



Major River Basins of the World

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Abstract

River basins are the hydrological units of the planet and as such play a critical role in the natural functioning of the Earth. While there have been advances in mapping river basins to facilitate analyses and inform basin management, information on river flow volumes, condition of freshwater habitats and species, as well as the degree of impact on rivers and freshwater biodiversity are still lacking for many parts of the world. This lack of information and, mostly a lack of appreciation for the intrinsic value and role that rivers and wetlands play in the well-being of millions of people, makes their conservation and sustainable management challenging in the face of development pressures and climate change. This chapter

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summarizes current status and trends in freshwater biodiversity, identifies threats to aquatic ecosystems, provides information of the ecosystem value of wetlands, and makes the case for an improved, and more integrated management and conservation of wetlands.

Keywords

River basins · Freshwater · Spatial data · Biodiversity · Ecosystem services · Values · Threats · Protection · Conservation

Introduction

River basins are the hydrological units of the planet and as such play a critical role in the natural functioning of the Earth; they are highly dynamic systems linked by topography, geology, and climate. The constant flow of water from rain and snow and ice melt over the continents has formed and reshaped the landscape for millennia – steep mountains are cut by fast cascading streams, major floodplain rivers wear away the continents carrying nourishing sediments that shape and replenish the coastal zone, and surface water percolates through permeable portions of the earth's surface to create systems of caves and tunnels where water collects and forms underground aquatic habitats.

Each river basin encompasses the entire area drained by a major river system or by one of its tributaries, and both the landscape and the river network that runs through it give each basin its unique characteristics. No two river basins are exactly the same, nor is a single river the same throughout the year, each is characterized by a unique combination of geographical location, climate, basin connectivity and the timing, volume, and duration of flow. Many riverine species are adapted to, and synchronized with, specific river flow patterns, such as spring peak floods or summer low flows. These patterns cue species to reproduce, disperse, migrate, feed, and hide from predators, and alterations to them can disrupt animal and plant life cycles and ecological processes with consequences for both people and nature.

While the majority of the world's rivers drain into the ocean or into another river, there are exceptions. These exceptions are known as endorheic or closed basins; some of the largest inland seas and wetlands in the world like the Caspian Sea or the Okavango Delta are closed basins. Rain that falls onto the endorheic basin flows downstream to form seasonal wetlands where water evaporates or seeps into the ground like in the Okavango Delta or forms a lake or inland water body like in the case of the Caspian Sea.

Proximity to water bodies has been a preference for the establishment of human settlements for millennia. Society has used rivers for transport and navigation, water supply, waste disposal, and as a source of food, and as a consequence we have heavily altered waterways putting the ecological functioning and the biodiversity of freshwater ecosystems at risk. Given the importance of freshwater ecosystems in sustaining human well-being, it is surprising how little we know about their

changing condition, their dependent species, or the roles that these species play in sustaining ecological functions within river basins.

Defining and Mapping River Basins

River basins can be categorized in different ways, from basin size and flow volume to climatic conditions and political or administrative boundaries. This last category is often used in the field of water resources management, as managing river basins that cross international boundaries requires a high degree of international cooperation. There are 263 river basins that are shared between two or more countries; 40% of the world's population lives in one of these transboundary river basins, which collectively drain over 45% of the world's land surface (UN Water 2009; TFDD 2012). The river basin with the highest number of riparian nations is the Danube, which runs through eighteen countries. Other major transboundary river basins with eight or more riparian nations include: the Amazon, Congo, Niger, Nile, Lake Chad, Rhine, and Zambezi (TFDD 2012).

Other ways of categorizing river basins, such as basin size, flow volume, mean annual discharge, or other physical metrics, require delineations of catchments and river networks on a consistent basis for the globe. Tabular inventories of major river systems usually including data on drainage area, river length, and discharge are available, but they do not allow for spatial analyses or overlays with existing geospatial data layers such as land cover, population, or climatic zones. It also makes global and even regional analyses and comparisons extremely biased given that only the largest rivers tend to be represented in these tabular inventories. Many of these tabular inventories also suffer from out-of-date information, differences in definitions of the extent of a river system, as well as differences in the time period or location for the measurement of discharge (Revenga and Kura 2003).

