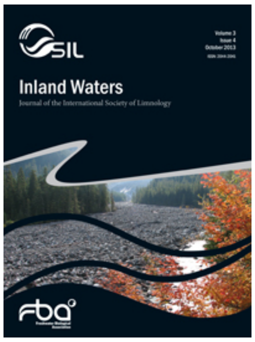

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Socio-ecological complexity and the restoration of river ecosystems

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Abstract

Understanding socio-ecological characteristics associated with rivers and their catchments, and using that understanding to effectively manage and restore river ecosystems, is an increasingly complex challenge. While great strides have been made in the last half century in understanding rivers as ecological systems, human exploitation of river water and riparian zones have frustrated river management to the point that many native species are imperiled or have become extinct, invasive species are rampant, water and sediment quality are in significant decline, environmental flows are neglected, and economic pressures are placing unprecedented demands on remaining resources. At the same time, there are societal expectations that river resources be restored or rehabilitated[1] to functional states, even while climate change, population growth, flow diversion, and the proliferation of chemicals impose additional burdens in ways that are not adequately understood. Therein lies one of the great challenges of this century. Can river systems be realistically restored or rehabilitated and, if so, what are the approaches and scales that have a chance of being successful? The 2013 E. Baldi lecture addresses these questions by examining 2 examples of river restoration: identifying socio-ecological attributes from those examples that have been successful as well as aspects needing improvement, and presenting principles for improving river restoration in highly complex situations. The principles are designed to enhance resilience and promote adaptive capacity within social–ecological systems—systems that continue to evolve.

Key words: conservation, environmental principles, rehabilitation, restoration, river, social dimensions, social–ecological

[1] The terms restoration and rehabilitation are used synonymously throughout the article.

Introduction

Nearly 40 years ago I was fortunate to attend an Edgardo Baldi lecture that, in many ways, defined my professional career, and I've always cherished that experience. It was presented by Prof. HBN Hynes at the 19th SIL Congress in Winnipeg, Canada, and the topic was "The stream and its valley" (Hynes 1975). As noted by the late Dr. Umberto D'Ancona, who delivered the first Baldi Lecture in 1953, the intent of the Baldi lecture is to discuss the most vital problems of hydrobiology in light of recent developments, and Professor Hynes did it in a simple but eloquent manner. I, as well as many other young professionals in the audience, realized that his powerful presentation marked a turning point in stream and river ecology. Thereafter, many researchers began looking at streams not as purely aquatic phenomena but as integral components of landscapes.

A landscape perspective views rivers in their social–ecological context. Nearly 2 decades after Professor Hynes' presentation, Jane Lubchenco led a call for a "new social contract for science" (Lubchenco 1998), along with others from various scientific disciplines. Lubchenco reasoned that the magnitude of human landscape change on the planet's ecological systems was creating tangible connections between ecological systems and human health, economies, social justice, and national security. The concept of what constitutes "the environment"

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changed rapidly. Urgent and unprecedented environmental and social changes challenged scientists to define a new social contract that devoted energy and talent to the most pressing problems of the day in exchange for public funding. The needs of society included, and still include, more comprehensive information, understanding, and technologies to support a more sustainable biosphere—one that is ecologically sound, economically feasible, and socially just. It was acknowledged that new fundamental research, more effective transmission of new and existing knowledge to policy- and decision-makers, and better communication of knowledge to the public would be required. This indeed is a daunting challenge, but how does it relate to limnology in general and rivers in particular?

Aquatic ecosystems are the ultimate recipients of materials from human action on the land and atmosphere (Turner et al. 1993, Naiman et al. 1995). Rivers are especially vulnerable because they transverse the landscape and are topographically the lowest points on the landscape. Fortunately, great strides have been made in the last half century in understanding rivers as integrated ecological systems. Yet, the economic uses of river valleys have frustrated management to the point that many native species are imperiled or are extinct, invasive species are rampant, water and sediment quality are in significant decline, environmental flows are neglected, and economic pressures are placing unprecedented demands on the remaining resources and on people, often those with the fewest resources to address the demands. At the same time, social expectations ask that river resources be conserved and restored (or rehabilitated) to functional states. Further, climate change, population growth, and the proliferation of chemicals place burdens on river resources and adjacent communities in ways that are not fully apparent. Collectively, therein lies a great challenge for this century—meeting social expectations, or an implied contract, to use riverine resources in a manner that is socially and ecologically acceptable. This requires that many river ecosystems be restored or rehabilitated. If that is possible, what are the approaches and scales that have a chance of being successful?

This article addresses that question by returning to the theme articulated by Professor Hynes, and taking it a step further to reveal the ever increasing complexity of rivers as social–ecological systems and exploring the implications of that added socio-ecological complexity on their management and restoration. Specifically, I will summarize 2 partially successful examples of river restoration, one from Australia and the other from the United States, identifying attributes that make them successful and aspects needing improvement; and from the broader literature I will offer guidelines and principles for improving river restoration in highly complex situations. Before beginning, however, a short summary may be useful for those not readily familiar with the ecological advances made in stream/river ecology in the years immediately following Prof. Hynes' lecture.

Background

I see 4 overlapping intellectual phases associated with river ecology and management since the early 1960s (Fig. 1): (1) discovery, (2) conservation, (3) restoration, and (4) effective integration of actions. The discovery phase can be characterized as a period of exploration and understanding, the conservation phase as protecting species and places, the restoration phase as reestablishing environmental functions and conditions, and the effective actions phase as the integration of conservation and restoration processes with social drivers and expectations so as to be successful over the long term. All phases are intertwined and continue to this day.

The discovery phase challenged and refined the conceptualization of how rivers function as ecosystems. Seminal examples include how river ecosystems change as they flow from headwaters to the sea (Vannote et al. 1980); integration of the effects of large dams and reservoirs on river corridors (Ward and Stanford 1983); discovery of new dynamics in hyporheic zones (Stanford and Ward 1988, Boulton et al. 1998); incorporation of the roles of large animals in shaping streams (Naiman 1988); realization of the importance of floods (Junk et al. 1989, Poff et al. 2010); seasonal flows (Bunn and Arthington 2002); riparian zones (Décamps 1996, Naiman and Décamps 1997); habitat mosaics (Stanford et al. 2005); the spatial dynamics of species and populations that have adapted to and prosper in continually changing habitats (Fausch et al. 2002); and the emergence of large river perspectives on what sources of organic matter drive ecosystem characteristics (Thorp and Delong 1994), among many others. Nearly all basic advances were enabled by collaborations with physical scientists, thereby expanding the understanding of controls and processes underpinning ecological systems. Rivers have come to be viewed as temporally dynamic, 3-dimensional, longitudinally connected systems in which the ecological characteristics of downstream reaches are intimately linked with processes occurring either farther upstream or within the floodplain, and influenced by local lithology and geomorphology. Populations across streams are linked through dispersal, gene flow, and the potential for recolonization following catastrophic disturbance and subsequent succession. Biotic assemblages clearly respond to upstream processes and changing stream morphology, as modified by biological feedbacks from riparian zones and large animals (Fig. 2).

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Aquatic ecologists recognized during this first phase that the world's freshwater biota were poorly inventoried (Stiassny 2002, Balian et al. 2008), lost species faster than terrestrial or marine ecosystems (Sala et al. 2000, MEA 2005), and were facing mounting anthropogenic impacts (Naiman et al. 1995, Dudgeon et al. 2006, Arthington et al. 2010, Strayer and Dudgeon 2010). About the same time came the realizations that productive river fisheries were maintained by landscape processes (Naiman et al. 1987, 1992, Bisson et al. 2003, Hilborn et al. 2003), that anthropogenic climate change was real and is influencing aquatic systems worldwide (Schindler et al. 1997), and that freshwater biodiversity was indeed in steep decline and not a theoretical or future problem but an ongoing and accelerating one (Fig. 3; Dudgeon et al. 2006).

As human populations and economies continue to expand, rivers are exploited for power generation, shipping, and water extraction as well as modified for flood control and other purposes; so much so that most of the world's rivers and floodplains are now physically and functionally altered (Postel et al. 1996, Nilsson et al. 2005, Poff et al. 2007, Tockner et al. 2008, Vörösmarty et al. 2010). Further, nearly 80% of the world's human population is threatened by a lack of water security and a continued lack of managerial precaution that jeopardizes biodiversity and the integrity of rivers as functioning ecosystems. For example, it has been estimated that habitats associated with 65% of world's continental discharge are classified as moderately to highly threatened (Vörösmarty et al. 2010; Fig. 4). Further, nearly one billion people live in areas likely to require action from climate change (2050 scenarios), and at least 365 million people live in basins almost certain to require action to ameliorate the impacts of climate-induced flow alteration (Palmer et al. 2008). Collectively, these observations have set the stage for the second and third phases focused on conservation and restoration.

