Chapter 1
Challenges in Riverine Ecosystem Management

Jan Sendzimir and Stefan Schmutz

This book is dedicated to those interested in the natural and social sciences and elements of governance that will support the sustainable management of rivers and aquatic ecosystems. Since elements of nature and society interact to determine the integrity and trajectory of these systems, they are referred to hereafter as social-ecological systems (SESs). This introduction opens the door to these topics in four steps. It begins by explaining why a book dedicated to river management and science is needed at this point. In the second part, it outlines the history of some of the major developments that challenge the integrity of SESs worldwide. In the third part, it describes several of the principal tools used to study as well as manage SES. Tools to measure the degree of degradation of an SES include indicators of biological integrity, ecosystem health, and resilience. Tools to assess and manage the trajectory of an SES include the DPSIR and adaptive management. The introduction closes by outlining the structure of the book through the progression of its chapters.

1.1 Justification of Book

Rivers are among the most threatened ecosystems of the world. For more than a century, river science has evolved to define these threatening trends and the mechanisms that cause them. What has emerged, while still incomplete, is a picture of imposing complexity, especially for managers, policy makers, and any concerned citizens interested in addressing these threats. This book surveys the frontier of scientific research and provides examples to guide management toward a sustainable future of riverine ecosystems. Principal structures and functions of the biogeosphere

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of rivers are explained; key threats are identified, and effective options for restoration and mitigation are provided.

Rivers increasingly suffer from pollution, water abstraction, river channelization, and damming. Fundamental knowledge of ecosystem structure and function is necessary to understand how human activities interfere with natural processes and what interventions are feasible to rectify this. The specifics of such management leverage points become clear through elucidation of cause-effect relationships, especially how socioeconomic drivers create pressures on rivers and how those pressures alter ecosystem functions and impact fauna and flora.

Modern water legislation strives for sustainable water resource management and protection of important habitats and species. However, decision-makers would benefit from more profound understanding of ecosystem degradation processes and of innovative methodologies and tools for efficient mitigation and restoration. This becomes especially important for threats where current policies are ineffective, and both policy and management must support research that identifies solutions. The book provides best-practice examples of sustainable river management from on-site studies, European-wide analyses, and case studies from other parts of the world. It will be of interest to researchers (graduate and post-graduate) in the fields of aquatic ecology, river system functioning, conservation and restoration, to institutions involved in water management, and to water-related industries.

The current wealth of textbooks on river ecology extensively describes structures and functions of riverine ecosystems but gives less attention to river management (Cushing et al. 1995; Giller and Malmqvist 1998; Naiman and Bilby 1998; Allan and Castillo 2007; Dudgeon 2008; Likens 2010). By contrast our book directly targets riverine ecosystem management by examining the formulation and application of policy and providing sufficient depth of river ecology to inform competent decision-making in governance.

1.2   Past and Future Trends

Riverine ecosystems have been systematically modified on increasingly large scales since the invention of irrigation, perhaps as much as 7000 years ago (Mays 2008). However, their historic degradation has been accelerated periodically by surges of economic and/or technological power as empires and technologies erupted and expanded. The most recent surges were powered by coal (late nineteenth century) and oil (post WWII). The harnessing of fossil fuels increased our capacity to mechanically move material by over four orders of magnitude enabling society to engineer and reshape the contours of rivers and the surrounding landscapes on unprecedented scales. Fossil energy drove the massive industrialization and globalization of Western Society that witnessed an unprecedented acceleration of the degradation processes in rivers and lakes worldwide since 1950. Riverscapes were reshaped to accommodate intensive agriculture and industrial uses as well as high-density habitation. However, industrial technologies also amplified access to energy

sources other than fossil fuels, especially hydropower. On average, humanity has constructed one 45 m high dam every day for the past 140 years (Bai et al. 2015).

