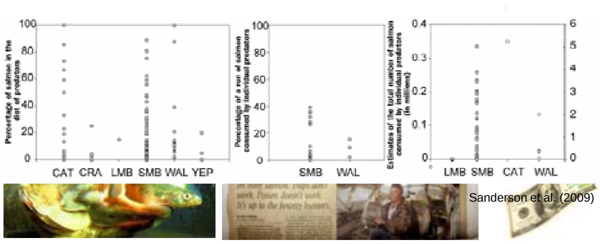
Rivers in hot water

- Climate changes will have direct implications for stream temperatures, which are only exacerbated by the removal or alteration of riparian habitat by logging and grazing that reduces shading and modifies channel morphology
- Elevated stream temperature is one of the most pervasive water quality issues threatening freshwater ecosystems in the PNW

1990 - damaged by livestock overgrazing

2003 - after livestock were removed and vegetation recovered

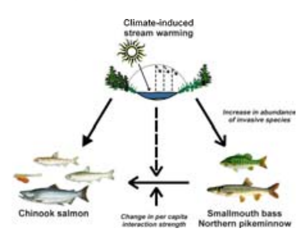
- Management efforts are further complicated by the fact that Pacific salmon (*Oncorhynchus spp.*) now share the riverine landscape with a number of non-native fish species
- Significant shifts in species ranges and the outcome of biological interactions are highly possible



Sanderson et al. (2009)

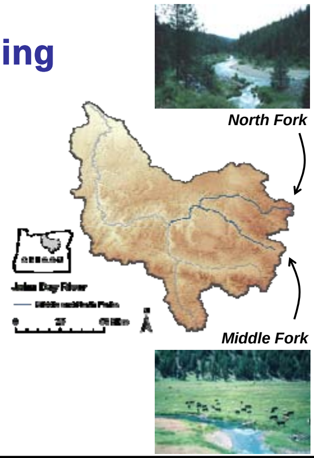
Project Goals

1. What are the predicted effects of regional climate change and local riparian management on riverine thermal regimes?
2. How will Chinook salmon, smallmouth bass and northern pikeminnow respond to projected temperature changes?
3. What are critical areas for riparian restoration and protection to mitigate the negative ecological impacts of climate-induced stream warming in the future?

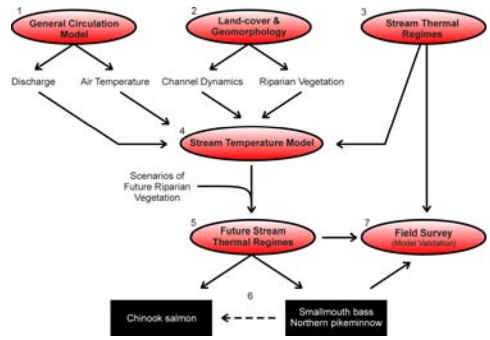


Ecological Setting

- Land use and resource extraction vary longitudinally
- Unregulated
- One of the few remaining wild spring Chinook salmon runs in the Columbia River Basin
- Active region of upstream invasion by smallmouth bass and northern pikeminnow

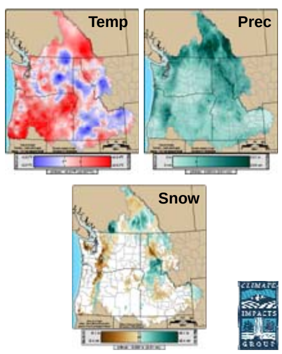


Research Elements

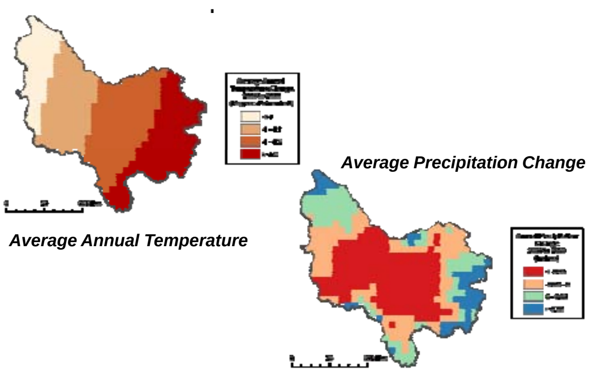


1. Develop climate-change projections of temperature and precipitation

- The Columbia River Basin is predicted to show consistent average increases in air temperature, higher winter-spring Q, lower summer Q, and earlier timing of spring peak events
- We are downscaling simulating future climate data from a suite of GCMs under three green-house gas emissions scenarios (B1, A1B, A2) for decadal time periods (2020-2100)

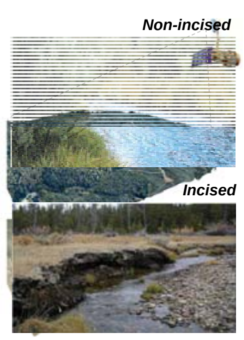


Projections for the John Day Basin



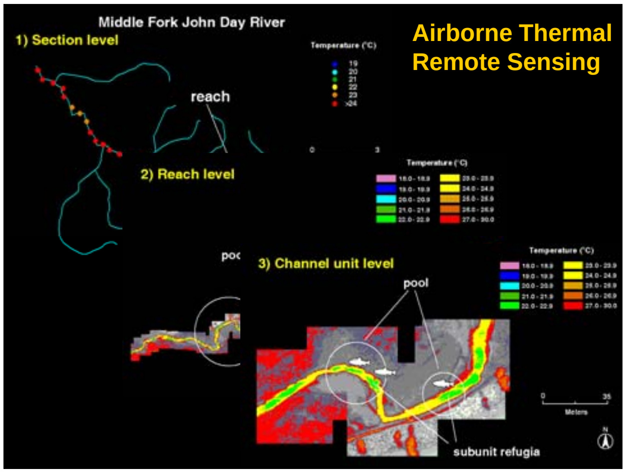
2. Characterize channel geomorphology and riparian land cover

- Thermal sensitivity of stream reaches to climate warming varies with geomorphic setting and degree of channel incision
- Stream reaches will be classified according to drainage characteristics, lithology, and field measured and modeled channel incision
- LandSat TM imagery will be used to quantify riparian land cover



3. Quantify multi-scaled thermal regimes

- Thermal regimes will be quantified using a network of digital temperature loggers at point locations
- Forward looking infrared (FLIR) thermal imagery will be used to map spatially continuous longitudinal patterns of stream temperature



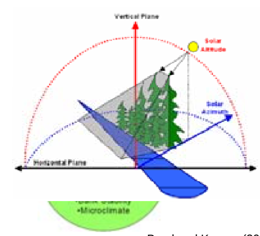
4. Develop a spatially-explicit stream temperature model

- Stream temperature is dependent on both heat load and stream discharge

$$\Phi_{total} = \Phi_{solar} + \Phi_{longwave} + \Phi_{convection} + \Phi_{evaporation} + \Phi_{streambed} + \Phi_{groundwater}$$

- Heat Source (v. 7) allows for the simulation of water temperature at the reach scale using high resolution spatially continuous data, coupled with deterministic modeling of hydrologic and landscape processes

- It includes important processes:
  - mass transfers from tributaries
  - groundwater inflows
  - landscape thermal radiation
  - adiabatic cooling
  - robust radiation modeling
  - etc ...



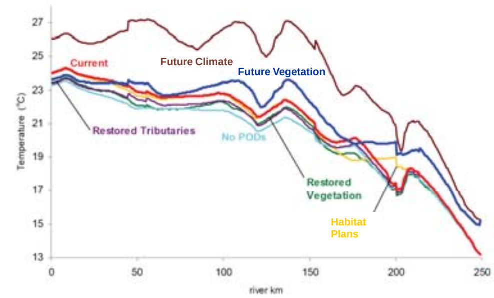
Boyd and Kasper (2003)

5. Forecast thermal regimes under scenarios of climate change and land use management

- Future spatiotemporal patterns in stream temperature will be predicted according to scenarios of projected climate change and riparian land-use

Scenario	Description
Future climate	Scenarios of projected temperature and hydrology
Future vegetation	Scenarios of projected land development
Restored vegetation	Complete restoration to estimated potential vegetation
	John Day Fish Habitat Enhancement Program
	Conservation and acquisition priorities (TNC, TFT)
Restored tributaries	Tributaries flow and temperature set to estimated potential
No PODS	No points of diversion
Ecological targets	Scenarios targeting specific ecological outcomes

What it might look like ...



6 & 7. Model ecological responses to future thermal regimes

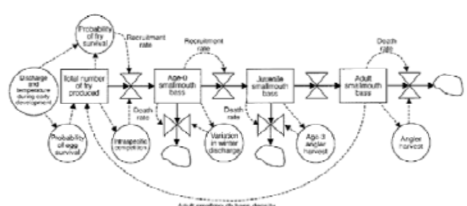
- Fish species responses to climate change and riparian management will be estimated according to psychological preferences and tolerances

- A number of additional key temperature benchmarks will be explored.

Parameter	Chinook salmon Egg/Alevin	Chinook salmon Juvenile	Chinook salmon Adult	Smallmouth bass	Northern pikeminnow
Lower lethal limit	1.7	0.8	0.8	10.0	8.1
Lower tolerance limit	4.0	4.5	3.3	12.3	10.1
Lower growth limit	4.5	10.0	-	20.2	16.1
Preferred temperature	6.0-10.0	12.0-13.3	7.2-14.5	25.0-26.0	18.1-22.8
Upper growth limit	12.8	15.6	-	27.0	24.4
Upper tolerance limit	14.4	19.1	21.0	29.5	26.0
Upper lethal limit	18.9	25.1	22.0	36.9	38.0
Migration	-	-	3.3-13.3	-	-
Holding	-	-	6.0-14.0	-	-
Spawning	-	-	5.6-12.8	12.8-20.0	13.0-15.0

- Statistical models linking species occurrence, abundance and spawning activities (SMB) to projected changes in thermal and hydrologic regimes will be developed

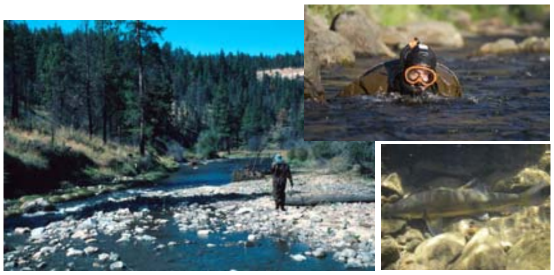
- We will explore bioenergetic models and age-structured models that account for environmental change, fish population dynamics, and harvest rates



Peterson and Kwak (1999)

Field surveys

- Continuous stream segments over 100 km of the Middle and North Forks will be systematically surveyed to map and obtain counts of fish and spawning nests in June, August and October

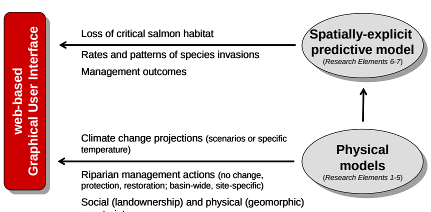


Prioritizing riparian management in a changing climate

- Our findings will help guide management strategies and policy aimed at minimizing the future range expansion of invasive species through protection (i.e., conservation easements) and restoration (i.e., riparian fencing) of riparian vegetation that creates and maintains coolwater habitat.
- Results from this project will make it possible to rank stream segments in terms of their ability to:
  - mediate the effects of climate change on stream temperatures
  - create suitable thermal habitat that favors native species over invasive species
  - establish thermal barriers to prevent upstream invasion
- Management portfolios (based on different ecological endpoints) will be distributed to local and regional agencies and NGOs

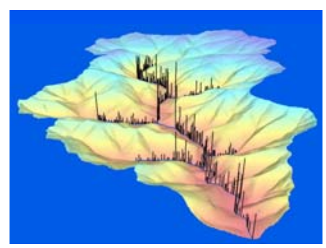
Outcomes

- Products from our research project will be integrated into a Graphical User Interface providing the user with animated maps and timelines of stream temperature change, salmon habitat availability, and bass and pikeminnow spread for a given climate change or land use scenario, or the option to export data for quantitative analysis

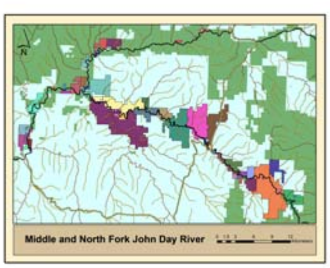


Outcomes

- Products from our research project will be integrated into a Graphical User Interface providing the user with animated maps and timelines of stream temperature change, salmon habitat availability, and bass and pikeminnow spread for a given climate change or land use scenario, or the option to export data for quantitative analysis



Challenges



Social
- Continuous land access

Scientific
- Incorporating climate-induced vegetation change into stream temperature modeling

Management
- Preparing managers for the possibility of implementing unconventional strategies

Interactions with clients

Ukiah, Oregon

Interactions with clients

Thank you

Beach grass invasions and coastal flood protection: forecasting the effects of climate change on coastal vulnerability

Eric Seabloom
Sally Hacker
Peter Ruggiero

Oregon State University


Beach grass invasions and coastal flood protection: forecasting the effects of climate change on coastal vulnerability

1. System Overview
2. Project Goals
3. Outcomes
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History of dune grass invasions on the Pacific coast

Prior to 1900, beaches and dunes were sparsely vegetated, little grass, shifting sand

Coastal dune grass invasions along the Pacific coast

European beach grass, *Ammophila arenaria* (L.)
American beach grass, *Ammophila breviligulata* Fern.

Colonized coastal dunes and beaches for nearly 110 years
40% of west coast shoreline consists of sandy beach or dune

History of dune grass invasions on Pacific coast

Pre–1900: Native beach grass, *Elymus mollis*

~1900: Widely introduced European beach grass, *Ammophila arenaria*

By 1950s: *A. arenaria* present along entire west coast, Canada to Mexico

1935: Introduced American beach grass, *Ammophila breviligulata, to* Columbia River

Elymus mollis

Ammophila arenaria

Ammophila breviligulata

Dune grass formed foredunes



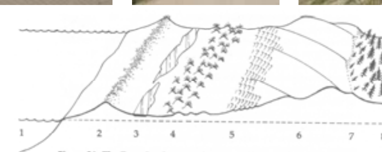
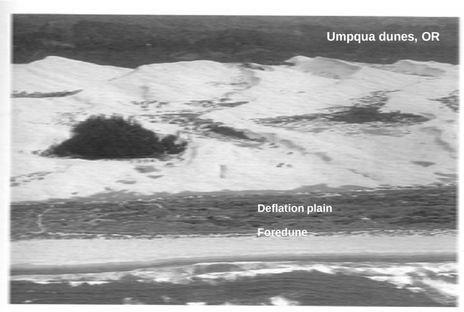


Figure 56. The Dune Landscape. 1 Ocean. 2 Foredune. 3 Deflation plain. 4 Beachgrass hummocks. 5 Transverse ridges. 6 Oblique dunes. 7 Retention ridge. 8 Forest. (Kellerman.)

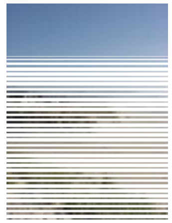
(from Schultz 1990)



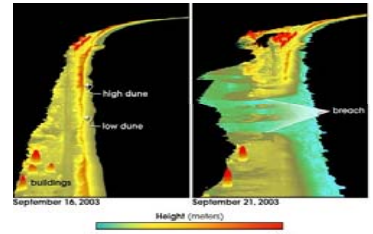
(from Komar 1999)

Consequences of Foredune

- Increases coastal protection from waves, wind, and possible tsunamis
- Increases land stabilization for development behind the foredune

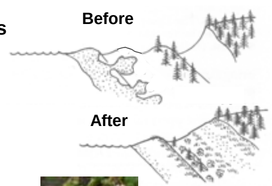

Foredunes: Coastal Protection



Cape Hatteras, before and after Hurricane Ivan, 2003

USGS Center for Coastal and Watershed Studies

Unintended consequences



Redistribution of sand
- overall open dune habitat decreases; "sand starved"
- dynamic nature of shifting sand gone

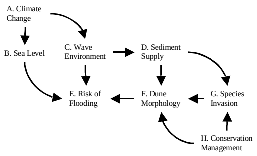
Decline in some species of native plants and animals
- Six federally listed endangered plants
- federally listed threatened Western snowy plover

Increase invasion of other species
- Scotch broom, gorse, weeds, etc.


Climate change and coastal Dunes

•Climate change is accelerating sea level rise and increasing storm intensities (IPCC 2007, Webster et al. 2005)
•Over the past 5 years, annual losses due to hurricanes averaged $35.8 billion, a 3-fold increase over the early 1990's (NSB 2006)
•Coastal dunes comprise 40% of the Oregon and Washington coasts (Cooper 1958, Komar 1997).





Beach grass invasions and coastal flood protection: forecasting the effects of climate change on coastal vulnerability

1. System Overview
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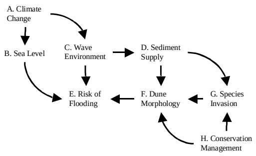
Project Goals

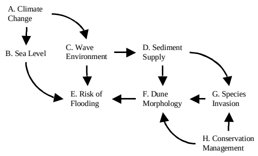
1. Determine effects of climate change on beach grass invasion (A → G)
2. Determine effects of beach grass invasion on the ability of dunes to mediate risk of climate change (G → E)
3. Determine effects of exotic grass management on the ability of dunes to mediate risk of climate change (H → E)



Project Goals

1. Determine effects of climate change on beach grass invasion (A → G)

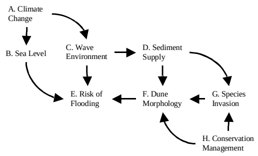
- Simulation models to estimate a range of likely sediment budgets under expected climate change regimes (A → D)
- Field experiments to determine the outcome of invasions under predicted sediment budgets (D → G)



Project Goals

2. Determine effects of beach grass invasion on the ability of dunes to mediate risk of climate change (G → E)

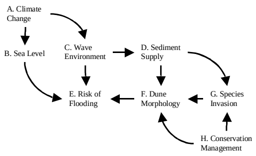
- Field surveys and lidar to determine effects of species invasion on dune morphology (G → F)
- Simulations modeling to determine the effects of dune morphology on risk under various climate change scenarios (F → E)



Project Goals

3. Determine effects of exotic grass management on the ability of dunes to mediate risk of climate change (H → E)

•Field surveys and lidar to determine effects of conservation management on species invasion (H→G; Fig. 1) and dune morphology (H→F)



Beach grass invasions and coastal flood protection: forecasting the effects of climate change on coastal vulnerability

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Preliminary Project Outcomes

Dune Bag Experiments at Hatfield Marine Science Center, Newport, OR
Phoebe Zarnetske PhD research

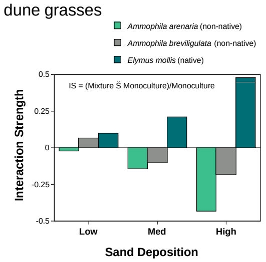
Species interactions x sand supply

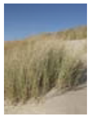
3 species: *A. arenaria, A. breviligulata, E. mollis*

3 sand addition levels: none, low, high

Preliminary Project Outcomes

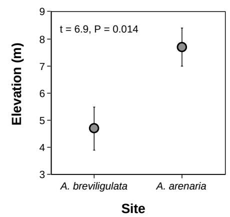
Sand deposition can alter competitive interaction among native and exotic dune grasses

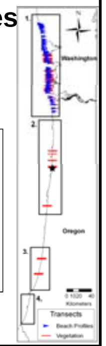




Preliminary Project Outcomes

Dunes dominated by the secondary invader (*A. breviligulata*) are 40% lower than those dominated by current invader (*A. arenaria*)

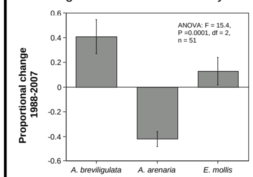


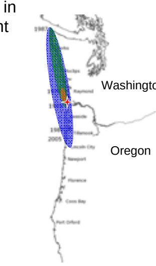


Preliminary Project Outcomes

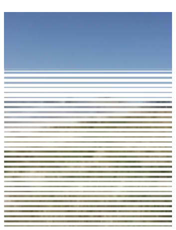
A. Breviligulata continues to spread and increase in dominance -- a continued decrease in dune height

Change in dominance over 20 years





Beach grass invasions and coastal flood protection: forecasting the effects of climate change on coastal vulnerability



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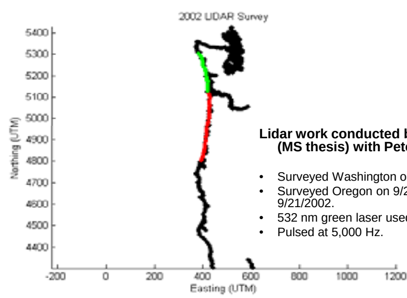
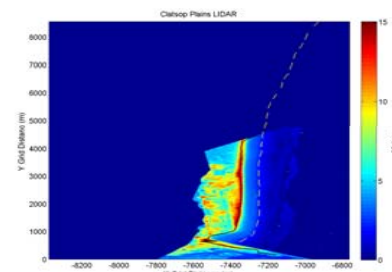
Project Challenges



Lidar work conducted by Jeremy Mull (MS thesis) with Peter Ruggiero

- Surveyed Washington on 9/18/2002.
- Surveyed Oregon on 9/20/2002 and 9/21/2002.
- 532 nm green laser used.
- Pulsed at 5,000 Hz.

