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Using Ecological Data as a Foundation for Decision-Making in the USA

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ABSTRACT

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Decisions that impact the quality of aquatic systems are being made daily throughout the world based on little or no ecological information (Barbour *et al*., 2004). Monitoring information, based on scientifically and rigorously tested ecological indicators, is integral to water quality management programs for protecting human health, preserving and restoring ecosystem integrity, and sustaining a viable economy. Under the Clean Water Act of the United States, water quality agencies of the states and tribes are required to conduct monitoring and assessment to address the mandates of the law. However, recent critiques of water monitoring programs have claimed that the United States Environmental Protection Agency (U.S. EPA) and State water quality agencies cannot make statistically valid inferences about water quality and the condition of the Nation's waters, i.e., whether they are improving, degrading or remaining the same; furthermore, we lack data to support management decisions regarding the Nation's aquatic resources. The National Wadeable Streams Assessment Program (WSA) was established in early 2004 to answer the question of what is the status of the Nation's waters, and to maximize partnerships among U.S. EPA, States and Tribes, and other agencies to establish a framework to address issues at state and local scales. Ecological data in any form require some measure of translation to be useable by the environmental manager, i.e., a hierarchy exists in the translation process from basic biological data in its rawest form through a series of manipulations in the analysis phase to reporting of the results and interpretation. This nationally focused program is a step towards ensuring adequate monitoring data exist in the future to assess water quality and make sound watershed management decisions throughout the USA; actions are taken to protect and restore water quality that maximize benefits and minimize costs; and sound science forms the basis of making informed decisions regarding our aquatic resource.

Key words: Communicating science, biological integrity, environmnetal monitoring, Clean Water Act, stream assessment, reference condition, ecoregion, stressor-response, ecological assesment.

RESUMEN

Utilizando la información ecológica como base para la tarea de decisiones en los Estados Unidos

Diariamente se están tomando decisiones que inciden en la calidad de los sistemas acuáticos basadas en escasa o ninguna información ecológica (Barbour et al.*, 2004). La información obtenida en programas de gestión, basada en indicadores científicos y basados en indicadores ecológicos, se integra en programas de gestión de la calidad del agua para la protección de la salud humana, la preservación o restauración de la integridad de los ecosistemas y el sostenimiento de una economía viable. Por mandato del Acta sobre el Agua Limpia de los Estados Unido, se han creado agencias a nivel de Estados o regiones para realizar programas de estudio y gestión para cumplir el mandato de la ley. No obstante, recientemente han surgido críticas a los programas de gestión señalando que la Agencia de Protección Ambiental de los Estados Unidos (U.S. EPA) y las agencias de calidad del agua estatales no pueden realizar inferencias estadísticamente válidas acerca de la calidad del agua y de la situación de las aguas de la nación, p. e. si estan mejorando, degradando o permanecen igual. Además, no tenemos datos para apoyar las decisiones de gestión en relación con los recursos acuáticos nacionales. El Programa de Estudio de los Ríos Vadeables (WSA) se estableció en 2004 para responder a la pregunta de cual es la situación de las aguas de la nación, y para maximizar la colaboración entre U.S. EPA, y las agencias estatales, locales y similares para realizar un marco de trabajo que permita establecer los objetivos a escalas estatal y local. La información ecológica de cualquier tipo* *requiere algunas medidas de traducción para que sea utilizable por los gestores ambientales, p. e. existe una jerarquía en el proceso de traslación desde datos biológicos básicos, en su forma poco elaborada, hasta una serie de manipulaciones en la fase de análisis para los informes de resultados y su interpretación. Este programa enfocado a nivel nacional es un paso para asegurar que existen datos adecuados de gestión a través de todo el país. Se están realizando actuaciones para proteger y mejorar la calidad del agua que maximice los beneficios y minimice los costes a la vez que establezcan las bases científicas para tomar decisiones teniendo en cuenta nuestros recursos acuáticos.*

