EPA United States Environmental Protection Agency

Proceedings

Joint Progress Review for U.S. EPA STAR Grants: (1) Effects of Climate Change on Coral Reefs and Tidal Marshes and (2) Regional-Scale Stressor-Response Models for Aquatic Ecosystems

June 8-9, 2006
Washington, DC

Introduction

Annual Review of EPA STAR Research on:

(1) Effects of Climate Change on Ecosytem Services Provided by Coral Reefs and Tidal Marshes

(2) Regional-Scale Stressor-Response Models for Environmental Decision-Making

The mission of the U.S. Environmental Protection Agency (EPA) is to protect, sustain, and restore the health of ecosystems and communities. To support this mission, EPA's Office of Research and Development (ORD) implements a coordinated research strategy comprised of in-house research conducted at its own Laboratories and Centers and extramural research sponsored by EPA ORD's Science To Achieve Results (STAR) Program. STAR awards are made to the academic community and non-profit research organizations through a highly competitive program of independently peer-reviewed proposals solicited by the ORD's National Center for Environmental Research (NCER).

This document summarizes research sponsored by two STAR solicitations: (1) *Developing Regional-Scale Stressor-Response Models for Use in Environmental Decision-Making*, and (2) *Effects of Climate Change on Ecosytem Services Provided by Coral Reefs and Tidal Marshes.* This research was funded by the STAR Ecosystem Protection Research Program[1] and the STAR Global Change Research Program.[2] The content of this document reflects presentations made by Principal Investigators at the annual progress review meeting held in Washington, DC, June 8-9, 2006.

The 2002 solicitation for *Developing Regional-Scale Stressor-Response Models for Use in Environmental Decision-Making* sought proposals for the development of regional-scale models that could be used to investigate, simulate, and predict interactions of multiple stressors on the health of aquatic ecosystems. The research objective was to develop the scientific information needed to facilitate state and local implementation of integrated ecosystem management practices. This document summarizes a portfolio of 11 separate modeling studies sponsored under this solicitation. The stressors to ecosystems include non-point sources of nutrients and sediments, alterations in stream flow due to development or climate variability, invasive species, and habitat alteration. Modeling techniques include innovative Bayesian statistical models, new approaches to coupled physical models, and individual-based models. These multiple stressor-response models are being developed for selected river systems, coastal estuaries, and lakes, and they are being implemented at scales from site-level to entire watersheds. Although this research is still in progress, in many instances the investigators already have begun working with resource managers who may ultimately benefit from the creation of these new modeling tools.

The 2004 solicitation for *Effects of Climate Change on Ecosytem Services Provided by Coral Reefs and Tidal Marshes* sought proposals for the development of quantitative relationships among tidal marsh and coral reef processes and their associated ecosystem services. EPA is particularly interested in research to: (1) characterize the relationships between the ecosystem processes associated with coral reef or marsh systems and the resultant ecosystem services they provide; (2) characterize the effects of climate change stressors on these ecosystem processes; and (3) provide a spatially and temporally explicit framework for assessing how climate change stressors alter the ecosystem services provided by these reef and marsh systems. These frameworks include methods for dynamic modeling and multi-attribute comparisons of the effects of different stressor scenarios on ecosystem services. This research is in its first full year of funding.

For further background on these topics, go to the following Web sites to read the two Requests for Applications (RFAs) that resulted in the award of the grants described in this report:

http://es.epa.gov/ncer/rfa/archive/grants/02/02regstressor.html
http://es.epa.gov/ncer/rfa/archive/grants/01/global01.html

For more information about the STAR Global Change Program for ecosystems research or the Ecosystem Protection Research Program, contact Iris Goodman at 202-343-9854 (Goodman.Iris@epa.gov). Finally, for more information on all research areas in EPA's STAR Program, please go to http://www.epa.gov/ncer.

The research described in this report has not been subjected to the Agency's required peer review and policy review, and does not necessarily reflect the views of the Agency. Therefore, no official endorsement should be inferred. Any opinions, findings, conclusions, or recommendations expressed in this report are not necessarily those of EPA, but rather those of the investigators who presented their research and other workshop participants.

U.S. EPA STAR Global Aquatic Ecosystem Services and Multi-Stressor Progress Review Workshop

10 Thomas Circle, NW
Washington, DC 20005

June 8-006

Agenda

This is a Joint Workshop and Progress Review for U.S. EPA STAR Grants on:

Topic I: *Effects of Climate Change on Ecosystem Services of Coral Reefs and Tidal Marshes*
Topic II: *Regional-Scale Multi-Stressor Models for Aquatic Ecosystems*

Thursday, June 8, 2006

8:00 – 8:30 a.m. **Registration**

8:30 – 9:00 a.m. **Welcome and Introduction from EPA**
Becki Clark, Division Director (NCER)
Joel Scheraga, National Program Director (Global Change Research)
Rochelle Araujo, Associate Director for Ecology (NERL)
Iris Goodman, Eco Team Lead (NCER)

Topic I: **Effects of Climate Change on Tidal Marshes and Coral Reefs**

9:00 – 9:30 a.m. *Effects of Climate Change on Ecosystem Services Provided by Hawaiian Coral Reefs*
Robert Buddemeier, University of Kansas

9:35 – 10:05 a.m. *Connectivity in Marine Seascapes: Predicting Ecological and Socio-economic Costs of Climate Change on Coral Reef Ecosystems*
James Sanchirico, Resources for the Future

10:10 – 10:25 a.m. **Break**

10:25 – 10:55 a.m. *Linking Impacts of Climate Change to Carbon and Phosphorus Dynamics Along a Salinity Gradient in Tidal Marshes*
Melanie Vile, Academy of Natural Sciences

11:00 – 11:30 a.m. *Climate-Linked Alteration of Ecosystem Services in Tidal Salt Marshes of Georgia and Louisiana*
Mark Hester, University of New Orleans

11:35 – 12:05 p.m. *Effect of Sea Level Rise and Climate Variability on Ecosystem Services of Tidal Marshes, South Atlantic Coast*
Christopher Craft, Indiana University

12:10 – 1:10 p.m. **Lunch**

Topic I (continued): 1:10 – 2:30 p.m. **Aquatic Ecosystem Services: Outputs, Impacts and Communication to Decision Makers (Discussion: EPA Scientists and STAR Grantees)**

Susan Julius, Office of Research and Development
Jordon West, Office of Research and Development
Mary Reiley, Office of Water

Topic II: **Regional-Scale Physical Models for Environmental Decision-Making**

2:40 – 3:10 p.m. *Development of Coupled Physical and Ecological Models for Stress-Response Simulations of the Apalachicola Bay*
Wenrui Huang and Hongqing Wang, Florida A&M University

3:15 – 3:25 p.m. **Break**

3:30 – 4:00 p.m. *A Shallow-Water Coastal Habitat Model for Regional-Scale Evaluation of Management Decisions in the Virginia Province*
Charles Gallegos, Smithsonian Institute

4:05 – 4:35 p.m. *Development of a Regional-Scale Model for the Management of Multiple-Stressors in the Lake Erie Ecosystem*
Joseph Koonce, Case Western Reserve University

4:40 p.m. **Adjourn**

Friday, June 9, 2006

8:00 – 8:30 a.m. **Registration**

Topic II (continued): **Regional-Scale Population Models for Environmental Decision-Making**

8:30 – 9:00 a.m. *Effects of Multiple Stressors on Aquatic Communities in the Prairie Pothole Region*
Patrick Schoff, University of Minnesota–Duluth

9:05 – 9:35 a.m. *Application of Individual-Based Fish Models to Regional Decision-Making*
Steve Railsback, Humboldt State University

9:40 – 10:10 a.m. *Stressor-Response Modeling of the Interactive Effects of Climate Change and Land Use Patterns on the Alteration of Coastal Marine Systems by Invasive Species*
Robert Whitlatch, University of Connecticut

10:15 – 10:30 a.m. **Break**

Topic II (continued): Regional-Scale Statistical Models for Environmental Decision-Making

10:30 – 11:00 a.m. *Adaptive Implementation Modeling and Monitoring for TMDL Refinement*
Song Qian, Duke University

11:05 – 11:35 a.m. *Bayesian Methods for Regional-Scale Stressor Response Models*
Conrad Lamon, Duke University

11:40 – 12:40 p.m. **Lunch**

12:40 – 1:10 p.m. *Developing a Risk Propagation Model for Estimating Ecological Responses of Streams to Anthropogenic Watershed Stressors and Stream Modification*
Vladimir Novotny, Northeastern University

1:15 – 1:45 p.m. *Developing Relations Among Human Activities, Stressors, and Stream Ecosystem Responses and Linkage in Integrated Regional, Multi-Stressor Models*
Mike Wiley, University of Michigan

Topic II (continued): Integrated Modeling and Monitoring for Adaptive Environmental
1:50 – 3:25 p.m. Management (Discussion: EPA Scientists and STAR Grantees)

3:25 – 3:40 p.m. **Closing Remarks:** Iris Goodman, U.S. EPA

3:40 p.m. **Adjourn**

Topic I: Effects of Climate Change on Ecosystem Services Provided by Coral Reefs and Tidal Marshes

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

Paul L. Jokiel[1], Robert W. Buddemeier[2], Pieter van Beukering[3], and Daphne Fautin[4]
[1]Hawaii Institute of Marine Biology, University of Hawaii, Kaneohe, HI; [2]Kansas Geological Survey, University of Kansas, Lawrence, KS; [3]Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands; [4]Division of Biological Sciences, University of Kansas, Lawrence, KS

Abstract

The objectives of this research project are to: (1) 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; (2) carry out an economic valuation of possible/probable changes, broken down by service, environmental type, and socioeconomic sector; (3) advance and refine methods of valuing both “unused” resources (e.g., the Northwestern Hawaiian Islands) and the cultural and spiritual, as well as aesthetic, services provided by coral reefs; and (4) develop and disseminate a suite of new and broadly useful technical, methodological, and conceptual tools.

