Chapter 29
Landmarks, Advances, and Future Challenges in Riverine Ecosystem Management

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Science and society are interlinked systems as research topics are defined by societal needs and research outputs trigger societal development. This was particularly the case in the environmental sciences within recent decades: the "Environmental Movement" emerged as a powerful social phenomenon in twentieth-century society via different pathways. Pioneers of the movement were protesters against large infrastructure projects such as hydropower dams or massive pollution of rivers. Green parties took up the momentum and provided political platforms for green thinking. Environmental legislation was implemented, and science contributed to a more sustainable management of aquatic ecosystems via the so-called triangle of sustainability linking environment, society, and economy.

Two environmental events in the 1980s exemplify this paradigm shift in Europe. In 1984, about 3000 activists occupied the Danube floodplains downstream of Vienna, Austria, to protest the construction of the Hainburg hydropower dam. The protest finally ended with withdrawal of the construction plans, and in 1996, the same reach of the Danube and its floodplains that hosted the protest became a national park. In 1986, during the Sandoz accident in Basel (Switzerland), 20 tons of a toxic pesticide mix flowed unhindered with the fire water into the Rhine. In the following 2 weeks, the spill spread more than 400 km downriver, destroying practically the entire eel population and other fish species in its path. As a consequence,

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environmental safety regulations were improved, risk management was established, and since then water pollution in the Rhine has decreased significantly.

In the USA, already a decade earlier, environmental targets had been implemented in *legal frameworks*, such as the *Clean Water Act* (1972) and the *Endangered Species Act* (1973), supporting environmental planning and conservation. In Europe, comprehensive environmental legislation did not become effective until the formation of the *European Union* (*EU*) in 1992 enabling the release of a series of directives enforceable over the entire union: the Nitrate *Directive* (1991), *Urban Wastewater Directive* (1991), *Birds & Habitat Directive* (1992), *SEA Directive* (2001), Water Framework Directive (*WFD*, 2000), and the *Floods Directive*, although some environmental directives (e.g., EIA Directive 1987) had been already implemented under the umbrella of the *European Economic Community* (*EEC*), established in 1957. These regional environmental developments were also reflected in international agreements, such as the *UN Conventions on Water*, *Sustainability and Biodiversity* (1992). Nowadays, legal frameworks consist of a complex network of international agreements, EU-wide directives for EU countries, and national legislations (see Chaps. 17 and 18).

Although not explicitly dedicated to aquatic ecosystems, a number of other *international initiatives* contributed to increase awareness of conservation needs. For example, the Millennium Assessment Report clearly pinpointed a 50% decline in diversity as measured by the Living Planet Index for freshwater vertebrate species (based on 323 species) between 1970 and 2000. This trend provides the factual justification for classifying freshwater ecosystems as the most threatened ecosystems on earth (www.millenniumassessment.org). Within freshwater ecosystems, running water species belong to the most endangered group of species as about half of running water species (vertebrates and crayfish) are threatened or their status is unknown (Collen et al. 2014).

Global threats are increasingly identified and addressed by *internationally agreed development targets*, such as the UN Sustainable Development Goals (2015) focusing on the protection and restoration of water-related ecosystem (goal 6.6). Assessing ecosystem status is nowadays seen as the fundamental basis for ecosystem management. For example, the continuous assessment of climate change and its potential impacts on ecosystems via the Intergovernmental Panel on Climate Change (reports from 1990, 1995, 2001, 2007, 2014) has raised public awareness and brought the climate change debate to the top political level. A similar approach is envisaged by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) founded in 2012 and currently supported by 125 countries. The first findings of research performed under the aegis of IPBES are expected in 2018.

The most comprehensive *monitoring of surface waters* worldwide has been undertaken within the implementation of the WDF in EU countries. Overall, 108,000 stations have been monitored in surface waters and groundwaters within the first monitoring cycle of the WFD by 2009 (see Chap. 19). Algae (phytoplankton and benthos), macrophytes, invertebrates, and fish have been surveyed in lakes and rivers (57,000 monitoring stations, EC 2009). The results indicate that the majority

