Congo River Basin

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Abstract

The Congo River is the second only to the Amazon in terms of size and freshwater species diversity. The basin covers 4 million km^2. The basin has over 1,200 fish species, 400 mammal species, 1,000 bird species and over 10,000 vascular plant species. It provides about 30% of Africa's freshwater resources, and about 77 million people living in the Congo basin rely on them. The basin has remained relatively undeveloped compared to other basins in Africa, but increased political stability is allowing development, with loss of riparian habitat through deforestation, and reduction of water quality through pollution and sedimentation being some of the main threats to the freshwater ecosystems. Effective environmental

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planning is essential to ensure that resources are managed wisely and the ecosystems that provide them are adequately protected. Additional surveying and monitoring of biodiversity throughout the basin is required. It will also be important to designate additional protected areas with a focus on freshwaters.

Keywords
Congo · Cuvette centrale · Ubangi · Kasia · Blackwater · Rapids · Forest · Fisheries · Habitat loss

Introduction

The Congo River basin is the second largest river basin in the world, after the Amazon, draining an area approximately the size of western Europe. The tropical forests in the democratic republic of Congo, which accounts for the greatest part of the basin, have a surface area of more than 2.0 million km^2, and they represent about 50% of the rain forests of the African continent. The Congo basin has an extremely large diversity of freshwater species, again, globally second only to the Amazon in terms of species richness. There is a dense system of tributaries that extends throughout the basin, providing an essential navigation system through large parts of Central Africa which otherwise has a poorly developed transport network. The rivers and surrounding forests also supply many important goods and services to the people living in the basin, providing food, sources of energy (eg. firewood) and income from local trades to large industries (such as mining). However, many areas these resources are not being managed sustainably, resulting in loss of the forest habitat, and severe degradation to many other areas, including the rivers.

The basin has remained in a relatively intact state compared to many other parts of Africa, and this is partly due to the poor network of communications, and long periods of political instability. These conditions have made large parts of the basin inaccessible. Hence, while we know that the basin has a unique and rich biodiversity, our knowledge of the overall biodiversity is still relatively poor. The development of more peaceful conditions, and a better communication network, has facilitated more extensive research into the ecosystems of the basin over the last several years. However, these conditions are also promoting increased economic activity, and unsustainable management of the resources in the basin. This is resulting in loss of the forest habitat, severe degradation to many other areas, including the rivers, and increasing loss of biodiversity.

Geographic Extent

The Congo River has the largest of Africa's river basins, covering about 4 million km^2 from 09° 15′ N to 13° 28′ S and 11° 18′ E to 31° 10′ E. It occupies almost all of the Democratic Republic of the Congo (DRC), much of the Republic of the Congo, and large portions of Cameroon, the Central African Republic, Zambia, and Angola

(Fig. 1). The main channel of the river is 4,374 km long (Runge 2007) and can conveniently be divided into upper (Lualaba), middle, and lower sections.

The Congo headwaters include three main branches: the Luapula River, which drains from Lake Bangweulu to Lake Mweru in the Bangweulu-Mweru ecoregion (Fig. 2) of northeastern Zambia, and the Lufira and Lualaba rivers in the Upper Lualaba ecoregion of southeastern DRC (according to freshwater ecoregions defined by Thieme et al. (2005) and Abell et al. (2008)). The Bangweulu basin, which supplies the Luapula branch of the Congo headwaters, is characterized by several lakes, none of which are more than 10 m deep, and Lake Bangweulu is the largest (2,070 km^2). Lake Bangweulu has several characteristic sand ridges that run from the southwest to the northeast and create long sandy spits and beaches. It is bordered to the east by large grassy swamps and a floodplain (Fig. 3a, b) such that the total combined area of the wetlands is at least 13,770 km^2 (Thieme et al. 2005). Several rivers drain into the Bangweulu wetlands, of which the largest is the Chambeshi River. Lake Mweru is deeper (37 m) and larger (4,413 km^2) than Lake Bangweulu according to Thieme et al. (2005), although there are also estimates of over 5,000 km^2, and is drained by the Luvua River.

