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# Fishing for conservation of freshwater tropical fishes in the Anthropocene

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**Abstract**

1. The ecosystem services provided by freshwater biodiversity are threatened by development and environmental and climate change in the Anthropocene.
2. Here, case studies are described to show that a focus on the shared dependence on freshwater ecosystem functioning can mutually benefit fisheries and conservation agendas in the Anthropocene.
3. Meeting the threat to fish biodiversity and fisher livelihood is pertinent in developing regions where there is often a convergence between high biodiversity, high dependency on aquatic biota and rapid economic development (see Kafue River, Logone floodplain, Tonle Sap, and Rio Negro case studies).
4. These case studies serve as evidence that biodiversity conservation goals can be achieved by emphasizing a sustainable fisheries agenda with partnerships, shared knowledge and innovation in fisheries management (see Kafue River and Kenai River case studies).
5. In all case studies, aquatic biodiversity conservation and fisheries agendas are better served if efforts focused on creating synergies between fishing activities with ecosystem functioning yield long-term livelihood and food security narratives.
6. A unified voice from conservation and fisheries communities has more socio-economic and political capital to advocate for biodiversity and social interests in freshwater governance decisions.

KEYWORDS
biodiversity, ecosystem services, fish, fishing, floodplain, hydropower, river

## 1 | INTRODUCTION

The apparent dichotomy between biodiversity conservation and resource exploitation has been a common narrative for almost all common-pool natural resources (Gowdy & McDaniel, 1995; White et al., 2009; Young et al., 2010), but is especially pervasive in fisheries (Redpath et al., 2013). In developing countries, freshwater fisheries are a valuable ecosystem service as a source of nutrition, livelihood and income (Lynch, Cooke, et al., 2016; Lynch et al., 2017; Welcomme et al., 2010), but the freshwater ecosystems from which they are

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derived are among the most threatened globally (Dudgeon et al., 2006; Strayer & Dudgeon, 2010). Freshwater biodiversity conservation efforts are undoubtedly necessary to protect biodiversity (Arthington, Dulvy, Gladstone, & Winfield, 2016), but restricting access to these resources may compromise fisheries-dependent communities exploiting biological productivity (Cardinale et al., 2012; Díaz, Fargione, Chapin, & Tilman, 2006; McShane et al., 2011). Overshadowing this interaction between fish conservation and exploitation are environmental and climate change in the Anthropocene, which threatens the health and functioning of the freshwater ecosystems that underpin both fish biodiversity and fisheries (Young et al., 2010).

In recent years, two divergent paradigms have emerged in what has been termed the 'new conservation debate'. One paradigm embraces biodiversity conservation at all costs (i.e. 'nature protectionists'), whereas the other embraces a more development-oriented agenda (i.e. 'social conservationists') focused on sustainable use and poverty alleviation (Miller, Minteer, & Malan, 2011). Beyond the ethical debates that arise with such discourse (Minteer & Miller, 2011), there is a practical need to consider opportunities that mutually benefit both biodiversity and society (Lynch et al., 2016). Emphasizing the ecosystem services provided by freshwater biodiversity can raise the vital need to protect and conserve ecological interests within an increasingly economically driven era (Cowx & Portocarrero Aya, 2011; Daily et al., 2000).

There is increasing evidence showing that biodiversity conservation can help to address poverty issues and increase ecosystem resilience (Adams et al., 2004; Brockington, Igoe, & Schmidt-Soltau, 2006; Folke et al., 2004). Similar successful synergies between conservation and exploitation are less common, however, for freshwater fish biodiversity but a critical target for the Anthropocene (Cooke et al., 2016; Cowx & Gerdeaux, 2004; Dudgeon et al., 2006; Vörösmarty et al., 2010; Welcomme et al., 2010). This task takes on greater urgency in tropical freshwater fisheries in developing countries because of the convergence of high biodiversity, high dependence on fisheries by local communities and rapid environmental change driven by economic development (Andrew et al., 2007).

The aim of this perspective paper is to draw attention to the opportunity for mutually beneficial cooperation between communities that seek freshwater fish conservation with those engaged in sustainable fisheries to meet shared threats in the Anthropocene. The all-encompassing threat to freshwater biodiversity from Anthropocene environmental and climate change necessitates forming alliances between stakeholders that value and depend on biodiversity and freshwater ecosystem function. Sections 1.1 and 1.2 review tropical freshwater biodiversity, the value of fisheries to humans and the threats to both in the Anthropocene. Section 2 describes five case studies where actions undertaken to preserve or enhance fishery productivity and fisher well-being have also served biodiversity interests. These illustrate how emphasizing sustainable inland fisheries as an ecosystem service of healthy and functioning freshwater ecosystems can positively contribute towards freshwater biodiversity conservation.

## 1.1 | Freshwater fish biodiversity and the value of fisheries

Fresh water comprises just 0.02% of the total water on Earth, yet freshwater ecosystems are among the most biodiverse (Moss, 2010). The >10,000 named freshwater fish species, a figure considered to be an underestimate of true species number (Balian et al., 2010), equate to roughly 40% of all global fish biodiversity and a quarter of all vertebrates (Dudgeon et al., 2006). Reasons for this high biodiversity include multiple isolating mechanisms, such as physical, chemical and biotic barriers associated with speciation, and in tropical systems, expanding and contracting floodplains combined with a lack of glacial extinction events (Hewitt, 2004).