Palabras clave: *Transmisión del conocimiento científico, integridad biológica, gestión ambiental, Acta sobre el Agua Limpia, información sobre los ríos, ecoregión, factor estresante-tipo de respuesta, estudio ecológico.*

INTRODUCTION

The 21st century will witness greater attention to water resource restoration, protection, and management. As the global demand for adequate supplies of clean water has escalated, so have concerns about public health and environmental quality (Barbour *et al*., 2004). There is evidence the increased demands have taken a toll on aquatic ecosystems. Ecological information obtained in the latter half of the 20th century has uncovered a serious decline in aquatic ecosystem health (Karr, 1995; Master *et al*., 1998). Decisions that impact the quality of aquatic systems are being made daily throughout the world based on little or no ecological information (Barbour *et al*., 2004). Monitoring information, based on scientifically and rigorously tested ecological indicators, is integral to water quality management programs for protecting human health, preserving and restoring ecosystem integrity, and sustaining a viable economy.

In the United States of America (USA), the Clean Water Act (CWA) of 1972 serves as the regulatory impetus for the restoration and maintenance of physical, chemical, and biological integrity (Fig. 1) as the long-term goal of environmental protection for aquatic resources (Adler, 1995). The sum of these three aspects constitutes the concept of ecological integrity, which is inherent in the water laws of most countries (Barbour *et al*., 2000). Under the CWA, the states are required to conduct monitoring and assessment to address the mandates of the law. In addition, First Nations, or Native American tribal authorities, have similar jurisdictional requirements as the states (Barbour & Gerritsen, 2006). Therefore, a multitude of water resource agencies exist in the USA to accomplish the stipulated regulations. Recent critiques of water monitoring programs have claimed that the United States Environmental Protection Agency (U.S. EPA) and State water quality agencies cannot make statistically valid inferences about water quality and the condition of the Nation’s waters, i.e., whether they are improving, degrading or remaining the same; furthermore, we lack data to support management decisions regarding the

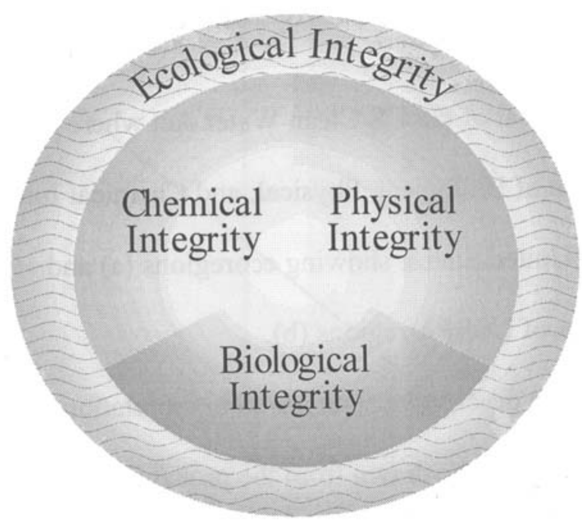

Figure 1. The Ecological Integrity goal of the US Clean Water Act where Ecological Integrity is a culmination of Biological, Physical, and Chemical Integrity. *La consecución de la Integridad Ecológica de la Acta sobre Aguas Limpias de los US es la culminación de la integridad biológica, física y química.*