Spatial databases with point, vector, and polygon data depicting surface water bodies and related information also exist, usually in the form of gazetteers, such as the Digital Chart of the World (DCW) (ESRI 1993). The great advantage of these databases is they allow for geospatial analysis and the integration of other data layers such as population, road infrastructure or land use. The disadvantage is that many of these databases tend to be of coarse resolution. The Digital Chart of the World, one of the first comprehensive database of this type developed in the 1990s, for example, includes a layer of rivers and lakes at 1:1 million resolution derived from the United States Defense Mapping Agencies' (now the National Geospatial-Intelligence Agency) Operational Navigation Charts whose information dates from the 1970s to the 1990s (Birkett and Mason 1995). While the DCW is considered consistent across the globe, its positional accuracy varies considerably between regions, and the database does not distinguish between natural rivers and artificial canals; the DCW has not been updated since 1992.

HYDRO 1K is another frequently used spatial hydrographic data set at one-kilometre resolution. Developed by the United States Geological Survey's

Eros Data Center (USGS 2000), it used to be the most comprehensive global database delineating basin boundaries. HYDRO 1 K, however, also has considerably inaccuracies with the location of actual river networks and most of the basins are not named, which makes some analyses difficult. Since 2013, HydroBASINS has become the most consistent and comprehensive global database in use for river basin analysis. Derived from HydroSHEDS a high-resolution elevation data obtained during a Space Shuttle flight for NASA's Shuttle Radar Topography Mission (SRTM), HydroSHEDS, which stands for Hydrological data and maps based on SHuttle Elevation Derivatives at multiple Scales, contains geo-referenced data on stream networks, watershed boundaries, drainage directions, and ancillary data layers such as flow accumulation, distances, and river topology information (<http://hydrosheds.org>) HydroBASINS (Lehner and Grill 2013) for the first time allows us to perform basic analyses, like calculating how many basins of each size there are in the world or deriving the upstream catchment of any point in a hydrologic network. When coupled with flow data, these global spatial drainage maps have additional applications, like the potential to generate stream hydrographs or classification of rivers by flow volume. Both modeled and observed discharge data for the world's rivers can be used in combination with these global drainage maps, and while observed data is preferable it is not always available on a consistent basis at global or even regional scales.

The World Meteorological Organization's Global Runoff Data Centre (GRDC) compiles and maintains a database of observed river discharge data from gauging stations worldwide. Coverage and reliability of hydrological information obtained through measurements in the GRDC varies from country to country, and although this is the best global database currently available, the number of operating stations has significantly declined in some regions since the 1980s – meaning the discharge data for some rivers have not been updated in decades (Revenga and Kura 2003). Modeled flow and discharge data are available from different rainfall-runoff models of varying complexity; many are derived for a single river basin and when possible calibrated with observed flow data; global models rely on flow calculations generated with input data from Global Climate Models.

Better and more reliable information on actual stream and river discharge, and the amount of water withdrawn and consumed at river basin scale, would increase our ability to manage freshwater resources more efficiently and set conservation measures for ecosystems and species. However, much effort and financial commitment would have to be made to restore hydrological stations and collect this type of information on a consistent basis.

The Biodiversity of Major River Basins

Freshwater ecosystems have a higher concentration of species relative to their area than terrestrial or marine biomes. Wetland ecosystems such as lakes, streams, rivers, and marshes occupy just 0.8% of the Earth's surface but support 6% of all described species, including 35% of all vertebrates (Dudgeon et al. 2006). More than 15,700

of the world's fish species, representing a quarter of all living vertebrates, live in fresh waters (Carrizo et al. 2013), with new species described each year. Between 1992 and 2011, an average of 333 new fish species, both marine and freshwater, were described each year (Eschmeyer and Fong 2012). Information on all fish species, including fresh and marine species, is available in The Catalogue of Fishes, a regularly updated searchable database (Eschmeyer et al. 2016). This is the most comprehensive database maintained since the 1980s where all freshwater fish species described are listed.

