United States
Environmental Protection
Agency

Workshop Abstracts

Joint Progress Review for U.S. EPA STAR Grants: Regional-Scale Stressor-Response Models and Consequences of Global Change for Aquatic Ecosystems

November 3-4, 2005
Arlington, VA

Introduction

Annual Review of EPA STAR Research on:

(1) Regional Scale Stressor Response Models for Environmental Decision-making

(2) Consequences of Global Change for Aquatic Ecosystems: Climate, Land Use, and UV Radiation

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) *Assessing the Consequences of Global Change for Aquatic Ecosystems: Climate, Land Use, and UV Radiation.* This research was funded by the STAR Ecological 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 Arlington, Virginia, November 3-4, 2005.

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 have already begun working with resource managers who may ultimately benefit from the creation of these new modeling tools.

The 2001 solicitation *Assessing the Consequences of Global Change for Aquatic Ecosystems: Climate, Land Use, and UV Radiation* sought proposals that contributed to the scientific literature and developed decision support tools designed to quantitatively and qualitatively relate watershed characteristics to aquatic ecosystem health and water quality. Principal investigators presented final research results that elucidate: (1) the impacts of climate change and land use in relation to ultraviolet radiation levels in Rocky Mountain streams, and the Lehigh and Ontonagon Rivers; and (2) how climate variability, and past, current and future land use practices influence the ecological structure of vegetation and animal communities relying on playa lakes in the Southern Plains.

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, contact Bernice L. Smith at 202-343-9766 (Smith.Bernicel@epa.gov). For information about the STAR Ecological 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.

[1] The primary focus of EPA ORD's Ecological Research Program is to:

(1) Assess the condition of the nation's ecosystems.
(2) Diagnose the causes of impairments to these ecosystems.
(3) Forecast how ecosystems respond to existing and emerging ecological stressors.
(4) Establish methods to set priorities for protecting and restoring impaired ecosystems.

[2] The primary focus of EPA ORD's Global Change Research Program is to improve society's ability to respond and adapt to future consequences of global change. This entails:

(1) Improving the scientific capabilities and basis for projecting and evaluating effects and vulnerabilities of global change;
(2) Conducting assessments of the ecological, human health and socioeconomic risks and opportunities presented by global change; and
(3) Assessing management and adaptation options to improve society's ability to effectively respond to the risks and opportunities presented by global change.

Assessments of the effects of global change on aquatic ecosystems (freshwater and coastal) and their services in the context of other stressors and human dimensions is the focus of the Ecosystem Focus Area of EPA's Global Change Research Program. Linked aquatic-terrestrial ecosystems also are considered to inform the impact of global change on aquatic ecosystem functioning and services. EPA's Global Change Research Program is consistent with the U.S. Climate Change Science Program (CCSP) and contributes to the many goals set forth in the CCSP Strategic Plan.

Joint Progress Review for U.S. EPA STAR Grants: Regional-Scale Stressor-Response Models and Consequences of Global Change for Aquatic Ecosystems

Sheraton National Hotel
900 S. Orme Street
Arlington, VA 22204

November 3 – 4, 2005
AGENDA

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

(1) *Regional-Scale Stressor-Response Models for Aquatic Ecosystems*
(2) *Effects of Climate, Land Use and UV Radiation on Aquatic Ecosystems*

***Posters of PI research will be on display both Thursday and Friday**

Thursday, November 3, 2005

7:30 – 8:30 a.m. **Registration and Poster Set-Up**

8:30 – 9:00 a.m. **Welcome and Introduction**
Becki Clark, Director Environmental Science Division, U.S. EPA, NCER
Joel Scheraga, Ph.D., National Program Director, EPA Global Change Research Program, U.S. EPA
Iris Goodman, Ecological Research Program Manager, U.S. EPA, NCER

Session I Theme: Regional-Scale Physical Models for Environmental Decision-Making

9:00 – 9:40 a.m. *Development of Coupled Physical and Ecological Models for Stress-Response Simulations of the Apalachicola Bay*
Mark Harwell, Ph.D./Hongquing Wang, Ph.D., Florida A&M University

9:40 – 10:20 a.m. *Developing Regional-Scale Stressor Response Models for Managing Eutrophication in Coastal Marine Ecosystem*
Robert Howarth, Ph.D., Cornell University

10:20 – 10:35 a.m. **Break** (PIs are available to discuss their posters)

10:35 – 11:15 a.m. *A Shallow-Water Coastal Habitat Model for Regional-Scale Evaluation of Management Decisions in the Virginia Province*
Charles Gallegos, Ph.D., Smithsonian Institution

11:15 – 11:55 a.m. *Development of a Regional-Scale Model for the Management of Multiple-Stressors in the Lake Erie Ecosystem*
Joseph Koonce, Ph.D., Case Western Reserve University

12:00 noon – 1:15 p.m. **Lunch**

Session II Theme: Regional-Scale Statistical Models for Environmental Decision-Making

1:15 – 1:55 p.m. *Adaptive Implementation Modeling and Monitoring for TMDL Refinement*
Kenneth Reckhow, Ph.D., Duke University

1:55 – 2:40 p.m. *Bayesian Methods for Regional-Scale Stressor Response Models*
Conrad Lamon, Ph.D., Duke University

2:40 – 2:55 p.m. **Break** (PIs are available to discuss their posters)

2:55 – 3:35 p.m. *Developing a Risk Propagation Model for Estimating Ecological Responses of Streams to Anthropogenic Watershed Stressors and Stream Modification*
Vladimir Novotny, Ph.D./Elias Manolakos, Ph.D., Northeastern University

3:35 – 4:15 p.m. *Developing Relations Among Human Activities, Stressors, and Stream Ecosystem Responses and Linkage in Integrated Regional, Multi-Stressor Models*
Jan Stevenson, Ph.D., Michigan State University

Friday, November 4, 2005

8:30 a.m. **Introduction**
Bernice Smith, Ph.D., Global Change (Ecosystems Research) Program Manager, U.S. EPA, NCER

Session III Theme: Regional-Scale Population Models for Environmental Decision-Making

8:30 – 9:10 a.m. *Effects of Multiple Stressors on Aquatic Communities in the Prairie Pothole Region*
Patrick Schoff, Ph.D., University of Minnesota–Duluth

9:10 – 9:50 a.m. *Application of Individual-Based Fish Models to Regional Decision- Making*
Roland Lamberson, Ph.D., Humboldt State University

9:50 – 10:20 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, Ph.D., University of Connecticut

10:20 – 10:35 a.m. **Break** (PIs are available to discuss their posters)

Session IV Theme: Climate, Land Use, and UV Radiation on Aquatic Ecosystems

10:35 – 11:05 a.m. *Interactive Effects of Climate Change, Wetlands, and Dissolved Organic Matter on UV Damage to Aquatic Foodwebs*
Scott Bridgham, Ph.D., University of Oregon

11:05 – 11:45 a.m. *The Influence of Climate-Induced Alterations in Dissolved Organic Matter on Metal Toxicity and UV Radiation in Rocky Mountain Streams*
William Clements, Ph.D., Colorado State University

11:45 a.m. – 1:00 p.m. **Lunch**

1:00 – 1:40 p.m. *Interactions Among Climate, Humans, and Playa Wetlands on the Southern High Plain*
Scott McMurry, Ph.D., Texas Tech University

1:40 – 2:20 p.m. *Assessing the Interactive Effects of Land Use, Climate, and UV Radiation on River Ecosystems: Modeling Transparency and the Response of Biota to UVR.*
Bruce Hargreaves, Ph.D., Lehigh University

2:20 – 2:30 p.m. **Break** (PIs are available to discuss their posters)

2:30 – 4:00 p.m. **Discussion Session**
This informal discussion session provides an opportunity for STAR grantees and staff of EPA Program Offices, Labs, and Centers to explore opportunities to further advance the research topics presented. The group will choose the topics to be discussed; preliminary suggestions include: (1) ways to share data, ideas, or modeling methods, and (2) ways to synthesize and communicate research results. To start off the discussion, we will have three speakers give brief remarks (i.e., 5 – 7 minutes):
Rochelle Araujo, Ph.D., U.S. EPA, NERL, ADE; Charles Noss, Ph.D., U.S. EPA, ORD; and Noha Gaber, Ph.D., U.S. EPA, NCER

4:00 – 4:10 p.m. **Closing Remarks**
Bernice Smith, Ph.D., Global Change (Ecosystems Research) Program Manager, U.S. EPA, NCER

Regional-Scale Physical Models for Environmental Decision-Making

Developing Regional-Scale Stressor-Response Models for Use in Environmental Decision-Making in Apalachicola Bay

