Proceedings

Global Change and Ecosystem Protection Research STAR Progress Review Workshop

June 16-18, 2004
Alexandria, VA

Introduction

The U.S. Environmental Protection Agency's (EPA) mission is to protect, sustain and restore the health of ecosystems and communities. To advance the science needed to support this mission, EPA's Office of Research and Development (ORD) conducts research in-house at its own Laboratories and Centers. EPA ORD's National Center for Environmental Research (NCER) also sponsors extramural research at universities and nonprofit organizations through its Science To Achieve Results (STAR) Program.

This report summarizes the results of an NCER annual meeting to review progress in extramural research sponsored by its STAR Program. At this meeting, principal investigators made presentations describing their progress in research sponsored by two STAR solicitations: (1) Consequences of Global Change for Aquatic Ecosystems: Climate, Land Use, and UV Radiation, and (2) Regional Scale Stressor Response Models for Environmental Decision-Making. This research will inform public policy by helping resource managers and local decision makers to anticipate the future, address uncertainties, and prepare for environmental challenges.

This research was funded by two STAR research grant programs: (1) the Global Change Research Program, and (2) the Ecological Research Program. The grant that investigates consequences of global change for aquatic ecosystems is sponsored by the Global Change Research Program. The grant investigating regional-scale modeling of multiple stressors is co-sponsored by the Ecological Research Program and the Global Change Research Program.

EPA ORD's Global Change Research Program seeks to understand the potential consequences of global change for human health, aquatic ecosystems, and social well being in the United States. This entails: (1) improving the scientific capabilities and basis for projecting and evaluating effects and vulnerabilities of global change in the context of other stressors and human dimensions; (2) conducting assessments of the ecological, human health, and socioeconomic risks and opportunities presented by global change; and (3) assessing adaptation options to improve society's ability to effectively respond to the risks and opportunities presented by global change as they emerge.

The STAR Global Change Research Program focuses on science to support assessments of consequences, and research on the human dimensions of global change research activities are focused on:

(1) Conducting integrated assessments of the potential consequences of climate variability and change on small geographic locations (i.e., a sub-regional level) within the United States.
(2) Assessing the consequences of interactions between human activities and a changing climate.
(3) Investigating the consequences of global change for aquatic ecosystems: water quality, Climate, UV radiation, and land use.
(4) Understanding the consequences of global change for aquatic ecosystem services.

EPA ORD's Ecological Research Program supports research to address EPA's statutory responsibilities for protecting, maintaining, and restoring ecosystems as described in EPA's enabling legislation for air, water, waste, and toxics. This research emphasizes aquatic ecosystems, because these systems integrate the effects of stressors in all other media and because of the specific mandates of the Clean Water Act. ORD's Ecological Research Program has the following four primary goals 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.

ORD's STAR Ecological Research Program is designed to complement EPA's in-house research in this area. In this report, the research described to develop methods to investigate, simulate, and predict interactions of multiple stressors on the health of aquatic ecosystems directly supports the goal of developing forecasting methods.

For additional background information on these topics, see the Appendix regarding the two Requests for Applications (RFAs) that resulted in the award of the grants described in this report.

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/ncer.

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

U.S. Environmental Protection Agency's Global Change and Ecosystem Protection Research STAR Progress Review Workshop

Hilton Old Town Alexandria
1767 King Street
Alexandria, VA 22314

June 16 – 18, 2004

Agenda

Wednesday, June 16, 2004

1:00 – 1:30 p.m. **Welcome and Introduction**
Bernice Smith, Global (Ecosystems) Program Manager, Environmental Sciences Research Division, National Center for Environmental Research (NCER)

Jack Puzak, Acting Director, NCER

Becki Clark, Director, Environmental Sciences Research Division, NCER

Michael Slimak, Ph.D., Associate Director for Ecology, National Center for Environmental Assessment (NCEA)

1:30 – 4:30 p.m. **Climate, Land Use, and UV Radiation**

1:30 – 2:00 p.m. ***Interactive Effects of Climate Change, Wetlands, and Dissolved Organic Matter on UV Damage to Aquatic Foodwebs***
Scott Bridgham, University of Oregon

2:00 – 2:30 p.m. ***The Influence of Climate-Induced Alterations in Dissolved Organic Matter on Metal Toxicity and UV Radiation in Rocky Mountain Streams***
William Clements, Colorado State University

2:30 – 2:45 p.m. **Break**

2:45 – 3:15 p.m. ***Interactions Among Climate, Humans, and Playa Wetlands on the Southern High Plains***
Scott McMurry, Texas Technical University

3:15 – 3:45 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, Lehigh University

3:45 – 4:00 p.m. **Break**

4:00 – 4:30 p.m. **Panel Session With Presenters**

4:30 p.m. **Adjourn**

Thursday, June 17, 2004

8:00 – 8:30 a.m. **Introduction**
Iris Goodman, Ecological Research Team Leader, Environmental Sciences Research Division, NCER

8:30 – 11:30 a.m. **Regional Scaling for Environmental Decision Making: Statistical Modeling**

8:30 – 9:00 a.m. ***Bayesian Methods for Regional-Scale Stressor Response Models***
Conrad Lamon, Louisiana State University

9:00 – 9:30 a.m. ***Developing a Risk Propagation Model for Estimating Ecological Responses of Streams to Anthropogenic Watershed Stresses and Stream Modifications***
Vladimir Novotny, Northeastern University

9:30 – 9:45 a.m. **Break**

9:45 – 10:15 a.m. ***Adaptive Implementation Modeling and Monitoring for TMDL Refinement***
Kenneth Reckhow, Duke University

10:15 – 10:45 a.m. ***Developing Relations Among Human Activities, Stressors, and Stream Ecosystem Responses and Linkage in Integrated Regional, Multi-Stressor Models***
Mike Wiley, University of Michigan

10:45 – 11:00 a.m. **Break**

11:00 – 11:30 a.m. **Panel Session With Presenters**

11:30 – 1:00 p.m. **Lunch**

1:00 – 4:00 p.m. **Regional Scaling for Environmental Decision Making: Physical Modeling**

1:00 – 1:30 p.m. ***Development of Coupled Physical and Ecological Models for Stress-Response Simulations of the Apalachicola Bay Regional Ecosystem***
Mark Harwell, Florida A&M University

1:30 – 2:00 p.m. ***Developing Regional-Scale Stressor Response Models for Managing Eutrophication in Coastal Marine Ecosystems***
Robert Howarth, Cornell University

2:00 – 2:15 p.m. **Break**

2:15 – 2:45 p.m. ***A Shallow-Water Coastal Habitat Model for Regional-Scale Evaluation of Management Decisions in the Virginia Province***
Charles Gallegos, Smithsonian Institute

2:45 – 3:15 p.m. ***Development of a Regional-Scale Model for the Management of Multiple-Stressors in the Lake Erie Ecosystem***
Joseph Koonce, Case Western Reserve University

3:15 – 3:30 p.m. **Break**

3:30 – 4:00 p.m. **Panel Session With Presenters**

4:00 p.m. **Adjourn**

Friday, June 18, 2004

8:30 – 8:45 a.m. **Introduction**
Iris Goodman, Ecological Research Team Leader, Environmental Sciences Research Division, NCER

8:45 – 10:30 a.m. **Regional Scaling for Environmental Decision Making: Population Modeling**

8:45 – 9:15 a.m. ***Application of Individual-Based Fish Models to Regional Decision Making***
Roland Lamberson, Humboldt State University

9:15 – 9:45 a.m. ***Effects of Multiple Stressors on Aquatic Communities in the Prairie Pothole Region***
Patrick Schoff, University of Minnesota–Duluth

9:45 – 10:00 a.m. **Break**

10:00 – 10:30 a.m. **Panel Session With Presenters**

10:30 a.m. **Closing Remarks and Adjourn**
Bernice Smith, Global (Ecosystems) Program Manager, Environmental Sciences Research Division, NCER

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

Interactive Effects of Climate Change, Wetlands, and Dissolved Organic Matter on UV Damage to Aquatic Foodwebs

Scott D. Bridgham[1], Paul C. Frost[2], Gary A. Lamberti[2], David M. Lodge[2], Patricia A. Maurice[3], Carol A. Johnston[4], Boris A. Shmagin[4], James Larson[2], Kathryn C.Young[3], Zhiyu Zheng[4], and Christine Cherrier[1]
[1]Center for Ecology and Evolutionary Biology, University of Oregon, Eugene, OR; [2]Department of Biological Sciences, University of Notre Dame, Notre Dame, IN; [3]Department of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, IN; [4]Center for Biocomplexity Studies, South Dakota State University, Brookings, SD

The overarching goal of this project is to provide a better understanding of how land use, climate, and ultraviolet radiation (UVR) affect foodweb structure in streams and rivers through their complex interactions with dissolved organic matter (DOM). The objectives of this project are to: (1) relate DOM concentration and chemical characteristics in a relatively pristine watershed to discharge, landscape characteristics, and stream geomorphology; (2) determine interactions among UVR intensity and DOM chemistry, photodegradation, and biodegradation; and (3) determine the response of stream foodwebs to the interactions among UVR intensity and DOM concentration and type.

We have taken a four-pronged experimental approach to address the different scales at which these processes interact. First, we have taken a whole-watershed approach to examine landscape controls over DOM characteristics and UVR penetration into the water column in the 3,600 km^2 Ontonagon River Watershed in northern Michigan. In September 2002, we sampled 60 streams for DOM concentration and molecular weight, absorption characteristics, and a large number of related inorganic water chemistry variables. Based on this initial survey, we have continued to sample 35 of these streams approximately every 2 months. We are using Geographic Information Systems (GIS) databases with a regression approach and principal components analysis to quantify the effects of the landscape features, stream geomorphology characteristics, and discharge on our water chemistry data. We also are mapping the depth of UVR penetration into the water column across the Ontonagon Watershed based on UVR depth profiles and UVR dosimeters placed in streams across the watershed. Second, we are using historical records of discharge, landscape characteristics, and DOM concentration at multiple scales (the Ontonagon River Watershed, the Upper Midwest, and the entire United States) to understand how climate regulates DOM concentrations and UVR penetration in streams and rivers. Third, we built a large artificial stream facility at the University of Notre Dame Environmental Research Center (UNDERC), where we are performing a number of experiments varying DOM concentration and source in conjunction with different UVR barriers to examine the direct and interactive effects of these two factors on foodweb structure. Fourth, we will perform a number of laboratory experiments to examine the effects of photodegradation and biodegradation on DOM consumption and chemistry.

In our initial sampling of 60 streams in September 2002, drainage density (cumulative stream length per unit area) was the best single predictor of DOM concentration (r^2 = 0.38) in the landscape. The percent of wetlands in the landscape predicted a small, but significant amount of the variation (r^2 = 0.18) in DOM concentrations. DOM molecular weight was negatively correlated with drainage density and the percent of the watershed in open water. The dominant positive relationship between drainage density and DOM concentration is surprising and somewhat counterintuitive. We are exploring other hydrogeological factors that may be correlated with drainage density and more directly account for differences in stream-water DOM concentration and physiochemistry.

We measured the attenuation of ultraviolet B (UV-B), ultraviolet A (UV-A), and photosynthetically active radiation (PAR) in 22 of the streams in the summer of 2003. High observed attenuation coefficients (K_d) of UV-B and UV-A resulted in shallow depths (< 20 cm, UV-B; < 65 cm, UV-A) of 1 percent transmission, even in streams with relatively low dissolved organic carbon. $K_{d\ UVB}$ and $K_{d\ UVA}$ were significantly correlated with stream DOM concentration and absorbance but to no other stream water chemistry variables. A statistical model that incorporated water depth, stream DOM concentration, and forest canopy cover predicted very low UV-B flux to the stream beds of most streams of this region.

