Evaluating the distribution of freshwater fish diversity using a multispecies habitat suitability model to assess impacts of proposed dam development in Gabon, Africa

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Abstract
Data scarcity impedes a comprehensive impact assessment of the 38 dams currently proposed within the highly biodiverse central African nation of Gabon. Here, we present a multiple-species MaxEnt distribution modeling approach to assess species richness for freshwater fishes at the landscape level and demonstrate its utility in identifying proposed dam sites in Gabon that fall in highly diverse areas. We modeled habitat suitability for 202 of Gabon's fresh and brackish water fish species based on georeferenced presence data from museum specimens and a set of ecologically meaningful environmental conditions. We removed poor performing species from the model and compiled the distributions of 114 well-performing species to generate a new metric, the species pseudorichness index (pR), defined as the cumulative number of species that are highly suited to the habitat in a given segment of river. We used pR as a proxy for true species richness and use this metric to evaluate the distribution of freshwater fish diversity relative to the proposed dam development in Gabon. We found that more than 80% of the proposed dams in Gabon overlap with areas of high pR, implying that planned hydroelectric development in Gabon may disproportionately affect high diversity areas. These dams deserve more focused baseline assessments and conservation action. This approach provides a rapid way to initiate a landscape-scale assessment of freshwater fish diversity to inform conservation decisions in areas that are species rich, but data poor.

KEYWORDS
biodiversity, conservation, development, hydropower, niche modeling, species richness

1 INTRODUCTION

In North America and Europe, few new dams are being constructed and more of them are being removed than built. This shift away from dam building occurs because the best sites have already been developed, new dams are too expensive, and the overwhelming environmental and social costs of dam construction outweigh the benefits (O’Connor, Duda, & Grant, 2015). De-emphasis on hydropower in the developed world contrasts with energy...
strategies in developing countries where an estimated 3,700 large dams (>1 MW) are planned or under construction, including dams on the world’s largest and most diverse river systems, the Amazon, Congo, Mekong, and the Ogooué (Winemiller et al., 2016; Zarfl, Lumsdon, Berlekamp, Tydecks, & Tockner, 2014). Developing countries need renewable and affordable energy resources to ensure long-term energy independence, but hydropower development poses threats to local animal populations, ecosystems, and human communities.

Hydropower dams dramatically alter the ecosystem, are often much costlier than expected, and have long-lasting socioeconomic and ecological impacts (Rex, Foster, Lyon, Bucknall, & Liden, 2014). Most large dams are designed to serve growing industries and urban populations, and decision-makers often underestimate or overlook their environmental impacts (Scott et al., 2011). Large dam development can displace rural communities, cause loss of livelihood, change food availability, and degrade water quality (Tilt, Braun, & He, 2009). Large dams change a river’s ecology and can result in habitat fragmentation (Fearnside, 2014), fisheries collapse (McCarthy et al., 2008), changes to sedimentation regimes (Lingon, Dietrich, & Thrush, 1995), large releases of greenhouse gases (Fearnside & Pueyo, 2012), and loss of aquatic and terrestrial biodiversity (Rosenberg, 2000). The impacts of hydropower development can be long lasting or permanent, but hydropower dams have a finite lifespan and those in the tropics tend to have a shorter lifespan due to higher sedimentation rates (Vauchel et al., 2017). Unfortunately, assessing the impacts of dam development in high biodiversity, data-poor regions such as Central Africa can be challenging as conservationists and decision-makers often suffer from a lack of baseline data.

Gabon has four existing dams including Kinguélé (57.6 MW), Tchimbélé (68.4 MW), Bongolo (5.5 MW), and Grand Poubara (157 MW). Only one of them (Grand Poubara) lies on Gabon’s greatest river, the Ogooué, which is the fourth largest by discharge in Africa and home to over 350 fish species. Because most of the Ogooué river network is free flowing and the watershed is sparsely populated (<5 people/km²), the Ogooué represents one of the most pristine large tropical rivers in Africa. However, Gabon aims to develop the capacity to produce 1,200 MW of hydropower energy and is considering the construction of 38 potential hydropower dams across the country—including 28 in the Ogooué watershed (AECOM, 2017; African Development Bank, 2011).

The impacts of these proposed dams on biodiversity and ecosystem function have not been fully evaluated. In order to identify proposed dam sites that will disproportionately affect fish biodiversity, we need to know how biodiversity is distributed across the landscape and at potential dam sites. Unfortunately, our understanding of Gabon’s freshwater biodiversity rests upon an incomplete sampling record limited to the reach of Gabon’s road network. Neither the time nor funding exists to conduct exhaustive baseline biodiversity assessments at every potential dam site.

