Mini-feature: What is river health?  

REVIEW  

Applying public health lessons to protect river health

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Abstract: Revealing, and indeed exacerbating, the globe's present water crisis is the failing ecological health of rivers. Those who would protect and restore river health can learn important lessons from humanity's continual fight against disease. We discuss four of these lessons, including their applicability to river issues: (1) recognize and respond to changing challenges, (2) avoid unintended consequences, (3) employ both cure and prevention, and (4) take a systematic approach. The overarching message from human health science is that we need to view human actions and their consequences for river health in an integrated way. In an effort to construct such a view of river degradation, we suggest that human actions jeopardize river health in five major ways: (1) altering physical habitat, (2) modifying seasonal flow of water, (3) changing the food base of the system, (4) changing interactions within the river biota, and (5) polluting with chemical contaminants. Another key lesson of human health science is the need for a commonly understood and robust measure of river condition, or health. Biological monitoring and assessment using the index of biological integrity for Japanese streams (IBI-J) provides a rigorous measure of river condition as well as guidance on the causes of river degradation. Examples of the index's use in Japan illustrate the importance of various stressors responsible for degradation, such as amount and types of effluent, proximity of dams and other structural alterations, and riparian condition. They also show the dangers of management driven solely by narrow water quality measures such as biochemical oxygen demand (BOD). We conclude that biological measures are important because they provide a strong scientific framework to inform the largely cultural process of deciding how humans treat rivers.

Key words: biological integrity, biological monitoring, public health, IBI, river health

Introduction

For most of the past 200 years, transformation of rivers was considered a sign of progress. Today, however, an unprecedented water crisis is earning headlines and attracting the attention of water managers, engineers, scientists, political leaders, and citizens (Karr 1995, Falkenmark 1998, Stevens 1998, Lundqvist 1998, Boon et al. 2000, Scientific American 2001, Gleick 2000). Japan is among the countries experiencing a water crisis, which threatens its rivers' many cultural and commercial values (River Council 1997, Takahashi 1997, Li et al. 2000). Worldwide, as a result, people and organizations are reevaluating fundamental, long-held assumptions about the relationship between rivers and people.

Arguably, the most serious symptom of the present
water crisis is the dramatically declining health of living rivers. “Health,” shorthand for flourishing condition, is a property of living things and, by extension, of living systems such as rivers (Karr 1999). One can speak properly of human health—defined by one author as “a sustainable state of equilibrium (harmony) between humans and other living things” (Last 1995), economic health, ecosystem health, or river health. A healthy organism performs all its vital functions normally and properly. A healthy economy provides for the well-being of its citizens without widening social inequities or environmental degradation. A healthy river sustains the supply of goods and services needed by both its human and nonhuman dependents. Applying the concept of health to rivers is a logical outgrowth of scientific principles, legal mandates, and changing societal values (Davis & Simon 1995, Karr 1996, 1999, Norris & Thoms 1999, Simon 1999, Jungwirth et al. 2000).

Our central thesis is that any effort to protect the health of rivers will have much in common with efforts over the past three centuries to eradicate human diseases such as cholera, smallpox, tuberculosis, and other health hazards associated with smoking and air pollution. We outline lessons from the experience of health professionals and describe how those lessons can improve river health. We follow these lessons with a synopsis of the dynamics of river degradation and suggest a framework for understanding the complex effects of human actions on river health. We end by discussing biological monitoring and assessment, key components of human health programs and also crucial for protecting healthy rivers and restoring degraded ones.

Learning across Disciplines: Lessons from Public Health

Just as diagnosing and healing disease in a person demands multiple tests and often multiple specialists, conquering epidemics demands multiple strategies and interdisciplinary research teams. So it will be with rivers if decision makers hope to go beyond lip service to lofty goals. What lessons can resource managers learn from the public health sciences, and how can they apply those lessons to improve river health?

To safeguard public health, public health practitioners aim to:

- Recognize and respond to continually changing health challenges
- Avoid unintended consequences, especially diseases introduced inadvertently by medical treatments (iatrogenic disease)
- Employ both preventive and curative approaches
- Take a systematic approach to diagnosis and treatment

Recognize and respond to changing challenges.

Health challenges faced by the first Homo sapiens included famine, vector-borne infection, combat, and accidents (McMichael 1993). New threats, such as contagious diseases, emerged as humans developed agriculture and established permanent settlements. Industrialization exposed societies to a remarkable array of chemicals—natural (e.g., heavy metals) and synthetic (e.g., chlorinated hydrocarbons)—with diverse health consequences (acute or chronic toxicity; carcinogenicity and teratogenicity; immune suppression and endocrine disruption). “Wonder” drugs controlled common pathogens even as natural selection strengthened the ability of those pathogens to resist the drugs.