In response to the improved understanding of rivers as ecologically dynamic yet dramatically altered by human actions (Phase I), came the rise in conservation (Kareiva and Marvier 2012; Phase 2) and restoration efforts (Roni 2005; Phase 3). Unfortunately, while considerable knowledge was gained in the discovery phase, it has not been sufficient to make conservation and restoration generally successful (Bernhardt et al. 2005, Roni et al. 2008). Early conservation efforts focused on legally designating endangered or threatened aquatic species for protection, buffering critical habitats by leasing water rights and riparian zones, establishing local conservation easements, identifying critical habitats or remaining

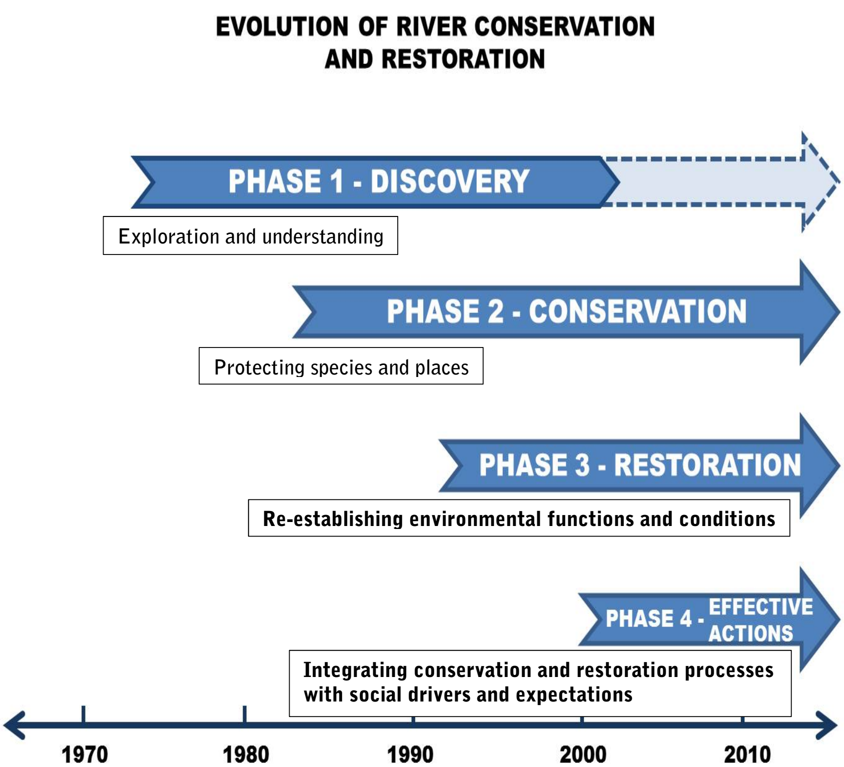

Fig. 1. Four general phases of the evolution of understanding riverine ecological patterns and the conservation and restoration actions that have occurred since the 1960s.

strongholds, purchasing segments of streams, and creating catchment councils and associations (Boon et al. 2000). Nearly all conservation efforts have been directed at selected places and species of concern in critical but often isolated river or stream habitats. Likewise, river restoration has been, for the most part, focused on recreating structural attributes (e.g., channel form, minimum flows, pools, and riparian cover) based on assumptions that ecological functions will follow (Good et al. 2003, Humphries and Winemiller 2009, Palmer and Filoso 2009, Palmer 2010; Sidebar 1).

Sidebar 1. Habitat, food webs, and effective restoration.

"However beautiful the strategy, you should occasionally look at the results." — Winston Churchill

Contemporary evidence suggests that ecosystem structure alone does not necessarily reflect functions supporting life. For example, field experiments in the US Pacific Northwest have shown that trophic manipulations (e.g., nutrient additions or salmon carcass introductions, but no habitat alteration) that boost the abundance of potential prey organisms measurably improve fish growth (e.g., Warren et al. 1964, Bilby et al. 1998). In contrast, restoration of physical habitats by creating pools or adding structures yields ambiguous evidence that these efforts increase fish abundance and biomass (e.g., Thompson 2006, Stewart et al. 2009, Whiteway et al. 2010). Although it may be premature to conclude that food availability and species interactions are more limiting to fish growth than the quality or quantity of the physical habitat, evidence is mounting that many habitat restoration activities are not effective in meeting stated goals and objectives, as originally anticipated. Moreover, most restoration efforts encompass what many think is best, have no stated goals or objectives, and few employ monitoring or assessment; therefore, there is little opportunity to improve future restoration actions directed at habitat (Bernhardt et al. 2005, Palmer 2010; Table 1).

Although conservation and restoration efforts have begun in earnest, a concurrent reality is that management and policy decisions that have already been made will result in continued environmental disruption as well as population and species extinctions (Palmer et al. 2005, 2008, Strayer and Dudgeon 2010). The trajectories for human population growth, human water use, climate change, use of fertilizers and chemicals, invasions by alien species, dam and hydrologic alterations, and overexploitation of fisheries, among others, are escalating (Fig. 5). The trends are expected to continue while sediments and toxins already *en route* from expanding land use practices find their way into rivers (Naiman et al. 2012; Fig. 6). For these and other related reasons, stresses on riverine ecosystems and organisms are likely to increase significantly in coming decades. Even with no new human impacts on inland waters, many populations and species probably are no longer viable over the long term and will disappear or change spatial distributions (Strayer and Dudgeon 2010, ISAB 2011). The prevailing picture for freshwaters is one of continued losses for the foreseeable future unless there is a significant change in professional perspectives, strategies, and actions.

Surprisingly, to date, many professional societies focused on freshwaters have not provided leadership in conservation of freshwater biodiversity or the restoration of freshwater ecosystems. These include the American Society for Limnology and Oceanography, North American Benthological Society (now the Society for Freshwater Science), Freshwater Biological Association, and Societas Internationalis Limnologiae (Rogers 2008, Table 1 in Strayer and Dudgeon 2010). Instead, the leadership in freshwater biodiversity conservation and restoration has been by scientific societies that focus on general conservation (e.g., the Society for Conservation Biology) or ecology (e.g., the Ecological Society of America), by nongovernmental organizations such as the World Wildlife Fund (WWF), DIVERSITAS, The Nature Conservancy (TNC) and NatureServe, and international

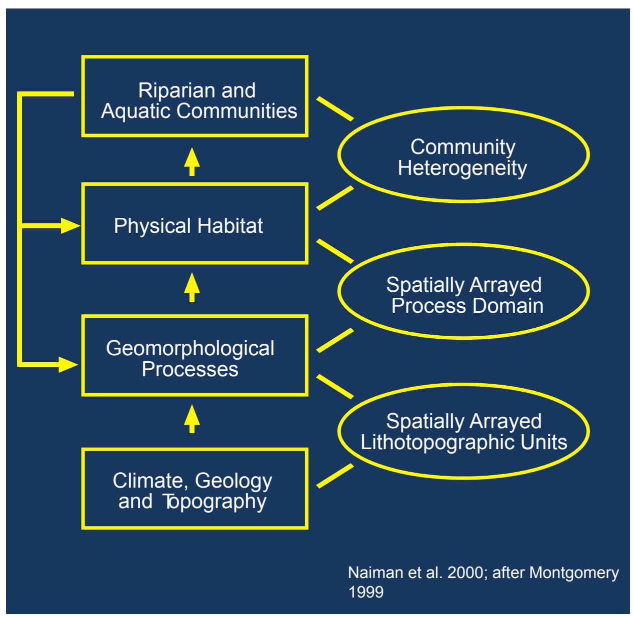

Fig. 2. Schematic representation of the relations among hydrogeomorphic processes, habitat dynamics, and riverine communities. Lithotopographic units are areas with similar topography and geology, and within which similar suites of geomorphic processes occur (Naiman et al. 2000; modified from Montgomery 1999).

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Table 1. Analysis of river restoration effectiveness for activities in the United States between 1990 and 2004 (Bernhardt et al. 2005). Original data are from the National River Restoration Science Synthesis (NRRSS) database.

