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Watershed Health Assessment Tools-Investigating Fisheries (WHAT-IF): A Modeling Toolkit for Watershed and Fisheries Management

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Abstract: The Watershed Health Assessment Tools-Investigating Fisheries (WHAT-IF) is a decision-analysis modeling toolkit for personal computers that supports watershed and fisheries management. The WHAT-IF toolkit includes a relational database, help-system functions and documentation, and multiple statistical and simulation modeling tools. The tools consist of a hydrologic and stream geometry calculator, a fish assemblage predictor, a fish habitat suitability calculator, and a process-based model to predict biomass dynamics of stream biota (the BASS model). The tools can be used to assess conditions and associated stressors in aquatic ecosystems, to examine causes of impairment, and to forecast ecological outcomes of habitat alterations and fisheries management actions. WHAT-IF also supports screening analysis, such as prioritization of areas for restoration and comparison of alternative watershed and habitat management scenarios. The toolkit was originally developed for the Mid-Atlantic Highlands region of the U.S.; investigations are underway to transfer the technology to other regions.

Keywords: fisheries; Mid-Atlantic; habitat suitability; restoration.

1. INTRODUCTION

Stream ecosystems are common and widespread habitats in landscapes that can support high diversity and productivity of aquatic organisms. As watersheds are utilized for agriculture and undergo urbanization, water courses accumulate pollution and aquatic organisms can be negatively affected. Fish are often used as assessment endpoints in streams by the U.S. Environmental Protection Agency (EPA) and other government agencies; they are easily measured and their overall health is determined by an integration of multiple watershed stressors. Although there are many ecological endpoints that are indicators of the condition of streams and watersheds, fish health is arguably one of the most important since fishability is a principal designated use for surface waters under the Clean Water Act.

In the Mid-Atlantic Highlands (MAH) region of the eastern United States over half of the streams have fish communities that are in fair or poor condition [USEPA, 2000]. The primary stressors in most watersheds are nonpoint source pollution, altered hydrologic regimes, sedimentation, and habitat degradation. The EPA concluded that physical habitat alteration represents the greatest stressor in this region [USEPA, 2000]. The Canaan Valley Institute (CVI), a nonprofit organization located in West Virginia, and their partners are working to implement regional watershed protection in the MAH. CVI's mission in the region includes support for a wide range of interest groups, local and state governments and nonprofit organizations. CVI distills the combined needs of a diverse group of stakeholders for more effective environmental management.

Management of stream ecosystems in the MAH involves the assessment of probable causes of impairment and management alternatives, as well as the forecasting of future conditions in a scientifically defensible fashion to more effectively protect and restore valued ecosystems. The EPA has long been committed to community-based environmental management and to providing the methods, tools and technical transfer required to achieve this goal. To serve this need in the MAH, the EPA Aquatic Ecosystem Team has collaborated with CVI to develop a Windows-based toolkit for analyzing and directing fisheries management and habitat restoration in the MAH, entitled WHAT-IF (Watershed Health Assessment Tools –Investigating Fisheries).

2. THE WHAT-IF TOOLKIT

The WHAT-IF software toolkit includes a relational database, help-system functions and documentation, and multiple statistical and simulation modeling tools to support the assessment and management of stream fisheries. Current tools consist of a hydrologic and stream geometry calculator, a fish assemblage predictor, a fish habitat suitability calculator, and a process-based model to predict biomass dynamics of stream biota (the BASS model).

2.1 Hydrologic and Stream Geometry Tool

The Hydrologic and Stream Geometry Tool predicts mean annual flow rate, width, depth, velocity, and cross-sectional area for MAH streams. The tool was developed using the regional regression method, which is based on the development of relationships between drainage area and stream hydraulic characteristics. All selected watersheds had a drainage area between 3 and 400 square miles, with high forest cover and low impervious surface cover. Only watersheds with USGS gaging stations and 10 years of observed streamflow data were used for the development of regional regression equations. In each gaging station, the mean annual streamflow was determined from historical streamflow data. Hydraulic channel geometry data such as width, depth, velocity, and cross-sectional area that correspond to the mean streamflow were determined from USGS channel measurement data.

To enhance the predictive potential of the regression equations and to reduce the variability not explained by the model, we developed regressions based on physiographic province. The Mid-Atlantic Highlands Region consists of four physiographic provinces: Appalachian Plateau, Blue Ridge, Ridge and Valley, and Piedmont. We combined the Ridge and Valley and Blue Ridge Physiographic Provinces as one and developed a total of three sets of regression equations.

2.2 Fish Assemblage Predictor Tool

The Fish Assemblage Predictor allows a user to predict a fish assemblage in a stream of interest based on characteristics of that stream and its watershed. It was developed using a statistical analysis of environmental data collected by the EPA in the MAH. Over five hundred 1st through 3rd order MAH streams were visited by EMAP field teams and sampled for fish.

