River Conservation
Challenges and Opportunities

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Chapter 1 Offprint

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Chapter 1

River Conservation: Going against the Flow to Meet Global Challenges

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Conservation is a state of health in the land. The land consists of soil, water, plants and animals, but health is more than a sufficiency of these components. It is a state of vigorous self-renewal in each of them and in all collectively. […] Land is an organism and conservation deals with its functional integrity, or health.

Aldo Leopold, 1949

Rivers are among the most diverse and threatened ecosystems on Earth, as they are impacted by increasing human pressures. Because rivers provide essential goods and services, conservation of these ecosystems is a requisite for sustainable development. Therefore, we must seek ways to conserve healthy rivers and to restore degraded ones.

1.1. Global change and implications for freshwater ecosystems

The Earth's human population reached 7 billion people on October 31, 2011 according to the United Nations (2010 Revision of the World Population Prospects), and is projected to rise to 10 billion by 2083. Despite some uncertainties in the precise rate of increase and consequent scenarios of future change, the rapid growth of humans is profoundly altering the Earth system and the biodiversity it supports. The local impacts of anthropogenic activities are not evenly distributed: only 1/8 of all humans live south of the Equator, whereas 50% are concentrated between latitudes 20°N and 40°N (Kummu and Varis, 2011) where the landscape and natural habitats have been irreversibly transformed by agriculture and urbanization, and there is intense competition for water resources.

The human footprint upon the planet does not solely depend on the number of people. The per capita use of resources, energy and space have profound impacts on the pressure imposed by a given number of people. For instance, average energy use increased 39% worldwide between 1990 and 2008, resulting in large increases in emissions of CO_2. The largest share of that growth was in the so-called emergent economies (the BRIC countries), where the increase ranged between 70 and 170%. Overall, the European countries, the US, Australia and other large economies are avid consumers of energy, mainly in the form of coal, oil and gas, and hence also make major contributions to greenhouse gas emissions. This extraordinary use of fossil fuel resources is leading to a global transformation of the Earth and its atmosphere and climate that is without precedent.

The impact of humans on the global environment has given rise to the term "Anthropocene", referring to a new, post-Holocene epoch when planetary changes are driven mainly by human activities. This term was promulgated by the Nobel

Figure 1.1:
A headwater stream in the Spanish Pyrenees. Headwater streams are by far the most abundant type of river in the world and, in total, they harbour a significant proportion of freshwater biodiversity, including many highly-specialised species. Such streams have strong links to the surrounding landscape, with important consequences for habitat conditions and the availability and type of food resources

Box 1.1

Key concepts in conservation

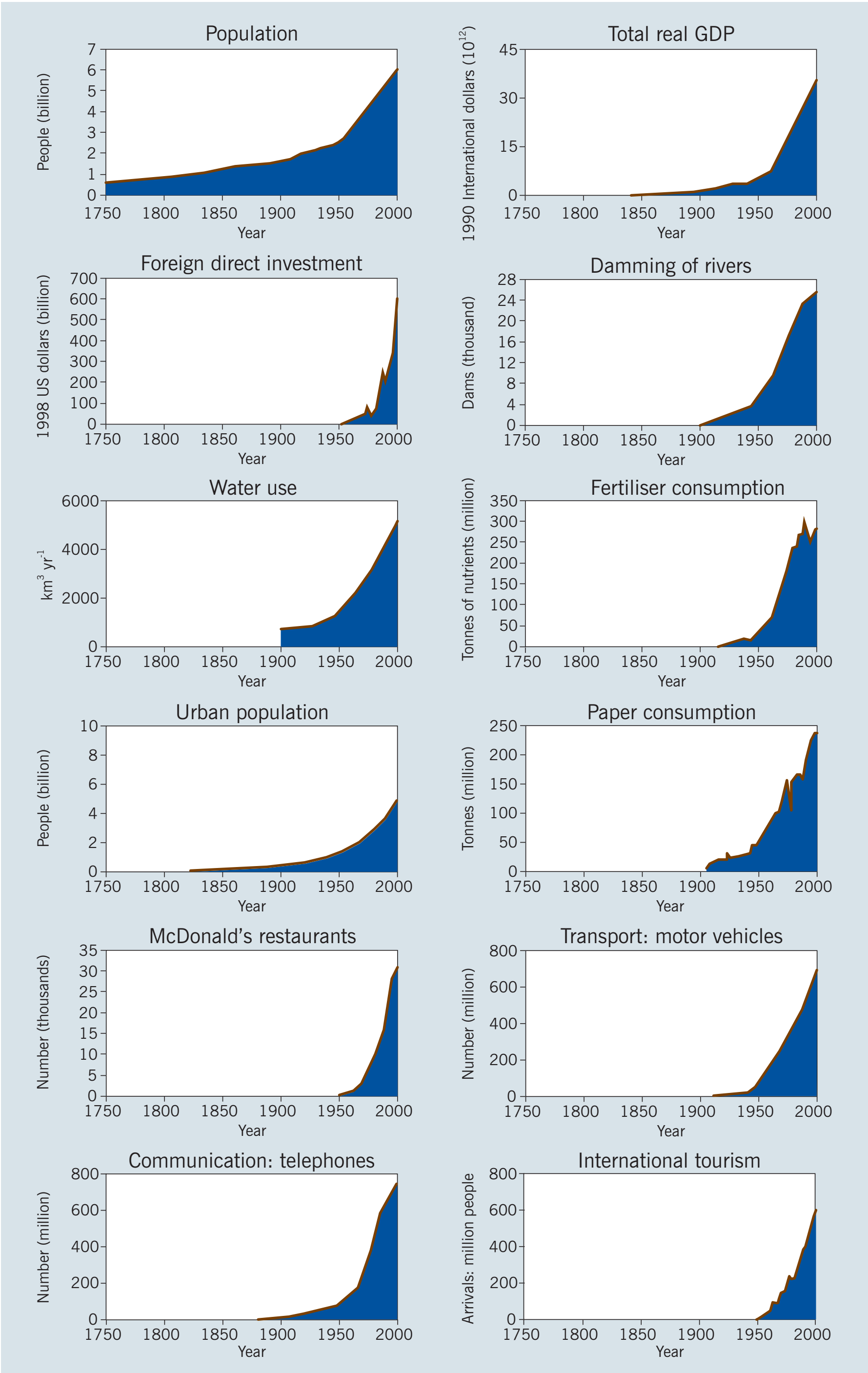
Biodiversity is a contraction of the wording "biological diversity", and thus, refers to the variability among living organisms, including all levels from genes to species and ecosystems. Biodiversity is the result of over 3 billion years of evolution, and ultimately is responsible for many of the characteristics that make this planet habitable, as for instance, the oxygen in the atmosphere, which is produced by plants and other photosynthetic organisms.