Project Challenges



= dhigh = shoreline determined from LIDAR survey

Beach grass invasions and coastal flood protection: forecasting the effects of climate change on coastal vulnerability

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Interactions with clients

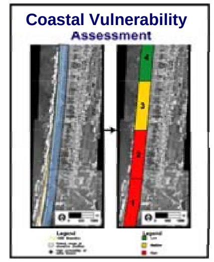
Quantitative Assessment of Flooding Risk on Long Beach Peninsula, WA

In cooperation with City of Long Beach, Coastal Communities of Southwest Washington, Washington Department of Ecology, Oregon Department of Geology and Minerals

2011 Meeting with Land Managers and Researchers

Conduit to provided information to individual land managers, scientists, and policy makers who are making the critical decisions about invasive species management.

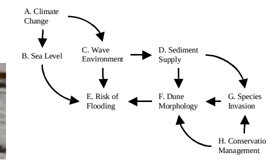
Based on highly successful 2008 PNW Dunes Workshop we conducted using funds from Oregon Seagrant
About 40 participants from 15 Federal, State, Local Agencies and NGO's
http://www.science.oregonstate.edu/~zarnetsp/PNW_Dunes_Website/



Voigt, Ruggiero, Kaminsky. 2000

Current conclusions

1. It is likely that changing sediment loads resulting from climate change will alter the composition of the dunegrass community
2. A rapidly spreading invasive dune grass is likely lowering dune heights and reducing their ability to protect coastal communities
3. Exotic grass management will require careful balancing to preserve endangered species and coastal protection function



Thanks:

Collaborators:
Sally Hacker, OSU
Peter Ruggiero, OSU

Graduate Students:
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Jeremy Mull

Field & Lab Assistants:
Vince & Autumn Adams
Lindsay Fitzgerald
Amanda Gladics
Jeremy Henderson
Hussain Ibrahim
Colin Jones
Thatcher Jones
Travis Lewis
Micah Rogers
John Schaefers
Chris Soto
Dave Worth
Jay Zarnetske

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Oregon Sea Grant Program

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Elevated Temperature and Land Use Flood Frequency Alteration Effects on Rates of Invasive and Native Species Interactions in Freshwater Floodplain Wetlands

Curtis J. Richardson, Neal Flanagan, Mengchi & Song Qian
Duke University Wetland Center
Nicholas School of the Environment, Duke University

- Global climate change and freshwater ecosystem studies & models suggest two key findings:
  1. water temperatures will increase (2 to 4º C) (IPCC 2007)
  2. the frequency and intensity of high flow stream events will increase

---

- **what are the implications of warmer water and altered hydroperiod on the establishment, abundance, and distribution of invasive species in river floodplain ecosystems?**

Likely Future Scenario

- Southeastern stream ecosystems will experience
  1. lower baseflows with more extended drought periods punctuated by
  2. more frequent and more intense storm events.

Likely Future Scenario

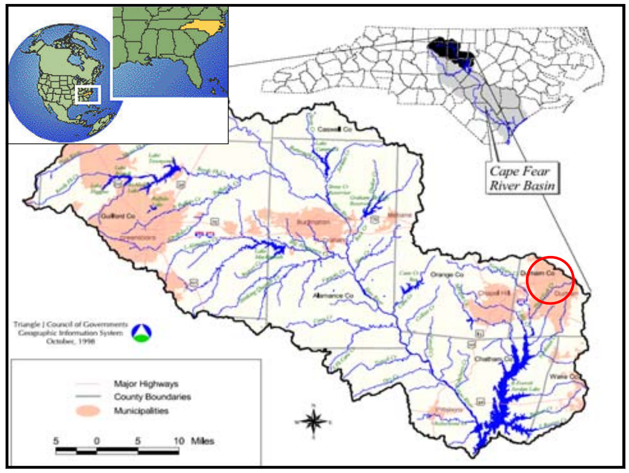
- Southeastern freshwater wetlands;
  1. will be inundated for less of each year than currently, and
  2. will undergo a greater number of rapid wetting and drying cycles as a result of extreme events.

Project Goals & Study Questions

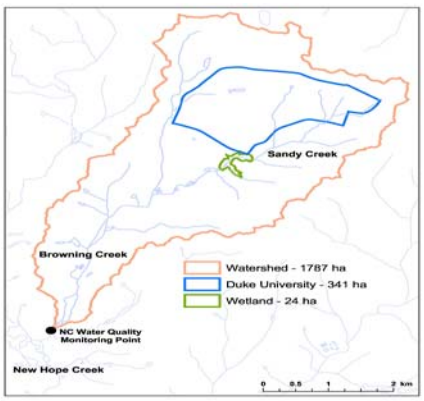
- Quantify effects of elevated wetland water temperature and pulsed water on
  - rates of species invasion
  - patterns of sediment and nutrient retention services?
- Assess how species-richness, diversity, productivity & invasibility change under varying water temp regimes?
- Determine have interactions between hydrology and temperature affected the current community composition/invasibility of SE floodplain ecosystems at the regional scale?

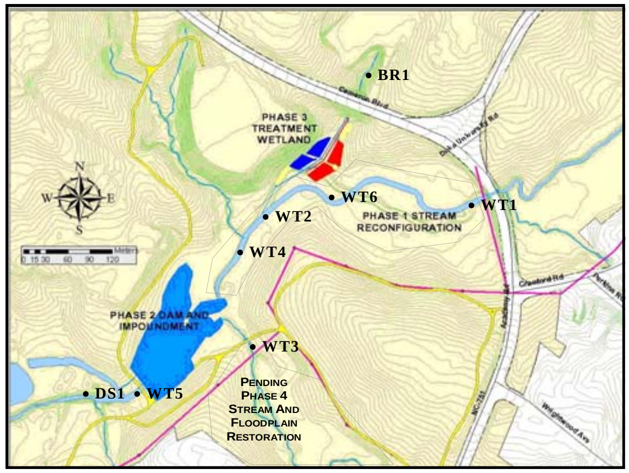
Experimental Levels

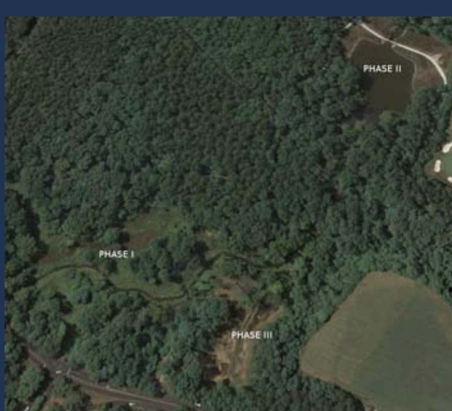
- Experimental Level 1
  - role of plant diversity on invasive species
  - pulsed water effects on wetland species
  - elevated temperature and pulsed water in controlled (experimental) wetlands
- Experimental Level 2
  - regional floodplain hydrology and temperature shifts in naturally occurring wetlands



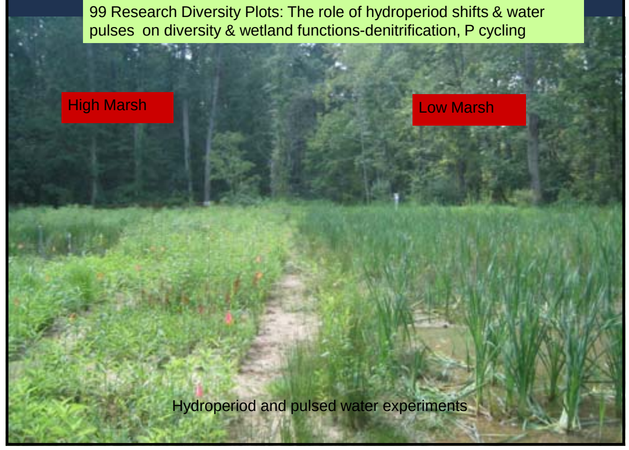
Duke University Sandy Creek Watershed

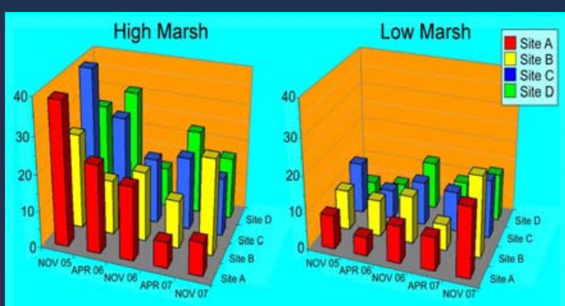






Google Earth



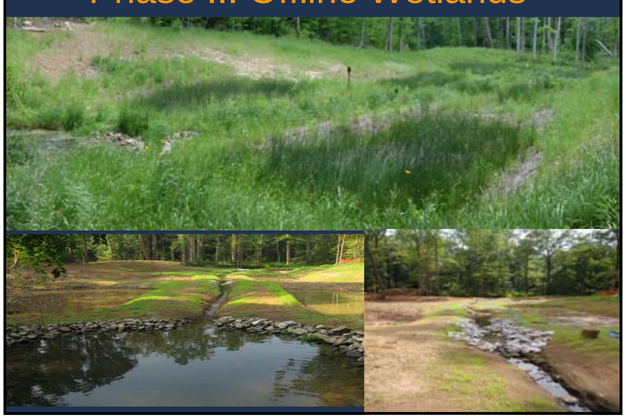


Fluctuation of plant species in High Marsh and Low Marsh through five semi-annual vegetation surveys.

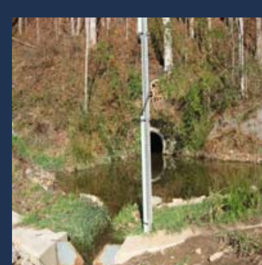
Experimental Levels

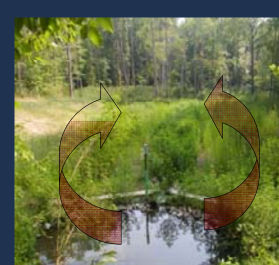
- Experimental Level 1
  - role of plant diversity on invasive species
  - elevated temperature and pulsed water in controlled (experimental) wetlands
- Experimental Level 2
  - regional floodplain hydrology and temperature shifts in naturally occurring wetlands

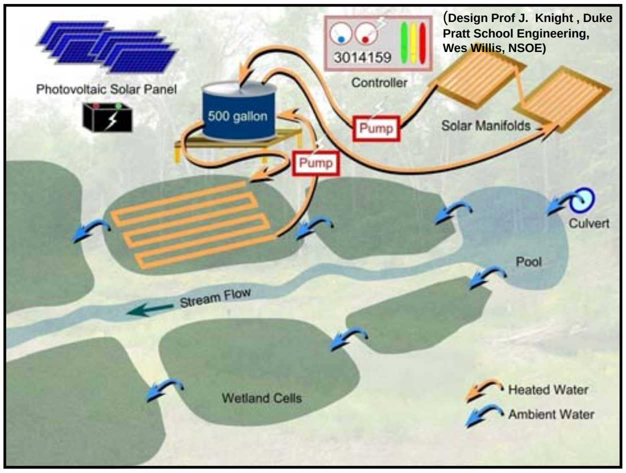
Phase III Offline Wetlands

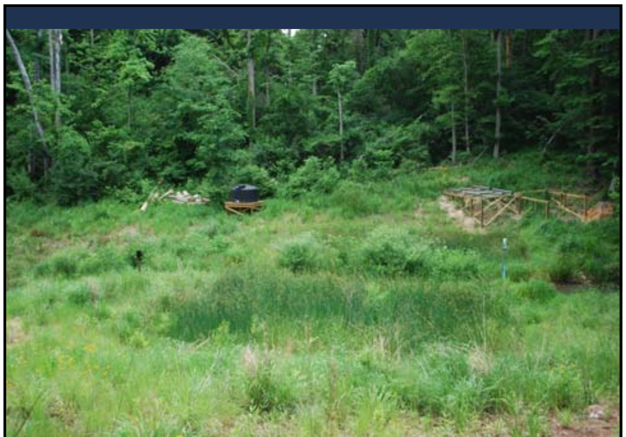


Storm water diverter / Weir









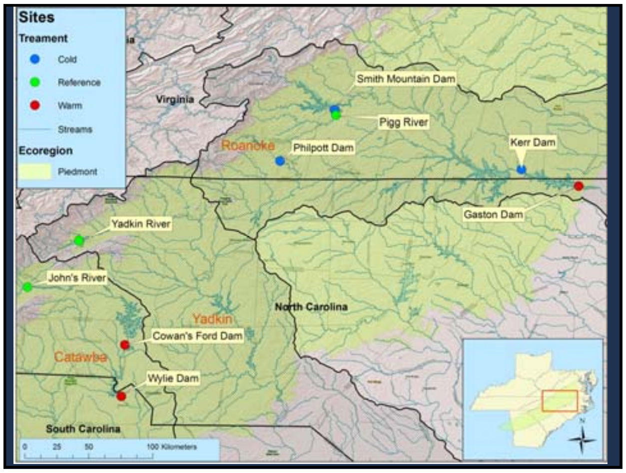
Experimental Level 2 (Regional Scale)

- We identified nine flood plains sites located on rivers throughout the North Carolina and southern Virginia.
- Wetlands studies downstream of:
  - 3 surface (warm water)
  - 3 bottom-releasing dams (cool water)
  - 3 undammed reference watersheds

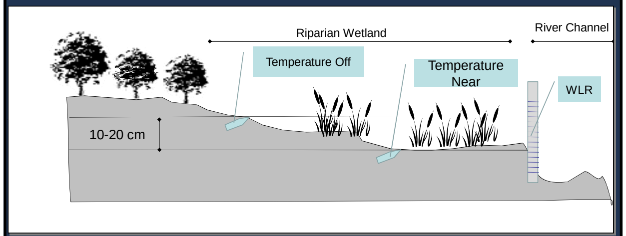
Regional Sites

Siting Criteria

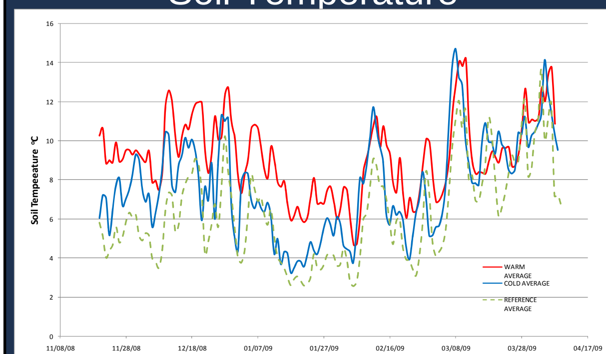
- Temperature regime
- Located within the Piedmont Ecoregion
- Headwaters in mountains
- High degree of hydrologic connectivity,
  - Frequently flooded
- Similar nutrient regimes
- Reference sites have no upstream dams
  - small ponds only



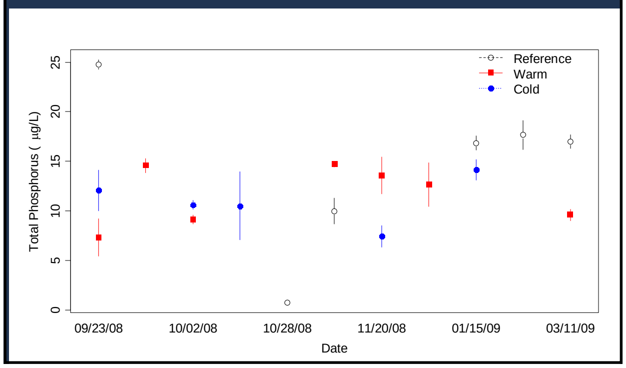
Site Layout



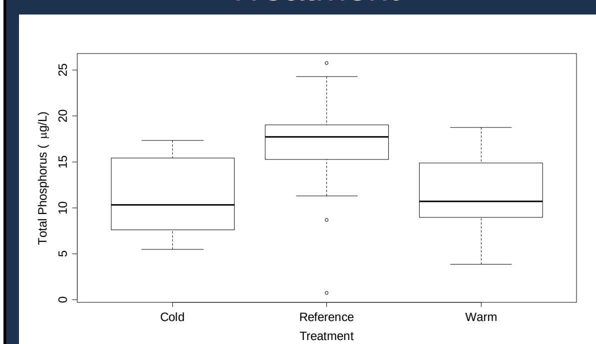
Treatment Average Near Shore Soil Temperature



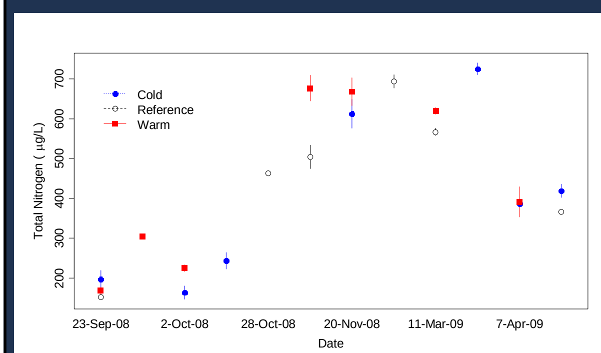
Water TP by Date



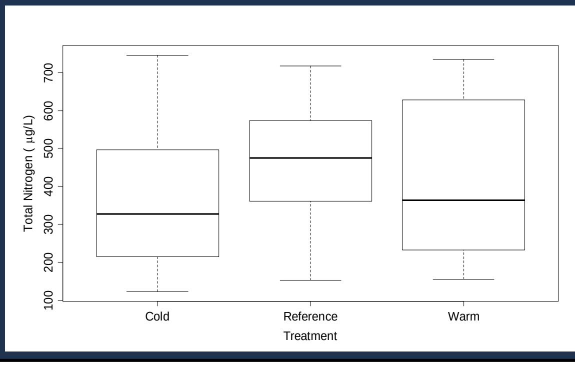
Water TP Concentration by Treatment



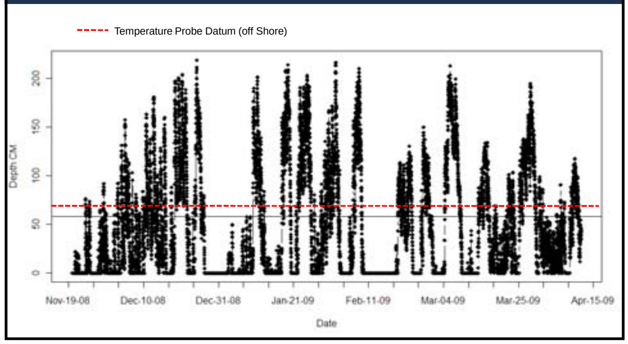
Water TN by Date



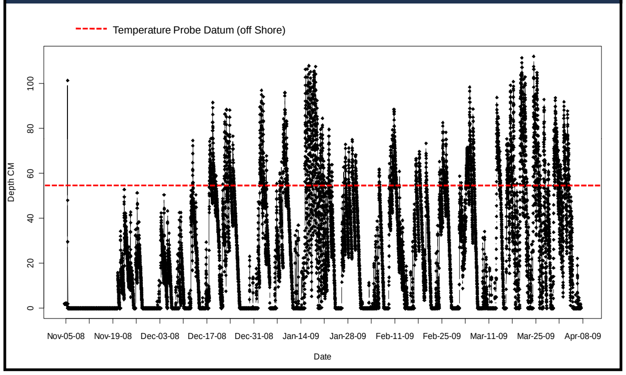
Water TN Concentration by Treatment



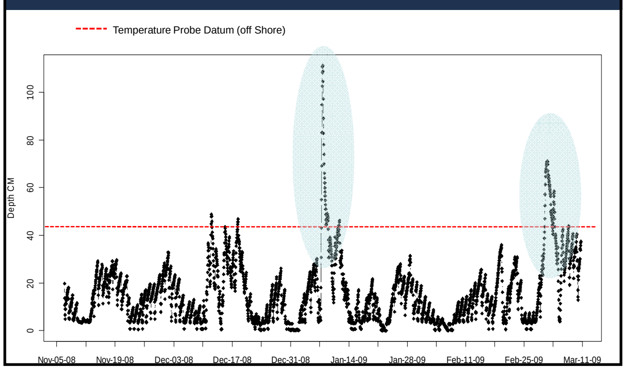
Smith Mountain Lake - Cold



Lake Gaston - Warm



Johns River - Reference



Temperature Probe Inundation

Treatment	Frequency	Average Duration (hrs)	Average Return Period (hrs)	Depth max/mean
Warm	131	5	18	4.96
Cold	127	8	16	5.02
Reference	53	17	40	8.69

Preliminary Year one Results

List of Non-native Invasive Plants in Research Sites

Arthraxon hispidus (small carpgrass)

Lespedeza cuneata (sericea lespedeza)

Ligustrum sinense (Chinese privet)

Lonicera japonica (Japanese honeysuckle)

Microstegium vimineum (Nepalese browntop)

Murdannia keisak (watermoving herb)

Myosotis scorpioides (true forget-me-not)

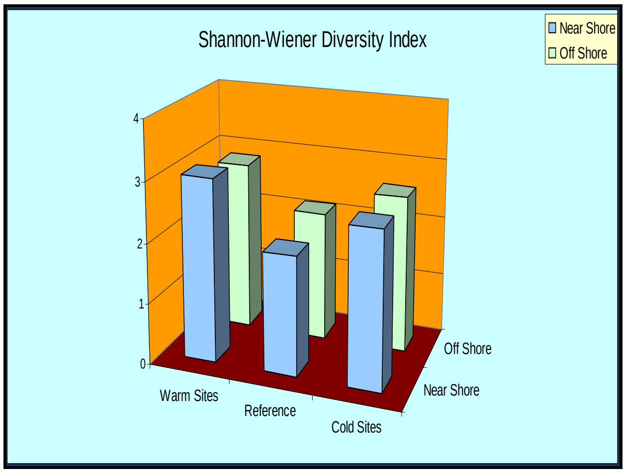
Polygonum caespitosum var. longisetum (Oriental lady's thumb)

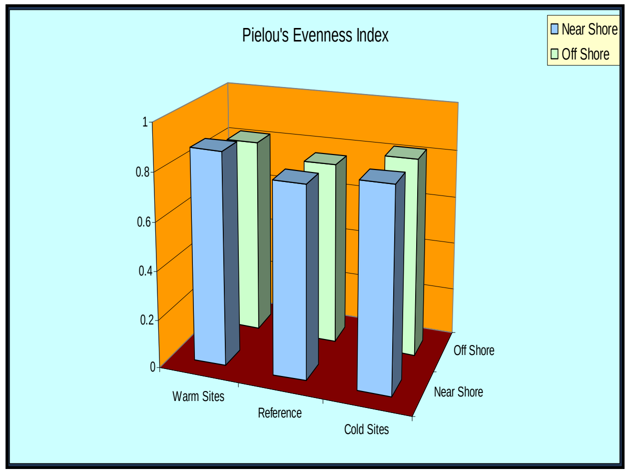
Polygonum hydropiper (marshpepper knotweed)

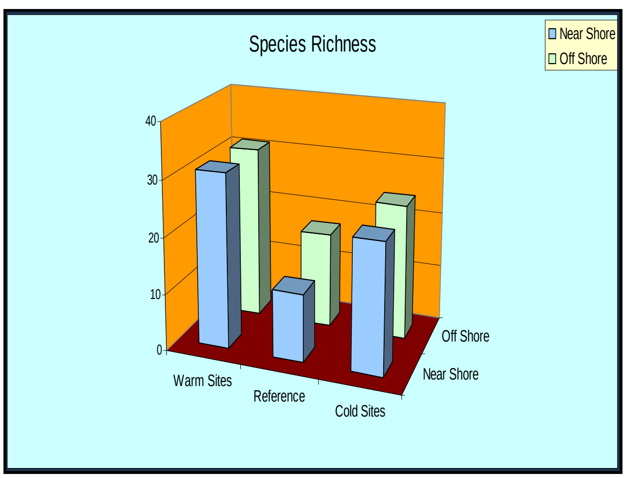
Most frequent species that totaled 50% of all occurrence.