Mark A. Harwell, Ping Hsieh, Wenrui Huang, Elijah Johnson, Katherine Milla, Hongqing Wang, Kevin Dillon, Glynnis Bugna, and John H. Gentile
Environmental Cooperative Science Center (ECSC),
Florida A&M University (FAMU), Tallahassee, FL

Abstract

Florida's Apalachicola Bay is the "last great bay" that is relatively pristine in the United States. The Bay is one of the nation's major producers of American oysters (*Crassostrea virginica*). It is significantly influenced by freshwater flows from the Apalachicola, Chattahoochee, and Flint River system (ACF), which drains approximately 60,000 km^2 of Georgia, Alabama, and Florida. Of particular concern are the present and anticipated reductions below the historical freshwater flows from the ACF system, particularly for urban use in Atlanta and center-pivot irrigation agriculture in Georgia. The valued ecosystem components (VECs) of the Apalachicola Bay ecosystem include oysters, recreational fisheries, salt marshes, and associated aesthetic, endangered, and recreational species of birds, fish, and invertebrates. Stressors include changes in salinity and turbidity, sea-level rise, nutrient inputs, tropical storms and hurricanes, and habitat alteration. Our objectives are to develop models that can be used to evaluate the stress-responses of the Bay to these natural and anthropogenic stressors, and provide scientific support to the environmental decision-making process following the U.S. Environmental Protection Agency (EPA) ecological risk assessment framework.

We have been developing a coupled physical and ecological model system to accomplish our objectives. The physical models include a 3-D hydrodynamic model (modified from the Princeton Ocean Model [POM]), a river flow model (MODBRNCH), and a water quality model (EPA WASP 6) to simulate the current, transport, salinity, sediment, and nutrient regimes of the Bay. These physical models are being coupled through a Geographic Information System (GIS) framework to ecological models (i.e., salt marsh, oyster population, habitat suitability and landscape metrics) to simulate effects of stressors on the VECs. Hyperspectral remote sensing data, acquired under separate funding from National Oceanic and Atmospheric Administration (NOAA), provide information for model calibration and stress responses.

To date, we have calibrated and validated a 3-D Apalachicola Bay hydrodynamical model to examine the effects of freshwater flow, tide, and current on estuarine salinity. We have developed a salt marsh soil salinity model 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. We continued to acquire spatially explicit databases for the Bay, including weather data, topography, and nutrient and salinity data for 2002-2004. We are now developing an oyster population model for Apalachicola Bay, and acquiring extensive existing databases for oysters in the Bay. Meanwhile, technical difficulties have developed in coupling of the hydrodynamical model with a water quality model, and in calibration of the MODBRNCH model. As a result, we are exploring alternate river and water quality modules for our coupled model system.

The next steps are to: (1) complete the linkage of the 3D hydrodynamic model to the water quality module; (2) complete the implementation and calibration of a river flow regime model; (3) continue the acquisition of data and implementation in the GIS database; (4) complete the development and calibration of the salt marsh ecological/hydrological model; (5) continue developing and coupling the oyster population model with hydrodynamic model; and (6) conduct a demonstration ecological risk assessment through development of the test scenarios related to climate change and ACF water management.

Question-and-Answer Session with Dr. Hongqing Wang, who presented for Dr. Mark Harwell

- One participant asked what unit was used for the suspended sediments concentrations in the model. Dr. Wang replied that it was milligrams/liter. These measurements will be checked against real data to determine if they are correct. The participant commented that he was surprised to see sea grasses in the system with the depth of suspended sediments and asked if there were water clarity measurements. Dr. Wang responded that there was monitoring for a number of water quality parameters.

- One participant stated that he was interested in the use of the Princeton Model and the application to the bay and asked if the project looked at how the grid size of the model affected the predictions of tidal flow. Dr. Wang responded that he was not the hydrologist on the project, but the grid size they are using should be suitable with some variation.

- Iris Goodman asked if Dr. Wang has any sense of the relative contribution of tidal and bay influences versus the water management in the uplands draining into the bay. Dr. Wang responded that if the river location changes, it will affect the salinity and oyster population in the bay.

- One participant stated that the bay has a strong west to east salinity gradient and 90 percent of the fresh water is coming from the Apalachicola River, and asked why there is low salinity in the western part of the bay? Dr. Wang responded that most of the ocean water is coming from the eastern part and the ocean current is east to west. The fresh water comes from the river mouth and reduces the salinity.

Developing Regional-Scale Stressor Response Models for Managing Eutrophication in Coastal Marine Ecosystem

Robert Howarth
Cornell University, Ithaca, NY

Abstract

Our goals are to: (1) develop a regional-scale model for analyzing nutrient inputs to coastal ecosystems; (2) develop a model-based classification scheme for the comparative analysis of the sensitivity of coastal ecosystems to these nutrient inputs; and (3) develop quantitative approaches for evaluating how other stressors such as climate change, land-use change, and sediment fluxes interact with nutrient inputs to affect coastal ecosystems.

The project has two interacting parts. First, we are developing and testing the Regional Nutrient Management Model (ReNuMa), a model designed to be used by managers to evaluate sources of nutrient and sediment fluxes from regions and large watersheds to coastal marine ecosystems, and to be responsive to watershed management practices. We are refining and modifying this model to increase its effectiveness as a tool to investigate the interacting effects of climate variability, climate change, and land-use change on fluxes of water and nutrients from regions and watersheds. Second, we have developed a nutrient-phytoplankton-zooplankton (NPZ) model of estuarine response to hydrologic forcing and nitrogen loading. We are using this model with available data sets (e.g., National Oceanic and Atmospheric Administration and Land-Ocean Interactions in the Coastal Zone) on physical and ecological aspects of coastal marine ecosystems towards evaluating the sensitivity of coastal marine ecosystems to nutrient enrichment, and to predict how climate change and other stressors interact with this sensitivity.

Progress to date includes: (1) additional analysis of interactions between hydrology and nitrogen fluxes in 16 Northeastern U.S. watersheds; and (2) development and preliminary testing of a watershed-scale regional nutrient management model (ReNuMa) and the NPZ model of estuarine response to nitrogen loading, which we are using to develop a process-based estuarine classification scheme. Analysis of the relationship between climate and Net Anthropogenic Nitrogen Inputs (NANI) to Northeastern U.S. watersheds suggests that 75-80 percent of nitrogen inputs are retained or denitrified in the landscape; those watersheds with higher precipitation or discharge export a greater fraction of N inputs in streamflow, possibly due to reduced denitrification. The ReNuMa model shows good agreement between observations and annual simulations of both streamflow and dissolved inorganic nitrogen at the regional scale, though better parameterizations may be required for individual watersheds. The NPZ model suggests that differences between estuarine responses to point source and non-point sources of nitrogen may result due to the differences in coupling with hydrology.

Nutrients are now the largest pollution problem in the United States. This set of tools will allow environmental managers to set priorities for targets in nutrient reduction, by source of nutrient, and among multiple watersheds in the context of relative benefit to be achieved in coastal water quality. It also will allow managers to explore scenarios for how land-use change and climate change may interact with plans for reducing nutrient pollution. This project will fulfill two high priority recommendations of the National Research Council (NRC) (2000) report on coastal nutrient pollution.

The major objectives for the next year include: (1) further development of the watershed model and preliminary testing in the Upper Susquehanna and other Northeastern U.S. watersheds; (2) further development and analysis of the dynamics of the NPZ estuarine response model and comparison with available estuarine datasets; and (3) coupling of the terrestrial and estuarine response models.

Question-and-Answer Session with Dr. Robert Howarth

- One participant asked why the coastal plain area was not shown on the graph showing the distribution of the 16 watersheds. Dr. Howarth responded they are using the U.S. Geological Survey (USGS) monitoring data for the river flux estimates and there are no gauging stations in that area. There are no USGS water quality data further downstream in any of the watersheds closer to the coast. The water that is upstream of the gauging stations is relatively rural. The highly industrialized, heavily populated area, which also is contributing to nitrogen to the coast, is not included in the analysis. The participant asked if correction factors were added. Dr. Howarth responded that in the statistical mass balance approach they are only dealing with the watersheds. He is fairly confident that they can understand, at least in a temperate zone, what is going on with human alteration of nitrogen cycling in relatively rural areas. He is not sure that when they get into hilly, urbanized areas that the parameters are valid. They have a separate effort funded by the Hudson River Foundation where they are trying to do mass balances for the lower Hudson River estuary in the New York City Harbor area. They are using the City of New York water quality data and plotting nutrient concentrations versus salinity to determine statistically nutrient input sources versus the city. That will give them at least one urban area in the next few years.