The pace and scale of dam construction and other forms of river modification are reflected in the scale of impacts on aquatic flora and fauna. The greatest acceleration of biodiversity loss due to human activities in human history has occurred since 1970 (Millennium Ecosystem Assessment 2005). The drivers causing loss of biodiversity and, hence, of ecosystem services are either steady, show no evidence of declining over time, or are increasing in intensity. By aggregating the trends of some 3000 wild species, the Living Planet Index has documented a 40% decline in average species abundance between 1970 and 2000. The more rapid decline (50%) of inland water species underscores their greater vulnerability, being closer to the workings and by-products of human enterprise, while both marine and terrestrial species declined by about 30%. The concomitant loss of biodiversity and ecosystem services has been driven by both steady and episodic changes to habitat (land use change and geo-engineering), climate, overexploitation of resources (water, soil, biomass), and pollution. Geo-engineering of rivers has systematically channelized rivers for transport and to increase drainage during high-water events and separated the channel from the floodplain to protect water-sensitive row crops and zones for high-density habitation, commerce, and industry and dammed rivers for hydropower (Zarfl et al. 2014) as well as for water storage as a hedge against drought. Damming rivers currently stores the equivalent of 15% of global annual river runoff (Likens 2010). As a result 48% of rivers (expressed as river volume) globally is moderately-to-severely impacted by either flow regulation, fragmentation, or both. Impacts could double should all planned dams be constructed by 2030 (Grill et al. 2015).

1.2.1 Future Trends in River Engineering

The threat of climate change challenges society to decrease its reliance on carbon as an energy base for the economy (IPCC 2014). Most scenarios of paths to a low-carbon future foresee electricity increasingly replacing fossil fuels in all sectors. Furthermore, renewable power technologies such as hydropower and offshore wind will play an increasing role in electricity generation (Riahi et al. 2012). As the prospect of worldwide carbon pricing becomes realistic, fossil fuels, especially coal, look increasingly suspect as energy sources, and hydropower becomes increasingly attractive. This is especially so in areas with expanding economies and extensive unexploited river reaches, such as China, which currently is building 130 major dams in its southwest (Lewis 2013) and has constructed more than half the new dams built since 1950 worldwide (Wang and Chen 2010). This construction boom has been driven in part by investment policies that have been naively uncritical and optimistic. Authorizing new dam construction has been facilitated by a history of underestimating construction costs by development banks (Ansar et al. 2014). These drivers are projected to increase dam construction globally over the next several decades (Fig. 1.1)
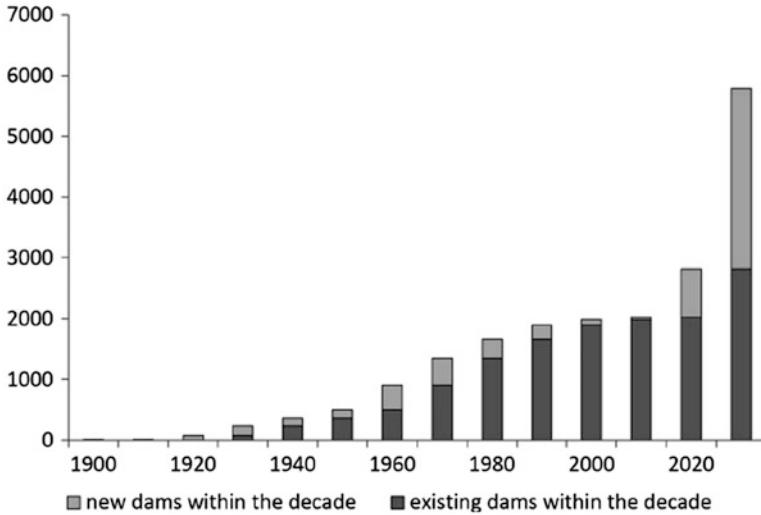
Fig. 1.1 Global pace of hydropower dam construction of existing hydropower dams (Lehner et al. 2011) and outlook for hydropower dams which are under construction or planned (Zarfl et al. 2014) (© Aquatic Sciences—Research Across Boundaries, A global boom in hydropower dam construction, 77/1, 2014, p. 162, Christiane Zarfl. With permission of Springer)

Surges of economic growth made it relatively easy to justify and ignore the impacts of riverine degradation. However, replacing lost riverine ecosystem services with economic and technological services may have seemed feasible when riding the updraft of a growing economy. But it becomes increasingly difficult in a world of increasing economic and ecological turbulence. When even the monumental riverscape engineering of the past century cannot prevent floods and droughts from disrupting communities and economies, the expenses of losing ecosystem services and of repairing and fortifying such an engineering system can no longer be ignored, and the search for alternative management paradigms becomes more attractive (Sendzimir et al. 2007). Indeed, more recent economic assessment that accounts more thoroughly with ecological considerations can be used to justify dam removal (Gowan et al. 2006; Lejon et al. 2009).

