WATER QUALITY IN THE 21ST CENTURY: PROACTIVE MANAGEMENT AT THE ECOSYSTEM LEVEL

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ABSTRACT

Natural resource management is a reflection of societal goals and depth of scientific understanding, providing an historical record of societal and scientific change. Throughout history management itself has been a reactive field: implementation always lags several years behind progress in science and shifts in social attitudes. Considered in this coritext, management has been variously effective at addressing existing problems but has rarely been successful at anticipating new challenges. The 21st century marks the first time that water quality, and perhaps natural resource management will function proactively, rather than reactively. This shift can be attributed to dramatic changes in our social and scientific scales of observation and thought, i.e. to a paradigm shift in water quality management. Significant deveiopments in the field of ecology enable a new frame of reference for ecosystems: that ecosystems are more than the sum of their parts and that ecosystems respond predictably to environmental stress. The move from a reductionist to a synthetic view of ecosystems is leading to the development of a valuable array of tools with which to think about, assess and monitor ecosystem health. Parallel to these scientific changes are changes in societal awareness itself, which enable management to occur at increasingly large spatial and temporal scales. We are at an unusual point in history: conceptual bridges finally exist between water quality science and water quality decision-making. Water quality management in the 21st century will be proactive, rather than reactive, with decision-making focussed on multiple objectives and ecosystem level services.

INTRODUCTION

Water quality management in the early part of the 21st Century will be characterized by proactive strategies focused at the ecosystem level. Those strategies will be founded in the newly emerging recognition that there are consistent similarities among ecosystem behaviors. These proactive, ecosystem level approaches will represent a dramatic departure from the traditional views of water quality which held that ecosystem complexity necessarily led to uniqueness in ecosystem behaviors. In fact, much of the world's water quality management in 1993 implicitly is based on the uniqueness of ecosystems. However, recent developments in ecology have provided a valuable array of tools with which to think about, assess and monitor ecosystem health. Those tools and those conceptual developments allow and encourage management strategies in 1995 that are very different from those of 1975.

Traditionally, water quality managers and applied aquatic scientists have focussed their attention on characteristics of populations or communities. Dynamics at the population scale are central to management for achieving some societal goals. However, management at this level forces societies into simplified, discrete choices. Scientists are learning more about the seeming generality of ecosystem properties and processes. At the same time, societies are expressing more "multiple use management" goals for aquatic systems. Increased scientific understanding shows greater complexities, leading us away from earlier theories of ecosystem organization such as the linear food web. Now we recognize that the food web and other ecosystem components are interactive through vertical and horizontal hierarchies (i.e., ecosystems are more than the sums of their parts). Yet, through that complexity there is generality. It is increasingly evident that ecosystems themselves have distinct, generalizable patterns of behavior and response. These patterns are influenced by the behavior of component parts such as populations and communities but are not restricted to them.

Management at the ecosystem level will be forced upon

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us by societal pressures as much as encouraged by increased scientific understanding. Policy makers and decision takers are interested in defensible, scientifically based decisions. However, if necessary, policy makers will make policy in the absence of scientific input, making decisions which affect the environment regardless of whether or not there is supportirig scientific evidence. In the face of conflicting evidence, the science which best supports the goals of decision takers will be used in support of their own decisions. In the absence of supporting evidence, decisions will be based on societal goals and where available, the closest analogous system.

It is clearly impossible to provide scientific evidence to support every decision: the sheer weight of the numbers of decisions and potential impacts prevents it. But if ecosystems have emergent properties, with predictable patterns among healthy and stressed systems, then society has tools for generalization and management. Using those tools, we can develop a suite of indicators with which we can reliably measure and anticipate responses to anthropogenic stresses. As managers and applied aquatic scientists increasingly are called upon to make and/or support decisions from local to global scales, the utility and importance of such indicators increases and their necessity becomes irrefutable.

FROM REDUCTION TO SYNTHESIS: EVOLUTION OF WHOLE ECOSYSTEM UNDERSTANDING

The science of management evolves less as a continuurn of the growth of knowledge and more in a series of paradigm shifts (KÜHN, 1970), much like the evolutionary theory of punctuated equilibrium (GOULD, 1977; SOMIT & PETERSON, 1992). The science of water quality management is undergoing a paradigm shift in its emerging attention to ecosystem level processes. Since the mid-1980's, aquatic scientists and managers have begun to recognize the practica1 significance of similarities among systerns at a higher organization level.