Change was constant, and still is, but the speed of change is escalating. Technological and other advances may reduce one health risk, but too often they add other risks to public health. To keep up, health scientists must both seek and use new knowledge.

Threats to public health are not constrained to bodily diseases. An increasingly important class of risks to individual health and societal well-being derives from declining ecological health—the disruption of Earth’s living systems (McMichael 1993, Chu & Karr 2001).

Declining river health is but one example of declining ecological health. The world needs international, interdisciplinary efforts to minimize the impacts of global change on public and ecological health (Soskolne & Bertollini 1998).

Avoid unintended consequences.

A first principle of medicine is “do no harm.” Yet diseases provoked by physicians (iatrogenic disease) or, more broadly, modern medicine, are commonplace. Infections contracted during a hospital visit are one example; secondary effects of many modern medications, such as pathogens’ resistance to antibiotics, furnish another.

Anyone familiar with natural resource or environ-
mental management is well aware of unintended consequences. “Magic bullets,” from pesticides to kill pests or hatchery fish to boost over-harvested wild salmon populations, have precipitated unexpected “illnesses” ranging from stronger pests to extinct fish. Similarly, many engineering and political schemes for managing rivers to benefit one group of people have given rise to unanticipated problems for others. Clearing land and straightening upstream river channels to reduce local flooding, for example, worsen flooding downstream.

**Employ both cure and prevention.**

Modern curative medicine concentrates on personal health crises, such as an acute infection or traumatic injury. But reducing the incidence or spread of diseases demands an understanding of the dynamics that cause disease, or epidemiology, a branch of preventive medicine. Modern epidemiology was born in the 1840s when John Snow conducted meticulous studies documenting the connection between drinking water and cholera. His 1855 book, *On the Mode of Communication of Cholera*, is still used in teaching epidemiology (Last 1998).

River management over the last decade has seen a similar lesson: it is both less expensive and more effective to protect healthy rivers than it is to restore degraded rivers to health. Channelizing the Kissimmee River in Florida, for example, cost US taxpayers about $30 million; the Kissimmee River Restoration Program, which aims to restore much of what channelization lost in natural flows, will ultimately cost about $500 million. And although it may be difficult to restore a fish population decimated by river degradation, it is impossible to bring back one that is extinct. In short, safeguarding healthy rivers—using preventive river medicine—will be easier and more cost-effective than restoring, or curing, them once they are degraded.

**Take a systematic approach.**

During a major cholera epidemic that swept through London in the 1840s, family doctor John Snow used strict logic, a carefully framed hypothesis, and systematic observations to document the association between the disease and public water sources. His work provided the theoretical and empirical foundation for modern epidemiology and was instrumental in the eventual control of “filth diseases” (Colwell 1996, Last 1997).

Reflecting on the sanitary revolution of the late nineteenth century and the twentieth-century response to diseases caused by smoking, John Last (1997) defined a five-step framework for controlling health problems: (1) awareness that the problem exists; (2) understanding its cause; (3) ability to control the cause; (4) sense of values that the problem matters; and (5) political will to conquer the threat. If all steps are not accomplished, or they are accomplished too slowly, the problem persists.

Consider scurvy, the seafarers’ scourge. In 1601, English captain James Lancaster did an important experiment: he served lemon juice every day to the crew on one of his four ships, and most remained healthy. But 40 percent of the sailors on the rest of his ships died. It was not until 150 years later that the British Navy conducted its own scurvy experiment, and then not until 1795 that the Navy finally stocked citrus fruits on its ships (Gardner 2001). Even though Last’s steps 1 through 3 were accomplished in 1601, it took nearly two centuries for the British Navy to take preventive action, and the British merchant marine followed suit only in 1865. Thus, Last’s steps 4 and 5 did not reach completion until 260 years after the problem, its cause, and even its cure were identified. Efforts to protect and improve the health of rivers should follow Snow’s careful approach, distilled into Last’s five steps, while avoiding the British Navy’s mistakes.

1. **Awareness of a problem.**

When cholera spread through Snow’s London, it was clear there was a problem. Similarly, it is now increasingly clear that human-caused degradation of rivers is a problem (Dynesius & Nilsson 1994, River Council 1997, Lundqvist 1998, Boon et al. 2000). Awareness of the problem in Japan is manifest at several levels. A publication of Japan’s River Council (1997) calls for efforts to reverse the decline in river health by protecting diverse habitats; preventing the hydrological cycle; and re-establishing the relationship between rivers and human communities (Li et al. 2000). The newly formed Ecology and Civil Engineering Society shows how scientific and professional views of rivers are also changing: the Society’s goal is to study “natural ecosystems under the influence of human activities, aiming at their conservation, utilization and
management, including development, assessment, monitoring and implications of the civil engineering works from ecological view points."