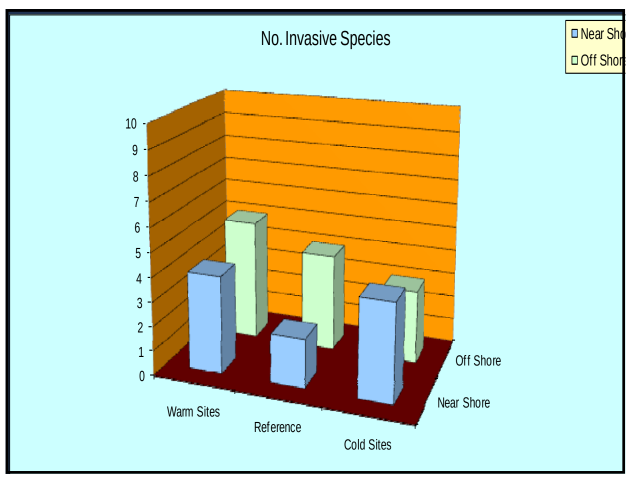
Warm Sites, Off Shore	Reference Sites, Off Shore	Cold Sites, Off Shore
Symphyotrichum sp. *Murdannia keisak* *Bidens laevis* *Hypericum mutilum*	*Ludwigia palustris* *Lonicera japonica*	*Phalaris arundinacea* *Myosotis scorpioides* *Polygonum amphibium* *Hibiscus moscheutos*
Warm Sites, Near Shore	**Reference Sites, Near Shore**	**Cold Sites, Near Shore**
Scirpus cyperinus *Eleocharis quadrangulata* *Symphyotrichum sp.* *Polygonum longisetum* *Bidens laevis* *Schoenoplectus tabernaemontani* *Murdannia keisak*	*Ludwigia palustris* *Scirpus cyperinus*	*Murdannia keisak* *Schoenoplectus tabernaemontani* Open water *Typha latifolia*

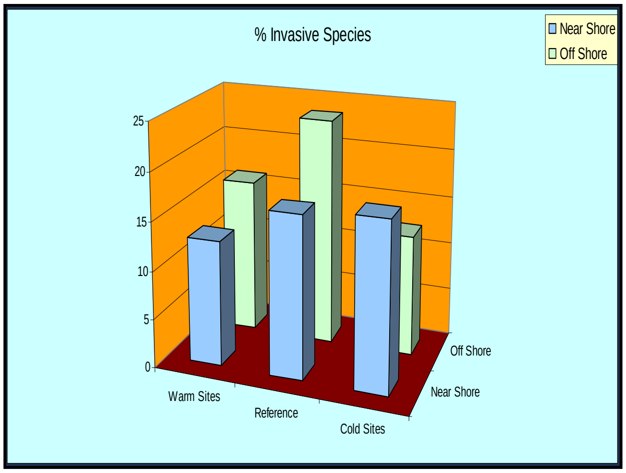
Non-native invasive species are highlighted in red.











Outcomes

- Provide data that will quantify climate change effects of temperature and pulsed water on invasive species in wetlands & provide information on community structure shifts
- Explicitly link hydrographic variation and elevated temperature with ecological functions.
- Identify specific hydrologic & biogeochemical characteristics of floodplains that enhance or inhibit establishment of invasive species.
- Identify feedbacks between invasive species and ecosystems processes that alter the invasibility of floodplain ecosystems.
- Identify potential management strategies for controlling invasive species.
- Validate a new quantitative modeling approach to evaluate shifts in linear or nonlinear thresholds of invasive species(year 2 & 3).

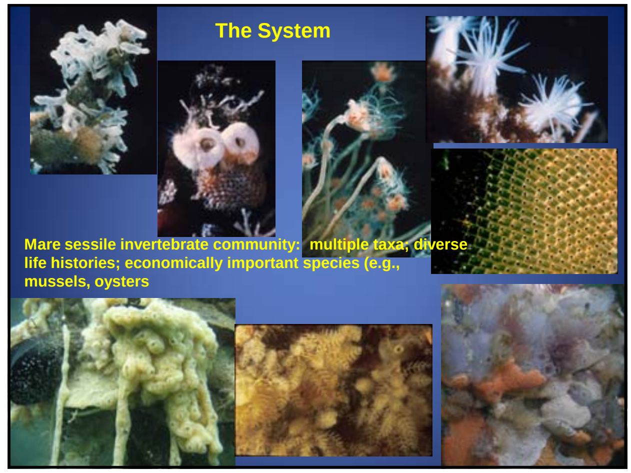
Lesson Learned/Challenges

- What is meant by invasive species definition varies greatly
- Plant community respond to both temperature and pulsed water events can be detected
- Threshold responses to disturbance may vary by season
- Difficult to separate out pulsed water effects from temperature effects at regional scale
- Mesocosm scale studies will allow for more temperature and water control to help in effect studies, but are difficult to set up and maintain & scaling is an issue
- Separating out environmental disturbance from climate change effects is difficult and will require new approaches to threshold analysis to augment Bayesian threshold analysis.

Interaction with Clients: A Broad Interest

- International interest –collaborations with Peking University, Potsdam Institute for Climate Impact Research, Finnish Environmental Institute, University of Liverpool, University of Utrecht, and Eurolimpacs Climate Change Program.
- Presentations- Ecological Society of America, Society of Wetland Scientists, numerous academic institutions and presentations to state government officials and review panels.
- Information requests & Coop with government agencies (USGS, USACE, South Carolina Sea Grant, North Carolina Wildlife Commission, and
- Creation of Duke Wetland web site with research project findings & reports, Popular Wetland Wire (www.env.duke.edu/wetland)

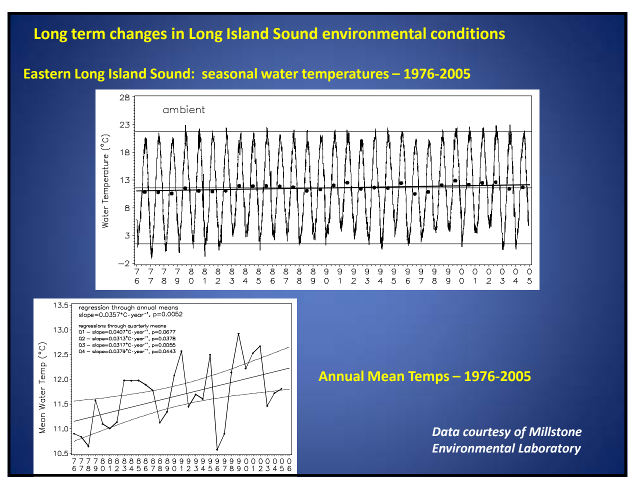

Interaction of Climate Change, Landuse and Invasive Species:
Tests of Contrasting Management Scenarios for Coastal Communities
Robert B. Whitlatch, University of Connecticut
Richard W. Osman, Smithsonian Environmental Research Center
This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # RD-83383801


The System
Mare sessile invertebrate community: multiple taxa, diverse life histories; economically important species (e.g., mussels, oysters

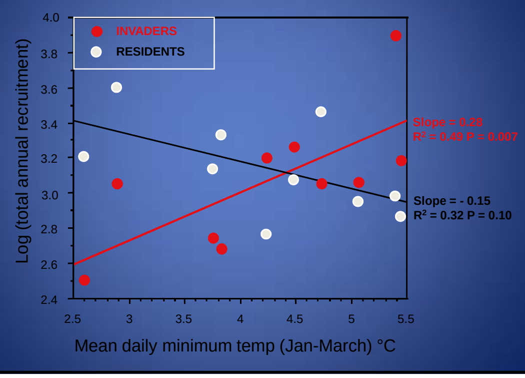

Local Recruitment (Fast)
Native Bryozoan Dominance
Recruit Predation (Fast)
Environmental Change/ Predator loss (Intermediate/Slow)
Predators/Storms (unpredictable)
Recruitment - Fast
Massive Recruitment (Fast)
Invasive Spp. Dominance (several sp. of ascidans)
Mussel/Algae Dominance
Warm/Cold Winter (Fast)
Climate Warming (Slow)
Diplosoma (invasive ascidian) Dominance
Growth & Habitat Change (Intermediate)


Non-native ascidians have become a dominant component of southern New England's fouling community over the past ~30 yrs

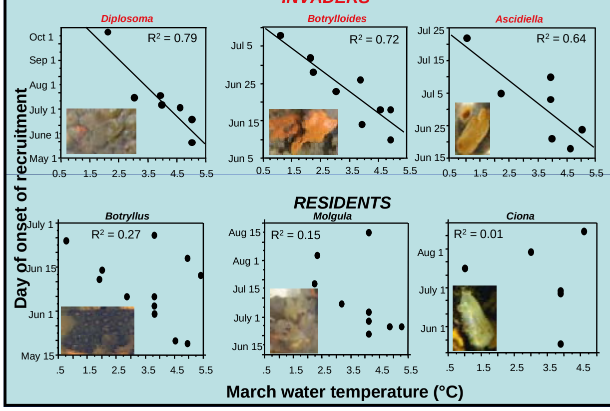

Why should we care about non-native marine species?
They can have detrimental effects on native species that may ultimately result in local reductions of native biodiversity
They can greatly modify habitats and reduce ecosystem services
They can have impacts on economically or commercially important species (e.g., green crabs preying on soft-shell clams, fouling species overgrowing mussels, oysters and scallops)
They can have impacts on human-made structures (e.g., species clog intake pipes, foul boat hulls)
Marine biofouling results in world-wide damages of ~$50 billion annually
Marine biofouling regularly contributes ~20-80% of the total production costs of marine aquaculture operations


Long term changes in Long Island Sound environmental conditions
Eastern Long Island Sound: seasonal water temperatures – 1976-2005
ambient
Water Temperature (°C)
Mean Water Temp (°C)
Annual Mean Temps – 1976-2005
Data courtesy of Millstone Environmental Laboratory

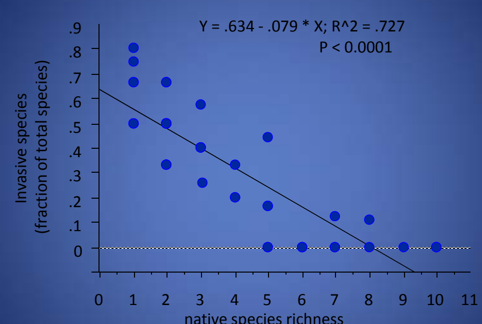
Rising winter temperatures (1991-2008): 1. Increases in the recruitment abundance of recent invaders. 2. Decreases in recruitment abundance of resident species



Timing of recruitment in relation to inter-annual variations in seawater temperatures: non-native vs resident species



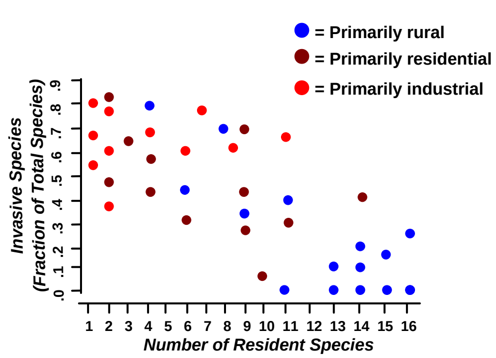
In coastal Connecticut waters there tends to be an inverse relationship between the occurrence of invasive species and resident species



Native biodiversity is important! Habitats with higher diversity of resident species appear less vulnerable to invasion

Variations in Land Use Along the Connecticut Coastline

Correlation between resident species richness and the fraction of exotic species in areas of different coastal land use



Project Goal #1 – Work with environmental managers and other stakeholders on different management scenarios for land use planning in the context of climate change and invasive species (*interaction with clients*)

1. Established a Project Management Advisory Board:
Mark Tedesco – Director – US EPA Long Island Sound Office; ***Paul Stacey*** – Director of Planning and Standards, Bureau of Water Protection and Land Reuse – CT DEP; ***Gary Wikfors*** – Scientist – NOAA, NMFS, Milford, CT ***Adam Whelchel*** – Director of Conservation Science – The Nature Conservancy, CT Chapter; ***Beth Doran*** – Director – Long Island Resource Center – CT DEP; ***Susan McNamara*** – Executive Director – Long Island Sound Foundation; **Ron Rozsa** – CT DEP Office of LIS Programs

2. Conducted first of three workshops with various managers and stakeholders – August 4, 2008 – Discussed management priorities and needs; broaden network with the managers/stakeholders; discuss project goals and outputs and how they can assist with management goals

3. Met with local shellfish, planning and conservation commissions – Towns of Groton, New London, Stonington, East Lyme/Waterford – discuss local management needs and goals of the project.

Goal #1 (cont)

4. Outreach

Aquakids host Molly McKinney with yours truly

Interviews:

Connecticut National Public Radio

New London Day

Boston Globe

Featured segment on *AquaKids* Episode 18
– aired in Connecticut 24 Jan 2009
-- aired nationally – week of 19 Jan 2009

Goal #2: Conduct mesocosm experiments examining the interactions of climate change (temperature increase) and land-use (nutrients) and the interactions between them in altering the ability of invasive species to Influence native communities

12 – 3 m diameter tanks
3 habitat types: eelgrass, rocky, unvegetated
Treatments: temp (1-2° C above ambient), nutrients (0.5-1.0x above Ambient), temperature x nutrient increases
Native and non-native species added – response variables: growth, mortality, competitive interactions, predation

Year 1: Conducted small-scale pilot study (4 tanks) to establish experimental/ monitoring protocols – full experiments will be conducted in Year 2 and Year 3

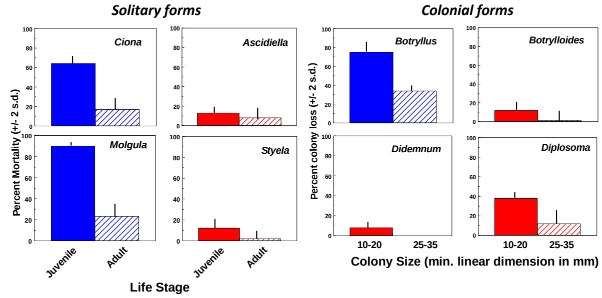
Goal #3. Conduct field experiments to assess temporal and spatial scales of potential efforts needed to manage invasive species – *to be conducted in Years 2 and 3*

Given the 'openness' of marine systems (aka larval transport), Attempts to control invasive species most likely will occur at Local scales

Removal experiments at different spatial scales
Seasonal experiments
Effects of variations in landuse

Goal #4 – Survivorship of predators and their effectiveness in controlling invasive species in different land use conditions

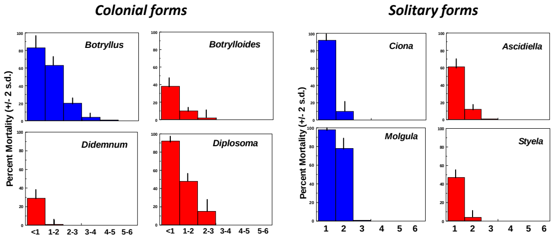
Effects of macro-predators (seastars, fish, crabs) feeding on juvenile and adult ascidian life stages (7 day expt.)



Goal #4. Conduct field experiments to examine survival of key predators on invasive species and how it varies with land-use.

Anachis and *Mitrella* feeding on a 1 day *Botrylloides* recruit

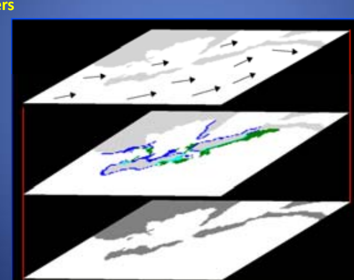
Effects of predation micropredators (snails, small crabs): Percent mortality of ascidian post-recruits (7 Day experiments using different colony sizes or different ages of native and non-native ascidians



Goal #5. Develop predictive models to assess potential alternative management strategies to evaluate multiple stressors at different spatial and temporal scales in different types of coastal systems

•Spatially explicit, individual-based model driven by hydrodynamic model

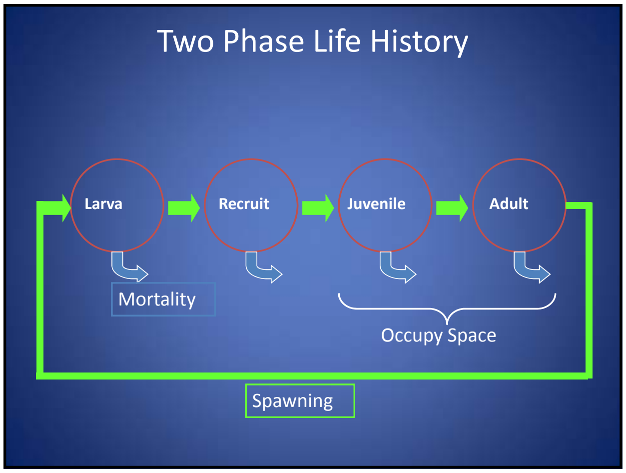
Model Layers

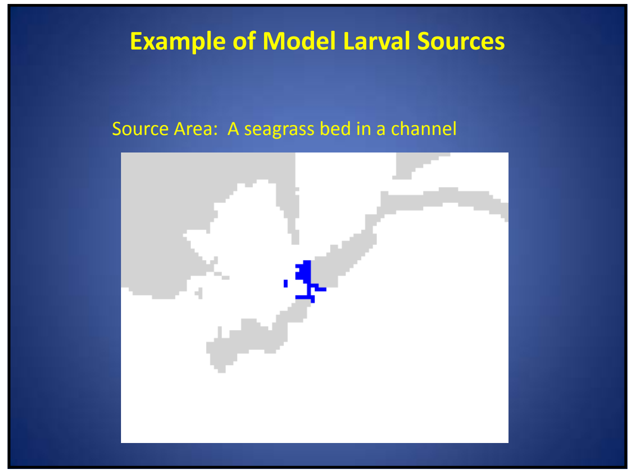


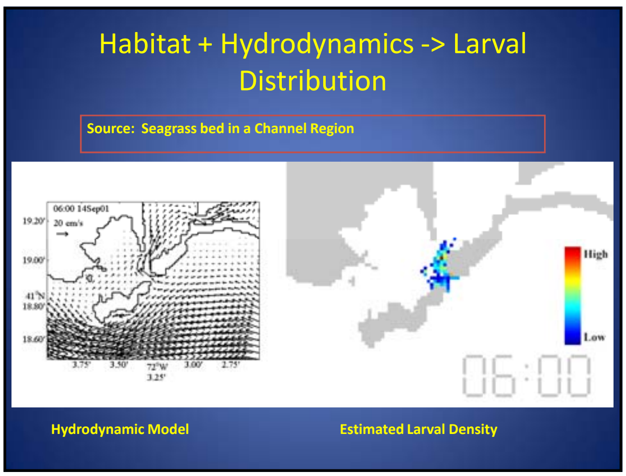
Hydro Model

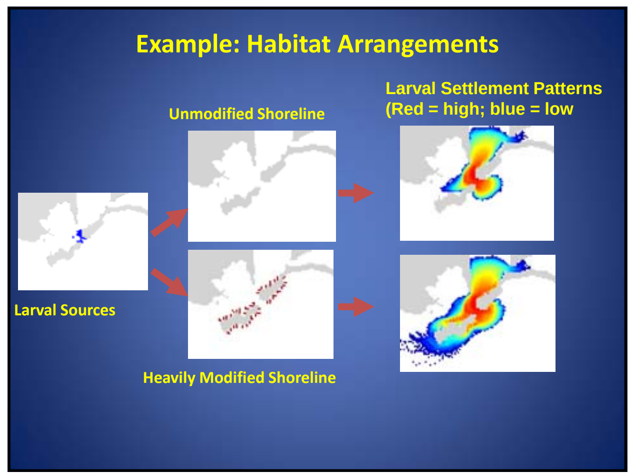
Benthic Habitats

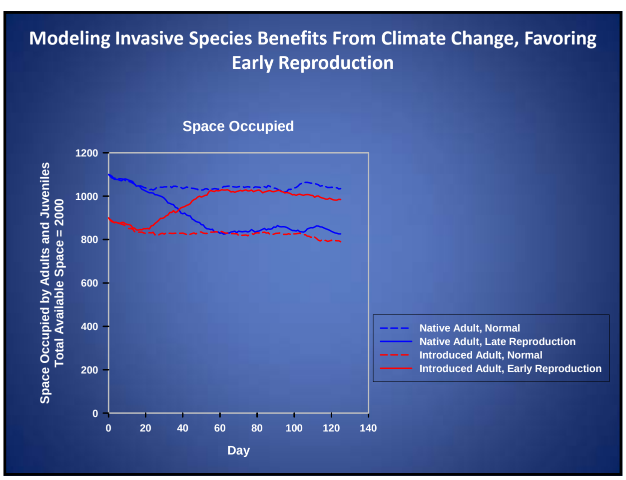
Coastline

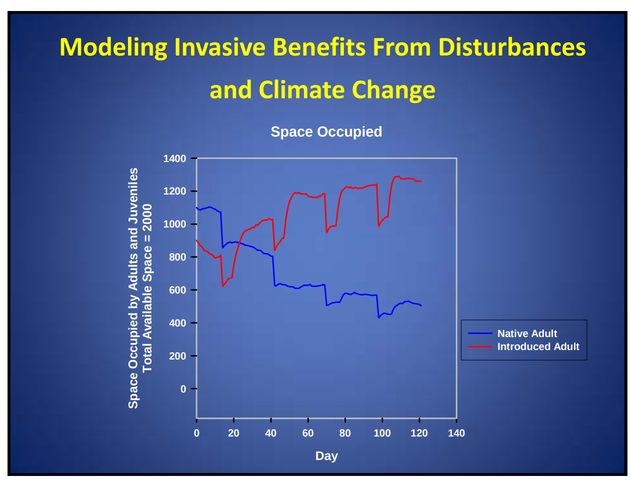

Two Phase Life History
Larva
Recruit
Juvenile
Adult
Mortality
Occupy Space
Spawning