All paradigms reflect society's current and recent view(s) of the world. The paradigms that guide societal approaches to water quality management are driven by broader views held by (local, regional or global) society in general. Changes in the paradigms that drove water quality management are evident frorn changes among societal views through the last several decades. In all cases, these trends are broad brush staternents about societal mores: it is also evident that water quality management practices and views lagged behind those of aquatic scientists by 5-10 years. That is, scientific knowledge is generally available for 5-10 years before it is ensconced into management practice.

- **Maximize efficiency: 1930's** In the 1930's, U.S. and western European societies were engrossed in maximizing productivity and efficiency. Ecosystems which exported energy were viewed as wasteful. Their energy was harnessed and "made efficicnt" through dams, power plants and production schemes.
- **Technofix: 1940's & '50's** In the post World War II years, technological solutions were offered for numerous needed or desired changes in U.S. and western European society. Ecosystems were seen as resilient and self-purifying: when anthropogenic influences exceeded resilience, technological solutions were called into play. Waste treatment plants and stream channelizations characterized the engineering approaches used to manage water quality.
- **Maximize productivity: 1960's** As a more global perspective emerged, productivity for human consumption dominated management philosophies. Ecological concepts of trophodynamics, efficiency of energy transfer between trophic levels, optimal exploitation of animal populations and other global production concepts drove management goals (GLIWICZ, 1992).
- **Management at the population level: 1970's & early '80's** In the 1970's, U.S. and western european societies began to understand effects of a wide variety of influences on individual populations. In the early 1980's, globalization emerged as people recognized the interconnectedness of biomes and hemispheres. Pollution control replaced increasing production as a central goal of western society. Applied ecologists conducted thousands of studies designed to assess environmental (i.e., population and community level) impacts, to establish criteria and to catalogue pollution effects. Many pollution-impact studies showed similar responses among ecosystems subjected to stress. However, few scientists and fewer managers looked at these studies from a synthetic, whole-ecosystem view. The focus of concern was with trophic levels or with discrete components (e.g., target populations) not with whole-ecosystems.
- **Management at the ecosystem level: a beginning in the late 1980's and '90's** Numerous ecologists working in terrestrial and aquatic systems have identified ecosystem level properties since the late 1960's (e.g., ODUM, 1969; WOODWELL, 1970; BORMAN *et al.*, 1974: NEESS,

1974). But not until the early 1980's did the whole-ecosystem approach gain the momentum (i.e., the theoretical basis and strength of scientific support) to lend it credibility. E.P. Odum's 1985 paper represents the seminal cohesive work upon which much of future management is, and will be based.

Odum's paper was the bellwether among a series of synthetic, ecosystem level papers published in the late 1980's. It did not create a paradigm shift but it did express the "leading edge" ideas in clear, concise format. His table of expected ecosystem-level responses to stress has served as a reference point for nearly 10 years. Even the words used in the titles of some of these papers indicate the shift in thinking that was taking place in the middle to late 1980s: phrases such as "ecosystem behavior" (RAPPORT & REGIER, 1985), "holistic management" (RISSER, 1985) and "ecosystern perspective" (BORMANN, 1985) were remarkable departures from the traditional concentration on site-specific science (see bibliography for more references).

Recent evidence frorn a wide variety of fields suggests that ecosystems do respond predictably to stress (e.g., ODUM, 1985; SCHINDLER, 1990; PERRY *et al.*, 1987; HARRIS *et al.,* 1985). However, there is not yet agreement among aquatic ecologists and managers about the utility and feasibility of managing at the ecosystem level. Some authors represent ecosystem ecologists who suggest that the basis of generality lies in ecosystem theory (e.g., ODUM, 1992). Other are empiricists who suggest that similarities arnong observations demonstrate the practica1 utility of the theory (e.g., PERRY *et al.*, 1987; RAPPORT, 1989). Others contend that current theories and data sets do not adequately account for the complexities that ecosystems exhibit in their response to and recovery from stress (e.g., CAIRNS, 1990; KAY, 1991; KELLY & HARWELL, 1990).

- **The 1990s and beyond: large-scale views and proactive management** In some ways, differences among those viewpoints are a matter of scale. The scale of our observations determines our understanding of a system. Those who focus on small scales inevitably focus on how one system, or its cornponents differs from another. At that scale, each ecosystem is unique and populations of ecosystems are highly variable. At a larger scale however, it is apparent that there are useful similarities even in the light of among-system variance. For example at the population and individual lake level, acidification threatens trout populations in the North American Great Lakes and selenium threatens bluegill populations in North Carolina. Synthetically, predators (i.e., the top trophic level) were eliminated by stress in both cases. Numerous such cases would then suggest that upper trophic level species were the most susceptible to disturbance.