While information on freshwater fish is more accessible and available, we still lack species information for many parts of the world, particularly for the tropics and especially for invertebrates, microbes, and aquatic plants. However, available data do provide a picture of species richness patterns across the world's river basins. Large basins with high discharge volumes tend to have more fish species, and as in the terrestrial and marine realms, tropical systems tend to have higher levels of species richness. River basins with the highest levels of fish species richness include the Amazon, Orinoco, Tocantins, and the Paraná in South America; the Congo, the Niger Delta, and the Ogooue in Africa; and the Yangtze, Pearl, Brahmaputra, Ganges, Mekong, Chao Phraya, Sittang, and Irrawaddy in Asia. Lake basins with the highest levels of fish richness and endemism include the great lakes of Africa's Rift Valley: Malawi, Tanganyika, and Victoria. Smaller river basins that are also relatively high in fish species include systems in the Southeast of the United States like the Tennessee, Mobile, and Alabama Rivers as well as Sanaga, Nyong, Ntem, and Benito rivers draining into the Gulf of Guinea in West Africa, the Kapuas River basin in Borneo, and small coastal basins of the Eastern Malay Peninsula, Eastern Central Sumatra, Western India, and Japan (FEOW 2008).

Species richness patterns for other taxonomic groups follow a similar pattern than that for freshwater fish; amphibian richness is consistently high in tropical Asian and South American river basins and in most of the tropical basins in Africa, including coastal basins in Madagascar (FEOW 2008). Australia's eastern coastal drainages and the Murray-Darling basin also have high numbers of amphibians. Freshwater turtles, which comprise more than 240 species, are most concentrated in warm and humid climates, but a few basins have particularly high species numbers including the Apalachicola, Mobile, and lower Mississippi Rivers in Southeastern United States and the Sittang and Irrawaddy Rivers in Southeast Asia (FEOW 2008). Freshwater dependent bird species are also predominantly present in tropical basins; river catchments with more than 125 freshwater-dependent bird species include those with important large permanent wetlands: the lower Paraná River in South America, the Lake Victoria and Upper Nile sub-basin in Africa and the Ganges, Sittang, Salween, Chao Phraya, and the Song Hong (Red) River in Asia (Hoekstra et al. 2010). Finally freshwater dependent mammal richness is concentrated in the Amazon, Magdalena, and Paraguay-Paraná basins, much of the western and central Africa river basins, Lake Victoria, and the upper Nile (Hoekstra et al. 2010).

No other major global habitat type or group of species has demonstrated such large and rapid declines. More than 50% of wetlands, from coastal marshes to peatlands, in North America, Europe, Australia, and New Zealand were drained or

Table 1 Number and percentage of assessed freshwater fish species under each Red List Category

Red List category	No. of species	% of assessed species
<i>Extinct (EX)</i>	66	1.1
<i>Extinct in the Wild (EW)</i>	8	0.1
<i>Critically Endangered (CR)</i>	422	6.9
<i>Endangered (EN)</i>	474	7.7
<i>Vulnerable (VU)</i>	914	14.9
<i>Near Threatened (NT)</i>	280	4.6
<i>Least Concern (LC)</i>	2,881	47.0
<i>Data Deficient (DD)</i>	1,083	17.7
Total	6,128	100.0