The future is never easy to predict, and this challenge is only compounded by the unprecedented levels of change anticipated over the coming century in nature, e.g., climate, and in human society, e.g., economy, demographics, and technology. While previous generations often migrated away from extreme challenges, that luxury no longer exists. There is no "away" to migrate to or to dispose pollution in. Novel levels of uncertainty only raise the challenge of improving the science and technology of managing rivers further. And the first step to make room for innovative ideas is to honestly admit that despite considerable advances, current science is not sufficient to deal with all of the anticipated uncertainty. This book reviews the current science useful to river management and then considers on what basis society can "learn its way into an uncertain future." It begins with assessing the level of

riverine degradation and builds on that information to consider ways to mitigate the damage and restore the function of environmental flows and ecosystem services in riverine systems.

1.3 Managing River Systems

1.3.1 Assessing Degradation

"You cannot manage what you cannot measure." (Deming 2000)

For more than half a century, management science has striven to base decisions primarily on experiment-driven data, not opinion, a trend in business management greatly influenced by Deming's philosophy (Hunter 2015). Management based on conventional, tradition-based intuition or opinion has often been the default option when measurement proves difficult. Efforts to measure are often stymied by resource (time, money) limitations and system complexity. However, since 1970 different "metrics" have been developed to measure ecosystem change as input to policy decisions about environmental management and restoration.

Biotic Integrity
In 1972 a national mandate to measure the status of aquatic ecosystems in the United States was provided by the goal of the Clean Water Act: "…restoration and maintenance of the chemical, physical, and biological integrity of the Nation's waters." For these purposes the term *integrity* "implies an unimpaired condition or quality or state of being complete" (Watershed Science Institute 2001). To put this mandate in practice, Karr (1981) developed an Index of Biotic Integrity (IBI) to assess the health condition of an aquatic ecosystem by multiple metrics representing quantifiable attributes of biotic communities. Depending on the types of metrics used, those indices integrate the concepts of biodiversity, functional traits, invasive species, fitness, and population dynamics.

The underlying assumption is that the employed metrics react to human pressures in a predictable way. Individual metrics are compared with reference values that roughly equal pristine or best available conditions and are then integrated into an index. The index represents a numeric estimate of how far the current condition deviates from the expected condition. It is commonly expressed as a verbal scoring system, e.g., high, good, or bad status, that is easy to understand by decision-makers and thus has been frequently introduced in legislative acts related to aquatic ecosystem management, e.g., ecological status assessment of the Water Framework Directive (WFD) in Europe. A number of different IBIs worldwide follow the same principal of a multi-metric index but vary according to the context of targeted biotic communities, the definition of reference conditions, the scoring method, and the used metrics (examples for fish-based IBIs, see Roset et al. 2007).

Ecosystem Health

In assessing the status of ecosystems, ecosystem health (EH) is an index that reflects evidence from more than just the natural sciences. It integrates data and analysis from the natural, social, and health sciences, often as input for collaborative decision-making that incorporates human values and perceptions (Muñoz-Erickson et al. 2007). This expands the scope of assessment from ecosystems out to the wider context of the surrounding society and its culture and economy. Assessing the health of *social-ecological systems* (SESs) demands integrating science inputs and societal values and thereby unpacking some of causes of the pressures behind the drivers that impact ecosystems. When the IBI measures how far a system has moved from "pristine" conditions, the parameters defining those conditions and the change away from them are assessed using natural science. EH might use the same or very similar measurements but adds the perceptions and values of people who live in that social-ecological system and who may be the sources of the drivers of change as well as the recipients of the impacts of those changes.

In general the health of a social-ecological unit is reflected in how its composition, organization, and functions remain relatively stable and sustainable over time (Costanza 1992; Rapport 1998). EH bridges natural, social, and health sciences not so much to provide the definitive scientific basis for policy nor to offer predictive descriptions of causation. Rather it offers a theoretical framework with related monitoring methods (Bertollo 1998) that can be practically applied for case-by-case assessments in real-world settings (Wilcox 2001).