Beyond the scientific issue of variance lies the managerial issue that scientists rarely make policy or implement management decisions. Science advances through increased understanding of variances among conditions. Policy and management are based on generalities; their conceptual framework includes recognition of the fact that "you can't please all the people all the time." Thus, policy makers can and rnust tolerate more variance in their data sets. They can, and will make decisions based on perceived generalities regardless of individual deviations from the norm. Much has been written about how recent developments in physics have blurred the line between "exacting" physicists and "generalist" philosophers. In the same vein, recent developments in ecology have blurred the line(s) between "exacting" ecologists and "generalist" managers.

This larger-scale perspective is critical. If managers are sufficiently proactive, the larger perspective enables them to act in time to prevent or mitigate decline before ecosystem damage is too severe. It enables scientists and managers to cooperate across local, regional and national boundaries. It also enables us to progress toward appropriate scientific and social solutions to ensure sustainable ecosysterns for the 21st Century.

STRESS IS CONTEXTUAL

Stress by definition is a force that results in a change in ecosystem behavior such that behavior is outside the bounds of "normal". In an ecosystem context, normal behavior means the ways in which a set of structural and functional relationships interact and maintain ecosystem integrity. This is accomplished primarily through a high degree of internal redundancy and the resultant resilience. The structural and functional characteristics of ecosystems serve as internal regulating mechanisms through feed-back control loops.

In a water quality management context, "normal" behavior rneans the continued provision of the variables which are of irnportance to society (e.g., fish production, drinking water quality, aesthetics). Water quality management seeks to preserve these variables as ecosystems respond to stress. The goals are to preserve (or assess) those variables.

Therefore, it is important to note that in an applied field such as water quality management, stress is contextually defined: our perception of an ecosystem and its responses is constrained by the scale of our observations and the goals of our analysis. The term stress implies some force that causes ecosystem behavior to fall outside our management expectations, but a pressure is not a stress until management expectations are altered by the ecosystem's response. The working definition of stress thus must be related to management goals.

STRESS, SOCIETY AND WATER QUALITY MANAGEMENT

Simply stated, stress affects ecosystem function and societies rely on those functions. Ecosystem stress influences society's ability to use and benefit from an ecosystem. For example, water metering and erosion control are significantly affected by moss cover in upper watersheds and are important services society expects from watershed ecosystems. That is disrupted by stress: mosses are highly susceptible to acid deposition and their disappearance often results in increased flooding and erosion from upper watersheds. Similarly, diseases of humans as well as other organisms often increase near stressed or mismanaged ecosystems (e.g., increases in schistosomiasis and malaria near irrigation developments, increases in trypanosomas near water supplies and road projects). From fisheries to flood control, societal uses evolve under expected conditions of supply and quality. The challenge of water quality management is to continue to provide expected products and services in spite of conflicting demands placed upon the ecosystem. Consequently, the ability to recognize stress and anticipate how an ecosystem will respond to it or recover from it is a vital skill for effective and timely management.

It is also important to note that management need not always try to eliminate stress; successful management involves keeping effects of stresses consistent with the natural processes in a system. In fact, some systems are stress dependent and the characteristics we value are ones which depend on some form of stress. The well known, unanticipated effects of the Aswan High Dam on Nile River Basin agriculture stand as an example. The ecosystem was dependent upon the annual stress (i.e., the annual flood). Removal of the stress decreased societal benefit.

Examples of other stress dependent systems include streams whose beds scour in spring, where the scouring removes a portion of the biologically productive benthic zone each year; the intertidal zone where wave shear serves as a physical re-set to drastically change species composition; high altitude forests where wind damage kills trees and creates open patches and dead snags; or mediterranean and boreal forests where fire devastates large areas, allowing shade-intolerant species to root and establish. In all cases, the goals of the manager are to maintain (optimize) delivery of goods and services rather than to minimize "stress" .

ECOSYSTEM RESPONSES TO STRESS IN A WATER QUALITY CONTEXT

As discussed above, there are a variety of viewpoints about the generality and utility of ecosystem responses to stress. The following summary is not intended to be exhaustive; it outlines variables and generalities most widely applicable and most likely to be useful in water quality management. These variables have been condensed from numerous sources, most of whom have relied upon or been influenced by ODUM (1985) (ODUM, 1992; KELLY & HARWELL, 1990; RAPPORT, 1989; SCHINDLER, 1990: PERRY *et al.*, 1987, and others).