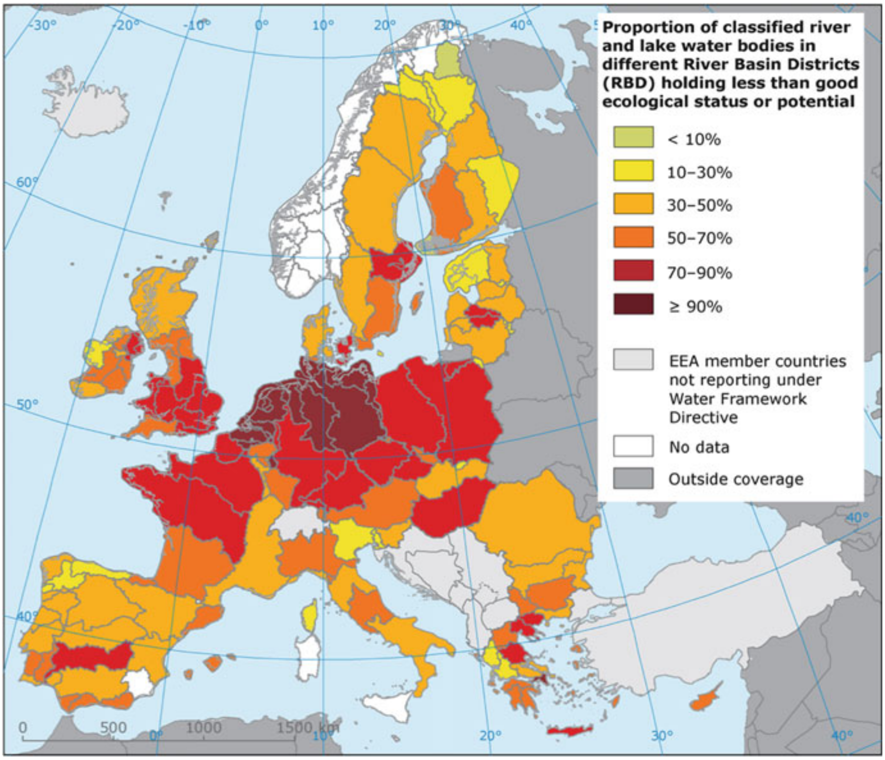

Fig. 29.1 Ecological status of surface waters in EU countries (www.eea.europa.eu, accessed 21 October 2016)

of rivers and lakes fail the WFD objectives of good status or potential, and significant restoration efforts are required (Fig. 29.1).

Hand in hand with the environmental movement, advances in environmental legislation and international initiatives have supported the expansion of the scope of scientific inquiry to include environmental issues, both in terms of theoretical ecosystem understanding and research application (Fig. 29.2). Sound *conceptual understanding of the functioning of natural ecosystems* is a prerequisite for developing effective restoration and management strategies. For a long time in riverine science, river ecosystems were perceived as a sequence of more or less isolated "river zones" (Thienemann 1925; Huet 1949; Illies and Botosaneanu 1963). The *River Continuum Concept* (RCC; Vannote et al. 1979) was the first concept linking important processes (such as P/R ratios, organic matter input, and functional diversity of organisms) along the longitudinal gradient of river catchments. This concept was complemented by subsequent concepts that integrated longitudinal irregularities (*Serial Discontinuity Concept*, Ward and Stanford 1995) and spatial/temporal dynamics as intrinsic features of running water ecosystems, e.g., *Flood Pulse Concept* (FPC) (Junk et al. 1989). The FPC introduces the role of flood