Here, we used a synthesis of distributional data from historical surveys and vouchered museum specimens paired with high-resolution environmental layers to map the distribution of suitable habitat for approximately one-third of Gabon’s freshwater fish species across the entire country, including reaches difficult or impossible to reach by roads. By stacking these distributions, we develop a new metric, the species pseudorichness index (pR), to predict the distribution of fish diversity at the landscape level and at each of the 38 proposed dam sites in Gabon. Our approach is rapid, cost-effective, transferable to other under-studied regions of the world, and can help identify and mitigate human-related impacts on freshwater ecosystems.

2 | METHODS

2.1 | Data sources

Presence records for Gabon’s fresh and brackish water fishes were compiled from three open-source databases including The Global Biodiversity Information Facility, FAUNAFRI, and Oregon State University’s Specify database. These sources provide data on expertly identified museum specimens. All specimens with uncertain identifications or low precision locality data were excluded from the dataset. Our final dataset included 314 fish species and 6,061 distinct point occurrences.

We collected relevant environmental data to characterize the riverscape and ran geoprocessing routines in ArcGIS Pro 2.3 (ESRI, 2019) to delineate a high-resolution drainage network segmented in 100-m reaches and obtain local channel gradient, mean annual discharge, valley confinement, elevation, and distance to the ocean for each reach. By using a 12.5 m resolution L-Band Digital Elevation Model (ALOS PALSAR, Japan Aerospace Exploration Agency and University of Alaska, Fairbanks), we incorporated the most accurate space-borne topographic data available for hydrological modeling (Shawky, Moussa, Hassan, & El-Sheimy, 2019). Lastly, we generated 100 m riparian buffers and computed zonal statistics of other potentially influential environmental predictors including land-cover (CCI, ESA), tree canopy percent (USGS, University of Maryland), erodibility (TNC), temperature, and precipitation (WorldClim 2).
2.2 Model construction

Our species-level habitat suitability modeling took a Maximum Entropy approach (MaxEnt; Phillips, 2005). MaxEnt is a machine-learning algorithm that builds relationships between presence-only records and a set of environmental variables to estimate a target probability distribution of maximum entropy based on the most uniform distribution (Merow, Smith, & Silander, 2013). To ensure that we were working with enough data to construct effective models, we excluded any species collected at fewer than four distinct sampling localities, developed models for the remaining species, and tested the model performance for each species. Species with lower performing models (i.e., area under the receiver operating characteristic, AUC < 0.75) were excluded from the final dataset. Of the 351 fish species known to occur in Gabon’s freshwater ecosystems, 114 species representing 62 genera were included in the final version of the multispecies model (Appendix S1). Species included in this analysis span many ecological guilds including estuarine and coastal lagoon, eurytopic, lentic, lotic, and rhithronic (sensu Welcomme et al., 2006) and include several range restricted and migratory species expected to be particularly affected by dam development.

For model optimization, we used the R package “MaxentVariableSelection.” This package identifies the most influential and uncorrelated environmental variables and finds an optimal regularization multiplier to avoid building overcomplex or overfitted models. It varies parameters among stepwise MaxEnt runs and assesses performance with the AUC (Jueterbock, Smolina, Coyer, & Hoarau, 2016) and Akaike information criterion (AIC) values. Due to the processing constraints of optimizing the model for all species, we grouped them by ecological guild. Final parameters were set by harmonizing the models with the highest AUC and lowest AIC values. During model optimization, the mean annual temperature was dropped from the analysis because of collinearity with elevation ($r^2 = .95$), and land cover and tree cover percent were dropped because of their small contribution to predictions (<5%). To test the model’s sensitivity to our cutoff thresholds, we ran the model with more and less restrictive scenarios. In our more restricted scenario, we removed all medium and highly range-restricted fish species from the dataset and re-ran the analyses with the remaining 101 species. In our less restrictive scenario, 240 fish species (AUC > 0.65) were included in the analyses. In both scenarios, the overall model performance remained relatively similar. We therefore retained all 114 fish species for the final model presented here (Appendix S1).

We developed the species pseudorichness index ($pR$) defined as the cumulative number of species that are highly suited to the habitat in a given segment of river. To generate the $pR$ index, we used a conservative occurrence probability threshold (mean + SD) for extracting only areas with high probability of occurrence for each species. We then stacked the outputs from the 114 species distribution models and tallied the number of species expected to occur at each point to quantify $pR$ and assess the distribution of freshwater fish biodiversity at the landscape level (Figure 1). The average $pR$ for Gabon’s freshwater ecosystems was 21 and we used a SD classification method to create four pseudorichness classes: low ($pR < 4$), medium-low (5 < $pR < 21$), medium-high (22 < $pR < 39$), and high ($pR > 39$; Appendix S2).