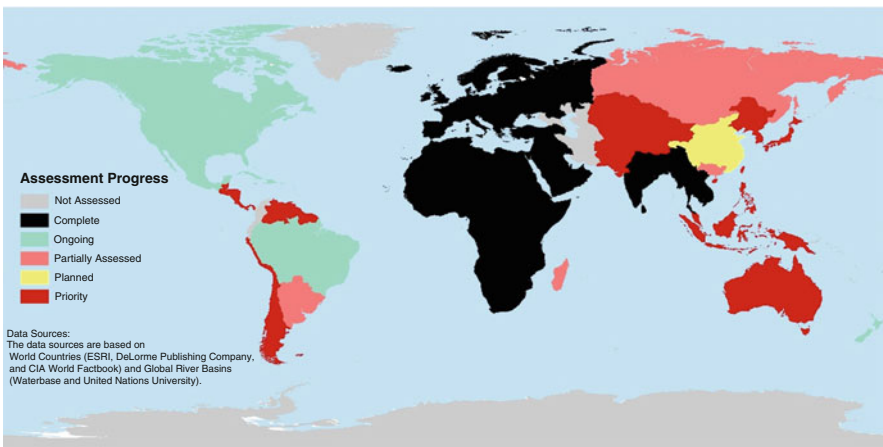


Fig. 1 IUCN Red List Assessment Progress for Freshwater Fishes. Redrawn from Carrizo et al. (2013) with updates from Smith et al. (2014), Garcia et al. (2015) and future assessment priority areas (see: <http://www.iucn.org/theme/species/our-work-ssc/our-work/freshwater-biodiversity/river-bank> [Accessed: 26 June 2016])

converted to other uses such as agriculture and urban development during the twentieth century (MA 2005), and while we do not have comprehensive data for other parts of the world many tropical and subtropical wetlands, particularly mangrove, swamp forests, and large-river floodplains, have been degraded or completely lost.

In terms of species, approximately one in three of all freshwater species are threatened with extinction, a higher degree of risk than for terrestrial species, and this risk is generalized across all regions of the world (Collen et al. 2014; IUCN 2015). While not all freshwater fish species have been evaluated for threat under the IUCN Red List, since 2002, there has been considerable progress with 6,128 species – or 39% – of species (Table 1) assessed by region (Fig. 1) (Carrizo et al. 2013; Smith et al. 2014; Garcia et al. 2015). These regional assessments suggest that

freshwater fish are not faring any better than other taxonomic groups. In Europe 200 out of 522 species of freshwater fish (Kottelat and Freyhof 2007) and one in four in East Africa had joined the Red List (Darwall et al. 2005), and 54% of Madagascar's native freshwater fish species are threatened (Darwall et al. 2005). In total of the 27 completely assessed families of fishes, 11 families have more than 50% of their species categorized as threatened, including eight families with threat levels affecting 84–100% of their species; among this imperiled group are paddlefishes, river loaches, Valencia toothcarps, sawfishes, rainbow fishes, and sturgeons (Carrizo et al. 2013). Freshwater turtles, in particular, seem to be at an even higher risk than other taxonomic groups, with nearly half of the species classified as threatened with extinction, primarily due to hunting for food and traditional Chinese medicine and for the pet trade (Turtle Conservation Coalition et al. 2011; Collen et al. 2014). Among the most threatened are freshwater cetaceans, such as the Yangtze River dolphin *Lipotes vexillifer* which is now considered to be functionally extinct (Allen et al. 2012). Overall, the top three threats driving these numbers are habitat loss and degradation, water pollution, and exploitation (Collen et al. 2014); habitat loss and degradation, in particular, effects more than 80% of species (Collen et al. 2014). Despite the fundamental ecological and economic importance to humans, freshwater ecosystems have not been of primary concern in conservation, planning, or policy-making.

Ecosystem Services and the Role that River Basins Play in Human Well-being

In addition to providing habitat for freshwater species, wetlands deliver a wide range of ecosystem services that contribute to human well-being, such as fish and fiber, water supply, sediment retention, water purification, climate and flood regulation, energy generation, coastal protection, tourism, and recreational and cultural opportunities. While we all depend on freshwater systems in one form or another, an estimated 1.5–3 billion people depend on groundwater, often recharged through wetlands, for their drinking water (MA 2005).

The consumption of safe water for personal use, such as drinking or hygiene, is a primary development goal, and despite having met it at the global level with over two billion more people having gained access to improved drinking water sources since 1990, challenges remain for an estimated 663 million people who still lack access to safe drinking water (WHO and UNICEF 2015). In addition, 2.4 billion people still lack access to a toilet and nearly 80% of the world's population is at risk of suffering from water stress (Vorosmarty et al. 2010; WHO and UNICEF 2015). While developed nations can offset the risk of water stress through investment in water technology, poor nations are not able to do so putting more people at risk of water shortages.