Example of Model Larval Sources
Source Area: A seagrass bed in a channel


Habitat + Hydrodynamics -> Larval Distribution
Source: Seagrass bed in a Channel Region
High
Low
06:00
Hydrodynamic Model
Estimated Larval Density


Example: Habitat Arrangements
Unmodified Shoreline
Larval Settlement Patterns
(Red = high; blue = low
Larval Sources
Heavily Modified Shoreline


Modeling Invasive Species Benefits From Climate Change, Favoring Early Reproduction
Space Occupied
Space Occupied by Adults and Juveniles
Total Available Space = 2000
0
200
400
600
800
1000
1200
0
20
40
60
80
100
120
140
Day
Native Adult, Normal
Native Adult, Late Reproduction
Introduced Adult, Normal
Introduced Adult, Early Reproduction


Modeling Invasive Benefits From Disturbances and Climate Change
Space Occupied
Space Occupied by Adults and Juveniles
Total Available Space = 2000
0
200
400
600
800
1000
1200
1400
0
20
40
60
80
100
120
140
Day
Native Adult
Introduced Adult

Lessons Learned:

Very important to include input by managers/stakeholders in the early stages of the project

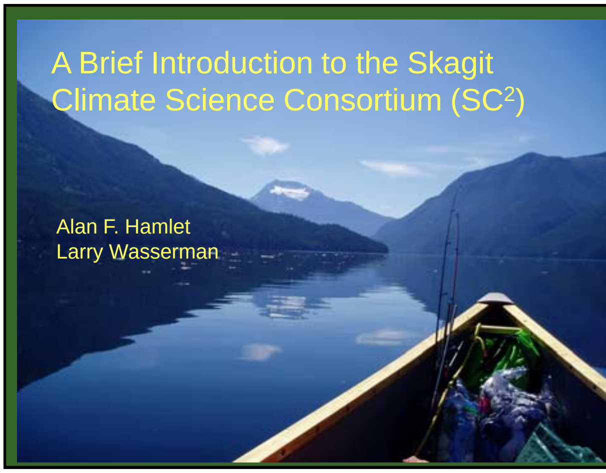
Managers often are dealing with the most current 'brush fire' and often are in a rapid response mode (a reality lesson, but also a challenge to the scientist)

Critical importance of long-term environmental data bases and associated population/community data

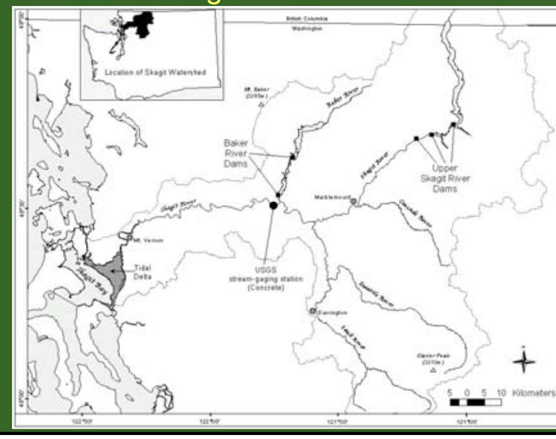
Challenges:

The most recent sea squirt alien, Didemnum vexillum, in eastern Long Island Sound (~25 m depth) – potential new stable point

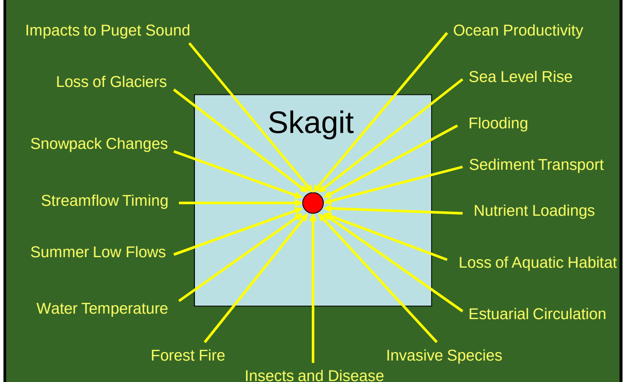
Concerns about "new" stressors – coastal acidification, power infra-structure disturbances – and how they interact with climate change and land use patterns



Skagit River Basin



Climate Change Impact Pathways



Some fundamental goals and objectives of SC2 are to:

- **Foster collaborative, interdisciplinary research** to understand and quantify the diverse impacts of climate change on the Skagit basin
- **Serve as an objective and non-politically affiliated source of scientific information**, data, and services to support long-term planning and climate change adaptation by stakeholders in the basin
- **Identify new scientific information, data, or services** that are needed to address climate change impacts in the basin, and generate research funding to address these needs
- **Establish and maintain long-term relationships** between scientists and stakeholders in the basin in the interest of generating trust, fostering effective collaboration and sharing of information.
- **Develop and maintain a web-based "clearing house" for scientific products and services** addressing climate change impacts and adaptation in the basin.

Some Current SC² Affiliations:

- **City of Anacortes, WA**
- **CSES Climate Impacts Group (UW)**
- **Lawrence Livermore National Labs**
- **Montlake Fisheries Science Center (NOAA)**
- **North Cascades National Park**
- **Pacific Northwest National Labs**
- **Seattle City Light**
- **Skagit River System Cooperative**
- **Swinomish Tribe**
- **University of Washington**
- **USGS**
- **Western Washington University**

Changes in Hydrologic Extremes

Changes in Glaciers

1973 2006

Recession of Whitechuck Glacier (Sauk Headwaters)

Photos courtesy of Dr. Mauri Pelto, Nichols College

Changes in Ecosystem Function

ALAN BERNER / THE SEATTLE TIMES

U.S. Environmental Protection Agency
Office of Research and Development
The Plight of Ecosystems in a Changing Climate: Impacts on Services, Interactions, and Responses Workshop

Plymouth Church
1217 Sixth Avenue
Seattle, WA

May 27–28, 2009

MEETING SUMMARY

INTRODUCTION AND OVERVIEW

The U.S. Environmental Protection Agency (EPA) Office of Research and Development's (ORD) "The Plight of Ecosystems in a Changing Climate: Impacts on Services, Interactions, and Responses" Workshop was held on May 27–28, 2009, in Seattle, Washington. The workshop brought together researchers from academia, private industry, regulatory agencies, and government to discuss ongoing and potential research on climate change and its effects on the environment, including ecosystem services. The meeting also served as a stimulus for increased collaborations among the various researchers and agencies. Approximately 88 individuals attended, and there were 49 people who called into the conference over the 2-day period.

DAY 1: MAY 27, 2009

Introductory Remarks
Brandon Jones, EPA, ORD, National Center for Environmental Research, and Roseanne Lorenzana, EPA, Region 10

Dr. Brandon Jones thanked the participants for attending and Dr. Roseanne Lorenzana of Region 10 for her help in organizing the meeting. He noted that EPA's new Administrator has placed a focus on ecosystems and introduced Dr. Lorenzana.

Dr. Lorenzana welcomed the participants to Seattle and explained some of the logistics of the meeting. She noted that Region 10 is comprised of Washington State, Oregon, Idaho, and Alaska and is particularly interested in climate change and its effects. One regional project involves the Skagit Watershed, one of the largest watersheds in Washington State. It is very important to the Puget Sound as it provides the system with 30 percent of its freshwater. The three EPA climate-related grants in the area total approximately $2.3 million, with an additional $800,000 provided by other grants or investments. She noted that collaborative research is important and invited Dr. Alan Hamlet of the University of Washington to say a few words about the Skagit Climate Science Consortium.

Dr. Hamlet acknowledged the instrumental efforts of Mr. Larry Wasserman, Swinomish Indian Tribal Community, in creating the partnership of the Skagit Climate Science Consortium. The group is an extension of the regional-scale planning occurring in the area with a focus on the Skagit River Basin, which is located in the North Cascades region of Washington State and has important influence in the area as it provides the largest freshwater drainage into the Puget Sound. The lower part of the basin has the largest human use, with extensive farmlands and a growing number of towns. The upper basin is fairly pristine, with the exception of several large hydroelectric projects. The basin provides a unique opportunity to explore the science of climate change in the context of ecosystem services and human development because of its still-functioning ecosystem and significant human use; it is a good area in which to explore how to maintain a balance between human use and functioning ecosystems.

Research has identified several climate change impact pathways in the region. The fundamental goals of the Skagit Climate Science Consortium are to understand the diverse impacts on climate change and assist long-term planning and adaptation in the basin. The specific goals are to: (1) foster collaborative and interdisciplinary research to understand and quantify the diverse effects of climate change on the basin; (2) serve as an objective, nonpolitically affiliated source of scientific information; (3) identify new science and specific information, data, and/or services that are needed and fund them; (4) establish and maintain long-term relationships between stakeholders and scientific organizations and practitioners; and (5) develop and maintain a Web-based clearinghouse of scientific information that can be accessed by stakeholders and provide the inputs that are needed for long-term planning and adaptation. The Consortium has many affiliations and partnerships, and more are expected to be added over time. Currently, the group is actively planning to fund three projects. The first project will foster understanding of hydrologic extremes, the second will explore changes in glaciers and the sediment regime, and the third will examine changes in ecosystem functions from the headwaters to the basin.

TIER I: EFFECTS OF CLIMATE CHANGE ON ECOSYSTEM SERVICES PROVIDED BY CORAL REEFS AND TIDAL WETLANDS

Effect of Sea Level Rise and Climate Variability on Ecosystem Services of Tidal Marshes
Chris Craft, Indiana University Bloomington

Dr. Chris Craft explained that there are large areas of tidal marshes on the East Coast from North Carolina to Florida; closer to the ocean, these marshes are salt marshes. The salinity of these marshes fluctuates based on tidal inundations. As the salinity decreases in the marshes further inland, species diversity increases. The marsh scale developed by William E. Odum describes regulation, habitat, and productivity functions. Among other things, salt marshes provide shoreline protection.

The main effect of climate change is rising sea levels, which cause erosion and saltwater intrusion. Therefore, the project goal is to develop a conceptual model that describes how tidal marsh ecosystem services vary along the salinity gradient and a simulation model of how sea level rise and climate variability will affect the delivery of ecosystem services. The project is based on three explicit hypotheses: (1) Rising sea level leads to inundation and loss of tidal marshes, especially tidal freshwater marshes and their ecosystem services. (2) Diking protects freshwater marshes against rising sea levels, but when marshes are diked, ecosystem services associated with connectivity are lost. (3) Greater interannual variability of climate leads to greater frequency of drought and reduction in ecosystem services in drought years; greater variability in rainfall leads to increased delivery of ecosystem services in wet years.

The researchers are examining how accelerated sea level rise will affect the area and spatial distribution of tidal marshes and their delivery of ecosystem services. The research is based on wetland habitats, particularly reduced salt and brackish marsh habitat and the near complete loss of tidal freshwater marsh, and ecosystem services, particularly reduced regulation functions (e.g., nitrogen and phosphorus retention, denitrification) and reduced production functions (e.g., plant productivity). The study region runs along the East Coast from the border between North Carolina and South Carolina to the St. Mary's River, which forms the border between Georgia and Florida. The focus includes the measurement of ecosystem services in three marsh types (tidal freshwater, tidal brackish, and tidal salt) near three river estuaries (Ogeechee, Altamaha, and Satilla) in coastal Georgia.

An example of ecosystem services measurement is nitrogen accumulation in soil; the researchers calculated rates of nitrogen accumulation in each marsh type and in each area, and the results indicated that nitrogen accumulation increases with a decrease in salinity and that potential denitrification increases in freshwater systems. The researchers scaled up to annual rates to compare the types of data and found that ecosystem services vary across the marsh gradient. Freshwater systems provide a higher level of ecosystem services with respect to nitrogen cycling. Research also indicated that brackish marshes have increased aboveground biomass and species diversity compared to salt marshes.

The Sea Level Affects Marshes Model version 5 (SLAMM 5) is used to model how rising sea levels affect wetland area and habitat conversation. SLAMM 5 uses elevation, the National Wetlands Inventory, tide range, historic sea level rise, and site-specific accretion rate data to parameterize the model. The researchers developed a salinity algorithm that is used to simulate saltwater intrusion into river-dominated estuaries as sea level rises. SLAMM 5 runs in 25-year increments to predict future scenarios; by the year 2100, the model predicts an increase in open water and decreases in salt marshes, tidal freshwater marshes, and tidal swamp in the Altamaha River estuary. SLAMM 5 also simulated the effects of accelerated sea level rise along 200 miles of the Georgia coast. The model predicted 20 and 24 percent losses of salt marsh and tidal fresh swamp, respectively, and minor gains in tidal freshwater and brackish marshes. There is a predicted cumulative loss of 12 percent of the wetland habitat, mostly salt marsh, but only a 4 percent loss in ecosystem services because freshwater marshes have increased amounts of ecosystem services per area. The researchers also examined the effect of diking, and as expected, the loss of connectivity in an area results in a loss of ecosystem services. Diking causes losses of connectivity, sediment deposition, water quality improvement functions, nitrogen retention, phosphorus storage, and denitrification; however, there is an increase in waterfowl habitat. Other research indicated that *Spartina alterniflora* aboveground biomass is positively correlated with freshwater, river discharge, and precipitation, and crab hole density is more strongly correlated with salinity. Sediment deposition is positively correlated with river discharge.

The researchers have identified several lessons learned from the project. (1) Different types of tidal marshes provide different levels of ecosystem services. (2) Tidal freshwater and brackish marshes have greater aboveground biomass, nitrogen retention in soil, and denitrification than salt marshes. (3) Climate change (i.e., sea level rise) will promote salt water intrusion and submergence, leading to habitat conversion and loss of tidal marshes, especially those at either end of the salinity gradient. (4) Wetland loss may not be as great as predicted because spatial models lack positive feedback mechanisms that enable marshes to increase surface elevation. (5) Although diking protects tidal marshes, it leads to loss of connectivity to estuarine waters and the ecosystem services that depend on connectivity. (6) Tidal marsh ecosystem services are more strongly correlated with variation in salinity, driven by river discharge, than by variation in temperature and precipitation. The researchers faced challenges in evaluating ecosystem services of fauna and wildlife and working with subcontractors. The researchers interacted with The Nature Conservancy and the U.S. Fish and Wildlife Service (FWS). Outcomes include SLAMMView, an interactive Web-based tool to visualize sea level rise that can be found at http://www.slammview.org, and several additional projects and publications.

Climate-Linked Alteration of Ecosystem Services in Tidal Salt Marshes of Georgia and Louisiana
Mark Hester, University of Louisiana at Lafayette

Dr. Mark Hester explained that drought-induced, sudden dieback of *S. alterniflora* tidal salt marshes had been observed in Louisiana in 2000, Georgia in 2001, and several other coastal states since; therefore, there is the potential for drastic alteration of ecosystem services driven by a decrease in *S. alterniflora* living stem density, which will be directly linked to degree of loss of ecosystem processes. The project goals are to: (1) elucidate the effects of climate change (increased drought severity) on tidal salt marsh ecosystem services (e.g., eutrophication control, carbon sequestration, sustainable habitat, faunal support) in two hydrogeomorphic settings (microtidal in Louisiana and mesotidal in Georgia); and (2) develop an exploratory structural equation model to explore causal relationships and ecosystem service latent variables.

The researchers are examining several ecological processes (nutrient cycling and transformation, primary productivity, decomposition, erosion, sedimentation, infaunal abundance, composition, and diversity) and their effects on ecosystem services, such as eutrophication control, carbon sequestration, maintenance of a sustainable and healthy habitat, refugia, and habitat support for fauna. The experimental approach will include a manipulative field experiment of *S. alterniflora* plant density in micro- and mesotidal salt marsh ecosystems in Georgia and Louisiana to identify six dieback areas within each state for establishment of large research plots with four vegetative conditions. A series of specific, *a priori*, process-driven hypothesis testing will be completed, and a structural equation model will be used to reveal relationships between stem density, ecosystem processes, and ecosystem services. Challenges the researchers have faced include Hurricane Katrina's landfall following setup of the experimental sites, a prolonged drought in Georgia, and personnel changes. The lesson learned is that improved communication and adaptive management are necessary components of the project.

Results indicated that, in terms of aboveground primary productivity and carbon assimilation, *S. alterniflora* cover reflected stem densities, and although the desired gradient is present in Louisiana, new dieback occurred in 2008 in three Georgia reference plots. An additional experiment indicated that higher *S. alterniflora* density provides more efficient utilization of leaf nitrogen for carbon assimilation. The researchers examined sediment accretion and net marsh surface elevation change and found that, in Louisiana, high-density plots had equivalent accretion rates to reference plots, high-density plantings increased surface elevation, and bare plots had lower accretion rates and lost elevation; in Georgia, reference plots had the greatest accretion rates, high-density and bare plots had lower but equivalent accretion rates, and the reference plots are losing elevation over time. When the researchers examined belowground productivity and decomposition, the high-density and reference plots had equivalent below-ground productivity rates. In terms of biogeochemistry, cyanobacteria mats in Louisiana plots were most abundant in low-density and bare plots, which has implications for a potential shift from a detrital to grazing food web. There was much greater interstitial ammonium in Louisiana, but there was no consistent pattern with stem density. Interstitial sulfides were much greater in Louisiana and often below detection in Georgia; because sulfides can inhibit plant uptake of ammonium, there may be less tight coupling of plant carbon and nitrogen relations in Louisiana.

In terms of secondary productivity, the presence or absence of certain meiofauna species showed interesting differences and loss of some services in Louisiana. In Georgia, meiofauna increased in vegetated areas, whereas in Louisiana, meiofauna increased in bare areas. Nematodes were larger in vegetated treatments in Georgia, but there was no difference in nematode size in Louisiana or copepod size in either state. The exploratory structural equation model will examine *S. alterniflora* stem density as the main driver on ecosystem processes and services that can be measured. It will be a two-group model, and Louisiana and Georgia are expected to be different. Key findings so far are that climate change (severe drought) can affect a suite of ecosystem services, *S. alterniflora* density is an important driver of many ecosystem services across the hydrogeomorphic setting, and the hydrogeomorphic setting is an important modulator of ecosystem processes and services. The researchers have interacted with clients throughout Georgia and Louisiana, resulting in several presentations and synergistic activities related to the project. Currently, the data are in the process of final integration. The structural equation model is a valuable management tool that identifies key differences in the strength of relationships between *S. alterniflora* density and hydrogeomorphic setting. The work has resulted in improved insights into climate variability that will help federal, state, and local agencies with future management and planning.