Human activities are transforming and degrading natural habitats at an increasing speed, resulting in **biodiversity loss** and often in the destruction of entire ecosystems. Increasing awareness of such problems gave rise to the development of **conservation biology**, or the scientific study of the status of biodiversity with the aim of protecting species, their habitats, and ecosystems from extinction. Conservation biology, thus, is part of a broader movement that aims to conserve nature and the quality of the environment as a way to ensure the well-being of oncoming generations, as well as to protect the intrinsic values of biodiversity.

Nature conservation can operate at different levels. Some actions focus on conserving **populations**, such as preventing overexploitation of a fish species; others focus on the **habitats** where these populations live, for instance, providing gravel beds as spawning areas for fish; still others focus on **ecosystem processes**, such as encouraging the growth of aquatic plants that can enhance water purification.

Prize-winning chemist Paul Crutzen, who argued that the effects of anthropogenic activities on the Earth's atmosphere were sufficiently important to mark the onset of a new geological epoch. While there is some controversy regarding the precise onset of the Anthropocene (some consider it began in the Neolithic period with the invention of agriculture, others associate its origins with the Industrial Revolution), its implications are evident from the ever-growing atmospheric burden of greenhouse gasses (CO_2, N_2O, CH_4...), in the vast amounts of resources appropriated by humans, in the extensive modification of land apportioned to provision of food and other needs, and in changes in the global cycles of water, nutrients and other materials, where the human contributions to the global systems far exceed those attributable to natural processes. As Steffen et al. (2007) have demonstrated, we are in the midst of a phase dubbed "the great acceleration" of population growth and resource use (Figure 1.2); quite evidently, however, this increase cannot proceed indefinitely on a finite planet. The question is not whether it will cease, but when this will happen and what will bring it about. In the immediate future, however, the human ecological footprint and hence the area of land and sea needed to supply the resources we consume and to assimilate our resulting waste, will continue to grow to the detriment of natural habitats and the biodiversity they support.

Figure 1.2: *The dramatically increasing use of resources during the Anthropocene, treated here as marked by the onset of the Industrial Revolution. Global population growth is shown also*



Source: Adapted from Steffen et al. (2007).

The impacts of human activities on the Earth have the potential to be reversible, so long as we do not transgress certain thresholds of sustainability. Unfortunately, some appear to have been crossed already. Of special concern are the effects on biodiversity and on global nitrogen cycling (Rockström et al. 2009). These and other human impacts are not transient and, instead, represent new "baseline settings" for ecosystems and the context in which conservation and management of endangered species must be addressed. Inland waters, and rivers in particular, may be especially vulnerable to Anthropocene impacts because of their strategic position within the global water cycle where they link the atmosphere, soil processes, the biological water in living plants and animals, and the oceans (Meybeck 2003). Maintaining the health of rivers in the Anthropocene world will be challenging: there is hope – but our credit is not unlimited.