River basins provide water and nutrients for agricultural activities, and therefore are key to maintaining our food security. To produce enough food to satisfy a person's daily dietary needs takes about 3,000 l of water – about one litre per

calorie – while only about two to five liters are required for drinking. Predictions indicate that, in the future, more people will require more water for food, livestock, and fish. Globally, 70% of water withdrawals are used for irrigation, even though in some regions like Asia and the Middle East and North Africa this percentage is closer to 80% (WWAP 2009). In comparison, industrial use (including energy production) and domestic water withdrawal are 20% and 10%, respectively (WWAP 2009). Globally, about 82% of cropland relies on rainwater, and only about 18% of cropland is irrigated; however, this small percentage produces 40% of the agriculture production (Darghouth et al. 2008). Asia has the largest irrigated area (70% of the global), mostly in China and India (Comprehensive Assessment of Water Management in Agriculture 2007).

The world's rivers and lakes support globally important inland fisheries, providing 33% of the world's fish catch and employing over 60 million people, of whom over half are women (UNEP 2010). The consumption of fish from inland waters is especially important for human nutrition in Asia and parts of Africa (UNEP 2010). Over one fifth of Africa's population regularly consumes fish, and nearly half of this comes from inland waters. China, Bangladesh, India, and Myanmar are the top inland fish producing nations (UNEP 2010). Specific river basins, like the Mekong, are particularly important; the Tonle Sap in the lower Mekong supports 40 million rural farmers who are also engaged in fishing at least seasonally (Sverdrup-Jensen 2002) and produces 2.1 million metric tons of wild fish with a retail value of between US\$4.2 and US\$7.6 billion in retail markets (Hortle 2009). Lake Victoria Basin in Africa is another example; the basin produces more than one million metric tons of fish annually (Balirwa 2007) with an annual export value of exceeded US\$300 million in 2007 for Nile Perch alone (LVFO 2008). As the human population continues to grow, the demand for fish both from capture fisheries and aquaculture will increase putting further pressure on freshwater ecosystems.

Water provision is a key ecosystem service and underpins numerous energy production options. Since traditional biomass energy is relatively inexpensive and more accessible than other energy sources, it plays a vital role in supporting economically poor populations, and if threatened, can greatly exacerbate poverty. Therefore, the proper functioning of freshwater ecosystems is vital. In addition to supporting biomass production and its use in hydropower installations, water is also used in oil and gas production and for cooling in electricity generation. In this manner, even industrial regions and wealthy populations are not immune to the effects of ecosystem deterioration on energy services, with the degradation of ecosystem services leading to a loss of capital assets (Williamson and McCormick 2008).

The indirect benefits derived from wetlands are equally valuable to humans, despite challenges in quantifying such contributions in monetary value. For instance, flood attenuation through wetlands and floodplains has been shown to be more cost-effective than building levies or paying to repair any damage caused. Since Hurricanes Katrina and Rita in 2005, the State of Louisiana in the United States has assigned 37% of revenues from new oil and gas projects to coastal protection and restoration, following research which suggests that an investment of US\$10–15 billion in restoring the Mississippi Delta could generate the equivalent of US\$62

billion by avoiding losses from storm damage and reduced ecosystem functions while gaining additional ecological benefits (Batker et al. 2010).

Wetlands play an important role in purifying water by filtering out and storing pollutants in their sediments, soils, and vegetation, and the natural ability of wetland systems to filter water has been used to treat wastewater from industry and mining as well as sewage. For instance, some floating plants, such as water hyacinth *Eichhornia crassipes*, can absorb heavy metals such as iron and copper. At least one third of the sewage from the city of Kolkata, India – which has a population of ten million people – is effectively treated by the East Kolkata marshes. The economic value of the purification function of wetlands can be huge (Ramsar Convention Secretariat 2010). In 1997, New York City found that it could avoid spending US\$3–8 billion on new wastewater treatment plants, plus an additional US\$700 million in annual operating costs, by investing US\$1.5 billion in land purchase and conservation management measures to protect wetlands in the watershed to achieve the same outcome (Ramsar Convention Secretariat 2010).