In order to assess the tradeoff between potential energy production and species richness at proposed dam sites, we generated a scatterplot and divided it into quadrants by the mean values across the landscape (Figure 2). In the best scenario, dams would be located in areas of low biodiversity and high potential hydropower production (lower right quadrant), and dams would be avoided at sites that produce little energy, but would be located at high biodiversity areas (upper left quadrant).

3 RESULTS

We developed a multiple-species MaxEnt model to predict the distribution of freshwater fish biodiversity in Gabon (Figure 1). We identified potential biodiversity hotspots and assessed the siting of 38 prospective dams in Gabon. High biodiversity areas ($pR > 39$) identified using this method lie in every coastal watershed, the Nyanga drainage, and throughout the Ogooué system, including its major tributaries the Ivindo and Ngounié. Coastal areas and main river channels demonstrate higher than average $pR$ values, with lower pseudorichness in smaller streams and the high elevation areas in central Gabon. Model performance at the species level was good to very good (0.75 < AUC < 0.98), with a mean test AUC of 0.85 (Appendix S1) among species retained in the final model.

In order to estimate the proportion of proposed hydropower dams located in regions of high and low fish diversity, we compared $pR$ at Gabon’s 38 proposed dam sites (Figure 1, Table 1). More than 80% of the 36 proposed dam sites in Gabon overlapped with areas of high species pseudorichness ($pR > 39$). Dam development in areas of high species richness will likely affect more fish species than those dams proposed in less diverse regions (Figure 1). The assessment of tradeoff between energy production and predicted species richness demonstrated that no dams fell within the optimal combination of low
species richness and high potential output (Figure 2). Contrarily, 27 smaller potential dams (producing <200 MW) are sited in areas of high species richness (upper left quadrant of Figure 2). These dams would produce little energy, but alter habitat used by a substantial fraction of Gabon’s ichthyofauna.

To validate the pR metric we ran a Spearman rank correlation analysis between observed richness and pR using data from 15 well-sampled localities of Gabon. Richness and pR were strongly associated ($r_s = .68$, $p$ value = .005) with most of the noise occurring in areas of low species richness (Appendix S3). The influence of different environmental variables in the distribution modeling varied among fish guilds, although topography-based conditions were the most important in training the best models. Elevation, distance to the ocean, valley-confinement, discharge and channel gradient were the most important variables in the overall pseudorichness model. When we re-ran analyses excluding the 13 range-restricted species the general findings were unchanged as all dam sites fall within the same quadrant as in Figure 2 (Appendix S4), but model performance decreased, especially in headwaters and tributaries; particularly in the coastal regions and the Ivindo river basin. We also ran a less restrictive analyses with AUC cutoff threshold (AUC > 0.65) resulting in the retention of 240 species in the final model. In this case, the patterns of richness across the landscape remained similar (Appendix S5),

**FIGURE 1** Map showing the predicted distribution for Gabon’s fish diversity and proposed hydropower dams. Blue colors depict areas of low species pseudorichness ($pR < 4$), green to medium-low ($5 < pR < 21$), yellow to medium-high ($22 < pR < 39$) and red to areas of high species pseudorichness ($pR > 39$). Existing dams appear as purple dots and proposed dam sites appear as black dots.
and tradeoff-analyses results remained unchanged as all dam sites fall within the same quadrant as shown in Figure 2 (Appendix S).

4 DISCUSSION

We successfully assessed potential impacts of proposed dam development in Gabon by modeling the distribution of freshwater fish diversity at the landscape level. The index of species pseudorichness ($pR$) developed herein provides a quantitative evaluation of the distribution of fish diversity across Gabon and at 38 potential hydropower dam sites. Concerningly, 80% of the proposed dams in Gabon overlap with areas of high species pseudorichness.

Such high diversity sites deserve extra attention from scientists, decision makers, and conservationists, ideally in the form of full faunal surveys and detailed impact assessments in advance of any construction. We encourage that dams are not sited in high biodiversity areas, areas with threatened or endemic species, or migratory corridors (Thieme et al., 2007; Winemiller et al., 2016). Thorough environmental impact assessments and social impact assessments should be conducted in advance of dam construction by independent parties (Moran, Lopez, Moore, Müller, & Hyndman, 2018). Such assessments should have the capacity to stop dam construction if deemed necessary (Égré & Senécal, 2003).