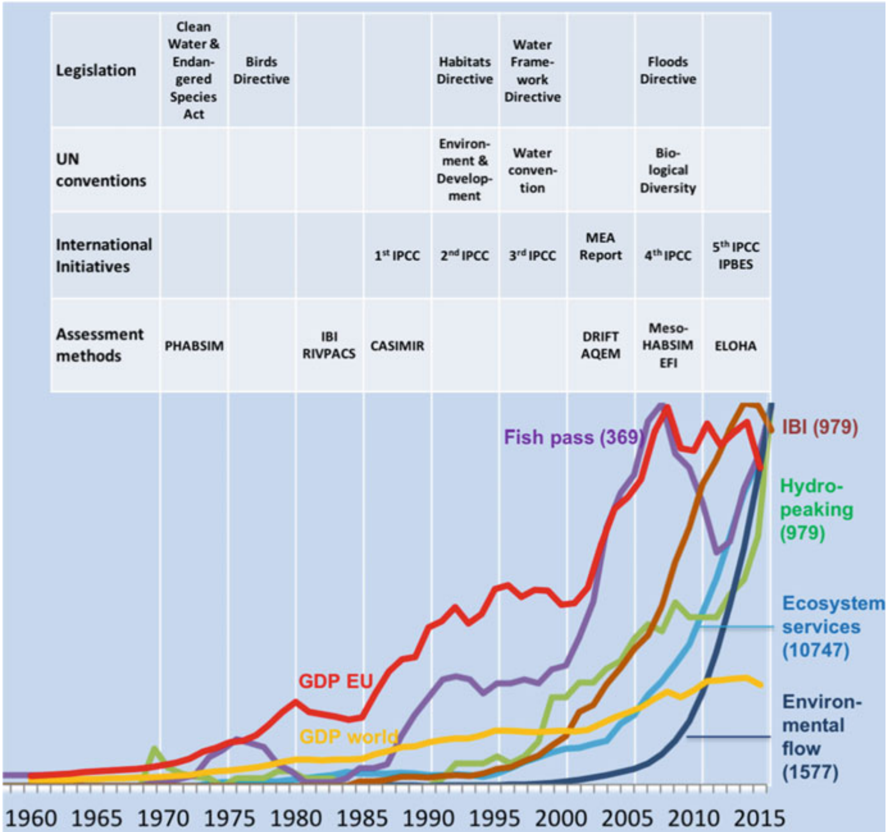

Fig. 29.2 Development of selected landmarks in riverine ecosystem management and economic development between 1960 and 2015. GDP: relative gross domestic product development. Other parameters: relative number of citations for keywords as indicated in figure (absolute number of citations in brackets). IBI: Index of Biotic Integrity (based on www.scopus.com, accessed 15 November 2016)

pulses in connecting aquatic and terrestrial environments at the landscape scale as measured by their changes over time. Together with its extension for temperate systems (Tockner et al. 2000), the FPC describes the role of discharge variability (flow and flood pulses) for ecosystem processes. The *Nutrient Spiraling Concept* uses the continuum perspective addressed in the RCC to develop a model of how elements (nutrients) interact with organisms in running water systems. It provides a framework for studying how transport and transformation processes interact and, thus, provides a basis to parameterize nutrient dynamics in river systems (Newbold et al. 1981). The *Riverine Productivity Model* (Thorp and Delong 1994; Thorp and Delong 2002) emphasizes the importance of autochthonous (aquatic) in-stream production for riverine food webs. This adds an important contribution to the energy balance of riverine food webs as the RCC and the FPC emphasize the importance of terrestrial subsidies for the riverine food webs.

Besides processes, structures play a major role in understanding ecosystem complexity. The *Concept of the Four-Dimensionality* of running waters (Ward 1989) links the three spatial scales (longitudinal, lateral, vertical) with the time scale. Static views of habitats, such as the Multidimensional Niche Concept (Hutchinson 1957), were replaced by dynamic concepts, such as the *Patch Dynamics Concept* (PDC, Townsend 1989) and the *Shifting Habitat Mosaic Conce*pt (SHMC, Stanford et al. 2005). The *Riverine Landscapes Concept* (Wiens 2002) extended the spatial scope to river-influencing, land ecosystems. While the PDC described the general role of distinct landscape units and their temporal variability and interactions, the SHMC addresses the high heterogeneity in riverine systems, a mosaic of diverse habitats at different successional stages driven by geomorphic dynamics. This allows the coexistence of a high diversity, e.g., species number, based on the connectivity between habitat patches with a regime of episodic disturbances that lead to periodical resets at different locations within the riverine landscape.

The *River Ecosystem Synthesis Concept* (RES, Thorp et al. 2006) represents an integrated model derived from aspects of other aquatic and terrestrial models, combining the view on distinct geomorphic river sections and various ecosystem properties to functional process zones (FPZs) and other aspects of riverine biocomplexity.

Theoretical concepts of ecosystem functioning triggered also *methodological developments in river science and application*. While river habitat was measured by labor-intensive field assessments and analyzed by simple 1D models in the past, nowadays, new instrumentation (e.g., acoustic Doppler current profiler) produces high-resolution data on bathymetry and flow velocity that can then be processed in 3D models (see Chap. 3). The new technologies reduce data acquisition costs and enable the analysis of high-resolution, spatial/temporal, habitat dynamics. When linked to GIS data on land use, those approaches can be integrated into catchment-scale analyses (see Chap. 13). Habitat analyses at various scales are linked to biotic assessments that range from microhabitat preference models for distinct species and life stages to biotic community assessment at reach scale up to species distribution models at catchment and continental scale. Micro- and mesohabitat models are nowadays standard models for assessing environmental flow and habitat improvement (see Chap. 7). Today, biotic community assessment methods such as the Index of Biotic Integrity are standard methods used for river management that are increasingly supported by modeling approaches and developed from site-specific to river-type, national and supranational assessment tools (e.g., European Fish Index; see Chap. 19).