In our first artificial stream experiment, we established high (10-12 mg C L^{-1}) and low DOM concentrations (3-5 mg C L^{-1}) in artificial streams exposed to or shielded from UV-B. DOM, in the presence and absence of UV-B, significantly increased the accumulation of periphyton chlorophyll α and ash-free dry mass (AFDM). UV-B removal increased chlorophyll α but not AFDM accumulation during the experiment. Our results show stimulatory effects of DOM on the accumulation of stream periphyton, both due to its attenuation of UV-B and its nutritional subsidy.

In summary, our results to date indicate strong landscape controls over DOM concentration and chemical characteristics, but that wetlands are less important than reported in other studies despite their large coverage within the watershed. Forest canopy cover and DOM in streams likely limit UV damage to aquatic foodwebs. Our initial artificial stream experiments show strong direct effects of DOM on aquatic foodwebs, with a secondary but important indirect effect due to its attenuation of UVR.

The 2-year, seasonal watershed sampling of water chemistry will be completed by the autumn of 2004. GIS databases mostly have been collected and are being finalized. We will sample C:N ratios in dominant soil types within the watershed this summer and will incorporate these into the GIS database. We will place plastic dosimeters in streams throughout the watershed for up to several days at a time. The dosimeters provide a quantitative UVR dose that will be used to calibrate and test our landscape UVR model. Two artificial stream experiments are planned this summer to examine: (1) the direct and indirect effects of canopy shading on UVR effects on stream foodwebs, and (2) the effects of different DOM sources on UVR impacts on stream foodwebs. We will do intensive longitudinal surveys of seasonal and diel changes in DOM concentration and chemistry in streams with and without lake sources. Short-term and long-term biodegradation of different sources of DOM, coupled with photodegradation experiments, will be investigated.

Question-and-Answer Session With Dr. Scott Bridgham

- One participant commented that with respect to the landscape, at low stream density there may be a greater concentration of wetlands in the landscape, but more variability in the proportion of wetlands. Because of the colinearity between stream density and wetlands, the percent wetland relationship may not be dominant. Dr. Bridgham replied that he will investigate whether wetlands close to the stream makes a difference and the correlation between stream density and percent wetland.

- Another participant asked if the subwatersheds are nested. Dr. Bridgham responded that the higher order points are not independent of the lower order points; therefore, the subwatersheds are nested in this modeling structure.

- One participant asked about the discharge effect. Dr. Bridgham replied that the discharge data will not be completed until the summer, but he expects discharge to have an effect.

- One participant asked how the attenuations are measured. Dr. Bridgham responded that he is using a spectrometer to measure profiles, obtain K_d values, and relate the K_d values to other factors. Another participant commented that integrating the different wavelengths into an ultraviolet (UV)B signal may cause new problems and suggested choosing a new wavelength within the UVB (i.e., K_d values change with depth so that the broader the band chosen to integrate, the more difficult it is to interpret K_d).

- Iris Goodman commented that UV radiation and discharge may change with climate change and asked how this will be handled. She also asked if the landscape metrics and relationships developed during this research project can be used to estimate these changes in a new, unsampled area. Dr. Bridgham replied that this would be possible within the Upper Great Lakes region. All things are not transferrable because there are most likely different correlates in other regions.

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

William H. Clements[1], Jill S. Baron[2], Diane M. McKnight[3], and Joseph S. Meyer[4]
[1]Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, CO; [2]Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO; [3]Institute of Arctic and Alpine Research, University of Colorado, Boulder, CO; [4]Department of Zoology and Physiology, University of Wyoming, Laramie, WY

Increased levels of atmospheric carbon dioxide and associated global climate change over the next 100 years are expected to have significant impacts on riparian vegetation, biogeochemical cycles, and hydrologic processes in the Rocky Mountain region. Although considerable research has been devoted to understanding these direct impacts of global warming, much less is known about the interactions between climate change and other forms of anthropogenic disturbance. For example, benthic communities in high elevation streams of the Rocky Mountains are subjected to intense levels of ultraviolet radiation (UVR) because of shallow depth and naturally low levels of light-attenuating organic materials. Benthic communities in many of these streams are simultaneously exposed to elevated metals from abandoned mines, the toxicity and bioavailability of which also are determined by dissolved organic materials (DOM). The goal of this interdisciplinary research is to investigate the influence of climate-induced changes in stream hydrology and DOM on responses of stream ecosystems to other anthropogenic disturbances. We integrated climate and hydrologic modeling with an intensive field monitoring and experimental program to test the hypothesis that changes in DOM increase bioavailability of heavy metals and exposure to ultraviolet B (UV-B) radiation. Our field monitoring program demonstrated that vegetation and hydrologic processes (e.g., snowpack, discharge) regulate the concentration and composition of DOM in streams. Spatiotemporal variation in the amount of fulvic acid and the source of DOM (e.g., terrestrial vs. microbial) have important consequences for metal bioavailability and UV-B penetration in streams. Photodegradation of water collected from several field sites resulted in a 13 percent decrease in DOM and a corresponding increase in potential UV-B exposure. Microcosm experiments conducted in experimental streams showed that combined effects of UV-B and heavy metals on benthic communities were greater than either stressor alone. Finally, results of a field experiment conducted in 12 streams along a gradient of metal contamination demonstrated direct effects of UV-B on structure and function of benthic communities. These results demonstrate that interactions between UV-B and other anthropogenic stressors may structure aquatic communities in Rocky Mountain streams. Changes in the quality and quantity of DOM resulting from climate change may increase the strength of these interactions. Large-scale field experiments will be conducted in the summer of 2004 to assess the interaction between heavy metals and UV-B radiation. In 2005, experiments will be conducted in the southern hemisphere to determine physiological and behavioral responses to UV-B radiation.

Question-and-Answer Session With Dr. William Clements

- One participant asked if community metabolism was obtained by measuring respiration. Dr. Clements responded that this is essentially correct. The difference in dissolved oxygen was measured between the light chamber (in which photosynthesis and respiration occur) and the dark chamber (photosynthesis only). The participant suggested a control for water without organisms.

- The participant asked if Dr. Clements has investigated whether metals can change the dissolved organic carbon (DOC) quality and concentration, thereby secondarily affecting UV exposure. Dr. Clements replied that he has not yet investigated this question.

- Iris Goodman asked about the effect of the temporal dominance of snowmelt on discharge of DOC and dissolved organic matter (DOM). Does the temporal variability affect Dr. Clement's interpretations of the data? Dr. Clements responded that this may explain a fair amount of the discharge patterns across the different streams. The modeling implications in terms of climate change are lower snow packs in some regions. In addition, the reduction in snow pack and the flush of DOC happen to coincide with greatly elevated metal concentrations in the streams.

- One participant asked if there is any relationship between pH and metal bioavailability. Dr. Clements responded that with the exception of Snake River, the streams are almost neutral. The participant asked about the altitude of the streams. Dr. Clements replied that the streams are within several 100 m of one another, and elevation explains little of the UV variation among sites (canopy, aspect, and shading explain more).

- Another participant asked if metal transport to the stream would be decreased by reduced snow pack. Dr. Clements replied that the pulse of metals appears to be associated with higher snow packs. He hypothesized that if climate change reduces snow pack in these areas, there will be less metals input to these systems.

- One participant asked how metals enter the system. Dr. Clements responded that typically there are small mines located in a small drainage (such as a tributary) to the Arkansas River (i.e., lateral transport across terrestrial systems, not wetlands). Each stream has one or two fairly isolated point sources of metals.

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

Scott McMurry, W.P. Dayawansa, Loren Smith, David Willis, Clyde Martin, Ken Dixon, and Chris Theodorakis
Texas Tech University, Lubbock, TX

This research project was designed to address the hypothesis that climatic variability and land use 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. The objectives include: (1) determining the structure and composition of floral, amphibian, and avian communities in different playa wetland systems; (2) classifying the playa system according to the hydroperiod and spatial distribution of wet playas using climatic, soil, and geomorphic data; (3) studying the dynamics of vegetative, amphibian, and avian community composition in response to hydroperiod and spatial distribution of wet playas as emergent properties of objectives 1 and 2; and (4) studying long-term (40 years) changes in climate (temperature, rainfall amounts, and patterns) and resulting interactions among human influences (e.g., irrigation practices, ground water levels, land use patterns), hydroperiod and distribution of playas, and responses of biota requiring playa lakes.

Forty playas are being studied in each year, beginning in 2003. These sites consist of 20 playas each in cropland and grassland watersheds, distributed across 8 counties in the Southern High Plains in west Texas. Amphibian and avian communities were monitored every 2 weeks on each playa beginning with inundation and continuing until the following spring (birds) or until the playa dries (amphibians). Plant communities were surveyed in dry playas. We are just beginning our second field season, and all results to date refer to preliminary analysis of efforts from 2003 only.

Climatic patterns in 2003 were atypical, with most rainfall occurring in June and overall rainfall for the region representative of drought conditions (area average rainfall about 10 inches for the year). Average hydroperiod in cropland and grassland playas was 13.3 and 13.8 weeks, respectively. Avian surveys resulted in 104 total species observed across all playas, with 86 and 80 species observed in cropland and grassland playas, respectively. No differences were observed for species richness between playa types, although cropland and grassland playas were pooled, and species richness was greater in summer than in fall surveys in dry playas and total playas, but not wet playas. In addition, mean area of the playas surveyed was 9.1 ha for cropland playas and 14.1 ha for grassland playas. Avian species richness was positively correlated with playa area for wet cropland and grassland playas, but not dry playas.

Amphibian communities were surveyed in the same playas used for avian surveys. Amphibian community composition is similar between playa types, with seven species observed across all playas. Great plains toads, plains spadefoot toads, and New Mexico spadefoot toads were the most prevalent species in all playas. Overall, average species richness as determined by seine counts was 2.0 and 1.85 for grassland and cropland playas, respectively. The most obvious difference in community composition between playa types was the presence of Woodhouse toads in cropland playas with their near absence in grassland playas. Spadefoot toads represent the most abundant species in the region and are explosive high-density breeders. Spadefoot numbers decreased in both playa types over time, but appeared to disappear faster in cropland than grassland playas. Conversely, tiger salamanders take longer to grow and mature, and their numbers decreased faster in cropland playas than grassland playas, with captures persisting in grassland playas into November.

Analysis of avian, amphibian, vegetative community data and playa characteristics are not fully complete for the 2003 field season. Currently, we are working on several models for analyzing temperature extremes and gradients, rainfall patterns, chemical and sediment loading, and economic responses that will be used to integrate field data and assess impacts of climate variation and economics on hydroperiod and ecosystem responses.

Question-and-Answer Session With Dr. Scott McMurry

- One participant asked if a simple mass balance approach could be used to obtain the hydrology and groundwater flux. Dr. McMurry replied that this approach seems logical. The problems in determining the amount of recharge to the aquifer may be complicated by political issues. Another participant asked if changes in the composition of the water (e.g., specific conductance) from the playas have been investigated to address the recharge issue and assess whether there is any UV effect. Dr. McMurry said that he has not yet taken water samples, but he would like to examine the possible UV effect.