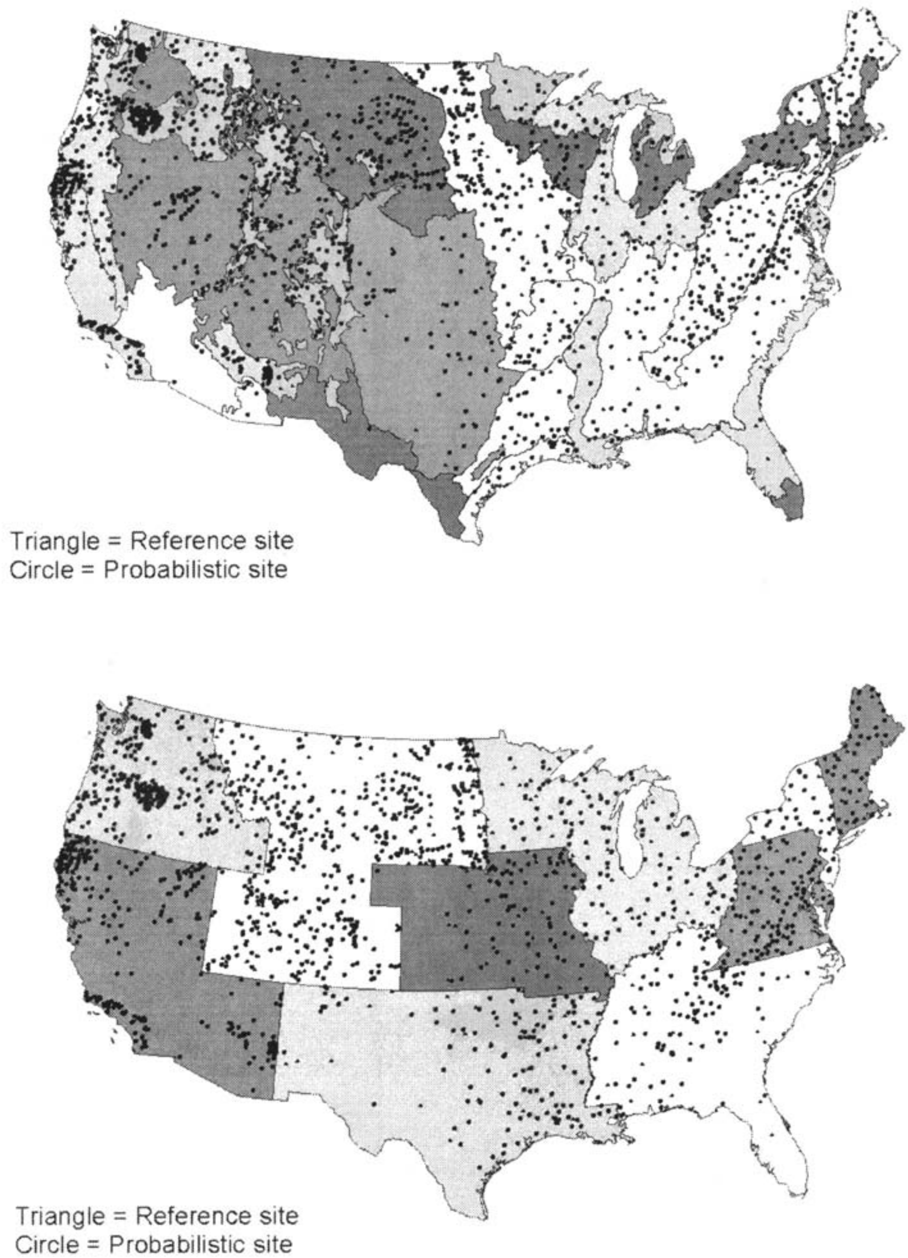

Figure 2. Map of the continental United States, showing ecoregions (a) and jurisdictional boundaries of U.S. EPA regions (b). *Mapa de la parte continental del los Estados Unidos mostrando las ecoregiones (a) y las fronteras jurisdiccionales de las regions U.S. EPA.*

Nation's aquatic resources. These critiques have stemmed from reviews of the U.S. General Accounting Office (2000), the National Research Council (2001), the Heinz Center Report (2002), and most recently, the draft Report on the Environment (EPA, 2003). The primary reasons for this inability to produce adequate reporting of ecological condition are (1) the monitoring designs used by water quality agencies target specific problems or waterbodies, which cannot be aggregated to accurately describe conditions across the country, and (2) the question of comparability among the agencies of the data gathering tools, which, to date, have precluded aggregating data and/or assessments for regional and national scales.