- **Functional attributes (e.g., production, respiration, nutrient cycling) are more robust than structural qualities (e.g., species composition or species diversity).** One of the key findings of ecological research has been that community assemblages differ among ecosystems, but that different assemblages fill parallel functional roles in nearly every system. Consequently, at the whole ecosystem level structure and function are not as closely linked as once thought; significant structural changes may be observed without concomitant observations of functional change. The principles of redundancy and homeostasis explain much of the variance in this relationship. That is, as long as there is sufficient redundancy, functional effects of increases or decreases of individual species will be buffered. Thus, structural attributes will change more readily in response to a given stress than will functional roles.

The scale of initial response will always be physiological (e.g, respiration or production of individual organisms). Physiological changes are then expressed in population responses such as growth and death. It is critical to establish the scale of interest for observation. At the whole ecosystem level, functional qualities such as nutrient cycling, community respiration or carbon cycling respond to stress more slowly than do component population structure variables. Clearly however, structural and functional roles are tightly interwoven. We separate them for convenience and to emphasize scale effects. In practice, each one defines the behavior of the other.

If structural changes are sufficiently pronounced, they will affect the ecosystem buffering capacity and functional changes will be evident. Functional changes also are generally more resilient than structural changes, rebounding more rapidly after removal of stress. But functional changes reflect changes in ecosystem structural integrity and character. A stressed system with evidence of functional change also may be unstable through time. In response, an ecosystem may "settle" into a different stable state. Alternatively, the instability may lead to wide oscillations which are not easily stabilized. From the standpoint of water quality management, this may mean a loss of desired goods and services from the water body. It may also and more typically mean that management agencies will spend large sums of money and further management input in order to keep goods and services flowing at expected levels from a system no longer structured to provide those resource flows.

• **Lifespans and reproductive rates decrease.** Organisms in stressed ecosystems have an increased energy consumption due to increased respiration and metabolic rates. Species are also more likely to spend longer periods in resistant stages such as eggs, resistant spores and pupa. These changes are the basis of many of the community level changes that follow, but from a managerial standpoint their importance varies. In some circumstances, reduction in fecundity and lifespan is important because it provides a reliable, early indicator of stress and can be used to initiate policy discussions on stress reduction. In other cases, where a specific desired population may be threatened these reductions provide a way to measure the degree of response and may provide the basis for new management rules, such as catch limits.

• **Generally, species at the lowest and highest end of the trophic spectrum are most susceptible to stress.** Many organisms at the lowest trophic levels have narrow, specialized niches which make them sensitive to small environmental fluctuations. At the highest trophic levels, predators are susceptible to stress because their limited numbers of progeny mean fewer chances for the appearance of successful, resistant, variations. For some types of stress such as heavy metals or organics, predators' longer life spans and higher trophic level places them at a disadvantage because it enables pollutants to accumulate in their tissues.

• **Interactions change.** As the number of species changes, members of interaction guilds also change. Most stressed systems have increased parasitism and disease and decreased incidence of positive interactions (e.g. mutualism and symbiosis). This response relates at least in part to opportunism on the part of parasites responding to decreased fitness of many individuals and species.

• **Diversity decreases.** Reductions in diversity are probably the most widely documented changes in stressed aquatic ecosystems. This change is critical because decreased diversity usually means decreased redundancy and thereby a decrease in self regulatory capability in stressed ecosystems. Globally, the fact that stress has a negative impact on diversity is the source of much litigation. This is particularly true in the case of the potential elimination of rare species, such as the snail darter or the Ganges dolphin. At a higher level, the principle is also used internationally to argue for preservation of wetlands, tropical forests and many other ecosystems.

Beyond diversity, other results are evident from loss of individual species. For example, SCHINDLER (1990) notes that "the earliest serious changes in ecosystems and food webs occurred when acid stress eliminated acid-sensitive organisms that were also the sole occupants of key ecological niches." The less redundancy there is, the greater the chances that subsequent or more prolonged stress will eliminate occupants of key niches.

• **Patchiness increases.** As individuals and species are removed from an ecosystem, there is a concomitant increase in spatial heterogeneity (patchiness). Through elimination of some individuals and colonization by other species, stressed ecosystems exhibit increased spatial (and temporal) unevenness. Consequently, while diversity of species at any one site is likely to be lower and dominance higher in a stressed system the distribution of species is more likely to be patchy in a stressed ecosystem.