The social importance of freshwater fisheries production parallels the ecological importance of freshwater fish biodiversity (Lynch, Cooke, et al., 2016). The reported annual production of fisheries occurring in inland waters is $11.47 \times 10^6$ t, which is roughly 12% of the total global fisheries production (Food and Agriculture Organization of the United Nations [FAO], 2018; Funge-Smith, 2018). Over 90% of freshwater harvest is destined for human consumption, with very little discarded as bycatch, and over 80% of this harvest occurs in low-income and food-deficit countries (Funge-Smith, 2018). Freshwater fisheries provide food for billions and livelihoods for millions worldwide (FAO, 2014). Despite efforts highlighting their value to food security, nutrition, livelihoods and recreation, fisheries and fishes are still largely overlooked in valuing freshwater services (Cooke et al., 2016).

The importance of freshwater fisheries as food cannot be overstated. Fish have high levels of essential minerals (i.e. calcium, iron and zinc) and vitamins, particularly vitamin A, essential to human health (Hansen et al., 1998; Kawarazuka & Béné, 2011). In some regions, freshwater fish supply the principal source of animal protein, micronutrients and essential fatty acids (Youn et al., 2014). Beyond nutrition and food security, more than 60 million people in low-income countries rely on freshwater fisheries as a source of livelihood, with women representing more than half the individuals in fisheries supply chains (FAO, 2014). Freshwater fishes have a larger role in nutrition for poor people worldwide than marine or aquaculture fisheries do (McIntyre, Reidy Liermann, & Revenga, 2016).

The full economic and social value of freshwater fisheries is undervalued because of the difficulty in assessing a highly dispersed and diffuse activity and inadequate infrastructure for reporting (Cooke et al., 2016). Official statistics provided by the FAO (see FAO, 2018; Funge-Smith, 2018) are probably under-reported by more than 60% (Fluet-Chouinard, Funge-Smith, & McIntyre, 2018). Household income from freshwater fisheries is difficult to assess because many of the transactions are local in scope; but where data exist, the contribution of inland fisheries is high. In addition, small-scale and subsistence freshwater fisheries in low-income developing countries are often part of mixed livelihood portfolios, so the full breadth of their contribution is underestimated (Béné, Macfadyen, & Allison, 2007), and thus undervalued.

## 1.2 | Threats to freshwater fishes

The Anthropocene represents a critical period for freshwater biodiversity (Reid et al., 2018; Strayer & Dudgeon, 2010). Current extinction rates for freshwater species are similar to, or greater than, those experienced during previous transitions between glacial epochs (Vörösmarty et al., 2010). An estimated 10,000 to 20,000 freshwater fishes are either at risk or already extinct (Dudgeon et al., 2006; Strayer & Dudgeon, 2010), and 65% of global river discharge and the aquatic habitats it feeds are under moderate to high threat (Vörösmarty et al., 2010).

Human use and alteration of freshwater systems are the largest drivers of threats to freshwater biodiversity (Brummett, Beveridge, & Cowx, 2013; Dudgeon et al., 2006; Vörösmarty et al., 2010). Fishes, and other freshwater biota, require a reliable quantity and quality of fresh water, distribution and availability of diverse habitats to support multiple life stages and species, refuge from extreme events, suitable connectivity between habitats, intact trophic interactions and the maintenance of essential life-history cues, such as seasonally appropriate changes in water temperature (Steel, Beechie, Torgersen, & Fullerton, 2017) and discharge, sensu the natural flow regime (Poff et al., 1997). Degraded and fragmented freshwater environments compromise the form and function of the ecosystem, and the ecosystem services they provide (Table 1).

Tropical water bodies are among the largest freshwater systems by volume, but they are also among the most stressed (McIntyre et al., 2016). Threats include, but are not limited to, damming, river engineering and associated morphological changes, water and sediment extraction, land-use change and non-point-source pollution, human population growth and growing per capita resource consumption (Dudgeon et al., 2006; Garcia-Moreno et al., 2014; Strayer & Dudgeon, 2010; Vörösmarty et al., 2010). Water development projects that alter or obstruct flow, such as hydroelectric power dams and agricultural irrigation, are at the forefront of human stressors on freshwater systems (Brummett et al., 2013; Liermann, Nilsson, Robertson, & Ng, 2012). Compounding these regional stressors are shifts in precipitation patterns under a changing climate (Comte & Olden, 2017; Fu, Wu, Chen, Wu, & Lei, 2003; Kundzewicz et al., 2014, 2008; Woodward, Perkins, & Brown, 2010).