Citizen activists too are expressing themselves, often in opposition to large-scale river-engineering projects. Local fishermen, scientists, environmentalists, and ornithologists proposed abandonment of a plan to divert Chitose, the largest river in Hokkaido, by digging a channel 200-400 m wide and 38-km long (Mainichi Shimbun 1999). That a growing number of individuals, professional organizations, and laws now acknowledge the need to protect river ecology, not just the need to engineer rivers for immediate human needs, suggests that a threshold of awareness has been crossed.

2. Understanding cause.
Understanding can take place at several levels. Snow's detailed studies, for example, documented the connection between drinking-water supply and cholera transmission. He recommended removing the pump handle from a well to break the chain of transmission, even though he knew nothing about the causative organism Vibrio cholerae, which would not be discovered for another 30 years.

Similarly, human actions are widely and correctly perceived as the cause of river degradation. Unfortunately, the various river researchers, managers, and users—who often operate in professional isolation—seldom agree on the details. Clearly, the River Council and the Ecology and Civil Engineering Society demonstrate the desire to broaden the narrow focus of single disciplines or particular industries. A broad focus on river health can ensure that we better understand place-specific causes of river degradation, as well as the mechanisms likely to restore that health.

Just as the complex health challenges human society faces can rarely be conquered by single individuals acting alone, the health challenges associated with river management require collaboration among individuals from diverse disciplines. A critical prerequisite for working together is the understanding and use of a common language. The recent Lake Biwa symposium titled “Ecological Health: Evaluation and Restoration of River Ecosystems” fostered exchanges among scientists, engineers, and citizens that could lead to agreement on that common language.

3. Ability to control the cause.
In medicine, the ability to control the cause of a health problem requires development of a technology or a set of steps that, if used, will actually control the disease. "Filth diseases" like cholera could not be halted without water treatment and purification technologies or the separation of drinking from sewage water; even today, more routine hand washing would stem the spread of colds and other minor illnesses. Vaccines conferring immunity also help fight diseases.

Many efforts have been made over the past century to control the causes of river degradation. The first efforts centered on curbing pollution with pollution permits and enforceable chemical water quality standards. But pollutants are not the only source of declining river health. Dams can block fish migration and destroy fish habitat; altered flows and habitat degradation interfere with life histories of river organisms. For such complex, interacting causes, straightforward "controls"—such as fish ladders or hatcheries—may lead managers to think that harm is averted, but, in reality, it is not. Too often, such attempts are narrowly conceived and implemented, and the results are less comprehensive than what is required to solve the problem (Lichatowich 1999).

4. Sense of values that the problem matters.
Snow realized that the unchecked cholera epidemic was devastating London, and his preventing access to a city well by removing the pump handle provides the first recorded instance of an appropriate measure to prevent the transmission of a waterborne disease (Colwell 1996). Although the British Navy and Merchant Marine were slow to stock citrus fruit, their eventual adoption of the practice meant that someone finally decided that the problem mattered enough to do something. Action required a conscious "redefining [of] the acceptable" (Vickers 1958).

As river degradation worsens, societal values shift. Large numbers of citizens are speaking out in public forums and filing lawsuits to force governments to strengthen river protection as well as water quality laws and their enforcement. In the United States, numerous successful court actions have forced state and federal agencies to implement more integrative programs (for example, TMDLs, or total maximum daily load models) to protect the nation's waters from the cumulative effects.
of point and nonpoint pollution (Houck 1999, NRC 2001). In Japan, a government decision to build a new dam to replace a 250-year-old dam on the Yoshino River met fierce opposition by local residents and environmentalists; their efforts stalled the plan (The Japan Times 2001).

The sense of values needed to protect and restore river health is rising throughout the world—in conservation laws, such as the US Wild and Scenic Rivers Act; in large-scale restoration plans, such as a South Florida Water Management District project to restore the Kissimmee River and the multiagency effort to restore the Everglades in the southeastern United States; or in plans to remove the Elwha Dam in the Pacific Northwest to restore wild salmon runs on the Olympic Peninsula (Karr et al. 2000). A citizens' group called the Global Rivers Environmental Network (GREEN) encourages and supports local schools and communities to monitor river quality. Local programs are springing up throughout the world (Showers 2000). Increasingly, natural processes are being taken into account in the design and execution of civil engineering projects from management of dams to control of urban runoff. Despite persistent controversies, a groundswell of public support for protecting river health exists.

5. Political will to conquer the threat.

Government-funded medical research programs, as well as government regulations, demonstrate the political will to protect citizens' health. Most developed countries set standards for food service in restaurants, meat inspection, the purity and effectiveness of prescription medicines, clean air and water, and workplace safety. Many of these regulations are effective because they deal with a tractable but narrow problem, and it is easy to identify a constituency for each effort.