Physical and economic water scarcity and limited or reduced access to water are major challenges facing society and are key factors limiting economic development in many countries. Many water resource developments undertaken to increase access to water have not given adequate consideration to harmful trade-offs with other services provided by wetlands. The projected continued loss and degradation of wetlands will reduce the capacity of wetlands to mitigate impacts and result in further reduction in human well-being especially for poorer people in lower-income countries, where technological solutions are not as readily available. At the same time, demand for many of these services will increase.

Threats to Major Rivers

River basins are subject to impacts from land-based activities occurring in the catchments as well as direct modifications to river reaches and flow regimes in the river network. Because of our dependence on freshwater, proximity to water bodies has been a preference for the establishment of human settlements for millennia. As a consequence we have heavily altered waterways to fit our needs by building dams, levies, canals, and water transfers. Loss and degradation of habitats, physical alteration, water withdrawals, overharvesting, pollution, and the introduction of nonnative species have all increased in scale and impact in the last century.

Of the many ways in which humans alter rivers, dams are probably the most widespread and significant in their impact. Today, the world's rivers are dotted with more than 50,000 large dams (Berga et al. 2006). Dams provide unquestionable benefits – from water supply to power generation – but they disrupt the hydrological cycle profoundly, suppressing natural flood cycles, disconnecting rivers from their floodplains, disrupting fish migrations, changing the temperature and velocity of in-stream flow, altering the deposition of sediments and essential nutrients to estuaries downstream, and flooding critical feeding and breeding habitats for many aquatic and terrestrial species. A 2005 analysis (Nilsson et al. 2005) that looked at

292 of the largest river systems in the world found that more than 60% of them were either strongly or moderately affected by dams. In addition, the livelihoods of populations living downstream of dams may be affected by dam-induced alterations of river flows through disruption of natural riverine production systems – especially fisheries, flood-recession agriculture, and dry-season grazing (Richter et al. 2010).

Another major impact that humans have on rivers is the amount of water we withdraw from them for human uses. By 2025, at least 3.5 billion people are projected to live in water-stressed river basins (Revenga et al. 2000). This per capita water supply calculation, however, does not take into account the coping capabilities of different countries to deal with water shortages. For example, high-income countries may be able to cope to some degree with water shortages by investing in desalination or reclaimed wastewater. Nearly three billion additional urban dwellers are forecast by 2050. While cities struggle to provide water to these new residents, they will also face equally unprecedented hydrologic changes due to global climate change. Currently, 150 million people live in cities with perennial water shortage, defined as having less than 100 l per person per day of sustainable surface and groundwater flow within their urban extent (McDonald et al. 2011). By 2050, demographic growth will increase this figure to almost one billion people, and climate change could increase water shortages for an additional 100 million urbanites (McDonald et al. 2011). Freshwater ecosystems in river basins with large urban populations and with insufficient water will likely struggle to maintain sufficient river flows to ecological processes (McDonald et al. 2011).

Overexploitation of resources is also a key driver in species extinction, although for some fisheries in particular the overexploitation took place decades ago, and new introduced nonnative fisheries and stocking programs have replaced the once plentiful wild and native fish populations and masked their decline. There is ample evidence of overfishing in once valuable and iconic fisheries – from salmon stocks in the Pacific Northwest of the United States to the Murray cod *Maccullochella peelii* in Australia's Murray-Darling basin and the sturgeons of the Caspian Sea. Overfishing has been a significant factor in the decline of the European eel *Anguilla anguilla* fishery, which used to employ 25,000 fishermen; eel stocks have steadily declined over the last 30 years with figures showing the number of new eel juveniles entering European rivers down to 1–5% of former levels and showing no sign of recovery even after eel stocking programs have been in place for years (ICES 2011). Even fisheries from relatively less altered rivers such as the Mekong in Southeast Asia have rapidly declined in the last decade; the Mekong giant catfish *Pangasianodon gigas* is considered critically endangered (Hogan 2013). Overexploitation is also the leading cause in the imperilment of other species, such as turtles. Recent assessments indicate that of the 263 species of freshwater and terrestrial turtles 45% are threatened, and one has already gone extinct (Turtle Conservation Coalition et al. 2011) mostly driving by overexploitation for the food and for use in traditional medicine and to a lesser degree by the pet trade; Asian and Malagasy species are at the highest risk (Turtle Conservation Coalition et al. 2011).