An extensive base of existing biological, environmental, and economic data and analyses has been combined with targeted surveys and experiments to characterize at least five diverse case-study sites. These sites will sample the region and permit generalization of the results using typologies. Existing biological response and socioeconomic valuation models are being adapted, extended, and linked. Climate change scenarios are being evaluated for their impacts on reef conditions, which in turn will be used by the ecosystem services valuation models. Spatial (GIS) analysis of the present economic value of coral reefs of Hawaii, and projected changes in their value, start with the Total Economic Value (TEV) of coral reefs. Major survey tools include Web-based diver/snorkeler surveys (use value), Web-based household surveys (non-use value), and face-to-face cultural surveys (“traditional” value). The project uses contingent choice surveys, now the preferred method for estimation of non-use values (e.g., existence value). GIS is used for visualization, analysis, integration, and communication of results.

A robust, modular model of coral growth/mortality and reef cover responses to both long-term mean and short-term extreme event components of climate change has been developed and is in external review. An initial set of mesocosm experiments is yielding data on reef community responses to carbonate saturation state. Both environmental and socioeconomic data have been assembled, and the survey tools are in final development. Value and threat maps compatible with the National Oceanic and Atmospheric Administration’s habitat maps and environmental data are being developed through interviews with local experts (researchers and managers). Adaptation of a biological/environmental Web site database for project use is in the process of being developed under the auspices of NBII (see http://geoportal.kgs.ku.edu/hexacoral/hawaii/biodata/ for the original version). In addition to the production of tools and datasets useful both within and outside of the project, significant findings to date include quantification of the high sensitivity of the frequency of reef bleaching mortality events to the underlying intra- and inter-annual variability of sea surface temperature. This is a relatively poorly predicted component of climate change, and forces heavier reliance on scenario-based analyses. Mesocosm experiments are showing high sensitivity of crustose coralline algae recruitment to saturation state; these are new findings about an important component of reef structures and communities, with implications for reef futures beyond the traditional focus on corals.

Preparations will be completed and the valuation surveys will be initiated, existing economic development projections will be incorporated, the environmental/climate change and economic evaluation of the sample sites will be systematically completed, and the variables and grid scales to be used for the upscaling (typologic generalization) process will be determined/tested. The dissemination process will be accelerated by establishing a project-specific Web site with both results and tools (e.g., online as well as downloadable tools and data).

Question-and-Answer Session With Dr. Robert Buddemeier

- One participant commented that, for many, the existence value of ecosystems is of greater magnitude than the use value, especially for remote ecosystems that people rarely visit. He asked whether the present study has any prior hypotheses about how the modeling will turn out, and if similar results will be found here. Dr. Buddemeier replied that his colleagues are addressing this issue and he does not have any information to share at this time.

- Another participant asked for clarification on how the models developed previously will be built upon. Dr. Buddemeier responded that model development has been a continuous process, with features being added continually. The basic model was developed through a contract with Stratus Consulting. By providing the users with a lookup table for carbon dioxide, from which they can enter values into the system, the model will create the saturation state values. The team currently is awaiting the results from an external peer review of the model, as well as results from beta testers. A continuing development of the models is expected in terms of usability and features.

- One participant asked whether a plan is in place to circulate the comments that emerge from the review process and to provide an update on the changes made to the model as a result of the comments. Dr. Buddemeier replied that he hopes to have the Web site up over the next few months and to have the model adapted for online use.

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

James N. Sanchirico[1], Kenneth Broad[2], Alan Hastings[3], Fiorenza Micheli[4], Peter J. Mumby[5], and Dan Brumbaugh[6]

[1]Resources for the Future, Washington, DC; [2]University of Miami, Coral Gables, FL; [3]University of California at Davis, Davis, CA; [4]Stanford University, Stanford, CA; [5]University of Exeter, Exeter, United Kingdom; [6]American Museum of Natural History, New York, NY

Abstract

This research project integrates theory and data from ecology, biology, and the social sciences to address major questions about the potential consequences of climate change (sea level rise, increases in sea level temperatures, and increased storm intensity) on coral reef-mangrove ecosystems. Using a structure that is representative of Caribbean ecosystems, several core questions are being explored systematically, 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 are being measured through the effects on fisheries, biodiversity, and social/cultural systems.

Addressing these questions requires building an integrated ecological-socioeconomic model. The following models are in development: (1) a simulation model of climate change and mangroves on the state of Caribbean coral reefs; (2) a trophic model of fish standing crop and production; and (3) a model to predict how fishing pressure, tourism development, and local economies will be affected by climate change stressors. Model development and parameterization are primarily based on the researchers' unique data set with meta-analysis and data mining of the literature employed when needed.

Initial progress in (1) is an extension to a model of coral-algal-grazer-disturbance interactions to investigate the potential consequences of climate change on different areas in the Caribbean. Projected temperatures and historical sea surface temperature (SST) climatologies are used to develop a time series of bleaching probabilities for each year from 2010 to 2100 under two emissions scenarios.* SSTs and bleaching probabilities vary with spatial location, as does predicted hurricane intensity. Preliminary findings demonstrate that while simulated bleaching events occur with high frequency over the 100-year period, coral recruitment and growth compensate for decreases in colony size due to changes in species composition. Key predictive factors are the abundances of urchins and parrotfish. Currently, reassessment of the parameters and data on whole-colony mortality from the coral bleaching literature are being undertaken.

Advances in (2) are in data analyses and developing models examining population and community dynamics of grazers (parrotfish) and predators (grouper and snapper). Initial data analysis suggests significant positive relationships between measures of fish community structure to ecological functions (e.g., grazing of macroalgae by herbivorous fishes, and secondary production) and fish diversity, both in terms of species and functional groups. Habitats supporting greater fish diversity also support greater grazing intensity and biomass of species targeted by local fisheries. The trophic model combines influences of incidental mortality

*Simon Donner (Princeton) provided projected SSTs obtained with the use of the Hadley Centre's HadCM3 coupled atmosphere-ocean general circulation model together with climate data from the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios.

(bycatch in fish traps) and predation by grouper on the demography and population dynamics of the stoplight parrotfish. How predator-prey interactions are affected by habitat configuration by including contributions of mangroves to predator populations also are being examined.

The socioeconomic team is analyzing fieldwork data and developing a bioeconomic model to couple with (1) and (2) that includes functional dependencies between mangrove and coral reef habitats. Model development is guided by the fieldwork that focuses on the interaction between local residents and their marine environment. To date, more than 200 interviews, 600 household surveys, extensive participant observations, and participatory mapping of resource use areas in six Bahamian settlements in Abaco, Bimini, Eleuthera, and San Salvador from 2001-2005 have been completed.

Preliminary findings reveal a number of relevant issues such as: (1) significant geographic and socioeconomic diversity exists implying that responses in one settlement may not correspond to those in other settlements. Understanding the underlying factors driving this diversity will enable the research team to predict likely responses to climate change; (2) local knowledge is important for adaptation to climate change stressors; (3) demographic trends are potentially exposing the settlements to greater risks from climate change, such as more individuals getting involved in tourism-related activities than fishing and an increasing number of women entering the wage-based economy; and (4) locals identified several land-based threats to coral reef-mangrove ecosystems, such as leaching from local dump sites and large tourist developments.

In addition, progress is being made in linking the subcomponents. For example, links between (2) and (3) include indirect effects through the impacts of fishing on grouper, a major predator of parrotfish, and effects of fishing/reserves on potential resilience of reefs through impacts on grazers.

Ongoing model development and data analysis of Caribbean coral reef ecosystems is developing a new understanding of changes in ecological services due to climate stressors, providing a framework for evaluating different management scenarios on ecosystem services, and highlighting mechanisms where climate stressors can cascade through the ecological and socioeconomic systems triggering responses that increase the vulnerability of the ecosystem.

Question-and-Answer Session With Dr. James Sanchirico

- Iris Goodman asked for clarification on whether the model is linking some of the trophic model interactions back to the reef resilience modeling so that the interrelationship is being captured. Dr. Sanchirico responded that the Stoplight parrotfish model will be coupled with the reef resilience model. The trophic model is going to affect the threshold. Coupling this trophic model with the socioeconomic model will determine where the threshold is and where the system goes.

- One participant asked Dr. Sanchirico to comment on how the study plans to link trophic model interactions to reef effects. Dr. Sanchirico replied that the model will be taken to completion with the reef resistance. He showed the slide titled "Model Schematic," commenting that the model will consider alternative stable states.