Number of Projects	37,099
Most Commonly Stated Project Goals	1. Enhance Water Quality
	2. Manage Riparian Zones
	3. Improve In-stream Habitat
	4. Fish Passage
	5. Bank Stabilization
Median Cost per Project	~US$45,000; many much larger
Percentage with Stated Goals	20%
Percentage with Assessment or Monitoring	10%; most were not designed to evaluate consequences of restoration
Ability to Improve Future Practices	Very Low

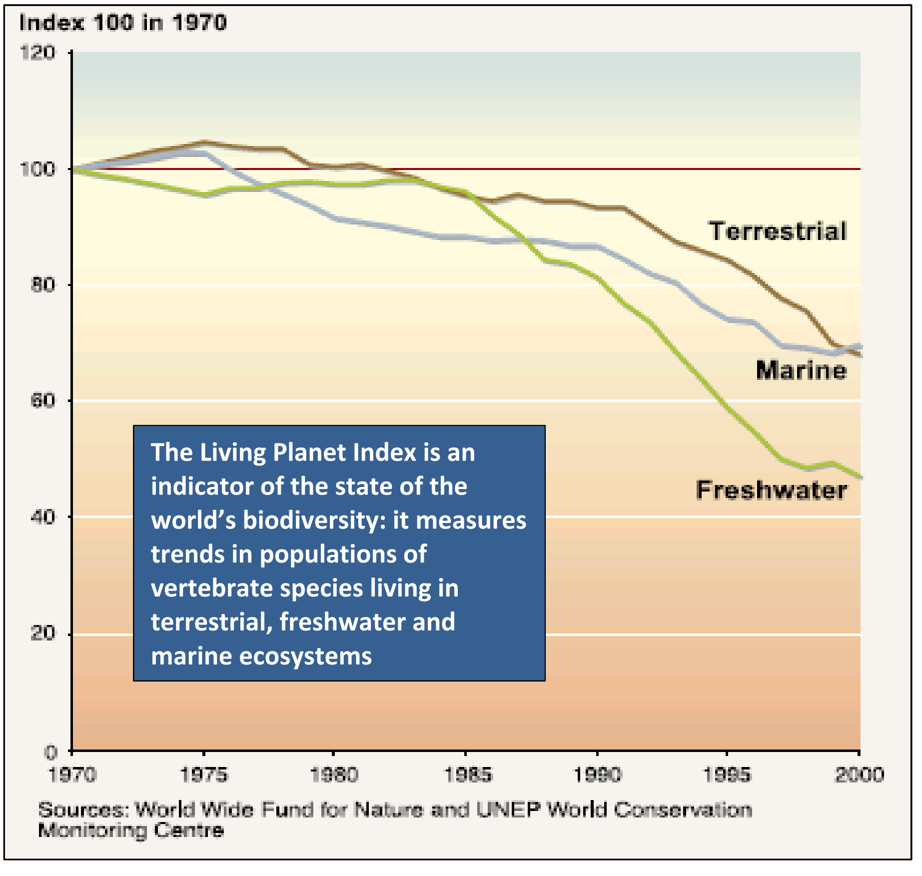

Fig. 3. The Living Planet Index, 1970–2000. The index incorporates data on the abundance of 555 terrestrial species, 323 freshwater species, and 267 marine species around the world. While the overall index fell by some 40% between 1970 and 2000, the terrestrial index fell by about 30%, the freshwater index by about 50%, and the marine index by around 30% over the same period (MEA 2005).

governmental organizations such as the United Nations (UN). For instance, WWF has been a leader in the development of the Freshwater Ecoregions of the World (Abell et al. 2008), DIVERSITAS has evaluated freshwater biodiversity (Dudgeon et al. 2006), and TNC has actively promoted the development and implementation of environmental flow allocations (Richter et al. 2003, Arthington 2012). The UN declared 2011–2020 the International Decade of Biodiversity, overlapping with the UN International decade for action "Water for Life" 2005–2015, and has recently launched the Intergovernmental Science-Policy Platform on Biodiversity and

Ecosystem Services (IPBES; Pereira et al. 2013). Individuals within the aquatic societies are integral to these efforts, and aquatic societies need to review their involvement.

The need to bridge the gap between science and application, and science and people, marks the emergence of Phase 4: effective integration of actions. This phase emerged in the last decade and acknowledges the social–ecological complexity associated with river restoration (e.g., multiple owners, jurisdictions, interests, values, and public involvement). Contemporary activities seek solutions that balance the intertwined social and ecological issues, and these activities are advancing in important international programs (Naiman 1992, Rogers 2006, Rogers et al. 2013).

All phases continue, and the need for discovery, conservation, and restoration to be better integrated with social complexities is central to effective progress. Today,

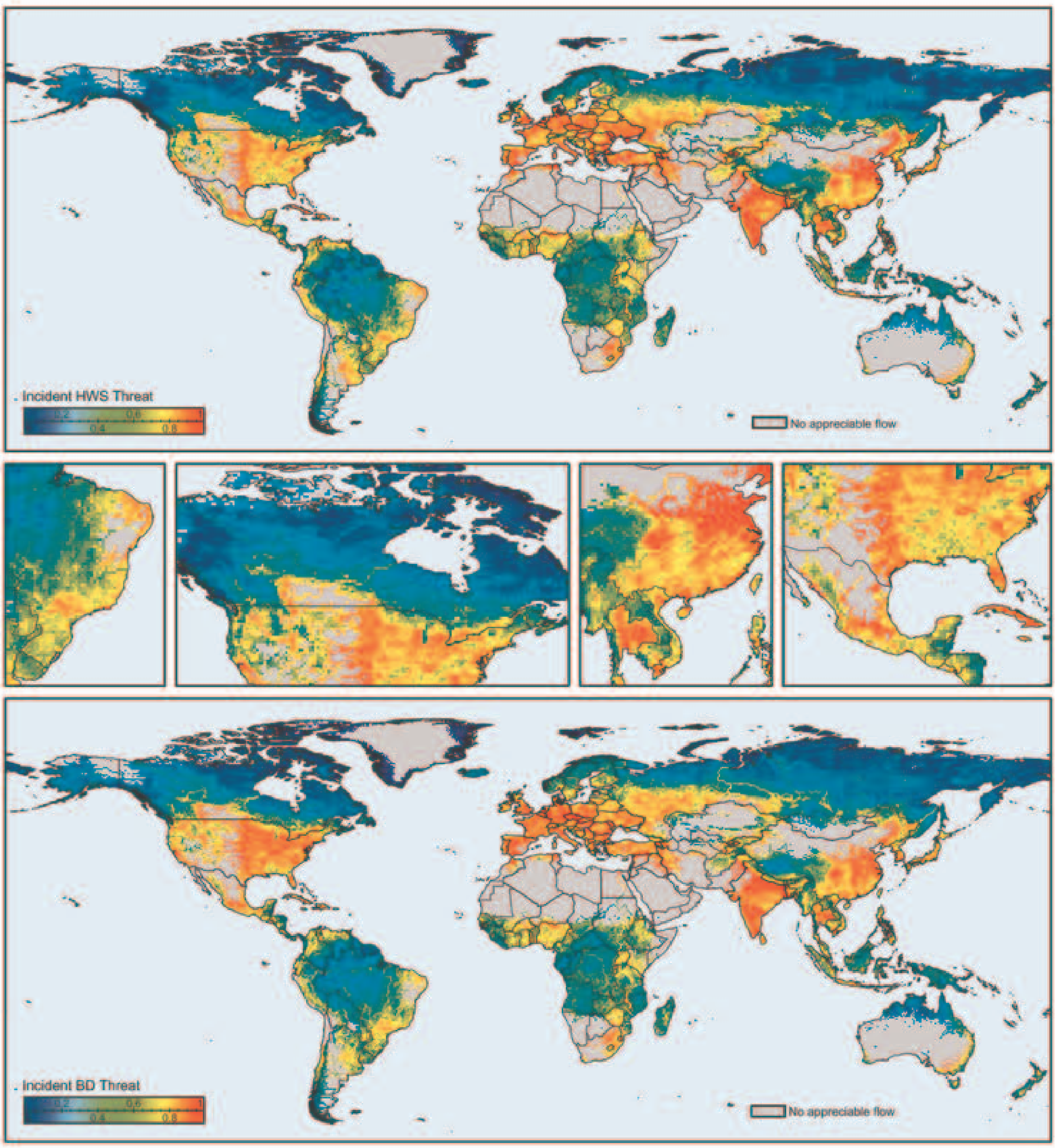

Fig. 4. Global geography of incident threat to human water security and biodiversity. The maps demonstrate pandemic impacts on both human water security and biodiversity and are highly related, although not identical. Spatial correlations among input drivers (stressors) varied, but were generally moderate. Regional maps exemplify main classes of human water security threat. Threat indices are relative and normalized over discharging landmass (from Vörösmarty et al. 2010).