Both measures (IBI and EH) require a reference condition to measure change from, whether it is defined by policy, e.g., for the WFD, or by historical research of pristine conditions, or is complemented by stakeholder opinions (EH). These different applications allow us to distinguish between short-term human impacts and long-term environmental changes. However, if riverine SESs are dynamic, then there may be no fixed and stable condition to refer to, no undisturbed point of origin. For example, rivers are physically dynamic. River channels can move laterally, as much as 750 m per year in the case of the pre-engineered Kosi River, which flows from Nepal into Bihar, India (Smith 1976). In the face of such dynamism, integrity measures based solely on a stable reference condition become suspect. This challenge became apparent as examples of sudden, nonlinear, and sometimes irreversible change in aquatic ecosystems emerged in the last decades of the twentieth century (Jackson 1997; Jackson et al. 2001; Scheffer 2004; Scheffer and Van Nes 2007). After decades of apparently stable, clear water conditions, a single summer storm could cause a shallow lake to "flip" and become turbid, irreversibly, for years afterward (Scheffer 2004). To assess how SES responds dynamically to extreme events, new measures had to be developed to provide a conceptual, and potentially a quantifiable, basis for research and policy for aquatic ecosystems.

Resilience

How can we assess the response of riverine SES to the impacts of slow processes (degradation, accumulation of pollutants) as well as extreme events? One measure developed by engineers to assess the performance of river infrastructure is

engineering resilience, measured in terms of the time required to return to an optimal state after an extreme event such as a flood. However, if aquatic systems can exhibit very different states, to name but two examples, clear or turbid, and remain in either state for extended periods of time, then perhaps the key question is not "What is the reference (optimal) condition?" but "What is the potential for the SES to move to an undesirable condition?" The fact that movement from one stability domain to another can be surprising (difficult to anticipate), rapid, and very difficult to reverse at best makes this a critical question for managers. *Ecological resilience* has been developed as a concept (Holling 1973) to help explore that potential for SES to remain in a "stability domain" (state) or move to another one. Where riverine restoration is an issue, the question can become: "What is the potential for a riverine SES to move from an undesirable to a desirable stability domain?" The resilience concept relates that potential to a system's capacity to absorb disturbance and recover afterward. That potential to change state rises as those capacities are lost.

Despite several decades of research, it has proven extremely difficult to measure this potential for movement between stability domains, i.e., regime change. One measure, referred to as a critical slowing down (CDS), has shown promise to reflect that an SES is close to a "tipping point," e.g., a point beyond which the SES moves inexorably to a new regime or stability domain. This proximity to a tipping point may be indicated when the system recovers slowly from relatively small perturbations, e.g., when the water column concentrations of nutrients like phosphorus or nitrogen are very slow to recover to average values following sudden spikes (Scheffer 2004; Scheffer and van Nes 2007; Scheffer et al. 2009). Measures like a critical slowing down (CDS) have been found in enough cases to be interesting but not often enough to be general, and there is even more so for a number of other indicators (for an overview, see Dakos et al. 2015). However, even if a more reliable measure could be found, that might not serve science or management very well. Quinlan et al. (2015) warn that:

> Measuring and monitoring a narrow set of indicators or reducing resilience to a single unit of measurement may block the deeper understanding of system dynamics needed to apply resilience thinking and inform management actions.

It is for these reasons that resilience has been applied mostly as a heuristic to help define and explore issues in ecology and natural resource management (Quinlan et al. 2015). However, resilience has also been used as a concept within planning processes and adaptive management exercises (Roux and Foxcroft 2011; Namoi CMA 2013). Resilience can be understood as a system's capacity to "... retain its basic function and structure by absorbing the impact of disturbance and/or recovering and rebuilding post-disturbance" (Namoi CMA 2013). Such a definition is too general to measure precisely (Cabell and Oelofse 2012). A very wide diversity of variables has been used not as direct measurements but as indicators of separate factors that individually and collectively contribute to this capacity in different contexts. Social science applications have assessed various human capacities to cope or adapt in the face of shock or stress as indicators of resilience. These capacities have been variously defined in terms of robustness and vulnerability (Pasteur 2011; Barrett and Constas 2014),

response to poverty (Mancini et al. 2012), capacity to learn and innovate (Carpenter et al. 2001), and capacity to organize and develop collaborative networks and adaptive institutions (Atwell et al. 2010; McKey et al. 2010) (for a comprehensive summary, see Quinlan et al. 2015).