- Iris Goodman commented that the U.S. Geological Survey most likely has some hydrology information. She asked about the depth of the Ogallala under the playas and the average playa depth. Dr. McMurry replied that the Ogallala is about 100-250 ft below the playas, and the playas are relatively shallow (2-4 ft). Iris Goodman commented that remote sensing of the playa areas would be a simpler way to obtain a synoptic view, which could be related to synoptic surface coverages of temperature and precipitation.

- Another participant asked if the climate predictions are from global climate model scenarios. Dr. McMurry responded that historical correlations among temperatures at various locations have been used to date. A goal of the project is to conduct 40-year predictions. Initial projections of peak temperature predict higher rainfall and higher temperatures, with evaporation always exceeding precipitation.

- One participant asked if any agrochemicals are present in the aquifer water. Dr. McMurry replied that there are few studies to assess agricultural chemical loading in playas, but there are few insecticides used in the area. To his knowledge, there is no evidence of agrochemicals in the aquifer.

- Another participant commented that it would be helpful to determine the kinds of temperature and precipitation changes that would drive the playas out of existence. Dr. McMurry responded that this is the approach that they plan to pursue.

Assessing the Interactive Effects of Landscape, Climate, and UV Radiation on River Ecosystems: Modeling Transparency to UVR and the Response of Biota

Donald P. Morris, Bruce R. Hargreaves, Frank J. Pazzaglia, Richard N. Weisman, and Craig E. Williamson
Lehigh University, Bethlehem, PA

The overall objective of this research project is to determine how current watershed and river properties (including land use, land cover, riparian forest canopy, and stream channel morphology) interact with climate and solar radiation to determine ultraviolet (UV) exposure of aquatic organisms. We also will establish how temperature affects UV resistance of organisms, how dissolved oxygen is affected by UV exposure, and how stream animals have adapted to survive UV exposure. Our results should help us to predict future ecological responses to changes in climate patterns and stratospheric ozone.

Our approach to studying ultraviolet radiation (UVR) exposure and its biological impact in streams combines the use of Geographic Information Systems datasets, laboratory and field experiments, and intensive field measurements of stream and water properties throughout the Lehigh River watershed of Northeast Pennsylvania. We are working at small and large spatial and temporal scales to tease apart how UV exposure is influenced by variations in climate and watershed properties, including natural and anthropogenic changes. Modeling the sources, loading, and transport of dissolved organic matter is central to our effort because dissolved organic carbon (DOC) has been shown to control underwater UVR attenuation in most aquatic systems. We also are examining suspended sediment and its relationship to stream channel morphology. At a monthly time scale, we are sampling across the entire Lehigh River watershed to characterize seasonal patterns for concentration and quality of DOC. In specific sub-basins (including natural experiments with paired catchments), we are using automated samplers to characterize changes in water quality on an hourly time scale during storm hydrographs. At a decadal temporal scale, we are using a collection of aerial photographs to explore the relationship between changes in land use and stream channel morphology that influence storm runoff and sediment transport. At monthly and hourly temporal scales, we are combining measurements of DOC and UV attenuation with other optical and chemical measurements (particulate spectral absorption, turbidity, colored dissolved organic matter spectral fluorescence, specific conductance, pH, dissolved oxygen) to help us predict UVR attenuation and ecological impacts of UVR exposure. We are developing a model to predict the role of forest canopy on exposure of low order streams to UVR using a combination of GIS data, field measurements (combining hemispherical photography of forest canopy with incident UVR measurements), and data on stream orientation and terrain elevation. The UVR resistance of benthic macroinvertebrates from selected sites is being testing using a laboratory solar simulator instrument at a range of water temperatures and in-stream experimental manipulations of UVR exposure.

To date, we have established strong spatial correlations between UV attenuation and DOC, between DOC and wetland area, and between sub-basin discharge and total area. Strong temporal correlations exist between DOC and specific conductance, indicating a role for shifts between surface water and groundwater. Suspended sediments strongly influence UV attenuation during storm runoff. We observed a surprising shift from soil-derived DOC to algal-derived DOC across the watershed (based on spectral fluorescence measurements). Both photolability and biolability of river DOC varied seasonally, and variations were correlated with specific conductance and DOC source, but photobleached DOC did not accumulate in the system during this unusually wet period. Aquatic macroinvertebrates varied in their resistance to UVR and appeared to generally lack temperature-sensitive photoenzymatic repair mechanisms for UVR-induced DNA damage. UVR reaching low order streams was strongly influenced by forest canopy, in particular, by the fraction of sky visible.

We plan to explore the influence of flow path on concentration and quality of DOC during storm runoff (using ion composition analysis and automated sampling from paired catchments), and we will continue to explore watershed properties to refine our model for DOC loading (evaluating effects of land cover while controlling for factors such as slope and soil type). We will complete our canopy assessment and optical model development; ultraviolet B (UV-B) intensity at the stream surface should depend more on sky visibility than orientation of the stream relative to the path of the sun, because of the dominance of diffuse light over direct light for UV-B wavelengths. Also, we will test macroinvertebrates in stream manipulations of UVR exposure to look for behavior responses; complete our quantitation of the impact on dissolved oxygen of DOC respiration and photobleaching; and complete the analysis of stream channel morphology and the relationship to current and historical aerial photographs and relate this to suspended sediment.

Question-and-Answer Session With Dr. Bruce Hargreaves

- One participant asked if the difference in wetland type between the Pocono and lowland areas, which may be driving DOC type, has been investigated. Dr. Hargreaves replied that he will analyze the diverse wetland types in the Pocono area and the sparse wetlands in the southern area to determine the DOC concentration and quality associated with different wetland types. He added that a multifactoral analysis (wetland area type, soil type, slope) will be essential.

- Another participant asked how Dr. Hargreaves will distinguish between direct man-made channel modifications versus those associated with the flow regimes. Dr. Hargreaves responded that the man-made effects may be mediated through flow regime, with climate as a constant. Stream velocity, stream turbidity, and stream channel shape are being measured to understand the current relationship and link historical and present-day data. The working hypothesis is that land cover changes modify stormwater runoff patterns that drive sediment transport, changing the shape of the stream channel. There also are some historical flow and rain data to test the modeling effort. The participant commented that there appear to be few channelization effects or bank hardening with bulkheads or erosion control structures. Dr. Hargreaves responded that the largest man-made influence in the region is the growing use of detention/retention basins with development, not channelizing.

- One participant asked about the algal signature data and whether there are more dams lower in the watershed. Dr. Hargreaves replied that the dams are primarily in the upper section. The data on quality changes with specific conductance are not valid for output from a reservoir, but most areas are free flowing and without dams. The participant asked for Dr. Hargreaves' interpretation of the specific conductance data. Dr. Hargreaves replied that the working hypothesis, consistent with the data measured to date, is that during a storm there is an initial wave of surface runoff with higher and more soil-like DOC, which is followed by a surge in displaced groundwater. This hypothesis will be tested further.

- Another participant commented that the correlation between land use and geology is strong and will impact channel morphology. How will Dr. Hargreaves distinguish between these factors in the hydrology modeling? Dr. Hargreaves responded that the southern part of the watershed will be used to separate these factors because there is an extensive aerial historic record, and the geology is fairly constant. The northern, Pocono area has undergone rapid development recently, and there is a limited photographic record. An area of fairly uniform geology, such as that found in the south, is needed to compare areas that have or have not been developed.

PANEL SESSION 1 WITH PRESENTERS

- Ms. Bernice Smith asked the panel to answer the following questions: (1) What will be the outputs or products from the research? and (2) Who are the expected users of the research (scientists, governmental decisionmakers, regulated community, or the public)? Dr. Bridgham responded that the most important output of these research projects may be a greater knowledge of the interactions among changing factors such as climate, land use, and UV radiation, as well as the quantification of the relative importance of these interactions in distinct geographical areas. In cases where the approaches are similar yet the results differ, the investigators should try to explain these differences and develop generalities of how these factors interact to affect aquatic ecosystems. Dr. Brigham added that other key outputs are models of how these factors will impact and interact in aquatic food webs (e.g., how DOM concentration and chemistry will affect UV radiation at different depths in streams vs. lakes). There will be two primary users: scientists and policy decisionmakers, who require information on the interactions among and the relative impacts of land use, climate change, and UV effects in aquatic ecosystems.

  Dr. Clements stated that a more complete understanding of how UV and DOM interact is another key output. Three of the four research projects address the role of DOM in attenuating light or influencing metal bioavailability. This would be of direct interest to decisionmakers as they begin to implement modeling approaches to improve on metals criteria. Furthermore, few studies focus on the effect of UV on streams, and these projects will provide a better understanding of how UV directly and indirectly affects loading systems (i.e., stream/benthic organisms).

  Dr. Hargreaves commented that existing models often are on small spatial scales and short time spans. The existing models should be improved and extended and should encompass all aquatic systems (not just streams, rivers, and watersheds). Users include managers at different levels and the public. For example, farmers experimenting with no-till agriculture would benefit from knowledge of its effect on DOC export, turbidity, and nutrients. Turbidity, oxygen, and temperature affect fish habitat quality as well as UV attenuation; thus, efforts to model the impact of UV could affect the characterization of fish habitat quality, which would benefit fisheries managers.

  Dr. McMurry commented that one of his outputs will be the development of models that describe the relationship among temperature changes, rainfall changes, land use practices, and so on. It is crucial to assess the feasibility and cost effectiveness of a suite of best management practices or mitigation strategies (e.g., buffer strips, excavating) that would lessen the effects of agricultural activities on the playas. The results can be extrapolated to other parts of the Plains (Nebraska, Kansas, Colorado, New Mexico) and can be used by policymakers and regulators to assist with future legislation on the implementation of land use practices, agricultural subsidies, or wetlands management. There is a great deal of interest from landowners regarding management strategies to increase playa health.

  Ms. Smith asked if stakeholders will be involved in identifying mitigation strategies and whether the efficacy of these mitigation strategies has been tested. Dr. McMurry replied that to his knowledge, nothing has been tested. A cost-benefit analysis could be conducted on a strategy to excavate sediment from a playa, but a private landowner most likely will not be willing to pay. A cost-benefit analysis also could be done using buffer strips that have been implemented to prevent sediment flow to a playa.

  Iris Goodman commented that with respect to mitigation strategies, it is important to consider the most sensitive variable (e.g., precipitation, temperature change, and the effect of changing climate or sediment infiltration and a loss of playa area).

- One participant commented on the striking similarities (DOC and UV) and differences (DOC sources, DOC amounts) among the regions described in these research projects. For general recommendations to decisionmakers on how climate change and land use will interact with UVB in streams, a general model is needed. Do the different regions under investigation encompass all of the variability in land use-DOC relationships, and what progress has been made in the development of a general model? Dr. Hargreaves responded that this could be an outcome in Phase II of his research project (which has not yet been funded); it would be instructive to work together to develop an overall model using data from the different climate regimes.

- Dr. Bridgham emphasized the large and significant role of DOM in structuring aquatic food webs. DOM affects the flux to aquatic ecosystems through changes in land use or climate. DOM may have a larger effect than UV radiation on aquatic ecosystems.

- Iris Goodman asked the panel members to comment on the temporal variability of their systems in a more global way. What are the appropriate time scales needed to investigate the various interactions? Dr. Clements replied that his system consists of snowmelt-driven streams, and the short-term temporal variation (peak discharge, peak DOC concentration) is fairly predictable from year to year. A time scale from early April to October appears to capture the majority of short-term variation in streams. The timing of the snowmelt has shifted somewhat dramatically during the last 5 years, however, and longer term records will be needed to discern the longer term changes in snow pack that drive this system.