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stream and river scientists are grappling with exceedingly complex questions. For example, is it possible to restore or rehabilitate streams so that they again become self-sustaining and productive ecosystems? If not, can streams/rivers, in general, be understood and effectively managed as hybrid or novel ecosystems that contain both old and new components? For those ecosystems judged as being successfully restored or rehabilitated, what are the approaches and scales underpinning success? While most restoration and conservation actions have not met stated ecological goals and objectives, especially for rivers and fisheries, some cases have been partially successful—and there is much to learn from these examples. In effect, the level of commitment, the complexity of the process, and the depth of understanding required goes well beyond anything imagined 40–50 years ago when the field of river ecology was taking shape.

Restoration and conservation: lessons from actions

There are many thousands of instances where conservation and restoration of streams and rivers have been undertaken (e.g., Buijse et al. 2002). These range in spatial scale from small segments (often <50 m) to entire catchments of several hundred square kilometers, temporal scales ranging from a few days to decades, and combinations of active and passive actions. At most,

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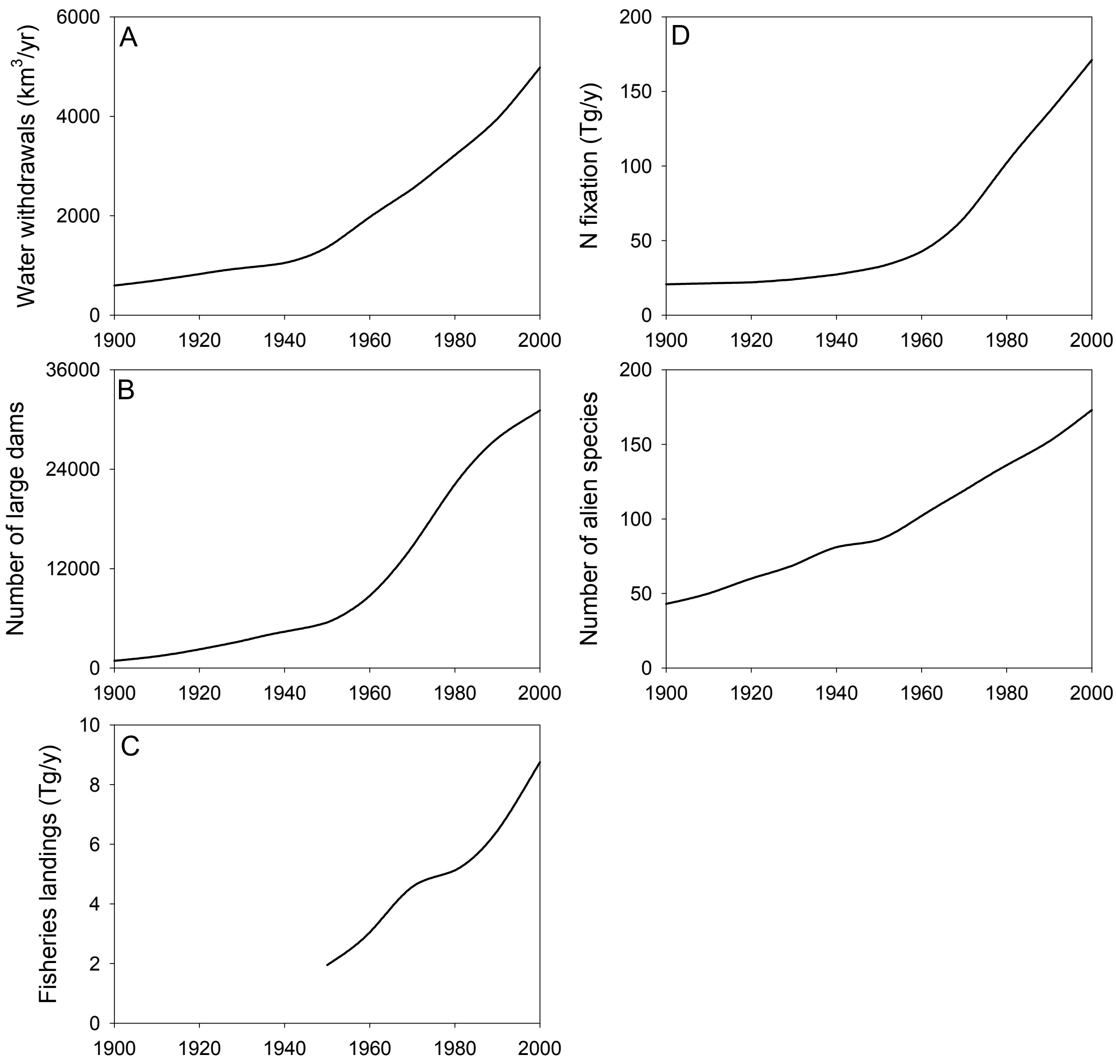

Fig. 5. Five examples of rising human pressures on the world's freshwater ecosystems. A. Global water withdrawals (after Gleick 1993). B. Number of large (>15 m high) dams (International Commission on Large Dams 2008). C. Fisheries landings from inland waters (Allan et al. 2005). D. Global inputs of anthropogenically fixed N. Input from all natural sources is 110 Tg/y (Vitousek 1994, Galloway et al. 2008). E. Number of known alien species in the Laurentian Great Lakes (Ricciardi 2006). (Figure modified from Strayer and Dudgeon 2010).

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however, there are only a handful of instances where conservation and restoration have been attempted at scales appropriate to the problem and concurrently address the key socio-ecological drivers of degraded conditions. To illustrate, I offer 2 examples, one from Australia and one from the United States, that adopt an ecosystem landscape perspective and, to contrasting degrees, the key socio-ecological complexities associated with degraded conditions. I have followed the Australian example for many years with great interest because of my deep and direct involvement with a program in the United States (i.e., the Columbia River Fish and Wildlife Program). The Australian example is noteworthy for its initial success, while the American example is still struggling to implement actions that could eventually make it successful. Both are important, as we will see, because they address underlying causes of river degradation; however, the Australian example has made more headway in addressing the complex socio-cultural issues needed for effective restoration.

South East Queensland Healthy Waterways Partnership (SEQHWP): Moreton Bay, Australia

Moreton Bay, located on Australia's east coast, is an estuarine home for 270 bird species, 740 fish species, 40 tropical corals, and several endangered sea turtles. While Moreton Bay represents only 3% of the Queensland coastline, it produces 13% percent of the state's commercial fish catch, provides ~30% of Queensland's recreational income, is a major port, and receives substantial inputs from the Brisbane and several other rivers (http://www.healthywaterways.org/).

Catchment and management issues. In the 1990s the ecological integrity of Moreton Bay was in serious decline, primarily from riverine inputs of organic matter, nutrients, sediments, and other chemicals (HWP 2007). The major water quality issues included excessive levels of sediment and nutrients from urban and nonurban catchments, and reduced environmental (natural) flows. The sediments and nutrients came from both point