THE NATIONAL WADEABLE STREAMS ASSESSMENT PROGRAM

The diverse geomorphologic land-forms and climatological regions of the USA underscore the importance of regional specificity in faunal distributions and composition (Barbour & Yoder, 2000). However, the basic premise of a bioassessment approach remains similar across the country. Therefore, a versatile method for sampling, and data interpretation, is needed that will provide some consistency in otherwise disparate areas of rainfall, temperature, and geology (Barbour & Gerritsen, 2006).

The National Wadeable Streams Assessment Program (WSA) was established in early 2004 to answer the question posed by the U.S. Congress, that is, what is the status of the Nation's waters. A secondary issue, and perhaps the most important for long-term sustainability, is for the WSA to maximize partnerships among U.S. EPA, States and Tribes, and other agencies by using the best combination of monitoring tools and strategies to answer key environmental questions at national, and regional scales, and to establish a framework to address issues at state and local scales. U.S. EPA's strategy for effectively targeting water quality actions that maximizes benefits and saves costs focuses on four key aspects, i.e., strengthen State programs, promote partnerships, use multiple monitoring tools, and expand accessibility and use of data.

The basic framework of WSA builds upon previous large-scale programs, such as the Environmental Monitoring and Assessment program (EMAP) of the U.S. EPA, and uses existing state agency expertise and knowledge of aquatic resources. Randomly generated sampling locations stratified by ecoregion (Level II; see Omernik 1987) and U.S. EPA region (Figs. 2a and b) enables reporting at regional scales. Standard Operating Procedures (SOPs) and a strict Quality Assurance Program is used to ensure the highest data integrity for the assessment. The data collection from 600 stream sites in the western USA (U.S. EPA Regions 8-10) over a four year period (2001-2004) complements the sampling of 500 stream sites in 2004 throughout USEPA Regions 1-7 (Fig. 2b). A report to the U.S. Congress is scheduled for December 2006.

SAMPLING SURVEY DESIGN OF THE WSA

The choice of a particular monitoring survey design should be based on the monitoring objectives and ultimate decision process incumbent upon the outcome of the study. Any well-designed monitoring and assessment program is inherently anticipatory in that it will provide information for present needs and those not yet determined (Yoder & Rankin, 1995). The fundamental challenge, given our inability to sample every lake and stream in the country, is how to select a subset of sites that can be used to infer conditions for all aquatic systems (Hughes *et al*., 2000). To obtain unbiased estimates of condition, the agencies now often use probability sample surveys. Sites or streams are selected using stratified random techniques such that the collection of sample sites is representative of the resource population of interest. Thus, one can make inferences from the survey results to the entire population. In the USA, streams are identified by resource type, i.e., intermittent, perennial, etc., and further stratified by size to obtain a framework for randomizing the streams to be sampled in the resource population of interest. This design is cost effective in that the entire resource does not have to be sampled –only a representative set of streams. This sampling design was developed by EMAP and has been used to assess the ecological status of waters on different scales of basin, statewide, regional, and national levels (Paulsen & Linthurst, 1994; Hughes *et al*., 2000).