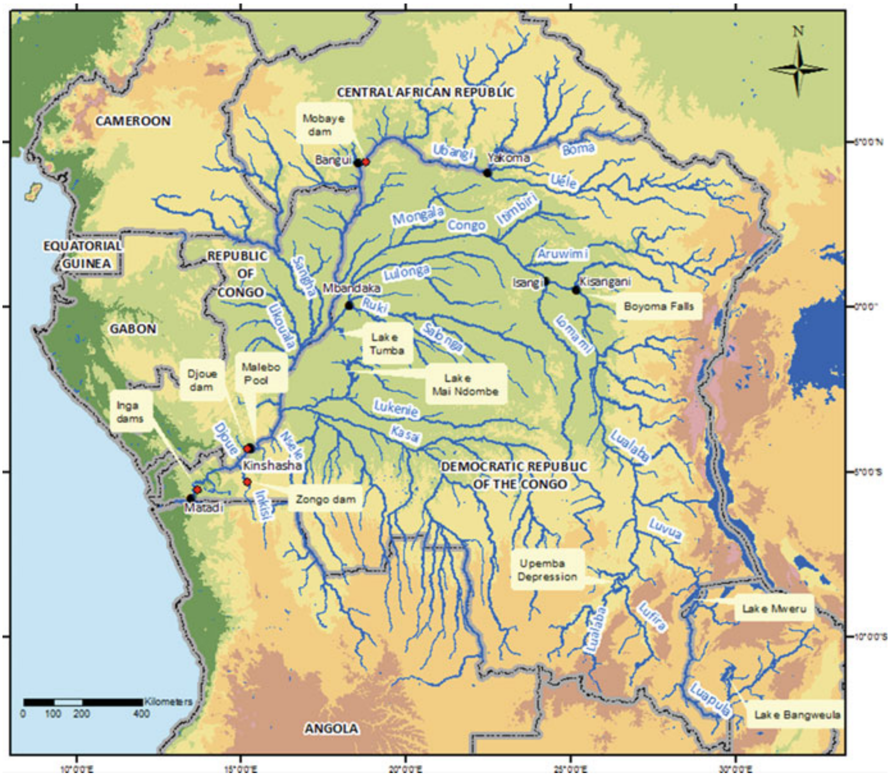

Fig. 1 Map of the Congo Basin (Topography from SRTM30 dataset. Rivers from HydroSHEDS)