• **Successional stage may be set back.** Some authors have suggested that succession does not occur in stream ecosystems (VANNOTE *et* al., 1980). Others have suggested that succession is more a spatial than a temporal phenomenon (PERRY & ROSE, 1984). It does appear accepted that there is a predictable pattern of structure and function that occurs through time and space in aquatic ecosystems. That pattern results in the goods and services which society demands from water bodies and which represent the end products of water quality management.

Under stress, ecosystem character reverts to another state (one seen earlier in space or time) which results in different availability of desired goods and services.

- **Organism size changes.** Early predictions of ecosystem response to stress hypothesized that organisms would be smaller under stressed conditions (ODUM, 1985). This has been shown to be true for some organisms and some trophic levels, but not for all. For example, the size of phytoplankton cells appears to increase while zooplankton exhibit smaller sizes (i.e., either smaller individuals of a species or replacement of one species by one with a smaller mean size).
- **Energetics change.** Stressed ecosystems are less energy efficient. In particular, respiration rates increase so that a smaller unit of biomass is supported by each unit of energy taken in and by each unit of energy respired. There is also greater reliance on energy from outside the system and a higher probability that the system will produce excess products (e.g., excess primary production, biomass) which will then be exported from the system.

For example, PERRY & TROELSTRUP (1988) reported that in aquatic systems stressed by insecticide application there is an increase in drifting organic matter and invertebrates. Stress also generally results in increased respiration, reduced decomposition and increased export of unused quantities of primary productivity.

Decomposition rates usually decrease under stress but vary with different species and stresses. Pesticide application for example, has been shown to reduce overall decomposition as it reduces the physiological activity of individual decomposers. Yet, acidification appears to have a species-specific effect on decomposition. (PERRY *et al.*, 1987)

- **Nutrient cycling changes.** Stressed ecosystems manage nutrients less efficiently, exporting more nutrients, increasing nutrient turn over in the system and increasing the horizontal dimension of nutrient cycling. In stressed ecosystems, there will be more exchange between adjacent ecosystems and a smaller percentage of the available nutrients will be held within the system during any given time period. Also, standing crop of nutrients decreases with stress and nutrient export increases. Nutrient losses may indicate system malfunctions (e.g., imbalances in the coordination of cycles for different nutrients), impairment in biological activity,or simply that one or more nutrients are supplied in excess of maximum ecosystem uptake rates (SCHINDLER, 1990).

EXCEPTIONS TO THE PATTERNS

There are exceptions to each of these generalities. For example, acidification would be expected to increased "leakiness" in terrestrial ecosystems. However, it apparently causes phosphorus to bind to aluminium in acidified soils. Consequently, phosphorus inputs to lakes are often reduced rather than increased from acid stressed terrestrial ecosystems (SCHINDLER ***et** al.*, 1985). Schindler has also identified an exception to the general observation that species at the upper and lower ends of the trophic scale are most sensitive to stress: middle level trophic species were most susceptible to stress from acidification in the Experimental Lakes Area. Other examples of exceptions to these stress-response rules come from studies which have shown that under resource scarcity (a specific stress) evidence of mutualism increases instead of decreasing as expected, and studies which demonstrate that the average size of individual fish has been reported to increase in some situations and to decrease in others, depending on the ecosystem and the nature of the disturbance.

As discussed above, decomposition rates are usually reduced, respiration rates increased and the quantity of exported or unused primary production is usually increased in stressed ecosystems. However, these responses are not uniform. For example, periphyton community respiration has been shown to increase in acidified lakes but not in eutrophic lakes. Exported or unused primary production generally does not change in acidified lakes but increases in eutrophic lakes.

These exceptions illustrate that these principles are general indications, with many notable system-specific exceptions. Traditionally, scientists have focused on these exceptions and unique qualities to conclude that there are not sufficient generalities to guide defensible decision making. The alternative view, presented here is that by seeking generality among several ecosystem and community level indicators a manager or a scientist can predict future responses within acceptable variances and thus guide decision making.

