# Chapter 17
# Sustaining Freshwater Biodiversity in the Anthropocene

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**Abstract** Globally, fresh water is a limited resource, covering only about 0.8 % of the world's surface area. With over 126,000 species living in its ecosystems, freshwater harbours a disproportionate share of the planet's biodiversity; it is essential for life, and central to satisfying human development needs. However, as we enter the Anthropocene, multiple threats are affecting freshwater systems at a global scale. The combined challenges of an increasing need for water from a growing and wealthier human population, and the uncertainty of how to adapt to definite but unpredictable climate change, significantly add to this stress. It is imperative that landscape managers and policy-makers think carefully about strategic adaptive management of freshwater systems in order to both effectively conserve natural ecosystems, and the plants and animals that live within, and continue to supply human populations with the freshwater benefits they need. Maintaining freshwater biodiversity is necessary to ensure the functioning of

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freshwater ecosystems and thereby secure the benefits they can provide for people. Thus freshwater biodiversity is also an important element of viable economic alternatives for the sustainable use of the freshwater ecosystems natural capital. In order to achieve this we need to do a better job at monitoring our freshwater biodiversity, understanding how the ecosystems function, and evaluating what that means in terms of service delivery.

## The Global Freshwater Crisis

Fresh water is essential for life, and thus its provision for agriculture, sanitation, and domestic use is central to meeting many of the Millennium Development Goals and the more-recently proposed sustainable development goals (Griggs et al. 2013; Pahl-Wostl et al. 2013a). However, from a global perspective it is an absolutely limited resource, representing no more than 0.008 % of the volume of water on Earth and covering only about 0.8 % of the global surface area (Mittermeier et al. 2010; see Fig. 17.1).

Fresh water is also a highly threatened resource. A characteristic of the Anthropocene world is a 'pandemic array' of human transformations of the global water cycle (Alcamo et al. 2008), including changes in physical, biogeochemical and biological processes. Water scarcity and quality degradation already impact more than 2.5 billion people on Earth, and by 2030 human demand for water is expected to exceed reliable freshwater supply by 40 % (Addams et al. 2009). There is, and will be, every attempt to close this water gap in order to support

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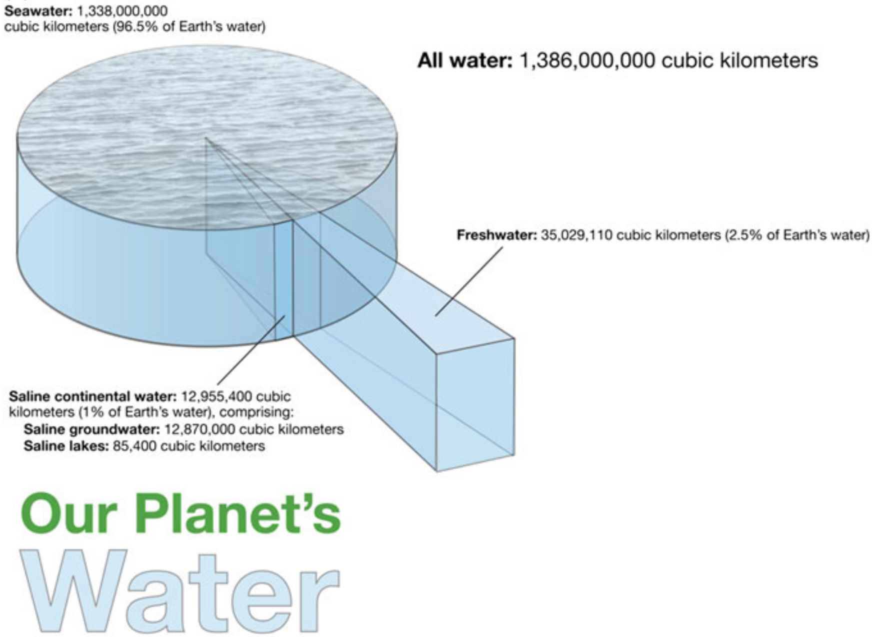
(a)

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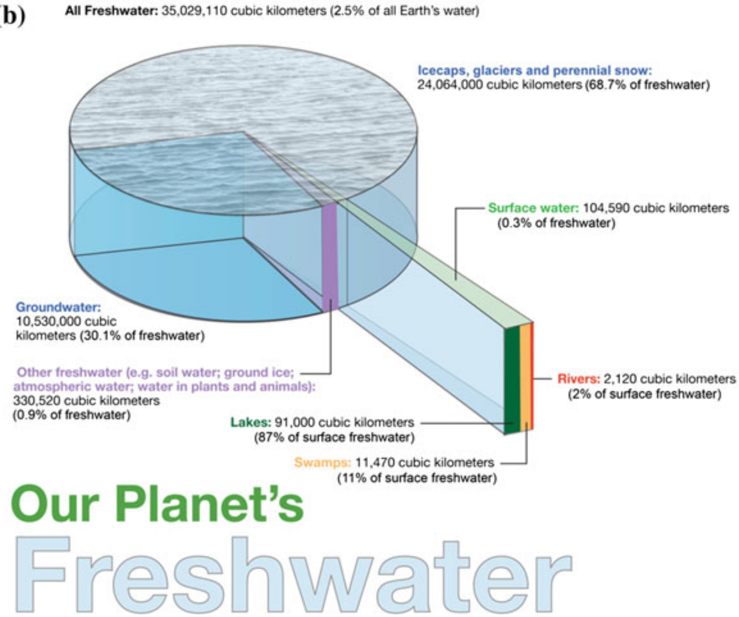


**Fig. 17.1** **a** Approximate quantity and proportionate amounts of all water on earth; **b** approximate quantity and proportionate amounts of fresh water on earth. Illustration prepared by Stephen Nash

social and economic growth around the world. Nations have already responded to the threats to human water security by massive investment in water technology and engineered systems (Zehnder et al. 2003; Vörösmarty et al. 2010, 2013). While these engineered solutions might address human water needs, they are not concerned with the biodiversity and ecological function of the systems. Instead they often add to existing threats to biodiversity and ecosystem function. They may involve increased appropriation of surface water flows that are essential for environmental needs, and increased extraction of groundwater resources that are also essential to surface ecosystems and may be non renewable (Taylor et al. 2012; Foster et al. 2013).