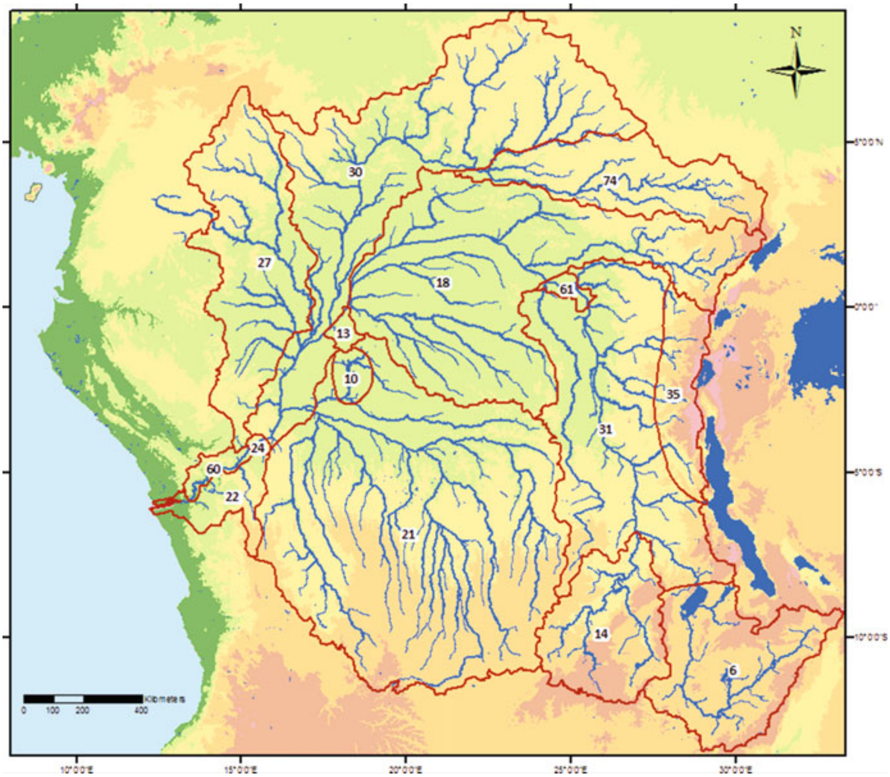

Fig. 2 Freshwater ecoregions of the Congo Basin. Ecoregions are numbered according to Thieme et al. (2005). *6* Bangweulu-Mweru, *10* Mai-Ndombe, *13* Tumba, *14* Upper Lualaba, *18* Cuvette Centrale, *21* Kasai, *22* Lower Congo, *24* Malebo Pool, *27* Sangha, *30* Sudanic Congo (Oubangi), *31* Upper Congo, *35* Albertine Highlands, *60* Lower Congo Rapids, *61* Upper Congo Rapids, *74* Uele (ecoregion boundaries from Freshwater Ecoregions of the World)

Considering the other two headwater branches, the Lufira River meets the Lualaba close to the Upemba (or Kamolondo) Depression which includes a mosaic of lakes and wetlands that seasonally extend between 8,000 and 11,840 km^2 (in the flood season). The Lualaba then passes over several falls and rapids and enters the Upper Congo ecoregion and is joined by the Luvua (draining Lake Mweru, see above). Within this Upper Congo ecoregion, the Lualaba runs north to Boyoma Falls (formerly Stanley Falls), just upstream of the town of Kisangani (formerly Stanley-ville). Several rivers drain to the Lualaba from the Albertine Highlands ecoregion of the central Rift Valley to the west. The Lomami runs parallel and to the west of the Lualaba in the Upper Congo ecoregion and joins the Congo downstream from Kisangani, at Isangi. The Upper Congo Rapids ecoregion, upstream from Kisangani, forms a boundary between the upper and middle sections of the Congo River.

The middle section of the Congo follows a large arc, heading west and then southwest from Boyoma Falls to Malebo Pool. Most of this middle section, below

Fig. 3 (**a**) Bangweulu grassy swamps (Photo credit: Kevin Cummings © Rights remains with the MUSSEL Project http://www.mussel-project.net/); (**b**) Aquatic vegetation in Bangweulu swamp (Photo credit: Maarten Van Steenberge © Rights remains with the photographer)

the Upper Congo Rapids, is within the large Cuvette Centrale ecoregion that covers most of the DRC. This ancient continental depression is thought to have formerly been a large endorheic lake, contained by uplifting around the basin. Once the lower section of the Congo River (in the Lower Congo Rapids ecoregion) cut back through the Crystal Mountains to meet the endorheic lake, possibly in the region of Malebo Pool, the lake drained leaving the extensive, pristine forests, networks of tributaries to the main Congo channel (see below), and flooded wetlands of the Cuvette Centrale. The lakes Mai-Ndombe and Tumba (which form two discrete ecoregions at the junction of the Sudanic Congo, Cuvette Centrale, and Kasai ecoregions) are thought to be remnants of the former lake (Lévêque 1997; Thieme et al. 2008). There are many other, smaller swamps that are either permanently or seasonally flooded. These forest swamps are typically "blackwater" containing very low dissolved oxygen and high carbon dioxide concentrations, hence low pH values in the range of 4 or 5. They typically have muddy substrates overlain by large amounts of allochthonous plant materials that

Fig. 4 Main channel of Congo River between Kinshasa and Bumba, showing wide anastomosing channels (Photo credit: Jos Snoeks © Rights remains with the photographer)

fall into the swamps from the forest cover or are washed in from stream networks (especially during flooding) (Stiassny et al. 2011). The Congo main channel in the Cuvette Centrale is a deep brown color from the muddy sediment load and is characterized by wide, anastomosing channels (Fig. 4) without surface rapids. Several large rivers drain into the Congo in this middle section, significantly increasing the volume of water flowing down the main channel of the Congo. The largest of these is the Ubangi, at the north of the Congo Basin. The Ubangi originates at Yakoma where the Boma and Uele rivers meet – the drainage of the latter comprising the Uele freshwater ecoregion. The Ubangi drainage forms most of the Sudanic Congo (Ubangi) ecoregion and extends from the Central African Republic to its junction with the Congo just south of Mbandaka. The Sangha runs north-south, parallel to the lower part of the Ubangi, forming the Sangha ecoregion, draining large parts of the Republic of the Congo and extending into Cameroon. Other large rivers joining the middle Congo from the north include the Aruwimi, Itimbiri, and Mongala.