1.3.2   Integrating Assessment, Policy, and Action

Development of tools to assess the state and trajectory of an aquatic SES has deepened our appreciation for their complexity and dynamism. This is especially so from the perspective of managers who must contend with a history of changes that have proven difficult or impossible to reverse. The practical potential of such tools is realized when they are applied to develop and guide the implementation of policies to manage such systems. This book considers several frameworks, such as DPSIR and adaptive management, which have been developed to integrate such tools both for research and as part of decision-support processes.

DPSIR

A wealth of cause-effect relations can influence the trajectory of an SES. Clarifying those relations can make management of an SES more flexible and adaptive. To this end several major management agencies (OECD 1993; EEA 1995) developed Driver-Pressure-State-Impact-Response (DPSIR) as a more detailed framework of relationships linking five categories that describe influences and reactions of systems (Fig. 1.2). DPSIR has been used extensively to analyze ecological and social factors influencing the resilience of aquatic SES in the face of anthropogenic pressure. For example, under the aegis of the Water Framework Directive, it has been applied to improve protection of groundwater, inland surface waters, estuaries, and coastal waters (Borja et al. 2006). It has also been used to assess the pressure of alien species (UKTAG 2013) as well as to support the design of an integrated river basin management plan by identifying the structure of environmental problems in a river basin

Fig. 1.2 DPSIR framework (After EEA 2003)
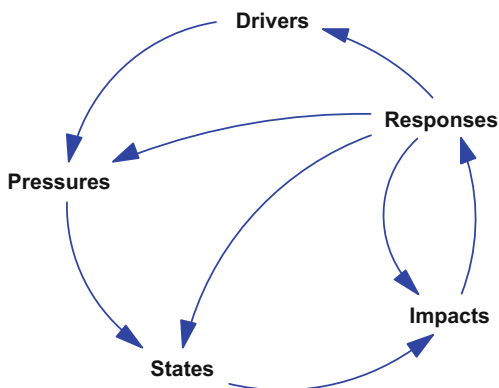
(Kagalou et al. 2012). Gari et al. (2015) conclude that two factors explain the wide-spread use of DPSIR, especially in the realm of policy-related science: "...it structures the indicators with reference to the political objectives related to the environmental problem addressed; and ... it focuses on supposed causal relationships in a clear way that appeals to policy actors (Smeets and Weterings 1999)." However, the use of DPSIR has been complicated by discrepancies in its application, such as the placement of the same variables in different categories (Gari et al. 2015).

As applied by the EEA (2003), the categories of the DPSIR framework are described as follows. Driving forces are created by the patterns of production and consumption that emerge from the intertwined social, demographic, and economic developments of society. These forces of society's metabolism drive the pressures that impact SES, e.g., emissions of chemical, physical, and biological substances and agents and shifts in land use and land cover. In response to these pressures, the state of an SES can shift physically (temperature), biologically (fish stocks), and/or chemically (atmospheric CO_2, water column nitrogen). Impacts resulting from shifts in ecosystem state are reflected in diminished functioning of the environment, e.g., lower human or ecosystem health, resource availability, and/or biodiversity. Any or all such impacts can precipitate responses to mitigate or adapt, which can emerge at the level of individuals and groups at different levels of organizations (Gari et al. 2015).

Management decisions to hold steady or change course benefit from precise measurements, but such choices grow out of many critical decisions that come beforehand. What should be measured, how, to answer what questions or policy dictates, and whose perspective should be included in the discussion? These are among a plethora of decisions that face river managers. With regard to measurements, who decides how to define the space and time dimensions of the reference condition? What is the baseline in time against which one measures change (degradation or progress) in ecosystem properties? For example, radically different conclusions can be drawn from the number of salmon found in 2002 in the Northwestern US Columbia River basin depending on when one sets the baseline. The baseline's date can inspire optimism (200% increase since 1930) or pessimism (90% decline since 1866) (Olson 2002). To shape sound research as well as policy, management must account for the false optimism inherent in such a *shifting baseline syndrome* (Pauly 1995), which can be reversed if management can integrate ecological restoration within the larger social context, restoring habitat connectivity, local fish populations, as well as local fisheries (McClenachan et al. 2015).