1.2. An atlas of global change

While it is indisputable that the global environment is changing, there are large differences between regions regarding the rate, intensity and the nature of change. The tropics, which harbour some of the most diverse and least-known ecosystems in the world, suffer high rates of habitat destruction, often associated with rapid increases in human population. Elsewhere, in parts of North America and Europe, for example, there have even been improvements in the state of the environment, as a result of large investment in environmental policies and implementation of relevant legislation. Note that on a global scale this does not always result in a net gain, since local improvements may be brought about by relocation of highly-impacting activities to countries where environmental standards are less strict.

Regarding rivers, the implementation of the Water Framework Directive in the European Union countries, or the Clean Water Act in the US, represent landmarks in sustainable management, although concerns about water quality remain. Water management is a priority for some developed countries, where human needs for water have been secured in most places. However, water security is often brought about by economic investment in water treatment, rather than by prevention of impacts on freshwater ecosystems, and the result is a gradual depletion of biodiversity (Vörösmarty et al. 2010). In this field the success of legislation, such as the EU Habitat Directive, has been much more limited, because improvements in water quality have not been matched by biodiversity gains.

Elsewhere, however, the effectiveness of technologies is compromised in many countries by lack of enforcement of legislation, widespread corruption, or the tendency to prioritise economic development over environmental protection. Countries with emerging economies often repeat the past errors of states with

Figure 1.3: *A tropical river meanders through the plains of the Amazon basin. Tropical rivers have rich and distinctive biodiversity that, among other things, sustains productive fisheries but, in many places, is currently threatened by ongoing and planned changes to the environment. Lowland rivers are tightly linked to their floodplains, which host rich terrestrial biodiversity*

relatively developed economies, with environmental issues ranking low in lists of national priorities.

Because water is a multi-user resource, societal and political interests often become entangled with river management and conservation, as the paradigmatic case of the Iberian Peninsula shows. In particular, parts of Spain and Portugal with a Mediterranean climate tend to experience water scarcity. For instance, in some of the Atlantic catchments water demand is less than 10% of water availability, but the ratio may be as high as 220% in Mediterranean catchments (Sabater 2008). This disparity is maintained by large-scale water transfers between the two regions. Even so, rivers in Mediterranean areas can dry out during extended periods of the year, with dramatic consequences for ecosystems and biodiversity. Thus, the water issue becomes a conflict between human uses and nature conservation, with the usual outcome that consideration about which human uses to satisfy take precedence, whatever the cost for nature. In short, nature does not receive the consideration enjoyed by human stakeholders when it comes to decisions over river water allocation.

The conflict for water for between humans and nature is especially evident in some nations affected by structural deficits. Inadequate management of rivers leads to misery and suffering as a consequence of poor sanitation, water-borne diseases, and flooding. Rural and urban areas often differ greatly in their water availability and safety, which adds to regional inequalities. It will be a significant challenge to meet the legitimate aspirations of growing human populations for a clean, readily-available supply of water, without compromising the water needs of ecosystems and nature.

Irrespective of regional variations, the Earth is changing as a consequence of growing human population and resource consumption. Although there have been a number of advances in nature conservation, many of them are currently threatened by the ongoing global financial crisis, since economic uncertainty tends to push conservation issues down policy agendas. Overall, the annual litany of threatened species added to the IUCN Red List shows the failure of the conservation movement to convince society of the importance of conserving nature, whereas the current economic model drives environmental degradation and loss of natural capital. In the context of a society where consumption is viewed as an essential component of economic "business is usual", nothing is durable and individualism is at stake, preservation of common goods such as biodiversity tend to rank very low in the priorities of most people.

A fundamental change in attitude will be necessary to reverse the Anthropocene trend of environmental degradation and biodiversity loss in inland waters

Figure 1.4: *A highly degraded stream flowing through Fes, Morocco, exemplifies the close relationship between human wellbeing and river health*

in general, and rivers in particular. This is what we mean by going against the flow. Thus this book not only concerns facts and figures relating to river ecosystems, it is also a book about human attitudes towards nature, and ultimately a book setting out our responsibility for managing and conserving nature for future generations.

1.3. Why is it important to conserve rivers?

Inland waters are perhaps the most endangered ecosystems on Earth. The decline in freshwater biodiversity is far greater than that in terrestrial or marine ecosystems (Chapter 6), and is attributable to their high species richness in a small area. Dudgeon et al. (2006) report that that 40% of the total fish diversity and one third of global vertebrate diversity (i.e. including amphibians, reptiles and mammals) inhabit freshwater ecosystems, which cover only 0.8% of the Earth surface and represent less than 0.01% of the world's water. Rivers alone constitute an even smaller fraction of this: 0.0002% of all water.

Why is it important to conserve rivers? To the well motivated person, the answer seems obvious: it is in our own best interests, and in the common interest, for us to do so. Nevertheless, despite efforts from the conservation movement, and despite the increasing number of laws and international treaties to conserve nature, the Earth's biodiversity and ecosystems – and rivers in particular – continue to be progressively degraded. While conflicts between humans and nature over water may appear irreconcilable, they are not, simply because healthy rivers are essential to society.