- A telephone participant asked whether coral bleaching changes already are being observed and whether there have been changes in fishing. Dr. Sanchirico replied that he does not have this information at this time.

- One participant asked how the process of linking all the variables was begun for the socioeconomic model. Did the team first map out where they wanted those linkages to be? Dr. Sanchirico responded that the process began at the habitat scale and proceeded with the idea to build a trophic model. He pointed out that it is important to build in how people will respond and how fishing pressure can vary across species and different habitats. The key is to understand how to couple all of those models. Dr. Sanchirico added that there is a very long tradition of ecologists and economists working together. This field is known as bioeconomics; it is natural for those in this field to think about where the points of intersection would be.

- A participant commented that from his experience on freshwater fish, the more you look at the literature of the temperature effects on fish, the less it seems that you know. For instance, when you look at the details of the studies, you realize there are various confounding factors (e.g., that temperature effects depend on the methods people use in the laboratories, the size of the fish, the conditions of the fish). Dr. Sanchirico agreed with this point. He added that a recent BBC report mentioned new results showing that corals might function well with increasing temperature because it will increase turf algae, which could possibly reduce some of the bleaching event. The study involved transplanting corals into warmer waters and they did fine. Thus, corals may not be affected as strongly as other species by climate change.

- One participant commented that researchers are trying to build simple models that are adaptable to change in current knowledge, with data selection done by the users. This is critical because there are large uncertainties and continuing developments in many fields.

The Effect of Climate-Change Induced Salinity Intrusion Into Freshwater Tidal Marshes

Melanie A. Vile[1], David J. Velinsky[1], Ashley Smyth[1], Nat B. Weston[1], and Scott Neubauer[2]
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Abstract

Tidal freshwater marshes (TFM) are often located in areas experiencing intense urbanization pressure, yet provide valuable services to coastal ecosystems. A climate change stressor that is unique to TFM is the intrusion of saltwater into previously freshwater zones. Marshes must accrete to keep pace with rising sea levels. In TFM, organic C accumulation is a major mechanism of marsh accretion, and understanding how changes in salinity will alter pathways of microbial metabolism of marsh C is critical. The overall objective of this research project is to understand how the biogeochemical cycling of C, S, N, and P affect the balance between C accretion rates and gaseous C losses from TFM.

A three-phase approach has been implemented to determine changes in TFM metabolism (e.g., CO_2 and CH_4 gas fluxes and SO_4^{2-} reduction); C, N, S, P sequestration; speciation; and porewater chemistry at sites along a low-salinity gradient in the Delaware estuary. Phase 1 involved finding field sites by making appropriate biological (vegetation) and chemical (e.g., salinity) determinations. Sites were obtained for all three phases of the project. Phase 1 also includes measurement of field-based fluxes along the salinity gradient (space-for-time substitute). For Phase 2, a long-term laboratory experiment was initiated using TFM cores exposed to manipulated tidal cycles and salinity (< 5 ppt) to study the long-term (months to years) impact of salinity on marsh metabolism. Phase 3 will involve large-scale field manipulations (reciprocal transplanting of cores) to examine longer term, ecosystem-level responses of marshes to elevated salinity.

In the summer of 2005, Ashley Smyth, a Research Experiences for Undergraduates (REU) student from the University of North Carolina at Chapel Hill, collected cores from two TFMs, and manipulated salinity levels for 2 weeks. CO_2 fluxes did not differ significantly under light (117 ± 9.7 mmol m^{-2} da^{-1}) versus dark conditions (112 ± 9.8 mmol m^{-2} da^{-1}), nor did CO_2 differ in control (126 ± 10 mmol m^{-2} da^{-1}) and salinity-amended (125 ± 12 mmol m^{-2} da^{-1}) cores, suggesting that a longer timeframe is needed to resolve the importance of photosynthetic algae/plants and the rate of sulfate diffusion into the sediment column in regulating C fluxes. In July and September 2005, a research scientist (Chris McLaughlin), and Postdoctoral Fellow, Dr. Nat Weston (Ph.D., University of Georgia) were hired to work full-time on this project. A large portion of this project has been spent on experimental design and method development. Dr. Weston has made considerable progress in initiating the long-term, salinity-manipulation laboratory experiment (Phase 2). Additionally, Dr. Weston has incorporated a new component of the project (not initially proposed) that links process-based biogeochemical rates with quantitative determinations of key functional genes for sulfate reducers and methanogens.

Currently, the laboratory experiment involves cores incubated without plants and in the dark under controlled temperatures. Plants and/or diatoms will be incorporated with a light regime. The field-based flux measurements using plexiglass chambers coupled to an IRGA for C fluxes are being implemented. This project is still in the planning stages for Phase 3.

Question-and-Answer Session With Dr. Melanie Vile

- One participant asked whether the studies assessed differences in carbon quality between the two sites because pronounced differences were not seen when sulfate was added. Dr. Vile responded that this is not being assessed thus far, but her team plans to do so. She commented that carbon is the main driver for why the observed patterns are being seen.

- Another participant asked whether an attempt was made to draw the saltwater through the cores, as would happen with a flowing tide, by putting the saltwater on top of the cores to let it drain through. Dr. Vile replied that the cores have a hole above the sediment to permit simulation of the tide coming in, across and then down. In the pilot study last summer, the saltwater was simply added to the top of the cores.

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

Mark W. Hester[1], Irving A. Mendelssohn[2], Samantha B. Joye[3], and Merryl Alber[3]
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Abstract

The objective of this research project is to elucidate the effects of climate change on tidal salt marsh ecosystem services in Georgia and Louisiana. The goal is to better understand how the ecosystem services of eutrophication control, carbon sequestration, sustainable habitat, and faunal support are influenced by climate change. Specifically, the goal is to determine how increased drought severity and associated changes in plant density alter these ecosystem services in salt marshes with tidal amplitudes ranging from microtidal (Louisiana) to meso/macrotidal (Georgia).

The approach is to take advantage of a unique and timely research opportunity afforded by recent, multiyear, 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 salt marsh areas (blocks) were identified in which permanent plots (7.5 m x 8.0 m) were established in both severely impacted dieback areas (complete dieback and loss of vegetation cover) and adjacent, relatively unimpacted reference marsh areas (high vegetation cover). Within the severely impacted dieback areas, *Spartina alterniflora*, the dominant salt marsh grass, was artificially established (transplanted) as a mechanism of controlling plant density independently from the drought-induced dieback. *S. alterniflora* stem densities were manipulated in the dieback areas as three treatments: high plant density (30 cm plant spacings), low plant density (90 cm plant spacings), and bare (no transplants). In each of the six blocks, in each of the two states, therefore, four experimental treatments were established (reference, bare, low plant density, and high plant density), yielding a total of 48 permanent plots in which alteration of ecosystem services (as described above) is being evaluated at several scales over two growing seasons.

Due to the displacement of University of New Orleans personnel from the impact of Hurricane Katrina, finalization of subcontracts with the University of Georgia were delayed until fall 2005. Landowner permission for plot establishment in Louisiana was granted in summer 2005, and access and research boardwalks were constructed by fall 2005. Plant density treatments were implemented in spring 2006. Georgia plot selection, treatment boardwalk construction, and plant density treatments were all completed in spring 2006.

Final plot establishment and treatment implementation has just been completed this spring with sampling scheduled to begin this summer. This research will greatly increase scientific 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, the data generated will have widespread applicability and value to coastal managers.

The first large-scale sampling is scheduled for summer 2006 with a second seasonal sampling scheduled for fall 2006. Within each plot, a suite of abiotic and biotic response variables will be measured, including biogeochemical variables (soil physical properties, porewater and solid-phase inventories, sediment metabolism and denitrification, and benthic microalgal production); belowground processes (belowground production, organic matter decomposition); aboveground processes (aboveground cover and productivity, instantaneous net CO_2 assimilation, photosynthetic nutrient-use efficiency); sediment elevation and accretion; and invertebrate responses (infauna and epifauna inventories, predation rates, and food-web analyses).

Question-and-Answer Session With Dr. Mark Hester

- Iris Goodman commented that she appreciates hearing about processes being related to functions and linked, ultimately, to ecosystem services, and that she is hopeful that the study can expand on this and demonstrate linkages as the research progresses. Because it is very difficult to quantify and understand the biogeochemistry and complexity of the soil environment, she asked: What are the possibilities or limitations in the results given to be able to scale the numbers up and extrapolate them to different areas? Dr. Hester responded that his group is hopeful of being able to do a fairly good job of scaling up. They are conducting treatments that are manipulating density. Further, the team has the reference marsh, which is not being impacted by any treatment, in addition to the availability of monitoring and comparing to bare soil. Dr. Hester added that he is part of a causation team that is looking at brown marsh dieback. The current study will provide a very good method of examining how climate change can cause stress and dieback of marsh macrophytes. The study will emphasize the importance of several traits of plants that make them integral to their environment, including carbon sequestration, maintaining habitat, helping to regulate nutrient transportation, and providing refugia.