- One participant asked if Dr. Howarth had addressed the role of hydrologic variability in terms of whether the wetness of the watersheds is really affecting the amount of nitrogen deposition. Dr. Howarth responded that they are just starting to work on it. They have looked at long-term averages for sinks. There also is a short-term effect of short-term storage and loss, and they will be looking at the historical data set for this data. For the Northeast watersheds, they have total nitrogen fluxes on an annual basis from the 1980s to the present. They also have nitrate data for a subset of about seven or eight of the watersheds, some of which go back to 1919.

- One participant asked if they expected more contributions from climate change on nitrogen flux to rivers in the watershed level compared to human inputs such as fertilizer use. Dr. Howarth responded that climate change affects the nitrogen deposition. On average, most of the nitrogen is not reaching the coast; it is going into the landscape where it is denitrified, and he thinks that it is climatically sensitive. The problem will be aggravated where climate change leads to wetter environments. There are places where climate change will not make it wetter. Most of the model projections say that the Mississippi River Basin will be dryer.

- One participant commented that there is much data on nitrification. He asked why there is variability that is not understood in nitrification and what the knowledge gap was? Dr. Howarth responded that there is a tremendous amount of data measuring denitrification in well-ends and in low-order streams. There are hot spots for denitrification. When you try to scale it beyond the plot scale, there are problems. The issue is of the water resonance time and whether the water that is draining off the landscape is really going through or under wetlands, or if it goes through the wetlands so quickly that it does not really process for denitrification. It is very hard to scale to an entire catchment basin to show how effective the wetlands are as a sink.

- Iris Goodman commented that EPA deals with the problem of how to best combine insights gained from monitoring and insights gained from modeling. Certainly, both have their limitations and there is no right answer.

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

Charles L. Gallegos, Donald E. Weller, Thomas E. Jordan, Patrick J. Neale, and J. Patrick Megonigal
Smithsonian Environmental Research Center, Edgewater, MD

Abstract

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.

Our modeling efforts 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 our model will be those indicators being used as delisting criteria for Chesapeake Bay, namely, chlorophyll, water clarity (diffuse attenuation coefficient), and dissolved oxygen.

Progress has been made on development of a three-compartment subestuary model. The model domain segments with different volumetric dimension, 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 (3 size classes) and zooplankton (3 size classes), and detritus. Nitrogen and phosphorus are tracked separately to allow for spatial or temporal changes in the limiting nutrient (double-currency system), and light propagation through water column is computed based on empirical bio-optical algorithms.

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 affects estuarine responses to multiple stressors. The descriptive portion of this task has been completed. We have identified 128 Chesapeake Bay systems that fit our local watershed-subestuary paradigm and have captured the boundaries of these systems in a Geographic Information System (GIS) database. Subestuary areas range from 0.1-101 km^2 and their associated local watershed areas range from 6-1664 km^2, with the National Land Cover Database land cover percentages ranging from 6-81 percent forest, 1-64 percent cropland, 2-38 percent grassland, and 0.3-89 percent developed land. We also analyzed digital shoreline and bathymetric data to calculate a number of subestuary metrics, including subestuary area and water volume, mouth width and area of vertical profile, proportion of shallow water ([2 m) area, elongation ratio, fractal dimension, the ratio of subestuary perimeter to subestuary area, and ratio of local watershed area to subestuary volume.

Question-and-Answer Session with Dr. Charles Gallegos

- One participant asked if there was any progress in measuring water clarity or transparency. Dr. Gallegos responded that there was a lot of progress in terms of the basic frame of the model. The model will be able to do a good job of predicting the diffuse attenuation coefficient from CDOM, particulate matter, and chlorophyll.

- One participant asked how they were handling the nitrogen versus phosphorus limitation. Dr. Gallegos responded that it will be from concentrations in the delivery water plus what is coming out of the sediments in relation to phytoplankton needs and demands. For phytoplankton, they are running an internal pool type of model. It is one of the things that will be examined in the generalized sensitivity analysis to determine if that level of detail really is needed to predict the limiting nutrient. It is being handled primarily by the sources.

- One participant asked how sensitive the model is to including the different size classes. Dr. Gallegos responded that he did not know how sensitive the model was to the different size structures. He wants to start out with something detailed and see how far down he can simplify it. One of the things that might survive is the effect on water clarity, because that is one place where size makes a difference.

- One participant asked whether taxonomic composition, which may play a major role in the potential for sinks, will be addressed in the model. Dr. Gallegos responded that if they handle it at all, it will be very parameterized in terms of sinking rates versus time from what they know about the changes in the taxonomic composition. He does not think that attempts to model that explicitly have been very successful.

- Iris Goodman commented that 18 metrics have been developed on the 128 systems. She asked if these metrics would be sufficient to parameterize the model in all the needed ways or would they need to add more parameters. She was interested in the notion of how they are working their way from these aggregated metrics to making these predictions spatially at all of these small estuaries. Dr. Gallegos responded that they will examine whatever data they can obtain. There is a lot of data for the Road River. About 30 of these systems have Chesapeake Bay program stations, and they should be able to obtain some aggregate measures. There also are a growing number of these systems that have Maryland Department of Natural Resources Eyes on the Bay stations that have probes recording at 15-minute intervals. They will be using data from these types of stations to develop relationships between exchange and other metrics.

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

Joseph F. Koonce[1] and Benjamin F. Hobbs[2]
[1]Case Western Reserve University, Cleveland, OH; [2]Johns Hopkins University, Baltimore, MD

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 Dr. Joseph Koonce

- One participant commented that the model is incredibly detailed and that it seems that the uncertainty analysis will be a daunting task. The participant asked if Dr. Koonce anticipated fully characterizing the error terms in the model parameters and the model specifications. Dr. Koonce responded that there is no question that there is pattern in the parameter space of these complicated models. The challenge is to have a framework in place so that they can easily generate the quantities of data that they need to characterize the patterns so they can begin to understand how the uncertainties actually work. A variety of parameter combinations give the same output predictions. There are other computational tools becoming available to do functional analysis. They are hoping to apply them in the parameter space. There are some very nice algorithms to begin to look for these patterns. In some of the preliminary work they have done in disaggregating fish population into age groups and into cohorts, they know that there is structure that there is structure in the parameter space.

- One participant commented that they have been trying to develop good models for predicting phosphorus loading, and asked what tools they are using and how well they work. Dr. Koonce responded that the International Joint Commission is collecting monitoring information on loadings. Unfortunately, with the changes in the Great Lakes water quality agreement in 1988, some of the monitoring schemes begin to break down. Dave Dolan of the University of Wisconsin at Green Bay is continuing to maintain the databases on river flows, sewage treatment, and effluents so that they are tracking the loading. The problem with the loading calculation is that all phosphorus in not equal. It may be the case that with the reduction in the sewage treatment plants of detergent phosphorus, there are more resistant forms of particulate phosphorus as the primary component of the loading. There is not a lot of good information on the composition of the loading. There are fairly good estimates of the seasonality and loading. In the Lake Erie ecosystem, there are four dominant tributaries in the connecting channel that makes it easier to investigate.

- Iris Goodman asked which break points in the ecosystem functions they were focusing on that might have the best results. Dr. Koonce responded that almost all of the break points that they know exist in the system have to do with the fish community composition. When predator-prey abundance tends to achieve certain threshold levels, the chance events that come with the strong year class of walleye, for example, can send the system into a very long-term predator-prey ossolation. This happened in 1988. The fisheries preference is to have a lot of large body predators in the systems. The management always is tending to put the system at risk.

Regional-Scale Statistical Models for Environmental Decision-Making

Adaptive Implementation Modeling and Monitoring for TMDL Refinement

Kenneth H. Reckhow
Duke University, Durham, NC

Abstract

The primary objectives of this project are to: (1) develop an adaptive implementation modeling and monitoring strategy (AIMMS) for Total Maximum Daily Load (TMDL) improvement; and (2) apply and evaluate AIMMS on the Neuse Estuary nitrogen TMDL in North Carolina. For this study, the models in AIMMS are the NeuBERN Bayes network estuary model linked with a Bayesian version of the U.S. Geological Survey (USGS) Neuse SPARROW model; AIMMS allows us to analytically integrate TMDL modeling with post-implementation monitoring to refine and improve the TMDL over time.