Rivers host a surprisingly large fraction of planetary biodiversity relative to their areal extent and volume, and biodiversity provides the life-support system for humans. Some of the biodiversity values are consumptive, that is, they provide resources that can be exploited: river fisheries, forming the base of many local economies, is an obvious example. River biodiversity is also the source of other cultural and recreational benefits (e.g. tourism) that do not depend on exploitation. More fundamental values of river biodiversity are related to the provision of ecosystem services: water purification, transport and transformation of organic matter and other materials, nutrient cycling, flood control, and others. In any case, the sustainable use of these resources is only possible if we maintain rivers in good health (Box 1.2: see also Chapter 11).

Box 1.2

Key concepts in river science

People tend to think of rivers as one-way pipes that transfer water from land to the sea, or from mountaintops to coastline. This is a gross oversimplification. **Rivers** are **ecosystems** that transport and process water and other materials, dissolved and particulate, organic and inorganic; such materials are derived from river drainage basins or catchments. Rivers are **hierarchically organized**: tributaries merge and create wider, deeper and newer tributaries with higher water volume, and so on. Water travels downstream and therefore effects are also transmitted downstream. This hierarchy also applies to the biological components of the ecosystem. Rivers host diverse **biological communities** distributed within a series of extremely complex **habitats** along the river course and in different parts of its channel. Because of the hierarchical arrangement, biological communities exhibit longitudinal transitions along the river; these are predictable in general terms, but their details depend on specific features of individual rivers. This longitudinal transition of species complement is one reason why rivers sustain so much biodiversity. In turn, this biodiversity constitutes a valuable **resource** for humans, with benefits that include provision of fisheries, shrimps, molluscs and edible plants.

Like all ecosystems, rivers are characterized by their **structure and functioning**. River structure is determined by features such as channel form, current speed, flow volume and water quality, and also by the composition and abundance of the biological communities they harbour (microbes, plants, invertebrates, fishes and so on). Their interactions and combined activities give rise to

Box 1.2 *(cont.)*: Key concepts in river science

river ecosystem functioning, which involves processes such as primary production by plants, transformation of organic materials, nutrient retention, water purification, and secondary production by fishes. In turn, these processes are at the base of **ecosystem services and benefits** of importance for humankind, such as the provision of clean water and flood prevention.

River ecosystems have four important **dimensions** (Ward 1989) that need to be accounted for in management plans:

— **Longitudinal**. Rivers change from source to mouth as they transport materials from the upper to the lower course and throughout the drainage basin. In turn, the physical characteristics of the channel, the range of habitats available and the associated biological communities, change also.
— **Vertical**. Rivers are linked to underground water. An important but often neglected part of the river is the hyporheos, which includes the mass of water circulating among the river sediments, hidden from view, but nevertheless the site of important chemical reactions and biological processes.
— **Lateral**. Rivers are tightly linked to their margins and floodplains, which are integral parts of river ecosystems. When rivers flood large quantities of materials and organisms are exchanged between the aquatic and terrestrial habitats.
— **Temporal**. Rivers are in constant change: in the short term, or on a seasonal basis, periods of rainfall and drought result in dramatic changes in river characteristics, floods disturb biological communities, but at the same time favour the migration of fish and trigger the reproduction of many organisms; in the longer term, river channels migrate laterally or vertically, as the river engineers its floodplain reaches or erodes its valley. Maintenance of this multiscale temporal variability is essential for river health.

Meyer (1997) adds a further relevant dimension: the **social** or **human context**. Rivers are affected directly or indirectly by multiple human activities, and effective river conservation cannot be based solely on the needs of wildlife. Instead, river conservation must take account of the needs and interests of people living along their banks and within the drainage basin.

Most of the early conservation efforts in rivers focused on flagship species of interest for the general public (e.g. salmon), whereas their habitats or ecosystems were neglected. This was problematic, since the decline of a species may be due to slow and or subtle degradation of habitat conditions, and not necessarily a result of over-exploitation or (in the case of migratory fishes such as salmon) dams blocking access to breeding sites. Furthermore, habitat degradation may affect ecosystem functioning, thereby indirectly impacting species of particular interest to humans. Thus, there is an inherent tension in conservation biology: species are the unit for conservation, but the need to provide conditions that allow a species to persist generally requires that conservation efforts focus also on ecosystem protection and/or restoration.