A primary focus of this article is to highlight synergies between fish conservation and fisheries, but the potential impacts of fishery exploitation on freshwater fishes must be acknowledged. Fishing can lead to undesirable changes in size distribution, community structure and extinction (Allan et al., 2005; Castello, Arantes, Mcgrath, Stewart, & Sousa, 2015). Notwithstanding these adverse impacts, fishing in tropical regions are primarily small-scale and dispersed activities. Indeed, the presence and impacts of freshwater stress and environmental change in these same systems makes it difficult to isolate a clear signal

**TABLE 1** Examples of Anthropocene threats to freshwater habitat, fish and fisheries

| Human activities | Mechanisms of impact to fish biodiversity and freshwater fisheries | Freshwater habitat response | Freshwater fish and fisheries response |
|---|---|---|---|
| Urban run-off<br>Water withdrawal<br>Forest removal<br>Dams<br>Climate change | Altered thermal regimes | Loss of cool water refuges, loss of natural spatiotemporal patterns in water temperature | Lethal high or low temperatures, shifts in growth rate and phenology, barriers to migration, altered food sources, increased disease |
| Urbanization<br>Water withdrawals<br>Forest removal<br>Dams<br>Climate change | Altered flow regimes | Reduced habitat quantity, increased temperatures, altered sediment regimes | Increased population density, reduced food resources, desynchronized food webs |
| Urbanization<br>Water withdrawals<br>Forest removal<br>Dams<br>Mining<br>Climate change | Shifts in transport of sediment and other materials | Reduced habitat complexity, fill and scour, lack of habitat elements | Reduced spawning gravels, smothering of eggs and juveniles, scouring of fishes |
| Channelization<br>Dams<br>Water withdrawal | Reduced channel complexity | Loss of habitat complexity, increased flow velocity, loss of bank habitat | Reduced opportunities for growth and local migration |
| Point-source pollution<br>Urban run-off<br>Forest removal<br>Mining | Reduced water quality | Reduced habitat quality | Direct lethal effects, direct sublethal effects on growth, indirect effects such as increased parasites and disease |
| Dams<br>Weirs<br>Point-source pollution<br>Water withdrawal | Barriers to connectivity | Reduced movement of sediment and wood, altered downstream flows and thermal regimes | Reduced habitat access, barriers to migration, effects of altered flow and temperature as already noted |

of the effect of small-scale fishing on fish biodiversity (Allan et al., 2005). Where large-scale negative impacts of overfishing do occur, they are mostly associated with high-volume industrial and commercial fishing activities, typically in the largest lake systems (Allan et al., 2005). Moreover, continued degradation of freshwater ecosystems in the Anthropocene may reduce the capacity of fresh waters to support even small-scale fishing activities.

## 2 | WHERE INLAND FISHERIES ENHANCE FRESHWATER AND FISH CONSERVATION

To illustrate the conservation benefits from pursuing fisheries as an ecosystem service, five case studies are described where actions undertaken to benefit the fishery and fisher livelihoods have also had positive impacts on the freshwater environment and fish biodiversity. These case studies include both temperate and tropical systems because their lessons are mutually relevant. They are the Logone Floodplain in Cameroon, Tonle Sap in Cambodia, Kafue Flats in Zambia, Rio Negro in Brazil and the Kenai River in the USA. The case studies described here are not an exhaustive list but represent a diversity of systems in which the authors specialize.

Each case study description is structured as: (a) a description of the freshwater, fishes and fishery system; (b) the threat faced by the ecological and fishery systems; and (c) the action(s) undertaken to promote sustainable fisheries and the resulting benefit to biodiversity and the fishery.

### 2.1 | Restoring livelihoods and ecosystem functioning by reflooding the Logone Floodplain, Cameroon

The Logone Floodplain in northern Cameroon covers roughly 7,000 km$^2$ and is annually flooded by overbank flow from the Logone River. The floodplain is a spawning and nursery ground for resident fish populations and Lake Chad. Fish biodiversity include species in the families Alestidae, Siluriformes, Mormyridae and Cichlidae (Bénech & Quensière, 1982; Durand, 1970; Ziébé, 2015). These fishes have evolved strategies to cope with dry-season conditions when the water area can be <5% of peak flood. In the dry season, longitudinally migrating fishes, such as mormyrids and a few Siluriformes, migrate to Lake Chad and return as flooding begins. In comparison, latitudinally migrating fishes, like Cichlidae and Siluriformes, spend the dry season on the floodplain in permanent water bodies and have evolved physiological adaptations to survive high temperature and low dissolved oxygen in stagnant water habitats. The floods drive the floodplain's ecological productivity and, in a semi-arid region, are an important ecosystem service supporting fishing, farming and pastoralist livelihoods (Loth, 2004; Moritz et al., 2016; Figure 1).

Fish biodiversity and productivity of floodplain ecosystems are dependent on flooding patterns and are threatened by flow management (Welcomme, 1995). In 1977, to stimulate regional economic growth and greater agricultural production on the floodplain, the Government of Cameroon and the World Bank implemented the Semry II rice production project (Loth, 2004). The project constructed the 2 km wide Maga Dam, diverting and storing flow from the Logone River for irrigation, which would have led to peak floods under normal discharge patterns to shrink by 30%. However, the 1980s sub-Saharan drought exacerbated the impacts of the dam, and peak floods following the construction of the dam were even smaller (Loth, 2004). Smaller floods led to less ecological productivity, less habitat and compromised the floodplain's connectivity with Lake Chad. A decline in fishes forced fishers to emigrate to other fishing grounds or diversify to non-fishery livelihoods such as farming (Loth, 2004). Increased resilience from this livelihood diversification (Allison & Ellis, 2001), however, was likely to have been small as the production of non-fishing livelihoods in the region would have still relied on the same source (i.e. floods).