For decision makers in Gabon, avoiding constructing dams in high biodiversity areas may be impractical due to country’s exceptionally rich fauna, and the strong correspondence between the areas of highest diversity and highest potential power output. Nevertheless, several strategies can minimize the negative impacts of dam development on fish biodiversity. First, avoid constructing dams at sites that have high species richness and relatively low energy production. Second, concentrate dam development in a small portion of Gabon’s freshwaters, either by constructing a series of dams on a single watershed (as is currently the case on the Mbei), or by constructing one or two large dams that produce enough energy for the entire country. Third, develop and manage existing and proposed dams in ways that mimic natural variation in the watershed, ensuring that flood plains and migratory corridors are maintained (Ferguson, Healey, Dugan, & Barlow, 2011; Murphy, Taylor, Pierce, Arismendi, & Johnson, 2019). Finally, consider energy solutions other than hydropower.

Despite our models ease and general utility, it is important to note some limitations of our approach. First, our model does not account for basin boundaries and thereby may overestimate species distributions, particularly for range-restricted species. This limitation could cause pseudorichness to exceed actual richness, particularly in isolated watersheds.

Second, our model is built on the third of Gabon’s described fish species for which we were able to generate the most robust predictions. By excluding rare or endemic species known to occur at fewer than five localities, the model may underestimate the true species richness present, and thus bias the analysis in the opposite direction.

Finally, our model does not capture other critical aspects of biodiversity, such as the presence and/or absence of endangered, iconic, or undescribed species at proposed dam sites. Several new species of fish have been discovered during recent sampling expeditions in Gabon, including *Paramormyrops ntotom* (Rich, Sullivan, & Hopkins, 2017), *Enteromius pinnimaculatus* (Mipounga, Cutler, Mve Beh, Adams, & Sidlauskas, 2019), and the two known species in the recently described genus *Cryptomyrus* (Sullivan, Lavoué, & Hopkins, 2016). Much of Gabon’s fish diversity remains undiscovered and undescribed, yet some of these species are threatened by proposed dam development, including the recently described *E. pinnimaculatus*, which is known to occur only at two localities, one of which is adjacent to a proposed dam site. Our model cannot predict the occurrence of rare or unknown species, and thus a full impact assessment and conservation strategy will need to incorporate other dimensions of biodiversity, ecosystem health, and ecosystem services. Estimation of species pseudorichness via MaxEnt as we have done herein can provide a rapid and effective initial foundation for assessment in data poor regions, but it should not form the totality of the analysis underlying management decisions.
| Dam name          | Code | River   | Expected production (MW) | Species pseudorichness (pR) | Diversity ranking |
|-------------------|------|---------|--------------------------|----------------------------|-------------------|
| Kinguele aval     | KAv  | Mbei    | 60                       | 74                         | High              |
| Igotchi          | Ig   | Nyanga  | 5                        | 74                         | High              |
| Mingouli         | Min  | Ivindo  | 460                      | 68                         | High              |
| Lifoula          | Lf   | Ogooué  | 135                      | 68                         | High              |
| Kouata-Mango     | K-M  | Ivindo  | 445                      | 67                         | High              |
| Souka-Minimal    | S-M  | Ogooué  | 85                       | 67                         | High              |
| Chutes Booue     | CB   | Ogooué  | 1,000                    | 67                         | High              |
| Ibola            | Ib   | Abang   | 61                       | 66                         | High              |
| Kongue           | Ko   | Vindo   | 435                      | 66                         | High              |
| Ndindi           | Nd   | Lagune Banio | 0.1                   | 66                         | High              |
| Liboka           | Lb   | Ogooué  | 121                      | 65                         | High              |
| Tsengue-Leledi   | T-L  | Ivindo-Ogooué | 565                 | 64                         | High              |
| Angouma          | An   | Lekoni  | 85                       | 64                         | High              |
| Ovan             | Ov   | M’voung | 3.5                      | 61                         | High              |
| Mafoula Matato   | MM   | Ogooué  | 88                       | 61                         | High              |
| Iroungou         | Ir   | Mougalaba | 2                      | 60                         | High              |
| Akieni           | Ak   | Akieni  | 76                       | 58                         | High              |
| Moulengei-Bindza | M-B  | Douli   | 0.1                      | 56                         | High              |
| Chutes de l’Imperatrice | CI | Ngounie  | 84                       | 55                         | High              |
| Derivation Ogooué-Lolo | O-L | Ogooué  | 550                      | 54                         | High              |
| Lebombi          | Le   | Lebombi | 42                       | 54                         | High              |
| Nemguembani      | Ne   | Abang   | 74                       | 53                         | High              |
| Fe II            | Fe   | Okano   | 35                       | 52                         | High              |
| Kinguele amont   | Kam  | Mbei    | 41                       | 48                         | High              |
| Dibwangui        | Di   | Louetsi | 10                       | 45                         | High              |
| Iboundji         | Ib   | Woubou  | 0.4                      | 45                         | High              |
| Tchimbele aval   | TAv  | Komo    | 55                       | 44                         | High              |
| Omvan amont      | OAm  | Mbei    | 35                       | 44                         | High              |
| Ngoumendjim      | Ng   | Komo    | 100                      | 44                         | High              |
| Omvan aval       | OAv  | Mbei    | 25                       | 43                         | High              |
| Makongonio       | Ma   | Louetsi | 5                        | 43                         | High              |
| Guetsou          | Gu   | Moussa  | 0.1                      | 41                         | High              |
| Lope             | Lo   | Ogooué  | 0.05                     | 33                         | Medium-high       |
| Mouyanama        | My   | Ngounie | 0.2                      | 23                         | Medium-high       |
| Faga             | Fa   | Abang   | 37                       | 19                         | Medium-low        |
| Mboungou         | Mb   | Lolo    | 0.3                      | 13                         | Medium-low        |
| Mounama          | Mn   | Ogooué  | 5                        | 12                         | Medium-low        |
| Booue            | Bo   | Ogooué  | 2                        | 6                          | Medium-low        |
In developing a multispecies MaxEnt modeling approach, we were able to predict patterns of biodiversity at the landscape level—moreover, our approach was successful in a highly diverse poorly studied region with biodiversity that is currently threatened by proposed developments. Overall, our approach is relatively inexpensive, rapid, and easily applicable to regions lacking data on biodiversity and biogeography. Our metric, pR, is readily transferable across regions and taxonomic groups, and may even work to predict patterns of terrestrial biodiversity. It provides a valuable first step in assessing potential impacts at the landscape level and can easily flag projects with high potential impacts on biodiversity.