- Iris Goodman reiterated that she was thinking mainly in terms of spatial scaling, whether there are possibilities to scale up the modeling or extrapolate it to similar areas. Dr. Hester responded that this is possible, and it is why his team has decided to pursue structural equation modeling to elucidate the linkages between the variables. By doing so, it is possible to determine what is controlling a particular variable response such as dentrification.

- One participant asked what the difference was between the two sites in Louisiana and Georgia—one was mentioned to be macrotidal and the other microtidal. He also asked how long the project will run. Dr. Hester responded that there are two main differences between the sites. One difference is the tidal range. When there is drought, there are higher tide ranges and these systems receive tidal flushing more regularly than what would occur in a microtidal environment. When the tide is lower and less frequent, surfaces are likely exposed for longer periods of time. The two sites also differ with respect to natural geologic setting. Louisiana is built on a deltaic plain, whereas Georgia is a coastal plain. Consequently, their sediment types and relative abundances would differ. Dr. Hester added that the timeframe of the project is limited to 3 years from start to report, and that his group will need to obtain a 1-year extension. Once the study is completed, however, it is hoped that the research can continue. The study infrastructure will have already been established and, provided the team could leverage more funds, EPA or some other agency could take on the sites and conduct longer term monitoring. Dr. Hester stated that another interest of his group is to develop some microbial ecology collaborations.

- One participant asked what the basis was for selecting the particular ecosystem services that were the focused endpoints. Dr. Hester responded that his team believed those to be important ecosystem services and that there was sufficient expertise within the group to measure outcomes in relation to those services.

Effect of Sea Level Rise and Climate Variability on Ecosystem Services of Tidal Marshes

Christopher Craft[1], Mandy Joye[2], Steven Pennings[3], D. Park[4], and J. Ehman[5]
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[5]Image Matters, Bloomington, IN

Abstract

A conceptual model will be developed that describes how ecosystem services of tidal marshes vary along the salinity gradient and how sea level rise and climate variability will affect their delivery of ecosystem services. Ecosystem services related to disturbance, gas regulation, soil formation, nutrient regulation, waste treatment, refugium, and food will be measured in replicate salt, brackish, and tidal freshwater marshes of the Altamaha, Satilla, and Ogeechee River estuaries in Georgia. Field data, GIS, and the Sea Level Affects Marshes Model (SLAMM) will be used to predict changes in marsh area and cumulative delivery of ecosystem services in response to simulated increases in sea level along the South Atlantic Coast (Georgia, South Carolina). The effects of climate variability will be evaluated by analysis of climate (rainfall, temperature, salinity, freshwater discharge, average tide level) and ecosystem services data collected annually since 2000 from permanent plots of 10 marshes of the Georgia Coastal Ecosystems Long-Term Ecological Research (GCE LTER) study domain.

In July 2005, six tidal marshes (two tidal fresh-, two brackish-, and two salt-water marshes) were selected for sampling on each estuary. Two soil cores, 0-60 cm in depth, were collected at each site for a total of 36 cores. Cores were processed and are being analyzed for bulk density, ^{137}Cs, ^{210}Pb, organic carbon (C), nitrogen (N), and phosphorus to determine rates of C sequestration, N and P retention, and sediment accumulation. Results from the Altamaha River estuary indicate that tidal fresh- and brackish-water marshes sequester C and retain N at rates that are three to five times greater than salt marshes. Using the Altamaha River estuary as a test case, SLAMM was used to simulate changes in wetland area and cover type in response to sea level rise under the A1B SRES (mean) climate scenario. The model predicts that 75 percent of tidal freshwater marsh and 38 percent of salt marsh will be converted by 2100, mostly through a corresponding increase in tidal flat and inland open water. Based on the above soils analysis, it is estimated that in the Altamaha River estuary, C sequestration will be reduced by more than 3,400 MT annually, and N retention in the estuary will be reduced by approximately 225 MT each year. The results suggest that tidal freshwater marshes, which are underrepresented on the landscape, provide a disproportionately high level of ecosystem services relative to their area and are most vulnerable to accelerated sea level rise.

In May and August 2006, samples will be collected from diked and undiked marshes to assess gas regulation (CO_2, CH_4, denitrification) functions. Soil cores also will be collected from diked marshes to quantify C sequestration, N and P retention, and sediment accumulation. In October, vegetation in diked and undiked marshes will be sampled to determine macrophyte productivity and biodiversity. SLAMM will be modified by acquiring LIDAR data, where present, to improve the elevation data and a salinity sub-routine to better model marsh migration up the freshwater-dominated estuaries will be developed.

Question-and-Answer Session With Dr. Christopher Craft

- One participant commented in relation to his work in New England, where marshes are accreting 1 to 2 mm per year. The conventional hypothesis is that the marshes in those areas are starved because of all the habitat changes that have occurred, including damming. In light of this, the systems described in the current research appear to be relatively open compared to the ones in New England. Based on this, why are those large changes predicted? The participant added that he likes the idea of adding freshwater inputs. In New England, the hypothesis is that because the wetlands have been altered so extensively, they are not providing any kind of buffer capacity to freshwater influx. In this regard, how should variations in freshwater inputs get factored into the model? Dr. Craft responded that he agreed that a system with a sea level rise of 1 to 2 mm per year is definitely in a vulnerable state. He referred to a paper by Dr. James Morris (Morris JT, Sundareshwar PV, Nietch CT, Kjerfve B, Cahoon DR. 2002. Responses of coastal wetlands to rising sea level. *Ecology*) in which he modeled accretion and rising sea levels. Dr. Morris concluded that sea level rise could increase to 1.2 cm per year in these systems before there would be a problem. Dr. Craft stated that he does not agree with that conclusion, which would amount to 4 inches in 10 years, a volume of sediment that is not coming in. He added that in his own research, the numbers are overstating how much of the wetlands will be lost because the model needs to factor in that the marshes will accrete faster as sea level rise accelerates. Another detail that must be considered, if not possible to be factored in, is land-use alteration in the watershed upstream. Atlanta is the headwaters of the Altamaha River, and as more land is cleared, these marshes will have much higher accretion rates now than they did 150 years ago. Regarding the second question, Dr. Craft mentioned that his colleague, Dr. Dick Park, is calculating the average discharge from the Altamaha River on a yearly basis, involving a calculation of the area and depth of the river. Defining the boundaries of the estuary is somewhat arbitrary, but given the calculated space, it is a much better way to describe how sea level rise could affect these big rivers, like the Hudson and Potomac Rivers.

- One participant commented that in the presentation it was mentioned that there are 200 metric tons of nitrogen lost to sequestration. He asked how the loss compares to the river intake of nitrogen. Dr. Craft replied that when figures are scaled up to bigger regions, the numbers become quite large and may not be as representative. When something is done too many times, such as cutting habitat space over and over, at some point the system will fall apart.

- Iris Goodman commented that she liked how this research proposes to combine the spatial analysis and changes in the ecosystem services. She suggested that it might be useful to have discussions about how the research grants can bolster this type of analysis. Dr. Craft commented that there are three possible scales at which to work: the micro, the plant ecosystem/plot scale, and the soil landscape scale. It was difficult to try to link all three scales in the research. He stated that people do a good job of linking two of the three scales.

- Another participant commented that LIDAR data would permit this type of analysis of the scales of magnitude. Dr. Craft agreed, stating that this type of data would make the model run better; whereas, the NED data that his team has used does not distinguish elevation between the three types of scales. The little LIDAR data they have used, however, has been helpful in differentiating those marsh sites. He added that the salinity algorithm also will be helpful to drive that salt wedge upstream. The participant mentioned that the amount of sulfate that would be needed to start changing these processes would be quite small—half a part per thousand.

Topic 2: Regional-Scale Stressor-Response Models for Environmental Decision-Making

Development of Coupled Physical and Ecological Models for Stressor-Response Simulations of Apalachicola Bay Regional Ecosystem

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Abstract

Research progress has been made during the past 2 years in the development of coupled physical and ecological models for the assessment of the effects of stressors on the Apalachicola Bay regional ecosystem. The 3-D hydrodynamic model has been improved to provide more accurate predictions of salinity variations in the Bay in response to various freshwater input scenarios. A sediment transport model has been coupled with the hydrodynamic model to simulate the sediment concentration and transport in the Bay, which can be used to support estuarine biological analysis and oyster dynamic modeling. A salt marsh soil salinity model has been developed to examine impacts of climate, tidal forcing, soil, vegetation, and topography on soil salinity distribution along different elevations in the Atlantic and Gulf of Mexico coastal region. Currently, the model is being applied to simulate the spatial distribution of pore water salinity and link the pore water salinity distribution to plant zonation in marsh areas of Apalachicola Bay. Meanwhile, simulations are being conducted on the effects of freshwater inflow on the variability of soil salinity distribution in the Bay through the linkage between freshwater flow and tidal salinity predicted by the 3-D hydrodynamic model of the Bay. This allows us to evaluate the linkage between soil salinity and tidal salinity in the salt marsh salinity model. The necessary data have been collected, and will continue to be collected, on climate, river flow, soil, tide, and vegetation to be used in modeling the soil salinity in salt marshes of the Apalachicola estuary. These field data will be used to calibrate and validate the modeling in the Apalachicola estuary. Meanwhile, an oyster population dynamic model has been developed to examine the effects of environmental changes, including freshwater input, estuarine salinity, nutrient concentration, predators, temperature, turbidity, and other water quality and sedimentation parameters, on the spatial and temporal patterns of mortality and growth of the Eastern oyster (*Crassostrea virginica*) in the Apalachicola Bay. This oyster model is being linked with the hydrodynamic model. Extensive existing databases have been acquired for oysters in the Bay for calibrating and validating the model. Sensitivity studies are being conducted on the effects of important coefficients such as assimilation efficiency, respiration coefficient, reproduction efficiency, and reproduction biomass threshold (factors that are related with oyster intrinsic characteristics) on oyster growth and biomass. Scenario analysis also will be designed and conducted to simulate the effects of long-term changes in the identified influencing factors on Apalachicola Bay oyster population dynamics, including: (1) freshwater flow (through salinity variation); (2) turbidity; (3) water temperature; (4) current velocity; (5) timing and rates of harvesting; and (6) seasonal mortality caused by predation and diseases.