Fresh waters are therefore in a state of global crisis; they are perhaps the most imperilled ecosystems on Earth, and inland waters are recognised as hotspots of endangerment (Dudgeon et al. 2006; Darwall et al. 2009; Mittermeier et al. 2010). Nearly every major river has been dammed resulting in the impoundment of over 10,000 km$^3$ of water (Chao 1995; Chao et al. 2008), the equivalent of around five times the volume of the Earth's rivers, and reservoirs trap more than 25 % of the total sediment load that formerly reached the oceans (Vörösmarty and Sahagian 2000). Around 70 % of available surface water is used annually for agricultural purposes alone (Wallace et al. 2003). Nutrient runoff has created algal blooms and anoxic dead zones. There is a very strong correlation between total phosphorus inputs and phytoplankton production in freshwaters (Anderson et al. 2002; Heisler et al. 2008), and runoff aggravates the formation of coastal dead zones, which have now been reported to affect a total area larger than the United Kingdom (Diaz and Rosenberg, 2008). More than two thirds of our upland watersheds are not protected (Thieme et al. 2010). Wetlands cover about 6 % of the Earth's surface. Depending on the region, between 30 and 90 % of these wetlands have already been destroyed or are heavily modified (Junk et al. 2013). Climate change will exacerbate the existing threats on wetlands such as land reclamation, pollution, water abstraction, overuse of resources, and facilitate invasion and establishment of exotic species as habitat conditions alter, reflecting (for example) shifts in flow and inundation patterns, increasing temperature and sea level rise.

There are clear signs that freshwater biodiversity is declining rapidly (Dudgeon et al. 2006; Darwall et al. 2009). Population trend data indicate that whereas terrestrial species show declines in the order of 25 % (95 % CL: 13–34 %) since 1970, the equivalent value for freshwater species is 37 % (21–49 %)—nearly one and a half times as high (Loh et al. 2005; and see Fig. 17.2). It should be stressed that these population trend data are based entirely on a selection of water-associated vertebrates, and lack adequate representation from the more species-rich invertebrates (Cardoso et al. 2011; but see also Balian et al. 2008).

While existing knowledge is inadequate, at least 10,000–20,000 freshwater species have become extinct within the last century or are currently at risk globally (Strayer 2006; Strayer and Dudgeon 2010). The IUCN Red List of Threatened Species currently only gives partial coverage to the world's freshwater species, currently listing 23,291, or 18.5 % of all known freshwater species. Accepting that the data may be biased towards inclusion of threatened species present in a region

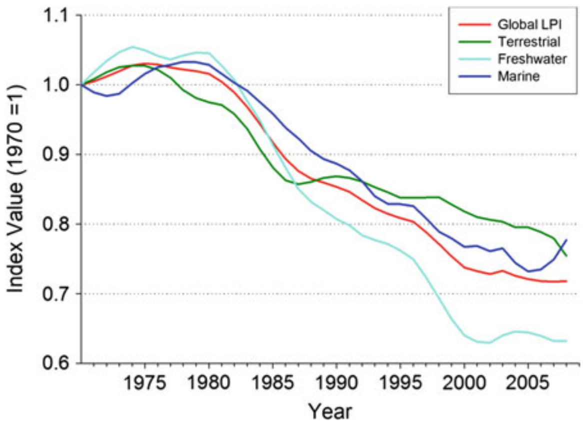


**Fig. 17.2** The Living Planet Index (LPI) tracks the fate of populations of thousands of vertebrate species, just like a stock market index tracks the price of a basket of shares. The global LPI (*red line*) has declined by 28 % between 1970 and 2008. The global LPI can be split into its components by realm: terrestrial (*green line*), freshwater (*light blue line*), and marine (*dark blue line*). While all components have declined, freshwater has done so much more (37 %) than the marine (22 %) and the terrestrial (25 %) ones

(rather than the more recent trend to provide a comprehensive coverage of all species regardless of the threat; see Darwall et al. 2009, Carrizo et al. 2013), the trends are nevertheless disturbing: 30.1 % of all freshwater species that have been assessed by IUCN are classified as threatened (i.e., 'Critically Endangered'. 'Endangered', or 'Vulnerable' according to Red List criteria (IUCN 2013). Amphibians, a primarily freshwater taxon, are the second most threatened group of organisms (after cycads) that have been assessed globally (IUCN 2013; see Text Box 1); but, in intensively-developed regions, over one third of the species in other freshwater taxa are threatened also (e.g. Kottelat and Freyhof 2007; Jelks et al. 2008; Cuttelod et al. 2011; Collen et al. 2014). Although knowledge of freshwater biodiversity is improving (Clausnitzer et al. 2009, 2012; Darwall et al. 2009; Tisseuil et al. 2012; see Text Box 2), information gaps in the tropics (Balian et al. 2008) mean that the overall threat extent may be even greater than currently estimated. The possible extinction of the Yangtze River dolphin, *Lipotes vexillifer* (Turvey et al. 2007; Smith et al. 2008), which would be the first human-caused extinction of any cetacean, is not only emblematic of the perilous state of freshwater biodiversity, but indicative of our reluctance to effectively address conservation needs. It is a matter of great concern that freshwater biodiversity is largely neglected or insufficiently addressed in almost all water-development projects (Pahl-Wostl, pers. comm.; Vörösmarty et al. 2013); for example, the Bonn declaration that resulted from the Global Water System Project, which gave rise to this volume, mentions biodiversity only implicitly.