Protecting river health will not be so easy. In the first place, the most common approaches still treat symptoms rather than the underlying disease. Stabilizing channels or installing woody debris, for example, treat supposed habitat symptoms when the real "disease" is altered watershed drainage networks. Musterling the political will to identify and treat root causes will be a primary challenge facing river managers. Multiple levels of bureaucracy and agencies with overlapping, sometimes conflicting, mandates make the task more difficult. The US Department of the Interior, for example, attempted to retain wetlands in Iowa in the 1960s, even spending money to create artificial wetlands of marginal quality, while the US Department of Agriculture paid landowners there to drain high-quality natural wetlands to free land for agriculture. These and similar legacies of government programs make it difficult to accomplish the recently articulated goals of river protection.

Understanding the Complexity of River Degradation

Human-caused river degradation threatens rivers' ability to supply goods and services that people take for granted: abundant clean water, harvestable fish and shellfish, recreation, and aesthetics. Moreover, as humans concentrate their activities in river floodplains, they and their economic, political, and cultural infrastructure become subject to flooding.

To apply public health principles to protect river health, one must first recognize that river degradation follows from many stressors (diseases). Some human activities—for example, dam construction, channelization, introduction of nonindigenous taxa, and overharvest— affect rivers and their biota directly. Others have more indirect effects: clearing natural vegetation in uplands, for instance, alters the delivery rates of water and sediment to river channels. Toxic contaminants can accumulate in food webs, influencing species abundances and distributions, especially top carnivores.

Cataloging the scores of human activities altering river condition quickly becomes overwhelming. The list is long and complex and, once soon recognizes, contains a seemingly infinite variety of combinations that may operate in particular watersheds. Moreover, those activities interact with topographical, geological, climatological, and biological differences among watersheds.

One way to cut through this complexity is to group human actions into five major classes, each of which jeopardizes river health (Fig. 1): (1) changes in the food web (energy source), (2) changes in chemical water quality (chemical variables), (3) modification of seasonal flows (flow regime), (4) alteration of physical habitat (habitat structure), and (5) changes in biotic interactions (biotic factors). When human actions influence one or more of these factors, or their
interactions, river health declines.

Seeing rivers in terms of their biological health can aid our efforts to understand, prevent, and reverse human impacts that degrade rivers. Environmental decision makers can and should use the condition of living systems as a benchmark, guide, and goal for their work (Karr 2000). Biological measures provide better information about actual environmental quality than chemical and physical measures (Keeler & McLemore 1996) because those biological measures are one step closer to the factors that constitute environmental quality for living things.

Seeing and measuring river health in biological terms lead to more integrated diagnoses than measuring only chemical or physical parameters, for the biota responds to all factors influencing a river. Furthermore, the results are more likely to prove cost-effective, because solutions may capitalize on natural processes (Karr et al. 1986). Since shading restricts light and limits algal growth, for example, river reaches (segments) with overhanging cover and healthy riparian corridors can absorb more soluble nutrients without suffering massive algal blooms than stretches lacking riparian corridors. Lowered algal production, in turn, changes food available to aquatic invertebrates and thus their community structure and the processing of organic matter. Understanding rivers' health in terms of their biology would provide an integrative view of river condition and facilitate efforts to improve that condition. Using this approach—which forms the core of the practice known as biological monitoring and assessment—scientists and managers throughout the world have succeeded in diagnosing the cause of declining river health and in identifying ways to restore health.

In the United States, biological monitoring has detected the effects of chemical contamination (Karr et al. 1986, Kerans & Karr 1994, Karr 1991); flow alteration; and land use, including urbanization (Kleindl 1996, Roth et al. 1996, Wang et al. 1997, Allan et al. 1997, Morley & Karr, in review), recreation (Patterson 1996), and logging (Fore et al. 1996).

Elsewhere on the globe, biological monitoring detected the effects of effluents from a bauxite plant in Guinea (Hugueny et al. 1996); effluents from salmonid aquaculture in a small river in France (Oberdorff & Porcher 1994); the effects of channelization and chemical effluents in small Venezuelan rivers (Gutierrez 1994); the cumulative effects of channelization, agricultural runoff, and urbanization in France's Seine River basin (Oberdorff & Hughes 1992); metal and organic pollution in central Indian rivers (Ganasan & Hughes 1998); urban point and nonpoint pollution gradients from "pristine" to "grossly polluted" in Thailand, Ghana, and Brazil (Thorne & Williams 1997); and the impact of diverse land uses on rivers in dry west-central Mexico (Lyons et al. 1995).
Biological Monitoring and Assessment

A doctor evaluating a patient depends on the patient to communicate what is amiss. The doctor will then do three things: (1) ask the patient to describe her or his symptoms; (2) request an appropriate set of laboratory tests; and (3) gather information on relevant environmental factors (home and work; recent travel; tobacco, alcohol, and drug use). But not all patients—infants, someone with severe dementia, or a pet dog or cat, for example—can volunteer such information. Neither can rivers.