The Lomami, Lulonga, Ruki (with several large tributaries), Lukenie, and Kasai rivers drain the central and southern parts of the Congo Basin. The Kasai and its tributaries form the very large Kasai ecoregion; several of those tributaries join the Kasai from the south and drain a large part of the southern and southwestern DRC and northern Angola.

Fig. 5 View over Malebo Pool, near Kintele, Republic of the Congo (Photo credit: Ian Harrison © Rights remain with author)

The flow of the Congo slows considerably at the end of its middle section fanning out to form Malebo Pool (a discrete ecoregion), a shallow, lake-like expanse up to 28 km across with many extensive sand islands (Fig. 5). The large cities of Kinshasa (DRC) and Brazzaville (Republic of the Congo) are situated at the pool's outflow, on its southern and northern banks, respectively. The short, lower section of the Congo (498 km long) starts at this outflow and includes the Lower Congo Rapids ecoregion comprising the main channel of the Congo from below the pool to Matadi and the Lower Congo ecoregion that lies to the south of the river between Kinshasa and Banana Point. The river descends 280 m over the Lower Congo Rapids ecoregion, with at least 32 and perhaps as many as 66 cataracts (Robert 1946; Beadle 1981; Thieme et al. 2005) (Fig. 6). The largest of these are the Inga Rapids (see below). The mouth of the Congo at the Atlantic Ocean is between Banana Point in the DRC and Sharks Point in Angola. The sediment-bearing plume of the river extends over 20 km into the Atlantic, although the surface freshwater plume extends up to 800 km from the mouth (Runge 2007).

Biodiversity

The Central African rainforests of the Congo Basin and adjacent Lower Guinea (to the west of the Congo Basin; Stiassny and Hopkins 2007) have the greatest biodiversity on the African continent, harboring over 1,200 fish species,

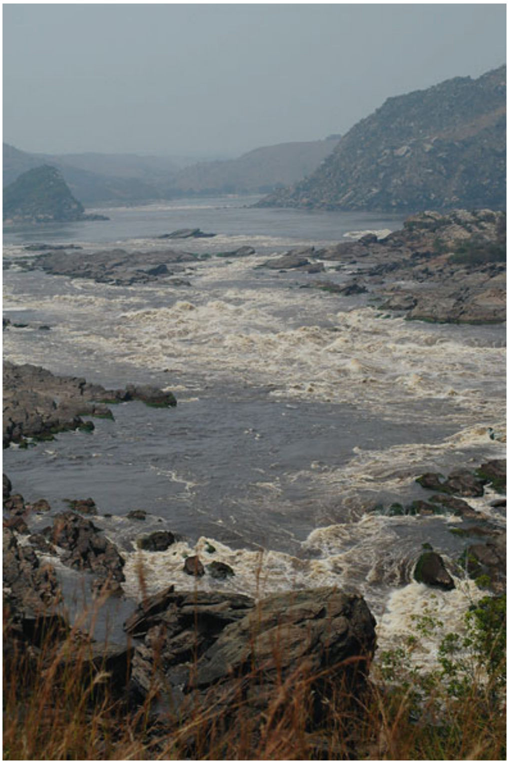

Fig. 6 Rapids in Lower Congo (Photo credit: Uli Schliewen © Rights remain with photographer)

400 mammal species, 1,000 bird species, and over 10,000 vascular plant species (CARPE 2001; African Development Bank 2006). There is also a rich herpetofauna, with over 280 aquatic frogs and about 20 aquatic snakes, turtles, and crocodiles (Brummett et al. 2009). The middle to lower sections of the Congo and the lower part of the Ubangi have more than ten co-occurring species of turtle, which is high (only two subbasins in the world have as many as 18 or 19 co-occurring species) (Buhlmann et al. 2009). These large numbers are also likely to be underestimates because taxonomic surveys are uncommon and the flora and fauna are poorly documented for the region (Brummett et al. 2011). As new surveys are undertaken and existing museum collections reexamined, new species are frequently discovered (e.g., Lévêque et al. 2005; Frost et al. 2006). There is a clear imperative for further research and field collections, to obtain better knowledge of the freshwater species diversity and its conservation status.