  Dr. Hargreaves commented that a longer time span is needed for model development in lakes. Large seasonal changes are observed with weather patterns, and equally large interannual changes are expected. To understand the mechanisms and processes that underlie different flow paths, however, a smaller spatial and temporal scale (hourly) is informative.

  Dr. McMurry stated that his interest is in long-term changes in the Southern High Plains under various conditions. The system is extremely dynamic (e.g., inches of rainfall vary dramatically from year to year), with limited historic data. The short-term information and historic data will assist with longer term predictions.

- Mr. Mike Slimak commented that when studying climate change, investigators should consider the issue of abrupt change and whether there are important thresholds in each system (i.e., the point at which there is a switch in ecosystem function could be an important threshold). The rate of climate change is an issue. The systems may not adapt to fast change as they do to relatively slow change; the systems may switch or change abruptly in response.

  Mr. Slimak asked Dr. McMurry if he has found any deformed amphibians in the High Plains. Dr. McMurry replied that there are very few. Mr. Slimak responded that parasites, which are not present in the playas, could be causing the deformities documented in other regions. The other potential causes of these deformities (UV radiation and pesticides) are present in the playa system. Dr. Hargreaves commented that because there is no salt around the edge of Dr. McMurry’s system, there is no buildup of water or pesticides (i.e., water is leaving through the cracks). The water must be leaving faster than it is evaporating because there is no salt residue.

- One participant asked if all of the investigators are measuring land use and colored (C) DOM export. Dr. Clements responded that he is not. Dr. Bridgham replied that he is measuring CDOM and a host of inorganic chemistry variables to examine controls over nutrient fluxes, but not CDOM absorbance. Dr. Hargreaves commented that this would be a valuable measurement, especially if a reliable estimate of response to photobleaching through spectral slope can be obtained. DOC-specific absorbance can be predicted from spectral slope in the UV range and the fluorescence index.

- Another participant asked the panel if any of the results have challenged expectations and how this will influence future laboratory work and the larger research community's views on climate change and aquatic ecosystem function. Dr. Clements responded that his results are consistent with expectations, although some lack statistical power. Dr. Bridgham replied that wetlands appear to be a poor correlate with DOM in his wetland-heavy landscape as compared to other studies, possibly because of flow paths. Different tracers will be used to gain an understanding of the different sources of DOM and flow paths to investigate the weak wetlands signal as compared to other studies. In addition, DOM in streams and rivers appears to have higher absorptivity for UV radiation than in previous lake studies, suggesting that it is important as a control over UV penetration into the water column. Dr. Hargreaves stated that he did not expect the large role and high proportion of algal DOC in many of the streams. DOC may make stream UV attenuation more sensitive to UV because algal production of DOC appears to respond to UV exposure. Dr. Hargreaves had assumed that DOC was acting as a filter and coming from elsewhere.

- Dr. McMurry commented that in his system, hydroperiods differ based on sediment loads in the playas, which in turn influence biotic responses. Dr. McMurry will examine thresholds ("% full") in future experiments. Despite shorter hydroperiods, full playas could still function at some level. What about playas that are only one-half full? There may be a threshold at which cropland playas fail and grassland playas continue to function at less than full capacity.

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

Statistical Modeling

Bayesian Methods for Regional-Scale Eutrophication Models

Conrad Lamon, III
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The goal of our research is to link multiple environmental stressors to eutrophication endpoints in regional-scale eutrophication models. This begs (at least) two questions. First, what is a region, and second, what is the model specification within that region? Our approach to this problem is to use modern classification and regression trees (CART) and hierarchical Bayesian techniques in conjunction with the U.S. Environmental Protection Agency's (EPA) Nutrient Criteria Database (NCD). Generally, these methods use a Markov Chain Monte Carlo approach iteratively to: (1) generate geographic regions at random, (2) fit models for those regions, and (3) update the probabilities associated with those regions based on model fit criteria. The use of Bayesian methods allow us to report prediction uncertainty, are consistent with available data, and allow updates and improvements, thereby conforming to the National Research Council's Recommendations for Total Maximum Daily Load Model Development (NRC, 2001). Such an approach has been recently demonstrated using EPA's National Eutrophication Survey data (Lamon and Stow, 2004, *in press*). Lamon and Stow (2004) report identification of four distinct regions in the continental United States and that $\log_{10}$(TP) is the most important predictor of $\log_{10}$(Chla) in the Northwest and Northeast, $\log_{10}$(lake depth) is the most important predictor in the Southwest, and $\log_{10}$(TN) is the most important predictor in the Southeast. The relatively low importance of $\log_{10}$(TP) as a predictor in the Southeast may explain the poor performance of models developed for lakes in the Canadian Shield when applied in the Southeast. Future activities include: (1) acquiring more potential predictor variables not included in the NCD, (2) applying the method demonstrated in Lamon and Stow (2004) to the NCD, (3) using important hierarchies identified in step 2 in a less structured Hierarchical Bayesian Modeling framework, (4) extending these methods to include nonlinear specifications in end node models, and (5) developing a toolbox to facilitate the application of these models and visualization of results.

References:

Lamon, E.C. and C.A. Stow. Bayesian methods for regional scale lake eutrophication models. *Water Research* (in press, 2004).

National Research Council (NRC). Assessing the TMDL approach to water quality management. Washington, DC: National Academy Press, 2001.

Question-and-Answer Session With Dr. E. Conrad Lamon, III

- One participant asked if the algorithm allows specifications other than latitude and longitude (i.e., areas or ecoregions that are more mechanistically derived). Dr. Lamon responded that the predictor values can be continuous or discrete; categorical variables such as ecoregions, states, or U.S. Environmental Protection Agency (EPA) regions can and are being used with the NCD dataset. The participant added that this would ensure that the starting point is based on physical issues, which would be less arbitrary. Dr. Lamon stated that he will address the spatial issue, but space may not be the most important variable. As shown by slide #19, the dendrogram representation of a CART model, including nonspatial variables in the tree structure, appears to result in a better fit to EPA NES data. The most important variable may be phosphorous level. Another participant commented that in his work developing region-specific models, there was little difference between the ecoregion and state breakdowns. Ecoregions, states, and so on may be surrogates for underlying causes. Dr. Lamon stated that latitude and longitude most likely are not a direct cause. If the purpose is to fit a model, spatial referencing and regionalization should be abandoned. If the purpose is to apply total maximum daily loads (TMDLs), however, a regulatory framework is required, and states or regions become necessary.

- Iris Goodman asked if the technique can analyze only one response variable at a time. Dr. Lamon replied that only one variable is possible at this point. Iris Goodman asked how different response variables will be integrated with respect to management issues as the work progresses. Dr. Lamon replied that he will seek guidance from EPA and utilize a decision-theoretic approach that involves assigning utility to different responses.

- One participant asked Dr. Lamon to comment on the relative contribution of the Bayesian model versus the ordinary least squares model. Dr. Lamon replied that to conduct a stochastic model search, a model probability must be calculated, which does not make sense in a classical framework (inference in a classical framework assumes that the model is correct). In the Bayesian framework, we use a ratio of likelihood based fit criteria (the Bayes factor) to evaluate evidence (contained in the data) for or against a model relative to a competing model to guide our stochastic model search.

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

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The main objectives and outcomes of this research project are: (1) a model that will include pollutant inputs and watershed and waterbody modification (pollution but not a pollutant) such as land use changes and land use, channelization and impoundments for navigation or flood control, and riparian corridor modification as the key root stressors; (2) development of quantitative and layered risk progression from the basic root stressors to the biotic endpoints (fish and macroinvertebrate IBIs); and (3) study the possibility of mitigating the stressors in a way that would have the most beneficial impact on the biotic endpoints with the model.

The research also will develop methodology for resource managers on how to use the developed model, how to monitor anthropogenic stresses, and how to estimate the impact of changes in the intensity of the stressors on the biotic integrity of the water body at the near field and far field impact zones.

The model will be *a posteriori* developed by using the wealth of data collected in the Midwest. Once the model is developed, it will be tested on two rivers in the Northeast: the Charles River in the Boston Metropolitan area and one other river to be selected. In the Northeast, acid deposition will be considered as one of the major stressors that is absent in the Midwest.

The model will be hierarchically layered and progressing in four layers from the lowest layer stressors to the highest layer to the biotic endpoints. The functional interrelationships between the layers will be developed and tested on subcomponent (deterministic) model levels and, overall, by artificial neural net modeling. The team will investigate how risks, due to stressors, propagate through the ecosystem to the biotic endpoint expressed by the indices of biotic integrity. The following hypotheses of the model are being investigated:

1. Are the effects of common stressors additive along the headwaters to an estuary continuum or do different factors limit the fish and shellfish?

2. How might environmental change threaten the ecosystem integrity? What are the potential thresholds and breakpoints of the ecosystem response to environmental change?

3. What is the uncertainty in the model predictions? How are model results extrapolated from one place to another and from one timeframe to another? What are the geographical limits of the model?

The model will address the following stressors:

1. Stressors associated with listed impairment in the current Clean Water Act (suspended and embedded sediments, nutrients and toxics).

2. Hydrological and hydraulical stressors such as impoundment and navigation, variability of flow and temperature.

3. Changes in land use patterns affecting habitats and pollutant loads.

The following tasks have been completed:

1. The interdisciplinary team from four universities has been assembled, and contracts have been issued.

2. Methodology for the project has been developed that includes all tasks, deadlines, and responsibilities. The pilot watersheds have been selected and information is being collected.

3. The database shell developed by the team member from the Illinois Water Survey is being adapted and used by the entire team. Data is now being downloaded for the selected watersheds from agencies and entered into the database.

4. Two technical reports critically evaluating the literature findings have been completed and will be published by the team on its Web site.

5. Four publications (journal and conference proceedings), describing the concepts of the model and its components and underlying theory, have been prepared and submitted for peer reviews and publication.

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

The team has now entered into the main exploratory and development phase. The next steps in phase II are:

1. Completing the database.

2. Analyzing and quantifying the risks expressed as Maximum Species Richness relationships for all stresses.

3. Developing risk propagation functions and links and neural net models.

4. River continuum issues. Several projects will address the effects of habitat, fragmentation, and other stressors on the individual metrics of the biotic endpoints.

In phase III of the research, the team will:

1. Finalize and test the model.

2. Develop a model manual and prepare a workshop for potential model users.

3. Develop a final report.

Question-and-Answer Session With Dr. Vladimir Novotny

- One participant commented that it would be interesting to compare the neural net and classification and regression tree models (both pattern recognition) to examine the inferences that arise from using parallel approaches with similar goals. Dr. Novotny replied that he will most likely conduct a parallel investigation using Bayesian methods. Neural nets, unlike Bayesian procedures, can handle nonlinear relationships.

- Iris Goodman stated that this neural net model examines the propagation of risk through the four hierarchal layers. Iris Goodman asked how the model handles the propagation of uncertainty in the estimates through the course- to fine-scale layers. Dr. Novotny responded that neural nets determine the parameters with the greatest impact. One of these parameters is randomness, which is associated with uncertainty or "white noise."

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

Kenneth H. Reckhow
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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 will be the NeuBERN Bayes network estuary model linked with the U.S. Geological Survey (USGS) Neuse SPARROW model; AIMMS will allow us to analytically integrate TMDL modeling with post-implementation monitoring to refine and improve the TMDL over time.