Like competent medical practitioners, river managers can deduce river condition through standardized "health evaluation" procedures. Sampling a river's biota with a standard protocol, followed by appropriate data analysis, is a robust way to both measure river condition and identify the likely causes of river degradation. The process combines biological monitoring (sampling the biota of a place such as a river reach) and biological assessment (using the samples to evaluate the condition of the sampled place). By applying biological monitoring and assessment in the context of relevant environmental factors (the kind and extent of human actions neighboring the sample site), river managers can improve their ability to protect (prevent "disease") and restore (cure "disease") river health.

Living organisms not only give clear signals about river health, they also attract popular attention, often reaching diverse groups emotionally. In the areas surrounding Lake Biwa, aquatic organisms have been central to people's daily lives for generations (Kada & Yuma 2000), and, although less connected to aquatic organisms today than in earlier generations, citizens still find a biological index appealing. Signals from the biota are more easily grasped intuitively than are chemical water quality data. Photos of a massive fish kill, for example, present an image having far greater impact than water chemistry data indicating contamination.

The history of modern biological monitoring goes back to the early twentieth century, when concerns were first raised about organic pollution and associated oxygen depletion (Kolkwitz & Marsson 1908). Within a few decades, the proliferation of toxic chemicals shifted the focus from biological to chemical monitoring; most efforts to protect water quality, at least in North America, relied on chemical standards (Karr & Dudley 1981, Adler et al. 1992). Direct biological monitoring in North America has come back since the development, widespread testing, and application of multimetric biological approaches to water resource assessment (Karr 1981, Karr et al. 1986, Ohio EPA 1988, Davis & Simon 1995, Barbour et al. 1999). Multimetric indexes, modeled after econometric indexes such as the Nikkei economic index, provide more comprehensive and robust assessments than narrowly focused chemical standards. They provide a view through a biological lens that was ignored through most of the twentieth century.

But biological assessments do more than indicate river health. Biological assessments based on multimetric indexes can also diagnose causes of degradation, suggest treatments to halt or reverse damage, and evaluate the effectiveness of management actions (see Karr 1991, Davis & Simon 1995, Karr & Chu 1999, Simon 1999, Jungwirth et al. 2000 for more detailed discussion and examples).

The index of biological integrity (IBI), the first multimetric biological index, was conceived to provide a biologically broad and ecologically sound tool to evaluate river condition (Karr 1981). Initially developed for fish assemblages in midwestern North America, IBI has now been adapted to invertebrate and algal assemblages and applied in regions throughout the world (Simon 1999, Jungwirth et al. 2000).

The success of biological monitoring programs is tied to identifying biological attributes that reliably signal resource condition. IBI's effectiveness depends on choosing from the many biological attributes that can be measured those few that are appropriate as index metrics. These metrics must vary systematically in quantitative value across a range of human influence. A properly constructed IBI typically incorporates metrics that span ecological levels from the individual through population, community, ecosystem, and landscape and that have differential sensitivities to various human activities.

Calculating an IBI for a river reach requires a sample from a site that represents the species composition and relative abundances of the sampled assemblage (Fig. 2). Standardized sampling protocols are required to ensure that data among sites are consistent and of sufficient quality to be compared.
Fig. 2. Steps in a biological assessment using the index of biological integrity (IBI; modified from Karr 2001). In this example, a sample site represented by a solid square has an IBI value of 16 in a four-metric system (data from Rossano 1995).

The value for each metric is based on a comparison to a regional reference, or minimally disturbed, site: the condition expected at places with little or no human influence. Each metric receives a score of 5 if its value deviates only slightly from the value expected for reference condition, 3 if it deviates moderately, and 1 if it deviates strongly. A typical IBI includes 8 to 12 metrics selected to reflect diverse biological signals (taxa richness and relative abundance of various taxonomic and ecological groups) and their sensitivity to diverse human influences (chemical contamination; introduction of exotic taxa; alteration of physical habitat, energy source, or flow regime). The maximum possible equals five times the number of metrics; the minimum value is equal to one times the number of metrics. A maximum IBI value indicates that a site has received little or no human disturbance; a minimum value indicates major divergence in the sampled biota from what would be expected at an undisturbed site.