Developments of scientific methodologies are closely linked to *data availability* (see Chap. 20). The integration of dispersed biodiversity data at species and site level into supranational databases, the collection of standardized WFD monitoring data across the EU, and satellite-based earth observation, just to mention a few, create data sources of unprecedented breadth and resolution. New data management systems and data mining techniques are required to handle those data. A network on International Long-Term Ecological Research (ILTER) sites, founded in 1993 in the USA, is gradually developing. ILTER is one of the few hosts of long-term data that are indispensable for analyzing and predicting long-term trends, which are key to understanding, for example, climate change impacts. However, at the moment in terms of rivers, it covers only 58 sites mainly located in Europe.

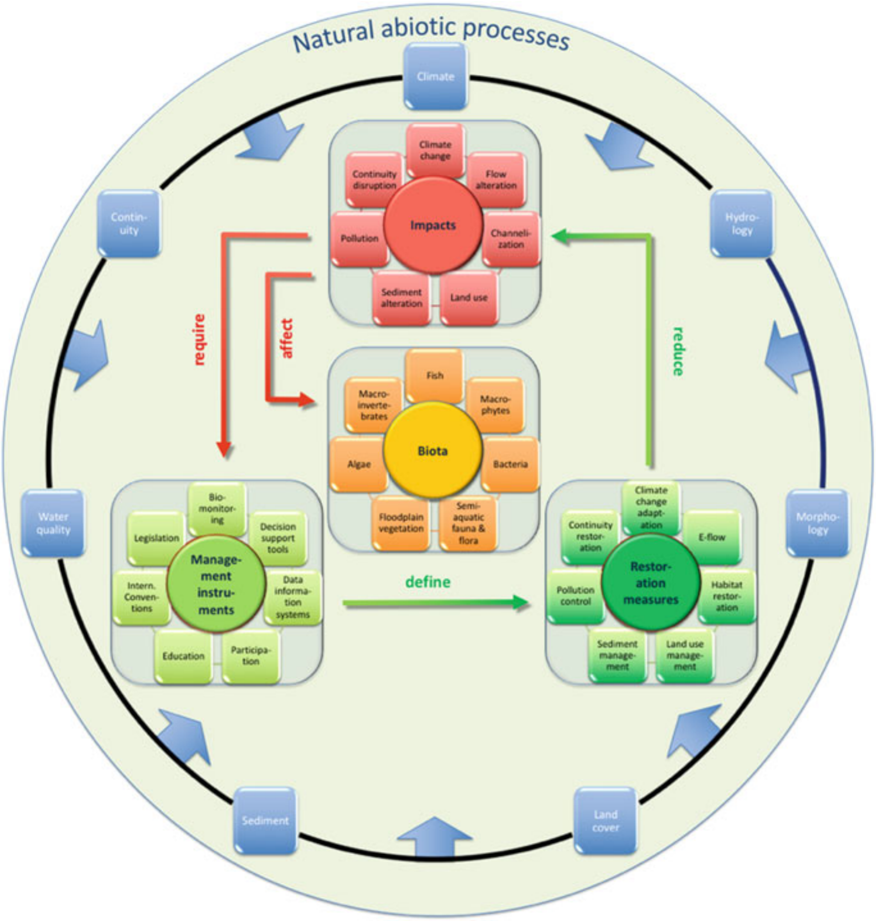

Fig. 29.3 Riverine ecosystem management: effects of natural abiotic processes, human-induced impacts, and restoration measures on biota

As described by a number of river concepts (see above), *essential elements of riverine ecosystems* are *river morphology hydrology*, *sediment*, *continuity*, *water quality*, *and biota*. Understanding the interrelation between abiotic system elements and biota and food webs is vital for assessing human impacts and developing effective restoration and mitigation strategies. Although treated in separate chapters in this book for practical purposes (see Chaps. 2–13), it is evident that the linkages among system elements are as important as processes within each system element. It is likely that while human stressors may alter each system element individually, interactions among stressors strongly affect overall system behavior and response (Fig. 29.3).

Finally, managers are facing a very complex system of natural and human-induced processes making it impossible to find simple solutions for restoring degraded rivers. Disentangling effects of multiple stressors, developing stressorspecific restoration strategies, and, lastly, integrating those again into *effective management programs* are a challenging task. Legacy effects have to be considered as human interventions may go back for several 100 years (see Chap. 2). Humans have polluted rivers since the first larger population agglomerations were established. Sewage treatment plants are known to combat pollution efficiently. However, diffuse inputs from agriculture require alternative land management strategies and protection of riparian vegetation and floodplains (see Chaps. 10 and 13). Toxicants still represent a relevant stressor in river ecosystems, despite major improvements of the situation over the last decades, at least in regions with a strong governmental regulation. Intelligent strategies are required to deal with how exposure to toxicants is complicated by mixtures, multiple stressors, and other features of the environmental context that all influence the magnitude of potential negative effects (see Chap. 12).