Linking Impacts of Climate Change to Carbon and Phosphorus Dynamics Along a Salinity Gradient in Tidal Marshes
Nathaniel Weston, Villanova University

Dr. Nathaniel Weston noted that sea level rise is of great concern, especially as its rate is increasing and accelerating; coastal tidal marshes are affected significantly by this rise. Marshes must accrete to keep pace with rising sea levels and do so via watershed inputs and carbon dioxide primary production. Rising sea levels and river evaporation will increase the amount of salt in the system. The goals of this project are to: (1) understand how salt water intrusion into tidal freshwater marshes will impact carbon, nitrogen, and phosphorus cycling; and (2) predict the response of tidal freshwater marshes and the ecosystem services they provide to scenarios of future climate change. The study site is the Delaware River estuary, which is comprised of freshwater between Philadelphia, Pennsylvania, and Wilmington, Delaware, and brackish below Wilmington. An increase in salinity has been observed over time in the brackish area of the estuary. The researchers will study watershed inputs, inorganic sediments, and microbial processes to determine the impact of climate changes on tidal freshwater marshes. Microbial respiration is carried out via methanogenesis in freshwater marshes and via sulfate reduction in salt marshes. The researchers will determine the importance of salt water intrusion in microbial processes via a long-term salinity intrusion experiment that measures sulfate reduction and methanogenesis rates as well as other biogeochemical measurements.

Results indicated that the increase in carbon dioxide flux following a saltwater intrusion event was statistically significant for 8 months following the event. Additionally, there was an increase in the amount of organic matter being mineralized. Sulfate reduction rates did not change, and methane flux increased significantly for 4 months following the event. Total carbon gas flux was significantly higher for 6 months following the saltwater intrusion event, with a 50 percent higher carbon gas flux during the course of the year following the event. This is linked to a decrease in soil organic matter, which becomes apparent 3 months after the event. The results indicate that relatively little is known about how microbial communities respond to changing environmental drivers (e.g., climate change); microbial response is important to composition. Therefore, the researchers initiated a field transplant experiment at four sites to understand how microbial communities respond to climate change. The field site monitoring measured carbon dioxide and methane flux, plant biomass, microbial rates, biogeochemistry, and microbial community composition. During the first year, the first two sites had a good seasonal signal of plant biomass, but the plants died at the third site during mid-summer as the salt levels increased. The plants at the fourth site died almost immediately. During the second year, species common to brackish or salt marshes grew, indicating a shift from freshwater to brackish or salt marsh. The response of freshwater marsh plants to salinity intrusion and inundation indicate that there is a significant negative relationship of plant biomass to productivity and inundation. The current transplant experiment researchers are conducting controls for elevation.

Inorganic sediment is a major input for watersheds. The researchers are examining monitoring data from the U.S. Geological Survey (USGS) from the 1970s to the present and found that there has been a steady and serious decline in suspended sediment in the Delaware River. USGS data on 42 additional East and Gulf Coast rivers indicates a significant decrease in suspended sediment in 48 percent of the rivers. Results indicate that the decline in plant production, which leads to decreased deposition of organic matter—combined with increases in microbial response and carbon dioxide and methane flux and a decrease in watershed inputs—leads to a loss of freshwater tidal marshes.

The challenges the researchers faced in carrying out the projects included controlling for marsh vertical elevation critical in field experiments, the increased diversity of plant species in tidal freshwater marshes, understanding the response of methanogens, and the number of complex and interconnected processes. The researchers integrated ongoing work with other groups (e.g., Partnership for the Delaware Estuary, University of Delaware, Rutgers University); communicated with local stakeholders; and presented their work at several national meetings.

Connectivity in Marine Seascapes: Predicting Ecological and Socioeconomic Costs of Climate Change on Coral Reef Ecosystems
Julie Kellner, Resources for the Future

Dr. Julie Kellner explained that the deteriorating health of the world's coral reefs threatens global biodiversity, ecosystem function, and the livelihoods of millions of people living in tropical coastal regions. The researchers have initiated a collection of team projects that focus on coral reef resilience, particularly in response to bleaching, hurricanes, changes in trophic and habitat relationships, fishing, and coastal development and management. The goals of the project are to: (1) integrate theory and data from ecology, biology, and the social sciences to address major questions about the potential consequences of climate change on coral reef ecosystems; (2) predict how fishing pressure, tourism development, and local economies will be affected by climate change stressors; and (3) provide guidance for future management. The study sites include a variety of different systems, including marine reserves and unprotected areas, in or near the Bahamas archipelago, Belize, and Bonaire.

Trophic relationships in the Caribbean are very complex interactions that involve predators and their recovery and relationships to lower species. Threats to reefs include coral bleaching and hurricanes. Coral bleaching is the response of corals to elevated temperatures or high levels of ultraviolet radiation in which they expel their symbiotic algae. Corals can recover these algae following weak exposure, but prolonged exposure can cause mortality. Hurricanes can damage, overturn, and kill corals, and the movement of sediments and debris causes scouring. Increased nutrients, as a result of hurricanes, can encourage algal growth. Macroalgae compete with corals, and reefs can switch from a healthy, coral-dominated state to an unhealthy, algal-dominated state. Grazers are important because they can influence the replenishment rate, growth, and fecundity of coral colonies. Grazing underpins the resilience of coral reefs to disturbance. Many different models, especially those simulating bleaching and hurricanes, have been used to determine the impacts of disturbances on coral reefs. Modeling indicates that mortality caused by bleaching depends on the magnitude and duration of thermal stress and each coral's thermal history, whereas mortality caused by hurricanes depends on strength of the hurricane (based on the Saffir-Simpson Hurricane Wind Scale) at the reef location and colony size.

When parrotfish (grazers) were not exploited, the models predicted the health of Belize's coral reefs and indicated that bleaching or bleaching combined with hurricanes will significantly decrease the amount of coral cover, leaving almost no coral cover by the year 2100, whereas hurricane-only scenarios increased the amount of coral cover. When parrotfish were exploited, all three scenarios (hurricanes only, bleaching only, and hurricanes and bleaching combined) reduced coral cover significantly by 2030, with no coral cover remaining by 2090. In terms of coral cover and the role of grazers, the researchers asked whether the loss of grazers reduces resilience and how the systems can be recovered for future resilience against disturbance. There is the potential for two different stable states in the system—low coral/high algae or high coral/low algae. The adaptive capacity of the system may change if left degraded. The model prediction was that increased grazing equals increased stability. The negative feedback loops in the system include increased macroalgal cover and reduced structural complexity, fish recruitment, coral cover, grazing intensity, and coral recruitment; the positive feedback loops are the opposite. Grazing intensity increases as herbivore biomass and coral cover increase. The modeling allows managers to meet the challenge of keeping reefs highly resilient by showing how resilient the reefs will be based on their initial coral cover; this illustrates to managers where their efforts should be focused.

No-take marine reserves decrease the fishing pressure, which is important for resilience and results in faster coral recovery within the marine reserve. The presence or absence of mangroves affects the density and biodiversity of species, and one ongoing project examines how important mangroves are to the community structure of important herbivores. The presence of mangroves increased the grazing intensity of two types of parrotfish. Absence of mangroves decreased coral cover and increased algae; modeling indicated that a current coral reef with 10 percent coral cover will have 12 percent coral cover in 50 years in the absence of mangroves. Presence of mangroves, however, increased resiliency, particularly following hurricanes, and decreased coral mortality; modeling indicated that a current coral reef with 10 percent coral cover will have 60 percent coral cover after 50 years in the presence of mangroves.

With regard to habitat conservation and ecosystem services, the researchers asked the following questions: (1) How does habitat (and loss thereof) affect the productivity of fisheries? (2) What does this imply for the economic value of habitat? (3) How do these values impact coastal land-use decisions? Bringing ecology into habitat valuation will enable the development of a model that allows for obligate and/or facultative associations, explores multiple habitat types, and links recent findings in ecology to the tools of economic valuation.

The researchers learned a variety of lessons during their research. Caribbean coral reefs appear to exhibit alternate stable states. There are threshold levels of coral cover, grazing, nutrients, and so forth. Restoring reef health becomes disproportionately more difficult as health declines. There is a need to act sooner rather than later. Coral resilience is linked with the probability that the reef does not become entrained in a shift toward a stable algal state. The researchers have conducted outreach to educators, practitioners, decision-makers, and the public via a Web site, booklets, videos, posters, teaching resources, newsletters, meetings, and presentations. The researchers have found that integrative models are useful, particularly for management and education.

Effects of Climate Change on Ecosystem Services Provided by Hawaiian Coral Reefs
Paul Jokiel, University of Hawaii at Manoa, Hawaii Institute of Marine Biology

Dr. Paul Jokiel explained that the goal of the project, which finished recently, was to integrate and extend existing models to develop a comprehensive, scenario-based analysis of the range of possible effects of global climate change on ecosystem services provided by the coral reefs of the Hawaiian archipelago and on the economic valuation of predicted changes. The developed model is available for online use and can be downloaded at http://www.kgs.ku.edu/Hexacoral; this availability provides for community involvement through hands-on testing and feedback. The challenges the researchers faced included building a model at three levels (climate change, biological response, and ecosystem services) and occurrence of the economic downturn at the time of the project's valuation survey. Many lessons were learned, but an unexpected lesson was that coral growth and mortality were central to all of the work. The researchers interacted with clients through presentations at various workshops and meetings. Additionally, four published papers from the project were cited in the *Federal Register* announcement of EPA's Ocean Acidification and Marine pH Water Quality Criteria Notice of Data Availability.

There have been a number of background studies since the 1970s regarding the response of Hawaii's coral reefs to temperature increases. The current mesocosm study experiments are conducted in continuous flow outdoor mesocosms that simulate the reef environment, and the experimental treatments include acidification to produce the carbonate saturation states predicted for the year 2100. Following acidification, noncalcifying algae increased by 52 percent, and crustose coralline algae recruits and cover decreased by 78 and 92 percent, respectively. Results of the mesocosm coral growth experiment showed that no mortality occurred in the acidified or control treatments, but coral calcification was reduced by 15–20 percent in the acidified treatment. Corals grown in the acidified treatment produced a more delicate skeleton, including thinner branches and a decrease in skeletal density, and there was no evidence of acclimation. Rhodoliths, which are accretions of crustose coralline algae, showed a 250 percent decrease in calcification following acidification compared to the control group. The mesocosm wall settlements experiment indicated that crustose coralline algae significantly decreased and bare substratum significantly increased following acidification. Results confirmed previous studies that showed that ocean acidification is affecting calcification but not the organic components of settlements. Additionally, there was no change in reproduction rates, consistent with prior studies. A flow-through experiment illustrated the net ecosystem calcification and indicated that the system as a whole is decalcifying despite coral growth; therefore, corals will continue to grow even as the reefs are dissolving.

The main focus of the research was to develop the Coral Mortality and Bleaching Output (COMBO) Model. Within the model, the user has control of all factors (sensitivities, probabilities, environmental inputs) via a user-friendly interface, and regionally appropriate default values are provided. Finally, the effects of quasisteady-state temperature, carbon dioxide concentration, and temperature variation are assessed independently in the model and accumulated into net change in cover. Calculations are performed in linked, user-accessible worksheets with options for replacing the built-in datasets, and output plots and tables are updated immediately as input values are changed. The sample output of the COMBO Model indicates that Hawaiian reef coral cover could largely disappear by the end of the century if fossil fuels use continues to expand. Additionally, the COMBO Model was updated to reflect the latest model ensembles for the current Intergovernmental Panel on Climate Change (IPCC) predictions and is more sophisticated and complex as a result. The resolution was increased and the noise was extracted to allow inclusion of bleaching thresholds and how these will affect the vulnerability of susceptible areas. The model was run many times with the same conclusion: It is extremely unlikely that viable coral populations will persist in the shallow waters of the Hawaiian archipelago in 2100, and precipitous declines likely will start in the northern region sometime between 2030 and 2050, with a steady decline during the entire century throughout the region. The model also indicates that bleaching events are important. Although Dr. Wolfgang Haider will present briefly on the socioeconomic modeling aspect of the project, Dr. Jokiel noted that hedonic price modeling suggests that coral reef presence and quality have a significant impact on house prices.

Tier I Discussion

Dr. Denice Wardrop asked EPA staff how the Agency will utilize the results of the studies, especially considering the management implications for long-term planning and policies. Dr. Jones responded that one of the goals of the workshop was for EPA to receive input from the researchers about possible next steps. With the new Administrator’s emphasis on climate change and its impact on ecosystems, the Agency would like to take basic science information and put it in a format that can inform the chain of command. The workshop discussions should include next steps, including input regarding the next Request for Applications (RFA). Dr. Lorenzana added that it is not too late for researchers to partner with the regions, which can be used to reach state and local partners. Each region has a Regional Science Liaison, who can be used as a resource. She noted that Mr. Thomas Baugh, the Region 4 Regional Science Liaison, was present at the workshop. Mr. Baugh explained that Region 4 is comprised of eight states (Kentucky, Tennessee, North Carolina, South Carolina, Georgia, Florida, Mississippi, and Alabama) and has the highest population of any of the regions. Dr. Lorenzana noted that Dr. Jones could help any of the grantees contact their Regional Science Liaison.

Mr. Baugh asked Dr. Craft to comment on the quality and quantity of the historical sea level rise data that are input into SLAMM 5. Dr. Craft responded that National Oceanic and Atmospheric Administration (NOAA) maintains long-term monitoring stations at various coastal locations, and the researchers used the NOAA rate from Ft. McAllister, Georgia, which is 3.1 mm/year. Generally, NOAA data are available for 50–100 years within 50–100 miles of almost any coastal site. The model’s weakness actually is the elevation data. The researchers used the National Elevation Dataset, which is rather coarse. The researchers are working to obtain Light Detection and Ranging (LIDAR) data. In terms of accretion rate data, it should be site-specific for input into SLAMM 5. Many of the data required for input are publicly available. He noted that it would be helpful if Region 4 could help acquire better LIDAR and elevation data.

Dr. Wardrop asked Drs. Craft and Jokiel about their experiences resulting from the Web availability of their models. Dr. Jokiel stated that people were actively using the Web site and models, which would evolve, especially as the subject matter (coral reefs) will be extinct by the end of the century if changes are not made. Dr. Craft explained that the SLAMMView Web Site is a method by which to visualize the modeling concept. The model itself is available at several Web sites (e.g., FWS). There have been so many requests for technical support that the staff are becoming overwhelmed and may need to start seeking financial compensation for technical support services in the future.

Dr. Robert Whitlatch asked the marsh researchers whether there was a manner by which to examine the ecosystem services provided by ground marshes that could provide some insight into loss of minerals and services. Dr. Hester responded that some current approaches could be applied to this problem. In terms of eutrophication and primary productivity of the sites, there may be seasonal variations in primary productivity that can affect nutrient cycling; the processes that can be measured at the site can be related to the services. Dr. Whitlatch asked whether the current models are easily adaptable to different systems. Dr. Hester responded that if the goal was to examine relationships between drivers of ecological processes and ecosystem services, then a structural equation model approach could be used; conceptually, this would be fairly easy to accomplish. Dr. Craft added that although SLAMM 5 does not incorporate this, it can be adapted with bathymetry data. Dr. Hester added that erosion could be incorporated into a structural equation model depending on the strength of the relationships. When using a structural equation model, it is possible to use the best available scientific data to create an *a priori* model and then further develop the model into the confirmatory model using hypothesis testing.

Dr. David Purkey asked Dr. Weston for his thoughts on the hypothesis that, in terms of the USGS sediment data, the level of water management and reservoir infrastructure development may be related to the decline in sediment. Dr. Weston agreed that this was probable. Damming and other efforts to decrease suspended sediments—because they are not helpful to rivers and streams—have been successful and do not consider the fact that marshes depend on receiving sediment from rivers and streams. The management implications are challenging because it is not desirable to deposit large amounts of sediment into rivers, although this would greatly help marshes and their management. Dr. Craft added that measuring accretion can be challenging, and marshes increase their accretion rate with organic matter in addition to sediment. In microtidal systems, organic matter appears to be more important than sediment amount.

Dr. Thomas Meixner noted that the tidal marsh studies deal with the influence of freshwater input into the marsh systems. As changes occur, are there management practices that can be put in place? Dr. Weston stated that there was no easy answer to this question. Climate change will affect precipitation patterns, which in turn will affect salinity levels. Warmer temperatures also increase evaporation and therefore salinity. Work can be focused on decreasing water withdrawals in the summer months so that there are less low river flows.

Mr. Baugh asked Dr. Kellner to elaborate on the connection between coral reefs and human health that she mentioned. Dr. Kellner explained that she was speaking in general terms; most models focus on the socioeconomic benefits (e.g., fishing, tourism). There are some biodiversity issues in terms of what coral reefs can provide for medical products.

Dr. Jones noted that ORD is interested in data translation and transfer issues. It is necessary to ensure that the right people receive the information in a timely matter, particularly in relation to global climate change (e.g., the expected loss of coral reefs within the next century). It is necessary to reach Congress regarding the impact of valuation on constituents. Part of the focus needs to be on how to best translate and transfer the information to the right people. ORD will develop a series of one-pagers regarding the grants with different language to reach different audiences. Dr. Purkey commented that it is challenging to translate basic science into real-life management decision-making. He suggested that the next climate-change-related Science To Achieve Results (STAR) RFA demonstrate a preference for proposals that are motivated by real-life management decisions that incorporate climate change so that the researchers will be motivated by this, making the audience more receptive to the research information. Ms. Lisa Macchio of Region 10 noted that basic research is very beneficial, but regional programs want to know its applications. It is important for researchers to explain how their results can be applied and inform decision-making (e.g., how models are useful in writing total maximum daily load reports). It would be beneficial to the Agency if researchers explained how to use the research in the grant applications and final grant reports.

Dr. Ramesh Reddy of the University of Florida asked whether there is a movement within EPA to place an economic value on ecosystem services. Dr. Jones responded that there had been an Economics and Decision Sciences Research Program within ORD, but it did not receive a good deal of support, so ORD is examining methods and partnerships to revive it; there have been many discussions within the Agency about how to accomplish this. NOAA has an advantage in this respect because of its role with fisheries, recreational areas, and so forth. EPA partners with other agencies that address valuation of ecosystem services. Dr. Lorenzana added that partnering with regional offices can help; Region 10 employs an economist who is working on ecosystem services and valuation.

Mr. Jerry Kuhn of Region 10 emphasized how critical it is for researchers to highlight the applications of their research for EPA staff because this information is essential for writing regulations; researchers need to use their science to advise the Agency. There is an ecosystem services valuation report available for the Puget Sound; it is the most comprehensive work on ecosystem services to date. Mr. Kuhn asked Dr. Jones to add the report to the workshop Web site.

Willingness to Pay for Mitigation of Climate Change Effects on Hawaiian Coral Reefs: A Contingent Choice Study
Wolfgang Haider, Simon Fraser University

Dr. Haider explained that the goal of the project was to estimate people's willingness to pay for mitigating the effects of climate change on coral reefs in Hawaii. The challenges were to separate use values from nonuse values, control for key components of the reef ecosystem, and design a payment vehicle that is applicable from the present but leads to uncertain outcomes in the future. The method chosen was a contingent choice survey. Environmental valuation includes bequest, option, and existence values as components. The attributes that were chosen for the discrete choice experiment were selected after much discussion and include coral cover, coral health, fish numbers, species diversity, water clarity, mitigation fees, presence or absence of turtles, and levels of relief (low, medium, or high). Survey respondents were provided images so that they could visualize their responses. The survey instrument was a fairly complex Web-based survey that included 1,000 mainland residents and 500 Hawaii residents. Pictures were combined with textual information to decrease variable interpretations of the questions. Dr. Haider showed examples of the survey questions and explained that the conservation fee referred to in the survey was the cost to visit a coral reef; this determined the nonuse value. Results indicated that water clarity, coral cover, mitigation cost, fish numbers, species diversity, and coral health were significant. The decline index also had a significant effect; people's willingness to pay increases with the forecast of a negative future. Additionally, respondents had a significant belief in climate change; mainland residents had an increased willingness to pay compared to Hawaii residents, whereas climate change believers had an increased willingness to pay compared to climate change skeptics.

TIER II: NONLINEAR RESPONSES TO GLOBAL CHANGE IN LINKED AQUATIC AND TERRESTRIAL ECOSYSTEMS

Hydrologic Forecasting for Characterization of Nonlinear Response of Freshwater Wetlands to Climatic and Land Use Change in the Susquehanna River Basin
Denice Wardrop, Pennsylvania State University

Dr. Wardrop explained that the Susquehanna River Basin is a 26,000-square-mile watershed, which provides 51 percent of the freshwater to the Chesapeake Bay. Wetlands in the area comprise approximately 2–4 percent of the landscape, and 73 percent of the wetland area is associated with headwater streams. The area is predominantly forested, and each individual wetland is less than 10 acres. The objective of the project is to characterize nonlinear responses through: (1) selection of a linked terrestrial-aquatic ecosystem that provides critical ecosystem services and ecological functions; (2) characterization of various global change scenarios, incorporating both climate and land cover, and a method of assessing their effect on the identified ecosystem through the primary forcing factor of hydrology (both alone and in conjunction with other human-associated stressors); (3) identification of potential nonlinear ecological responses in the selected ecosystem as a result of these changes; and (4) estimation of the resultant change in ecosystem services on watershed and basin-wide scales. Scenarios of climate and land cover change generated by various departments are input into predictive hydrologic scenarios. These scenarios, combined with hydrology and ecological function models and functional loss estimates of plants and macroinvertebrates, are used to obtain valuation of change in ecosystem services and identification of nonlinearities.