Question-and-Answer Session With Dr. Hongqing Wang

- Iris Goodman asked whether there is any sense of the magnitude of importance of climate variables versus water management scenarios in terms of the relative effect downstream. Dr. Wang replied that, at this time, the water management scenarios are very important to affecting the bay ecosystem components.

A Shallow-Water Coastal Habitat Model for Regional Scale Evaluation of Management Decisions in the Chesapeake Region

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Management decisions to protect estuaries are being made in the context of unprecedented environmental changes, including rising concentration of atmospheric CO_2, increased ultraviolet (UV) radiation, especially the damaging UV-B, and changes in land use patterns. Interactions between altered rainfall regimes and changes in land use patterns will have consequences for the delivery of sediments and nutrients to estuaries. Projecting the effectiveness of management actions must proceed on the basis of predictions from mathematical models, because experimental manipulations cannot be made on the relevant scales.

The modeling efforts of this research project focus on shallow tributary embayments and small tidal creeks of Chesapeake Bay, because the ecological importance of shallow systems far exceeds their volumetric contribution to the bay. The end points for the model will be those indicators being used as de-listing criteria for Chesapeake Bay, namely chlorophyll, water clarity (diffuse attenuation coefficient), and dissolved oxygen.

Progress has been made on the development of a three-compartment subestuary model. The model domain segments with different volumetric dimension are lying in between boundaries at the mouth and at the head of the subestuary. The watershed is considered to be an upstream boundary where multiple stressors, such as inorganic nutrients, sediments, and dissolved organic matter, are discharged. The downstream boundary is considered to be the Chesapeake Bay, or a major tributary, such as the Potomac or James River. Each subestuary segment has multiple ecological components (26 state variables), including nutrients, size-fractionated phytoplankton (three size classes) and zooplankton (three size classes), and detritus. Nitrogen and phosphorus are tracked separately to allow for spatial or temporal changes in the limiting nutrient (double-currency system). Light propagation through the water column is computed based on empirical bio-optical algorithms. For the estimates of dissolved oxygen, an empirically parameterized primary productivity algorithm has been incorporated. The primary productivity algorithm also incorporates the harmful effects of ultraviolet radiation as a function of biological weighting function. A pilot Monte Carlo simulation was performed, by randomly changing the exchange coefficient at the downstream boundary and N loading from the local watershed, to simulate variability in watershed size and mouth geometry.

One project objective is to analyze how the geographic variability in physical structure and human use among the linked watershed-subestuary systems of Chesapeake Bay affect estuarine responses to multiple stressors. The effects of watershed use and subestuary characteristics on submerged aquatic vegetation (SAV) abundance were analyzed for 101 shallow subestuaries of Chesapeake Bay and their local watersheds. Subestuary areas range from 0.1-101 km^2, and their associated local watershed areas range from 6-1664 km^2. Watershed land cover percentages range from 6 to 81 percent forest, 1 to 64 percent cropland, 2 to 38 percent grassland, and 0.3 to 89 percent developed land. The landscape analyses were applied to develop a number of subestuary metrics (such as subestuary area, mouth width, elongation ratio, fractal dimension, etc.) and watershed metrics (such as watershed area, ratio of local watershed area to subestuary volume, etc.). The SAV coverage was calculated for each subestuary in each year during 1984-2003 as a proportion of potential SAV habitat (area < 2 meter depth). In addition, the SAV abundance was found to be strongly linked with subestuary and watershed characteristics. A regression tree model indicated that 60 percent of the variance in SAV abundance was explained by subestuary fractal dimension, mean tidal range, local watershed land use, watershed to subestuary area ratio, and mean wave height. Similar explanatory power was found in wet and dry years, but different independent variables differed. Repeated-measures ANOVA showed that SAV abundance declined with the dominant watershed land use in the following order: forested, mixed-undisturbed, mixed-developed > mixed-agricultural > agricultural > developed. Change point analyses indicated strong threshold responses of SAV abundance to the proportion of developed land, point source nutrient inputs, and the density of septic systems in the watershed.

Question-and-Answer Session With Dr. Charles Gallegos

- One participant asked why the Monte Carlo simulation was chosen among the options available. Dr. Gallegos explained that the ultimate goal is to choose the distribution that is expected to be found. The purpose is to get their feet wet and see if the model is going to be stable. The team expects to simulate results according to a distribution of how they think those areas are distributed. There are broad, rounded embayments in Chesapeake Bay in which the exchange can be very high. There also are some fairly constricted mouths where low exchange values are expected. The team is hoping to obtain that information from the distribution of the physical metrics that they have put together from the spatial analysis.

- One participant commented about the dendrogram of relative importance of the various factors—the classification analysis—that waveheight came out to be important, and asked if that was the result of the exposure of these sites. Dr. Gallegos responded that likely the result is partly the result of exposure, but added that it might have been there in a counterintuitive way, with more at the higher end. He stated that he would ask Yong Li if that, in fact, is the case. The waveheight was derived from a NOAA product, so the team needs to reexamine it to ensure that it applies on this scale. The participant stated that most of the sites appear to be rather protected. Dr. Gallegos agreed with this statement, adding that at the higher side of the fractal dimension separator, which is an indicator of complex shoreline cove and pocket characteristics, waveheight with that qualifier may actually be some kind of flushing in type of indicator.

Development of a Regional-Scale Model for the Management of Multiple-Stressors in the Lake Erie Ecosystem

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Abstract

The objective of this research is to develop a regional-scale, stressor-response model for the management of the Lake Erie ecosystem. Stressors addressed include effects of land use changes and Total Maximum Daily Load (TMDL) targets for nutrients, habitat alteration, and natural flow regime modification at the scale of individual watersheds, coupled with whole lake ecosystem effects of invasion of exotic species and fisheries exploitation. Model predictions focus on effects of stressors on production and abundance of Lake Erie fish populations as indicators of the health of the Lake Erie ecosystem and will be incorporated into a multi-objective decision making tool for use by Lake Erie water quality and fisheries managers along with other resource planners. The research approach involves joining multi-level modeling with multi-objective risk decision tools. The research plan focuses on: (1) linking changes in watershed habitat and nutrient loading regimes proposed for the TMDL process to Lake Erie ecosystem health; (2) quantifying uncertainties in model predictions and determining the effects of uncertainties on management decisions; (3) evaluating interaction of stressors, particularly focusing on cross-scale additivity of stressors; (4) developing tools to evaluate ecological risk of land-use changes in watersheds of the Lake Erie ecosystem; and (5) identifying and evaluating critical break-points in ecosystem integrity of the Lake Erie ecosystem and of its integrated management. Highlights of research of the second year of the project (June 1, 2004 to May 31, 2005) included:

- Completion of field work and testing of models for establishing a habitat supply inventory for the entire Lake Erie watershed. Products include one MS Thesis, two manuscripts submitted for publication, and one manuscript in preparation. Work also has involved developing both ESRI and open source implementations of Geographic Information System (GIS) data analysis layers for use with public groups and managers.

- Using models (IHACRES and SWAT) parameterized in task 1.2, work has continued to use models to develop a functional (hydraulic transport) representation of land cover effects on flow and nutrient loading. The product of this work is currently an M.S. Thesis, which is nearing completion.

- Assembly of a component-based DEVS modeling and simulation framework to perform cross-scale analysis of the interaction of stressors. The products are a new software package and a number of presentations. Work is coordinated with the Everglades ATLAS model. Products include a software library, a modeling framework that incorporates a DEVS modeling and simulation platform, and model repository for assembly and execution of hierarchical models.

- Development and testing of a decision analysis framework to explore the tradeoffs associated with dam removal from selected tributaries in the Lake Erie ecosystem.

Question-and-Answer Session With Drs. Joseph Koonce and Ben Hobbs

- There were no questions.

Effects of Multiple Stressors on Aquatic Communities in the Prairie Pothole Region

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Abstract

The Prairie Pothole Region (PPR), forming the northeastern edge of the Great Plains, encompasses a large area of diverse wetlands that represent crucial aquatic resources for flood control and aquatic and terrestrial production. Because most of the PPR is subject to mixed use agriculture and open grazing, the wetlands are routinely exposed to a variety of anthropogenic stressors, such as pesticides, nutrients, and domestic animal pathogens. In addition, higher latitudes are exposed to increased ultraviolet B radiation (UV-B). Climate models indicate that the PPR is likely to be severely impacted by climate change through increasing temperature and reduced precipitation.