The intentional or accidental introduction of nonnative species is also a leading cause of species extinction in freshwater systems. Exotic species affect native fauna through predation, competition, disruption of food webs, and the introduction of diseases. The spread of exotic species is a global phenomenon, especially with increasing aquaculture, shipping, and global commerce. Worldwide, two thirds of the freshwater species introduced into the tropics and more than 50% of those introduced to temperate regions have become established (Welcomme 1988). Many introductions are usually done to enhance food production and recreational fisheries. But these introductions in most cases have hastened the decline of native fish. In Africa's Lake Victoria, for example, the introduction of Nile perch into the lake and its increase in abundance in the 1980s led to the disappearance of more than 100 of the native haplochromine cichlid fish species (Witte et al. 1992).

Finally, the IPCC 5th Assessment Report (Jiménez Cisneros et al. 2014) provides abundant evidence that freshwater systems will likely be strongly impacted by climate change and that the expected changes to water quantity and quality resulting from increased temperatures and altered rainfall patterns will significantly affect food production and availability, increasing the vulnerability of the rural poor particularly in arid and semiarid areas of the developing world. Key direct implications of warming temperatures and melting snowpack and glaciers are warmer waters, greater runoff during a shortened melt season, and longer low-flow seasons. The threats to biodiversity emerge as phenological disturbances, habitat loss, harmful temperatures, water chemistry changes, and more (Poff et al. 2002). Many freshwater animal and plant species rely on specific melting events to cue behaviors such as migration, spawning, and seed release. For instance, a fish species may require long winter seasons to allow its young to mature before the rush of spring floods. If those floods come too early, the young will be washed away by the intense flood currents and be more susceptible to predation. While cold-water dependent species such as native salmonids are projected to disappear from large portions of their current geographic range (Poff et al. 2002), as warming causes water temperature to exceed their thermal tolerance limits; behavioral or life-history adaptations may allow other species, particularly warm-water species, to persist in altered meltwater flow regimes and temperatures, and some (e.g., carp, bass) may even expand their range (Poff et al. 2002). Unlike terrestrial species and even aquatic insects with aerial or wind-dispersed life stages, freshwater species are limited in their ability to move or shift their ranges to other suitable habitats as hydrological regimes change, as most are confined to individual basins and generally unable to move from one unconnected catchment to another. This migratory adaptive behavior is even more challenging today, as we have excelled at building dams and other infrastructure, altering potential migratory river corridors that may have otherwise allowed species to relocate and adapt. Climate change will also affect how we manage and operate existing water infrastructure. And a conclusion by the IPCC 5th Assessment Report Working Group II suggests that current practices are not robust enough and that because of the cross-cutting nature of water management, many other policy arenas will be impacted, from energy production to food and water security (IPCC 2014).

Protection of Rivers and Other Aquatic Habitats

Despite the values and degree of imperilment of freshwater ecosystems, protection and conservation of inland waters has come at a slow pace, especially when compared to the protection of terrestrial and more recently marine ecosystems. For decades protected areas have been a key conservation strategy for terrestrial and marine habitats, but for inland aquatic habitats, such as rivers, lakes, marshes, and groundwater aquifers, this has not been the case. The traditional approach of fencing off an area for its protection and management is not only unlikely but impractical when it comes to protecting linear aquatic habitats such as rivers. Many terrestrial protected areas award only partial protection to aquatic habitats and important issues such as longitudinal and lateral connectivity and maintenance of essential hydrological processes (i.e., environmental flows) are not considered. Moreover, it is not uncommon to find that rivers have been used for the sole purpose of demarcating a terrestrial protected area boundary, instead of integrating them into the protected area's conservation and management objectives. A review by Abell et al. (2007) points out that many freshwater habitats and species have not benefited as much from terrestrial protected areas largely because they have not been designed or managed for aquatic ecosystems and are especially vulnerable to pressures occurring outside the protected area.