Several concurrent activities have proceeded during the first year of this project. Immediate attention was directed toward linking the USGS Neuse SPARROW watershed model with the NeuBERN estuary model, as these models are solved with different time steps. At the same time, work has occurred with each model separately to address important modifications. We have refit Neuse SPARROW as a Bayesian model, accounting for spatial correlation. In addition for SPARROW, we are beginning to work on a strategy for revision of the model parameters to account for land use change or best management practices implemented as part of a TMDL. For NeuBERN, we are re-specifying the nutrient-phytoplankton model to add more mechanistic detail.

All of this work is a prelude to the key task: develop and apply an integrated modeling and monitoring approach for adaptive implementation of TMDLs. We are beginning the development of a “value of information” assessment strategy that will be used with the linked SPARROW-NeuBERN model to identify additional monitoring/research that will yield the greatest improvement in the TMDL forecast. At this point, we plan to do this work in two distinct phases because of the limited time period to assess estuarine response to TMDL implementation. In phase 1, we will develop and apply the value of information procedure for the combined models. In phase 2, we will demonstrate how newly acquired data can be used to update the model and improve the TMDL forecast.

Question-and-Answer Session With Dr. Kenneth Reckhow

- Dr. Novotny asked if the model can incorporate more stringent compliance. Dr. Reckhow replied that he can easily use an exceedance other than 10 percent. In terms of monitoring, it is not clear whether the 10 percent is a sample or a population characteristic. In addition, the model forecasting requires uncertainty analysis.

- One participant asked how the 40 μg/L chlorophyll a criterion was chosen and whether a measure more important to stakeholders than chlorophyll should be used. Dr. Reckhow responded that he is involved in a project to determine the best predictive criterion of an elicited designated use and the criterion level associated with different percentages of attainment. This would inform decisionmakers of: (1) the risks posed by different levels of nonattainment; and (2) the basis for a criterion. The chlorophyll criterion was selected in 1979 by a group of scientists charged with deciding the level of chlorophyll that should be associated with a narrow designated-use statement.

- Another participant asked whether all of the conditional probabilities used in model construction must be derived from the watershed under investigation. Dr. Reckhow replied that this is not the case. The participant asked how the data are weighted in postimplementation model refinement (i.e., data derived from the response of the system versus underlying data potentially derived from another system). Dr. Reckhow responded that the model is decomposable, so the majority of conditional probabilities were derived via expert elicitation or nonlinear regression analysis of data from the system. A cross-sectional estuarine data set was used for one of the relationships, which is justified because the cross-sectional model reflects common behavior over time in a sample of estuaries that includes the Neuse. The data update would be Neuse specific.

- One participant asked about what occurs when a use is unattainable. Dr. Reckhow responded that EPA needs to provide better guidance on use attainability analysis. In addition, some designated uses may not be realistic because they were selected somewhat arbitrarily in the 1970s to meet 1985 goals. Dr. Reckhow added that the stakeholder component was included in his research to determine how to implement adaptive management procedures to ensure that a use can be attained.

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

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Nutrients, sediments, dissolved oxygen (DO), temperature, and hydrology are common ecological factors in streams affected by humans, and all have profound effects on valued ecological attributes. The objectives of this research project are to relate human activities to these common stressors and to relate those stressors to the natural fisheries capital as well as ecological integrity of stream ecosystems.

We have started a preliminary review of a preexisting database of land use, water chemistry, algae, invertebrates, and fish from about 200 Michigan streams to determine relations among anthropogenic stressors and valued attributes. This database is the result of three past and two ongoing, large-scale surveys of streams in the upper Great Lakes region. We expect that results of approximately 1,000 streams will be compiled for the region by the conclusion of our study. A study of nitrification potential of streams with different levels of agricultural activity was conducted to refine methods and get preliminary results on relationships between human activities and nitrification potential in streams.

Low DO is not likely a significant stressor of fish and ecological integrity in a high percentage of streams in the upper Great Lakes region; however, this relationship probably varies among ecoregions and with stream hydrogeomorphology. Low DO and great responses of biota are rare in regions with deep glacial tills and poorly developed soils where intense agriculture is uncommon, but also hydrologic mixing is high and potential for algal blooms is low. However, low DO stress is most likely in low-gradient channelized streams and where agricultural activity is great. Confined animal feed operations present an important problem that may have limited spatial extent, but are intense where they occur.

In a study of oxygen demand related to nitrification potential in streams with a wide range of agricultural activities, little relation between oxygen regulation by N-based oxygen demand and agricultural activity was observed. Higher N-based oxygen demand was found in sediments than in the water column of streams. Ammonia transformation methods of measuring N-based oxygen demand were found to be the most precise among the many methods that could be used to measure this parameter.

Two major strategies are planned for the next year. First, we plan to supplement ongoing surveys of algae, invertegrates, fish, water chemistry, and land use in the Great Lakes region with intensive surveys of oxygen depletion. Oxygen depletion and temperature in streams will be assessed in a limited number of streams (40) with diurnal sampling by survey teams and automated metering. In addition, a more extended survey of early morning and late afternoon DO and temperature will be conducted in additional streams to characterize DO conditions in a broader range of stream conditions. Second, we plan to conduct an intensive study of stream conditions in a region of Michigan with numerous confined animal feeding operations and especially intense applications of manure waste to fields. The location and loading of waste on fields is known. Ecological surveys will be conducted of streams in this region, which are mostly low-gradient streams and highly susceptible to interactive effects of low current velocity, channelization, high temperature, and low DO.

Question-and-Answer Session With Dr. Mike Wiley

- Dr. Novotny commented on the similarities in the various research projects, despite the focus on different stressors. He stated that information sharing and data sharing among this small research group could be advantageous. Iris Goodman suggested evaluating similarities and differences in the approaches and the data.

- One participant asked about the methods used to determine the threshold responses. Dr. Wiley responded that the issue is scaling mismatch; analytical approaches are needed to make the statistical connections. The next step will be to use the Michigan and Wisconsin data sets to produce a similar biological response index for hydraulic stresses, temperature, and nutrients that can be forward applied to the Mid-Atlantic Highlands data. That is, the biota will be used to bring the scale of stressor and response "into sync" so that thresholds are more likely to be seen.

PANEL SESSION 2 WITH PRESENTERS

- Iris Goodman commented that all of the investigators appear to be using a combination of data sources: existing predictor variables from physical information and their own field-generated data. Should data from different sources be treated differently in a statistical framework? Dr. Wiley replied that different data sets should be treated differently with respect to their pedigrees. The source of the data is significant, and methods are needed to pool disperse and disparate data.

  Dr. Reckhow stated that an analysis should be reflective of a population in a region at a certain time. That is, the sampling design should provide an unbiased estimator of the population's characteristics. Attentiveness to a sample's space-time attributes will allow inferences about the entire population. In addition, data collected by different sampling methods cannot always be pooled.

  Dr. Novotny commented that investigators commonly rely on other people's data when conducting a regional study. Regional data are plagued by inconsistencies in methodology and meaning. Dr. Novotny stated that an open-access, centralized data bank may be useful to address the issues of data availability and compatibility.

  Dr. Lamon commented that he makes dummy variable adjustments to account for data source or method in his research with the Nutrient Criteria Database. The source agency or method number are examples of categorical variables that may be included in the tree portion of the Bayesian TREED models we are developing, and disparate data sources or methods that cannot be compared are identified by the algorithm and assigned to separate subsets. Dr. Lamon added that the source (method not agency) seems to be important and appears as an early split in the trees produced in preliminary analyses with the NCD data.

- Iris Goodman asked the panel members to describe how the model output from forecasts and simulations will be depicted with respect to space and time. Dr. Wiley responded that he will use river classification units and map the data spatially by time. Dr. Reckhow replied that his model, which is specific to the Neuse and generalizable to technique, will provide a probability-density function reflecting the concentration of the relative criterion over space-time in the water body. Dr. Novotny stated that he is developing a cause-effect model; thus, as the cause (stressor) changes, the model should reflect the change. Time averaging is needed; the endpoint response changes annually or seasonally (not daily). Dr. Lamon stated that he is not using any specific time-series analysis method at this time, although the work includes a month index for seasonality. In the second phase of the analysis a more hierarchal approach will be utilized, allowing time sequencing and temporal autocorrelation to be incorporated into the project.

- Iris Goodman stated that modeling simulations inform decisionmakers. She asked how these models will assist with decisions on managing for different objectives. For example, should people manage to achieve the largest improvement in system response or to reduce uncertainty in model forecasting? Dr. Reckhow replied that the most important objective of a postimplementation monitoring program with respect to a Total Maximum Daily Load (TMDL) is whether compliance with some criterion has been achieved. Some monitoring activities are informative in assessing compliance (of interest to regulators), and other monitoring activities/experiments are more informative in improving the model and future TMDL forecasts (of interest to a different clientele). The decision of whether resources will go toward achieving compliance, doing better science, and so on depends on which client's utility function matters most. Dr. Wiley stated that his stakeholders include watershed nonprofit groups and local governmental units, who may be more concerned that a system is moving in the right direction than the accuracy of model predictions.

- Ms. Smith asked Dr. Reckhow to define compliance monitoring versus effectiveness monitoring. Dr. Reckhow replied that compliance monitoring assesses whether compliance with a criterion was achieved. In contrast, effectiveness monitoring assesses whether a goal (e.g., load reduction) for a watershed was achieved through some action or set of actions. A third issue is monitoring or experimentation that leads to improved models.

  Ms. Smith asked Dr. Reckhow to expand on the issue of the value of information assessment strategy. Dr. Reckhow replied that information assessment is analogous to a sensitivity analysis. That is, what is the model forecast sensitive to with respect to uncertainty in input to the model (hypothetical monitoring activities) when assessing compliance with a criterion? Ms. Smith asked how methods such as field experimentation will be incorporated into the model. Dr. Reckhow responded that field experiments will be incorporated using the same principle, but directed at a different objective (e.g., assessing what will be learned from an experiment rather than assessing compliance with some criterion). The model captures uncertainty in the forecast and the reduction in uncertainty associated with proposed actions, enabling an assessment of the value of the sample information.

  Ms. Smith asked how metadata is incorporated in the analysis process. Dr. Novotny stated that he used a dummy variable to account for nonunified data in a regional context, but future investigators should not have these problems. Dr. Reckhow commented that metadata is vital to allow another team to understand the nature and limitations of the data. Protocols for metadata will be critical to data sharing.