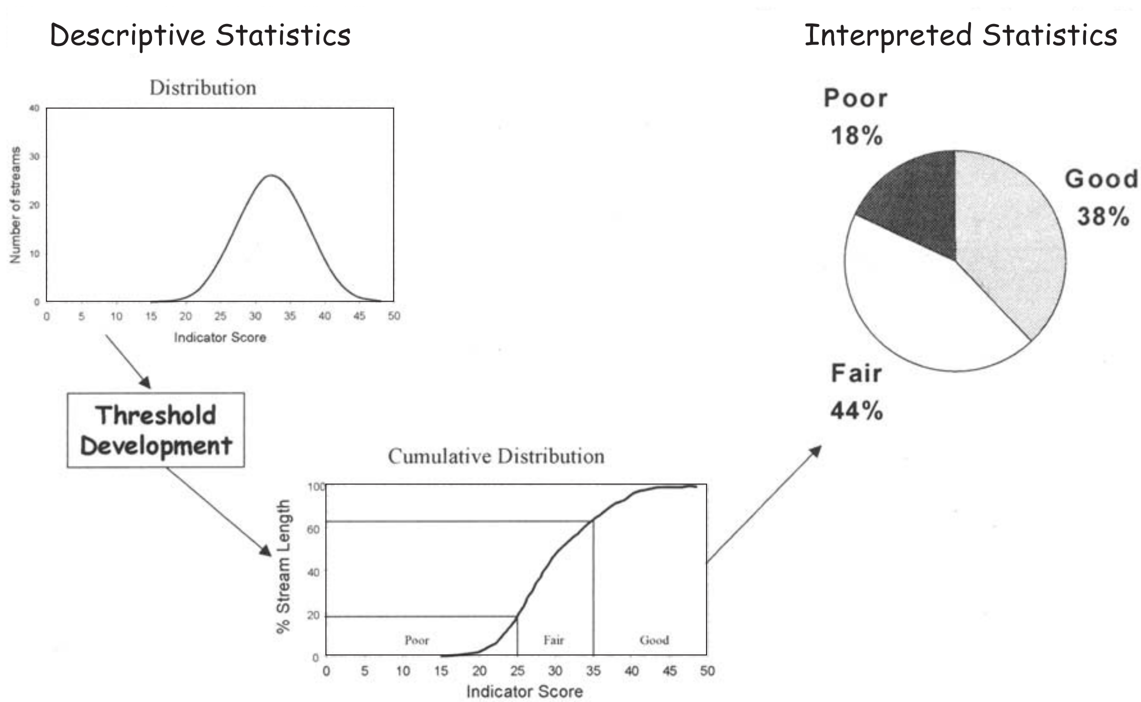

Figure 3. Data analysis process from descriptive statistics to interpretation. *Proceso de análisis de datos desde la descripción estadística hasta la interpretación.*

Answering two basic questions is the goal of the WSA: (1) What percentage of the nation's wadeable streams resource is in good condition? And, (2) What is the relative importance of stressors as evaluated in the WSA? For addressing the first question, information from the stream biota, i.e., the macroinvertebrate assemblage for the WSA, forms the basis of the assessment. The endpoint is based on our knowledge of reference conditions that serve as the basis for deriving relevant thresholds for making condition assessments (Fig. 3). The second question requires that we have information on the key stressors derived from chemical, physical, biological and watershed data, that might be affecting the overall ecological condition of the water resource in various parts of the USA. The estimate of the extent of stressors throughout the water resource along with the relationship between the stressors and biological indicators provide some sense of the cause of degraded waters (Fig. 4).

ESTABLISHING REFERENCE CONDITIONS AS BENCHMARKS FOR THE WSA

In the USA, we stress the importance of establishing strict criteria on the physical characteristics of catchments and streams to serve as reference sites (Barbour & Gerritsen, 2006). Many individual nations, and the European Union as a whole, have codified the concept of reference condition in legislation aimed at protecting and improving the ecological condition of running waters (Stoddard *et al*., 2006). However, the selection of reference criteria is often a mixture of data analysis and professional judgment. Reference sites ought to be derived from streams that represent minimally disturbed conditions in each region (Bailey *et al*., 2004). For the WSA, short-term objectives were established to quickly characterize the background biological expectations of the various regions by using a combination of sampling a select few reference streams provided by the states, use of existing state biological data from