To reverse declines in the floodplain's terrestrial biodiversity and the loss of livelihoods for fishers, farmers and pastoralists, a multiyear reflooding programme (1988 and 1992–1995) recovered 65–93% of the lost flooded area (Loth, 2004), and a recovery of terrestrial animal and plant biodiversity was observed (Scholte, Kirda, Adam, & Kadiri, 2000). Ecological monitoring did not include fish biodiversity, and the impact of restoration efforts on aquatic biodiversity cannot be quantitatively evaluated. Nevertheless, fishes almost certainly benefited, as an additional 1,777 t of fish are estimated to have been caught in the extra 200 km$^2$ of reflooded floodplain (Loth, 2004; Welcomme & Hagborg, 1977). The return of fishers to the floodplain in the years following the reflooding is further supporting evidence that there was an improvement in fisheries production. Although the reflooding programme was ultimately not aimed at fish biodiversity conservation per se, fishes benefitted from flood restoration intended to support fisher livelihoods.

### 2.2 | Community–government co-managing for the fishery and conservation in the Tonle Sap, Mekong River, Cambodia

Cambodia's Tonle Sap Lake in the heart of Indo-Burma is an important part of the Lower Mekong Basin. The annual wet-season monsoon expands the floodplain up to double its dry-season extent, and the flooded habitat serves as an important fish nursery (Campbell, Poole, Giesen, & Valbo-Jorgensen, 2006; Poulsen et al., 2004). The ecosystem has high biodiversity with >300 fish species, with an especially high biodiversity of cyprinid species, including 12 iconic 'giant' species, such as the giant Mekong catfish (*Pangasianodon gigas*), giant barb (*Catlocarpio siamensis*) and giant stingray (*Himantura chaophraya*) (Lim, Lek, Touch, Mao, & Chhouk, 1999; Poulsen et al., 2004). The Tonle Sap is one of the world's most productive fisheries (~400,000 t annually), providing food security and livelihoods for millions of people in the region (Baran, Jantunen, & Chong, 2007). Similar to the Logone Floodplain system, many fish species have evolved diverse life-histories, feeding strategies and adaptations to the pulsing drought–flood conditions, such as the air-breathing snakeheads (*Channa* sp.) and climbing perch (*Anabas testudineus*) and


**FIGURE 1** Fish biodiversity in the Logone floodplain includes species from Alestidae, Mormyridae and Clariidae families (a). The reflooding programme brought back fish biodiversity and productivity as well as the return of a regionally important dried catfish fishery (b).

seasonally migrating carps, like silver carp (*Cyclocheilichthys enoplos*) (Campbell et al., 2006).

The lake currently faces multiple stressors, including overfishing, and is experiencing declining biodiversity and fish size (McCann et al., 2016; Ngor et al., 2018). Historically, the lake fishery comprised large lots, and fishing access in each lot was operated under leasehold agreements. In an effort to address overfishing pressure and to increase fishing access for communities excluded from the fishery, the government introduced directives in 2000 and 2012 that converted the leasehold lot structure into smaller zones designated as either community-managed fisheries (>400) or government-managed conservation sanctuaries (18) (Hortle, Lieng, & Valbo-Jorgensen, 2004; Kim, Mam, Oeur, So, & Blake, 2013). However, the foundation for community fisheries management was not yet fully established when the directives were announced, and unforeseen challenges emerged. For example, historical management rules controlling commercial and middle-scale fishing, including permitting, seasonal closures and gear restrictions, were now obsolete and there was confusion in how to control them under the new system (Ishikawa, Hori, & Kurokura, 2017). Although commercial fishing was officially banned, similar operations still occurred under the new rules by exploiting unclear definitions and becoming organized 'subsistence' fishing activities. In another example, the newly created conservation sanctuaries were not clearly marked or communicated to fishers (Ishikawa et al., 2017). Indeed, the immediate effect under the new directive was an increase in unregulated and minimally monitored fishing.

To address these problems, appropriate and supportive legislation is being developed and country-wide efforts are being undertaken to educate and train fishers about the law and how to manage fisheries (Oeur, Kosal, Sour, & Ratner, 2014). The Cambodian Government is also revising the Fish Law using a co-management approach, and there is greater involvement of fishers in management decisions (Fisheries Administration, 2016). Training and empowering fishers alongside more robust legal provision for community governance has led to more sustainable fishing activities and greater compliance with new legislation, including communities taking initiatives to establish their own conservation zones within their fishing lots (Oeur et al., 2014). The government-managed conservation sanctuaries have also been successful with increases in fish abundance and biodiversity within their boundaries (Chheng & Elliott, 2016). Empowering and inclusion of fishers in management has led to increased equity, reduced fishing pressure, reduced conflict and improved floodplain protection (Nam et al., 2015; Sovannara, 2014). Improved functioning of community management has restored resident fish biodiversity and increased household fish catches (Brooks & Sieu, 2016; Milne, 2013; Sovannara, 2014).