After the completion of the Bayesian analysis of SPARROW, we focused on two fronts. First, we started a series of studies on the use of a simple Bayesian approach for updating nutrient loadings and nutrient concentrations. Second, we started to use the Neuse River Digital Watershed (from the NSF-CUAHSI program) to provide annual nutrient loading data and revise our Bayesian SPARROW model to update model parameters as well as estimate nitrogen loadings when new data are available. In this report, we describe progress made in these two areas.

Information synthesis is usually the motivation for employing Bayesian analysis; thus, Bayesian analysis serves as perhaps the ideal approach for the analytics of adaptive implementation. The conventional application of a Bayesian approach emphasizes the combination of prior information (in this case, from the TMDL forecast model) and a single set of data (post-implementation monitoring data). It is shown, however, in Bayesian statistics texts that sequential updating using the posterior from the previous step as prior is equivalent to updating using all of the data together; thus, sequential updating provides a means to investigate possible temporal patterns in the data, which is attractive for adaptive implementation of a TMDL.

As an example of sequential Bayesian updating for adaptive implementation of a TMDL, a series of computer programs were developed to automate the process of updating water quality concentration estimation from model predictions and subsequent monitoring data. These programs use Bayesian analysis results for (log) normal random variables, and the conjugate family of prior distributions. The process has three steps. First, a number of procedures were developed for converting TMDL model forecasts of water quality concentrations to a prior distribution of the underlying concentration distribution parameters. Second, a program was developed to produce the posterior distribution of the underlying concentration distribution parameters and the posterior predictive distribution of future observations, based on the pre-TMDL model forecast (the "prior") and the first year of post-implementation monitoring data (the "sample"). Third, the "posterior" distribution of the underlying concentration distribution parameters is then converted to a prior distribution of the same parameters for the next time period, and the process repeats when new data are available.

To demonstrate this process, a Bayesian SPARROW model-predicted 1992 nitrogen concentration distribution for the Neuse River Estuary was used to develop a prior distribution of the mean and variance of log nitrogen concentrations, and the sequentially updated posterior predictive distributions for each subsequent year. The same process was repeated for the chlorophyll α concentration distribution in the Neuse River Estuary. The prior distribution for chlorophyll-α was developed using an empirical model (NeuBERN) and the results from the SPARROW model. Although the prior distribution based on NeuBERN overestimated the chlorophyll α concentration, the sequentially updated posterior predictive distributions (based on post-

implementation measurements) quickly converged to a distribution similar to the observed chlorophyll-α concentration data.

Question-and-Answer Session with Dr. Kenneth Reckhow

- One participant commented that he thought that much of the Neuse was phosphorus limited. He asked if that would explain the poor prediction for chlorophyll-α. Dr. Reckhow responded that he agreed. The challenge is how to conclude definitively that a water body is limited by a particular nutrient. They will add a phosphorus component to the model.

- One participant asked what approach would be used to reparameterize SPARROW to handle subcatchments. Dr. Rechhow responded that they will use approaches that allow them to estimate parameter sets that will capture the covariants. They will not be identifying individual parameters.

- One participant commented that that you are exceeding expectations when you have very low chlorophyll levels. From his recent experience, there is considerable discussion among stakeholders to establish a lower criterion. Dr. Reckhow responded that the results he presented are not widely known; people have not recognized how much things have improved in the Neuse. One of the recommendations in the National Academy of Sciences study of the TMDL program was for the states to take the triannual review of standards more seriously.

- Iris Goodman commented that it is a challenge for everyone to develop ways to communicate to people in the fastest, most expeditious way to get to the answers they are seeking. Dr. Reckhow responded that you should try to listen to both the monitoring and modeling people, but ultimately the monitoring data may begin to dominate.

Bayesian Methods for Regional-Scale Stressor Response Models

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Abstract

We developed regional-scale eutrophication models for lakes, ponds and reservoirs to investigate the link between nutrients and chlorophyll-α. The Bayesian TREED (BTREED) model approach allows association of multiple environmental stressors with a biological response with simple linear models, while identifying subsets of the data in which the models fit well. Nutrient data for lakes and ponds (water body type = 4) and reservoirs (water body type = 5) across the United States were obtained from the U.S. Environmental Protection Agency (EPA) National Nutrient Criteria Database. The nutrient data consist of measurements for both stressor variables (such as total nitrogen and total phosphorus), and a response variable (chlorophyll-α), used in the BTREED model. Variables used in subsetting include ecoregion, water body type, month and categorical variables representing the nitrogen and chlorophyll analytical methods used. Markov chain Monte Carlo (MCMC) posterior exploration is used to guide a stochastic search through a rich suite of candidate tree structures to obtain models that better fit the data. The Bayes factor provides a goodness of fit criterion for comparison of resultant models. We randomly split the data into training and test sets; the training data were used in model estimation, and the test data were used to evaluate out of sample predictive performance of the model. An average relative efficiency of 1.02 between the training and test data for the four best fitting (highest log-likelihood) models suggests good performance in out of sample predictive efficiency relative to other eutrophication models. We found that the 98,169-observation dataset produced large, complex trees, making their structure difficult to interpret. Adjustments may be made to priors to control the size/complexity of resulting TREED models, improving interpretability to some extent. Some increased complexity, however, stems from the binary tree structure itself. We therefore intend to address these problems on two fronts. First, we are working to incorporate more predictor variables into our dataset for use in the end node models, in the hope of reducing the need to explain variability in the chlorophyll-α response with added complexity in the tree structure. Second, we are in the process of shifting our modeling framework to a more purely Bayesian Hierarchical one, in which the binary tree structure is absent. Knowledge of the tree structure identified using the BTREED approach will provide valuable information for use in determination of the hierarchical structure for use in the new framework.

Question-and-Answer Session with Dr. E. Conrad Lamon

- One participant commented that he had chaired an NRC committee on coastal eutrophication. They were asked by Congress and EPA's Office of Water to comment on nutrient criteria development for coastal waters. The committee had a strong consensus that concentration data were not helpful and that the criteria should be loadings to estuaries. The response of estuaries is not well correlated with standing concentrations. Total nitrogen and total phosphorus have a lot nonbiologically active pulls (e.g., phosphorus is stored in all sorts of inorganic forms). What managers are managing are the inputs, not the concentrations. He asked if Dr. Lamon would consider looking at load as one of the variables as opposed to concentrations for their lake analysis, and wondered what the advantage is to be able to predict chlorophyll from either total nitrogen or total phosphorus in the data set. Dr. Lamon responded that you need to know the relationship between nutrients and chlorophyll to reduce chlorophyll. At an annual average scale, you may get better results with load. They are using the nutrient criteria database and they do not have load information. They could go to the upstream river locations of each lake and find USGS data to map and calculate loads, which may be easier and better than using SPARROW estimates.

- One participant commented that he just completed a project where the task was to identify the commonly measured criteria that are most predictive of the designated use. He consistently found that chlorophyll was the best predictor of designated use, which suggests that what Dr. Lamon is doing is appropriate. He also stated that they commented on the National Academy of Sciences study on TMDLs as to where the criterion should be placed. If you stop with load, there is a good deal of hidden uncertainty between load and designated use that is missing from the prediction. You move from action, load, concentration, and then chlorophyll or some biological response in the designated use. If designated use is the driving factor in the objective, their structural equation modeling strongly suggested that chlorophyll was the appropriate predictor for eutrophication related impacts.

- Iris Goodman commented that Dr. Lamon's analysis showed the strong importance of method in controlling the trees. She asked if Dr. Lamon would prepare a 500-word essay that could be distributed to EPA Program Offices. Dr. Lamon agreed to prepare the essay. She also commented that in looking at some CART techniques that are not Bayesian based, one of the important aspects of those methods for users is to be able to do interpretation on the tree structure itself. She urged the group in their collaborations to begin looking at additional kinds of predictor variables that ultimately are useful for managers to gain a better understanding of the issues that they need to address. She offered to provide contacts from the landscape ecology grants who might have suggestions on important predictor variables that are ultimately useful for interpreting the tree structure.

- One participant asked if the BTREEDs were inverted multiple regressions rather than reverse ANOVA. In nutrient criteria development, one of the issues is how rigid the breaks are between 2.6 m and 16.3 m depth. He asked if one would expect a different relationship between loading, concentration, and endpoints like chlorophyll-**ɑ** or biological diversity to break at those specific levels, or if it is just a continuous gradient between nutrient concentrations and chlorophyll and it happens to be breaking at those points. Dr. Lamon responded that the breakpoints were not absolute or precise. This is an exploratory type method to indicate the important structure in the data that can be further developed with a fully Bayesian hierarchical approach in which a distribution on the split point could be obtained. The method does identify the change points fairly well. The participant asked if Dr. Lamon had classified the systems based on size but not on DOC. Dr. Lamon responded that there were fewer DOC than nitrogen or chlorophyll measurements to go with the phosphorus. The participant commented that the first step is to classify what you predict to find in the system so natural features are used to classify expected conditions. The next step is to look at how the systems vary along a phosphorus gradient (e.g., how a valued attribute such as chlorophyll changes along a phosphorus gradient). Dr. Lamon responded that it is classifying based on the change points and then the continuous is in the regression model.