The increasing stress on water resources that is associated with increasing population and economic growth of the Anthropocene will likely commit us to further extinctions. To this can be added a substantial (perhaps unquantifiable) extinction debt associated with human actions that have been taken already (Strayer and Dudgeon 2010). The likely consequences of climate change for water availability in rivers do not augur well for biodiversity, at least for some regions (Ngcobo et al. 2013; Reid et al. 2013; Pearce-Kelly et al. 2013; Tedesco et al. 2013). Moreover, and as noted above, likely adaptation measures to be taken by humans to adjust to a warmer world may also be damaging (Palmer et al. 2008), and scenarios for the riverine biota in areas where the human footprint is already pervasive (see Vörösmarty et al. 2010) are especially bleak. Biodiversity loss has been shown to significantly affect the ecological function of ecosystems (Hooper et al. 2012). In the case of freshwater ecosystems this may mean that they have a reduced capacity to provide certain services such as food, nutrient cycling, and water filtration that are essential for supporting human livelihoods and health, beyond the supply of water itself (Horowitz and Finlayson 2011; de Groot et al. 2012; and see below).

## Importance of Freshwater Biodiversity

There are at least 126,000 species of freshwater animals and vascular plants; this is estimated as perhaps up to 12 % of all known species on earth, and includes one-third (>18,000 species) of vertebrates, which is far more than would be expected from the limited extent of inland waters (Abramovitz 1996; Dudgeon et al. 2006; Balian et al. 2008, 2010). This total number of species is certainly an underestimate (Balian et al. 2010) since it omits several taxonomic groups that are likely to be rich in freshwater species (e.g., fungi, algae, several 'protozoan' taxa). It also does not account for the fact that many new species are being described annually, even in the case of the better known groups such as freshwater fishes and amphibians (for example, since 2005 amphibians are being described at a rate of one new species every 2–3 days; Frost et al. 2006; Reid et al. 2013). Nor does it account for recent losses of species that became extinct before they could be described by scientists. An almost unknown ecosystem type is the vast groundwater body. An estimated 50,000–100,000 stygobiont species, i.e. species that finish their entire life cycle in the subterranean freshwater realm, occur globally (Culver and Holsinger 1992). However, less than 10 % of these species are described up to now (Stoch and Galassi 2010). Ground waters are characterized by a very high proportion of endemic and cryptic species, although there is a major lack of information on their ecology and their functional performance.

Freshwater organisms and their ecosystems are valuable in their own right, but are also vital for providing people with many different goods and services (de Groot et al. 2012; Russi et al. 2013). Russi et al. (2013) have noted that the biodiversity of wetland ecosystems are at the core of the nexus between water, food and energy. However, while biodiversity loss does affect ecosystem function (Hooper et al. 2012; see above), there is limited understanding of this relationship for many ecosystems. It is not known how much biodiversity could be lost without seriously jeopardizing ecosystem functions and services, which makes it very difficult to accurately predict the management needs of freshwater systems under changing environmental pressures (Dudgeon 2010; Stuart and Collen 2013). While much research has yet to be conducted, there is evidence that biodiversity improves water quality (Cardinale 2011) and that the loss of biodiversity impacts human livelihood and well-being (Cardinale et al. 2012). To some extent it may seem obvious that we should expect some relationship between biodiversity and ecosystem functioning as, for example, conservation of fish biodiversity is necessary to maintain a productive fishery (Reid et al. 2013). One possible relationship is that ecosystem function may be enhanced in a near-linear fashion as species richness increases. Alternatively, the loss of species may have no effect on function until some critical threshold, or tipping point, is reached whereupon the remaining species can no longer compensate for loss of the others and complete failure may occur. A third possibility is that functioning may be unaffected by the loss of certain species, but greatly impacted by the loss of others, or even by the order in which they are lost. This last 'idiosyncratic hypothesis' holds that the identity of species lost may be more crucial than the number remaining, and there is some evidence that this relationship applies in freshwater ecosystems (e.g. McIntyre et al. 2007; Gessner et al. 2010; Capps and Flecker 2013). Recent findings (e.g., Cardinale 2011; Cardinale et al. 2012), and uncertainty over the form of the relationships between biodiversity and ecosystem functioning (see Dudgeon 2011; Tomimatsu et al. 2013), strongly suggest that it would be prudent to adopt the precautionary principle and minimize further species declines or losses. By the same token, the introduction of non-native species may have marked effects on ecosystem functioning (reviewed by Strayer 2010; see also Capps and Flecker 2013), and should be avoided.

## Valuing Freshwater Biodiversity and Ecosystems

Appreciation of the need to protect species and nature for their own sake is taken as axiomatic by many scientists, but is often put aside when it comes to addressing the pressing demands of growing human populations and their need for water security and other necessities (Vörösmarty et al. 2013). One good rationale for halting the degradation and destruction of freshwater systems is that of enlightened self-interest; people rely on rivers lakes and wetlands—not only for water, but the other goods and services that they provide that are of immense value, far beyond the mere economic value of water (Costanza et al. 1997; Russi et al. 2013).