### 2.3 | Harmonizing conservation with hydropower development in the Kafue River, Zambia

The Kafue Flats in Zambia is a broad alluvial plain 440 km long and 60 km wide (~6,500 km$^2$) along the lower reaches of the Kafue River, a principal sub-catchment of the Zambezi River. The floodplain ecosystem supports exceptional productivity because of periodic inundation of a complex array of lagoons, disconnected river channels, marshes and floodplain grassland (Chapman, Dudley, Miller, & Scully, 1971). This provides habitat for a high diversity of 440 bird species, plus numerous grazing animals, including the endemic antelope, Kafue lechwe (*Kobus leche*), which has a current population less than a third of what it was in the 1970s (Shanungu, Kaumba, & Beilfuss, 2015; World Wide Fund for Nature, 2017). Aquatic biodiversity is similarly high, with 77 fish species recorded in the Kafue system, of which ~20 species are commercially important, particularly three-spotted tilapia (*Oreochromis andersonii*), redbreast tilapia (*Coptodon rendalli*), banded tilapia (*Tilapia sparrmanii*), silver butter catfish (*Schilbe intermedius*), African sharptooth catfish (*Clarias gariepinus*) and blunt-toothed catfish (*Clarius ngamensis*) and, more recently, several non-native species including Nile tilapia (*Oreochromis niloticus*) and greenhead tilapia (*Oreochromis macrochir*) (Chabwela, 1992). Historically, the floodplain fishery was composed mainly of tilapiine and catfish species (Zambia Department of Fisheries, 2017, unpublished data; Figure 2), with natural variability in productivity driven by seasonal flooding, which is influenced by the intertropical convergence climate pattern (Chapman et al., 1971).

Over the last 30 years, the fish and wildlife biodiversity of the Kafue Flats have been subject to numerous threats (Cowx, Lungu, & Kalonga, 2018). The increasing use of small-meshed nets in the fishery has led to a proliferation of Nile tilapia and other small-sized fishes, like stripped robber (*Brycinus lateralis*) and *T. sparrmanii* (D. Tweddle, personal communication, May 2018). This changing fish community has occurred alongside the invasion of non-native red-claw crayfish and the non-native giant sensitive plant (*Mimosa pigra*) around the shores of the major lagoon systems. Both have had impacts on the fisheries: red-claw crayfish damage catches in the nets, and *M. pigra* smothers the shallow littoral breeding habitat of native tilapiine species (Cowx et al., 2018; Shanungu, 2009). Perhaps the greatest current threat to the biodiversity of the Kafue Flats, however, is hydropower development in the form of the Itezhi-Tezhi and Kafue Gorge Dams (Deines, Bee, Katongo, Jensen, & Lodge, 2013). Itezhi-Tezhi is a storage dam, and before its construction in 1978, floods used to extend from between 22 and 60 km from the river channel, but they now only extend 10–15 km. After the completion of Itezhi-Tezhi, annual fish production was estimated to have fallen from around 10,000 to 6,000 t (Cowx et al., 2018). Of great concern, however, is the upgrading of Itezhi-Tezhi from a regulating reservoir that supplements the Kafue Gorge dam into a stand-alone hydropower system (Deines, Bee, Katongo, Jensen, & Lodge, 2013), which will generate daily discharge variability from 20 to 25 $m^3 s^{-1}$ at night, up to 315 $m^3 s^{-1}$ to meet peak demand during the day (Figure 2; Cohen Liechti, Matos, Boillat, & Schleiss, 2015). This would create daily fluctuations in downstream water height as extreme as 1.5 m and affect floodplain ecosystem functioning (Kalumba & Nyirenda, 2017), possibly collapsing both terrestrial and aquatic biodiversity (Chansa & Kampamba, 2009).

In response to the proposed hydropower development, stakeholders, including Zambia Wildlife Authority and the Department of Fisheries, created community-based natural resources management boards to oversee the exploitation of natural resources to the benefit of the local communities (Nkhata & Breen, 2010). They highlighted the importance and value of the key ecosystem services delivered by the Kafue Flats to the national power company to seek a holistic power production regime at Itezhi-tezhi that considers the system's natural resources. This was done by raising awareness of the impacts the proposed flow management would have on fisheries and wildlife, such as the globally important Kafue lechwe, as well as on local sugar agriculture and aquaculture production. The aim was to find a flow management plan that would maintain the natural flood cycle and avoid the daily hydropeaking that would have destroyed the ecosystem by optimizing the use of water to benefit the multiple stakeholders and