THE NEED FOR ASSESSMENT

Ultimately, resource managers cannot understand and evaluate the significance of community and ecosystem level impacts or potential resource damage without assessing predicted impacts under field conditions (LAPOINT & PERRY, 1989). Despite characteristic changes in response to stress (e.g., elimination of upper trophic levels) ecosystem-level effects are often difficult to detect. Responses by individual species may be compensatory or remain masked as they translate from the individual to the system level. Scientists and managers employ ecosystem indicators to approach response to stress: attributes which serve as warning signs or clues that components of the ecosystem and hence the system itself is under stress,.even when large scale changes take place, are not evident. A wide variety of ecosystem structural and functional attributes could be quantified and used as indicators.

Despite the necessity and utility of indicators, single indicators and single species analyses remain notoriously unreliable across systems, although they may be excellent in any given ecosystem. These factors have led to the suggestion from many fronts that we develop sets of indicators that can be used to monitor water quality at an ecosystem level (AUSMUS, 1984; PERRY *et* al., 1987) .

RAPPORT (1990) reviewed some of the ecosystem variables that have been used with varying degrees of success. His review included: observed abnormalities, indicator and integrator organisms, changes in biotic size spectra, the "Ecosystem Distress Syndrome", the "Index of Biotic Integrity and the "Risk Assessment" metric. Rapport's conclusion was What stands out is that those indicators that are best descriptors of ecosystem health... are the least helpful when it comes to both diagnostic and early warning potential (page 613). Further, he states that When it comes to reflecting the integrity of the ecosystem, all four indicator classes serve moderately well. When it comes to providing early warning of pathological change, indicator/integrator organisms or groups of such organisms have the decided edge. Indicator or integrator organism groups include the guild concept applied in the functional feeding concept of MERRITT & CUMMINS (1984). Terrestrial scientists have taken the guild analysis further to develop landscape level response metrics (SEVERINGHOUSE, 1987). For example, BROOKS & CROONQUIST (1990) suggest that avian response guilds are particularly sensitive and integrative indicators of riparian wetland disturbances.

The utility of any metric or measure of response, including a guild is controlled by the goals and objectives of the manager. Water quality decision makers operating in a regulatory context must balance many competing priorities (LAPOINT & PERRY, 1989). In a regulatory context, hazard assessment and risk analysis require the use of tiered testing schemes which incorporate a 1) hierarchy of toxicity tests of increasing complexity, 2) chemical data and 3) expected exposure regimes to arrive at 4) predictions of safe levels of contaminants. Thus, measures of response must be selected to represent multiple and hierarchically structured endpoints. In that selection, the scale of deviations from the norm and the speed and nature of recovery may be the two most important questions for regulatory decision makers (LAPOINT & PERRY, 1989). In that context, selection of variables at the ecosystem level may be the most efficacious choice.

BEYOND MONITORING AND ASSESSMENT: MANAGEMENT AT THE ECOSYSTEM LEVEL

The results presented in this paper represent striking developments in ecological theory, especially in the linkages between theory and management. These developments have emerged over the last decade but are not yet ensconced into practice. They do however, stand ready to make enormous contributions to our ability to achieve sound environmental management policies and practices. Traditionally, science has been concerned with quantifying and explaining patterns in nature; the courts and decision makers have been concerned with risk management (i.e., risk avoidance) and burden of proof. Acceptance of the fact that certain elements of ecosystem structure and function respond predictably to stress allows management to be proactive rather than reactive. In this acceptance lays the bridge between science and policy, the bond toward common ground for scientifically based management decisions. But the bond is not yet strong enough to support the weight of the water quality management decisions of the 21st century. Decision makers are still making decisions while scientists investigate how these variances can be accurately measured and explained.

We have at our disposal a wide array of laboratory, microcosm, mesocosm and even selected whole ecosystem tests. Tiered testing protocols and monitoring via sets of biotic indicators have emerged and are being accepted as the appropriate approaches to ecosystem assessment. The importance of these protocols will continue to grow because they represent our first tactic of the management paradigm of the future: in a regulatory context they are scientifically defensible and valuable; in a management context they represent indicators of ecosystem level issues and management guidelines; in a monitoring and assessment context they constitute quantifiable measures. They are becoming more widely accepted and our understanding of them will grow exponentially in the next 20 years.

The growth in the next 20 years will be in definition of water quality goals, objectives, strategies and tactics at the ecosystem level. As has become common in 20th century society, our tools have grown ahead of our concepts and questions. As we become more comfortable with how to measure the effects of water quality management at the ecosystem level, we must learn more about why. That is, 21st century society will demand multiple goods and services from nearly all water bodies. Water quality specialists must be able to phrase proactive strategies for management at that level. That need represents the challenge posed to aquatic scientists in management as well as education as we look toward the future.

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