Economic values of inland wetland ecosystem services are typically higher than those of many terrestrial ecosystems. For example, the total economic value of inland wetlands (exclusive of lakes and rivers) was estimated at 25,682 Int.$/ha/year, compared to 5,264 Int.$/ha/year for tropical forests (where 'Int' refers to a translation of the original values into US$ values on the basis of Purchasing Power

Parity; see de Groot et al. 2012). The non-market services of freshwater ecosystems (e.g., regulating, habitat, and cultural services) represents 94 % of the overall economic value of inland wetlands, and 55 % of the overall economic value of rivers and lakes, according to the data provided by de Groot et al. (2012) (and see Text Box 3 for discussion of a specific example of non-market services). There is now a growing appreciation that sustainable use of all types of wetlands is usually economically more beneficial than conversion to alternative uses if all or most services are taken into account (de Groot et al. 2012). Jenkins et al. (2010) showed that restoration of wetlands in the Mississippi Alluvial Valley can provide a high return on the public investment for the restoration.

This potential economic return from careful management of the natural capital of freshwater ecosystems is important for both regional and global economies. Currently up to 0.75 trillion dollars (750 billion USD) is spent per year to maintain the infrastructure and operating costs of water management around the world, and two-thirds of this expenditure is in America and Europe (Zehnder et al. 2003; Addams et al. 2009; Vörösmarty et al. 2013; Boccaletti, pers. comm). These costs are likely to increase as middle and low income countries start to become more affluent and develop their own infrastructure. Hence, it is important to look beyond the traditional reliance on hard-path infrastructure and to work with nature, and use the natural capital it provides (Palmer 2010; Vörösmarty et al. 2013). The objective of such an approach should be to meet the requirements of regional and global economies while also reducing the intensity of threats to the biodiversity supported by these ecosystems (Totten et al. 2010).

## Conservation Gaps (Protected Areas and Their Management)

Despite its ecological, economic, and cultural importance, freshwater biodiversity is evidently not adequately protected by existing conservation actions. Darwall et al. (2011b) compared the distribution of threatened freshwater species (crabs, fishes, molluscs, and odonates) with the distribution of protected areas in Africa. Their results showed that while 84–100 % of the studied species had some part of their range in protected areas, only 50 % or fewer of the species had at least 70 % of their range (mapped to river catchments) contained within a protected area (see red boxes in Table 17.1). Given the high degree of connectivity within freshwater ecosystems, such that impacts can spread rapidly and from areas far outside of the protected part of a species range, this lack of protection leaves freshwater species highly vulnerable.

It has also been shown that freshwater ecosystems are not adequately included in the global network of protected areas (e.g., Allan et al. 2010; Herbert et al. 2010). Globally, almost 70 % of rivers have no protected areas in their upstream catchment (Lehner et al. in prep), and yet upper catchment protection is important because this affects the delivery of water in adequate quantity or quality to

**Table 17.1** Percentage of species within existing protected area networks in Africa

| | (a) Intersect PA [n = 2,725] | | (b) 70 % catchment in PA [n = 619] | | (c) Catchment contains a designated Ramsar site [n = 190] | |
|---|---|---|---|---|---|---|
| | Total taxa (%) | Threatened taxa (% ) | Total taxa (%) | Threatened area (%) | Total taxa (%) | Threatened taxa (%) |
| Amphibia | 95.7 | 99.4 | 70.8 | 49.2 | 62.2 | 45.3 |
| Birds | 99.1 | 96.2 | 95.9 | 74.2 | 91.7 | 61.4 |
| Mammals | 97.6 | 98.4 | 88.4 | 98.4 | 80.1 | 62.5 |
| Crabs | 92.5 | 88 | 50 | 36 | 44.3 | 24 |
| Fishes | 87.4 | 93.9 | 48.5 | 31.4 | 46.6 | 33 |
| Molluscs | 80.8 | 84.1 | 21.7 | 33.1 | 54.8 | 35.2 |
| Odonata | 86.4 | 100 | 73.7 | 50 | 82.4 | 39.7 |

Percentage of species from major taxonomic groups (a) captured within protected areas based on overlap of any point of occurrence in the species range with a protected area; (b) based on the overlap of 70 % of the species range (mapped to river catchments) with a protected area; and (c) based on presence of the species within catchments that also contain a Ramsar site. The lower four groups (crabs, fishes, molluscs, and odonates) are the freshwater groups assessed as part of IUCN's Global Freshwater biodiversity Assessment; the top three groups are other higher vertebrates that have been previously assessed, for comparison. Adapted from Darwall et al. (2011a)

downstream habitats. There is, therefore, an important need for careful consideration of optimum placement of protected areas to secure freshwater biodiversity under rapidly environmental alterations.

Holland et al. (2012) describe a methodology for identifying priorities for freshwater protected areas via the development of freshwater Key Biodiversity Areas (KBAs), which has also been used by institutions and funding organisation for planning frameworks (e.g. the Critical Ecosystem Partnership Fund). Freshwater KBAs are defined on presence of threatened and endemic species or ecologically unique assemblages of species (Table 17.2), and are mapped using HydroBASINS (Lehner 2012) which is the best available digital hydrology resource for mapping connectivity within catchments, incorporating river basin boundaries, lakes, and river networks.