The researchers were challenged with scaling issues, needing to determine: (1) the assessment unit; (2) how to stratify the study area for the purpose of sampling, modeling, and subsequent upscaling; (3) the scale in which to express the final results; and (4) how to resolve extent and resolution differences in scale of the various components of the project. The assessment unit needed to: (1) integrate freshwater wetlands with important contextual landscape, (2) be of a spatial and temporal scale that matched ecosystem services, (3) be of a scale capable of being modeled, and (4) be representative of the range of conditions in the Susquehanna River Basin. The various interdisciplinary researchers solved this by discussing the spatiotemporal scale used in each discipline. The biological data were at a wetland scale, whereas the other disciplines were working at a reach scale or greater; the researchers realized that the reach scale could work for all data. The researchers downloaded data from the IPCC's fourth report, which includes 21 models from 12 countries; some models have multiple realizations with different horizontal resolutions. To chose the most ecologically relevant model, the model output and observational data were placed on a one degree grid within the Susquehanna River Basin; the models were a tolerable fit, predicting wetter springs and drier summers compared to actual precipitation. An overall squared error was computed for each variable and model and normalized over all models to compute the overall performance index by averaging over all of the metrics. Six of the 10 selected metrics deal with mean, and four with variability and extreme events. In terms of model performance, the mean generally was the best fit except in extreme scenarios. The researchers identified several lessons learned. Models differ dramatically in their ability to predict the climate of the Susquehanna River Basin. The model mean is superior to any individual model and specific to region. The raw model output was not as bad as expected.

The three scenarios prepared for the hydrology model were: (1) daily output from 1960–1990 to establish a baseline, (2) daily output from 2035–2065 to show the effect of climate change, and (3) impact of the change in mean climate versus change in variability. The multiscale Penn State Integrated Hydrologic Model (PIHM) incorporates climate and land-use effects. The PIHM finite volume approach uses a triangular irregular network (TIN) to allow nested grids and is calibrated across the ecoregions of the Susquehanna River Basin. The model can decompose nearly 100 square miles of watershed into nearly 1,000 TINs and predict changes in terms of depth to water table, stream flow, and left- and right-bank baseflow. In considering hydrological modeling, the researchers learned that: (1) scale-appropriate and ecologically relevant hydrologic scenarios can be predicted, (2) ecologically relevant and powerful metrics are difficult to identify, (3) there is a spatially heterogeneous response to a homogeneous forcing function, and (4) absolute values of predictions are difficult to utilize in a meaningful way. The researchers also asked whether changes in hydrologic regime could result in loss of wetland area and/or loss of function through physical changes and the loss of functional process zones. A reach classification was devised that encompasses the entire riparian area. The researchers also are examining land-use change and disturbance in addition to hydrology. The assumption is that hydrological complexity leads to ecological complexity.

As more work is completed, the researchers are utilizing feedback loops to revisit the climate change scenarios to assess whether the right climate model was chosen. There has been a good deal of interaction with clients, including assessments for various groups near the Chesapeake Bay and Mid-Atlantic region. The major lesson learned is the importance of scale. The researchers will continue to perform hydrologic modeling, characterize and validate physical and functional reach characterizations across physiographic provinces, and define the distributions of hydrologic parameters for each reach type and disturbance cell and extrapolate the results basin-wide.

Sustainable Coastal Habitat Restoration in the Pacific Northwest: Modeling and Managing the Effects, Feedbacks, and Risks Associated With Climate Change
John Rybczyk, Western Washington University

Dr. John Rybczyk stated that the project's study site is the Skagit River System, with a focus on the estuarine delta area. Historically, the Padilla Bay was part of the Skagit River Delta, but estuaries currently exist only on the fringes because of human intrusion. The Padilla and Skagit Bays now are isolated from each other with no dynamic exchange. Historically, the Skagit Bay was comprised of all estuary habitats of some type, but because of dikes and levies, these estuaries exist only on the fringe. How can the area be restored, especially in light of recent sea level changes? The experimental approach was to link sea level rise predictions to LIDAR data and known elevation distributions of vegetation in the tidal marshes of the Skagit River Delta. Sea level rise scenarios were run to determine how the vegetative communities have changed and how and where to plan for restoration.

Approximately 3,000 hectares of intertidal eelgrass beds, an important habitat for the Pacific Northwest, were examined in the Padilla Bay, which has no compensation mechanisms in the face of sea level rise as it is cut off from its historical source of freshwater and sediment. The researchers investigated whether eelgrass beds in Padilla Bay were at risk and whether they were accreting at a rate that keeps pace with sea level rise; it appears that the areas are erosional rather than accretional and are losing elevation at a rate of approximately 0.57 cm/year. These types of analyses must be taken with caution when making long-term predictions, however, because they ignore climate change-induced alterations in salinity, tidal regime, river flow, and sedimentation. The analyses imply linearity, but because of system feedbacks, response to sea level rise is nonlinear. Decomposition, primary production, and sediments change in relation to elevation, and these nonlinear dynamics also must be considered.

The goals of the project are to: (1) develop a predictive simulation model, incorporating nonlinear elevation feedbacks, of the ecological and geomorphological consequences of sea level rise and river flow alterations in Padilla and Skagit Bays; (2) use the model to guide the course of restoration efforts, given climate change, in the Skagit River estuary; (3) link a spatially explicit hydrodynamic/sediment model to a mechanistic wetland elevation dynamics and vegetation model; and (4) initialize and calibrate the model using extensive site-specific data collected for the project. Currently, the researchers are cataloging soil salinity, vegetative communities, and elevation as well as developing an extensive data network. The unit (elevation/vegetation) model builds a sediment cohort that grows in response to above- and belowground productivity and mineral matter inputs and then compacts and decomposes; what remains contributes to wetland elevation, which in turn is affected by sea level rise. The relative elevation model was extended to model a three-dimensional surface instead of a single point, which was used to determine how eelgrass beds will shift with various sea level rise scenarios. The next step will be to integrate the unit model with the hydrodynamic model, which incorporates tides, winds, and river flows and simulates salinity, flow rate and direction, and sediment. The researchers have interacted with a number of clients, including the Skagit Climate Science Consortium, which includes a diverse group of stakeholders. The focus is to integrate the results of several modeling efforts within the Consortium into one overarching model.

Nonlinear Response of Pacific Northwest Estuaries to Changing Hydroclimatic Conditions: Flood Frequency, Recovery Time, and Resilience
Anthony D'Andrea, Oregon State University

Dr. Anthony D'Andrea explained that floods and delivered sediment are increasing. This project focuses on flooding events, an important focus for the Pacific Northwest, which receives a great deal of precipitation. Climate models predict an increase in total precipitation, particularly the frequency of extreme, high-rain events. River flow and flooding in the Pacific Northwest are increasing and further are amplified by seasonal rainfall patterns. Additionally, a combination of watershed and estuarine changes have decreased buffering capacity and led to increased sediment flux with potentially important but unknown effects; rapid sedimentation during floods can lead to abrupt changes in benthic intertidal communities. During the last 30 years, documented changes have occurred in Pacific estuaries, including reduction in benthic abundance and diversity, alteration of tideflat habitat, and rapid growth of nonindigenous species.

Because most studies are anecdotal or focused on limited numbers of species, the overarching goal of this project is to complete community-level studies of flood sedimentation impacts on estuarine benthic communities. The approach is a manipulative field study simulating the effects of the frequency of floods on Pacific Northwest benthic intertidal communities. Researchers are focusing on four interconnected key research questions dealing with recovery, impacts of flood sedimentation, within-year frequency of floods, and impact of floods on community susceptibility to nonindigenous species. The specific project goals are to: (1) design and implement a manipulative field study to determine the ecological effects of flood sedimentation on intertidal benthic macroinvertebrate communities; (2) use a combination of high-resolution benthic sampling and multivariate analyses of benthic community metrics to track the initial mortality, recovery, and resilience of the benthic community; (3) collect and analyze sediment samples parallel to the benthic community samples to track changes in important sediment properties that have direct or indirect effects on survival or habitat suitability of sediments to the benthic invertebrate community; and (4) synthesize the datasets from the study to develop an empirical and theoretical framework for predicting the effects of flood sedimentation events on tideflat macrobenthic communities in Pacific Northwest estuaries and how these changes impact ecologically and economically important biotic resources and ecosystem services.

The study site is Netarts Bay, chosen because of its large tidal area, relatively pristine state, and accessibility, among other reasons. The study plots are of uniform intertidal height and divided into three experiment groups: control, single flood, and multiple floods. Challenges and lessons learned are that ironic weather cannot be predicted, and the multiple uses of the bay complicate fieldwork. Dr. D'Andrea described the procedure for creating the flooding events and the sampling approach. The researchers observed flood layer and physical properties, including temporal change and sediment physical properties and geochemistry. In terms of temporal change, the key observation was that there is persistence as well as potential long-term impacts despite high current speeds at the site. Researchers observed a seven-fold increase of total organic carbon in the flood plots relative to control, which is a persistent feature through at least the first 150 days following the flooding event. The researchers tracked changes in oxygen patterns—which can be an indicator of stress to benthos—to assess impacts on the benthic microalgal community that can actively oxygenate surface sediments and provide food resources for benthos. Under dark conditions, there was no significant difference between the experimental groups; however, under dark conditions, there was little or no benthic photosynthesis in flood groups, which could add additional food limitation stress for surviving benthos.

The researchers measured the benthic community by observing changes in community structure and diversity and functional changes. Uni- and multivariate analyses were used to identify key community metrics and track community changes. The study community was comprised of two smaller communities, surface-dwelling and deep dwelling; the deep-dwelling community is the less mobile. There was a large amount of behavioral response to flooding; mobile species immediately vacated the flood plots, and there was a significant reduction in species richness for at least the first 72 days following the flood event. Infaunal abundances were consistently lower in flood plots compared to controls, and the effect of the disturbance was measurable and significant more than 2.5 months following the flood event; this appeared to be driven by changes in density of *Leptochelia dubia*, which in normal conditions comprises approximately 60 percent of the surface population.

The researchers concluded that flood sedimentation alters benthic intertidal habitat. The deposited flood layer persisted for more than 1 year with little physical or biological mixing, and the properties of flood sediments were distinct from ambient intertidal sediments. The remaining benthos in flood plots may be food limited, as indicated by a combination of high total organic carbon, deep oxygen penetration, and slow recovery of benthic microalgae. There were significant decreases in abundance and species richness, and depressed abundances lasted at least for the first 70 days. Additionally, the flood layer was not readily recolonized, even by mobile species. Finally, species traits (e.g., behavior) may be important in determining community response and resilience to rapid sedimentation disturbance events.

Nonlinear Response of Prairie Pothole Landscapes to Climate Change and Land Management
Carter Johnson, South Dakota State University

Dr. Carter Johnson stated that the overarching goal of his research project is to complete and test a new simulation model (WETLANDSCAPE) that will examine nonlinear or threshold effects caused by climate change and land management on complexes of glaciated prairie wetlands. The prairie pothole region in which the study is taking place is comprised of 1 million square kilometers and has a high amount of biodiversity; approximately two-thirds of all ducks in North America are produced in this region. There is a north-to-south temperature gradient as well as an east-to-west precipitation gradient across the area; the temperature gradient is the strongest. The area is comprised of three types of wetlands: temporary, seasonal, and semipermanent. WETLANDSCAPE simulations show the differences in the water regimes in the three wetland types. Productive prairie wetlands must cycle through four well-known vegetative cover cycles: dry marsh, regenerating marsh, degenerating marsh, and lake marsh. Climate can be evaluated by assessing how well the wetlands progress through the cycle; this is the basis of the Cover Cycle Index (CCI).

WETLANDSCAPE can predict the CCI of geographic regions under different scenarios. The best predicted climate is in the area with the fewest wetlands, and the areas that are predicted to have the best productivity and waterfowl nesting currently are forested. Dr. Johnson showed sample graphs of CCI plotted against warming trends. Most weather stations in the prairie pothole region have reported productive conditions in the 20th century; only three sites have been enhanced by increased warming. Most sites currently have optimal conditions, so any increase in temperature will decrease productivity. Hydroperiod frequency is defined as the number of days per year there is standing water; frog populations need at least 100 days of standing water to reach "boom" population levels. Historically, 22 years per every 100 have a hydroperiod frequency of at least 100 days. A 2°C rise in temperature allows for only 7 "boom years" out of 100, and a 4°C rise reduces this number to 1 year. Waterfowl depend on boom years and will not frequent wetlands that only have 1–5 boom years out of 100. Area crop types differ in their rates of evaporation, transportation, and runoff. In areas with unutilized grass, a 41-year simulation predicts that wetlands will dry up in approximately one-half of the years. Small grain crops cause dry years one-third of the time, row crops one-quarter of the time, and grazed grass one-fifth of the time. This suggests that there may be mitigation options via farm management; simulations suggested that mitigation can help in the 2°C warming scenarios.

Dr. Johnson displayed a conceptual map of the modeling process to determine cost-effective mitigation of climate impacts on waterfowl productivity. Four models provide input into one another; the climate model provides weather scenarios to WETLANDSCAPE, which provides wetland/watershed characteristics to the mallard model, which provides waterfowl response to the economic cost-effectiveness model, which provides the ultimate values. The challenges that the researchers faced were the expected-but-surmountable challenges in fine-tuning and calibrating a new simulation model. Additionally, the researchers interacted with the U.S. Forest Service, FWS, and the public. The wildlife conservation community (federal, state, and private) is using the research findings to develop long-range plans to mitigate for climate change effects on waterfowl, and the researchers participated in a national workshop at Ducks Unlimited headquarters to write a white paper on waterfowl and climate change policy.

Innovative Management Options To Prevent Loss of Ecosystem Services Provided by Chinook Salmon in California: Overcoming the Effects of Climate Change
David Purkey and Lisa Thompson, University of California, Davis

Dr. Purkey explained that most of the Chinook salmon habitat in California has been dammed, and the last place the species thrives is in the Butte Creek Watershed; however, increasing temperatures threaten this habitat. The long-term goals of the project are to: (1) investigate how climate change and land-use practices change temperature and flow regimes within California watersheds, (2) determine whether these changes will lead to a reduction in salmon habitat and a resulting reduction in salmon abundance, and (3) determine how a reduction in salmon abundance will affect local biodiversity through food web interactions. The goals during the first year of the project, which just finished, were to develop a watershed model, parameterize a baseline salmon population dynamics model, and develop a site-specific food web conceptual model.

The Butte Creek Watershed has several subwatersheds. Two reservoirs located in adjacent watersheds operate seasonally. Salmon visit a series of deep pools in this area in which the water temperature can be managed. The analytical approach to the problem is to combine climate data with the Water Evaluation And Planning System (WEAP) and Salmonid Population Model (SALMOD) models to examine tradeoffs between freshwater services and the salmon population. The models are built with elevation bands and information on soils and land use and cover. The WEAP software was calibrated with historical data from 1983–2003 and a model-to-model comparison. Following calibration of the hydrology, operations were input, including infrastructure (diversions, reservoirs, powerhouses), flow requirements, and operation rules. The overall watershed hydrologic response can be compared; the model is well representative of the overall volumes, and other statistical indicators are within acceptable ranges. The temperature model domain was divided into 40 subreaches characterized by a series of riffles, runs, and pools; the proportional length of each of these geomorphic types was combined in the modeling assumption. There is reasonably good calibration of the model, although a small amount of divergence occurs below the powerhouse. Modeling indicates that potential management options include using Philbrook Lake to modify the temperature in Butte Creek when necessary. Temperature calibration was one challenge that the researchers faced.

Dr. Lisa Thompson explained that SALMOD is a computer model developed by the USGS that simulates the dynamics of freshwater salmonid populations. SALMOD structure includes holding/spawning adults, eggs and alevin, fry, 0+ parr, and 1+ parr; inputs into the model include temperature, habitat, flow, fecundity, growth, mortality, and movement. Data sources for the model include government reports, peer-reviewed publications, and books. SALMOD can graph relationships, including egg mortality versus temperature, fry growth rate versus temperature, and fecundity versus weight. Preliminary output of the model matches what is expected to be observed within the system. Juvenile outmigration is the gold standard to ensure that the watershed is productive; the baseline model generates reasonable juvenile abundance, and calibration is planned with California Department of Fish and Game outmigrant trap data. Challenges with SALMOD included program limitations and calibration. The researchers are examining marine-derived nutrients above and below the migration barriers to determine how much benefit the salmon currently bring to the ecosystem and will use this information as a surrogate for what would be lost if the salmon were lost.

The researchers have interacted with clients via presentations and have worked with several international, national, state, and local organizations. Currently, the tasks are on track, and an efficient and effective multidisciplinary research program has been established. Stakeholders and other parties, such as resource managers and watershed groups, are interested in the research outcomes.

Hydrologic Thresholds for Biodiversity in Semi-Arid Riparian Ecosystems: Importance of Climate Change and Variability
Thomas Meixner, University of Arizona

Dr. Meixner explained that the three hypotheses of the research project are that: (1) decadal scale climate change and variability alter riparian aquifer recharge through mechanisms that depend on the magnitude, frequency, and seasonality of flooding, and exert the greatest change in reaches that receive minimal groundwater inflow from the regional aquifer; (2) riparian vegetation structure responds nonlinearly as riparian aquifers are dewatered and key hydrologic thresholds for survivorship of plant species are exceeded; and (3) decadal scale climate variability and change alter riparian ecosystem water budgets that in turn change vegetation structure and function and the ecosystem services provided to society. Riparian ecosystems are classified as wet, moist, or dry, and biodiversity decreases as the system moves from wet to dry. Hydrology systems generally are understood by mountain-block, mountain-front, and basin-floor recharge; additionally, basin groundwater mixes with flood recharge. Riparian well water composition falls between that of basin groundwater and monsoon runoff; storms and floods propagated in the system are critical sources for approximately one-half of the water in the riparian system. The experimental design uses a climatic gradient to understand how differences in hydrology affect vegetation and how climate change will affect the winter storms that are a critical source of water in the system.

Three projects are planned to study the first hypothesis. The study area for the first project is a 14,000-square-kilometer watershed in Arizona. Results indicate that downstream wells have the least evaporation signals, and upstream wells have the most. Additionally, there is a multidecadal storage of flood waters within the basin. The study site for the second project is the Upper San Pedro Basin in Arizona. A very simple flood model based on vegetation was used that captures the storage of floodwater and its re-release. The third project attempts to understand mountain recharge systems. The idea is that climate is a driver, and empirical relationships have been developed. Dr. Meixner described the temporal discretization of the empirical model; the model works well to estimate seasonal recharge.

The second hypothesis is being investigated via a series of three projects. The first project monitored surface flow monthly at ephemeral to perennial sites at multiple rivers, and vegetation was sampled along the active channel. Results indicated that wetland perennial herbaceous plants show a consistent pattern of sharp decline in abundance as stream flow becomes nonperennial; the researchers concluded that the abundance of a key stream community type (i.e., riverine marshland) will decline with increasing aridity. The second project examines variance through time via multiyear field monitoring of vegetation and soil seed banks at ephemeral, intermittent, and perennial sites through the wet/dry period. Results indicate that in years with wet winters, flood runoff sustains flows at ephemeral sites, allowing for the development of ephemeral wetlands. Additionally, soil seed banks provide resilience and allow distinct plant communities to develop in years with varying flow conditions, and the diversity of seed banks is influenced by proximity to perennial reach. The conclusion is that spatial distribution of wet and dry reaches influences vegetation response to stream flow changes. Citizen wet/dry mapping, an annual volunteer effort to map the wet and dry reaches of San Pedro, provides critical data. Another threshold is groundwater depth and decline of woody riparian plants, which the third project investigates via monitoring at multiple wells and rivers and sampling woody vegetation for abundance and composition. Preliminary results indicate that woody species, grouped by strategy type, show similar trends among rivers.

Three projects are being undertaken to study the third hypothesis. The first project investigates wet/dry scenarios, and the second project involves a modeling approach that estimates the potential seedling densities of riparian tree species. Preliminary results for the second project indicate that modeled densities vary among San Pedro River sites with different stream hydrology and among years with different flow conditions. The third project explores historic legacies by analyzing aerial photographs of the Upper San Pedro River from 1935, 1955, 1978, and 2003 to assess temporal and spatial trends in vegetation cover-type abundance. Results indicate that as a result of past extreme disturbance, pioneer woody vegetation has been expanding since 1953. Recruitment events are relatively rare, but when they occur there is a large return of trees. Riparian forest patterns are a product of interactions between recent climatic cycles and land and water use as well as past extreme events that set in motion trajectories of change.

Currently, greenhouse studies of plant rooting depth and response to water table decline are underway. The researchers also are classifying riparian plants into strategy groups based on response to drought and flooding. In the course of the study, the researchers learned that flexibility is critical, and a simpler model is preferable to a more complex model for these studies. Several presentations were made to stakeholders and clients. The next steps are to build a seasonal groundwater model of San Pedro, develop scenarios, and continue the greenhouse studies and classification of riparian plants.

Tier II Discussion

Dr. Jokiel showed diagrams, figures, and graphs that highlighted: (1) the projected impacts of climate change on food, water, ecosystems, and extreme weather events and the risk of abrupt and major irreversible changes; (2) projections based on continuing "business as usual" for emissions versus paths for stabilizing carbon dioxide emissions to limit temperature changes; (3) irreversible climate change resulting from carbon dioxide emissions; and (4) carbonate chemistry of coral reefs. It is important to make the general public and decision-makers aware of all of the possible outcomes resulting from climate change. He noted that the carbon dioxide that already has been produced cannot be retrieved.