Scale dependencies and upstream/downstream effects are evident in all riverine ecosystem elements. Long-term flow alterations may be as critical as short-term alterations (see Chaps. 4 and 5). Sediment seems to be as important as flow, but understanding of sediment processes lags behind, making it difficult to identify effective and sustainable mitigation measures (see Chap. 8). While building fish passes is supposed to be an adequate mitigation measure for continuity disruptions, their efficiency, in particular, for downstream migration, is still questionable. Furthermore, the overall response of fish communities to multiple stressors in the context of multi-fragmented, river systems has to be explored in more detail (see Chap. 9). By restoring habitats, providing environmental flow, and building fish passes, we can improve habitat quality and connectivity. However, some impacts are not reversible or are hard to mitigate. Large dams cause such altered ecosystems since dams fundamentally change former riverine ecosystems into lake-type or hybrid systems, and restoration measures are, in general, limited here (see Chaps. 6 and 24). In addition to the challenges described above, our current understanding of causal relationships underpinning ecological processes becomes increasingly obsolete over time and needs revision, as the environmental conditions drift away from "natural" conditions due to climate change (see Chap. 11).

Many methods and successful applications of *river restoration* at local scales are presented in this book. However, comprehensive restoration of running water is lacking in most of the rivers worldwide. We are increasingly running the risk of losing the necessary free space to experimentally explore alternative restoration interventions. For example, river widening, as one of the favorite morphological restoration measures, requires space that is increasingly becoming the limiting factor, particularly in areas with natural constraints and high levels of development, such as the Alps. But even if land is available, land owners have to be convinced, subsidies provided, and implementation procedures developed to be successful. Strategic planning at catchment and even larger scales is necessary to cope with conflicting interests and new infrastructure development. However, even with best intensions and maximal support, we might not be able to significantly restore heavily impacted rivers in all cases due to how society (acceptance of existing land uses) and ecosystems have shifted over time and become irreversibly locked into a new regime. Accepting this fact may redirect our efforts into restoring and protecting less-impacted rivers in order to successfully provide other ecosystem services (see Chap. 15).

Apparently, where, when, and how to restore rivers are not trivial questions that should be answered by gut decisions but require scientifically based knowledge of ecosystem functioning, underlying mechanisms of restoration processes, and involvement of all relevant stakeholders. While the need for inter- and transdisciplinarity has been invoked so many times that they have become worn-out buzzwords, they remain as concepts that are rarely applied in routine river management. As solutions are not straightforward and may only evolve over time, we cannot manage only based on certainty. We must manage by learning along the way what needs to be done. In that context, the principle of adaptive management seems an appropriate way to manage under very uncertain conditions, e.g., climate change, by using comprehensive monitoring of the human/ecosystem to periodically challenge our science and policies within structured learning cycles (see Chap. 16).

One might say that restoring rivers for ecological purposes is a luxury only rich countries can afford. However, when it comes to providing essential or well-appreciated services for human beings (e.g., water supply, fisheries, or recreation), the functioning of riverine ecosystems becomes the foundation of sustainable development (see Chaps. 14, 27 and 28). Therefore, the concept of ecosystem services is very helpful to make the linkage between ecosystem functioning and ecosystem services better understandable for stakeholders and the public and apply it more widely in river management (Chap. 21). The importance of ecosystem services will only increase as society adapts to climate change by lowering the use of fossil fuels, which were used initially to replace ecosystem services. If fossil fuels can no longer provide alternative services, then ecosystem-driven services must be enhanced to replace them.

Environmental movements triggered societal transformations and redirected the research agenda. However, environmental movements come and go, and economic crises can easily remove environmental tasks from the political agenda, as seen recently. Therefore, the *institutionalized involvement of stakeholders and interested public in decision processes* is very important to keep the dialog on environmental issues alive. NGOs play a critical role in this process, but openness of all participating actors (decision makers, administration, stakeholders, NGO, science) is required to elaborate sound and widely accepted solutions (see Chap. 23). Finally, adequate capacity building and educational programs taking up the challenges in riverine ecosystem management are required to guarantee sustainable development of riverine ecosystems in the long run (see Chap. 22).

Aquatic ecosystems such as rivers will become increasingly important in sustaining and improving our quality of life by providing such services as food, water, transport, and the aesthetics that define a region. The science of understanding and managing rivers cannot provide the luxury of high certainty anymore, which we now understand was an illusion in the first place. However, in an increasingly unpredictable world, it can provide the best questions, methods, and potential solutions to test as society adapts to uncertainty. As improved restoration efforts return the natural beauty of river valleys to many regions of the world, river science will become a vital bridge between the integrity of nature and of society.

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