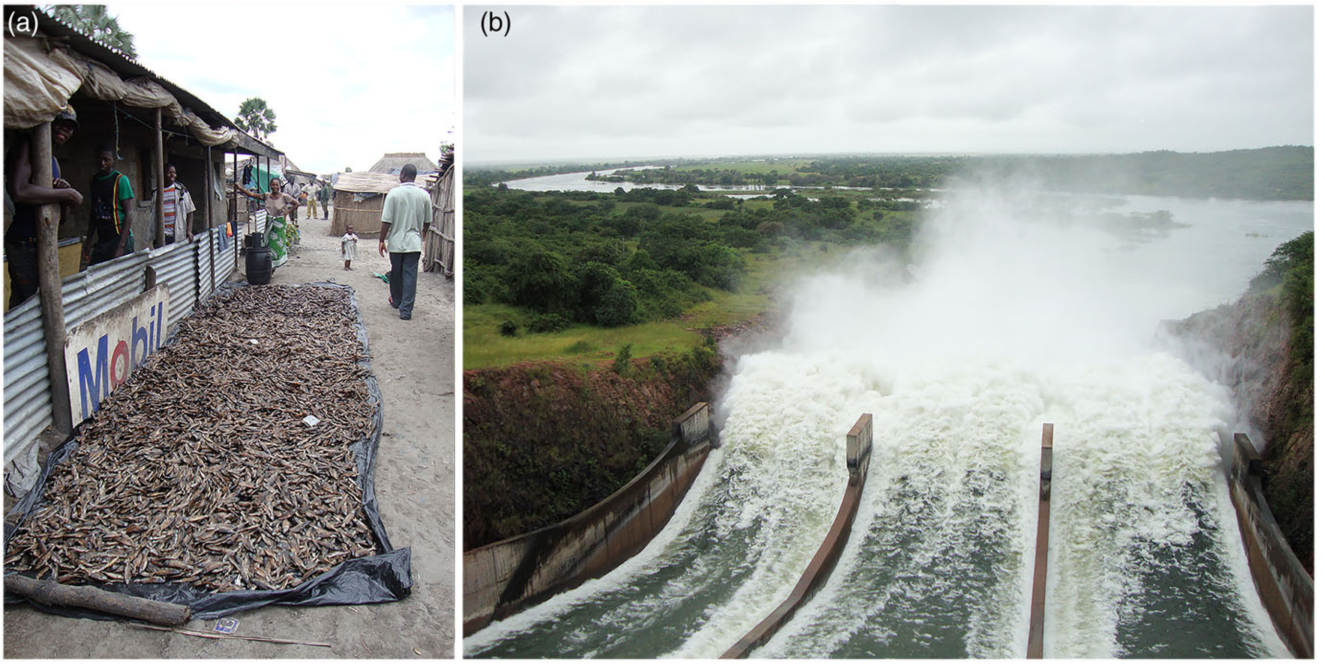


**FIGURE 2** Small-scale fisheries in the Kafue Flats contribute to local community livelihood and nutrition (a), but their productivity is threatened by the Itezhi-Tezhi dam and its manipulation of discharge entering the floodplain (b).

maintain ecosystem services. In this case study, mobilizing key stakeholders through the resources management boards was pivotal in putting pressure on the power company to change its strategy (Haller & Chabwela, 2009), although the extent of the compromise between power generation and system functioning on the modified flow regime remains to be seen.

### 2.4 | Promoting sustainable wild-caught aquarium fisheries, Rio Negro, Brazil

The Amazon basin covers 7,000,000 km$^2$, of which 4,100,000 km$^2$ are located in Brazil (Alho, Reis, & Aquino, 2015). Freshwater biodiversity in the Amazon basin is unparalleled for both flora and fauna, boasting more than 2200 species of fish alone, although this is likely to be an underestimate (Albert & Reis, 2011). The Rio Negro is the largest black-water river in the world at 2,230 km long, with a catchment area of 696,000 km$^2$ (Filizola et al., 2010). With more than 750 fish species described and 90 species endemic to the river basin, the Rio Negro is unique compared with other basin tributaries owing to characteristically nutrient-poor waters and low pH constraints (Alho et al., 2015). It is critical habitat for IUCN Red List species, and intact tropical forests also provide atmospheric carbon sequestering services. In addition, the river has an active aquarium fishery because of the concentration of ornamental fishes (Zehev, Vera, Asher, & Raimundo, 2015).

The health and productivity of Rio Negro fishes are dependent on the health and functioning of the interconnected river, floodplain and forest ecosystems (Firchau, Dowd, & Tlusty, 2013). Environmentally destructive practices, such as slash-and-burn agriculture, threaten the functioning and production of Rio Negro's terrestrial and aquatic ecosystems. The river's aquarium fishery began in the mid-twentieth century and has proved to be a sustainable source of economic revenue and is at present the main economic driver in the mid Negro River (Alho et al., 2015; Chao & Prang, 1997; Zehev et al., 2015), contributing towards alleviating social poverty (Pelicice & Agostinho, 2005). Indeed, the aquarium fish trade accounts for more than half of the economy of the Barcelos municipality (Dowd & Tlusty, 2000; Monticini, 2010), with the cardinal tetra (*Paracheirodon axelrodi*) constituting more than 80% of this catch (Chao, 2001; Figure 3). An emerging threat to the Rio Negro's aquarium fishery is commercial captive breeding programmes, as increased production can reduce demand for wild caught fish harvested from this fishery (Alho et al., 2015). The potential loss of livelihood from an alternative source of fish can reduce community reliance on wild biodiversity and erode the need to protect it.

Project Piaba is a community-based organization stationed in Barcelos with a mission to ensure that the Rio Negro aquarium fishery continues to be a sustainable source of livelihood (Dowd, McFarland, & Joyce, 2017; Dowd & Tlusty, 2000; Norris & Chao, 2002). Poorly managed harvest by the aquarium trade can have adverse impacts (see Raghavan, Ali, Philip, & Dahanukar, 2018), and the project works towards limiting negative impacts of fishing and ensuring the fishery is sustainable. Even to this day, local fishers still persist with manually laborious gear such as collapsible minnow traps, rapiché dip nets and Cacuri traps, because these techniques have a low environmental impact and fish can be taken without damaging the underlying habitat (Chao, 2001). Providing a sustainable and economically viable