Regions of greatest species richness are found along the main channel of the Congo and its two main tributaries, the Kasai and the Ubangi (Brooks 2011). This is mainly because fish species richness is very high for these rivers. The Congo River has the highest species diversity of fishes of any freshwater system in Africa and, globally, is second only to the Amazon (Lundberg et al. 2000; Teugels and Thieme 2005).

High freshwater biodiversity in the Congo Basin is likely due to the dense and extensive hydrographic network and long geomorphic stability largely unaffected by the rifting and Miocene volcanism in Eastern Africa. In the Cuvette Centrale, the large amounts of allochthonous materials (see above) provide rich nutrient resources. However, the waters have low dissolved oxygen and high carbon dioxide concentrations (see above) and restrict the habitat availability to species that are adapted to these conditions (e.g., fishes with accessory breathing organs). Although many of the rivers of the Congo Basin are low-gradient, “blackwater” systems (Thieme et al. 2005; Stiassny and Hopkins 2007), there are also some high-gradient rivers, such as those draining the Albertine Highlands. Stream width, depth, current velocity, and substrate type all affect the spatial and temporal distribution of freshwater species (Lowe-McConnell 1975; Kamdem-Toham and Teugels 1997) effectively partitioning the resource base and increasing opportunities for novel forms to evolve (Hoeinghaus et al. 2003; Dejen et al. 2006). The large amounts of intact forest cover through many parts of the Congo Basin contribute to regional rainfall (Sheil and Murkiyarso 2009), increase productivity, and support community diversity.

Hydrographic barriers between habitats prevent mixing of populations of freshwater species and promote diversification. These barriers may be waterfalls (such as those at the edges of the Congo channel) or rapids in the main channel of the Congo (Thieme et al. 2005; Brummett et al. 2009, 2011). Recent morphological and molecular analyses show that the extremely fast horizontal and vertical currents in the Lower Congo isolate fish populations along the river and laterally across it, thereby promoting diversification of populations over extremely small distances (Jackson et al. 2009; Markert et al. 2010; Lowenstein et al. 2011; Alter et al. 2015).

Malebo Pool and the Upper Congo Rapids in the vicinity of Boyoma Falls are particularly rich in species (Brooks 2011). The Lower and Upper Congo Rapids regions are especially high in species with restricted ranges; this is unsurprising because species found in these regions are generally adapted for life in the fast-flowing and turbid waters of rapids rather than the slower flowing parts of the Congo. In 2011, droughts in the Congo Basin resulted in unusually low water levels that allowed fish collections by one of us (MLJS) in parts of the Congo channel above Malebo Pool that are usually inaccessible. Interestingly, the collections included species that were previously thought to be restricted to the Lower Congo Rapids below Malebo Pool. These results suggest that the apparent restricted ranges of some species may be the result of a simple lack of knowledge, and they are more widespread than currently believed.

Ecosystem Services

The Congo provides about 30% of Africa’s freshwater resources (Brummett et al. 2009), and about 77 million people living in the Congo Basin rely on them. However, the DRC, covering most of the basin, lacks adequate policies or enforcement for sustainable management and conservation of these freshwater resources.

Congo Basin fishes are an important food resource for local communities and supply markets in towns and cities throughout the basin. Upward of 20% of the population living in the rainforests of Central Africa is thought to be engaged in river fisheries (Brummett and Teugels 2004), and artisanal and traditional fisheries account for 90% of the catch from the Central African rainforests (Mino-Kahozi and Mbantshi 1997). The maximum total annual catch between 1980 and 1984 was 119,500 tons/year (not including the Ubangi) with a production value of US$47.8 million/year and an estimated potential catch of 520,000 tons/year, with a value of US$208 million/year (Neiland and Béné 2008). Fishes represent over 40% of the animal protein supply to people living in the DRC (UNEP 2010) – although this includes fisheries from the Rift Valley lakes. In the region of the Salonga National Park, in the Cuvette Centrale, fishing represents 61% of the total cash income even for households that are dependent on more than one activity (i.e., not just fishing) (Béné et al. 2009). Men and women are both involved in fishing; men tend to fish the main channels for larger fishes and they sell their catch, while women fish river margins for smaller fishes that are kept for home consumption. Fishing is a "bank in the water" for these communities (Béné et al. 2009) because it provides people with quick access to cash that is necessary to buy basic necessities and manufactured goods and for their children's education. Even so, the fishery could be better managed to reduce waste and thus take pressure off other forms of non-timber forest products, including other bushmeat (Shumway et al. 2003).