The overall goals of the project are to: (1) quantify the relationships among factors directly affected by climate change (e.g., hydroperiod), differing land use, and amphibian community structure and composition in the prairie pothole region; (2) quantify the relationships among physical and chemical wetland attributes (e.g., hydroperiod, thermal regime, pH, and DOC), UV-B radiation, and land use (including associated pesticide use) on amphibian organismal and community responses; (3) quantify the effects of multiple stressors (shortened hydroperiod, increased UV-B radiation, and atrazine exposure) on the health and organismal responses of *R. pipiens*; and (4) Use regional climate scenarios and hydrologic models in conjunction with empirical data gathered through field and mesocosm studies to predict potential effects of multiple stressors on prairie pothole wetlands and their associated amphibian communities.

Data on stressor impacts were analyzed at three spatial scales: landscape (67 sites), wetland (35 sites), and mesocosm. Sites within the landscape and wetland scale studies were designated as seasonal (SS) or semi-permanent (SP) and were further classified as crop or grassland land use. Landscape-scale (level I) study sites are distributed across the U.S. portion of the PPR; wetland-scale (level II) study sites are concentrated in east-central South Dakota. Mesocosm studies (level III) were conducted at the Oak Lake Field Station of South Dakota State University.

Eleven amphibian species were observed in total, and species richness per wetland ranged from zero to five. No species richness differences were observed between row crop and grassland wetlands, however, more species were observed in Central Tall and Northern Tall Grassland Ecoregion wetlands than in Prairie Coteau, Northern Short and Northern Mixed Grassland Ecoregion wetlands. Northern Leopard Frog (*Rana pipiens*) was represented across the entire PPR, with adults in 44 sites breeding evidence in 29 sites. Logistic regression indicated probability of *R. pipiens* presence was significantly influenced by the interaction of hydrology and land cover ($p = 0.02$), while *R. pipiens* breeding in a wetland was significantly influenced by hydrology, but not by landcover or an interaction of the two treatments ($p = 0.08$).

Fewer of the wetland scale sites produced numbers of metamorphic *R. pipiens* necessary for malformation surveys in 2004 than in 2003. Seven of 13 sites (54%) surveyed produced malformed frogs. In these sites, a total of 3.5% (26/748) displayed at least one identifiable malformation. As in 2003, hindlimb malformations constituted a majority (71.4%) of the total. Malformation prevalence was not significantly correlated with surrounding land use or atrazine concentration. Metamorphic frogs were collected from wetlands representing a range of land-use types for analysis of gonadal dysmorphogenesis.

Based on a repeated measures ANOVA including both intensive and extensive sites, hydrology and land cover were significant predictors of several water quality parameters. Seasonal wetlands were significantly

more alkaline than semi-permanent wetlands, with seasonal crop wetlands significantly more alkaline than all other treatments ($p < 0.001$). Land cover also influenced specific conductivity (µS) and DOC (ppm), both of which were significantly higher in wetlands surrounded by grassland than row crop (specific conductivity, $p = 0.056$ and DOC, $p < 0.0001$; intensive sites only). As expected, hydrologic regime influenced maximum depth and water temperature (both day and nighttime); semi-permanent wetlands were deeper and colder than seasonal wetlands.

Ultraviolet-B radiation surface levels and attenuation rates (through the water column) were measured in 20 sites in 2003 and in 34 sites in 2004. UV-B was rapidly attenuated through the water column [K_d (attenuation rate) = 6.24 - 58.93 m^{-1}]. Preliminary analysis indicates that DOC and color, which are the dominant factors in UV-B attenuation in lakes, may not be the primary influences on UV-B attenuation in PPR wetlands.

Triazine (atrazine and simizine) concentrations assessed in water collected in mid-April, mid-May, and late June 2004, ranged from non-detectable (< 0.01 ppb) to 7.124 ppb, with concentrations 0.01 ppb present in 71% of wetlands sampled in Survey 1, and in 100% of wetlands in Surveys 2 and 3. Triazine concentrations were higher in wetlands where land use within a 90 m buffer was classified as > 70 % crop than in those where grassland comprised the greatest proportion of the buffer (7.124 ppb v. 0.657 ppb, respectively). Semi-permanent wetlands with corn in the 90 m buffer had higher mean atrazine concentrations, and corn presence was the best overall predictor of wetland atrazine concentration for Surveys 2 and 3 (ANOVA, p = < 0.001-0.025). However, neither land use (crop v. grassland; ANOVA, $p = 0.662$) nor hydrologic regime (ANOVA, $p = 0.878$) were significant predictors of maximum atrazine concentration in April-July 2004.

Question-and-Answer Session With Dr. Patrick Schoff

- There were no questions.

Application of Individual-Based Fish Models to Regional Decision-Making

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Abstract

This project's goal is to develop and demonstrate the usefulness of individual-based models (IBMs) of stream salmonids as a tool for regional decision-making. The specific objectives are to: (1) adapt their IBM that simulates stream reaches to watershed-level assessment, (2) conduct a demonstration assessment, and (3) examine uncertainties and sensitivities in the regional assessment.

The Individual-based Stream Trout Research and Assessment Model (*inSTREAM*), which simulates how habitat variables such as flow, temperature, and turbidity affect the growth, survival, and reproduction of individual trout and, consequently, trout population dynamics was revised and updated. After extensive review of new literature, peer review, and testing, a final public release of *inSTREAM* software, example input files, and complete documentation are being produced. To make the model more useful at regional scales, an approach was developed for synthesizing input to *inSTREAM* for sites throughout a watershed from habitat surveys and other data that are available widely. This approach was used to create input for 99 sites throughout our study watershed, on second- to fourth-order streams. Uncertainties and sensitivities have been investigated in two ways. First, parameter uncertainty effects were analyzed with a three-phase approach that looks at individual-parameter sensitivity, interactions among particularly important parameters, and sensitivity of management decisions to uncertainty in key parameters. Second, sensitivity of *inSTREAM* to input data was examined using the synthesized input, examining how predicted trout populations respond to inputs such as the availability of cover and spawning gravel and study site length.

Data collected in stream habitat surveys can be combined with other available information to synthesize input to *inSTREAM* that captures how characteristics such as the frequency and size of habitat unit types (pools, riffles, and runs) vary with elevation through a watershed. The model's primary predictions—mean annual biomass of adult trout—are quite sensitive to a small number of parameters. Only one of these parameters, which controls how predation risk varies with water depth, were unexpected but not surprising. Interactions among parameters were common; the effect of uncertainty in two parameters often was stronger than the sum of effects of each parameter by itself. Despite these sensitivities, model results for management (the rank of alternative management scenarios by predicted trout population biomass) was quite robust to parameter uncertainty. Primary model predictions are quite sensitive to some habitat input variables, especially hiding cover availability. Experiments conducted collaboratively with the U.S. Forest Service found that, in simulated trout populations, cumulative effects of multiple stressors (increases in temperature and turbidity, physical habitat degradation) can be stronger than if each stressor acted independently, even when temperature and turbidity changes are temporally isolated.

Complex ecological simulation models such as *inSTREAM* have been widely believed to be too sensitive to parameters to be useful, but this project's analyses show that model results of most importance to decision-making can be quite robust to parameter uncertainty. The model's sensitivity to some input variables confirms that it is useful for predicting effects of changes in habitat to trout populations; hiding cover seems particularly important. An assumption widely used in assessing cumulative impacts of multiple stressors, that impacts can be assumed independent and their effects multiplicative, is not supported by this model.

The next steps for the project include the following: (1) The public release version of *inSTREAM* will receive final testing and be posted at http://www.humboldt.edu/~ecomodel. (2) The model documentation is now in production as a U.S. Forest Service/U.S. Environmental Protection Agency report. (3) The researchers are collaborating with Dr. Robert Van Kirk (Idaho State University) in an application of *inSTREAM* to the question of how altered flow releases in the Teton River basin affect competition between native and non-native

trout populations. (4) The researchers are collaborating with the U.S. Forest Service in an application to analyze how alternative forest fire restoration practices affect trout population recovery.

Question-and-Answer Session With Dr. Steve Railsback

- One participant commented on the RMA2 program that Dr. Railsback mentioned in his presentation. He noted that Dr. Railsback had stated that the program was a readily available off-the-shelf program. For his own research pursuits, the participant commented that his group is very interested in using the *inSTREAM* model to help them understand the fine scale processes as they are being scaled up. A concern, however, is incorporating products that will have limited availability for support. The participant asked for clarification on Dr. Railsback's outlook regarding the compatibility of the various software packages. Dr. Railsback explained that the version of RMA2 being used by his group is a commercial front end to a public domain hydrodynamic model. He added that Humboldt State University has a site license for the model. The setup is such that the hydrodynamic modeling, which was created by an engineering professor at the university, was used to produce a series of output models that are then imported into the group's fish model. Specifically, the user is given a lookup table of depth and velocity in each cell that can be used by the fish model.