Physical Modeling

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

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The Apalachicola Bay ecosystem is a relatively pristine system on the coast of the Florida panhandle. It is home to the Apalachicola National Estuarine Research Reserve (ANERR) and is one of the Nation's major producers of oysters. The Bay is significantly influenced by freshwater flows from the Apalachicola, Chattahoochee, and Flint River system (ACF), which drains almost 50,000 km^2 of GA, AL, and FL. Of particular concern are the present and anticipated reductions below the historical freshwater flows into the Bay from the ACF system because of human usage, particularly for urban use in Atlanta and for center-pivot irrigation agriculture in GA. Valued ecosystem components (VECs) of the Bay include: salt marshes, oysters, recreational fisheries, and the associated aesthetic, endangered, and recreational species of birds, fish, and invertebrates. Stressors identified as affecting the Bay include: changes in salinity, changes in sediment dynamics and turbidity, sea-level rise, nutrient inputs, tropical storms and hurricanes, and habitat alteration along the coast. This research project is developing a set of coupled physical and ecological models that can be used as assessment tools to evaluate the stress-responses of the Bay's ecological systems to natural and anthropogenic stressors. A three-dimensional hydrodynamical model (based on the Princeton Ocean Model) is being calibrated to the Bay and subsequently will be coupled with the U.S. Environmental Protection Agency (EPA) WASP 6 water quality model to simulate the current, transport, salinity, sediment, and nutrient regimes of the Bay. The MODBRNCH River model is being calibrated to the Apalachicola River system, and will be coupled to the Bay hydrodynamic-water quality model. This physical model will be coupled through a Geographic Information Systems' framework to a set of ecological models to simulate ecological effects on the salt marsh ecosystem, the oyster populations of the Bay, and the habitat mosaic distribution of the Bay ecosystem. The salt marsh model is the initial ecological model that is presently under development. Under separate funding, high-resolution hyperspectral remote sensing imagery has been acquired for the Bay and associated ecosystems, which is presently being analyzed to provide information for model calibration and stress responses. Using EPA's ecological risk assessment framework, once this coupled model system is developed, it will be tested against potential scenarios of environmental stressors to demonstrate the utility of the models as a tool for ecological risk assessment and risk management of the regional ecosystem. The coupled model product will be available for support to the environmental decisionmaking process for the Apalachicola Bay and ACF regional ecosystem.

Question-and-Answer Session With Dr. Mark Harwell

- One participant asked who will be involved in the demonstration risk assessment. Dr. Harwell responded that he may ask stakeholders for a set of plausible scenarios under Apalachicola-Flint-Chattahoochee management or conduct a demonstration project to provide bounds (e.g., no constraint on water release vs. significant drawdown for urban or agricultural use).

- Iris Goodman asked if the three ecological model subcomponents—salinity, oysters, and habitat suitability—address all of the valued ecosystem component (VEC) endpoints. Dr. Harwell replied that there are too many stressors affecting the system to address all of the endpoints; instead, the model can handle a subset of all possible stressors (e.g., turbidity, salinity, fecal coliform transport, nutrients). The stressors were prioritized based on their importance to the system, with water management-associated stressors deemed most important. Water management affects the system through salinity, and salinity, in turn, affects oyster health.

Developing Regional-Scale Stressor Models for Managing Eutrophication in Coastal Marine Ecosystems, Including Interactions of Nutrients, Sediments, Land-Use Change, and Climate Variability and Change

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Our goal is to: (1) develop a regional-scale model for analyzing nutrient inputs to coastal ecosystems; (2) work toward development of a 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 continuing to develop and test the Regional Nutrient Management Model (ReNuMa), a model designed to be used by managers to evaluate sources and magnitude of nutrient and sediment fluxes from regions and large watersheds to coastal marine ecosystems, and to be responsive to watershed management practices; we are explicitly refining and modifying this model to increase its effectiveness as a tool to investigate the interacting effects of climate variability, potential future climate change, and land-use change. Second, we are working toward the development of a classification scheme for the sensitivity of coastal systems to nutrient pollution. We are particularly interested in how climate change and other stressors such as sediment loading and water diversions interact with this sensitivity.

For the first part of our research, we have developed a new module that tracks atmospheric deposition of nitrogen onto the landscape and that predicts downstream fluxes of this nitrogen as a function of the extent of deposition. Previous models have underestimated this term in regions where deposition is greater than 10 kg N per hectare per year (as occurs in much of the northeastern United States). We also have been working toward the development of a better predictive capability for retention and loss of nitrogen through denitrification; our analysis with a comparative study of large watersheds shows (paradoxically) that these losses are greater in wetter climates. For the second part of our research, we have started to use simple, first principle models of interactions of nutrients with the biota to develop a classification scheme for sensitivity to nutrient pollution. Our preliminary work with these models suggests a strong nonlinearity of response of estuaries to water residence times.

Nutrients are now the largest pollution problem in the United States. The set of tools that we are developing 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. Also, it 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 report (2000) on coastal nutrient pollution.

For the ReNuMa model, our next step is to finalize the module on denitrification and nitrogen retention in the landscape as a function of climate, and we will begin to add improved modules for loss of nutrients from agricultural systems. For the work on sensitivity of estuaries to nutrient pollution, we will further develop our first principle models and begin to test these against available data sets. We also may work to develop better data sets for estuarine responses, focusing on weekly to seasonal time scales and addressing interannual variability (current data sets stress annual, average behavior).

Question-and-Answer Session With Dr. Robert Howarth

- Dr. Howarth commented that the data are for average, long-term, total nitrogen fluxes from a U.S. Geological Survey database. Ammonia is a small part, and all of the watersheds have consistent organic nitrogen export (60-70% of the load in watersheds with relatively few nitrogen inputs under human control). In watersheds where nitrogen load and nitrogen flux are increasing, all of the increase is in nitrate (90-95% nitrate).

- One participant commented that he conducted an empirical analysis on the Neuse similar to Dr. Howarth's conceptual diagrams (tradeoffs in residence times, etc.), and his results appear to verify Dr. Howarth's synthesis of all the simultaneous processes. Dr. Howarth stated that rather than searching for statistical patterns *de novo*, this research was designed to develop a conceptual basis that can be used to search for linear and nonlinear patterns.

- Another participant asked how the climate change scenarios will be generated and if this process can be standardized among investigators. Dr. Howarth replied that to date, he has explored the effect of current climate variability on nutrient flux for the model. The goal is to have modules in the model that will allow managers to evaluate options to reduce nitrogen by a certain percent and to determine if the solution will work with future climate. The major climate change models, which project different climatic futures, will be used to generate daily meteorologic data using a range of scenarios. Managers will evaluate the sensitivity of their option to the range of possible future climates. Dr. Howarth stated that standardizing the process among investigators would be beneficial to avoid confusion. A participant suggested that Dr. Howarth contact Project Officer Janet Gamble for ideas on scenarios in this regional area and information regarding a climate service/land use Web tool. Dr. Howarth stated that an early version of his model can be downloaded from the Web.

- One participant commented that climate change scenarios differ regionally in terms of the degree of predictability. For example, two global climate models result in very different responses to precipitation in the Florida Gulf Coast region, but more consistent responses in other parts of the United States. The predictability varies by stressor; temperature may be more consistent within a region than precipitation. Thus, this group of investigators may not be able to use consistent climate change scenarios or drive from the national assessment, although a sensitivity analysis could be used to circumvent this fundamental problem. Dr. Howarth agreed and stated that some fluxes will be more sensitive to climate change than others and will vary regionally.

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

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Management decisions to protect estuaries are being made in the context of unprecedented environmental changes. For example, increased ultraviolet (UV) radiation, especially the damaging ultraviolet B (UV-B), has been documented and is expected to continue even at temperate latitudes. The carbon dioxide (CO_2) concentration of the atmosphere rose by 30 percent in the 20th century and is continuing to climb at a rate of about 1 percent per year. The effects of CO_2 and other greenhouse gasses on global climate change are highly uncertain, but alteration of rainfall and runoff patterns are considered likely. Interactions between altered flow 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. However, the effects of simultaneous, multiple stressors have not been incorporated previously into models of ecosystem processes.

Our modeling efforts focus on shallow tributary embayments and small tidal creeks of the Chesapeake Bay, because the ecological importance of shallow systems far exceeds their volumetric contribution to the Bay. Their importance derives from the many hectares of potential habitat for submersed aquatic vegetation created by their highly indented shorelines, and from their role as spawning and nursery grounds for finfish and as refuge habitats for juvenile fish and crabs. The end points for our model will be those indicators being used as de-listing criteria for the Chesapeake Bay, namely chlorophyll, water clarity (diffuse attenuation coefficient), and dissolved oxygen.

We will represent shallow sub-estuaries as well-mixed compartments, which receive and process inputs from their local watershed and exchange materials at their seaward boundaries. Mass balance modeling techniques will be employed for the model structure, with rate processes dependent on interactions among stressors. For stressor interactions in the watershed, we will consider interactions between climate-induced flow alteration with changes in land use, as they impact delivery of nutrients and sediments to the estuary. In wetlands, we will consider the interactions between rising CO_2 and wetland distribution on delivery of dissolved organic matter (DOM). In the estuary, we will model interactions among nutrients, sediments, DOM, and UV-B on plankton growth and light penetration. We will use a Monte Carlo approach that will facilitate investigation of alternative management scenarios, and predict cumulative distribution functions of the delisting criteria for comparison with reference curves that are currently under development.

Progress to date has consisted of identification of component models from the literature for selected processses, identification of data sets for model testing, and preliminary analyses of morphometric features of a number of tributary embayments and their watersheds. A field program for determining the concentration of colored dissolved organic matter (CDOM) in runoff from different land uses and in marsh pore water as a function of CO_2 concentration was instituted in the spring of 2004.

In the coming year, we will focus on Geographic Information Systems analysis of small tributary embayments, coding and testing of model components, and analysis of CDOM flux data.

Question-and-Answer Session With Dr. Charles Gallegos

- Iris Goodman asked if the data from the 80 sites are being used to set up boundary conditions for the shallow-water tributary embayment (STE) simulations. Dr. Gallegos replied that he is using these basic morphometry data (e.g., watershed area, watershed area to estuary area ratios, volume, the width of the opening in relation to length). Hundreds of sites will be needed to obtain the simulation boundaries and the range of conditions.

- One participant asked if main-channel nutrient loading, as well as local watershed effects, influence the STEs. Dr. Gallegos responded that this influence is large and that the main-stem exchange can overwhelm, depending on where a subestuary is located along the main axis. Changes in main-channel nutrient loading will be included in overall scenarios because regional (not local) managers may have the ability to impact this variable.

- Another participant asked how this generic model treats such variations in a generic sense. Dr. Gallegos replied that he will run a Monte Carlo simulation using many different morphologies and inputs. The participant asked if the generalized sensitivity analysis will yield acceptable behavior regions for key response variables, which in turn will determine feasible parameter sets. Dr. Gallegos agreed and added that the parameter sets will be refined by discarding physically meaningless behaviors, and only a subset of those parameter sets will meet management criteria. The participant asked if the reliability of the generic model's functional relationships can be evaluated. Dr. Gallegos replied that he will evaluate a few select systems and calibration in the traditional sense (i.e., certain systems have basic monitoring in place that can be used to examine salinity and chlorophyll regimes on a more standard time-series basis).

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

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The objective of this research is to develop a regional-scale, stressor-response model for the management of the Lake Erie ecosystem. Stressors addressed will 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.

Our 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 the watershed of the Lake Erie ecosystem; and (5) identifying and evaluating critical breakpoints in ecosystem integrity of the Lake Erie ecosystem and of its integrated management.

The first year's research has focused on the development of geodatabases, a multi-modeling framework to explore cross-scale interactions of linked watershed-lake processes, and adaptive decision analysis methods for the management decision domain of the Lake Erie ecosystem. To tackle the scientific uncertainty confounding representation of cross-scale interactions, we have employed a landscape approach to identify classes of landscapes, which provide spatial data for models, a basis for designing internal model structure, and a hierarchical structure for information exchange between models of varying extent and resolution. In our preliminary work, we have shown that land use/land cover changes at 30 m pixel resolution can be linked to tributary fish habitat utilized by Lake Erie fish species at the level of river valley segments (average area of 0.5 km^2). Further, we are applying various hydrologic transport models at the scale of these catchments to predict TMDL contributions for phosphorous and sediment. Our multi-modeling framework is based on a common discrete event simulator and includes extensible markup language (XML) interfaces to structure models of landscape objects and data to provide hierarchical communication among models. The XML interfaces also provide an extensive meta-modeling framework for representing and understanding cross-scale interactions.