A fundamental question for scientists is how much biodiversity can be lost without seriously compromising natural processes? Although some general principles have emerged (Hooper et al. 2005), there is still much debate on the relationship between biodiversity and ecosystem functioning. The "conventional" view, also called the diversity-stability hypothesis, states that as we lose species, ecosystem function is affected proportionally. A second possibility (the redundancy or rivet hypothesis) is that loss of species has no effect on function until some critical threshold below which ecosystem functioning fails. A third possibility, called the idiosyncratic hypothesis, holds that there are no general rules, that functioning may be unaffected by the loss of certain species, but greatly impacted by the loss of others. According to this hypothesis some species would be more important than others. Amongst these (see Box 1.3) may

Box 1.3

All species are not equal

All species should be viewed as deserving the same level of protection. However, conservation biologists pay special attention to certain species because of their overall significance to the ecosystem as a whole:

Engineer species. Are species that modulate the availability of resources for other species, and so, change the environment creating new habitats. The best known riverine engineer is the beaver, whose dams convert fast-flowing reaches in ponds, flood riparian areas, etc. Other engineers are riparian trees, which create architecturally complex habitats and exert a profound influence on channel form.

Keystone species. Are species that have a disproportionate effect on biological communities, because of their size or activity. Many top predators are keystone species, since their effects on prey cascade down food chains, affecting the entire food web.

Sentinel species. Are species that, because of their sensitivity to changes, can give an early warning of oncoming problems. Thus, scientists can use them like the miners used canaries to detect the existence of toxic gases; typically, they are species with a very low tolerance to pollutants.

Umbrella species. Are species that have a large requirement for space, and therefore protecting them provides protection to many other species. This is the case of the Pacific salmon that helped protect the wood accrual and the river integrity in the Pacific Northwest. Some species may confer this overall protection because they attract public attention **(flagship species)**, as in the case of the platypus in Australia, or dolphins in many tropical rivers.

On the other hand, excessive proliferation of certain exotic **invasive species** is a major threat to biodiversity, as they can displace native species (by completion or predation) thereby tending to homogenize ecosystems throughout the world (Chapter 8).

Figure 1.5: *The Yangtze river dolphin was declared "functionally extinct" in December 2006 after extensive surveys along its home river had failed to yield any sightings. The dolphin has not been reported in the wild since then, and none remain in captivity*

be top predators, which, by feeding disproportionately on certain prey species affect assemblege structure, food webs and ultimately ecosystem functioning, or species that actively modify habitats, like the beaver, whose dams create ponds and reduce the downstream transport of material. A related point is that the magnitude of variability in ecosystem processes increases when species are lost and this tends to reduce the likelihood that multiple ecosystem functions can be sustained (Peter et al. 2011).

One thing is certain: the species cannot be conserved in nature unless we also maintain their habitats and the ecosystems within which they are embedded, plus the linkages between these ecosystems and their surroundings (Chapter 10). This is an especially complex challenge for river networks, which exhibit connectivity in multiple dimensions (lateral, vertical, longitudinal; see Box 1.2) that complicate management and conservation efforts. Therefore, protection of a given species, habitat or river segment cannot be focused on a single location, but needs to include upstream and downstream reaches, the riparian zone or floodplain, and even influences from the entire drainage basin and atmospheric inputs (e.g. nitrogen deposition). A basin-wide perspective for conservation and management is therefore essential (Chapter 12). Further, rivers are dynamic ecosystems, and this often conflicts with management that attempts to conserve rivers as they are now, or as they were in some moment of the past. Since change is an essential characteristic of healthy riverine ecosystems, then conservation and management plans must take account of this changeability and complexity. We know that this is challenging in human-dominated landscapes where the desire for stability or predictability of environmental conditions takes priority over the need to allow rivers to undergo (for example) seasonal flood-pulse cycles (Chapter 2).

1.4. The main threats to river conservation

Rivers offer prime examples of ecosystems threatened by multiple stressors (Figure 1.6), with the interactions between stressors being especially complex because of the hierarchical arrangement and complexity that characterize river systems (see Box 1.2). The effects may be synergistic, and are certain to be further amplified by changes in the global water system driven by climate change, with uncertain – but very likely detrimental – consequences for river ecosystem structure and functioning.

One of the main threats to river ecosystems are alterations of the hydrologic regime (Chapter 2), as they directly affect the availability of water, which is the essential environment for many riverine species and an important force shaping habitats both in the channel and on the floodplain. Rivers, originally characterised by flows that varied with the regional climate, are increasingly affected by either direct impacts such as damming and water abstraction, or indirect ones such as increase of impervious areas in their drainage basin. In most cases the