- One participant asked how the model could be used to predict the effect of environment changes, such as climate change. Dr. Lamon responded the model could be used to the extent that climate changes cause changes in nitrogen or phosphorus concentrations in a lake. Temperature, however, is not included in the model. If temperature were included for climate change predictions, it would be outside of the range for past observation, which could be a problem with regression-based methods.

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 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).

The tasks completed are:

- Development of the database software shell.
- Development of a watershed loading Geographic Information System (GIS) based model.
- Development of Neural Net algorithms for modeling input/output (cause/effect) response of the ecological system (supervised ANN learning).
- Development of Neural Net unsupervised Self-Organizing Maps (SOM), followed by Canonical Correspondence Analysis derived (mined) from two large databases.
- Analysis and quantifying the risks expressed as Maximum Species Richness relationships for major stresses.

The workshop presentation features an application of unsupervised Artificial Neural Networks (ANN) yielding SOM. Indices of Biotic Integrity (IBI) and its metrics for fish were analyzed by ANN, followed by Canonical Correspondence Analysis (CCA) to extract (mine) knowledge on the impact of watershed and water body stresses on biotic integrity of receiving waters. Two large databases of measurements of about 50 parameters, including fish numbers from 2000 sites in Maryland, and about the same number of sites and a greater number of parameters from Ohio were used for the analysis, development and testing of the methodology. Self-Organizing Mapping by ANN discovered nonlinear clustering of the fish metrics of the IBIs that was then overlaid with clustering of environmental variables to find correlation between the metrics, their clusters and individual impact parameters. CCA then quantitatively identified the parameters of the greatest importance, the Cluster Dominating Parameters. This analysis has wide spread ecological implications and enables quantitative assessment of the impact of multiple stresses on IBIs and similar multimetric biotic indices.

Using the information on the top Cluster Dominating Parameters, an input-output ANN model was developed by supervised learning using the Ohio database. The model was very accurate for data used in calibration (randomly selected 75% of data, R = 0.99) and adequately accurate for verification with the remaining 25 percent of data (R = 0.76).

The team members have created a Web site where all reports and other publications or their abstracts will be available: http://www.coe.neu.edu/environment.

Question-and-Answer Session with Dr. Vladimir Novotny

- One participant asked how much the SOM was picking up the natural variabilities that the State of Ohio uses in their classification of expectant conditions in the weather to the streams. Dr. Novotny responded that it has something to do with the ecoregions. The northwest is part of the Lake Erie ecoregion. There was some relationship to ecoregions. Dr. Manolakos commented that they are training the SOM based on the metric scores as recorded in the database. They assume that the metric scores take into account the location of the sites.

Regional-Scale Population Models for Environmental Decision-Making

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 classified further 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.

UV-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 µ 0.01 ppb present in 71 percent of wetlands sampled in Survey 1, and in 100 percent 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 percent crop than in those where grassland comprised the greatest proportion of the buffer ([7.124 ppb vs. [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, $p = < 0.001\text{-}0.025$). However, neither land use (crop vs. 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

- One participant asked how far away the grasslands wetlands are from where the atrazine is used, and what the distance is over which the drift would be occurring. Dr. Schoff responded that it is a large drift and it is reasonable. It always is windy in the Prairie Pothole Region. One of the challenges in the 2003 season was to conduct UV attenuation measurements because the water surface has to be calm. It would be calm before 10 a.m. and after 5 p.m. The original presumption of the study was that atrazine would be run-off from agricultural fields. In this area, it does not appear to be happening.

- One participant asked why the DOC was not related to UV attenuation, and whether it is because the UV attenuation varied but not the DOC concentration. Dr. Schoff replied that the statement was correct. The participant commented that in areas with a lot of sun and long residence time, there could much photobleaching, which could change the transparency. Dr. Schoff responded that there is a lot of wind-driven mixing that takes place.

- One participant asked how the atrazine is applied. Dr. Schoff replied that much of the atrazine was applied by air. The participant asked if the sites were small or big fields and whether the grassland and crop land potholes were next to each other. Dr. Schoff responded that they attempted to locate crop sites that were embedded within a cornfield and were able to find about 50 percent of the sites within the vicinity of a cornfield. In North Dakota and South Dakota, most of the corn is grown for forage; therefore, the fields are smaller and more interspersed. In Iowa and Minnesota, they had a harder time finding crop sites.

- One participant asked if atrazine could be moving through the groundwater. Dr. Schoff responded that it could. The participant asked if GIS and distances from crop fields could be used to look at potential controlling factors. Dr. Schoff responded that a long-term study of the hydrology of the potholes has been set up in the Prairie Coteau ecoregion. He commented that their study is being done under a period of drought. Some areas are persistently wet and some are persistently dry. He suggested that EPA may wish to consider establishing a long-term study program to long at a 10-year time scale and capture some of the natural variations.

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 for nutrient criteria, Total Maximum Daily Loads (TMDLs), and stream management. The objectives of our research 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 used in water quality assessment. At the broad spatial scale, stream conditions throughout the southern Michigan region were surveyed and existing data from a variety of sources were compiled. We refined stream survey methods to relate early morning DO to human activities, contaminants and habitat alterations, and VEAs by sampling conditions at low flow, more than 3 days after rain events, and during early morning hours; thus controlling variation in DO as a result of natural factors. Preliminary results show: nitrogen and phosphorus 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. Interestingly, indirect relationships in the causal pathway from land use to nutrients, algal biomass, and low DO often were more precise than direct relationships, which indicates high temporal variation in intermediate factors.

At finer scales, we established master watersheds with either continuous DO and water quality monitoring or spatially intensive and repeated sampling. These watersheds will be used to parameterize processed based models. The instrumentation and continuous monitoring of Crane Creek is providing parameters for DO responses to complex interactions among processes operating at three temporal scales: (1) diurnal variation with light periods and photosynthesis; (2) daily development between weather-related events of biological assemblages that regulate diurnal variation in DO; and (3) weekly variation in weather disrupting hydrology of streams and related biological community development.

A processed-based model relating precipitation and land use to water quantity and quality was refined using intensive sampling of Cedar Creek. The model shows the importance of groundwater routes of transport of contaminants to streams in the poorly developed soils with high permeability. These soils are typical of many watersheds in the glaciated region of the upper Midwest and Great Lakes Region. Nitrate concentrations in Cedar Creek were predicted much better by a model that included groundwater inputs than traditional models without it. A 10-year simulation of the Cedar Creek watershed highlighted the significant role land use plays in influencing the distribution of nutrient concentrations in groundwater and in streams.

Future activities will integrate results of our broad and fine scale field assessments in a suite of statistical, processed-based, and hybrid models. Many of our statistical models are being used by the Michigan Department of Environmental Quality to establish nutrient criteria. We will continue to refine our models to improve understanding of how human activities can be managed to support ecological integrity, aquatic life use, and fisheries of stream ecosystems.

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 our IBM that simulates stream reaches to watershed-level assessment; (2) conduct a demonstration assessment; and (3) examine uncertainties and sensitivities in the regional assessment.

We are using and enhancing *inSTREAM* (individual-based stream trout research and assessment model), an existing IBM that represents how flow regimes and water quality parameters such as turbidity and temperature affect individual trout and, consequently, trout populations. The first objective is being met by developing ways to synthesize input for *inSTREAM* from data that are commonly available for western streams. The second objective is being met by conducting an example assessment of how changes in turbidity regime and flow regime, and presence of an exotic predator fish, affect a watershed's trout populations. The third objective is being met by two studies; one examines parameter uncertainty and sensitivity in *inSTREAM* applied to a single reach, and the second examines how sensitive model results are to uncertainty and variability in the channel shape and hydraulic input used to represent a site.

The preliminary results are: (1) Stream habitat survey data collected by the California Department of Fish and Game has been combined with other widely available information and stochastic modeling techniques to synthesize input for *inSTREAM*. These methods can be used to generate input representing a variety of sites within a region. (2) Site-specific example assessments show that *inSTREAM* is useful for predicting trout population responses to stressors such as flow regime alteration, increased turbidity, and introduced fish. Collaborative research with U.S. Forest Service scientists is improving our model of a key process: how turbidity affects fish feeding efficiency. We also used *inSTREAM* to model interactions between wild trout and stocked hatchery trout, and how the interactions could change if hatchery practices are changed to enhance survival of stocked fish. (3) A parameter uncertainty analysis showed that the primary output of *inSTREAM*, adult trout biomass, is not highly sensitive to any unexpected parameters and that the model can easily be calibrated to reproduce the observed size and abundance of yearling and adult trout.