On the basis of this preliminary work, we have been able to secure cooperative agreements with various planning initiatives. In particular, the functional approach that we have developed for land-water interactions has led to collaboration with Ohio's Balanced Growth Initiative, and we are sharing our databases and models to identify priority conservation areas in the Lake Erie Basin of OH. An unexpected outcome is the development of a meta-structure for model and decision analysis tools that improves quality assurance and quality control for the project and model applications.

Planned activity for the next year will expand on this year's work. Milestones for next year include: full implementation of multi-modeling framework and application to stressors, completion of error analysis of linked multi-models, analysis of error on management decisions, and further analysis of ecological risk of nutrient inputs and land-use changes in the Lake Erie watershed.

Question-and-Answer Session With Dr. Joseph Koonce

- Dr. Novotny asked what expertise Dr. Koonce will use in his complex modeling scheme. Dr. Koonce replied that there are more than two investigators involved as well as a community that is concerned with the same problem. One advantage is that the model-driven architecture and discrete event simulation systems are open source activities; thus, some of these components already have been developed. After recoding some existing work, the basic shell is ready to accept the models. In addition, the same problems more generally intersect systems biology. The functional genome programs face many of the same challenges (e.g., high-performance computing). The frameworks are in place, and the focus is on the cross-scale additivity problem in the context of influencing select decisions.

- One participant asked how Dr. Koonce will estimate the 600 parameters and their covariance structure. Dr. Koonce replied that the analysis becomes complex with such a large parameter space. Parameter space is ordered, that is, multiple sets of parameters will result in the same trajectories of model behavior. Detailed studies of parameter space will be conducted with something capable of being parallelized and thus used in high-performance computing.

PANEL SESSION 3 WITH PRESENTERS

- Iris Goodman commented that a key theme discussed by the panel is how to conceptualize large systems and processes occurring at different spatial and temporal scales of projects in their initial stages mechanistically.

- Mr. Slimak stated that risk managers cannot relate to or do not care about the outcomes of certain risk assessments. He asked about the role of the social sciences in the panelists' projects. Dr. Hartwell replied that the social sciences are not explicitly incorporated in his research project; however, he involved social scientists and stakeholders in the identification of ecological and societal VECs such as water management and oysters. Dr. Hartwell is involved in a second research project to assess stakeholder/decisionmaker knowledge of global climate change. The initial results suggest that the "state of the knowledge" is poor. The state of the knowledge should be improved and the science articulated in terms that stakeholders understand. In addition, an extensive team of National Oceanic and Atmospheric Administration (NOAA)-funded economists are investigating environmental valuation and quantification of VECs to capture economic, efficiency, and long-term sustainability issues.

  Dr. Howarth stated that information gleaned on the sensitivity of estuaries to nutrient pollution will be used by EPA's Office of Water in developing nitrogen criteria and NOAA in developing monitoring strategies; social science is not involved. There is a social science need, however, in the watershed modeling part of the research project. A U.S. Department of Agriculture grant will be used to incorporate the stakeholder community in model development: economists will add cost-benefit analysis to the modeling framework, communication scientists will determine how to best convey the output and availability of the model, and the Susquehanna River Basin Coalition will ensure that the model is useful to stakeholders.

  Dr. Gallegos stated that although the social science component is not directly built into his research project, such interactions are a part of his work with the Estuarine and Great Lakes Program. General interests and scientific jargon often make the interactions difficult. The most useful product for social scientists may be a range of scenarios (e.g., nutrient delivery for 100 percent forested to 100 percent row crop watersheds).

  Dr. Koonce stated that social science has been included in his project in several ways. Dr. Benjamin Hobbs provides expertise on decision processes, which incorporate value systems. In addition, there is interest from the larger community and natural partners in several areas (e.g., urban planners). A mutual framework is needed to facilitate interactions between scientists and citizen groups/decisionmakers. At the same time, the government is interacting with watershed partners to determine how to organize the data to answer similar questions. EPA has created a social landscape with many sophisticated stakeholder groups, who influence the design and applications of research. The projects often are influenced by public groups with differing interests (a general direction for a watershed, a margin of safety for regulators). A set of tools is needed to facilitate intergroup communication about issues such as tradeoffs and limited resources.

- Dr. Koonce asked if value of information and social science are important issues for EPA. Ms. Smith responded that she wanted to clarify the term and determine how it might influence the research. Iris Goodman commented that EPA is not monolithic and perspectives differ. Iris Goodman would use value of information to integrate monitoring questions with modeling simulations to determine the most cost-effective monitoring design to meet an objective. Mr. Slimak stated that the Office of Management and Budget has stressed outcomes (e.g., reduction of air pollution) rather than outputs (e.g., journal articles) of research programs, which is a social as well as natural/physical science question.

- Dr. Bridgham asked how the potential interactive effects of multiple stressors (climate change, radiation, etc.) are built into the models and how the model output from multiple stressors is tested against an experimental framework, which is a difficult task in aquatic ecosystems. Dr. Howarth replied that he has reliable historical data on nutrient flux in all 13 watersheds under investigation in the Northeastern United States from the mid-1970s or earlier. The model is being built based on simple first principles and scaling for average behavior for the 1990s, but a test of the interaction of climate with land use change or nutrient use will determine how well the model backcasts. There have been large changes in farming and land use practices and significant climatic oscillations, and an experiment over time will be used to test the model.

  Dr. Harwell stated that it is difficult to handle all of the interactions among multiple stressors; there are too many stressors, too many combinations, and too much natural variability. The model construct can be used, however, to identify and prioritize the most important direct stressor-effect relationships through sensitivity analysis. These relationships can be used to examine changes in parameters such as temperature or precipitation. The objective is to gain knowledge of first-order, primary effects at a regional scale, without investigating every possible interaction.

  Dr. Gallegos stated that investigators should utilize the interactions that they have the most knowledge of and explore the consequences of those interactions (e.g., the inhibition of photosynthesis by UV light). A library of biological weighting functions for different systems and data on how nutrients influence recovery of inhibition by UV are being built into his model. As a large number of possible scenarios are examined, some subtle interactions may emerge.

  Dr. Koonce commented that the issue of cross-scale additivity of stressors is fundamental to understanding complex systems. Natural systems filter; they allow very strong cause-effect relationships to appear in some contexts and not others. The systems are complex causal networks, and simple cause-effect linkages are rare and context sensitive. The question of how strategically selected subsets of stressors interact across scales must be addressed when taking a regional approach.

Population Modeling

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

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The impact of stress on fish populations is an emergent phenomena resulting from the stress felt by individual fish and exhibited as part of their collective dynamics. Individual-based models are particularly well suited for use as stress-response models because they provide for the application of stress directly on virtual individuals and, as a result, the population-level response emerges naturally. This provides the potential for the emergence of complex and unexpected dynamics arising from the interaction of multiple stessors. Our objective is to gain an understanding of the dynamics that may emerge from combinations of stress on salmonids, particularly the impacts of variation in flow and temperature regimes, turbidity, and competing species. In addition, we are developing methods for incorporating the local results of our individual-based models into a linked, larger scale model for use in regional decision-making.

Over the past several months, we have been actively progressing on three fronts: (1) conducting sensitivity analysis of the model; (2) developing a two-species version of the model (competition); and (3) developing an understanding of the complexity involved in applying the model at a regional scale.

In addition, we have completed indepth investigations in three areas:

- Refinement, updating, and documenting the model has been completed; the latest version is fully documented in "Model formulation document for inSTREAM: the individual-based stream trout research and environmental assessment mode," S.F. Railsback, B.C. Harvey, R.H. Lamberson, and S. Jackson, Mathematics Department, Humboldt State University, May 2004.

- A study of the relationship between the habitat preference and habitat quality models with habitat usage by virtual trout is presented in "What can habitat preference models tell us? Tests using a virtual trout population," S.F. Railsback, H.B. Stauffer, and B.C. Harvey, *Ecological Applications* 2003:13(6):1580-1594.

- The impact of turbidity on virtual trout is examined in "Elevated turbidity reduces abundance and biomass of stream trout in an individual-based model," B.C. Harvey and S.F. Railsback, *Canadian Journal of Fisheries and Aquatic Sciences* (in revision).

What do empirical observations of habitat selection (e.g., animal density) tell us about habitat quality? Which is a better predictor of population response to habitat alteration: an empirical model of density as a function of habitat, or a mechanistic understanding of how intrinsic habitat quality varies with habitat? Habitat quality at a particular location in our virtual stream was measured as the fitness potential (FP). The habitat type provided an average animal in the absence of competition. We defined habitat preference by density (DEN), the number of individuals observed using that habitat type divided by the area of habitat of that type available to the population. In spite of the fact that the fitness measure used to compute FP is the same as the one used by our virtual fish in choosing habitat, we found that there was not a close correlation between FP and DEN. In addition, neither FP nor DEN was a good measure of the response of fish to changes in flow. Habitat usage is a complex function of growth, survival probability, competition, and habitat availability. Simple habitat indices and habitat preference models do not seem to capture the complexity of habitat selection in a dynamic environment.

Laboratory studies have shown that turbidity reduces the ability of trout to see and capture food, yet it also reduces risk because the trout are more difficult for predators to see. What are the overall consequences of these opposing effects on trout populations? Sublethal effects of turbidity are notoriously difficult to evaluate, in part because turbidity varies widely and in part because effects on mortality, growth, and reproduction are very difficult to measure in rivers. We used the individual-based trout model to examine these issues, using it to predict population-level consequences of individual-level turbidity effects. Inspection of habitat use, feeding strategies, and sources of mortality in the simulations suggested that the model fish response to changes in turbidity was realistic. Fish occupied slower, shallower water under high turbidity as one would predict, because increased turbidity reduces predation risk in shallower water and it makes drift feeding less profitable by reducing reactive distance to drifting prey. Under higher turbidity conditions, fish more frequently used active search strategies rather than drift feeding strategies. Terrestrial predation was slightly reduced in highly turbid water; however, this was complicated by the fact that some fish were apparently forced to occupy habitat with a higher predation risk because of difficulty in finding food.

There are limits to what can be inferred about the fitness value of habitat from observed habitat selection. A reliable understanding of habitat usage may require a mechanistic approach, which not only involves the key fitness elements of growth, survival, and reproductive success, but also includes competition and habitat availability.

The key next steps in our study include: (1) completion of the sensitivity analysis, including interactions for the more sensitive parameters; (2) an investigation of structural sensitivity for the model; (3) an indepth study of the impact of variation in temperature and flow regimes; (4) completion of the two-species version of the model (predator-prey); and (5) development of methods for scaling up local scale results to regional scale decision-making.

Question-and-Answer Session With Dr. Roland Lamberson

- Dr. Novotny asked if this research could improve the Habitat Quality Index. Dr. Lamberson replied that fish with selection criteria for habitat quality do not react as predicted by an index model. A more complex measure of habitat quality is needed that takes into account competition, seasonal changes, and critical habitat used for a short time period. This research tool is being developed to study such complexities, but will not result in an improved index-like model.

- One participant asked if the habitat selection component of Dr. Lamberson's model is similar to the Steven Fretwell free distribution model with a size component. Dr. Lamberson replied that his model has many of the same characteristics, but the Fretwell model has equal access to every site. In Dr. Lamberson's model, many good habitats are not utilized.