There are two versions of the tool – both predict a stream’s fish assemblage, but in one version that assemblage is defined by the relative biomass of member species, and in the other version the assemblage is defined by the relative abundance of the member species. Both versions were developed using two statistical steps. The first step was a cluster analysis, using either relative biomass or relative abundance. The cluster analysis resulted in the formation of groups of streams with similar fish communities. If a group had six or more member streams (1% of the total sample size), it was defined to be a dominant fish assemblage of the MAH region. The relative biomass clustering produced 14 dominant assemblages, and the relative abundance clustering produced 18 dominant assemblages. Note that these two sets of assemblages are similar, but not identical. Relative abundance clustering tends to emphasize smaller, non-game species, while relative biomass clustering emphasizes larger fish species. The assemblage of fishes defined by the dominant clusters is not identical to the fish community found in any particular stream of the group. Instead, the list of species within a cluster should be thought of as a pool of species that could be found in streams of this type. The second statistical step involved discriminant analysis, in order to develop the predictive capability to place unsampled streams in clusters with known streams, and therefore predict their fish assemblages.

2.3 Fish Habitat Suitability Tool

The Fish Habitat Suitability Score (HSS) calculator was developed to use habitat information for a particular stream to calculate a suitability score for each fish species that ranges from 0 (unsuitable) to 1 (fully supporting of the species). We developed such models for each of thirteen MAH stream fish species/groups using multiple logistic regression and six instream habitat measures: depth, temperature, substrate, percent riffles, cover, and riparian vegetation. The HSS calculator can estimate the change in suitability associated with habitat alteration. The calculator can also help environmental planners and managers in the MAH evaluate the response of fish species to stream management actions and restoration scenarios. It enables managers to compare the effects of restoration across different streams, thus allowing them to optimize their restoration efforts and focus efforts on streams where they can expect the greatest improvement in fish habitat.

2.4 BASS Model

The Bioaccumulation and Aquatic System Simulator (BASS) is a computer model that simulates the population and bioaccumulation dynamics of age-structured fish communities. Although BASS was specifically developed to simulate the bioaccumulation of chemical pollutants within a community or ecosystem context, it can also simulate population and community dynamics of fish assemblages that are exposed to a variety of non-chemical stressors such as altered thermal regimes associated with hydrological alterations or industrial activities, commercial or sports fisheries, and introductions of non-native or exotic fish species.

BASS's model structure is flexible: users can simulate both small, short-lived species (e.g., daces, minnows) and large, long-lived species (e.g., bass, perch, sunfishes) by specifying either monthly or yearly age classes for any given species. The community's food web is defined by identifying one or more foraging classes for each fish species based on either body weight, body length, or age. The dietary composition of each of these foraging classes is then specified as a combination of benthos, incidental terrestrial insects, periphyton, phytoplankton, zooplankton, and/or other fish species. There are no restrictions on the number of chemicals or the number of fish species that can be simulated, the number of age classes that fish species may have, or the number of foraging classes that fish species may have.

3. MODELING ISSUES

3.1 Spatial Data

All of the tools in WHAT-IF were developed based on data collected by the EPA's Environmental Monitoring and Assessment Program (EMAP). This large dataset provided information on physical, chemical, biological, and habitat measurements for primarily wadeable stream sites in the MAH. All the data were collected according to specified protocols, and are available digitally [Lazorchak et al., 1998]. One feature of WHAT-IF is map window technology, which provides the user with retrieval and query access to all of the EMAP data. Users can visualize all the sites on a map window interface (Figure 1) and can select sites for WHAT-IF applications. We are considering the adaptability of the toolkit to different systems, where similar large data sets are available; for example, collaboration is underway with the USEPA's National Health and Environmental Effects Research Laboratory data for estuaries and coastal environments in the Gulf of Mexico, and the EMAP-WEST database.

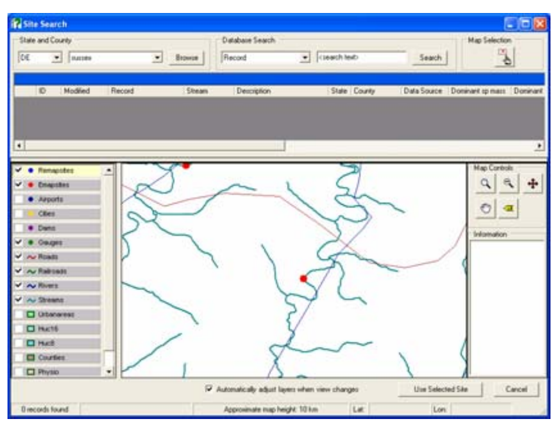

Figure 1. Map interface window for the WHAT-IF toolkit.