The application of these methods to Africa and several parts of Asia (Allen et al. 2010, 2012; Darwall et al. 2011b; Molur et al. 2011) has identified a large number of potential KBAs which may be compared to protected areas to identify gaps in both spatial coverage and management focus. Once these gaps have been identified it is then possible to start developing management plans to address those gaps. However, equally as important as identifying the sites where protected areas should be implemented, is identifying the proper management plans for these locations. Abell et al. (2007) described an integrated approach to selecting and managing freshwater protected areas that first identifies focal sites or habitats that are important for species or communities, then defines critical management zones that would support the integrity of these areas, and subsequently embeds these zones within a wider catchment management scheme that integrates multiple user needs (Fig. 17.3). Such focal sites and crucial management zones would be

**Table 17.2** Criteria and thresholds for defining freshwater KBAs, based on Holland et al. (2012)

| Criteria | Threshold |
|---|---|
| 1. Globally threatened species or other species of conservation concern | One or more CR, EN, or VU species |
| 2. Species (or infraspecific taxa as appropriate) of restricted range) | 20,000 km$^2$ for crabs, fish and molluscs and 50,000 km$^2$ for odonates |
| 3. Group of species that are confined to an appropriate biogeographic unit or units | At least 25 % of the total species from a specific taxonomic group occurring within a sub-catchment must be restricted to the ecoregion (Abell et al. 2008) in which the subcatchment is located |

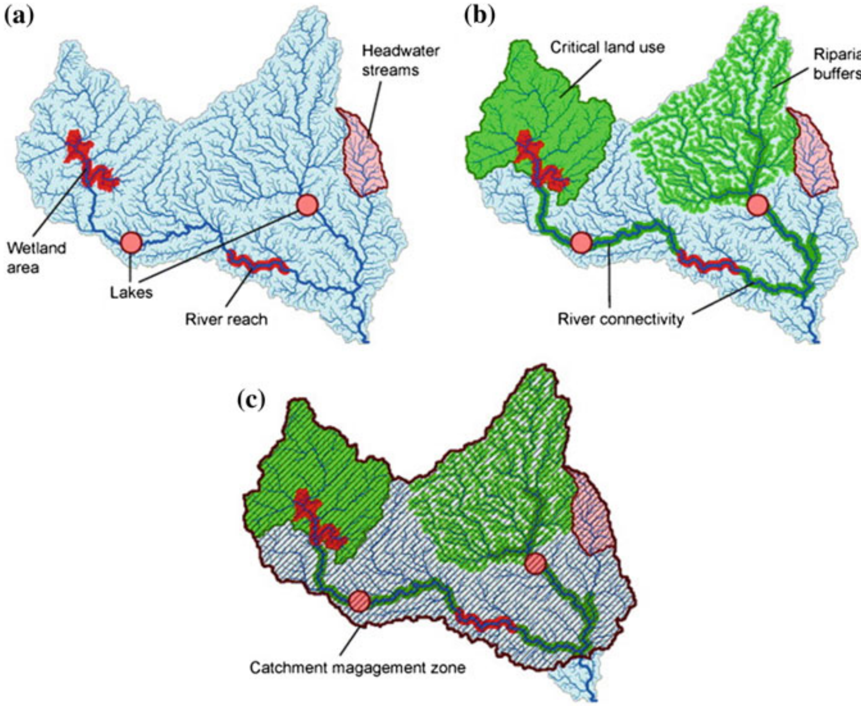


**Fig. 17.3** Schematics of proposed freshwater protected area zones as proposed by Abell et al. (2007). **a** Freshwater focal areas, such as particular river reaches, lakes, headwater streams, or wetlands supporting focal species, populations, or communities. **b** Critical management zones, like river reaches connecting key habitats or upstream riparian areas, whose integrity will be essential to the function of freshwater focal areas. **c** A catchment management zone, covering the entire catchment upstream of the most downstream freshwater focal area or critical management zone, and within which integrated catchment management principles would be applied. (Reprinted from Abell et al. (2007). Copyright (2007), with permission from Elsevier)

represented as part of the management approach within a freshwater KBA. The objective is to move beyond protection directed just to the actual sites holding target species, towards protective management of the wider associated catchment.

## Freshwater Management Plans

The importance of well-thought out management structures has been highlighted by several studies (e.g., Broadmedow and Nisbet 2004; Dudgeon et al. 2006; Ramsar Convention Secretariat 2010), and simple, single-factor, ‘rules of thumb’ approaches to management are often unsuccessful. For example, Pittock et al. (2010) outlined the status of five wetlands sites in the Murray Basin, each of which is recognised as an “icon site” for the restoration of ecological health in the basin by the Australian government. Despite such recognition, all of these sites have experienced declines in ecological character. Despite this deterioration, there was limited implementation of any conservation or mitigation measures, and degraded habitat was not compensated nor had it been restored in any way. The most recent government initiatives have been to change flow patterns, but apparently not in a carefully thought-out way, with the result that more stress is placed on some areas in favour of others (Pittock et al. 2010). In addition, a single focus on flows, important as they are, is not a sufficient management response to the array of threats these wetlands face, and a series of multiple-factor initiatives integrated across all five sites would have been more likely to result in conservation gains.

Protected area managers often tend to underestimate the stress on freshwaters in protected areas (Thieme et al. 2012). In addition, even in developed countries, resources are limited: a third of the protected areas in the southeastern United States surveyed by Thieme et al. (2012) lacked any budget for freshwater management or protection, and over half had no staff time allocated to freshwater management activities. At the European level, almost 70 % of rivers fail to achieve “good ecological status” according to the EU Water Framework Directive, and most likely will not meet this status until 2015 or later unless there is significant extra allocation of resources to river protection.

There are a number of specific challenges that face those attempting to manage fresh waters with the aim of conserving biodiversity, while meeting human needs for water. While terrestrial conservation strategies tend to emphasize areas of high habitat quality that can be bounded and protected, this ‘fortress conservation’ approach is not suitable for river segments or lakes embedded in unprotected drainage basins unless the boundaries can be drawn at a catchment scale (see, for example, Dunn 2003). This is hardly ever possible, and the shortcomings inherent in fortress conservation are particularly acute for freshwater biodiversity because protection of a particular component of the biota or habitat, for example in rivers, requires control over the upstream drainage network, the surrounding land and riparian zone, and—in the case of anadromous species and the risk of invasive species—downstream reaches as well. It is a major challenge to reconcile the need for a catchment-scale approach to conservation of freshwater biodiversity when this requires that large areas of land need to be managed in order to protect relatively small water bodies.