Multiple Threats to Marine Biodiversity: The Interactive Effects of Climate Change and Land Use Patterns on the Alteration of Coastal Marine Systems by Invasive Species

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Abstract

Climatic warming is projected to increase the Earth's average surface temperature by 2-5^{o}C during the next 50-100 years, and evidence exists that climate change has contributed to a rise in the heat content of the oceans during the past 50 years. Direct and damaging ecological responses of warming are expected, and coastal ecosystems are particularly vulnerable as they are less buffered from temperature increase than more oceanic systems. Resulting alterations in the distribution patterns of species, coupled with the enhanced vulnerability to invasions by exotic species, can result in profound changes in communities and ecosystems. Coupled to the effects of climate change on the land-sea margin is the intense use of these areas for industry, agriculture, habitation, and exploitation of living and nonliving resources. These have resulted in a host of problems (e.g., eutrophication, coastal erosion), which often lead to habitat degradation and reduced ecosystem function and biodiversity. These problems are occurring in a global setting of climate change and sea-level rise, the implications of which are not currently well understood or subject to accurate prediction.

Central to the ecological effects of climatic warming on marine coastal and estuarine systems is the potential invasion of habitats or regions by exotic species. Biological invasions pose a significant threat to biodiversity, directly or indirectly alter local community composition, and influence ecosystem services. Unfortunately, the processes and environmental conditions that determine invasion success are known for only relatively few species. Understanding the effects of climate change, coupled with multiple stressors, on the invasion process is critical to predicting and assessing the extent of ecosystem modification as well as to developing strategies for habitat management. Coupled with this lack of knowledge is the strong potential that species introductions resulting from climate change will be accelerated by existing and expanding human-related activities in the coastal zone. For example, increased nutrient loading can switch the dominant primary producers from submerged aquatic vascular plants to macroalgae and phytoplankton, decreased biodiversity, and altering trophic structure. Systems with their biodiversity lowered by human-related activities are likely to be more vulnerable to invasion by new species. Invaders, therefore, are potentially unique in being both important and easily recognized indicators of stress and also being a stress on native species with which they interact.

Over the past two decades, the southern New England (USA) coastal zone has been used as a model to study the interactive effects of climate change, land use, and invaders on ecosystem function and biodiversity. The abundance of invaders has increased during this period coupled with a decline in the numbers of resident species. More intriguing is that invader recruitment has been enhanced by warming water temperatures, whereas native recruitment has declined. Equally important is diversity of coastal land-use patterns in the region, ranging from highly urbanized systems to relatively pristine habitats. The conversion of watersheds from natural to human-dominated systems has caused profound changes to the coastal ecosystems (e.g., alteration of water balance, and sediment and nutrient delivery). Recent invaders are almost exclusively found in coastal systems that possess reduced biodiveristy and that are most heavily impacted by human activities. In addition, there are strong within-habitat inverse relationships between resident diversity and invader diversity, suggesting that variations in local environmental conditions that influence local biodiversity are important components in response of coastal ecosystems to invasion susceptibility. Key predators also are absent from environmentally degraded sites, further enhancing the susceptibility of these areas to invasion.

Question-and-Answer Session With Dr. Robert Whitlatch

- There were no questions.

Adaptive Implementation Modeling and Monitoring for TMDL Refinement

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Abstract

The objective of this work is to investigate the effects of changes that occurred in the watershed on nutrient loading to the Neuse River estuary, to facilitate adaptive management. To investigate the effects, the model should be able to: (1) incorporate all available information generated in the watershed, and (2) incorporate information about the changes that occurred in the watershed over time. The current SPARROW setup limits the use of information to those generated by long-term monitoring stations. This limitation excludes many monitoring stations that were designed to be irregularly monitored or stations put on line recently. Many monitoring stations inside the Neuse River watershed were not used in the initial SPARROW model development for this reason. The approach will be based on two recent project developments.

One is the development of a digital watershed—a database including both geospatial and observational time series data for the Neuse River Basin. This database includes water quality data from the U.S. Environmental Protection Agency, as well as water quality and stream discharge data from the U.S. Geological Survey. The primary advantage of the database is that it provides the information infrastructure needed to query for observations across space, time, and variable type more efficiently and effectively. Also, because the Neuse database acts to decouple data management needs from modeling activities, it will be easier to integrate new observations into the modeling system and to have other models operate off the same data infrastructure.

The other development is the reach-based SPARROW model and its Bayesian updating procedure. When initially developed, SPARROW was a sub-watershed based model, and the watershed configuration cannot be changed once the model is developed. As a result, a SPARROW model cannot be updated using additional monitoring data from stations other than the ones used in its original development. There are many water quality stations that were designed to be monitored irregularly or on a rotating basis (e.g., stations monitored by EMAP). Using the recently developed local database, including all available water quality/quantity data throughout the Neuse River Basin, the SPARROW structure was modified to make the individual stream reach as the basic building block. This modification is possible because the initial SPARROW was fitted to 1992 data, and the resulting posterior distributions of model coefficients are used as informative prior distributions. Using informative prior distributions, the model was refitted using fewer observations. By restructuring the watershed configuration, a single structure can be maintained that allows different monitoring stations to be used at different time steps. This change makes it possible to update model coefficients using available monitoring data throughout the watershed, and is not limited to those stations with long-term records.

Question-and-Answer Session With Dr. Song Qian

- Iris Goodman commented that SPARROW was used initially for the prior distributions and then monitoring data were used for the posterior distributions. She asked whether the changes in the posterior distribution are attributed solely to the inference from the Bayesian model or also to the aggressive nitrogen reduction. Dr. Qian responded that originally when the model was used to predict the chlorophyll concentration, the loading model, SPARROW, used 1992 data. The SPARROW model, when coupled with the chlorophyll model, overpredicts the chlorophyll concentration. It is unknown whether this overprediction is caused by the model or because of the level of the chlorophyll concentration. To answer this question, a mechanism is needed to quantify information in the watershed from 1992 to 2000 and then see if there are any changes in the chlorophyll concentration.

Regional Scale Stressor-Response Models in Aquatic Ecosystems

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Abstract

This research project seeks to use modern classification and regression trees and hierarchical Bayesian techniques to link multiple environmental stressors to biological responses and quantify uncertainty in model predictions and parameters. A systematic method for identification and estimation of regional scale stressor-response models in aquatic ecosystems will be useful in monitoring and assessing aquatic resources, determining the Total Maximum Daily Loads, and for increased understanding of the differences between regions (Lamon and Stow, 2004). The response variable is chlorophyll *a*, a measure of algal density, and the stressors include nutrient concentrations of Total Nitrogen (TN) and Total Phosphorus (TP) from the U.S. EPA Nutrient Criteria Database (NCD, U.S. EPA, 2004) for lakes/ponds and reservoirs of the continental United States (Das, 2003; Freeman, 2004; Freeman et al., 2006). The NCD has observations for both stressors and biological responses determined by using methods that are not consistently available at the continental scale. As a complement to the tree structured models previously reported (Freeman, 2004; Freeman, et al., 2006), a multilevel modeling approach was used to estimate a linear model for prediction of log CHLA using predictors log TP and log TN. In this approach, the impact of covariates was adjusted at all levels (observation, higher level groups) for the simultaneous operation of contextual and individual variability in the outcome (Congdon, 2001). Separate regression coefficients were allowed for inference regarding similarities and differences between each of 14 ecoregions, and each of 2 waterbody types, lakes/ponds and reservoirs. Also, adjustments were made for the confounding effects of the factor variables indicating the type of nitrogen measurements (TNsource - 3 levels) and the type of chlorophyll *a* measurements (Chlasource - 4 levels) used. The Deviance Information Criterion (DIC, Spiegelhalter, et al., 2002) was used to make inferences regarding the tradeoff between model complexity and model fit. A graphically based ANOVA decomposition (Gelman, 2005) was used to investigate the relative contributions of each regression term above to overall variance as an aid to interpretation of the results.

Preliminary results of the multilevel analysis indicate that the type of chlorophyll *a* measurements (Chlasource) accounted for the largest portion of variation in the intercept terms and the $\log_{10}$(TP) slope terms. The waterbody type factor accounted for the most variation in $\log_{10}$ (newTN) slopes. As suggested by the TREED model analyses of Freeman, et al. (2006), all factors investigated had a significant impact on the intercepts and slopes of the multilevel models. Future efforts will be focused on: (1) obtaining more predictor and factor variables for multilevel regression models (predictors: temperature, watershed characteristics, inflow characteristics, waterbody morphometry; factors: month); (2) more spatial coverage than provided by non-missing data in the NCD; (3) use of data imputation methods for observations with missing values to allow full use of the larger dataset (which also may help with spatial coverage); and (4) development of tools to aid in the use of these models.

References:

Congdon P. Bayesian Statistical Modeling. New York: John Wiley and Sons, Ltd., 2001.

Das A. 2003. Regional water quality models for the prediction of eutrophication endpoints. Master's Thesis. Department of Environmental Studies, Louisiana State University (http://etd.lsu.edu/docs/available/etd-0916103-154052/).

Freeman A. 2004. Regional scale eutrophication models: a Bayesian treed model approach. Master's Thesis. Department of Environmental Studies, Louisiana State University (http://etd.lsu.edu/docs/available/etd-07082004-120520).