Large floodplain fisheries, such as those of the Cuvette Centrale, are highly dependent on the seasonal flood cycle because the large fish populations are sustained by seasonal access to the flooded forest. The species can feed and spawn in the flooded regions, and the floods bring extra nutrients from the forest into the aquatic ecosystem, thereby increasing their productivity.

Commercial fisheries for the aquarium trade do not appear to be a threat to native fishes in Central Africa at present (Stiassny et al. 2011). Instead, Brummett (2005) has proposed that there are opportunities for a locally managed, sustainable fishery for the aquarium trade in African freshwaters that could support rural livelihoods and integrate the community in conservation of freshwater habitats.

The river network in the Congo Basin is an important transport and trade route, supplying goods and services that are essential for local economies and livelihoods. Hydropower is another important resource supplied by the Congo River. At the end of 2005, most of the capacity for generating electricity within the Congo Basin came from hydropower, and this is a small fraction of the overall hydropower potential of the basin (Brummett et al. 2009). The largest dam project for Central Africa is in the Lower Congo Rapids ecoregion at Inga. Two dams (Inga I and II) are operational, but are working at only half their installed capacities of 358 and 1,424 MW, respectively (Brummett et al. 2009). Numerous plans have been proposed to build more dams at Inga with capacities ranging from 4,500 to 39,000 MW and then later, if realized, would represent the largest hydroelectric power generation project on the planet. An objective for these dams is the production of hydroelectric power that could be exported to other parts of Africa (SNEL 2002) and even beyond to southern

Europe. However, the environmental and social effect of the dams, associated infrastructure, and transmission lines could be very significant (Brummett et al. 2011; Winemiller et al. 2016; and see below).

Other existing dams in the Lower Congo include the 17 m Zongo Dam on the Inkisi River (built to supply power to Kinshasa) and the 36 m Djoue Dam on the Djoue River near Brazzaville (FAO 2013). The 30 m Mobaye Dam is on the Ubangi, and in the upper parts of the Congo, several large dams have been built on the headwaters of the rivers, to supply power for mining industries in the region. Three large dams of over 70 m exist on the Upper Lualaba, and smaller dams (less than 20 m) are on the Lufira.

Threats to Biodiversity

Within the basin, loss of riparian habitat through deforestation and reduction of water quality through pollution and sedimentation are two of the main threats to freshwater ecosystems (Brummett et al. 2011). Yet even by the mid-1990s, 37% of the total exploitable forest within the DRC had been designated for timber concessions (Meditz and Merrill 1994).

There are multiple causes of deforestation in addition to commercial logging: land conversion for mining, agriculture, and human habitation; and felling of trees for firewood, especially for the production of charcoal for cooking fuel that is transported, often over long distances, into towns and cities. The Congo Basin had lost an estimated 46% of its rainforest to logging and conversion to agriculture and continues to lose forested watershed at an average rate of 7% per year (Revenga et al. 1998). Deforestation is particularly severe in the Lower Congo Rapids, Upper Congo, and Kasai ecoregions (Brummett et al. 2011), and the clearing of riparian cover for charcoal production, often denuding tributaries near population centers, is an increasing threat at local and regional scales (e.g., Iyaba et al. 2013).

Conversion of forest to oil palm is especially evident in the Upper Congo ecoregion, and Chinese subsidization is anticipated to support significant oil palm expansion around Lac Tumba (Brummett et al. 2011). Highly destructive slash and burn agriculture already occurs in many parts of the basin and has denuded riparian vegetation along large sections of the entire Congo main channel. Deforestation opens up habitat for exploitation by other activities, such as mining for gold, diamonds, and other minerals. This occurs in several parts of the Congo Basin and is a particular problem in the Upper Lualaba and Kasai ecoregions (Brummett et al. 2011; Darwall and Smith 2011, Fig. 2.1; Stiassny et al. 2011). Other potential, extractive threats include oil and gas extraction. Oil in the lower part of the Kasai drainage (Shumway et al. 2003) and methane under Mai-Ndombe could attract industrial activity with potentially dire environmental impacts (Brummett et al. 2011; Darwall and Smith 2011: Fig. 2.1).