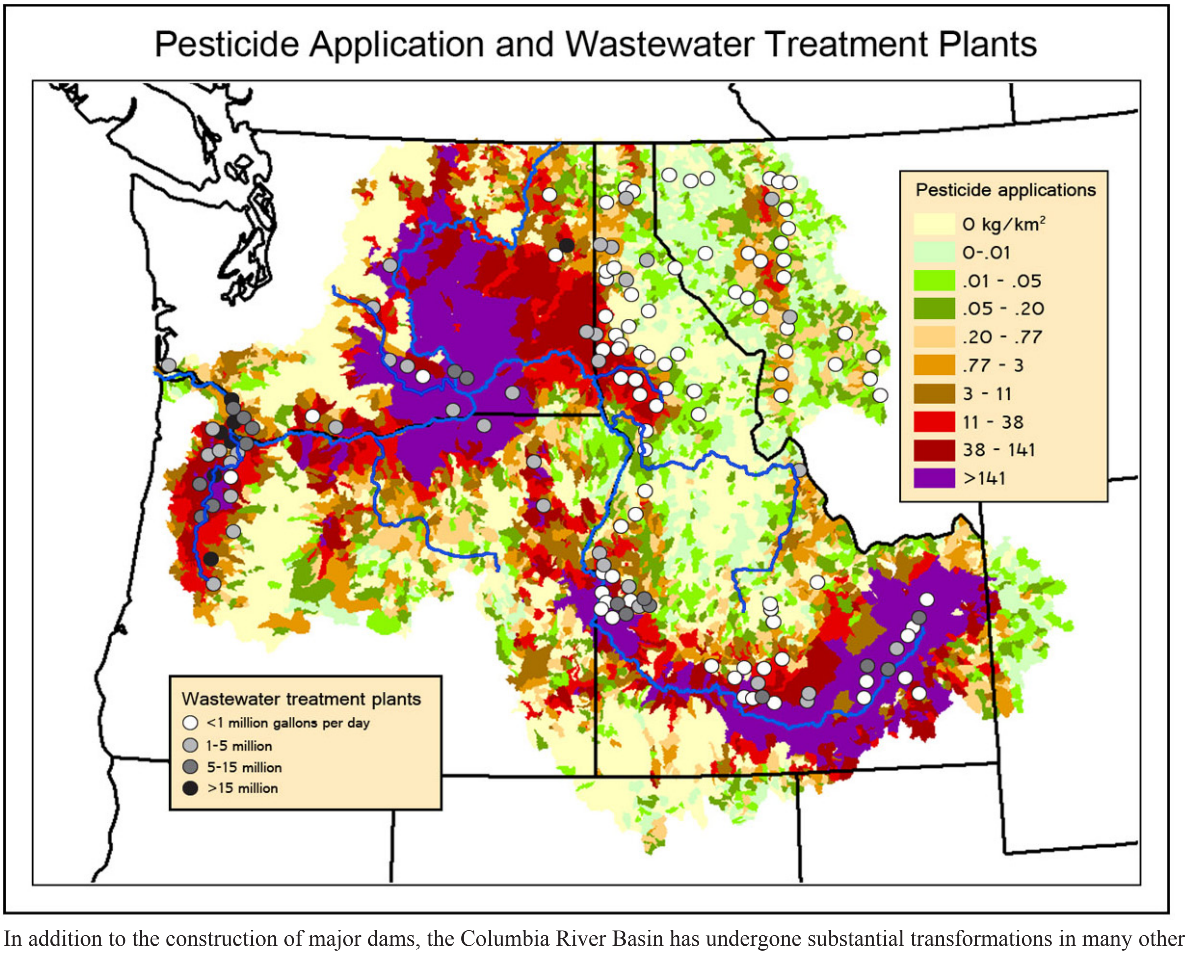

Fig. 6. In addition to the construction of major dams, the Columbia River Basin has undergone substantial transformations in many other ways (ISAB 2011, Naiman et al. 2012). An example is the widespread application of pesticides (246 compounds evaluated; average 1999–2004) and construction of numerous wastewater treatment plants. The aggregate application rate of pesticides is ~46,000 mt of active ingredients annually; these chemicals are concentrated mostly in agricultural lands along water courses.

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sources and diffuse sources. Scientific investigations identified the sources and relative contributions using innovative geochemical methods, which were fundamental for establishing a way forward. Solutions to the excessive levels of pollution required reducing current inputs and minimizing the impacts of future population growth as well as addressing the socio-economic drivers of the region.

In 2001 an innovative and highly successful regional planning approach was initiated for managing the waterways and catchments draining into Moreton Bay (Fig. 7). Based on needs to restore an ecological balance between land and water, it was crucial to adopt a holistic approach that focused attention on all subcatchments, from headwaters to the estuary. A regional plan (The Strategy) was developed with broad-based support and was implemented by state agencies, local governments, industries, and community organizations (http://www.healthywaterways.org/). The Strategy provided a common vision, values, and measurable water quality objectives and scientific information to assist integration with local plans and legislation. Having The Strategy was crucial, and its initial success is attributed to strong local political leadership and advocacy. A number of local government leaders provided effective support and, most important, these leaders accepted key roles within the partnership to oversee delivery of The Strategy. While currently at a crossroad as The Strategy has matured, the conservation and restoration actions can be described as mostly successful as judged by attainment of the initial objectives. The key attributes of the initial success were shared goals, strong socio–economic engagement and leadership to achieve the goals, extensive collaboration, and adaptive governance.

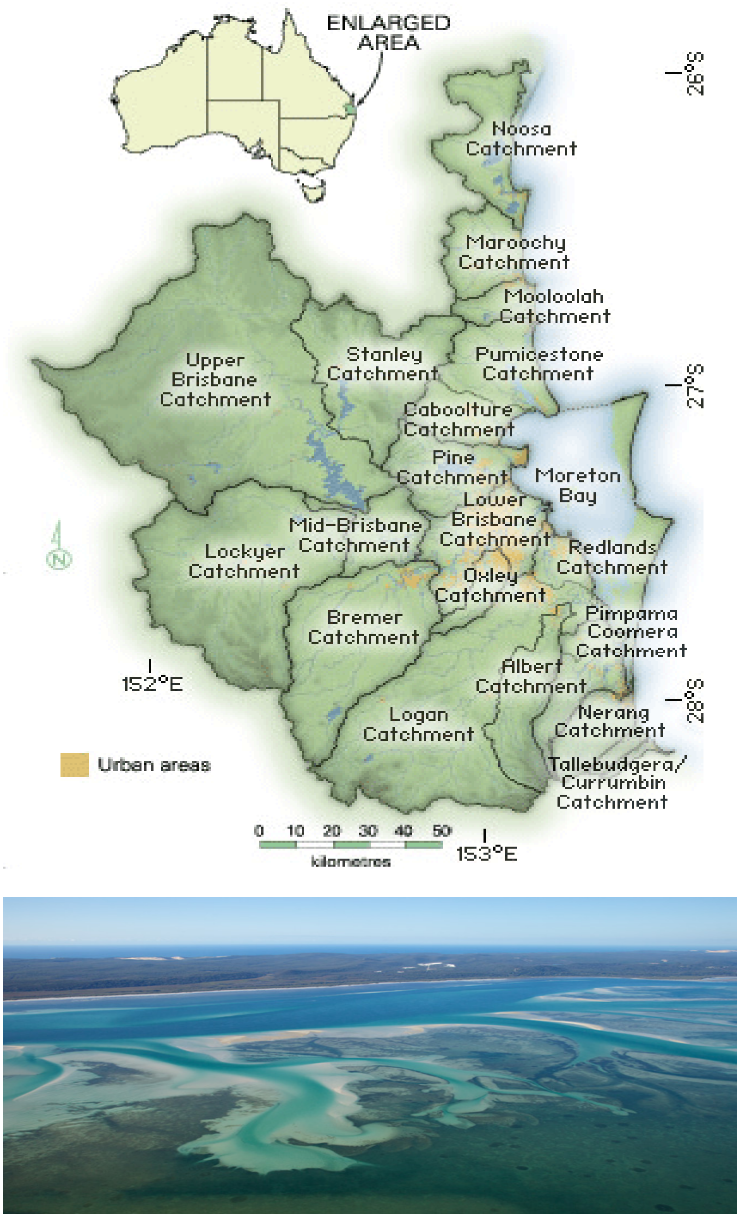

Fig. 7. Location and catchments of Moreton Bay, Australia.

Socio–economic engagement. Stakeholder involvement included >60 organizations undertaking management actions in The Strategy. An implementation group consisted of a range of stakeholders that regularly assessed the status of management actions and reported progress to a regional coordinating committee of the Queensland government. This arrangement effectively provided an on-going audit of stakeholder commitments, a step often overlooked in the resource management planning and implementation, and helped focus on areas needing improvement.

Much time and effort was spent on technical feasibility and the social, cultural, and economic aspects of environmental choices. Methods included community consultations, feedback from stakeholders and government officers, decision analysis to determine priority management actions, and cost–benefit analysis of different management actions. In addition, Brisbane hosted RiverFestival, an annual celebration of the river, with music, art, poetry, stories, sport, and science—all embracing a strong social–ecological sustainability message with stakeholders and the broader public.

Collaboration and adaptive governance. Using a mix of regulatory and voluntary measures, the partnership defined and implemented a set of management actions to resolve catchment–bay issues. Linking the management of a coastal marine bay with the management of catchments required a broad-based program. This included collaboration among government, industry and community, local political leadership, and consensus among stakeholders regarding the objectives and management actions, and decision making based on solid scientific information.

Science, while vital in the overall process, was not entirely responsible for the initial success of the restoration. Scientific investigations revealed considerable knowledge of southeast Queensland rivers, highlighted serious issues in the catchment, and identified specific locations where restoration actions were required. The latest scientific and modeling results were provided to stakeholders on a regular basis using a "report card," enabling them to be fully informed and thereby allowing decisions to be made quickly. Communication of information was based, as much as possible, on diagrams and conceptual models. Effective communication methods and skills by scientific personnel greatly increased confidence with stakeholders, the community, and decision makers.

Significance of the Moreton Bay restoration process. A strong body of scientific information about the types and sources of pollution and the need for environmental flows was critical for supporting effective actions, for illustrating the value of communicating that information to stakeholders, and for motivating them to be involved in the work and the decisions[2,3]. One main driver for change in Moreton Bay was increasing expectations about improving water quality and uses, and the recognition of potential losses incurred by tourism, fishing, and agriculture if the overall situation did not quickly improve. A major coordinated scientific research program highlighted the key assets being endangered and the potential of Moreton Bay to improve citizens' quality of life, if restored.