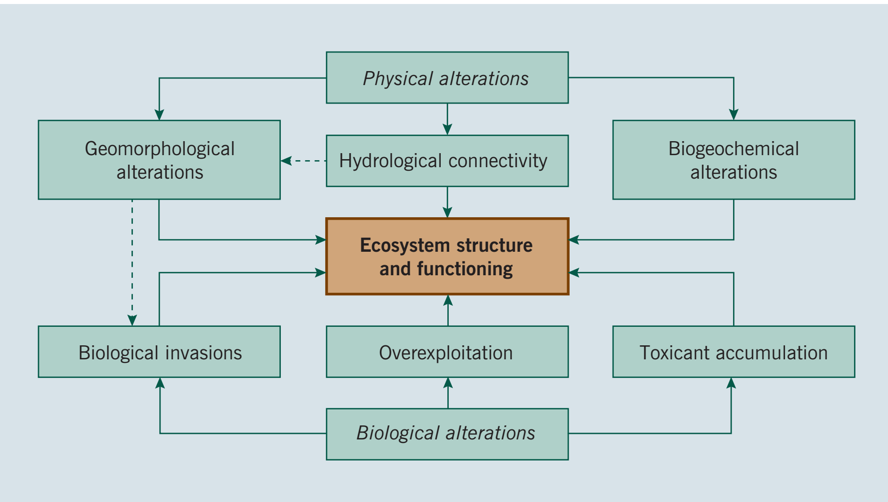


Figure 1.6:
Physical and biological alterations interact through complex feed-backs and affect the biodiversity and functioning of river ecosystems

frequency, timing and magnitude of floods and droughts are altered, which has detrimental consequences for organisms adapted through natural selection to the natural water regime. In some cases rivers, once wild and noisy, simply cease to flow for long periods, as a result of excessive water drawdown, or are reduced to concrete-lined channels or drains. Such "silenced" rivers are the paradigm of an impaired ecosystem.

Rivers are diverse and dynamic ecosystems but also are among the most endangered habitats in the world. Their degradation reduces biodiversity and ultimately affects human society

Humans have wrought profound changes upon the physical structure of river channels, impairing their life-supporting architecture for riverine communities (Chapter 3). Natural river channels are complex and dynamic, and many species are adapted to and depend upon these characteristics for survival. Even humans have relied on these features, as shown by the example of the ancient Egyptian civilization that depended on the flood cycle of the mighty Nile. Nevertheless, as the technological capacity of humans rose, increasing discomfort with the capricious flooding and wandering of rivers led to huge investments of effort to harness their powers, by damming, building levees, channelizing, or otherwise controlling channel form and mobility. Many rivers are today but a caricature of the complex and dynamic ecosystems they once were, and biodiversity and ecosystem functioning are consequently profoundly compromised.

Pollution is an epidemic and well understood threat to rivers. Sometimes pollution can be caused by natural, even essential substances, when they appear in too high concentrations. This is the case of nutrients, that can be a blessing or a curse, depending on the local conditions (Chapter 4). Nutrients are essential elements for primary producers such as algae and other plants, but when concentrations are too high they result in changes that can lead to fouling of water, lack of oxygen, and declines in biodiversity. Human activities are greatly increasing the amount of nutrients circulating worldwide across biogeochemical cycles, and thus, more and more nutrients tend to reach rivers. This can happen either through diffuse sources, such as atmospheric deposition of nitrogen or nutrients applied as agricultural fertilizers that run-off the land or percolate through the soil into rivers, or through point or end-of-pipe sources such as urban wastewater. Nutrients offer a clear example of the complex relationship between human actions and river health. Some pollutants are more insidious, as they are novel substances, synthesised by humans for various purposes, but which nevertheless end up in rivers. This is the case of pharmaceutical drugs, pesticides, and other substances with potentially-powerful biological effects, which are frequently detected together with their degradation products. These so-called emerging pollutants pose a large challenge to science and environmental management, as very little is known of their action mechanisms in the biota, of their mobility and accumulation in food webs, nor of their interactions in complex mixtures, as can often be found in rivers (Chapter 5). Depending on their chemical characteristics, many pollutants remain within water or are stored in the sediments. Others are more volatile, and thus distributed in the air, can "hop" across watersheds to areas far from where they were originally released. Viewed in this way the entire Earth functions as a huge distiller, with pollutants volatilizing in warm areas and being deposited in cooler localities. The high concentrations of pollutants detected in apparently pristine regions like the Arctic or high-mountain areas show the pervasive effect of human actions, and the need for global responses to the current threats.

As a result of these and other drivers including overexploitation, river biodiversity is declining even faster than its terrestrial or marine counterparts (Chapter 6). This places a profound responsibility on the current generation, since societal decisions taken in the next few decades will determine the long-term fate of riverine (and other) biodiversity, and the opportunities (or not) that future human generations will enjoy to appreciate, understand and benefit from that heritage. As species are being lost, serious concerns are raised about the effects of loss of biodiversity on ecosystem functioning – an important and developing field of current scientific research (Chapter 7). Biological invasions are also a cause for serious concern (Box 1.3; see also Chapter 8), as opportunistic exotic species are both promoted by environmental degradation and pose a major threat to native biodiversity. Indeed, the global spread and proliferation of native species may well result in the Anthropocene becoming known also as the Homogocene.

Rivers are threatened by changes in the amount and timing of water flow, changes in channel form, excess nutrients and pollution, and spread of invasive species

This list of threats to river ecosystems is by no means fully comprehensive. Moreover, global climate change, which may override or magnify, the impacts of some of them, will affect river ecosystems and humans alike. Human adaptation to climatic uncertainty will certainly lead to engineering responses that will further alter river systems globally since, as shown by Vörösmarty et al. (2010), enhanced human water security is generally accompanied by greater pressures upon river ecosystems.