Our results so far confirm that *inSTREAM* can be, when applied and analyzed carefully, a uniquely powerful tool for understanding the effects of multiple stressors on fish populations. The model is now in use by several resource agency and university scientists, and we conducted our first training class in July 2005.

In the final year of the project, we plan to finalize a public release of *inSTREAM*, including its software, a complete description of the model, and a guide to using it. These products are now in peer review prior to publication. A demonstration assessment will be completed using the South Fork Eel River watershed as a site. The analyses of uncertainties and sensitivities will be completed with studies of how sensitive the model's ranking of management alternatives is to uncertainty in parameters and in site-specific input data.

Question-and-Answer Session with Dr. Roland Lamberson

- One participant asked if the turbidity took into account watershed properties or just flows. For example, watershed properties such as logging could have a big impact on that relationship. Dr. Lamberson responded that turbidity was just an input parameter. They have a model for turbidity that they use in some cases to generate data.

- Iris Goodman commented that this was an interesting effort with a lot of challenges to try to scale it up to a regional application. It also could be very useful as a heuristic device in a simulated situation where you could take a simulated hypothetical system to try to reproduce and understand the most critical combinations of stressors. Dr. Lamerson responded that one of the major thrusts of the model is to be able to use it to look at individual behavior characteristics and how they impact the emergent population levels. They have looked at habitat selection and the interactions between wild and hatchery fish. In developing the model, they looked at density dependence in fish populations.

- One participant asked how the sensitivity impacts were calculated. Dr. Lamberson responded that they used professional judgment to establish the reasonable range for the parameter value. They then did simulations to investigate sensitivity of abundance of adult mature fish.

- One participant asked how important parameters for the indices of fish integrity (e.g., embeddedness, substrate, gradient) were incorporated into their model. Dr. Lamberson responded that they have detailed habitat structures. The stream structure is the actual stream structure from a real stream in California. There is difficulty in reproducing characteristics of a river because of problems in reproducing the gradients. Their gradients are much deeper; they used digital elevation maps to reproduce the gradients. Dr. Steve Railsback commented that they did not directly input emeddedness. They look at habitat parameters that reflect the amount of velocity shelter. If a substrate is coarse and large, there are places where fish can sit behind it and reduce its swimming speed, which reduces how much energy it needs to grow. If it is a highly embedded substrate, there are no velocity shelters. If the fish wants to sit in the current and feed, then it has to swim against the whole velocity of the river. Embeddedness also may affect food production. They do not try to model growth and production of the food that the fish eat because it could double or triple the complexity of the model. They do try to calibrate the model to try to reproduce observed growth rates by the adjusting their food production parameter. Substrate embeddedness would affect the food production. Channel shape and gradient are in the model but indirectly because they are in the hydrolic model that predicts the depth and velocity of the cells at different points for a different flow.

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

Ecological responses of global warming are expected and coastal ecosystems are particularly vulnerable because they are less buffered from temperature increase than more oceanic systems. Resulting alterations in species distribution patterns, coupled with the enhanced vulnerability to invasions by exotic species, can result in profound changes in communities and ecosystems. Added to the effects of climate change is the intense human-related use of these areas, which have resulted in a host of problems that often lead to habitat degradation and reduced ecosystem function and biodiversity. We have been using the southern New England coastal zone 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 the past 20 years and there has been a decline in the numbers of resident species. 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.

Question-and-Answer Session with Dr. Whitlatch

- Iris Goodman asked Dr. Whitlatch to discuss the implications on a functional basis of the increased cuttlefish invaders. Dr. Whitlatch replied that this most recent invader is causing a lot of concern in the shellfish industry. It has been reported that 40 square miles of Georgia's banks are covered by this species, which influences the scallop fishery. The fishing activities of the fishers are acting to disperse the organisms over a wider area. It has serious potential economic implications.

- One participant asked if it was a gross generalization to say that we might have some positive effect on the invasive species if we improve water quality. Dr. Whitlatch responded that water quality is correlated with it. The chlorophyll data for Long Island Sound is not very good. These organisms are all suspension feeders. It could be the interaction of temperature and productivity that is actually facilitating more recruitment (i.e., more eggs and sperm). As you increase the water quality of very polluted areas, you start to see invaders coming in. This also is true for shipworms. Docks that were built around the turn of the century were not affected by shipworms, but when the water quality is increased there is a shipworm problem; as a result, the docks are falling down. There are positives and negatives for cleanup of the coastal zones.

- One participant asked if there might be threshold effects in terms of the relationship between loss of biodiversity and invasives. Dr. Whitlatch responded that they have seen other types of threshold effects in their system. Predators of recently settled invaders are vital in controlling invaders. When those predators are removed or not present there is an abundance of invaders.

- One participant commented that Dr. Whitlatch had shown a strong negative relationship between biodiversity and invaders, and asked if it was expected to see that relationship in other systems if space was not such a strong major limiting resource. Dr. Whitlatch responded that if you do the same experiment and use a native species as the invader, you see exactly the same effect. It is not the fact that the native species are somehow collectively acting together to reduce the effects of a new species invading the environment. They are collectively reducing the amount of available space at any one particular time. The more species you have, the less space you have because of variations and fluctuations of their life histories. In soft sediment systems, they have tried to do similar experiments but there is no effect. Animals are not as space limited in soft sediment systems; they live in a three-dimensional sediment column, and they can partition their space both horizontally and vertically.

Climate, Land Use and UV Radiation on Aquatic Ecosystems

Interactive Effects of Climate Change, Wetlands, and Dissolved Organic Matter on UV Damage to Aquatic Foodwebs in the Ontonagon Watershed, Northern Michigan

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Abstract

Understanding the factors controlling ultraviolet radiation (UVR) flux into aquatic ecosystems is critical given its direct and indirect effects on many ecological processes. The strongest attenuator of light and UVR in aquatic ecosystems is dissolved organic matter (DOM), which previous studies suggest is controlled at the landscape scale primarily by wetland area and the discharge regimes of rivers and streams. Climate change may reduce DOM concentrations in aquatic ecosystems, thereby exacerbating UVR effects, by changing the amount and flow paths of DOM from upland and wetland ecosystems. We hypothesize that the linkages among wetland area and type, DOM, and climate will be the most important factors determining the amount of UVR damage to aquatic ecosystems at the landscape scale. Our objectives are to: (1) relate DOM concentration and chemistry in various tributaries of a relatively pristine watershed in the Lake Superior drainage basin (Ontonagon River in northern Michigan) to wetland and upland landscape characteristics and discharge via multivariate analysis; (2) determine interactions among UVR intensity and DOM chemistry, photodegradation, and biodegradation; and (3) determine the response of stream foodwebs to the interactions between UVR intensity and DOM concentration and type.

We have addressed these objectives through a combination of landscape and hydrological analyses; extensive sampling of water chemistry and UVR attenuation profiles in numerous streams for 2 years; analysis of the chemistry, photodegradation, and biodegradation of DOM; and experiments quantifying the effects of DOM concentration and source on UV damage on stream biota in a series of artificial stream experiments.

We sampled a dozen times over a 2-year period water chemistry and determined discharge in 35 subwatersheds in the Ontonagon watershed. Additionally, we did an initial survey of 60 sampling locations within the Ontonagon River watershed in September 2003. Thus, we have developed an extensive spatial and temporal dataset of water chemistry within this 3600 km^2 watershed. The best published landscape correlate with DOM flux in streams and rivers is with soil carbon:nitrogen (C:N) ratios. As this information was not available otherwise, we sampled 155 representative soils in the dominant soil types within the watershed to estimate the spatial coverage of soil C:N ratios within the watershed.

We have measured the spatial and temporal variation in the attenuation of UVR in a variety of streams within the Ontonagon Watershed and related UVR dosage to stream biota to water depth, water chemistry, and canopy cover. Additionally, we used plastic dosimetry strips to obtain a better spatial and temporal of UVR dosage within the watershed.