Over the past century, narrow monitoring approaches have been tried, with limited success. Water samples taken for chemical monitoring, for example, represent only the brief instant of sampling; in contrast, the biota present at any instant is a result of conditions over days, months, even years before sampling. Models such as the instream flow incremental methodology (IFIM) or the physical habitat simulation model (PHABSIM; Stalnaker et al. 1995, Nakamura 2000) have been appealing because these models seem to quantitatively integrate hydrological, physical habitat, and biological information. But these models assume that the relationships between flow, habitat, and biota are simple, deterministic, and well known—which they are not—so the models’ predictive ability in biology is limited (Scott and Shirvel 1987, Nakamura 2000). Similarly, many river managers assess physical habitat conditions, assuming a direct and simple link between physical habitat and resident biota. But a river reach with clear
water cascading over cobbles and numerous riffles and pools may look healthy even while its flow may be regulated, ephemeral, or have unseen contaminants; the biota may not be thriving at all. Thus, simple measures of the chemical or physical environment are not reliable indicators of river health, whereas a biological sample can quickly reveal how healthy the reach actually is.

Skeptics argue that knowing a river’s biological condition does not explain the causes behind that condition. But the same criticism applies to chemical or habitat monitoring: water samples say nothing about the source of any contaminants present, and the existence of physical degradation says nothing about how or why the degradation occurred. Moreover, neither measures of chemical water quality (see discussion of BOD below) nor measures of physical habitat actually demonstrate that river health is or is not degraded. Success in monitoring river health and in diagnosing, and ultimately treating, the causes of degradation can only come from biological knowledge coupled with awareness of local and regional chemical and physical stressors associated with human activity. Protecting river health is not an either-or affair. It is a challenge to put diverse pieces of a puzzle together.

Among its many advantages, then, IBI is both integrative and quantitative, and it reflects distinct attributes of biological systems, including temporal and spatial dynamics. Even though an IBI is one number, one does not lose information contained in constituent metrics because each metric contributes to the total, and its meaning can be explored individually. Finally, professional judgment is incorporated in a systematic and ecologically sound manner (Karr 1991). Moreover, use of IBI resolves a major problem by providing a measure of resource condition that is both scientifically rigorous and easily understood by citizens as well as scientists and engineers from diverse disciplines.

**Development and Application of IBI in Japan**

Adoption of the multimetric IBI approach for use in Japan has advanced on several fronts (Rossano 1995, 1996, Koizumi & Matsumiya 1997) using both fish and invertebrates. IBI-J (index of biological integrity for Japanese streams; Rossano 1996) is derived from a study of benthic invertebrate samples from 113 sites in the Kansai region. Field samples of stream invertebrates from each site were counted, identified, and tabulated. The degree of human influence was qualitatively evaluated for each site (Fig. 3). Data from about half the sites were examined to determine which biological attributes were strongly associated with human activity. Those with a clear quantitative

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**Fig. 3.** A priori classification system for ranking Japanese streams according to intensity of human influence (Rossano 1995). Sites were assigned to one of 21 possible categories based on amount and types of effluent, proximity of dams and other structural alterations, and type of riparian vegetation. Even without quantitative measures from each site, this approach allowed sites to be ranked across a range of human influence (from Karr and Chu 1999).
Fig. 4. Index of biological integrity, IBI-J, for 113 sites in Kansai district (Rossano 1995). The top panel shows IBI-J calculated from half of the 113 site data set (circles), which was used to select and test metrics for use in the IBI-J. The middle panel shows IBI-J calculated from the second half of the data set (pluses); the metrics and scoring criteria used for these data were the metrics and criteria developed from the first half. In the bottom panel, all 113 IBI-J are plotted together; the indexes from both sets correspond closely, ranking the sites comparably according to intensity of land use from low to high. The range of human influence against which the IBI-J are plotted comes from the classification scheme shown in Figure 3 (from Karr and Chu 1999).

change in value along the human influence gradient were retained as metrics in IBI-J.

Estimates of degree of human influence based on observations are sometimes criticized as subjective. But visual estimates of habitat features (e.g. qualitative habitat evaluation index (QHEI) developed by Ohio EPA; Rankin 1995) and environmental quality scores (Lyons et al. 1995) are commonly used in water resource assessment. A more objective site-ranking approach based on road density (km/km²) provides a quantitative measure of human influence in benthos (B-IBI) and fish (F-IBI) studies in Hyogo Prefecture watersheds and Ise Bay watersheds (Rossano, manuscript).

IBI-J comprises twelve metrics: total number of taxa; number of mayfly, stonefly, caddisfly, long-lived, intolerant, and clinger taxa; percentage of individuals belonging to tolerant taxa, legless organisms, mud burrowers, and predatory taxa; and relative abundance (percentage) of the three most abundant taxa. Among the 12 metrics, some seemed more sensitive to sedimentation (e.g., clinger taxa richness) than others (e.g., legless organisms). Mayfly taxa seemed much less tolerant of low pH than were stonefly or caddisfly taxa. Thus, unusually low mayfly taxa richness may be indicative of acidification. Other metrics, individually or in sets, may indicate other types and degrees of disturbance (Yoder and Rankin 1995).