1.5. What needs to be done? Elements for a debate

It is now clear that effective river conservation needs to take a landscape perspective, since rivers depend crucially on processes occurring in their riparian areas (Chapter 9) and on connectivity with the land and across the river network (Chapter 10). This was made clear almost 40 years ago in a seminal paper in which Noel Hynes (1975) stressed the close relationship between the stream and its valley. The relationship between the river and its drainage basin casts the spotlight away from the water alone to conservation of the surrounding land-

Box 1.4

Conservation, an ethical question

One of the current arguments to conserve rivers is that they provide **ecosystem services**: i.e. goods and other benefits that are important to society. These benefits decrease or can even disappear when river ecosystems are degraded. Assuming this is correct, it can be a powerful argument for conservation, especially if we are able to value these services in economic terms. Evidence that services produce economic benefits would provide a strong incentive for decision-makers and managers to implement effective conservation measures for river ecosystems. The relationship between nature conservation and ecosystem services is not straightforward, and matters such as inter-generational value (or inheritance value) of biodiversity may not be easily monetarised.

The question remains of whether we should value species or ecosystems only inasmuch as they benefit us humans directly. This is not a scientific question, but an ethical one, and scientists are no better equipped than anyone else to provide the right answer. Nonetheless, ethical questions are an important part of the human dimension of river conservation. Humans, by their very existence, modify the environment, and thus, a large human population will always have an impact on nature. We cannot avoid exploiting natural resources and transforming the landscape to some degree. The value of nature is not determined solely by the satisfaction it provides for human needs, since species and ecosystems that evolved through millennia cannot be defined purely in terms of their utility for a relatively recently-evolved sentient ape. Instead, these products of evolution have their own intrinsic value – in and of themselves.

This ethical issue can be put as follows: species have their own right to exist and, if that is the case (or even if it is not) humans have the obligation to pass on to our descendants an intact version of the diverse biosphere that we ourselves have been fortunate enough to enjoy. *Homo sapiens* is the only species on our planet capable of pondering and acting upon ethical concerns about the species with which we share both a planet and an evolutionary history, and it behoves us to act in a way that avoids driving them to extinction.

scape, this is by no means a simple matter. River ecosystems face many threats, as do many humans dependent on scarce, unpredictable and/or contaminated water sources. Pressures on rivers from burgeoning human populations, their need for drinking water, for water for agriculture and industry, are all growing, and the looming spectre of anthropogenic climate change adds uncertainty as to how pressure on water resources may change in the medium and longer term. We have already lost some significant components of freshwater biodiversity, but far more are in decline. Nonetheless, appropriate action now has the potential to make a large difference for future generations. This is a time for action: the present generation is likely the last with a chance to preserve a significant fraction of the biodiversity inherited from our ancestors and thereby bequeath it to our descendants.

Although species that have become extinct are gone forever, part of the damage done to freshwater ecosystems is potentially reversible (Chapter 11). Visible signs of this include the dramatic improvement of water quality in many European rivers (Tockner et al. 2009), and the growth of citizen stewardship related to river conservation in several countries (Chapter 13). Rivers are especially resilient ecosystems: pollutants tend to be diluted and washed downstream much faster than they disappear from soils, and river biota, shaped by natural selection in a highly variable environment, shows remarkable resilience and, so long as connectivity within rivers is maintained, rapid re-colonisation ability. Recovery of degraded rivers also requires alleviation of human stressors or pressures upon them, which demands both scientific understanding and, perhaps more importantly, political will.

One possible avenue for effective conservation is to increase efforts in river restoration. Ecosystem restoration is an activity devoted to recovering lost structure and functions, and thus, should not be confounded with "gardening" river margins in urban areas, as it often is. Instead, river restoration should focus on recovering the dynamic characteristics of rivers, characteristics that include the channel lateral mobility and the capacity to flood the floodplains, upon which many important ecological features and ecosystem functions depend (Chapter 11). But to what state should a river be restored? In some parts of the world the answer can be straightforward, but in regions such as Europe with an environment substantially modified by humans for centuries, the question is not trivial. Should we restore a river to its state 100 years ago? To the pre-industrial state? To its state in the Middle Ages? As we go further back in time, we have less precise information on the state of the river, and must face the possibility that land use transformation, the establishment of non-native or invasive species, and climate shifts may make it impossible to restore the river to its original state. In such circumstances, it may be more appropriate to aim at river rehabilitation: i.e. changing the condition of the river to an extent that some ecological functionality can be maintained and some enhancement of biodiversity brought about.

Irrespective of whether the goal is river restoration or rehabilitation, conservation and management practices must be integrated within a landscape framework. As mentioned above, river conditions are the product of activities within their drainage basins, and the solution to problems at one locality within the river network often lies some distance away within the catchment or upstream.