Thus all the necessary elements for freshwater management and the conservation of its biodiversity need to be included in water policies. Management of water resources must take account of aquatic biodiversity in and of itself, as well as its contribution to ecosystem functions and the goods and services used by humans, while also establishing monitoring schemes that can underpin adaptive management. Planning conservation initiatives or the activities needed to support them—for example, establishing protected areas and conducting biological inventories (Gaston et al. 2008; BioFresh, 2013)—requires high-quality spatial data on patterns of biodiversity and threat. Unfortunately, prioritization of conservation activities has been largely directed at terrestrial habitats, focusing on primarily terrestrial vertebrates as target species (e.g. Rodrigues et al. 2004). Identification of areas that support particularly high freshwater species richness has lagged behind efforts for the terrestrial realm, and the first attempt at mapping global freshwater ecoregions and hotspots was unveiled relatively recently (Abell et al. 2008). This is an important development because we lack confirmation on whether terrestrial and freshwater hotspots overlap (Strayer and Dudgeon 2010), and the analysis at the scale of river catchments throughout Africa suggests that such overlap is low (Darwall et al. 2011a). In addition, terrestrial vertebrates are poor surrogates for the overall freshwater diversity in a given area (Rodrigues and Brooks 2007).

A recent example of a major conflict among potential users of water is the actual boom in hydropower development, in Europe and globally. Although the utmost principle of the European Water Framework Directive (WFD) is to avoid the deterioration of the status of water bodies, we actually experience an unrestrained development in hydropower production; in particular of small-scale facilities. This rising conflict among different users of water occurs mainly because different directives are responsible for managing the different components of water (e.g., biodiversity conservation, irrigation, navigation, water quality). There is an urgent need to develop synergies among the different users, for the benefit of humans and the ecosystem (Pahl-Wostl et al. 2013b).

Knowledge of the status and condition of the biodiversity present within fresh waters provide an essential basis for making decisions that will allow sustainable management of these ecosystems. Many taxa are good indicators of environmental health. For example, the amphibiotic life cycle of dragonflies (with aquatic larvae and terrestrial adults) and their sensitivity to structural habitat quality, make them well suited for use in evaluating long-term and short-term environmental change in aquatic ecosystems and the associated riparian habitats, which are resources heavily utilized by local communities (Kalkman et al. 2008; see Text Box 4). Amphibians have been used as indicators of the general health of the ecosystem (e.g., Welsh and Ollivier 1998; Rice and Mazzotti 2004). Molluscs—as well as other macro-invertebrates—are sensitive to water quality and flow, and are potentially useful in bio-monitoring programs (Strong et al. 2008); many are also threatened with extinction (Johnson et al. 2013) although global assessments of the conservation status of, for example, freshwater snails are lacking. Global biodiversity databases such as the IUCN Red List of Threatened Species can, through the provision of information on species distributions and their sensitivity to identified threats, help to inform decisions on the potential impact of developments on freshwater ecosystems.

Rockström et al. (2009) defined a set of 'planetary boundaries' that describe a safe operating space for humanity. Bogardi et al. (2012, 2013, 2013) noted that in a few decades we may transgress those planetary boundaries for freshwater, indicating that we will have failed as an international community to establish political targets or economic incentives for change. To avoid this, we must develop policies and governance that will protect freshwater ecosystems and ensure the long-term provision of freshwater services to humans (Pahl-Wostl et al. 2013b). An important approach will be to take full account of the "nexus" between water, food and energy, as one of the most fundamental relationships and increasing challenges for society (Bogardi et al. 2012; Lawford et al. 2013a; Russi et al. 2013). While biodiversity, and particularly wetland ecosystems, are at the core of this nexus (Russi et al. 2013), freshwater ecosystems and biodiversity often fail to be considered when this nexus is discussed. Their exclusion may cause a permanent source of conflict because synergies among the various users are not exploited and consensus cannot be achieved. A possible reason for excluding biodiversity and the ecosystem as pari passu partners is the complexity and uncertainty they may add.

## Next Steps to Meet Global Conservation and Management Needs

As noted above, substantial gaps in knowledge of global freshwater biodiversity still remain, and considerable research is required to provide baseline data that can be used to inform conservation initiatives and action for this imperilled biota. These data should include satellite and in situ observations, combined with procedures to combine and model these global data sets (Lawford et al. 2013b) (Fig. 17.4).

We need to ensure a better allocation of environmental flows in order to allow for sufficient hydric resources to properly support ecosystem functions while also attending human requirements (Poff and Matthews 2013), and this needs to be tied with research on how climate change will affect those allocations. Modification of flows in some regions is likely to be unavoidable, to meet essential human requirements. When this occurs, the implementation of comprehensive environmental impact assessments with recommendations as to how to mitigate the most deleterious impacts is crucial.