Freeman AM, Lamon EC, Stow CA. 2006. Regional nutrient and chlorophyll-*a* relationships in lakes and reservoirs: a Bayesian TREED model approach. *Environmetrics* (in review).

Gelman A. Analysis of variance—why it is more important than ever (with discussion). *The Annals of Statistics* 2005;33(1):1-53.

Lamon EC, Stow CA. Bayesian methods for regional-scale eutrophication models. *Water Research* 2004;38: 2764-2774.

Lamon EC, Qian SS. Regional scale stressor-response models in aquatic ecosystems. 2006 (in progress).

U.S. EPA. 2004. Nutrient Criteria Oracle Database. U.S. Environmental Protection Agency, Washington, DC. http://www.epa.gov/ost/criteria/nutrient/database/.

Spiegelhalter DJ, Best NG, Carling BP, van der Linde A. Bayesian measures of model complexity and fit (with discussion). *Journal of the Royal Statistical Society B* 2002;64:583-640.

Question-and-Answer Session With Dr. Conrad Lamon

- Iris Goodman commented that she would like to see the mapping of the statistical distributions back onto something spatial, to see if there is any spatial coherence in them.

Developing a Risk Propagation Model for Estimating Ecological Responses of Streams to Anthropogenic Watershed Stresses and Stream Modifications

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Abstract

The goal of this research project is the development of a regionalized watershed-scale model to determine aquatic ecosystem vulnerability to anthropogenic watershed changes, pollutant loads, and stream modifications (such as impoundments and riverine navigation).

In the first phase of this research (first 2 years), a particular artificial neural network (ANN) structure, the Self Organizing Maps (SOMs), was established and demonstrated that it can be used to pattern and profile the distribution of stressors in large stream ecosystems, and discriminate sampling sites according to multi-stressor impact. SOMs were used to analyze the biological integrity of the streams in the States of Ohio and Maryland. This type of ANN analysis is called unsupervised learning. Using Canonical Correspondence Analysis (CCA) and Principal Component Analysis (PCA), the research teams are identifying the ranking of stressors as to their impact on Indices of Biotic Integrity (IBI) and Cluster Dominating Parameters (CDP).

In the second phase of the research (third year), the research teams are capitalizing on the very promising results of the first phase. Supervised ANN-based prediction capabilities are being added as a step following the hierarchical unsupervised nonlinear clustering of sampling sites according to fish IBI metrics vectors distribution. The objective is to be able to build simple yet powerful models that could be used to predict the IBI and its metrics (both fish and macroinvertebrate).

The team at the University of Wisconsin (Milwaukee) is using an extensive fish, habitat, and land cover database for the State of Wisconsin and has developed a GIS-based system to be used for analyzing impacts of stream habitat and fragmentation, hydrological and hydraulic parameters, and watershed land use of the stream biological integrity, using also SOMs and correlating them to the various "stressor" metrics calculated from the GIS Database.

Because habitat parameters have been identified as the stressors that have the greatest impact, significant effort is now devoted by both teams to synthesize and analyze the habitat metrics. Most of the current metrics identified, for example, in the Rapid Biotic Assessment Protocols are observational (i.e., they cannot be predicted). The research teams are striving towards developing predictive habitat indices and measures.

Also, the database for storing and querying vast amounts of data from several states (Ohio, Maryland, Massachusetts, Wisconsin, Minnesota) has been completed.

In last year's presentation, the development of an application of unsupervised ANN yielding SOMs was featured. CCA then quantitatively identified the parameters of the greatest importance, the CDP. SOM unsupervised learning has been expanded now, using data from Wisconsin and Minnesota.

In addition, SOM was used for identifying the main parameters affecting habitat. With Ohio data, significant cross-correlations were found between habitat metrics of the Quantitative Habitat Evaluation Index (QHEI) (e.g., embeddedness with gradient and substrate quality). Also, QHEI and IBI clusters are being compared to look for similarities and relationships.

The team in Wisconsin analyzed SOMs in two different time periods, 1990-2000 and 2001-2005. Examination of the clustering sites by SOM and CCA as well as PCA showed that the SOM patterning of only 4 (out of 12) component fish metrics accounted for most of the biological variation among sampling sites.

The SOM analyses will be finalized, and predictive models by supervised learning with ANN will be developed. The Northeastern team will perform another SOM analysis for Ohio data because a new and more comprehensive analysis will be available this year. Development of the habitat metrics models will be finalized. Also, the risk propagation model will be completed. The analysis of clustering will be linked to the formulation of biotic criteria, and a methodology will be proposed. The final report then will be prepared. In addition, a workshop will be organized in 2007; a workshop proposal will be prepared and submitted to EPA by July 2006.

A Web site has been created by the team members where all reports and other publications or their abstracts will be available at: http://www.coe.neu.edu/environment.

Question-and-Answer Session With Dr. Vladimir Novotny

- Iris Goodman mentioned that the group is under a no-cost extension; they are at the point of trying to summarize the results and interpret all of the maps. Dr. Novotny confirmed that his team is in the first month of their no-cost extension and that they will be analyzing their results. They will not be developing any new models; the setup for all models is completed. The biggest problem was selecting the data, which was very time-consuming.

- One participant asked what scale was used to evaluate the land-use variables. Dr. Novotny responded that the data will be a huge matrix site. When the Ohio people were collecting the data, they collected the metrics of the fish and the habitat, as well as some chemical data. They had some good and some less useful information on the land use of the watershed draining to the site. The model is for the entire State of Ohio. The databases are different for the other states and they use different metrics for IBI. As a result, the scope is monitoring the states, but the data are local.

- Iris Goodman commented that some of the top methods and variables that were determined to be most influential are the same variables that turned out to be more influential in other programs such as the Environmental Monitoring and Assessment Program. In some ways, the work discussed is a type of independent confirmation of the influence of these variables.

Developing Relations Among Human Activities, Stressors, and Stream Ecosystem Responses and Linkage in Integrated Regional, Multi-Stressor Models

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Abstract

Nutrients, dissolved oxygen (DO), and hydrologic alteration of streams are commonly affected by humans, and all have profound effects on valued ecological attributes (VEAs). Few models explain relations among human activities, these stressors, and VEAs with sufficient precision to develop nutrient criteria, total maximum daily loads, or manage streams. The objectives of this research project are to refine relationships among human activities, multiple common stressors, and the fisheries and ecological integrity of stream ecosystems.

A multi-scale strategy is being employed to refine several tools for water quality assessment. At the broad spatial scale, stream conditions throughout the Lower Michigan Peninsula were examined using new and existing data compiled from a variety of sources. Land-use patterns were related to biological condition with both urban and agricultural activities significantly but indirectly stressing biological communities. At an intermediate scale, the stream survey methods were refined and a set of six separate tributary systems were sampled to relate biological condition along complex agricultural and hydrologic gradients to early morning DO, human activities, contaminants and habitat alterations, and VEAs by sampling low flow conditions. To focus on DO effects, sampling was conducted well after rain events and during early morning hours; thus controlling variation in DO due to natural factors. Results to date show that nitrogen, phosphorus, and carbon concentrations were positively related to agricultural land use in watersheds; algal biomass increased with nutrient concentrations; and early morning DO concentrations decreased with increasing algal biomass. Biological response patterns suggest that metabolic stresses have driven much of the observed declining diversity and shifts in community composition. Interestingly, stressors acting through indirect relationships in the causal pathway from human activities to ecosystem response often had higher observed correlations than did stressors with more direct effects. This indicates higher temporal-spatial coherence in the variation of multiple local stressors.

At finer scales, master watersheds were established with either continuous water quality and hydrologic monitoring, or spatially intensive and repeated sampling. These watersheds are being used to parameterize a suite of process-based (mechanistic) models. The instrumentation and continuous monitoring of Crane Creek in Ohio is providing parameters for DO responses to complex interactions among processes operating at three temporal scales: (1) high-resolution hourly variation associated with diurnal patterns and base-level oscillation in Lake Erie; (2) daily development between weather-related events of biological assemblages that regulate diurnal variation in DO; and (3) weekly variation in weather affecting the hydrology of streams and related biological community development.

A process-based modeling approach relating precipitation and land use to water quantity, quality, and biological response was refined using intensive sampling of Cedar Creek. The model shows the importance of nutrient transport through groundwater to streams in soils with high permeability, which is typical of many watersheds in the glaciated upper Midwest and Great Lakes regions. Nitrate concentrations in Cedar Creek were better predicted by a model that explicitly included groundwater inputs than traditional models based on overland transport alone. Multi-year simulations of the Cedar Creek watershed highlighted the significant role that changing land use plays in influencing the distribution of nutrient concentrations in groundwater, and in mediating the influence of those nutrients on the biota in Michigan streams.

Future activities will focus on completing the integration of results of the broad and fine-scale field assessments in a suite of statistical, process-based, and hybrid models. Many of the statistical models already are

being used by the Michigan Department of Environmental Quality to establish nutrient criteria. The models will be refined to improve understanding of how human activities can be managed to support ecological integrity, aquatic life use, and fisheries of stream ecosystems.

Question-and-Answer Session With Dr. Mark Wiley

- There were no questions.

U.S. EPA STAR Global Aquatic Ecosystem Services and Multi-Stressor Progress Review Workshop

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