The landscape framework is necessary not only when addressing pollutants originating in the drainage basin. Rivers are non-linear ecosystems that form branched networks through which water and material are transported longitudinally. This architecture imposes special constraints upon the movement of aquatic animals, which has important implications for the long-term viability of populations. For instance, when any factor causes the loss of a given species in a particular reach, the population of this species can sometimes recover if there are upstream sources of colonists. Populations inhabiting other streams in the same network can also be a source of colonists, but only if there are no barriers (such as dams or waterfalls) to dispersal from the source to the receiving reach. Therefore, this type of barriers can produce far-reaching impacts by blocking animal migration. A broader perspective is needed when considering the loss of a species from an entire drainage since, in this case, recolonization will only occur by way of dispersal across a terrestrial landscape (possible for dragonflies, not so for fish) or by fully aquatic animals travelling along the coast between river mouths. This can only occur if the species concerned has tolerance for saline water. For species that can neither travel across land nor tolerate salt, there may be a case for human intervention to reintroduce native species to degraded rivers so as to facilitate restoration or rehabilitation efforts.

The present environmental crisis cannot be attributed to a lack of knowledge. Indeed, it could be argued that it is rather a product of a failure to apply the knowledge that already exists. Nevertheless, many scientific questions remain to be addressed. There is an urgent need to gain knowledge of the effects and fate of the many toxic compounds (pharmaceuticals, cosmetics, and a host of pesticides and other chemicals) that are being added to inland waters globally, so as to better understand their effects on humans and ecosystems (Chapter 5). We need better knowledge of the transport and fate of pollutants in the biosphere, of their bioaccumulation and of their interactions. We also need deeper understanding of biodiversity and its relationship to ecosystem functioning and the benefits enjoyed by humans since, at present, the function and ecological role of the vast majority of species remains unknown or uncertain (Chapter 6). This is particularly so for microorganisms. An entirely different challenge is posed by the need to enhance river restoration and rehabilitation efforts: we must define ways to restore the dynamism of fluvial channels, so as to provide the appropriate conditions to maintain biodiversity and ecosystem functioning, and to do so in a highly modified human-dominated landscape. Maintaining the spatiotemporal variability of river ecosystems (e.g. the annual flood cycle), to which the native biota are adapted, provides one of the best defences against the invasion by exotic or non-native species. It is also necessary to find ways of connecting populations of animals that have been fragmented by dams or by highly-altered river reaches. Environmental water

Box 1.5

Sustainable development; what is it?

Sustainable development is a widely-used term, but one that is often applied in very loose, even contrasting ways. **Sustainability** implies use of resources in a manner that does not restrict the opportunities of future generations to use them.

Sustainability can be seen as a three-legged stool with **social**, **economical** and **ecological** legs. The social leg is linked to the goals we desire as a society; the economic leg refers to the ways we devise to reach these goals; and the ecological leg concerns the limits imposed by nature. Each leg is essential to the stability of the stool; in particular, the stool will collapse if the ecological limits of the system are exceeded and that leg is no longer able to support the whole.

Management of fisheries offers a good example. Societies must decide the needs to be met when exploiting a fishery; this might include goals such as deriving the highest possible revenue in the long term, or combining fish production with conservation of leisure opportunities. To achieve this, resources must be used in an economically sound way, by investing money in renewing the fishing boats or establishing size limits. Whatever decisions are made, they must take account of the ecological context, the biological capacity of the fish population to be harvested. Many fisheries have been doomed as a result of political decisions (on economic or societal grounds) to exploit more than the sustainable limits proposed by scientists, or simple inaction and failure to introduce legislation to control overfishing. In the long term, of course, decisions that fly in the face of ecological reality are hardly likely to benefit societies or the fishery stocks they (over)exploit.

allocations (e-flows) for rivers must also be defined so as to meet the needs of intact ecosystems while, at the same time, satisfying human needs for water. This will be a major challenge in more arid regions (for example) where water that is allowed to flow to the sea may be regarded by human users as "wasted". Again, the need to achieve this balance highlights the necessity of gaining a better understanding of the relationship between biodiversity and ecosystem functioning.

Above all, it is essential to educate citizens and to demonstrate and convey the importance of freshwater biodiversity to ecosystem functioning as well as the need to protect both that diversity and the benefits accruing to humans. Arguably, awareness is the key thing for society; once we become aware, then we will force governments to proceed with conservation action and embed such action in appropriate policies. To date, however, it seems that public perception of the importance of freshwater biodiversity, and the need to protect it, falls far short of what conservation biologists wish for, and fuller engagement of the scientific community will be needed to translate our good intentions into the necessary action by public stakeholder groups. In the future, our generation will be judged, not by how we tackled the financial crisis, nor by the beauty of our architecture, but by the biological heritage we leave, and especially by the state of the environment. Success in that regard will require an innovative combination of scientific knowledge, political conscience and economic perspicacity with societal willingness. We must hope it is not too late to bring this about.

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