Our hydrological modeling research has taken a two-pronged approach. First, we have used USGS gauging station data, land-use data, and factorial analysis to examine landscape controls over seasonal and annual river discharge at four spatial levels (U.S. conterminous, U.S. Great Lakes basin, Upper Michigan, and Ontonagon watershed). Second, we recently hired a postdoctoral associate to use a basin-scale model to predict discharge and seasonal DOM concentrations in all 35 subwatersheds of the Ontonagon that we have been studying. Substantial progress has been made on parameterizing this model, and when complete we will use global climate model predictions to examine how climate change will affect DOM concentration and UVR penetration within the Ontonagon watershed.

We constructed a large artificial stream facility to examine experimentally how DOM and UVR interact in controlling food-web structure in streams. A number of different experiments have been completed and are being prepared for submission for publication.

Our major findings to date are: (1) As predicted, DOM is the major control over UVR dosage to aquatic biota and in streams and rivers with high DOM concentrations, such as the Ontonagon Watershed, most biota experience very low UVR exposure. (2) Although wetlands are a significant landscape predictor of DOM concentration and chemistry in streams, the area of different types of wetlands is important (some even having a negative correlation with DOM concentration), and other factors are important in predicting DOM concentrations in the complex glacial geology of our study area. (3) Climate and landscape effects on discharge and DOM concentration likely will have a much larger effect on aquatic biota in wetland-dominated watersheds than will UVR effects.

As soon as the soil C and N samples have been analyzed, we will use multivariate statistics to relate DOM concentration and chemical characteristics to season, discharge, and landscape characteristics in one of the most complete datasets to have attempted this at a relatively large watershed scale. When the basin-scale hydrological model is fully parameterized, we will add in our empirical landscape predictors of DOM dynamics to test how anticipated climate change will affect discharge, DOM concentration and chemistry, and UVR dosage of biota throughout the Ontonagon Watershed.

Question-and-Answer Session with Dr. Scott Bridgham

- One participant commented that the soil C:N as a control for DOM is going to be a reflection of the dominant trees and it will probably be responsive to the atmospheric deposition. Dr. Bridgham responded that one paper that was published had a $r^2 = .99$ (no variation) for the United States. The best correlation is not just the C:N ratio. In terms of cerol carbons, its value would be as an index of huminification. The more nitrogen, the lower the ratio; this results in more humified organic matter, which probably would reflect the amount of DOM.

- One participant asked if the photodegradation of the DOM could be related to the C:N ratio from whatever forms of nitrogen are present and, therefore, affecting different levels of production molecules such as hydrogen peroxide. Dr. Bridgham responded that this comment was correct. The huminification would have everything to do with the chromofores and their effect on light. It was beyond the scope of the study to look at some of the other photochemistry aspects. Most of their DOM was terrestrially derived.

- One participant commented that in many streams the residence time is too short to have an extensive photochemical effect, but it is more likely in ponds or lakes where it would be a bigger factor. Dr. Bridgham responded that many of the streams in their study are quite flat, wetland dominated, and with low flow. The other factor is high attenuation, so most of the water is not exposed to the sun. They did a fair amount of photodegradation and biodegradation work to try to understand the controls. There was a huge effect on DOM chemistry but not much effect on concentration.

- One participant asked Dr. Bridgham to comment on the role of DOM concentration versus the optical properties of DOM for different wetland types. Dr. Bridgham responded that very little work has been done in this area. Some studies have looked at different DOM concentrations, with very high DOC concentrations of 50 to 100 milligrams carbon per liter. There has been very little work done on mineral soil wetlands, including how the flow pathways would change and the effect of the DOM as it goes through the mineral soil down to the streams. These transport, biodegradation, and sorption mechanisms that will have huge effects on both the concentrations and the chemistry. Almost no work has been done in this area.

The Influence of Climate-Induced Alterations in Dissolved Organic Matter on Metal Toxicity and UV Radiation in Rocky Mountain Streams

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Abstract

The primary goal of our research was to investigate the influence of climate-induced changes in hydrology and dissolved organic material (DOM) on responses of stream ecosystems to the combined stress of ultraviolet radiation (UVR) and heavy metals. We hypothesized that changes in climate and UVR will alter the quality and quantity of DOM in Rocky Mountain streams. Because DOM regulates light attenuation and metal bioavailability in these systems, we predicted that exposure to UVR and metals will increase as a result of changes in DOM. We integrated climate and hydrologic modeling with an intensive field monitoring and experimental program to test the hypothesis that reductions in DOM increase bioavailability of metals and exposure to UV-B (280-320 nm) radiation. We estimated effects of climate-induced alterations in stream hydrology on DOM using DayCent-Chem, a model that simulates carbon, water, and nutrient flux to streams. In controlled laboratory experiments with a full-spectrum solar simulator, we irradiated DOM collected from six field sites for 24 hours and quantified changes in Cu complexation using a Cu^{2+} selective electrode. Additionally, we conducted field and microcosm experiments to test the hypothesis that UV-B exposure impacted benthic communities and that effects varied among locations along a metals gradient.

Analyses using the DayCent-Chem model showed that increasing temperature linearly by 2.5 ^{o}C over a 50 year period increased DOC concentrations relative to control runs. Results of our monitoring studies indicated that across 21 watersheds there was a significant relationship between DOM concentration and stream discharge. However, the timing of peak discharge and maximum concentrations of heavy metals, DOC and other physicochemical variables that influence metal toxicity varied among streams. Uptake of metals by the caddisfly (Trichoptera) *Arctopsyche grandis* was predicted by the biotic ligand model (BLM), a model that accounts for physicochemical factors influencing metal bioavailability. Results showed close agreement between observed and predicted metal levels in these organisms. After 24-hour exposure to simulated sunlight, DOM absorbance decreased by approximately 17-25 percent, significantly increasing exposure of benthic communities to UV-B. Photobleaching of DOM also increased the fraction of bioavailable Cu^{2+}, potentially increasing toxicity to aquatic organisms. Microcosm and field experiments conducted in Colorado and New Zealand showed significant effects of UV-B on benthic communities. Results indicated that mayflies (Ephemeroptera) were especially sensitive to UV-B, and that effects differed among locations. Our findings are significant because they demonstrate that benthic communities in shallow, alpine streams are exposed to intense UV-B radiation and that climate-induced reductions in DOC are likely to increase both metal bioavailability and UV-B exposure. In most cases, effects of these two stressors were additive; however, there were some examples where combined exposure to metals and UV-B were greater than either stressor alone. In the final phase of our research we are continuing to investigate the influence of hydrology and increased temperature on DOC concentration and export using the DayCent-Chem model.

Question-and-Answer Session with Dr. William Clements

- One participant asked if there were data on the contribution of autochthonous versus allochthonous DOC to the streams. Dr. Clements responded that Dr. Diane McKnight has done work using fluorescence index on characterizing not just autochthonous versus allochthonous but also a detailed quantitative analysis of the different types of carbohydrates and carbons. There is a seasonal variation in the relative importance of autochthonous versus allochthonous. Allochthonous appears to dominant in these alpine streams.

Interactions Among Climate, Humans, and Playa Wetlands on the Southern Great Plains

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Abstract

We measured avian, amphibian, and plant communities in 80 playas split between 2 years. In each year, 20 playas each were sampled in cropland watersheds and native grassland watersheds. Physical features of all playas were measured, including sediment depth, hydroperiod, basin volume, and playa area. This project was designed to address the hypothesis that climatic variability and landuse practices (e.g., crop production, conversion to grasslands) dictate hydroperiod and spatial distribution of wet playas, influencing the ecological structure of vegetation and animal communities that rely on playa wetlands for many life requisites. All field data have been collected, and we are in the process of analyzing all results and coordinating field data with model projections for climate effects on playa hydrology.

Grassland and cropland playas used in this study were in either fine or medium textured soils. Playas in fine textured soils were typically larger and contained less sediment than those in medium textured soil. Cropland playas contained more sediment (2-4 times greater) and had greater volume loss than grassland playas, regardless of soil texture. Hydroperiod was similar between cropland and grassland playas in 2003 (100 vs. 97 days, respectively) but not in 2004 when average hydroperiod length in grassland playas was 76 days longer than in cropland playas. Hydroperiod differences between years likely reflect differences in annual precipitation. Total rainfall in 2004 was about three-fold greater than in 2003.

Analysis of the avian and amphibian community data still is in progress. Preliminary results suggest that overall richness of avian communities is similar between cropland and grassland playas, ranging from six to eight species in each playa type. Exotic avian species were, however, typically observed in cropland playas to a greater degree than grassland playas. Species richness was typically two- to three-fold greater in wet playas than dry playas in both years. Also, avian community richness often was positively related to playa size, but this was dependent on the hydrologic state of the playa and season (e.g., wet playas in autumn, $r^2 = 0.497$; dry playas in summer, $r^2 = 0.443$).