**FIGURE 3** Sustainable exploitation of wild-caught cardinal tetra (*Paracheirodon axelrodi*) from the Rio Negro aquarium fishery supports community livelihood and underpins conservation efforts to protect the habitat (a). Fish being held in transfer stations along the bank of the river (b).

livelihood also has benefits that extend beyond the fish and fishery: it reduces community involvement in other potentially more environmentally damaging livelihoods, including exploitation of less renewable biodiversity and natural resources, such as timber, and protects the terrestrial ecosystem. This conservation extension is encapsulated in the organization's *Buy a Fish, Save a Tree* slogan (Norris & Chao, 2002). The project has also developed and trained fishers on animal welfare best capture and handling practices to maximize the value of caught fish to maintain market competitiveness in light of captive breeding programmes entering the market. Another effort seeks fair trade labelling to inform aquarists from where their fish come and the benefits of sustainably caught wild fish (Zehev et al., 2015). Because of its success in creating synergies between human needs and freshwater biodiversity conservation through sustainable livelihoods, the Project Piaba model is now used in other Brazilian fisheries (Pelicice & Agostinho, 2005), in India (Firchau et al., 2013) and in other tropical fisheries.

### 2.5 | Linking fisheries with habitat and biodiversity conservation, Kenai River, USA

Alaska's Kenai River in the north-west region of North America is prime habitat for more than 34 species of fish, including dolly varden (*Salvelinus malma*) and eulachon (*Thaleichthys pacificus*), where the latter is listed as threatened under the United States Endangered Species Act. The river also supports Chinook (*Oncorhynchus tshawytscha*) and sockeye salmon (*Oncorhynchus nerka*) populations, and their anadromous migrations are vital to both freshwater and terrestrial ecosystems because of nutrient input from post-spawning decomposition of their bodies (Gende, Edwards, Willson, & Wipfli, 2002). Salmon also have important socioeconomic value to local communities and the state of Alaska by supporting commercial and sport fisheries worth over a billion US dollars annually (Schoen et al., 2017). Alaskan salmon have a strong cultural value as an important food source for many subsistence fishers. Personal-use fisheries on the Kenai Peninsula, using dip nets and gill nets, have increased from about 20,000 household days per year in the mid-1990s to well over 40,000 household days (Fall et al., 2013).

Increasing development, the loss of freshwater habitats and degraded water quality have contributed to a declining Kenai River salmon population and a loss in genetic diversity (Johnson, Kemp, & Thorgaard, 2018). In particular, Chinook salmon populations in the Kenai and other Alaskan rivers have declined sharply over the last decade to the lowest level in 30 years (Schoen et al., 2017). Furthermore, the returning adult salmon now are smaller than before (Lewis, Grant, Brenner, & Hamazaki, 2015). In 2018, the numbers of returning adult Chinook and sockeye salmon were sufficiently poor to lead the Alaska Department of Fish & Game to declare emergency closure of their fisheries (Alaska Department of Fish & Game, 2018). Tracking the response of non-salmonid fish biodiversity in light of the observed declines in salmon populations is difficult because of data gaps (Kenai Peninsula Fish Habitat Partnership, 2011). However, a similar downward trend is likely given that the myriad threats thought to be driving salmon declines, including climate, landscape and human disturbance (Schoen et al., 2017), are not specific to salmon only.

The Kenai Fish Habitat Partnership was set up to address the threats of degrading aquatic habitat, declining fish populations and loss of fisher livelihood. The partnership consists of more than 30 organizations, and the large number reflects the complex and large spatial extent of environmental threats across the peninsula as well as the diversity of stakeholders, including government agencies, sportfishing groups and Alaska Native Tribes that depend on or are involved in the Kenai River. The stated vision of the partnership is 'for future generations to have healthy, sustainable fish and aquatic ecosystems', and they work to identify freshwater habitats for conservation, evaluate current condition, and rank threats from human action to specific habitats (Kenai Peninsula Fish Habitat Partnership Plan 2011). The plan has developed mitigation strategies for four primary threats: aquatic invasive species, climate change, road development and residential development in the riparian area. Another successful project stemming from a partnership between Kenai Watershed Forum, Kenaitze Indian Tribe, Alaska Department of National Resources and Department of Fish & Game was a coordinated prohibition and buy-back programme of highly polluting boat motors (Environmental Protection Agency, 2011). The programme dramatically reduced the use of these motors in the lower Kenai River summer Chinook salmon sport fishery, improving water quality in a major spawning and rearing area for Chinook salmon, as well as a migration corridor for other Pacific salmon species.

## 3 | CONCLUSIONS: PARTNERING CONSERVATION AND FISHERIES

The objectives of freshwater fish conservation and fishery exploitation are often viewed as opposites; however, emphasizing the services delivered by sustainable exploitation of fisheries, as illustrated by the case studies presented here, can ultimately benefit fish biodiversity. The dominant threat to fish biodiversity in these case studies came from modification and degradation of freshwater ecosystem functioning and health. A focus on the ecosystem services provided by freshwater fish biodiversity and stressing the importance of fisheries to communities helped rehabilitate the freshwater ecosystem to the benefit of both fish and humans (Cowx & Portocarrero Aya, 2011). The Tonle Sap and Rio Negro case studies show how involving fishers in the management of the resource can be effective at preventing overfishing and other undesirable practices. In light of the threat to freshwater ecosystems from increasing environmental degradation in the Anthropocene, it is mutually beneficial and fundamentally desirable that there is greater cooperation between groups with overlapping dependence on, or are concerned with, fish biodiversity, fishery productivity and the health of freshwater ecosystems.