The need for more data is an obvious priority, but conservation biologists must also be ready to make the most of the data that are currently available, and to use these to help landscape managers make appropriate decisions. There are many

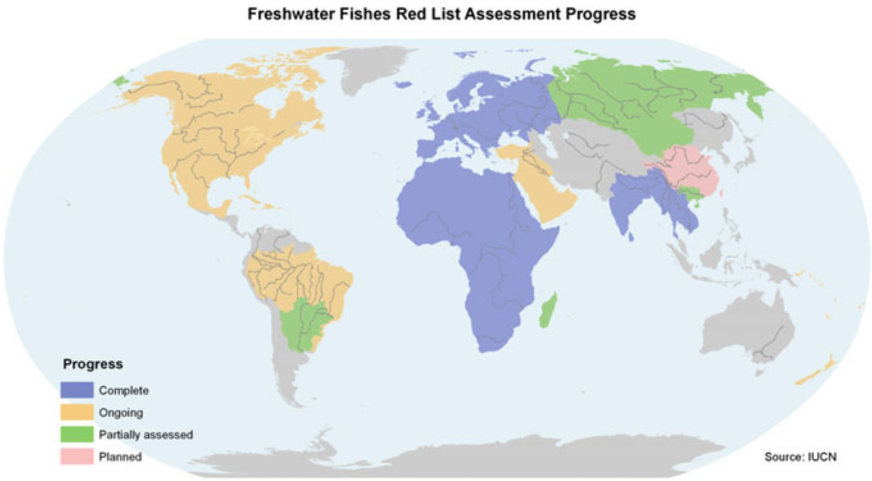


**Fig. 17.4** Map showing the progress towards completion of Red List assessments for freshwater fishes in different parts of the world

excellent systems for collating biodiversity data into integrated systems that can support monitoring and measurement of change (Scholes et al. 2012; and see discussion above on the IUCN Red List). Some databases are specifically designed to collate and present ecological information, drawn from multiple data sets, to assist private and public-sector decision-makers in developing ecologically sustainable business and management practices (e.g., see Text Box 5). When developing new analytical tools for evaluating impacts on freshwater biodiversity it will be important to look carefully at the needs of the likely users. In some cases in the past, the relevant users and stakeholders have not been sufficiently engaged during the process of tool development (Morrison et al. 2010).

While awareness of the extent of threats to freshwater biodiversity has grown during the last decade, a great deal more needs to be done in order to conserve it. A major challenge we face is to raise awareness of the tremendous diversity of species living within our freshwater ecosystems, as they remain largely unseen and unvalued. The fact that most freshwater species live in a habitat that very few people explore or appreciate leaves them highly vulnerable to the impacts of the Anthropocene. Many freshwater species, some of which may be truly impressive creatures, such as *Pangasianodon gigas*, the Giant Mekong Catfish, are heading for extinction yet few people will even notice their passing. As this chapter indicates, it is often the very activities that enhance human well-being and water security which place freshwater species at risk (e.g. Vörösmarty et al. 2010). It remains a huge challenge to manage the Anthropocene global water system in a manner that will meet the water, food and energy needs of people, while allowing for sufficient semblance of natural ecosystem functions to remain in order to sustain biodiversity. For some large, iconic animals it may already be too late to reverse population declines, but it would be a travesty to permit the many freshwater species now recognized as globally threatened to follow path of the Yangtze dolphin into our history books. We already have much of the knowledge and many of the tools we need to protect freshwater biodiversity; we must now demonstrate the will to act.

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## A.1 Appendix

**Box 1: Balancing Development and Biodiversity Conservation**

The Kihansi dam generates about 20 % of Tanzania's electricity. It is located in the Udzungwa Mountains, where the Kihansi River plunges off an escarpment. Because of its steep drop and dependable water flow, it was selected to develop a hydropower project that was started in 1994. Before the dam was completed, biological surveys of the area yielded the discovery of several species new to science, most famously the Kihansi spray toad (*Nectophrynoides asperginis*), which was endemic to a very small area of about 2 ha in the spray zone of the Kihansi Falls, the smallest distribution known for a vertebrate (Poynton et al. 1998).

As a result of these biological findings, the government agreed to let 10 % of the river flow to continue its original course—a reduction from over 16 to about 2 $m^3/s$ (Rija et al. 2011); this reduced flow proved insufficient to maintain the mist zone that created the toad's habitat. In combination with other events, such as a one-time flushing of pesticide-rich sediments accumulated at the dam and the possible occurrence of an amphibian fungal disease (Krajick 2006), the toad's population crashed from an estimated high

**Photo 17.1** Kihansi spray toad (*Nectophrynoides asperginus*) © Kurt Buhlmann

of over 20,000 individuals in 2003 to less than five individuals seen in 2004 (Channing et al. 2009). There have been no confirmed records since, and the species has been listed as Extinct in the Wild in the Red List of Threatened Species since 2009.

In 2000, some toads were collected from the field in an attempt to establish a captive breeding programme in the US (Bronx and Toledo zoos) that collaborates extensively with Tanzanian authorities. There have also been attempts to recreate the natural spray zone at the bottom of the gorge by means of an artificial sprinkler system, though it is becoming clear that this may not be sufficient, as some elements of the original ecosystem are still absent—for instance, the waterfall created continuous winds that replenished the area with wet silt (Rija et al. 2011). Since 2010, there are ongoing efforts to try to reintroduce some captive bred toads back into the spray zone of the falls, with the first ones released in 2012, but the road ahead is not easy (Khatibu et al. 2008). Millions of dollars have been spent to try to prevent this species from going extinct and change its Red List status from Extinct in the Wild back to Critically Endangered, which would be a first in recorded history. In spite of this, for many locals the dam is the source of their access to electricity that they cherish, even if it comes at the cost of a little known toad (Photo 17.1).

**Box 2: Rapid Assessment (AquaRAP) Programs for Fresh Waters**

Since 1996, 13 Rapid Assessment Programs have been implemented to specifically target freshwater ecosystems, focusing on surveys across watersheds or basins. The AquaRAP program has several objectives, listed by Alonso and Willinck (2011). These include increasing the priority given to conservation of freshwater systems; catalysing multinational, multidisciplinary, collaborative research on freshwater systems that includes training of students; highlighting the importance of systematic research and collections for conservation; and generating a body of reliable data about the selected watersheds.