Applying the standard scoring process developed in the United States, Rossano (1995) defined the scoring criteria applicable for Kansai region samples. The sum of values across individual metrics yielded the final IBI-
The generality of the pattern from these data was then evaluated by applying the metrics and Japan-specific scoring criteria to the other half of the data; the two data sets were very concordant (Fig. 4; see Rossano 1996, Rossano 1996).

Within the integrative IBI-J, information from each metric is still available for study and for appropriate inferences by water managers. For example, the presence of the long-lived perlid stonefly Oyamia lugubris in a Japanese river indicates that the site has not recently undergone catastrophic pollution episodes. That same river also will likely have a rich community of mayflies and caddisflies and of clingers and intolerant species. IBI-J simply captures in quantitative form the cumulative pattern across biological metrics (see Fig. 5). And it does that in statistically and biologically robust ways without loss of the metric-level information (Fore et al. 1994, Karr & Chu 1999).

Oxygen-demanding wastes have long been recognized as a primary factor in water resource degradation (Kolkwitz & Marsson 1908). Yet an exploration of the relationship between water quality and IBI-J scores in seven watersheds in Japan’s Chugoku district illustrates the inadequacy of water resource decisions based solely on analysis of biochemical oxygen demand (BOD). Areas with high BOD (> 1.5 ppm) do have low IBI-J, but the converse is not true (Fig. 6). Because areas with low BOD may span a range of river health as measured by IBI-J, river protection policies based narrowly on BOD will be fundamentally flawed.

Just as IBI reveals broad differences among sites, a more detailed examination of differences across IBI metrics yields additional insight about patterns and may also provide evidence of specific causes of degradation. The single measure of total taxa richness does not distinguish among moderately and heavily degraded Kansai district sites (Fig 7, left panel, rank 6 and rank 16 in the ranking scheme used to develop IBI-J). The clinger taxa richness metric, however, clearly distinguishes rank 6 sites from rank 16 sites (Fig 7, right panel). Sites classed as rank 6 have more taxa associated with cobble surfaces that are free of sedimentation and overgrowth of attached algae, whereas rank 16 sites supported fewer of those taxa.

Many other indications of river condition, including potential causes of degradation, can be discovered by carefully examining the behavior of specific metrics, thereby uncovering so-called biological response signatures (Yoder & Rankin 1995). For example, sites that are affected by sedimentation tend to have low clinger...
Fig. 7. Total taxa richness does not distinguish rank 6 sites from rank 16 sites; however, clinger taxa richness clearly separated the two groups. Rank 6 sites are located in rural areas moderately affected by domestic effluent (data from Rossano 1995). Rank 16 sites are located in suburban areas affected by domestic effluent and regulated flows (see ranking scheme in Fig. 3).

taxa richness, and acidified sites tend to have fewer mayfly taxa. An isopod, Asellus hilgendorfii hilgendorfii, is present in high density in channelized rivers (Rossano 1996).

River Health as a Social Construct

Because the preferred “use” of a river depends on one’s point of view, not everyone defines a “healthy” river by the same criteria. For a carp fisherman, a healthy river supports an abundance of carp, but someone wishing to go swimming might find the turbid, carp-supporting river unhealthy. Defining health for a particular stream, then, requires scientific, cultural, and social consensus. IBI cannot provide that consensus, but it does provide a common standard of measurement—a benchmark—that serves as a foundation for developing consensus (Karr 2000).

Most people would agree that a minimally disturbed site with a very high IBI-J is healthy. Most would also agree that a severely degraded site is unhealthy. The middle segment of the gradient constitutes the primary source of controversy for decision making, because social and cultural perspectives play an important role in judging such places; if a place’s condition is culturally acceptable, it can perhaps be deemed healthy.

We see IBI-J as a primary contributor to the process of integrating scientific and cultural perspectives as society moves toward a broader understanding of river health. That process requires exploration of four questions:

1. What is the condition, or health, of the river in biological terms?
2. Is that condition acceptable in scientific and cultural terms?
3. Is the river self-sustaining, or does it require human intervention to maintain its current condition (to prevent further degradation)?
4. Do conditions upstream affect conditions and health in reaches downstream of a sampled site?