Significant additional consequences of deforestation, agriculture, and mining are erosion and increased sediment loads into freshwater systems, as described for the

Lac Tumba region by Inogwabini et al. (2006) and for the Nsele by Iyaba et al. (2013). In the Lower Congo Rapids, small-scale mining and sandstone quarrying along the river increase the turbidity and sediment deposition that are already high due to sediment runoff from the heavily deforested hillsides. The increased sediment load to the Ubangi River near Bangui has reduced river depth to the extent that shipping is impeded several months of the year (Brummett et al. 2009; Darwall and Smith 2011: Fig. 2.1). Increased surface runoff from cleared land also increases flooding risk. Loss of riparian cover and disturbances to hydrology and water quality significantly affect aquatic biodiversity (Growns and Davis 1991; Bradshaw et al. 2007, 2009; Brummett et al. 2009, 2011). Industrial development, such as mining, has been hampered by civil unrest in the DRC and neighboring countries (e.g., Rwanda, Angola), and this has reduced the potential threats posed to freshwater ecosystems. As areas restabilize (e.g., the Kasai Basin), there is high probability of resumed mining and associated impacts; therefore it is especially important that effective environmental planning is included during recovery (Thieme et al. 2005; Brummett et al. 2011).

While there are fewer dams in the Congo Basin than in many other parts of Africa, and most are in the Lower Congo Rapids ecoregion or in the headwaters (in the Upper Congo and Upper Lualaba ecoregions), additional dams are likely to be built (Winemiller et al. 2016, and see above). As currently implemented, dams have a profound impact on natural flow regimes and sediment load that determine ecosystem structure and function (Bunn and Arthington 2002). The associated power stations and other infrastructure, including clearing for power lines, roads, and housing for workers, also add significantly to deforestation, pollution, and siltation impacts on the aquatic system.

Pollution is also a serious threat from human settlement and industry in parts of the Congo Basin. Ninety-five percent of factories in the DRC discharge their waste directly into rivers and other freshwater systems (UNEP 1999). Pollution is greatest near large urban centers such as Kisangani (Thieme et al. 2005) and around Brazzaville and Kinshasa where large quantities of sewage are released into Malebo Pool and the Congo River. Lead and waste oil originating from industry, from cars, or from boat traffic add to this pollution. Significant pollution by heavy metals, particularly lead and cadmium, as far as approximately 300 km downstream from Kinshasa has been reported (Shumway et al. 2003), and the main channel of the Ubangi is affected by pollution from the city of Bangui (Brummett et al. 2011; Darwall and Smith 2011: Fig. 2.1).

Habitat disturbance is also caused by invasive species. In the Congo Basin, the greatest threats come from introduced aquatic plants that can cover vast expanses of water surface, thereby reducing available light, impacting water quality, and rendering the habitat unfavorable to many species. The most significant invasive plant species in Central Africa are *Pistia stratiotes*, *Eichhornia crassipes*, *Cyperus papyrus*, and *Lasimorpha senegalensis* (Ghogue 2011). According to Welcomme (1988), 16 fish species have been introduced to the Central African region; however, there is relatively little information on their impacts on native faunas, and, compared to many other parts of Africa, the number of exotic species is modest. Efforts to impede the introduction of additional exotic species, particularly of tilapiine cichlids, are of high priority.

Migration due to civil unrest in Central Africa has forced human populations to migrate into previously unsettled areas, and displaced populations often settle along waterways (Thieme et al. 2008) where they cut riparian forest for cooking fuel, with concomitant effects on ecosystem condition (see above). The influx of people into previously undisturbed areas, with their need to use the available natural resources for their well-being (e.g., food, housing), places pressure, particularly on national parks and reserves, which are attractive areas for relocation. Areas where this is a particular problem include the eastern parts of the Upper Congo, Uele, and Albertine Highlands ecoregions and the Sangha ecoregion near the confluences of the Sangha, Likouala, and Ubangi rivers (Brummett et al. 2011).