Mr. Burney Hill asked Dr. Jokiel whether there are any species or refuges that may continue to exist in spite of climate change. Dr. Jokiel responded that the ocean as a whole is becoming acidified, so this would be unlikely. Caribbean reefs will disappear first, followed by Pacific reefs and the Indonesia coral triangle; this is not a hopeless situation if it is reversed now. Because fossil fuel cannot be burned indefinitely in any case, it behooves mankind to stop now rather than later and use solar, wind, and other types of power. When people realize the potential future conditions, they will be motivated to change their habits; alternative energy resources are vast.

Dr. Curtis Richardson of Duke University asked Dr. Johnson whether there were any efforts to determine whether to put resources in the eastern United States versus the western United States. Dr. Johnson responded that there were few hold-outs for maintaining the level of restoration in the West. He noted that restoration only resulted in recovery of 1 percent of wetlands in the previous few decades. FWS is close to making policy decisions in this area, but the decision to choose East versus West is politicized. Dr. Richardson noted that waterfowl populations were not the only issue in the West; water retention and loss is a significant issue, as are landscape problems. Dr. Thompson asked whether efforts could move north to Canada. Dr. Johnson responded that northern Canada appeared to be affected most, but there is hope in the aspen parklands; there may be some potential if the current drainage in the area ceases and restoration begins.

Dr. Purkey asked Dr. Wardrop, in terms of scaling up from headwater systems, what the plans were to introduce the water management dynamic into the analysis. Dr. Wardrop responded that most of the management already is in the headwaters, with large management projects in place, as the headwaters are the major producers of ecosystem services in the system. Dr. Purkey asked Dr. Wardrop whether the model allows for pumping scenarios, and Dr. Wardrop replied that it does. A participant asked whether soil mechanisms are included in the model. Dr. Wardrop answered that soils are a complicated geology, but they are included.

Dr. Wardrop noted that condition assessments in her watershed indicate that more than one-half of the wetlands are in fair or degraded condition and asked whether other researchers were making the argument that the resources are in an impaired condition and any actions that improve the resource condition can help in response to climate change. Dr. Meixner responded that in the San Pedro Basin the argument has been made that current usage will drain the basin eventually, and climate change will worsen this condition. Resource managers, however, do not know how to respond to this argument, and people are nonresponsive to using to less water. Dr. Purkey reported that the same response was seen to the news that the salmon habitat in California is very vulnerable.

Dr. Derek Poon of Region 10 stated that the question is what strategies can be undertaken if resources and watersheds are degraded before climate change effects are seen. This is a very difficult question, not answered in many places; the answer will not come from a piecemeal approach.

Ms. Susan Julius, EPA, noted that EPA Oregon produced a report on climate adaptations, including a series of management activities that could be undertaken for various ecosystems. There must be a paradigm shift that includes short- and long-term strategies. Solutions will be different for different areas and even for different seasons within the same area.

Dr. Richardson noted that the European climate change program is approximately 5 years ahead of the United States' and also struggles with how to separate climate change effects from disturbance. There may be synergies that can be exploited. He noted that projects need to be brought to the user groups to encourage forward progress. As some government policies and recommendations have been disastrous in the past, governments often are cautious about making recommendations; sound science is necessary to ensure the proper actions and recommendations.

Dr. Jason Rohr asked whether uncertainty had been considered and sensitivity analyses had been performed in the mathematically based risk assessment models. Dr. Purkey noted that his group still is in the model-building phase, but these will be included. Climate uncertainties are relatively easy to capture; it is necessary to identify areas in which there is acceptable uncertainty and find stability. Dr. Wardrop agreed and added that the concern is that no uncertainty analysis will mitigate a bad scientific decision. It is necessary when using external tools to determine whether they are ecologically relevant to the current work. It is important, as Albert Einstein noted, to define the question to be solved; sometimes researchers attempt to answer too many questions. Dr. Rybczyk added that uncertainty and sensitivity analyses are relatively easy to perform in ecogeomorphic models; many of the problems are in the initiation, calibration, and validation, especially when scale is increased.

Dr. Haider noted that, as the only social scientist present at the workshop, he had a unique perspective. He stated that people are responsible for adaptation; the general public and policy-makers need to be convinced of the consequences of climate change. There are many organizations in various fields that communicate this idea to the public; the information that the researchers at the workshop generate can feed into this decision process, but it needs to be translated. EPA's RFAs must include a social science component to interpret, translate, and determine how to proceed once the basic science information is generated.

Dr. Jones explained that EPA's National Center for Environmental Economics has a Web site that can be searched for information, reports and other publications, and workshops regarding valuations of climate change, ecological benefits, and so forth. EPA realizes that many different disciplines need to be a part of these types of decisions. Scientific knowledge takes time to acquire, but some decisions need to be made quickly. The role of scientists is to provide data and tools to the decision-makers, and scientists can suggest workshops that are necessary to move forward.

Dr. Purkey described a grant with Google to use Google Earth technology to understand climate change as well as collaborative work with the University of Kent that uses the same approach that Dr. Haider suggested. Dr. Wardrop added that it is necessary to match the scale of the social and physical sciences to the decision-making scale. Dr. Meixner stated that it is critical to consider that decision-makers often do not make rational decisions based on science but rather decisions based on instinct. Dr. Poon added that EPA does not have land-use authority and cautioned not to lose sight of the fact that local government changes are critical.

Dr. Jones thanked the participants for a productive discussion and recessed the meeting at 4:41 p.m.

DAY 2: MAY 28, 2009

Before the presentations began, Dr. Jones asked participants to provide input to the Agency regarding how to best use their research. Dr. Wardrop noted that it would be helpful for EPA to include in its RFAs more direction and guidance regarding how to ensure that the research can be translated and applied. Dr. Jones noted that he would take this suggestion back to his office and explained that the new management structure has a new focus on outreach and communication.

Integrated Bioclimatic-Dynamic Modeling of Climate Change Impacts on Agricultural and Invasive Plant Distributions in the United States
Wei Gao, Colorado State University, and Xin-Zhong Liang, University of Illinois at Urbana-Champaign

Dr. Wei Gao explained that biological invasions of nonindigenous species are serious threats to natural and managed ecosystems, causing approximately $120 billion in damage annually. Additionally, the rapid growth in trade worldwide and globalization exacerbates the United States' invasive species problems. Climate is the dominant determinant of the geographic distribution of native or invasive plant species, and climate change already has caused unequivocal shifts in distributions and abundances of species and pushed certain native species to extinction. The overall objectives of this project are to: (1) better understand how global climate changes affect U.S. agricultural and invasive plant species distributions with a focus on crop production; and (2) account for adaptation of alternative crops and invasion of nonnative species to enable decision-makers to design effective management and control strategies for a sustainable future agro-ecosystem. The proposed research will: (1) develop a robust species environmental matching model to best capture the observed agricultural and invasive plant species distribution using the conditions from a climate-ecosystem predictive model; (2) make projections for the potential niche distributions of alternative crops adaptable to the likely range of climate changes in the future using the climate-ecosystem predictive model; and (3) project the geographic distribution and abundance of U.S. agricultural weeds and invasive plant species by integrating a newly developed species environmental matching model and future soil and bioclimatic conditions simulated by the climate-ecosystem predictive model.

Dr. Gao introduced Dr. Xin-Zhong Liang, who explained that most general circulation models (GCMs) for climate prediction are based on IPCC models, but the researchers on this project used a model computational domain design to regionally downscale global model projections. The results of an assessment of the northeastern United States showed that the researchers' model predictions were closer to actual precipitation and temperature than IPCC's model; the IPCC model was even less accurate when predicting mean summer precipitation because of the biases present. The regional model can reduce biases, and combining models into a mosaic ecosystem model further reduces biases. A dynamic crop growth model can be integrated with satellite remote sensing to predict annual yields and help regulate market supply-demand, make strategic assessment of optimal operation practices, and project food trends as a result of climate change. The species environmental matching method relates observed species distributions to environmental envelopes with the assumption that the fitted observational relationships are an adequate representation of the realized niche of the species under a stable equilibrium or quasi-equilibrium constant. Cheatgrass was used in the study because it is not native to Washington State. Cheatgrass entered the United States through Washington State from Eurasia during the 19th century and now is widely distributed throughout the mainland United States, with the exception of Florida; no insects are available to control its spread. The presence of cheatgrass throughout several states was examined, and the modeling results predict that increasing temperatures will significantly increase the amount of cheatgrass.

Because it is important to determine how crop productivity will be affected by climate change, the researchers will examine the possible distribution of crops in the future. Additionally, another STAR grant, which will begin in August 2009, was secured to study water quality. Water quality and agricultural impacts on the United States following climate change will be studied. The next steps in the current grant are to expand the modeling system to predict most major crops, incorporate multisubgrids of land use and land cover, develop the capabilities to simulate air pollution impacts on crops, study agriculture water quality problems, and study the agro-ecosystem carbon cycle.

Global Change and the Cryptic Invasion by Transgenes of Native and Weedy Species

Cynthia Sagers, University of Arkansas

Dr. Cynthia Sagers noted that the formal definition of a transgene is neutral (i.e., it does not imply "good" or "bad"); it simply is defined as a gene from one species that has been introduced into the genome of another species through biotechnology. Because of increasing global population, increases in the quality and quantity of food are necessary, and biotechnology can introduce beneficial traits into existing crop systems to help with this goal. Agricultural systems have a marked influence on native species, and there is evidence for crop-to-weed gene flow and hybridization with native species. Evolution of crop and weed systems ensures sexual compatibility between native species and crops in some part of their range. The inevitable transgene flow from crops to weeds and natives is a serious issue because it can introduce herbicide resistance and result in aggressive weeds. Factors that support gene flow are coexistence, sexual compatibility, hybrid vigor, and selective benefit. The manner by which native and weedy species will respond to climate and land-use change and whether the likelihood of transgene escape shifts with these changes are important issues.

Canola has remarkable genetics and was the result of crossing a weed with cabbage in Canada. It is a robust crop that is becoming increasingly important as alternative food sources are explored. Because canola is sexually compatible with least 44 brassicaceous species, it is inevitable that it will expand into the wild. The number of areas in the United States in which canola is cultivated has grown exponentially since 1992 because of its increased use as a biodiesel and nontrans-fat cooking oil, among other reasons. Additionally, it spontaneously hybridizes with congener *Brassica rapa*.

This project began in Oregon with an EPA National Health and Environmental Research Laboratory project that studied insect resistance in canola. The project utilizes green fluorescent protein to determine whether the plants carry the transgene. There are three levels of competition between the parentals and hybrids. The conclusion of the research is that risk of transgene flow is a function of genetic background, competition, and level of selection.

A new project in North Dakota has begun that utilizes greenhouse and field work to determine how climate and land-use changes will influence the adventitious presence of transgenes. The objectives of this project are to: (1) characterize variability among weedy populations in traits related to outcrossing; and (2) incorporate these parameters into existing climate and land-use change models to assess the changing risk of transgene flow. Three different sexually compatible weeds— *B. rapa* L., *B. nigra* L., and *Sinapis arvensis* L.—that are predominant throughout North America will be examined. The project will begin with weed studies, the objectives of which are to map local distributions, monitor transgene flow, and model risk. The objectives of the sentinel plant study are to measure transgene flow and assess geographic variation in gene flow rate. The greenhouse study will evaluate genetic variability of functional traits among *B. rapa* populations and measure pollinator preference in a controlled environment. The objectives of the modeling are to develop phenological maps for sexually compatible relatives and create a probabilistic model of the changing risks of transgene flow. Transgene bans create problems, and the policy requires attention, especially given that three different federal agencies regulate transgenic species.

A Multiscale Approach to the Forecast of Potential Distributions of Invasive Plant Species
John Silander, University of Connecticut

Dr. John Silander explained that the New England area is an invaded landscape that is dominated by woody bird-dispersed species. There have been 111 invasive plant species identified in New England, the vast majority from East Asia or Eurasia. Of these, the most pervasive are woody invasives that are native to East Asia. The majority of invasion sites are dominated by 18 percent of all fleshy-fruited, bird-dispersed invasive species.

A primary objective of the project has been to predict the areas in which invasive species potentially will spread in the regional landscape. The project's approach to modeling potential distribution is to use spatially explicit hierarchical Bayesian models based on a prior U.S. Department of Agriculture (USDA) project that incorporate many different explanatory variables (e.g., climate, site, land use). The response variable is presence/absence data regarding *Celastrus orbiculatus*, which is a woody liana native to East Asia that is found in edge habitats; native presence/absence data from Japan and New England and Japan climate data layers also will be incorporated. The characteristics of the local field survey sites include habitat type and canopy closure. The potential distribution of *C. orbiculatus* is predicted as a function of climate, habitat, canopy, and land use/land change using four models: (1) New England climate only, (2) Japanese climate only, (3) New England and Japanese climates, and (4) New England and Japanese climates with local habitats and land use/land change. The researchers examined which models had the best fit and verified the results by comparisons with independent herbarium records. The best model fits include climate variables from New England and Japan, land use/land change, and local site characteristics. Factors across species that influence invasive species richness at a site include positive (edges and open canopies, road density, deciduous forests, and warmer summers) and negative (conifer forests and active agriculture) factors.

Results indicated that constantly forested landscapes (i.e., land-use characteristics) discourage the occurrence of invasive species. The researchers examined 70 years of digital land-use change from aerial photographs, satellite images, and groundtruthing and determined that land-use history is critical to predicting the distribution of invasive species in New England. Because these are static models, however, the goal was to develop a model that would determine the manner by which invasive plant species spread across the landscape over time. The species tend to be distributed by birds, so the question was whether birds, particularly the invasive European starling introduced in New York from Europe in the 19th century, are assisting with the spread of invasive plant species. Is there mutual spread across the region?

Results indicate that there appears to be parallel, joint spread, with the birds arriving in advance of *C. orbiculatus*. When the feeding choice behavior of the starlings was examined, it was determined that they prefer invasive fruits. The birds travel long distances, up to 200 km per day, and can disperse seeds over a wide area. The modeling approach to determine how birds respond to landscape characteristics was to develop a cellular automaton model of the dispersal and growth of *Celastrus* across the New England region using grids of five landscape types. The model was evaluated and seeded, and results indicated that the model was more accurate when local and long-distance dispersals were used. The model provides historical, present, and future predictions of spread. Future predictions indicate that the landscape does not fill because conifer forests have a blocking feature against the spread of these invasive species. Simplifying the model using binary landscapes shows a slightly poorer spread and performance than the more fully specified landscape heterogeneity. Using uniform landscape scenarios, the landscape fills over time; however, in random landscape scenarios, the landscape does not fill with *Celastrus*. Additionally, there appears to be a 30–40 year lag between the spread of the invasive starlings and *Celastrus*.

The researchers concluded that the most pervasive invasive plant species in New England tend to be woody and with bird-dispersed fruits. Hierarchical Bayesian models provide accurate, static predictions of the potential distributions of species using climate, land use, and local site traits as explanatory variables. Native range data combined with invaded range data are critical to accurate predictions. Models calibrated from invasive plant (*Celastrus*) demographic data and starling movement yield predictions that agree with the observed spread of invasives over space and time. Finally, regional land-use patterns are critical to the patterns of spread of both invasive plants and starlings.

Predicting Risk Invasion by Salt Cedar and Mud Snails
Leroy Poff, Colorado State University

Dr. Leroy Poff explained that climate change is likely to enhance the spread of invasive species in river ecosystems, which is particularly important because these species can alter ecosystem structure and function, contribute to native species declines, and cause economic damage. The goal is to understand how climate change influences the spread of these species, as local factors will determine the success of invasion. The working hypothesis is that within the thermally suitable envelope, local invasion success will be dictated by habitat suitability and dynamics (e.g., hydrologic, geomorphic) and biotic factors, which can be modeled at the ecologically relevant scales to establish the likelihood of success. Human responses to climate change must be accounted for because they will contribute to the risk of invasion.

The challenge of the project is scaling the problem, and the project framework uses a hydrogeomorphic template with the idea that species population success is a function of magnitude, frequency, timing, and duration of flow events that limit establishment success or cause mortality. The key point is that effectiveness of flow regime varies with geomorphic settings. The research plan is to combine flow regime and geomorphic setting (i.e., natural disturbance regime) to explain current distribution of nonnative salt cedar and New Zealand mud snail and project the future likelihood of invasion. The specific goals of the project are to: (1) develop an ecological response model to explain the current distribution and dominance of two invasive species across the interior West in terms of climatically driven, local-scale environmental drivers; (2) use downscaled projections of regional climate change to describe possible future streamflow regimes and incorporate the effect of water management on those future flow regimes in a geographic region of the western United States; (3) disaggregate the subbasin-scale flow regime output from the WEAP model and construct reach-scale flow regimes for the drainage network in the entire region; (4) use the ecological response model to examine the risk of invasion for river reaches throughout the region for different combinations of climate change scenarios and modes of dam operations in a geomorphic context; and (5) model long-term invasion success for the two study species under interannual flow regimes, representing a range of hydrogeomorphic settings.

One hypothesis under Goal 1 is that the current distribution and abundance of salt cedar and New Zealand mud snail can be explained statistically in terms of site-scale hydrogeomorphic setting and dynamics. The second hypothesis is that the probability of species occurrence or dominance at a site will reflect a hydrogeomorphic threshold. To identify the study region, researchers used GCMs to identify areas in which temperature changes will promote salt cedar range expansion and then overlaid these areas with areas on the edge of the current salt cedar range. The region of conservation and management concern chosen is an area surrounding the Green, Yampa, and White Rivers in Wyoming, Utah, and Colorado. The Goal 2 hypothesis is that the WEAP modeling platform can be used to generate subbasin scale and weekly flow regimes and infer the effects of dam operations on natural flow regimes for subbasins in the region. The researchers, based on lessons learned, probably will not pursue Goal 3 but will use WEAP instead. To accomplish Goal 4, an empirical ecological response model will be applied to develop risk-based predictions of invasion risk throughout the region. Under the model, the geomorphic base map combined with the flow regime base map results in an invasion risk map. The hypothesis regarding Goal 5 is that stochastic population dynamics models can estimate year-to-year population sizes based on reach geomorphology and long-term (projected) flow regime and therefore assess the long-term viability of nonnative species.

There are several expected outcomes of the project, including a more mechanistic (dynamic) and appropriately scaled basis for projecting invasion risk, a risk map, a framework for thinking about the spatial distribution of threats and how to contemplate proactive management, and possibly the future inclusion of social processes to examine cost-benefits of spatially distributed water management. The challenges have been projecting ecological response models for salt cedar and New Zealand mud snails that can be applied to future environmental conditions, scaling climate and hydrologic models to match ecological response and measurement scales, and representing risk in a robust manner that allows for linked multimodel uncertainties. The researchers have interacted with the U.S. Bureau of Reclamation and The Nature Conservancy and have planned discussions with Wyoming and Colorado state agencies. Currently, the researchers are developing a WEAP model for the upper Green and Yampa River Basins that eventually can be used to address a number of water management issues in these basins and have generated interest from nongovernmental organizations and state and federal agencies.

Integrating Future Climate Change and Riparian Land Use To Forecast the Effects of Stream Warming on Species Invasions and Their Impacts on Native Salmonids
Julian Olden, University of Washington

Dr. Julian Olden explained that the project began in September 2008. The prospect of dramatic climate change during the next century underscores the need for innovative science and new decision-support tools for efficiently managing freshwater ecosystems. Climate-induced changes in the geomorphic and physical processes that drive stream ecosystems in the Pacific Northwest are imminent. Cumulative effects and complex interactions among multiple agents of environmental change may limit the success of current and future river management efforts. Climate changes will have direct implications for stream temperatures, which are exacerbated by the removal or alteration of riparian habitat by logging and grazing that reduces shading and modifies channel morphology. Elevated stream temperature is one of the most pervasive water quality issues threatening freshwater ecosystems in the Pacific Northwest. Management efforts are further complicated by the fact that Pacific salmon now share the riverine landscape with a number of nonnative fish species, and significant shifts in species ranges and the outcome of biological interactions are highly possible. The goals of the project are to: (1) determine the predicted effects of regional climate change and local riparian management on riverine thermal regime; (2) investigate how Chinook salmon, smallmouth bass, and northern pikeminnow will respond to projected temperature changes; and (3) ascertain the critical areas for riparian restoration and protection to mitigate the negative ecological impacts of climate-induced stream warming in the future.

The study site is unregulated, and land use and resource extraction within the site vary longitudinally. It contains one of the few remaining wild spring Chinook salmon runs in the Columbia River Basin as well as an active region of upstream invasion by smallmouth bass and northern pikeminnow. The researchers are utilizing a combination of a GCM, land cover, geomorphology, and stream thermal regimes to develop a stream temperature model, which will be used to run future riparian vegetation scenarios to determine future stream thermal regimes. A field study will be performed to validate the model. The ultimate goal is to determine how Chinook salmon are affected.