AquaRAPs have confirmed the fact that our knowledge of biodiversity is woefully low for many parts of the world. Just in Latin America, AquaRAPs have identified 238 new basin and country records for fishes in addition to 105 species new to science. New records have also been identified for number of records for planktonic and benthic organisms, but the numbers are certainly underestimates of the total number of species, since there are often not enough taxonomists working on these groups to allow species identifications.

The conservation and management impacts of AquaRAP have been important, resulting in the creation of new protected areas, and the provision of information and advice that has been used by decision-makers (Alonso and Willinck 2011). Harrison et al. (2011) give several examples of where AquaRAP surveys have provided critical data for biodiversity assessments of African freshwater species, as well as application of information for management decisions. For example, the AquaRAP expedition to the Okavango Delta, Botswana catalyzed a process for resolving conflicts between local fishermen and sport fishermen in the delta.

**Box 3: Iconic, Flagship Fishes and River Conservation**

Large-bodied river fishes are particularly vulnerable to human impacts arising from overexploitation, pollution, dam construction and habitat alteration because many of them are slow growing and/or late maturing and migratory, and thus apt to encounter a variety of threats or stressors at different times and locations during their lives (reviewed by Dudgeon et al. 2006; see also Limburg and Waldman 2009). Examples include the Mekong giant catfish, the Yangtze paddlefish, African tiger-fishes, sturgeon, salmonids and a variety of other anadromous species. Many of these species have (or had) economic value which contributed to their exploitation and subsequent decline. However, this value also provides an opportunity for species protection that is predicated on the adoption of a payment for ecosystem services (PES) model. One example is provided by Everard and Kataria (2011) who describe the benefits obtained by a local community in the Himalayas of northern India from protection of a large ‘flagship’ fish species in the Western Ramganga River. The golden mahseer (*Tor putitora*: Cyprinidae), which may exceed 50 kg, is a favoured species for recreational angling. Along with associated cultural and wildlife tourism, angling generates income that creates incentives for protection of intact river systems by the local rural populace. They benefit economically from sustainable mahseer exploitation through catch-and-release fisheries, thereby establishing a PES market involving local people, tour operators and visiting anglers. This PES market is

**Photo 17.2** Mekong giant catfish (*Pangasianodon gigas*) © Zeb Hogan

sustainable provided that people can benefit economically to a greater extent than they would through killing of fish for sale and consumption.

As Everard and Kataria (2011) explain, creation of local incentives through PES may be the most effective means for preventing destructive over-exploitation of large fishes. The Western Ramganga River model is potentially transferable to other rivers that support potential flagship fish species. It offers means of supporting regional development through involvement of riparian populations in markets for large, iconic fishes, especially where such species also have symbolic or cultural values. It must be stressed that sharing of the benefits of recreational angling markets is essential to promote self-interested resource stewardship of the type practiced along the Western Ramganga River, because without distribution of the revenues from tourism (for instance, where profits accrue to a few business operators only), local people are unlikely to have any incentive to protect freshwater ecosystems (Photo 17.2).

**Box 4: Guardians of the Watershed. Dragonflies as Flagship Species for Water Quality**

Dragonflies are employed successfully as indicators of ecosystem health in environmental impact assessments and monitoring programs, particularly in Australia (Bush et al. 2013) and Europe (Sahlen and Ekestubbe 2001). They can be used as environmental sentinels and as the whistleblowers for freshwater health, providing an easy tool not only for environmental impact assessments, but also for freshwater monitoring, carried out by various stakeholder groups. Using dragonflies as a flagship species—beautiful, easy to observe and positively perceived throughout—a monitoring scheme can be applied not only at the level of decision makers and conservationists, but also at the local community level.

**Photo 17.3** Violet dropwing (*Trithemis annulata*) © Viola Clausnitzer

Recent projects in Angola and Tanzania, which included stakeholders from various backgrounds, have shown that the general problems of environmental health can also be explained here by using dragonflies as flagship species. Once the connection between the presence of certain species and habitat quality is understood, dragonflies can act as the guardians of the watershed—indicating the quality of the water habitat without the need of expensive or difficult tools or survey protocols (see report at www.speciesconservation.org/case-studies-projects/amani-flatwing/4044 (Photo 17.3).

**Box 5: The Integrated Biodiversity Assessment Tool**

The Integrated Biodiversity Assessment Tool (IBAT) for business (https://www.ibatforbusiness.org) has been developed through a partnership between UNEP-WCMC, IUCN, BirdLife International and Conservation International. IBAT is a web based decision support tool that provides planners with access to critical spatial information on conservation priorities (e.g. species, protected areas and key biodiversity areas) to inform decision-making processes with the intent of addressing any potential biodiversity risks associated with a development as early as possible. Hence, IBAT can help its users integrate biodiversity risk assessment into development plans; this reduces potentially costly impacts to critical ecosystems and supports well-informed decisions about where to invest effort in sustainable use and management of natural ecosystems. Commercial users currently support underlying data maintenance and update processes via a subscription service. This tool is currently supported by a number of private and public sector users including 25 extractive companies, and is being updated to include more specific functionality related to freshwater including direct access to data on species and sites as well as summarized indices intended to support existing water risk assessment tools in use by the private sector (e.g. WBCSD's Global and

Local Water Tools). It has been referenced by International Finance Corporation's safeguard systems and featured as a case study by the International Council on Mining and Metals (ICMM) of good biodiversity practice. A free version for non-commercial users (e.g., governments, NGOs or academics) is also available for conservation planning and research purposes (https://www.ibat-alliance.org/ibat-conservation/).

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