The program is currently at a crossroad, and it is difficult to determine if the program will be effective in the long term. While the coordinated science, monitoring, and reporting delivered significant gains, guided investment in point-source pollution control, identified environmental flow needs, and raised awareness of the issues in the region, the program has never been able to successfully address diffuse (nonpoint) pollution problems. With each major wet season, as occurred in the 2012 and 2013 floods, overall environmental quality has declined. Further, the political will seems to be deteriorating with no champions to lead the way forward. Like so many restoration programs, it is difficult to be successful when issues become socially complex, the political leadership diminishes, and broad public support declines. Successful implementation of effective actions (Phase 4) remains in doubt.

Restoring the Columbia River (USA) – a lesson in scale and complexity

The Columbia is one of the great rivers of North America draining over 1.7 million km^2 (an area similar to France). Beginning in British Columbia, Canada, the river travels 2044 km through 14 major dams before reaching the Pacific Ocean in the United States. Fed mostly by melting snow, the Columbia River basin spans 7 US states and a portion of British Columbia (Fig. 8). In all, the Columbia and its tributaries comprise 174 USGS HUC-4 subbasins that encompass climatic conditions and topography as varied as any river in the world, from alpine to desert to rainforest. The Columbia Basin's salmon and steelhead populations (*Oncorhynchus* spp.) were once among the largest in the world, with approximately 10 million fish returning annually.

Catchment and management issues. Salmon and steelhead, along with other native fish and wildlife, have declined significantly; recent decades have seen a combined total of <2 million adult salmon and steelhead return, and most are produced artificially in >200 hatcheries. Numerous human activities contributed to this decline, especially the construction of extensive hydropower and agricultural systems that dramatically changed environmental conditions.

The 14 major dams and hundreds of additional smaller dams control water flows in the modern Columbia River. Storing runoff, reducing flood flows, shifting flows from the natural spring/early summer peak to fall and winter to generate electricity for the region's peak power demand, and blocking, inundating or reconfiguring major river reaches have substantially changed flow regimes (Fig. 9). Further, the dams, reservoirs, and fish passage facilities block or impede the migration of important anadromous fishes. Collectively, the dams and agriculture make a substantial contribution to the region's economic prosperity while also having significant adverse effects on native fish and wildlife (Lichatowich and Williams 2009, Naiman et al. 2012). The US Congress passed the Pacific Northwest Electric Power Planning and Conservation Act in 1980 to (in part) conserve and restore native fishes and wildlife while providing for coordinated, region-wide planning to meet future demand for power. Nearly all conservation and restoration actions are targeted at improving fish passage and local habitat.

[2] Moreton Bay Catchments, Report Card: http://www.healthywaterways.org/HealthyWaterways/2010ReportCardResults/CatchmentResults.aspx

[3] The Brisbane Declaration on environmental flows: http://www.eflownet.org/download_documents/brisbane-declaration-english.pdf

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Drivers and objectives of restoration. The goals, objectives, scientific foundation, and actions for the Columbia River's restoration are organized within a "Fish and Wildlife Program," an integrated approach to regional mitigation and recovery (NPCC 2009). The program addresses Endangered Species Act (ESA) requirements, the broader requirements of the Northwest Power Act, and the policies of the US states and Indian tribes. The program includes a specific set of objectives, describes the strategies to be employed, and establishes a scientific basis for conservation and restoration (Table 2). The Fish and Wildlife Program has had considerable input from basin stakeholders that has weakened or compromised consistent adherence to its scientific principles (ISAB 2013). The expectation is that the program will guide decision-making and provide a scientific foundation for evaluating success.

Has the Fish and Wildlife Program been successful? The answer is yes – and no. Like any large, long term and complex activity, there are successful aspects and there are others in need of substantial improvement (Lichatowich and Williams 2009, Cosens and Williams 2012). The successful aspects of the program relate to acquiring and protecting land and water for fish and wildlife benefits; refurbishing physical structures such as culverts and irrigation diversion screens to improve fish passage; monitoring, evaluating, and improving fish migration through the hydrosystem; building a strong constituency among agencies, Tribes, and interest groups; and having the foresight to establish a strong and well-funded research and restoration program. The net effect has been to partially stabilize the number of returning adult salmon, albeit at a level much lower than seen historically. Most fish are now generated through hatchery programs rather

Fig. 8. Map of the Columbia River Basin (United States and Canada) showing the major tributaries and dams. The US states are Washington (WA), Oregon (OR), Idaho (ID), Montana (MT), California (CA), Nevada (NV), Utah (UT), and Wyoming (WY).

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than natural habitats, and most wild populations are not considered viable. Nevertheless, the ultimate ability of the program to improve anadromous fish populations, especially wild fish, will be determined by the ability of decision-makers to evolve in terms of governance, program implementation, and engaging the public. In essence, the Columbia River is a lesson in incomplete restoration.

There are 3 main programmatic areas needing substantial improvement to make the Fish and Wildlife Program successful, and these issues relate to many other restoration programs:

- **Establish a better balance between artificial fish (hatchery) production and habitat restoration**. A stated goal is to use habitat restoration as the primary means for the recovery of fish populations (NPCC 2009); however, artificial production of salmon by hatcheries is the main approach used to maintain population numbers, and there are no documented cases where habitat restoration has successfully reestablished population abundance (ISAB 2013). Further, there are also no documented cases where a natural population's abundance has materially improved through hatchery practices, such that the return of wild salmon increases relative to reference populations. While artificial production strategies incorporate contemporary understanding of scientific risks of using artificial production as a tool to rebuild wild populations and/or to provide for harvest while minimizing adverse impacts of hatchery fish on natural stocks, this strategy is not being adequately informed and implemented (Naiman et al. 2012, ISAB 2013). Significant risks include a loss of diversity in timing and behavior of migrating individuals, genetic straying, and unusually large aggregations of predators feeding on hatchery-released fish. Consequently, the heavy reliance on hatcheries, while providing harvest opportunities, may be reducing the viability of native populations and foreclosing options for the future. This should not be surprising because a species-centric approach often is not as effective as an ecosystem approach (e.g., Carpenter et al. 1995, Venter et al. 2008). A healthy ecosystem is much more likely to "solve" the problem than a narrow species focus.
- **Employ adaptive management as originally intended.** Adaptive management has been a central tool of the Fish and Wildlife Program since the 1980s. Adaptive management calls for a deliberate effort to conduct management experiments that provide useful information for future decision making; information that would not otherwise be available (Holling 1978, Lee 1993) and is a direct attempt to overcome the pitfalls identified by Bernhardt et al. (2005) and Roni et al. 2008 (Table 1). The use of adaptive management is also a system policy, combining monitoring, evaluation, and research so that the aggregated effects

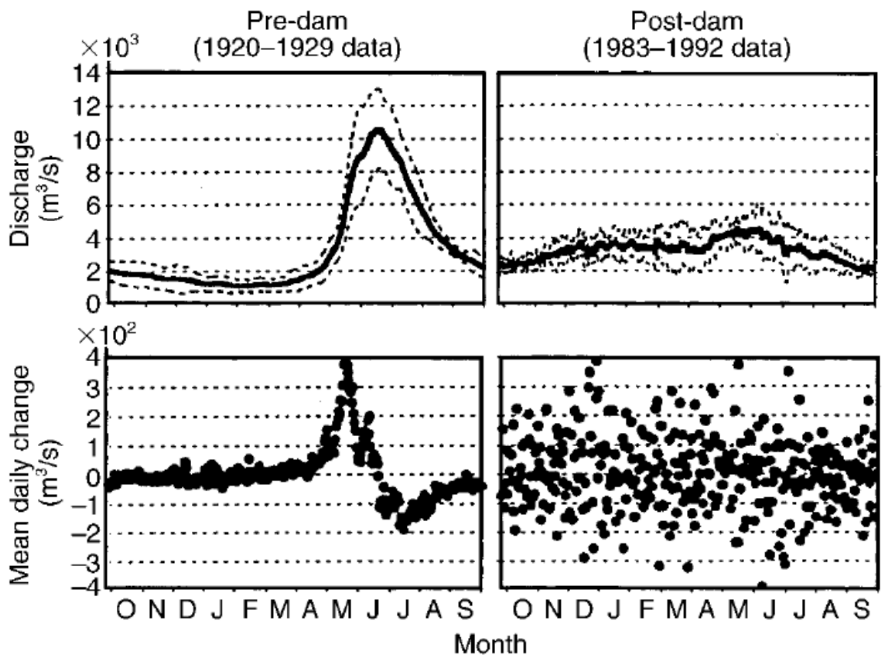

Fig. 9. Effect of upstream dams on discharge of the Hanford Reach of the Columbia River, Washington, USA (Naiman and Turner 2000, from Stanford et al.1996). Peaking power flows are especially detrimental to fish.

