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COMMENTARY

We need better understanding about functional diversity and vulnerability of tropical freshwater fishes

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Abstract Here we extend a discussion initiated by Toussaint et al. (Sci Rep 6:22125, 2016) concerning the relationship between global patterns of freshwater fish functional diversity (FD) and its vulnerability to human impacts. Based on a set of morphological traits, they concluded that Neotropical freshwater fishes have highest FD, but low vulnerability given high levels of functional redundancy. This conclusion implies that conservation efforts for freshwater fishes should emphasize temperate regions. This

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perspective is risky, because Toussaint et al.'s study seriously underestimates the full scope of FD, including important ecosystem services provided by fishes in the tropics. We briefly discuss some additional and well-documented aspects of tropical freshwater fish FD and conclude that tropical fish FD is highly vulnerable.

Keywords Conservation policy · Extinction risk · Functional traits · Ecosystem services · Megadiverse regions · Multidimensional niche

Toussaint et al. (2016) offered a thoughtful and much-needed analysis of global patterns in functional diversity (hereafter FD) of freshwater fishes. We applaud their effort to incorporate FD into discussions about the conservation of freshwater biodiversity and for providing a major stimulus for new research. Here we comment on their conclusions and argue for a more comprehensive perspective on FD and, particularly, threats to FD of tropical fishes in megadiverse regions. Toussaint et al. found greatest FD in the Neotropics, the region with highest species richness of freshwater fishes. Their study inferred that functional vulnerability, i.e. potential loss of FD represented by threatened species as assessed by IUCN (2015) and potentially threatened species that occur in a single basin as assessed by Tedesco et al. (2012), is low in the tropics compared to higher latitude regions. They advocate for a greater research and conservation focus on functionally unique species in Palearctic and Nearctic regions, because species in those regions likely contribute disproportionately to ecosystem processes, whereas many vulnerable tropical species are functionally redundant. Few would disagree with their recommendation to broaden the research agenda; however, their analysis clearly underestimated the FD of tropical fishes and its contributions to ecosystem processes and services, as well as the vulnerability of tropical fishes to human impacts. Importantly, their conclusion has potentially harmful implications for conservation given the political challenges in many developing countries in the tropics.

Briefly, we address four main points. First, there is general consensus (e.g. Flynn et al. 2009; Hoeinghaus et al. 2009; Laliberté and Legendre 2010; Cadotte et al. 2011; Vitule et al. 2012; Costa-Pereira and Galetti 2015) that loss of FD can result from a wider range of negative impacts than those considered by Toussaint et al. (2016). Species loss at a regional scale is not required to have significant reduction of FD and impairment of ecosystem processes and services. Population declines lower than the thresholds applied for species assessments for the IUCN Red List of Threatened Species™ (hereafter the "Red

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List") can still be sufficient to impair important species interactions and ecosystem processes (e.g. Pendleton et al. 2014; Correa et al. 2015). For example, prochilodontid (e.g. *Prochilodus* spp.) and loricariid (e.g. *Hypostomus* spp.) fishes are important ecosystem engineers in the Neotropics. The influence of these species on ecosystem processes, such as nutrient cycling and benthic primary and secondary production, are functions of local population abundance (Flecker and Taylor 2004; Flecker et al. 2010; Mormul et al. 2012; Winemiller et al. 2015). Overexploitation of formerly abundant stocks can change nutrient dynamics (Flecker 1996; Flecker and Taylor 2004; Taylor et al. 2006; Flecker et al. 2010) or riparian forest dynamics (Correa et al. 2015; Costa-Pereira and Galetti 2015). Moreover, rare species can have important contributions to the functional structure of assemblages (Leitão et al. 2016), yet most rare fishes are poorly studied while being highly vulnerable.