To develop climate change projections of temperature and precipitation, the researchers are downscaling simulated future climate data from a suite of GCMs under three greenhouse gas emissions scenarios for decadal time periods from 2020–2100. Channel reach morphologies will be classified to describe the thermal sensitivity of stream reaches to changes in temperature and riparian vegetation cover, and reach classifications will be based on a hierarchical scheme that accounts for differences in valley fill, degree of channel incision, and channel pattern. Thermal regimes will be quantified using a network of digital temperature loggers at point locations, and thermal imagery will be used to map spatially continuous longitudinal patterns of stream temperature. The Heat Source Model Version 7 allows for the simulation of water temperature at the reach scale using high-resolution spatially continuous data coupled with deterministic modeling of hydrologic and landscape processes, allowing the development of a spatially explicit stream temperature model. To forecast thermal regimes under scenarios of climate change and land-use management, future spatiotemporal patterns in stream temperature will be predicted according to scenarios of projected climate change and riparian land use. To model ecological responses to future thermal regimes, fish species responses to climate change and riparian management will be estimated according to thermal preferences and tolerances, and a number of additional key temperature benchmarks will be explored. Field surveys will be completed to verify the models.

The project findings will help guide management strategies and policy aimed at minimizing the future range expansion of invasive species through protection and restoration of riparian vegetation that creates and maintains cool-water habitats. Results from this project will make it possible to rank stream segments in terms of their ability to mediate the effects of climate change on stream temperatures, create suitable thermal habitat that favors native species over invasive species, and establish thermal barriers to prevent upstream invasion. Management portfolios based on different ecological endpoints will be distributed to local and regional agencies and nongovernmental organizations. Products from the project will be integrated into a graphical user interface providing the user with animated maps and timelines of stream temperature change, salmon habitat availability, and bass and pikeminnow spread for a given climate change or land-use scenario or the option to export data for quantitative analysis. The challenges include the issue of continuous land access, incorporating climate-induced vegetation change into stream temperature modeling, and preparing managers for the possibility of implementing unconventional strategies. The researchers have interacted with several local, state, and federal agencies and nongovernmental organizations.

Elevated Temperature and Land Use Flood Frequency Alteration Effects on Rates of Invasive and Native Species Interactions in Freshwater Floodplain Wetlands
Curtis Richardson, Duke University

Dr. Curtis Richardson noted that global climate change and freshwater ecosystem studies and models suggest two key findings: Water temperatures will increase approximately 2–4ºC, and the frequency and intensity of high flow stream events will increase. The question is what the implications will be of warmer water and altered hydroperiod on the establishment, abundance, and distribution of invasive species in river floodplain ecosystems. A likely future scenario is that stream ecosystems in the southeastern United States will experience lower baseflows with more extended drought periods punctuated by more frequent and intense storm events. Another likely future scenario is that freshwater wetlands in the southeastern United States will be inundated less each year than currently and undergo a greater number of rapid wetting and drying cycles as a result of extreme events.

The goals of the project are to: (1) quantify the effects of elevated wetland water temperature and pulsed water on rates of species invasion patterns of sediment and nutrient retention services; (2) assess how species richness, diversity, productivity, and invasibility change under varying water temperature regimes; and (3) determine how interactions between hydrology and temperature affected the current community composition/invasibility of floodplain ecosystems in the southeastern United States at the regional scale. There are two experimental levels to the project. The first is site-specific and involves the role of plant diversity on invasive species, pulsed water effects on wetland species, and elevated temperature and pulsed water in controlled wetlands. The second experimental level involves regional floodplain hydrology and temperature shifts in naturally occurring wetlands. The study site is in the Cape Fear River Basin and includes 10,000 acres of forest and wetland on the Duke University campus and 24 hectares of wetland on the edge of the main Duke University campus. The three phases of the project are: (1) stream reconfiguration, (2) dam and impoundment, and (3) treatment wetland. A fourth phase, stream and floodplain restoration, is pending. There are 99 study plots, which were used in a previous study regarding the effect of diversity on ecosystem functions. The current study will examine the role of hydroperiod shifts and water pulses on diversity and wetland functions. Previous results indicated that the plots with the highest diversity prevented invasive species. Pulses are related to diversity and invasive species, with areas of high and low marshes.

Results that show the fluctuation of plant species in high and low marsh conditions indicate that high marshes decrease species diversity, and low marshes increase species diversity; invasive species appear to be intolerant of flooding. To accomplish the third phase, a Weir system is used to divert stormwater and raise water temperature. To accomplish the regional experimental level, nine flood plains sites located on rivers throughout North Carolina and southern Virginia were identified; some have a 5–6°C temperature gradient downstream of dams. Criteria for choosing the site include the presence of mountain headwaters, a high degree of hydrologic connectivity, and similar nutrient regimes; the reference sites must have no upstream dams. The researchers asked whether water temperature relates to species variety; there is no pattern of difference in water quality.

Results indicate that there is a large number of nonnative, invasive species. The most frequently found species at each type of site included at least one nonnative, invasive species, with the exception of near-shore reference sites, in which they were absent. Diversity indices indicate that diversity increases in warm conditions when species richness, number of invasive species, and percent invasive species were examined. The projected outcomes of the project are to: (1) provide data that will quantify climate change effects of temperature and pulsed water on invasive species in wetlands and provide information on community structure shifts, (2) explicitly link hydrographic variation and elevated temperature with ecological functions, (3) identify specific hydrologic and biogeochemical characteristics of floodplains that enhance or inhibit establishment of invasive species, (4) identify feedbacks between invasive species and ecosystems processes that alter the invasibility of floodplain ecosystems, (5) identify potential management strategies for controlling invasive species, and (6) validate a new quantitative modeling approach to evaluate shifts in linear or nonlinear thresholds of invasive species. The researchers learned that invasive species definitions vary greatly, threshold responses to disturbance may vary by season, and it is difficult to separate out pulsed water effects from temperature effects at the regional scale. Additionally, mesocosm scale studies will allow for more temperature and water control to help in effect studies but are difficult to set up and maintain; scaling is an issue. Separating out environmental disturbance from climate change effects is difficult and will require new approaches to threshold analysis to augment Bayesian threshold analysis. The researchers have interacted with a number of international institutions and federal agencies and have presented at several national scientific conferences.

Climate Change: Pathogens and Decline of Ectotherms
Jason Rohr, University of South Florida

Dr. Rohr explained amphibians are highly threatened, and there has been global enigmatic amphibian decline. The project focuses on amphibian diseases because many enigmatic extinctions are thought to be a result of infectious disease, often chytridiomycosis caused by the fungus *Batrachochytrium dendro-*

batidis (Bd). The fungus has been implicated in hundreds of amphibian extinctions during the last four decades and is thought to be the most deadly invasive species on the planet behind humans. There is some evidence that *Bd*-related declines are linked to climate change. Additionally, amphibian declines are parallel to reptilian declines.

The researchers have an interest in climate variations because it is hypothesized that the ectotherm immune system is temperature dependent. If immunity lags behind temperature change, then increased temperature variability associated with climate change could make ectotherms more susceptible to pathogens. This hypothesis was tested via a seasonal field survey of newt immune parameters, and results showed that seasons with dramatic temperature changes coincided with suboptimal immunity. The greatest level of suboptimal immunity was at the monthly time scale, which led to the question of whether variability in temperature at the monthly scale explains widespread amphibian extinctions putatively caused by disease and, if so, how this predictor compares with other hypothesized predictors. The goal of the project is to use a weight-of-evidence approach to evaluate the level of support for the hypothesis that temperature variability facilitates parasite invasions in ectothermic hosts and subsequent host declines. The project focused on the genus *Atelopus* because 71 of 113 *Atelopus* species are presumed extinct, theoretically as a result of chytridiomycosis; most of these extinctions have occurred since 1980. Spatiotemporal data on the extinctions are available for the last year species were observed and the year they were thought to decline. There are four contrasting hypotheses regarding enigmatic/*Bd*-related declines. A spatiotemporal hypothesis is that declines are caused by the introduction and spread of *Bd*, independent of climate. Three of the hypotheses are based on climate—the chytrid-thermal-optimum hypothesis, the mean-climate hypothesis, and the climate variability hypothesis.

The objective of the study is to evaluate the level of support for the spatiotemporal-spread and climate-based hypotheses using published *Atelopus* extinction (i.e., last year observed) data. The first question the researchers addressed was whether there is a spatial structure to the timing of the *Atelopus* extinctions. Mantel's Test and Bayesian model averaging were used to identify parsimonious locations of *Bd* introduction and subsequent spread. An evidentiary path spreading through the environment was found that supports the spatiotemporal theory, and the extinctions through time followed classic disease dynamics and were consistent with a spatially spread epidemic. The researchers then investigated the climate-based hypotheses, the ultimate hypothesis of which is that the El Niño-Southern Oscillation (El Niño) drives amphibian declines. The researchers asked whether it is necessary to control for the density-dependent spatiotemporal spread when testing climatic hypotheses and detemined that it is. The years of amphibian decline and last years observed match well with El Niño, suggesting a strong correlation. The researchers then investigated what features of El Niño years are associated with amphibian declines by examining regional predictors (e.g., cloud cover, temperature-dependent *Bd* growth, precipitation, temperature) with and without a 1-year lag. When the univariate predictors were examined, none were significant without a 1-year lag; with a 1-year lag, however, several univariate predictors became significant, including mean absolute value of monthly differences in temperature, Bd growth (negative predictor), frost frequency, precipitation, $temperature_{max}$, and wet day frequency. Results of best subset model selection indicate that mean absolute value of monthly differences in temperature and diurnal temperature range are significant and consistent with climate-based hypotheses.

The researchers investigated whether monthly temperature variability explained *Atelopus* extinctions by examining data through time and found that there was a significant correlation between monthly variations in temperature and extinction. Amphibian extinctions often have occurred in warmer years, at higher elevations, and during cooler seasons; therefore, the researchers asked whether monthly variability in temperature also is greater at these times and locations. Results confirmed that these times and locations have greater monthly variability in temperature. Because the belief is that El Niño increases temperature range and month-to-month variability, the researchers ran an experimental test with Cuban tree frogs and *Bd*. The researchers were curious about the finding of negative relationships between temperature-dependent *Bd* growth in culture and amphibian extinctions. Frogs die more frequently at cold temperatures, although *Bd* growth increases in culture at warm temperatures; therefore, it is necessary to examine the interaction between the host and pathogen to understand the extinctions. The researchers found that temperature variability increases *Bd* loads on frogs.

The temporal pattern of extinctions is consistent with a density-dependent spreading epidemic, and there is a strong El Niño signature after controlling for density-dependent spread. The pattern of extinctions appears more congruent with the climate-variability hypothesis than with the chytrid-thermal-optimum or mean-climate hypotheses; experiments support the climate-variability hypothesis. The researchers plan to quantify the impact of diurnal variability on *Bd* spread and virulence, test the climatic variability hypothesis on other ectothermic hosts and pathogens, and test whether temperature variability can explain global ectothermic declines.

Beach Grass Invasions and Coastal Flood Protection: Forecasting the Effects of Climate Change on Coastal Vulnerability
Eric Seabloom, Oregon State University

Dr. Eric Seabloom explained that dunes in the Pacific Northwest are unique, understudied systems, and the physical environment is strongly shaped and influenced by plants; therefore, dune grass is an important species. Prior to 1900, beaches and dunes were sparsely vegetated, with little grass and shifting sand; since then, there has been a history of dune grass invasions on the Pacific Coast. European beach grass was introduced in 1900 and dominated along the West Coast from Canada to Mexico by the 1950s; American beach grass was introduced from the East Coast in the 1930s. Dunes now have a gradient of landscapes: ocean, foredune, deflation plane, beach grass hummocks, and transverse ridges. The foredune, intentionally created to enhance protection, increases coastal protection from waves, wind, and possible tsunamis and increases land stabilization for development behind the foredune. Unintended consequences of foredunes include redistribution of sand, a decline in some species of native plants and animals, and increased invasion of other species. A balance between protecting the coast and decreasing extinctions is needed as climate change accelerates sea level rise and increases storm intensities.

Climate change affects sea level rise and wave environment, which in turn affect risk of flooding, sediment supply, dune morphology, and species invasion, the latter two of which are targets for conservation management. There is a complex set of interactions between biological conditions and mandated management. The objectives of the project are to determine the effects of: (1) climate change on beach grass invasion, (2) beach grass invasion on the ability of dunes to mediate risk of climate change, and (3) exotic grass management on the ability of dunes to mediate risk of climate change. Simulation models to estimate a range of likely sediment budgets under expected climate change regimes and field experiments to determine the outcome of invasions under predicted sediment budgets will be used to accomplish Objective 1. To accomplish Objective 2, field surveys and LIDAR will be used to determine the effects of species invasion on dune morphology, and simulations modeling will be used to determine the effects of dune morphology on risk under various climate change scenarios. To accomplish the last objective, field surveys and LIDAR will be used to determine the effects of conservation management on species invasion and dune morphology.

In examining how sand supply rate affects species interaction, the researchers found that sand deposition can alter competitive interaction among native and exotic dune grasses. This potential change in sand supply has the potential to change species populations and distribution, which has strong implications for dune size. Dunes dominated by the secondary invader (American beach grass) are 40 percent lower than those dominated by the current invader (European beach grass), which has obvious implications for coastal protection. During the previous 20 years, there has been a change in dominance; as American beach grass increases, European beach grass decreases. There has been no change in native beach grass. The American beach grass has moved from Washington State to Oregon in the past 20 years, and there is the potential for it to spread along the entire West Coast. Continued domination of American beach grass will result in a decrease in dune height along the coast.

A challenge of the project will be to determine the shoreline from LIDAR surveys and create a risk map for the entire Washington State/Oregon coastline. The researchers have interacted with local and state clients from Washington State and Oregon and will participate in a 2011 meeting with land managers and researchers. Thus far, the researchers have concluded that it is probably that changing sediment loads resulting from climate change will alter the composition of the dune grass community, and a rapidly spreading invasive dune grass likely is lowering dune heights and reducing their ability to protect coastal communities. Finally, exotic grass management will require careful balancing to preserve endangered species and a coastal protection function.

Ecological Impacts From the Interactions of Climate Change, Land Use Change, and Invasive Species
Robert Whitlatch, University of Connecticut

Dr. Whitlatch stated that the project's system focuses on shallow, subtidal, sessile invertebrate communities, which involve multiple taxa, diverse life histories, and economically important species. Following 20 years of study of these communities, researchers have determined that in New England there are four different community states that are dominated by different factors. There are a variety of forcing functions that occur on a variety of spatiotemporal scales that contribute to the movement of one community state to another. During the past 30 years, nonnative ascidians have become a dominant component of southern New England's fouling community, defined as a group of organisms that grow on hard substrata in marine environments. Nonnative marine species must be considered because of their detrimental effects on native species, biodiversity, habitats, and ecosystem services. They can impact commercially or economically important species and man-made structures. Marine biofouling results in world-wide damages of approximately $50 billion annually and regularly contributes a majority of the total production costs of marine aquaculture operations.

Long Island Sound temperatures during the past 20 years have shown an increasing trend of large interannual variation and increased temperature. Rising winter temperatures increase the recruitment abundance of recent invaders and decrease the recruitment abundance of resident species. When the timing of recruitment of nonnative and resident species in relation to interannual variations in seawater temperatures was examined in Long Island Sound, it was determined that invaders respond to increased water temperatures by recruiting earlier, but native species do not. In coastal Connecticut waters, however, there tends to be an inverse relationship between the occurrence of invasive species and resident species. Native biodiversity is important because habitats with higher diversity of resident species appear less vulnerable to invasion. Coastal Connecticut has varied land use, with different areas being primarily industrial, residential, or rural. Organisms respond to variations in land use; primarily industrial areas of the coastline have dominant numbers of invasive species, whereas rural areas have dominant numbers of native species.

The goals of the project are to: (1) work with environmental managers and other stakeholders on different management scenarios for land-use planning in the context of climate change and invasive species, (2) conduct mesocosm experiments examining the interactions of climate change and land use and the interactions between them in altering the ability of invasive species to influence native communities, (3) conduct field experiments to assess temporal and spatial scales of potential efforts needed to manage invasive species, (4) conduct field experiments to examine the survival of key predators on invasive species and how it varies with land use, and (5) develop predictive models to assess potential alternative management strategies to evaluate multiple stressors at different spatial and temporal scales in different types of coastal systems. Clients are embedded in the project goals.

To accomplish Goal 1, the researchers established a project management advisory board, conducted a workshop with various managers and stakeholders, met with local planning and conservation commissions, and conducted various types of outreach. To accomplish the second goal, a small-scale pilot study was conducted to establish experimental and monitoring protocols; the full experiments will be conducted during the next 2 years, as will Goal 3. Under Goal 4, the effects of macropredators feeding on juvenile and adult ascidian life stages were examined; nonnative species are not eaten by predators. Also under Goal 4, the role of macropredators was examined, and results indicated that snails influence the mortality of nonnative species and can be an effective measure for invasive species control. To accomplish Goal 5, a spatially explicit, individual-based model driven by a hydrodynamic model is being developed, but it is a complicated process. Another complication is dealing with a two-phase life history (larval and benthic). The researchers run a hydrodynamic model and examine larval distribution over time; how shoreline modifications affect larval distribution is examined. How invasive species might benefit from climate change also will be explored; it is important to observe the effects of distribution and climate change because they play a very important role in the success of invasive over native species.

The lessons learned have been that it is very important to include input by managers and stakeholders in the early stages of the project; managers often are dealing with the most current crisis and are in a rapid response mode. Additionally, long-term environmental databases and associated population and community data are critically important. New stressors (e.g., coastal acidification) and power infrastructure disturbances, and the manner by which they interact with climate change and land-use patterns, are challenges.

Tier III Discussion

Dr. Lorenzana, in response to concerns regarding how researchers might interact with decision-makers, stated that the primary function of EPA Regional Science Liaisons is to be a conduit between researchers (inside and outside of ORD) and decision-makers at the state and local levels. Ms. Nancy Cavallaro of USDA added that researchers also can interact with USDA extension agents who work with states.

Ms. Cavallaro commented to Dr. Seabloom that a stabilized shoreline destabilizes the coast farther down and asked how to prioritize which area of the coast is of greatest concern. Dr. Seabloom responded that any location on the coast that has sand is stabilized; destabilization and changes occur in areas that have jetties. In these areas, huge sections are accreting, and others are eroding. Part of the project modeling work examines erosional areas.

Ms. Cavallaro asked the three USDA grantholders about their client interactions. Dr. Sagers responded that stakeholders in her project are farmers, developers of transgenic organisms, and everyone who consumes any type of crop. Because many transgenic crops are herbicide resistant, herbicide development has decreased. As herbicide resistance increases, the food supply is decreased because relatively few herbicides are in development. North Dakota has been a receptive environment for her research. Her expected outcome is to provide recommendations to agencies and producers. Dr. Silander noted that there are a variety of stakeholders for his project because the data are valuable to make predictions. The hundreds of citizens, from high school through retirement age, who help collect the citizen data are stakeholders. The goal is to predict where to look in the landscape to best mitigate climate change effects. Other stakeholders include landscape managers in national and state parks and forests and local conservation organizations. Dr. Gao replied that policy-makers and farmers are the stakeholders for his project, which will provide predictions to its stakeholders. The researchers work closely with the major cotton farmers and provide them with results, with a focus on crop production.

Ms. Cavallaro noted that at the recent American Geophysical Union meeting that took place in Toronto there was a great deal of discussion about climate change and modeling. In the last decade, the eastern United States has cooled on average, whereas the western United States has warmed at an average higher than that of the global warming average. Because of the lag in how climate is changing, variability is important. Dr. Silander agreed and noted that the major challenge is dealing with the limitations of climate modeling. There is a range of 16 different deterministic GCMs available, and changes are modeled on a large, grid-cell basis. The thought is that temperature predictions are more reasonable on a means basis, and precipitation has even greater uncertainty. Stochastic models incorporate uncertainty, so the hope is to obtain regional climate models that are not merely scaled down. It would be beneficial for researchers to communicate and collaborate to achieve this. The National Center for Atmospheric Research is trying to develop stochastic versions of its models. Dr. Liang added that he had not presented information about how his project's regional model had been developed and noted that it improved hybridization and decreased uncertainty; the laboratory has published many papers regarding this, and he is willing to share the results. Dr. Purkey noted that the State of California is using six models and two emissions scenarios with 12 future climate projections for its Capital Improvement Plans involving hydrology. It is important to articulate that different types of analyses are needed to help decision-makers understand what the predictions mean and how to make a decision.

Dr. Wardrop noted that it is challenging to educate people regarding what changes are ecologically related; it is necessary for funding agencies to convey to climate scientists what they would like to know.

Dr. Poff commented that he is interested in the issue of regionally downscaling models because that is where the real uncertainty is; from a thermal perspective, this is not so difficult to accomplish, but from a precipitation standpoint it is very challenging. It is difficult for models to capture atmospheric processes at the regional scale that are important in driving regional precipitation. He asked Dr. Gao whether his laboratory's modeling approach produces ecologically relevant hydrographs that can be used. Dr. Gao agreed with Dr. Poff's assessment regarding temperature and precipitation. His publications generally show how model improvements were made. Because of the differences between regions, the data must be used together. Dr. Poff asked whether historical precipitation was captured. Dr. Liang responded that the hydrologic model did capture it very well.

Ms. Cavallaro noted that predicting competition of invasive species is complicated, especially as competition depends on the rate of climate change. Competition becomes very difficult to predict if the rate of climate change cannot be predicted.

Closing Remarks

Dr. Jones thanked the presenters, organizers, and USDA for their efforts. He noted that he has many suggestions and comments to share at EPA headquarters. He will contact the presenters regarding permission to publish the presentations on the workshop Web site; proceedings of the workshop will be available in the future. Dr. Lorenzana thanked the attendees for their participation and adjourned the meeting at 12:22 p.m.