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Table 2. Fundamental elements of the Columbia River Fish and Wildlife Program (NPCC 2009).

Vision	Describes what the program is trying to accomplish with regard to fish and wildlife, in the context of other desired benefits from the river
Biological Objectives	Describes the ecological conditions and population characteristics needed to achieve the vision
Implementation	Strategies, procedures, assumptions and guidelines, which guide or describe the actions leading to the desired ecological conditions
Science	Provides the foundation, which ties the program framework together

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of the program can be detected, assessed, and improved over time. Monitoring and evaluation provide feedback on the outcome of projects within the adaptive management cycle.

Unfortunately, adaptive management is not being practiced as originally intended (e.g., Lichatowich and Williams 2009, Westgate et al. 2012; J. Shurts, NPCC, pers. comm.), and its implementation has not been successful overall (Cosens and Williams 2012). While project leaders nearly always state that adaptive management is used to modify the tasks and work elements, projects almost never have (1) an experimental design to identify whether biological objectives have been met by employing specific strategies, or (2) a decision tree that would be used to modify management based on updated scientific information. Often projects continue tasks and work elements, even when monitoring data indicate that biological objectives are unattainable. Project sponsors are understandably reluctant to abandon efforts in which they have invested much time and energy. The reasons why adaptive management has not been implemented effectively are varied and complex but can be summarized as overconfidence in the projected restoration outcomes, an unwillingness to terminate unproductive activities and, as well, by the lack of real experimentation, effective monitoring, scientific consensus, and adaptive governance (Cosens and Williams 2012, ISAB 2013; J. Shurts, NPCC, pers. comm.).

- **Integrate conservation and restoration actions with the local social–cultural setting.** The public reflects diverse social, political, and economic conditions and, as well, ecological awareness (Smith et al. 1998). Nevertheless, if conservation and restoration are to be successful, the public needs to be actively engaged and informed. Consciously recognizing broader interests, concerns, and skepticism can help avoid costly delays in restoration projects, lack of support and political impasse. Effective conservation and restoration projects articulate what matters to people in the catchment, a recognition of their needs and concerns. This is perhaps the most difficult issue to overcome for traditional science and management (Kania and Kramer 2011, ISAB 2011). Further, conservation and restoration success ultimately depends on how well scientists and managers engage each other and society, not as experts but as co-learners and interactive players who are willing to change (Rogers 2006).

Although the Fish and Wildlife Program has a history of stakeholder involvement for ambitious subbasin planning and an ongoing public information effort, the current program needs improvement in public outreach and public responsibility as critical components of implementation; and these are foundational aspects for restoration success. One example where public outreach would be useful is the current tension associated with artificial production. The program's vision and objectives associated with fish abundance, diversity, and resilience are potentially at odds with hatcheries. The fishing public, local businesses, and the fishery and hatchery managers have a good understanding of the social and economic benefits of abundant fish; however, many do not understand the risks associated with abundance gained largely through artificial production. The notions of biological diversity, resilience, and carrying capacity as keys to future sustainability require broader understanding and support to achieve the ultimate objective of restoring a reasonably intact and productive native fish community (ISAB 2011).

Achieving successful conservation and restoration for rivers

Ideas and strategies for addressing complex issues are not new. Inspiring examples can be found in education, medicine, post-war reconstruction, agriculture, and others, and there are important lessons to be learned from these

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Table 3. Principles for enhancing resilience and adaptability in river restoration (ISAB 2011, 2013).

Principles to Enhance Resilience	**Description**
The abundance, productivity, and diversity of organisms are sustained by complex and adaptive ecosystems.	Physical and biological components of ecosystems act synergistically to produce the abundance, productivity, and diversity of plant and animal communities. Management actions to maintain ecosystem services are most effective when undertaken with an understanding and appreciation of the natural limits and underlying structure and function of the ecosystem, and the dominant forces being imposed on the ecosystem.
Biological diversity allows ecosystems to persist in the face of environmental variability.	The diversity of species, populations, and life history traits within biological communities contributes to ecological stability in the face of disturbance and environmental variability by providing a greater range of options to absorb, or respond to change. Management actions are most meaningful when they contribute to long-term maintenance of the diversity of locally adapted populations of native species and of all the habitats needed to support their full life cycles.
Human health and well-being are tied to ecosystem conditions.	Human actions have a pervasive impact on the structure, function, and resilience of ecosystems, while at the same time, our health and well-being are tied to ecosystem conditions.
Principles to Enhance Adaptability	
Biological and cultural diversity provide the raw material for reorganization and adaptability during unexpected transitions to new ecosystem regimes.	Basic elements critical to adaptability include the biological diversity of fish and wildlife species represented by genes, populations, and species, and the cultural diversity of people and communities represented by learned behaviors, ideas, values, and institutions.
Ecological management is adaptive and experimental.	The complexity of ecological systems routinely disables attempts to command and control them. Seek to be flexible and adaptable in management responses to a world in which change occurs continuously and unpredictably at different scales. Because knowledge is limited, the only practical response is one of discussion, experimentation, and learning (Harris 2007). Experimental management demands deliberate interventions directed at understanding key ecosystem dynamics and creating new knowledge through scientific inquiry.
Socio–economic understanding and engagement is required to make management actions more sustainable.	Effective management actions follow from the cultural values and incentives of people who live in the landscape, who use its land, water, or living resources, or who are concerned about sustaining its habitats and fish and wildlife populations. Societal knowledge is filtered by values to create intentions that may become actions. Developing mechanisms and networks for the communication, sharing, and review of new knowledge can enhance the diffusion and adoption of innovative actions.

efforts that can be applied to river conservation and restoration. In the case of Moreton Bay (and several adjacent rivers), the underlying strategic principles were sound, and the proponents took a comprehensive catchment-scale view. Treating the problem as complex has a real advantage because it looks at reality (Rogers et al. 2013), eventually making a broad-based consensus easier to achieve. In the case of the Columbia River and most other rivers, efforts fall short of the goals because, most important, the social aspects are neither well developed nor well integrated with the physical restoration efforts, and the species-scale focus does little to create a public or scientific consensus. When broad support is lacking or fragmented, there is little public responsibility taken to ensure longer term success, creating a rather pessimistic assessment of the general situation. That does not need to be the case going forward if resilience and adaptability in social and ecological systems can be enhanced (Table 3), however, and if restoration and conservation actions adopt an ecosystem/landscape perspective. The world of river conservation and restoration science has an opportunity, and a responsibility, to enter a new era via exhibiting leadership in step with the social landscape of conservation and management.

Emerging priorities include pursuing conservation within the context of complete, working landscapes/

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ecosystems, rebuilding public support, partnering with the corporate sector, and paying attention to human rights and equity. In a brilliant essay, Kareiva and Marvier (2012) offer a set of fundamental axioms about nature that help define the context within which conservation and restoration must work, and these axioms also apply to rivers. While we inherently recognize these as important, they are not fully embraced nor appreciated in most restoration efforts:

- Pristine nature, untouched by human influences does not exist.
- The fate of nature and people are deeply intertwined.
- Nature can be surprisingly resilient.
- Human communities can avoid the tragedy of the commons.
- Local conservation and restoration efforts are deeply connected to global forces.

Further, based on these axioms, Kareiva and Marvier (2012) present practical statements or observations of what conservation and restoration efforts need to do to be successful:

- Actions must occur with human-altered catchments.
- Actions will be successful only if people support conservation and restoration goals.
- Actions should be conducted in cooperation with corporations, when possible.
- Actions will succeed only when conservation/restoration and economic objectives are maximized.
- Actions must not infringe on human rights and must embrace the principles of fairness and gender equity.

These observations are directly relevant to successfully implementing effective actions (Phase 4). The Moreton Bay Partnership has, for the most part, been able to incorporate these observations whereas Columbia River stakeholders have, for the most part, not done so. Taken together, Karieva and Marvier's observations are vitally important for effectively addressing the complexities of river restoration—but how can it be done? The field of social engagement surrounding environmental issues is offering new and innovative insights into how scientists, working with others, can contribute to effective solutions. One approach that may offer a better way forward is referred to as collective impact (Kania and Kramer 2011; Fig. 10).