The mutual benefit of aligning objectives to combat freshwater degradation are illustrated well in the case studies presented here. In the Logone Floodplain reflooding to reverse the impact of the dam on fisher livelihood restored habitat to the benefit of fish and humans. In the Kafue River, concerns over potential loss in biodiversity and livelihood led to cooperation to fight the threat of flow regulation for hydropower. In the Tonle Sap Lake, Cambodia, capacity building and empowering fishers has led to increased conservation and a more sustainable fishery. In the Kenai River, coordinated efforts by fishers and conservationists have brought salmon biodiversity concerns to the centre of societal attention and led to numerous successes for protecting aquatic biodiversity and fisheries by beginning to address the threats from pollution, dams and habitat loss. Project Piaba in the Rio Negro has empowered local communities and their desire for protecting the environment to sustainably exploit fish biodiversity which also reduced the exploitation of other less renewable natural resources, such as timber.

Improving partnership between conservation and fisheries organizations can lead to beneficial changes in their respective governance. For example, fisheries can benefit from conservation research by designing system-specific fishery management plans that account for, and are sensitive to, local fish community ecology. Identifying key habitat areas, migration pathways and increasing understanding of food web and population dynamics have direct utility when designing fisheries management that is more synergistic with system production (Arlinghaus, Lorenzen, Johnson, Cooke, & Cowx, 2015). The philosophy of sustainable fisheries management is steeped in a conservation agenda. Conversely, fish conservation can also benefit from being receptive to a fishery agenda. Project Piaba conducts outreach in large public aquaria and, in conjunction with trade groups, such as Ornamental Aquatic Trade Association Ornamental Fish International, the Pet Industry Joint Advisory Council, and the World Pet Association, are working to educate hobbyists of sustainable practices and conservation threats (Ornamental Aquatic Trade Association, 2016). The IUCN-SSC Freshwater Fish Specialist Group has recognized aquarium fisheries as an opportunity for freshwater fish conservation and has established the Home Aquarium Fish Sub-group to pursue environmental and socioeconomic benefits through the global aquarium trade.

The future of freshwater fishes and fisheries is dependent on integration and accurate valuation of its contribution in freshwater governance. At present, the impacts of the development projects on biodiversity and society are often not adequately recognized (Cooke et al., 2016; Taylor, Bartley, Goddard, Leonard, & Welcomme, 2016). Despite multiple and repeated calls for integration, freshwater governance still falls short in building synergies across economic, social and biodiversity interests (Lynch, Beard, et al., 2016). Policies rarely address conflicting needs, causing ecosystems and their services to lose out to more economically tangible water resource projects. Indeed, freshwater systems are primarily managed as a source of water for consumption, irrigation and power, or controlled to limit potential damage by flooding. The demands on freshwater ecosystems will continue to grow in the Anthropocene because of growth in human population size and per-capita resource-use as well as the compounding effect of climate change.

Increased synergy between biodiversity conservation efforts and fisheries exploitation can champion sustainable development of freshwater ecosystems by emphasizing their contribution to biodiversity, economic growth and social equity—the three pillars of sustainable development. The Convention on Biological Diversity, the Ramsar Convention on Wetlands and the Sustainable Development Goals emphasize that integration across these pillars is necessary for sustainable development, and freshwater fisheries are an overlooked partner in these policy initiatives (Lynch et al., 2017). Greater adoption of the ecosystem services concept can emphasize the contribution of freshwater fisheries to the sustainable development agenda (Cowx & Portocarrero Aya, 2011).

Healthy aquatic systems are fundamentally important for human livelihood and wellbeing, and a synergistic dynamic approach is needed to address the 'wicked problem' of freshwater conservation in the Anthropocene (Jentoft & Chuenpagdee, 2009; Rittel & Webber, 1973; Sivapalan et al., 2014). The fisheries community must develop relationships with other freshwater sectors to become more relevant in the complex freshwater governance landscape (Irvine, Castello, Junqueira, & Moulton, 2016; Lynch, Beard, et al., 2016), and the sector needs to continue to strive for sustainability, given its reliance on natural biodiversity and productivity. Similarly, fish conservation groups must be aware of the possibility that efforts seeking to limit fisheries may also threaten access to its vital services that vulnerable cohorts of society depend upon. Instead, emphasizing the social and economic value of fisheries services from natural biodiversity can help raise their necessary profiles and thereby address the wide array of freshwater threats (Dugan et al., 2010; Ziv, Baran, Nam, Rodriguez-Iturbe, & Levin, 2012). Moreover, addressing the broader scope of extrinsic threats is likely to have a greater impact on the sustainability of freshwater fishes and their fisheries than controlling fish harvest (Beard et al., 2011). Unifying conservation and fisheries communities to be a combined voice for environmental and social interests within the current economically dominated freshwater governance landscape (Beard et al., 2011; Cowx, Arlinghaus, & Cooke, 2010; Cowx & Gerdeaux, 2004) will provide a bridge between water for people and water for fishes in the Anthropocene.

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