Second, current assessments of freshwater fish species extinction risk published on the IUCN Red List are not comprehensive for all regions and therefore do not reflect the full extent of extinction vulnerability of fishes in many regions. Many tropical species, including those that appear in regional Red Lists, have not yet been assessed by IUCN such that the total number of threatened species is likely to be much higher than that currently reported (IUCN 2015; Jarić et al. 2016). This is the case for many Neotropical fishes (e.g. El Salvador—*Amatitlania coatepeque*, Costa Rica—*Piabucina boruca*, Colombia—*Apteronotus magdalenensis*, Venezuela—*Bryconamericus charalae*, Chile—*Orestias agassizii*, Argentina—*Trichomycterus johnsoni*, Brazil—*Isbrueckerichthys epakmos*, *Rhamdiopsis moreirai*, *Spintherobolus ankoseion, Steindachneridion parahybae* and *Steindachneridion doceana*). In many tropical regions, local stocks currently fail to support viable fisheries (Allan et al. 2005; Hoeinghaus et al. 2009; Vieira and Rodrigues 2010). Similarly, several large migratory fishes (e.g. *Pseudoplatystoma* spp., *Salminus* spp.) have been eliminated from major segments of Neotropical rivers, yet they are not included on regional red lists because they persist in other segments, including some where they were stocked (e.g. Clavero and García-Berthou 2005; Vitule et al. 2014). Currently, levels of threat to the FD of megadiverse tropical fishes is poorly documented and clearly underestimated.

Third, the ecomorphological paradigm assumes that clusters of specimens or species within morphological spaces represent functional groups (Thuiller et al. 2010; Azzurro et al. 2014). Although some aspects of fish morphology provide reasonable surrogates for components of ecological performance, and Toussaint et al.'s (2016) finding for highest FD in the tropics is consistent with prior research (e.g. Winemiller 1991), important life history, physiological and behavioral dimensions of the niche are missing from analysis based solely on body shape measurements (Winemiller et al. 2015). For example, some tropical fish species are morphologically similar but differ in their physiology, ecology and spatial distributions (e.g. Lobón-Cerviá and Bennemann 2000; Nunes et al. 2014; Duponchelle et al. 2016). In addition, fishes have indeterminate growth influenced by environmental variation and populations with broad size distribution diversity; therefore, FD should have significant intraspecific and seasonal variations (e.g. Blanck and Lamouroux 2007). Analysis of more kinds of traits and intraspecific variation would enhance estimates of FD for conservation applications (Skóra et al. 2015).

Finally, future threats to biodiversity are greater in the tropics compared with temperate regions where species diversity tends to be much lower, the most severe human impacts have already happened, and restoration is a serious undertaking. The tropics experienced profound changes during the twentieth century that impacted freshwater ecosystems and fishes (e.g. Dudgeon et al. 2006; Bovarnick et al. 2010; Vitule et al. 2012; Araújo et al. 2013; Castello et al. 2013; Lees et al. 2016). Given the demographic and economic

realities, impacts to tropical freshwater ecosystems (e.g. overfishing, dams, watershed deforestation, pollution, biological invasions) will only increase (Allan et al. 2005; Casatti 2010; Pelicice et al. 2014; Azevedo-Santos et al. 2015, 2016; Vitule et al. 2015; Agostinho et al. 2016). In Brazil, efforts to restore impacted native fish stocks have been largely ineffective (Pelicice et al. 2015) and this failure likely is associated with the FD of tropical fishes, such that a single solution may not be effective for all species. The high FD of megadiverse tropical fish assemblages does not mitigate the need for conservation; instead, it increases our conservation challenges.

In our opinion, Toussaint et al.'s finding of low FD vulnerability of tropical fishes misinforms conservation. The current biodiversity crisis is particularly serious in megadiverse tropical regions (Frehse et al. 2016). The suggestion that threatened freshwater fishes in the tropics might merit less attention compared to temperate fishes misleads policymakers in developing countries, some of which are facing serious political, social and economic challenges that hinder conservation initiatives.

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