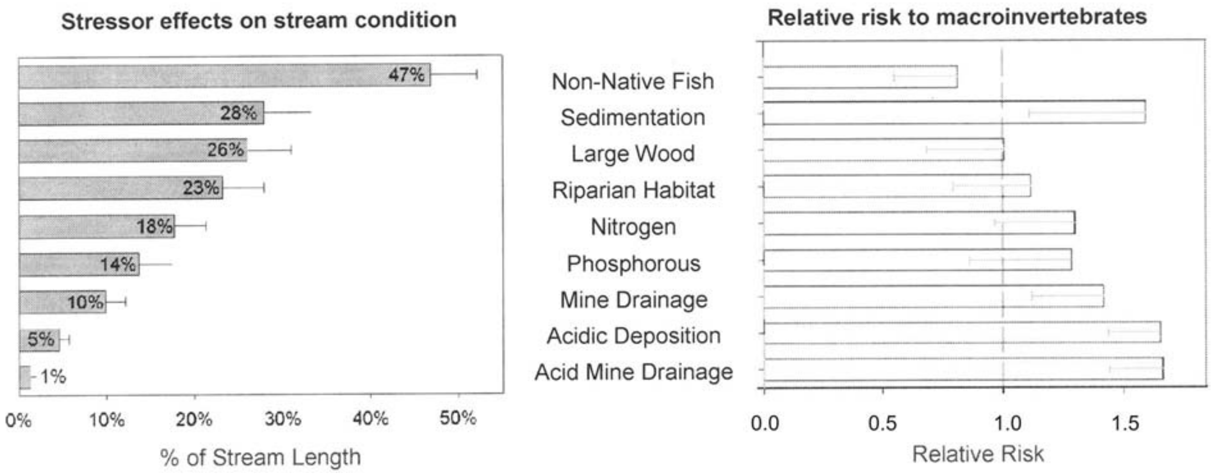

Figure 4. Example of inferences that will be drawn from the probability sampling to answer the basic questions of the WSA. *Ejemplo de inferencia que puede se dibujado desde el muestreo probabilístico hasta responder preguntas básicas de la WSA.*

their ecoregions, and consensus-based decisions regarding appropriate indicators and endpoints.

The short-term process to establish reference conditions for the WSA is based on the use of reference sites across the country and entails the following:

- Use a combination of sampling (this field season) at targeted reference sites that are derived from state data, analysis of existing state data where appropriate, and consensus-based decisions of expected values of selected endpoints (also derived from state databases and expert knowledge).
- Select approximately 10 best reference sites to be sampled this year for each ecoregion (Level II), based on recommendations obtained from state databases. Selection of sites within an ecoregion will also consider some stratification by certain characteristics, such as elevation, catchment size, etc., where possible. Convene a technical expert workgroup to develop a consensus-based framework for background from existing state and federal programs. Use results from the subset of reference sites sampled this year in combination with other appropriate data and information to aid in establishing supportable benchmarks for the assessment.

Results from sampling the small subset of 10 sites/ecoregion with the same methods will enable our developing a notion of range and variability within a small subset of least disturbed sites, and assist in identifying other candidate reference sites from within the random sample survey. This population of reference sites is considered to be minimal and insufficient for full calibration of indicators, but is intended for approximations of benchmarks for endpoints, given the coarse reporting unit of Ecoregion Level II. To supplement this information, we used existing state and federal data, where possible, to help develop a framework for expectations of ecological conditions. The Technical Expert Workgroup will meet on several occasions to discuss the best approach to develop a framework for assessment. Part of the discussions was devoted to indicators and endpoints that will form the basis of the assessment for the final report.