Constructive and effective engagement with these questions can help build a comprehensive overview and a flexible approach that managers need to deal with uncertainty. However, the global decline of river socio-ecosystems reflects a history of management that did not meet these challenges but defaulted to convention and tradition based on previous knowledge and historical relationships. Historically, river management regimes have evolved as complex webs of relationships that reinforce each other and create a momentum carrying them down a development path. In this way, a river system advances along a trajectory determined by complex feedbacks of interacting actors, policies, technologies, and concepts (Sendzimir et al. 2007).

Sometimes such feedbacks reinforce one another in ways difficult to change. When such histories of relations eliminate novelty based on new information or innovation, then management becomes *path dependent* (David 1988; Arthur 1994; Page 2006), i.e., locked into previous decisions, and it loses the initiative to adapt to changes (Barnett et al. 2015). For example, if the history of investment in the science and technology of dam and dike infrastructure makes it unthinkable to open such barriers as part of managing for droughts or floods, this constricts the range of options for research and policy. It is as if the way forward for science or managers can only proceed along a narrow set of rails. These constraints hamper our attempts to experiment by moving laterally. This inertia from path dependence can be especially challenging for managers who seek to experimentally develop policies to address uncertainty arising from the dynamism of nature and/or society. In response to such challenges, decades of experimentation have produced a range of tools to engage these twin challenges and make decision-making and policy formulation more flexible and comprehensive (Gunderson et al. 1995). This book reports on the opportunities afforded by these new approaches under the general rubric of adaptive management and governance.

1.3.3   Adaptive Management and Governance

The challenge of understanding and managing complex systems like aquatic ecosystems is compounded by their dynamism. Initial success at restoring ecosystem integrity often cannot be sustained (Scheffer 2004). So often have initial policy successes collapsed and remained so, despite all efforts at restoration, that the dysfunctional inertia following these surprising reversals has come to be known as *policy resistance* (Sterman 2000, 2002). Attempts to control disturbances (flood, fire, and pests) have often led to larger and more profound disruptions. For example, policies to constrain flood volumes within channels bounded by dikes have not stemmed the trend of increasing flood damages (Sendzimir et al. 2007; Gleick 2002; Pahl-Wostl et al. 2007).

The possibility that path dependence gives rise to policy resistance has provoked a search for ways to improve how we make science-based decisions, a search that has driven experimentation to integrate science and policy in one decision-making process. If ongoing change in ecosystems and society can render any inflexible policy obsolete, then management must dynamically adapt as a counter to perennial uncertainty. Adaptiveness requires the sustained capacity to learn and to flexibly manage. For 40 years a variety of separate experimental lineages [e.g., policy exercises (Toth 1988a, b), adaptive management (Gunderson et al. 1995), group model building (Vennix 1995; Senge 1990), soft systems methodology (Checkland 1989)] have worked in parallel to develop decision-making processes that address the challenge of learning while managing. Within this book we report on one such process, known as adaptive management

Fig. 1.3 Adaptive management: cyclic learning—decision process (After Magnuszewski et al. 2005)
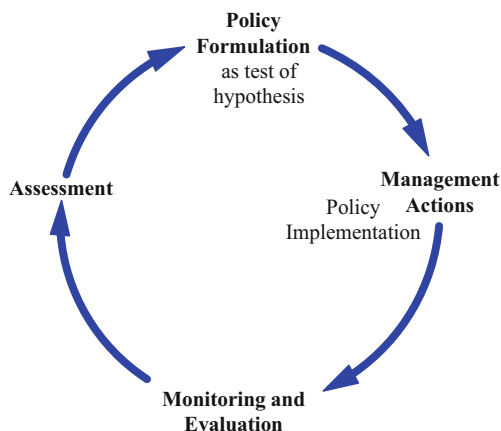
(AM), which offers a framework to integrate the knowledge, methods, and operations of the research, policy, and local practice communities. It has been developed over four decades of experimental applications to understand and manage crises of collapsed fisheries, agriculture, forestry, and rangeland grazing (Holling 1978; Walters 1986; Gunderson et al. 1995). In addition to incorporating multiple perspectives, AM increases adaptive capacity by shifting decision-making processes from linear (crisis–analysis–policy) to a cyclic process (Fig. 1.3). This process structures learning and iteratively integrates how we modify assessment and policy formulation, implementation, and monitoring in order to track and manage change in the world (Magnuszewski et al. 2005).