What results emerge if we apply these four questions to IBI-J in Japanese rivers? The 12-metric IBLJ spans a range of values from severely degraded (12) to near pristine (60). A relatively undisturbed cold-water river in western Japan would support healthy populations of cherry salmon (Oncorhynchus masou macrostomus), a minnow (Phoxinus oxycephalus), and a sculpin (Cottus pollux) and have a IBI-J near 60 (question 1 resolved). With increasing human activity in the watershed, those species would decline and even disappear, replaced by the algae-grazing ayu (Plecoglossus altivelis). IBI-J at a hypothetical 40 for the ayu stream would fall well below the value of the undisturbed cold-water river characteristic of the area in earlier centuries. Yet local citizens may be very pleased with their neighborhood river because ayu is a prized fish. The shift in condition is culturally preferred, so the river’s condition could be defined as appropriate for the region (question 2 resolved). Can these biological conditions be sustained without intervention from humans? If so, the answer to question 3 is yes, and the river is judged healthy. On the other hand, if normal river processes cannot support the ayu system, requiring massive human subsidies such as a major ayu hatchery, the answer to question 3 is no, and the situation is not healthy. Similarly, if downstream degradation caused by conditions of the site in question is detected, then, by cultural definitions the site is not healthy (question 4 answered no). If human actions cause the ayu to disappear, and a self-sustaining but less desirable nonnative black bass fishery (Micropterus salmoides)
develops, many would conclude that the degradation is unacceptable and the river is now unhealthy. Perhaps worse, a successful bass population might spread throughout rivers in the region, with massive loss of other water resource values.

Multimetric biological indexes such as IBI are mainstream in many water resource situations throughout the United States: 48 states have (42) or are developing (6) multimetric approaches (Davis et al. 1996). The few patterns illustrated here for Japanese rivers indicate that these indexes have considerable potential to guide the management of river health in Japan as well. The indexes are valuable communication tools for diverse audiences, and they are scientifically strong. By using the results of biological monitoring to describe the condition of rivers and their adjacent landscapes and to diagnose causes of degradation, we can develop restoration plans, estimate the ecological risks associated with potential land uses in a watershed, or select among alternative restoration or development options. Used in this way, IBI provides a scientific framework to inform the largely cultural process of deciding the fate of a nation’s rivers.

Conclusion

Although water resource scientists, engineers, and managers rarely think of themselves as public health practitioners, lessons from public health can inform and improve management of the world’s waters. Like public health practitioners, river managers today confront continually shifting challenges, from ever-increasing numbers of new pollutants to new societal wishes for and expectations of their water resources. Many past and present human activities have unintended consequences for the world’s rivers—as when dams for “clean” hydropower decimate salmon populations, or upstream farming wipes out coastal fisheries. As the crisis of freshwater quality and quantity deepens (Johnson et al. 2001), river managers must learn how to avoid consequences like these. And at the same time that water managers strive to protect still-healthy rivers—public health’s preventive medicine—they must also restore, or cure, degraded rivers. In all these efforts, a systematic approach combining biological monitoring and assessment with interdisciplinary teamwork will raise the likelihood of success in sustaining the world’s living rivers.

Acknowledgments

This paper was prepared with support from US Environmental Protection Agency and National Science Foundation Water and Watersheds Program, EPA Grant 825284010 and the Consortium for Risk Evaluation (CRES) by Department of Energy Cooperative Agreement #DE-FC01-95EW55084 and #DE-FG26-00NT40938. We are grateful to Ellen W. Chu, Ikuko Morishita, Colin Soskolne, Christopher Rossano, and Elena S. Karr for their thoughtful reviews.

摘 要

河川環境は人間の活動によって大きく変化する。原因を取り除き、健全な河川に戻すことが大きな課題である。この課題へのアプローチを、河川が抱えている問題をこれまで人間が長く対処してきた健康維持の実践経験においては求めて考えた。すなわち、1) 次々に変化する健康への影響の認知し対処する。2) 二次感染など予期しなかった病原の発生を食い止める。3) 防治と治療を大切にする。4) 病気の克服には包括的にかつ系統的な対策を講ずることが考えられる。これらから、人間活動とそれによってひきおこされる河川の健康状態の変化を総括的にとらえる観点が必要であることが教訓として得られる。そのために、人間活動が河川の健康状態を変化させる観点として、次の5点：生息場所の構造、流量の季節変化、食物源、生物間の関係、水質汚濁（Fig.1）を取り上げた。さらに、河川がどの程度健康であるかを診断するため、解裏やすくかつ強力な手法の開発も必要である。水環境カルテル（index of biological integrity for Japanese streams, IBI-J）は、河川の状態を総括的に測り、健康状態を損なう原因を提案する指標である。IBI-Jを使った研究例から、河川の健康状態を損なう要因として、排水の量と種類、ダムなどの構造物との距離、河畔植生の有無などが重要であることが示唆された。これらは、生物化学的素要素量（BOD）などの単一の観点だけに立脚して河川管理を進めることの危険性を指し示す（Fig.6）。IBI-Jのような生物学的環境評価法は、人間が河川をどう扱うかを決める際の多分に文化的な過程に対して科学的な情報提供をするための枠組みとして重要である。
References


Karr & Rossano: Applying public health lessons to protect river health