COMMUNICATING THE SCIENCE FOR DECISION-MAKING

To answer the questions set forth for the WSA, reporting or communicating the results and recommendations is the underpinnings of the entire study. Effective communication of assessment re-

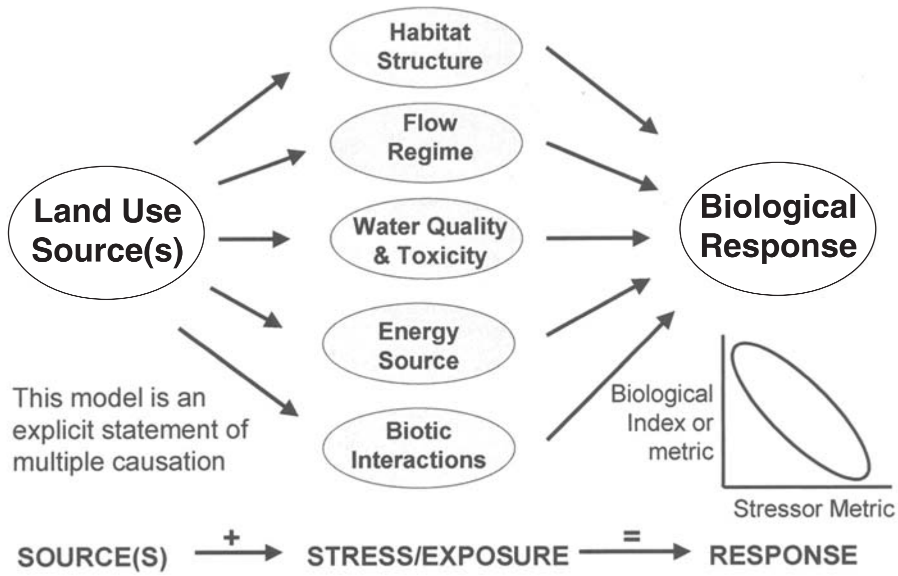

Figure 5. Conceptual relationship of human activities or land use, stressors, and response indicators (D. Allan, personal communication). *Relaciones conceptuales de las actividades humanas o uso del suelo, factores perturbadores y indicadores de la respuesta de dichos efectos (D. Allan, comunicación personal).*

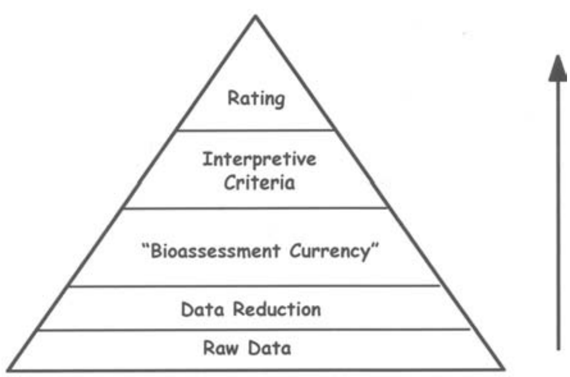

Figure 6. Hierarchy of data manipulation and translation from basic biological data to making informed decisions. *Jerarquía del procesado de los datos y su transferencia desde datos biológicos básicos hasta la toma de decisiones teniendo en cuenta dicha información.*

sults is critical to making scientifically sound and socially meaningful decisions (Preston *et al*., 2004). The model for translating the scientific findings into useable information for decision-makers relates objectives, measurable attributes (indicators), and testable hypotheses that help answer the assessment's questions (Stevenson *et al*., 2004). Three fundamental categories of variables should be communicated to environmental managers: response, stressor, and human activity variables (Fig. 5). Response variables are measures or indicators of the valued ecological attributes that are directly related to management goals, program objectives, and ecosystem services (Stevenson *et al*., 2004). Response variables are similar in concept to assessment endpoints as defined by Suter (1990). Stressors are the physical, chemical, and biological factors that affect responses. Human activity variables describe the spatial and temporal extent of human activities in a watershed, as well as their intensity (Stevenson *et al*., 2004). Stevenson *et al*. (2004) point out that the response, stressor, and human activity categories of variables are fundamental because of their roles in managing ecosystems. Human activities produce the contaminants and habitat alterations (stressors) that affect valued attributes. Decision-making by environmental managers is to control stressors, which is necessary to restore or protect valued attributes. Understanding stressor-response and stressor-human activity relationships enable management