3.2 Interface with Users

Oxley et al. [2004] have noted that the level of flexibility is an issue for applied modeling systems, where a high degree of flexibility can be costly and complex but low flexibility can be too restrictive. We have chosen to create an interface driven by assessment questions that were developed in communication with clients. Feedback from all Mid-Atlantic Highlands States and multiple nonprofit organizations on WHAT-IF and associated training workshops have led to updates on the original toolkit in order to incorporate aspects of state regulatory and monitoring needs. The collaboration of model developers with partners and clients has been very successful in the Mid-Atlantic region due to the essential role provided by the partners, translating regional environmental needs into product specifications as well as translating EPA products back to its constituents.

Users interact with the software interface to frame the problem by selecting endpoints and assessment questions of interest, accessing data and models to establish causal relationships between environmental characteristics and endpoint status, and performing multiple model executions and visualizations of projected outcomes so that management can evaluate associated ecological costs and benefits. Three example applications are provided as tutorials; these show changes in fish health and productivity in relation to the management actions of stocking, harvest, and riparian restoration. Help-systems and supporting documentation are also provided.

3.3 Software Engineering

WHAT-IF has been developed using N-tier architecture and object-oriented design on the Microsoft .NET platform. The tiers consist of a database management system (MySQL), business/science logic (models), and graphical user interfaces. Business logic caters to the web as well as windows clients. The web interface was developed in ASP.NET and runs under Microsoft Internet Information Services (IIS). The windows client is written as windows forms in C# language. The business logic has been developed as a library using C# language. The business logic interacts with the database tier using ADO.NET and SQL.

3.4 Model Complexity

A more detailed formulation of a stream system would include a spatially-explicit watershed hydrology model and a hydrodynamic and water quality model. Additionally, global change and landscape change could be represented with linked models. Such systems exist (e.g., Oxley et al., 2004), however, this modeling approach increases both the uncertainty and the complexity of the modeling system. The WHAT-IF model can be considered a biological endpoint model, and it is receptive to output from complex upstream models that predict water quantity and quality.

3.5 Distinguishing Between Natural and Human Influences

Fausch et al. [1988] concluded that in order for predictive habitat models for stream fish to be useful for managers, they should include variables that can be affected by management practices. Most of the environmental influences considered in the WHAT-IF models vary naturally, yet all may be altered directly or indirectly by anthropogenic activities. Ideally, predictive fisheries models for stream management would be sensitive to the most common stream restoration activities in the MAH, which include projects that increase large-sized substrate, instream cover, and riparian vegetation [Canaan Valley Institute, 2002]. However, in some cases the models were most sensitive to more natural factors such as temperature and depth. The importance of natural environmental factors could be reduced by subsetting the data based on these measures. This would reduce the number of sites available for model development within each subset and create the complexity of multiple models, but may be a useful next step.

4. CONSIDERATIONS FOR MANAGEMENT

WHAT-IF was originally developed to assist CVI with their goal to develop and implement solutions to restore damaged areas and protect aquatic systems. To achieve this goal, CVI has produced its Highlands Action Program that details the need for a prioritization toolkit that combines ecological, social, political and economic tools for environmental stewardship [CVI, 2002]. Productive, sustainable fisheries are valued aquatic endpoints. Planned restoration activities in the region include riparian zone restoration and stream channel design to mitigate near-stream inputs, stabilize stream banks, trap sediments, and decrease stream temperatures to encourage trophy trout fisheries. In addition, ongoing acid mine drainage remediation is being conducted to decrease metals and increase pH. WHAT-IF has been designed to provide information on the response of fisheries endpoints to the planned restoration activities.

A next important step for watershed management in the MAH would be to couple WHAT-IF's ecological analyses with political and economic analyses, to relate cost estimates of restoration activities and their associated ecological benefits in order to assess trade-offs in management and restoration [Holmes et al., 2004; Sharma and Norton, 2005]. Rather than building these factors in to a single model, we suggest a sequential approach where ecological concerns are the primary filter. Only restoration activities that are ecologically feasible and beneficial should be assessed for their political and socioeconomic viability. The outcomes of such an approach would involve allocation of state and local funds to restoration activities and fisheries management programs in streams and rivers in an optimal way based on all considerations.

5. CONCLUSIONS

Large available data sets such as those provided by EMAP provide a unique opportunity for the development of management models. The WHAT-IF toolkit, developed for the MAH region, provides a means of organizing information so that it can be viewed and immediately used for management and decision analysis. The intermediate level of detail and flexibility of the toolkit were chosen to make it both useful and accessible to users. These models can be developed into true decision analysis tools when they incorporate socioeconomic and political criteria, however, we envision this as more of a sequential analysis, rather than an all-inclusive modeling approach.

6. ACKNOWLEDGEMENTS

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