The only clear exception is the protection of aquatic habitats with a defined surface area, such as lakes, lagoons, marshes, and other wetlands. Under the Convention on Wetlands, also known as the Ramsar Convention – so named for the city in Iran where it was signed, signatory countries have protected 2,231 coastal and inland wetlands with a total surface area of nearly 215 million hectares (www.ramsar.org; Accessed: 16 March 2016). For surface water bodies, thus, establishing protected areas continues to be a customary conservation approach; but to be effective, their design and management has to also include protection, or at a minimum, sound management of important features and processes that are essential to sustaining the wetlands being protected. These key features include rivers or groundwater aquifers that feed into the particular lake or wetland but are often located outside the protected area boundary.

Protecting linear features like rivers and streams by means of a protected area is not always feasible. Only a hand full of countries including the United States, Canada, Australia, and New Zealand currently afford certain protections to entire rivers or portions of rivers. The United States and Canadian systems, where the concept of “wild river” originated, have been the model followed by other countries in establishing river protection frameworks. Undoubtedly, rivers, particularly the middle reaches and floodplains, are underrepresented in the global protected areas network, but figures showing exactly how underrepresented they are have been hard to come by. A key limitation has been the lack of inventory and assessment of freshwater ecosystems and their condition, even at national level; a limitation that has hindered the tracking of progress of individual countries towards their commitments under the Convention on Biological Diversity (CBD). The Parties to the CBD in 2004 agreed to “establish and maintain comprehensive, adequate and representative systems of protected inland water ecosystems within the framework of

integrated catchment/watershed/river-basin management” (decision VII/4, CBD Conference of the Parties 2004). One of the key targets of the CBD’s 2011–2020 Strategic Plan for Biodiversity developed in 2010 is to effectively conserve at least 17% of each of the world’s ecological regions by 2020 for terrestrial and inland water ecosystems and 10% for marine and coastal areas.

The assumption that terrestrial protected areas protect the freshwater ecosystems that lie within them remains ingrained in the thinking and approach of most nations. Until recently there was no global spatially explicit database of river networks at enough resolution to allow for a detailed estimation of how much protection – at least in terms of coverage – terrestrial protected areas convey to waterways. In 2010, however, WWF in collaboration with McGill University and UNEP-WCMC released an assessment of the extent of coverage of rivers by protected areas by calculating both the length of rivers that lie within protected areas and the length of rivers that have their entire upstream catchments under protection (WWF 2010). The WWF analysis shows that 69% of the world’s rivers are without protected areas in their upstream catchment and that smaller headwater streams are more protected at catchment level than are larger rivers. The analysis therefore points to opportunities to increase the representation of freshwater ecosystems in the global protected area network. The analysis also shows important regional differences. Central and South America lead the way in river protection, both at river length within protected areas and upstream catchment levels. Asia, North America, and Europe/Middle East have fewer river miles and upstream catchment areas protected (WWF 2010). While this first estimate of river coverage does not assess if protected areas are indeed protecting freshwater processes and species, it does provide a sense of how many lotic ecosystems could be protected if management of the existing protected area network were tailored to address freshwaters.

Protected areas can and do work for freshwaters, but the way we design and manage them is essential. Protecting freshwater ecosystems requires new approaches that incorporate the connectivity of freshwater systems and their key processes, such as spring peak flows that cue aquatic species to migrate, reproduce, feed, etc. Many of these approaches already exist but are usually not considered within a protected area framework. Zoning rules, such as establishing riparian buffers to control runoff, bank erosion, and provide shade, are in effect in many basins but are not per se protected areas. Water recharge areas or fishing reserves are other examples of protection that contribute to the conservation of freshwater habitats. Protected area design needs to start including these approaches and protected area management needs to start looking beyond the terrestrial park boundary if we are to reduce the rate of loss of freshwater species and the habitats upon which they depend.

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