Collective impact. Examples from other disciplines suggest that large-scale social change arises from better cross-sector coordination rather than from the isolated intervention of individual organizations. One might expect that greater progress could be made in alleviating many of our most serious and complex social problems, not just river restoration, if nonprofits, governments, businesses, and the public joined together around a common agenda to create collective impact, as was done for Moreton Bay and a few other small rivers (and possibly could be done for the Columbia). It doesn't happen often, not because it is impossible, but because it is so rarely attempted. Funders and nonprofits alike overlook the potential for collective impact because they are used to focusing on independent action as the primary vehicle for change, also known as "isolated impact" (Kania and Kramer 2011). As a result, countless conservation and restoration actions are often working at odds with each other and exponentially increasing the financial and human resources required to make meaningful progress. Recent trends have only reinforced this perspective (Bernhardt et al. 2005, Roni et al. 2008; Table 1).

The social sector is filled with examples of partnerships, networks, and other types of joint efforts, but collective impact initiatives are distinctly different. Unlike

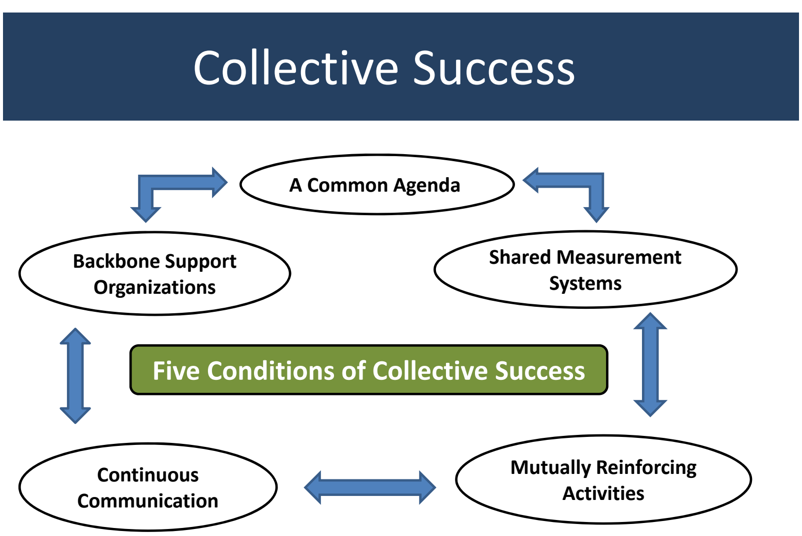

Fig. 10. The 5 conditions needed for collective success. All are interactive and necessary (after Kania and Kramer 2011).

Table 4. Specific conditions required to have a collective impact (Kania and Kramer 2011).

Common Agenda	Collective impact requires all participants to have a shared vision for change, one that includes a common understanding of the problem and a joint approach to solving it through agreed upon actions
Shared Measurement Systems	Developing a shared measurement system is essential to collective impact. Agreement on a common agenda is illusory without agreement on the ways success will be measured and reported. Collecting data and measuring results consistently at the community level and across all participating organizations not only ensures efforts remain aligned, it also enables participants to hold each other accountable and learn from each other's successes and failures.
Mutually Reinforcing Activities	Collective impact initiatives, in this case restoration, depend on a diverse group of stakeholders working together, not by requiring all participants do the same thing, but by encouraging each participant to undertake specific activities at which it excels in a way that supports and is coordinated with the actions of others.
Continuous Communication	Communication is about developing trust. Developing trust among nonprofits, corporations, and government agencies is a monumental challenge but can only be accomplished through open and continuous dialogue by the leadership
Backbone Support Organizations	Creating and managing collective impact requires a separate organization and staff with a very specific set of skills to serve as the backbone (or core) for the entire initiative. Coordination takes time, and none of the participating organizations has any to spare. The expectation that collaboration can occur without a supporting infrastructure is one of the most frequent reasons for failure

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most collaboration, collective impact initiatives involve a centralized infrastructure, a dedicated staff, and a structured process that leads to a common agenda, shared measurement, continuous communication, and mutually reinforcing activities among all participants. Adaptive problems, such as river conservation and restoration, are socially and ecologically complex, the solution is not known, and even if it were, no single entity has the resources or authority to bring about the necessary change. Reaching an effective solution requires innovation, sharing new information, and learning by the stakeholders involved in the problem, who must then adapt their own behavior to create a solution (Kania and Kramer 2011).

There are 5 conditions underpinning the success of collective impact: a common agenda, shared measurement systems, mutually reinforcing activities, continuous communication, and backbone support organizations (Table 4; Kania and Kramer 2011). Together they can lead to true alignment and powerful results. In the best of circumstances, backbone organizations embody the principles of adaptive leadership: the ability to focus people's attention and create a sense of urgency, the skill to apply pressure to stakeholders without overwhelming them, the competence to frame issues in a way that presents opportunities as well as difficulties, and the strength to mediate conflict among stakeholders. Barmuta et al. (2011) make a strong case for this approach with direct relevance for biodiversity conservation in freshwaters.

How do These Ideas and Principles Apply to Limnology?

While there has been great scientific progress in the 40 years since Prof. Hynes gave his remarkable Baldi lecture, there are major challenges ahead for limnology, especially if it is to continue to be an important contributor to environmental and societal well-being. Basically, limnological sciences need to evolve to keep pace with social–ecological complexities. In broad terms, traditional limnology addresses the functional relationships and productivities of inland water communities as they are affected by their physical, chemical, and biotic environments (Wetzel 1983). In the world today, as well as into the future, I would broaden that description to include a working understanding of social–cultural environments as they relate to river conservation and restoration.

Why have some conservation and restoration activities been (partially) successful while others have not? Important attributes include a strong science program, adopting a landscape/ecosystem-scale perspective, using adaptive management to keep conservation and restoration actions on productive paths, a continuing science-policy dialogue (science informs management and management needs guide science), substantial public engagement, and continuing financial support (Fig. 11). All are interrelated, and all are essential. These attributes are well-illustrated by the Moreton Bay

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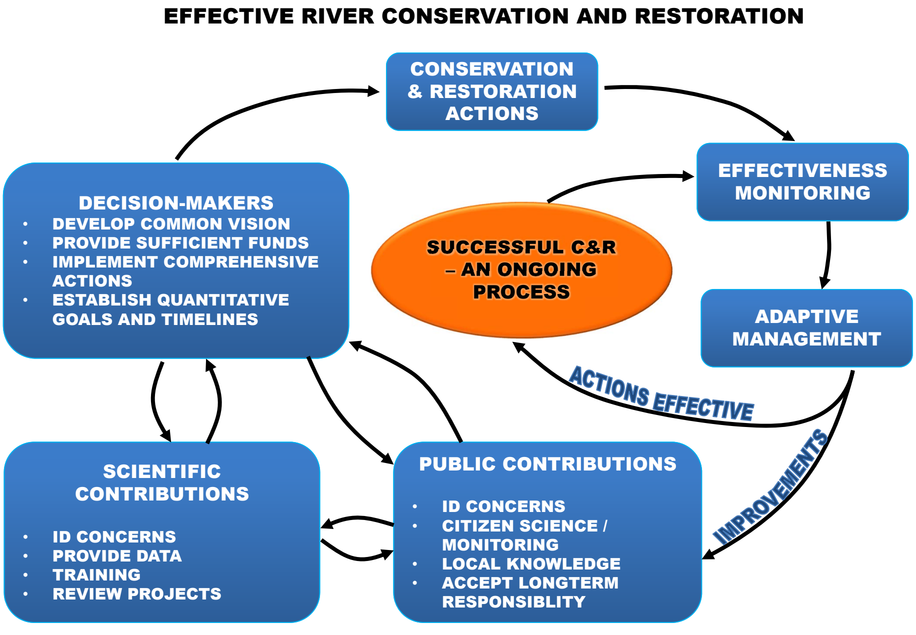

Fig. 11. Schematic diagram of the process needed for effective river conservation and restoration (Phase 4).

and Columbia River examples through both their successes and failures. The need to fully incorporate these attributes into conservation and restoration programs is urgent with the ongoing global alteration of freshwaters and the associated consequences for human and nonhuman communities (Palmer et al. 2005, Alcamo et al. 2008).

Looking ahead I see new and exciting opportunities for limnological sciences. Water issues, and especially those associated with rivers, will remain at the forefront of the public's environmental concerns. Yet, despite the globally expanding demands on water resources, society's expectation that rivers can be conserved and successfully restored will remain. And therein lies opportunity. Limnological sciences have important contributions to make, but to be successful those efforts need to be well-integrated with the efforts of other disciplines and stakeholders to provide a collective impact. Doing anything less means staying on the same river conservation and restoration trajectory; a trajectory that has a poor track record in terms of enduring success. There are many pathways to success, but the most important step is the first one—identifying and understanding impediments to success. Much has been learned about rivers via the discovery, conservation, and restoration phases of the last several decades. It is now time to fully embrace and implement the fourth phase, effective integration of actions, by applying a landscape perspective that integrates social understanding into the complex equation.

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