- Dr. Bridgham asked if this model could be used as a venue to examine the court decision that hatchery fish and native fish (salmon stocks) are the same, despite the fact that the fish do not behave similarly and exhibit different success rates. Dr. Lamberson responded that a thesis by graduate student Eric Stuart will address this topic. Experiments were conducted in Idaho to reproduce the behavior of wild versus hatchery fish (cutthroats) and determine the impact of hatchery fish on wild fish. Hatchery and wild fish do not appear to be the same species in terms of interactions in the environment.

  Another participant asked if the underlying fish model is deterministic in its parameterization. Dr. Lamberson replied that it is not. There is a large amount of stochasticity, and the model uses probabilities of reactions in particular situations.

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

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The Prairie Pothole Region (PPR) of the American Great Plains is an area of diverse wetlands that represent a critical aquatic resource for flood control, and aquatic and terrestrial production. The majority of wetland areas are embedded in an agricultural matrix, where they are exposed to combinations of pollutants and pathogens. The PPR is likely to be severely impacted by climate change through increasing temperature and reduced precipitation. The goals of this project are to: (1) quantify relationships among factors directly affected by climate change (e.g., hydroperiod), differing land use, and amphibian community structure and composition in the PPR; (2) quantify the relationships among physical and chemical wetland attributes (e.g., hydroperiod, thermal regime, pH, and DOC), and stressors, including ultraviolet B (UV-B) radiation, and land use (including pesticide use) on amphibian organismal and community responses; and (3) 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 are examined at three spatial scales: landscape, wetland, and mesocosm. Sites were designated as seasonal (SS) or semi-permanent (SP) and were divided into crop or grassland land use. We also will develop spatially explicit simulation models to investigate the hydrologic and vegetative dynamics of individual wetland basins and wetland complexes to changes in temperature and precipitation in the PPR anticipated from the Intergovernmental Panel on Climate Change scenarios.

Of a total of 27 sites in 2003, we designated 13 SP-grass, 4 SP-crop, 8 SS-grass, and 2 SS-crop. All 10 of the seasonal sites and 13 of the 17 semipermanent sites dried in 2003. Differences were found in amphibian species richness, salinity, and temperatures between SP and SS wetlands. *Rana pipiens* bred in 63 percent of all sample sites, with little difference between crop and grass sites. UV-B attenuation was measured in 18 sites in July, with rates ranging from 4 to 25 percent at 10 cm depth. Malformation assessments were performed on 1,480 metamorphs collected from 20 wetlands. Malformations were found in 3.0 percent of the specimens, and were distributed mostly in hindlimbs, eyes, and jaws. Prevalence in individual wetlands ranged from 1.5 to 7.8 percent. The overall malformation prevalence is slightly higher than that recently reported in the Midwest (2.0 percent). An increase of 3°C and a 20 percent decrease in annual precipitation results in extensions to the length of drought conditions, declines in hydroperiod, declines in the number of functioning wetlands across the region, and optimum wetland conditions (a 50:50 mixture of open water and vegetation) shifting geographically to the east and south.

Wetlands embedded or partially embedded in crop areas were much less abundant in the PPR than we had expected. In addition, obtaining landowner permission for access to wetlands, particularly those designated as crop sites, was a more difficult task in the PPR than in comparable mixed-use areas in the Midwest.

Field crews started work on the landscape scale studies in February 2004, and began work on the wetland scale studies in April. A dry winter complicated efforts to obtain sites, especially SS and SP crop sites. The mesocosm-scale experiments are being expanded to include a very low dose of atrazine, observed in laboratory animals to have endocrine disrupting effects.

Question-and-Answer Session With Dr. Patrick Schoff

- One participant asked if the primary dependent variable is amphibian malformation. Dr. Schoff replied that gonadal dysmorphogenesis is the primary dependent variable, and all other variables are considered independent in the mesocosms. In the field work, however, there is uncertainty as to the level of atrazine in the wetlands so this may not be the case. The wetlands have been embedded in corn areas because that is where atrazine is found. At the concentrations found in groundwater, atrazine does not cause gonadal malformations. Dr. Lucinda Johnson added that other dependent variables include community structure, egg mass number, metamorph number, percent cover, vegetation, and habitat structure. Thus, wetlands, communities, and animal health all will be used as dependent variables.

- Another participant asked if the loss of open wetlands in the increased temperature scenario is a result of invading upland plants. Dr. Johnson replied that increased temperature leads to increased evaporation, lower water levels, and increased encroachment of emergent and upland grassland species. The participant asked how hydroperiod is reduced and if concentrations change. Dr. Schoff responded that water is removed, but the concentrations remain the same.

- One participant commented that the experimental design (hydroperiod by atrazine treatments) could influence the response variables in several ways. If atrazine (like reduced hydroperiod) enhances development, these studies would provide a platform to study the mechanism of interaction between atrazine and reduced hydroperiod. Dr. Schoff replied that studies on the effect of atrazine on development are limited, but suggest that atrazine delays development.

- Dr. Bridgham asked if native grassland is separated from pasture, which could be important for the frog response. Dr. Johnson replied that the imagery used to separate cropland and grassland does not distinguish between native and nonnative grasses. Frogs may respond more to structure than species; thus, there will be little response if the structure of the native and nonnative grasses are similar. Dr. Bridgham stated that the structure of the native and non-native grasses may be very different.

  Another participant commented that in California, grazing was found to increase the hydroperiod of vernal pools and asked if grazing might affect this research. Dr. Schoff responded that on the areas with historical data, there is very little grazing. He will be better able to answer this question at the end of the 3-year project period.

Stressor-Response Modeling of the Interactive Effects of Climate Change and Land Use Patterns on the Alteration of Coastal Marine Systems by Invasive Species

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We are using southern New England coastal habitats as model systems to address the interaction of climate change and anthropogenic stresses resulting from variability in land use patterns in the response of recently introduced marine invasive species and how these species act to alter coastal ecosystems. The primary goals of this research project are to develop a stressor-response model of these interactions for ecosystem managers to assess regional coastal environmental problems, as well as use invasive species as "sentinels" of the interaction of climate change and environmental degradation. Our previous work indicates that: (1) warming of coastal waters is correlated with an increasing abundance of invasive marine species, and (2) lower biodiversity characteristic of more stressed habitats make these areas more susceptible to invasion. Using this information, we are experimentally testing these interactions over a range of coastal habitats to address such issues as: What are the significant interactions among the multiple stressors (land use and climate change)? Are the effects additive or nonadditive? We are in the process of developing a stressor-response model, which simulates these interactions and can be used by managers to discern the habitats most vulnerable to the multiple stressors. We will examine the uncertainties of the model predictions, how the model results can be extrapolated, both spatially and temporally, and how the model can be tested and validated.

During the first year of the project, we have accomplished the following principal tasks. First, we have developed a complete quantitative and qualitative characterization of the coastal land use patterns of the State of Connecticut and the State of Rhode Island west of Narragansett Bay. Coastal land use patterns (which include the entire coastal watersheds) were partitioned into 12 categories ranging from more "urbanized" (e.g., commercial/industrial) to more "pristine" (e.g., forests, wetlands) habitat conditions. In addition to this analysis, we have included information on marina location and number coupled with other environmental parameters, supplied by the State of Connecticut Department of Environmental Protection (e.g., nitrogen loading, chlorophyll fluorescence), for the various coastal embayments and estuaries. Second, we have conducted a broad-scale biological survey of 15 different embayments, with varying land use patterns, to assess the relative abundance and species composition of native and non-native fouling species. Very preliminary multivariate statistical analysis indicates that species diversity of some of the fouling organisms (e.g., non-native ascidians) appears to correlate in a consistent manner with increasing marine shoreline changes in nitrogen loading. We will couple a field and modeling component that delineates the impacts on shallow water habitats resulting from changing land use with an experimental field component, which examines directly the interacting effects of increasing water temperatures and anthropogenic stresses on the rates of species introductions and the impacts of these on native communities. Third, field experiments are being set up to simulate predicted temperature changes, and the population and community responses of native and recently introduced species will be compared. Transplant experiments also will be conducted to determine the interactive effects of warming water and existing stresses on the degree to which native communities may be altered by the increased success of newly introduced species. The measurement and modeling of nutrient inputs as a function of land use and resultant changes in benthic communities, including the degree to which species introductions change the dynamics, will enable us to examine likely community and ecosystem changes in these coastal habitats as a function of climate change. The model will be designed to present easily understood scenarios to managers and planners.

PANEL SESSION 4 WITH PRESENTERS

- Ms. Smith asked how the panelists' models accommodate species adaptation to stressors. Dr. Lamberson responded that in terms of behavioral adaptation, individuals move to avoid risk turbidity, temperature, etc.). Fitness is computed by movement away from risk. In terms of evolutionary responses, a genetic algorithm approach will be used. Dr. Schoff replied that a change in community structure would be expected. A single species can adapt only a certain degree to less open water and a loss in the proximity of water bodies. The community would change composition; species such as the leopard frogs may be lost. Dr. Lamberson added that health responses are difficult to predict. Because the larval stage is vulnerable to predation and parasites, it may be advantageous to accelerate passage through this stage. This would be contravene, however, to poor environmental conditions that prevent breeding the following year.

- Iris Goodman commented that many of the same concepts and/or techniques may apply in the Prairie Pothole region and the playas. Iris Goodman asked how individual-based models will be aggregated upward to examine regional-scale effects. Dr. Lamberson responded that because of computational limitations, the model will be looked at as a sample. At a watershed level, for example, streams of different orders and characteristics will be used as samples to build up the watershed. The model will be built in a modular format, using different first- and second-order samples in the watershed.

- One participant asked how much information is needed about stream geometry when creating a grid system on the environment and scaling up the individual-based models. Is a large amount of empirical information needed? Dr. Lamberson replied that a large amount of empirical information was used to develop the gridwork: sites were surveyed and new cross sections done at each transition in stream character to examine depths, velocities, and so on.

- Ms. Smith commented on the lack of political will to save the prairie potholes and asked Dr. Schoff how his research will be used by local stakeholders. Dr. Schoff replied that in this case, "local" means state and regional users. The research will demonstrate how global climate change will affect the North Dakota/South Dakota/Minnesota hunters and fishermen who use the Prairie Pothole region. Because the economies of these states depend in large part on open prairie potholes, the research may prompt governments to take action to mitigate the effects of warming. In addition, if the research shows the physical and concomitant biotic changes in the Prairie Pothole region, the governments will have time to prepare and modify their economic forecasts or land use planning strategies.

  Dr. Schoff added that he does not know if there is a lack of political will to address problems in the Prairie Pothole region. His concern is a lack of constituency because of the sparse population in this area of North and South Dakota. The region is very valuable on an ecological basis, but few people understand the science. On an economic level, a small group of state residents and recreational users are concerned.

- Another participant asked if the distribution of parameters at the end of runs is examined as a potential measure of the effects of multiple stressors, given the stochasticity in the original parameterization of the individual-based models. One panelist responded that a large sensitivity analysis is being conducted, but this issue is not fully understood.

- Dr. Novotny asked if the panelists' models can be used for impounded streams. Dr. Lamberson replied that the hydraulics can be reparameterized for different situations and different fish species. The model is physically transportable from one site to another as well as biologically transportable from one species to another.

Dr. Bridgham asked what population models or higher order models using averages and population deviations miss by not considering emergent properties from individual-based interactions. Dr. Lamberson responded that critical details may be missed in classic population models by not including emergent properties on an individual level.

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