The search for durable solutions to crises in ecosystems and society has repeatedly expanded the scope of inquiry outward from science to develop policies based on a broader base of experience and practice. Initial experiments (Holling 1978) acknowledged government and local practice but focused mostly on bridging disciplines within science. Subsequent experiments worked to include government (Walters 1986), local practitioners (Light and Blann 2000). However, managing aquatic ecosystems proceeds over time scales (decades) that far exceed those of individual projects or individual management campaigns. To make ecosystems sustainable, the adaptive potential raised by AM must be sustained over periods long enough to institutionalize adaptive and sustainable practices.

This drive to build long-term ecosystem sustainability proposed *adaptive governance* as a framework that would foster AM while addressing social aspects neglected in initial AM experiments (Gunderson et al. 2016). Specifically, it should create a workspace where formal and informal institutions can collaborate to understand and manage complex issues in social-ecological systems (Schultz et al. 2015). Adaptive governance would be distinguished by its capacity to increase the importance of learning and to bridge previously separate levels: formal/informal, scales of administration (polycentricity), in ways that embrace cross-scale interactions in ecosystems and society (Chaffin et al. 2014; Chaffin and Gunderson 2015).

1.4   Structure of the Book

Science can expand knowledge along two fronts defined by depth and breadth of information. This book sacrifices some depth of detail in order to better describe the breadth, e.g., the diversity of knowledge from different disciplines and their interconnections. This may disappoint specialists, but it best serves managers interested in practical insights from a wide spectrum of important aspects of riverine ecosystem management. Overall this book is designed to provide a general understanding of socio-ecological river systems that is grounded by specific examples from problem-oriented research. Given how global change may manifest as increasing variability in natural and/or social systems, governance toward a sustainable future of riverine ecosystems will greatly depend on integrating knowledge across disciplines.

The book is structured to guide the reader from a broad understanding of the structure and function of riverine social-ecological systems to an appreciation of human impacts and, finally, to interventions to manage such evolving systems. This starts with a basic knowledge of ecosystem structure and function. It then expands to include the consequences of human impacts as well as interventions to mitigate and restore these systems and the management tools required to realize them.

The foundations of understanding riverine structure and function are established in Part I. It introduces key system elements and characteristics of riverine ecosystems such as hydrology, morphology, connectivity, sediment, floodplain, riverscape, and water quality. Against this background understanding of riverine ecosystem functioning under natural conditions, the effects of human impacts and biotic responses are described. River management requires assessing these impacts, which begins with careful definition of the baseline or reference conditions against which change is measured. On this basis, one can analyze the dynamics generated by biotic responses as well as the potential effects of human intervention.

Understanding the history of human impacts and identifying tipping points of ecosystem degradation are important for setting up management objectives (Chaps. 15 and 16). The effects of pressures are described in this book in the way they affect key abiotic system elements and associated biota. Hydromorphological processes shape river channels, determine flow patterns, and define available habitat (Chap. 3). Channelization as a result of agriculture, urbanization, and infrastructure development including hydropower and navigation results in habitat degradation, disruption of river continuity, floodplain decoupling, river bed incision, and flow alteration (Chaps. 3–9). River restoration strives for improving in-stream habitat quality, recoupling floodplains, provision of flood retention areas, reestablishment of river continuity, and sustainable sediment management. Dams and water abstraction for irrigation, hydropower production, drinking water, and other purposes reduces discharge, alters flow regime, disrupts river continuity, and results in habitat loss (Chaps. 3–9).

Part II focuses on the management of riverine ecosystems and provides insights into state-of-the-art methodologies of integrated river basin management including international and EU water legislation (Chaps. 15 and 17), the concept of adaptive

management (Chap. 16), challenges in managing international rivers (Chap. 18), and supporting methodologies and concepts such as ecosystem services (Chap. 21) and ecological monitoring and assessment (Chap. 19). The last Part III provides more detailed case studies of problem-related research with a focus on large rivers (Danube River, Chaps. 24 and 25), species conservation (sturgeon, Chap. 26), floodplain management (Tisa River, Chap. 28), and bioassessment and fisheries in developing countries (Burkina Faso, Chap. 27).

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