Average amphibian community richness also was similar between cropland and grassland playas, with about three to four species observed on average in each playa type in 2003 and 2004. Cropland playas, however, were more likely to have no species (2003) or only one species (2004) compared to grassland playas, which always had at least two species. Overall, species richness was strongly related to hydroperiod in playas, with richness dropping sharply when hydroperiod fell below 100 days.

Current modeled predictions of hydroperiod and water volume in cropland playas show marked reductions over a 50-year time horizon, depending on the use of soil management practices such as furrow dikes or buffer strips. Indeed, although hydroperiod may remain stable during the first 16 years of cultivation (no furrow dikes), the rate of reduction in hydroperiod is rapid once it begins. For example, assuming a maximum of 123 wet days from May 1 to August 31, a typical cropland playa will have only 100 wet days after 26 years, leveling off at about 35 wet days after 39 years. In comparison, a typical native grassland playa is projected to lose only about 5 wet days after 50 years under the same conditions. These projections are dependent on cultivation strategies, crop type, soil texture, and climate, but suggest the potential for rapid deterioration of cropland playas subject to cultivation pressure, and are supported by empirical data from our study and others. We are in the process of modeling playa hydrology given stochastic temperature and rainfall data, and

assessing the influence of different crop types, watershed slopes, soil textures, and mitigation strategies, such as furrow dikes and buffer strips, on hydroperiod and water volume.

Although preliminary, our data support the rapid reduction in playa hydroperiod (and increased rates of water loss) as cropland playas fill with sediment. These changes in hydrology will have effects on playa function as related to biotic community composition. Indeed, the effect of cultivation and subsequent sediment loading on the hydrology of cropland playas is already occurring as evidenced by data from our study and others. Plant, avian, and amphibian community composition are subject to these alterations in cropland playas. For example, our data suggest that as hydroperiod length falls below 100 days, amphibian richness suffers from the loss of species with longer larval periods (often the rarer species in the community).

Question-and-Answer Session with Dr. Scott McMurry

- One participant asked what the restoration potential was for the playa sediments. Dr. McMurry responded that it could be done; however, there are questions about what the playa will look like and how it will function. No one knows, but it will be better than it is when it is fossilized. The participant asked if the vegetation regrows quickly. Dr. McMurry responded that no one knows. The first thing that needs to be done is to put in protection for the playas that are left. The only reason that there are playas left in native grasslands is because they exist in areas that a hard to farm. There are no incentives to protect them. It may become economically feasible to protect them in the future because it costs a tremendous amount of money to irrigate cotton fields by pumping out of the aquifer. It is somewhere between $3 to every $1 for pumping out of the ground versus pumping out of a playa. A lot of farmers pump out of the playa. The problem is that no one knows if the playa will be full of water in any given year. When the playa fills up with sediment, then it will have water fewer times and for shorter periods of time.

- One participant commented that he had heard that cotton was the most heavily pesticide applied crop that can be grown. Dr. McMurry responded that cotton gets pesticides, herbicides, insecticides, and defoliants. The participant commented that the amphibians living in these playas are fairly terrestrial, so they are being exposed both in the fields and in the playas. He asked if there was any indication of that type of stressor on richness or diversity. Dr. McMurry responded that over the past 2 years they have been conducting a side project to collect sediment in water. Last summer, they monitored 12 playas and collected water samples and tadpoles each week for a month. They are in the process of analyzing the data. Other studies that have been conducted have shown that amphibians from cropland playas weigh less and have smaller body size, and the populations tend to be denser. There are alterations in physiological and immune function endpoints. There are effects happening that may have something to do with the differences in the availability of food, differences in the per capita food amount, or other stressors related to hydroperiod. As part of another study, they have differences between crop and grass playas with respect to the rate that the water is lost. The rate of water loss out of crop playas is significantly faster than in grass playas.

Assessing the Consequences of Global Change for Aquatic Ecosystems: Climate, Land Use, and UV Radiation

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Abstract

Our primary objective in this study is to determine how current stream and landscape properties in the Lehigh River watershed influence the aquatic ecosystem response to variations in climate and solar ultraviolet radiation (UVR) and how past changes in land use have influenced stream processes. Our findings will contribute to understanding future responses of aquatic ecosystems to environmental changes, including anticipated increases in extreme weather conditions and increases in UV-B associated with ozone destruction in the stratosphere.

Our approach is to examine watershed and stream properties and processes on different scales of space and time to learn about functional relationships that influence UV impact. Biotic responses to UVR were tested by placing stream macroinvertebrates in a laboratory solar simulator, and by manipulating UV-B *in situ* for stream trophic groups. For stream-watershed interactions, we sampled stream water periodically across the entire watershed during base flow and storm flow conditions and also established stations at several headwater streams with automated equipment for sampling and monitoring rainfall, canopy throughfall, and stream water. Our samples were analyzed for properties that influence UV attenuation. We also made *in situ* and laboratory measurements of photobleaching rates and biolability of stream colored dissolved organic matter (CDOM). The role of the stream canopy on UVR exposure was examined with two complementary approaches: direct measurement of the canopy UVR transparency for specific stream reaches, and proxy measurements for predicting UV transparency (fisheye camera images from below the canopy and satellite images from above). We also digitized aerial photographs that record changes in land use and stream channel morphology since the 1940s to relate current storm flow patterns measured with *in situ* flow recorders.

In stream experiments with macroinvertebrates, the abundance of chironomids was enhanced during exposure to UVR, in spite of their sensitivity to UV-B. The optical quality and source of DOC differed by region: streams in Lehigh Valley region were enriched in algal CDOM whereas Pocono streams were dominated by wetland soil CDOM. On average, 14 percent of stream dissolved organic carbon (DOC) was consumed by bacteria during 2-day microcosm experiments, but this number increased to more than 40 percent when the water was photobleached by the equivalent of 2 days of sunlight. Forests have lower DOC export than streams during baseflow, but during storms the canopy is a major contributor to stream CDOM in forests. Turbidity and CDOM change on different times scales during storm runoff. We developed a method to relate laboratory water quality measurements directly to *in situ* UV attenuation. Stream DOC is correlated with percent area of wetlands in the watershed and in the absence of wetlands is correlated with percent area of farmland. At any given site, stream DOC is inversely correlated with specific conductance, a reflectance of the lower concentration of DOC in ion-rich groundwater.

In our previous work in lakes, we observed large variations among groups of organisms in their sensitivity to UVR and that DOC was a strong determinant of UV attenuation. We also expected suspended particles to have a bigger impact on UV attenuation in streams compared to lakes, especially during storm runoff. We also knew that UVR exposure of streams would be reduced in forested areas because of shading by the canopy. We now have UV-specific information on these factors for stream ecosystems in our region that can be tested for generality in other regions.

Our next steps include: (1) exploring the observed patterns for stream-watershed interactions in other parts of the watershed; and (2) determining whether shrubs and crop vegetation also contribute to CDOM in streams during storm runoff. We plan to integrate measurements of biolability and photolability with estimates of canopy UVR transparency to estimate the turnover of stream DOC (and corresponding oxygen demand) across the watershed.

Question-and-Answer Session with Dr. Bruce Hargreaves

- One participant questioned an outlier data point on the graph for canopy transmittance for diffuse irradiance. Dr. Hargreaves stated that everything is equivalent. Direct light and diffuse light change together. Diffuse light varies primarily on the openness of the canopy, whereas direct light depends on where the canopy opening is versus where the sun is, the time of day, and which way the steam is oriented. He could have said in his presentation that there is a high variability in the direct transmittance. If things are equivalent, you get a positive relationship, but there is a great potential for direct light to be all over the map. In reference to the outlier, that kind of data is not useful without a detailed mapping of where the gaps are in the canopy.

- One participant commented that r^2 is meaningful in terms of statistical significant when you have bivariant normality (i.e., you have a normal distribution in any direction). The reason that the r^2 is equal to 0.8716 is largely due to the point on the right. The r^2 does not have any meaning when virtually all of the data points are clustered in one spot. Dr. Hargreaves agreed. They find that relationship when they look at their wetlands. There is variation around the regression but they also find a trend. The data shown were a subsampling of their analysis. Dr. Hargreaves stated that he would have to fill in the gaps for his data if he were to compare to the r^2 of 0.1825 that Dr. Bridgham reported that had a more even distribution.

Joint Progress Review for U.S. EPA STAR Grants: Regional-Scale Stressor-Response Models and Consequences of Global Change for Aquatic Ecosystems

Sheraton National Hotel
900 S Orme Street
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November 3 – 4, 2005

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