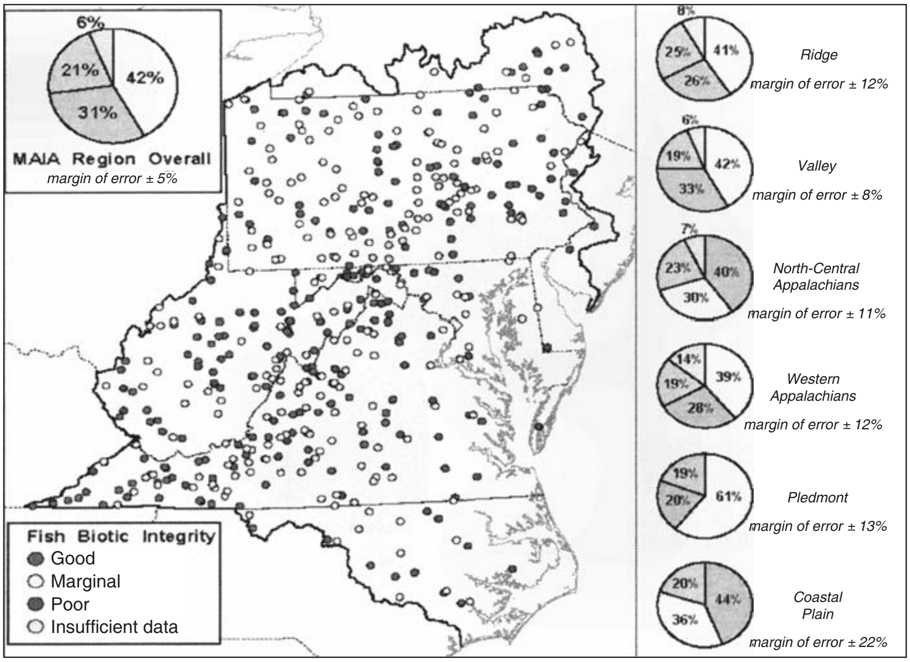

Figure 7. Example of a graphical display illustrating how ecological results will be summarized and communicated in the WSA report. *Ejemplo de presentación gráfica ilustrando como los resultados ecológicos pueden ser resumidos y comunicados en un informe WSA.*

of human activities to restore and protect ecosystems.

Most decisions are binary: a resource, or portion thereof, is in good condition or not; a site has exceeded criteria or not; a site has been degraded or not (Barbour & Gerritsen, 2006). In some cases, a decision requires classifying a site or waterbody into one of several categories, such as exceptional, good, limited resource waters, etc. (e.g. Yoder & Rankin, 1995). However, ecological data in any form requires some measure of translation to be useable by the environmental manager. There is essentially a hierarchy in the translation process that the scientist must use to move from basic biological data in its rawest form through a series of manipulations in the analysis phase. This process articulates, through bioassessment currency that has been calibrated for the water resource, a foundation for making decisions relevant to the ecological status or restoration (Fig. 6). In the WSA reporting, graphical displays are used to illustrate the condition of the resource by ecoregion and USEPA region (Fig. 7). Without a powerful communication format, we will fall short of our goals.

FUTURE DIRECTIONS OF ECOLOGICAL ASSESSMENT IN THE USA

The purpose of this paper was to convey how ecological assessment was progressing in the USA and how we are formulating an approach to adequately describe the condition of the Nation's water resources. A nationally-focused program, called the Wadeable Streams Assessment, is the center of a major collaborative effort among a multitude of State and Federal agencies to obtain the answers to critical questions such as the condition of our aquatic resource and the relative composition of stressors affecting that resource. From this effort, a framework exists for future directions to encompass the following:

- We have adequate monitoring data to assess water quality and make sound watershed management decisions throughout the USA.

- Actions are taken to protect and restore water quality that maximize benefits and minimize costs.
- Sound science forms the basis of making informed decisions regarding our aquatic resource.

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