Overharvesting of freshwater species, although not as intense as in many other parts of Africa, has been reported for many regions. High levels of fishing occur along the Congo and its tributaries in the vicinity of Malebo Pool (supplying markets of Kinshasa and Brazzaville; Thieme et al. 2005, 2008); in the Mai-Ndombe ecoregion (Stiassny et al. 2011) and neighboring Lac Tumba ecoregion (Inogwabini et al. 2010), with declining yields and loss of large species; and in the region of Mbandaka (supplying the town's markets; Shumway et al. 2003), with a high proportion of juveniles in fisheries in the Mbandaka-Ngombe region (reported for 2003), indicating the stocks were overexploited (ERGS Research Group, cited in Thieme et al. 2005; Stiassny et al. 2011). Unregulated fishing also occurs in parts of the Cuvette Centrale (Iyaba and Stiassny 2013), Kasai, Upper Lualaba, and Bangweulu-Mweru ecoregions (Darwall and Smith 2011, Fig. 2.1; Stiassny et al. 2011). In the latter, Lake Bangweulu supports an important fishery, although it is at risk from overfishing. The most common cause of overfishing in the Congo Basin is the use of very fine mesh nets and fish poisons that indiscriminately kill individuals of all sizes for many species (Shumway et al. 2003; Inogwabini 2005; Stiassny et al. 2011) and destroy fringing vegetation and nesting areas (Mbimbi et al. 2011).

Climate change potentially creates additional layers of stress to freshwaters in Africa and is likely to compound some of the threats noted above. While it is expected that aquatic species will experience hydrological change over the next several decades, it is not clear what the ecological effects will be. This uncertainty is partly because climate change models for Africa are in their infancy, and impacts are likely to be complex and regionally specific (Schiermeier 2008; Matthews et al. 2011). Thieme et al. (2010) expected that runoff and discharge would increase in the Guinean-Congolian forests, but other regional changes have been described; for example, Inogwabini et al. (2006) describe a decrease in precipitation and increase in temperature in the latter part of the twentieth century. African ecosystems and species have a history of resilience in response to dramatic eco-hydrological changes (Matthews et al. 2011). Therefore, conservation efforts should be directed at enabling these climate-adaptive capacities in preparation for new climate regimes (see below).

Conservation and Management Priorities

The Congo Basin is rich in natural resources (see section "Ecosystem Services" above); as development proceeds across the basin, it is imperative that this is accompanied by effective environmental planning to ensure that resources are managed wisely and the ecosystems that provide them are adequately protected. Such environmental planning is dependent upon a comprehensive and reliable baseline of ecological and environmental data; without which it is impossible to identify conservation priorities or assess when natural resources are being used sustainably. However, much of the Congo Basin is understudied, and significant gaps remain in our knowledge of the distribution of species, their ecology, and the extent of threats they face. Central Africa has the highest proportion of "data-deficient" species for any part of Africa, according to IUCN's assessments of the status of the freshwater biodiversity present (Brooks 2011). Hence there is a priority to conduct more surveying and monitoring throughout the basin. This also requires increased investment in local resources to support this work, including the training of additional in-country scientists and conservation managers.

Only 3% of the Congo Basin's 5,255 subcatchments are included within existing protected areas (Linke et al. 2012); therefore it will be important to designate additional protected areas with a focus on freshwaters and their biodiversity (Harrison et al. 2016). The importance of conserving as much original habitat as possible cannot be overstated, since this is the key to ensuring the resilience of the existing biodiversity. Plans for designating protected areas must take into account the high connectivity within the dense network of rivers in the basin (Brooks 2011). There is also a need for additional resources for management of existing protected areas, especially those that are being affected by human encroachment through civil unrest (Stiassny et al. 2011).

There is a growing consensus that effective management of freshwater ecosystems requires an understanding of the environmental flow requirements that sustain the ecosystem at the same time as supplying the necessary freshwater services to people (Poff and Matthews 2013). This is especially important in preparation for adapting to the modified hydrological conditions that will result from climate change. Several management actions can help ensure species resilience to climate change (Thieme et al. 2010), most notably minimizing perturbation of water quality and maintenance of natural flow regimes. Maintaining connectivity between freshwater ecosystems and protection of spatial and thermal refugia will also be important; hence there is a need to identify optimum sites for designation as protected areas (see above).

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