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CONFLICT OF INTEREST
The authors have no conflict of interest to declare.

AUTHORS CONTRIBUTIONS
J.S.C. conceived and wrote the manuscript. J.A.O. conducted the distribution modeling and prepared the figures. J.S.C. and B.L.S. led the classification of fish species into guilds and compiled data on species occurrences. I.A. and B.L.S. provided critical feedback and guidance. All authors edited the manuscript and all approved the final submission.

ETHICS STATEMENT
No humans or animal specimens were harmed in the preparation of this manuscript.

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REFERENCES
AECOM. (2017). Actualisation du schema directeur d’électrification du Gabon (Tech. Rep). Ministère de l’Eau et de l’Énergie. Republic du Gabon.

African Development Bank. (2011). Republic of Gabon: Country strategy paper 2011–2015.

Égré, D., & Senécal, P. (2003). Social impact assessments of large dams throughout the world: Lessons learned over two decades. Impact Assess Project Appraisal, 21, 215–224.

Fearnside, P. M. (2014). Impacts of Brazil’s Madeira river dams: Unlearned lessons for hydroelectric development in Amazonia. Environmental Science and Policy, 38, 164–172.

Fearnside, P. M., & Pueyo, S. (2012). Greenhouse-gas emissions from tropical dams. In J. H. Lehr, J. Keeley, & T. B. Kingery (Eds.), Alternative energy and shale gas encyclopedia (pp. 382–384). Hoboken, New Jersey: Wiley.

Ferguson, J. W., Healey, M., Dugan, P., & Barlow, C. (2011). Potential effects of dams on migratory fish in the Mekong river: Lessons from salmon in the Fraser and Columbia Rivers. Environmental Management, 47(1), 141–159.

Jueterbock, A., Smolina, I., Coyer, J. A., & Hoarau, G. (2016). The fate of the Arctic seaweed Fucus distichus under climate change: An ecological niche modeling approach. Ecology and Evolution, 6(6), 1712–1724.

Lingon, F. K., Dietrich, W. E., & Thrush, W. J. (1995). Downstream ecological effects of dams. Bioscience, 45(3), 183–192.

McCarthy, T. K., Frankiewicz, P., Cullen, P., Blaszkowski, M., O’connor, W., & Doherty, D. (2008). Long-term effects of hydropower installations and associated river regulation on river Shannon eel populations: Mitigation and management. Hydrobiologia, 609, 109–124.

Merow, C., Smith, M. J., & Silander, J. A. (2013). A practical guide to MaxEnt for modeling species’ distributions: What it does, and why inputs and settings matter. Ecography, 36(10), 1058–1069.

Mipounga, H. K., Cutler, J., Mve Beh, J. H., Adams, B., & Sidlauskas, B. L. (2019). Enteromius pinnimaculatus sp. nov. (Cypriniformes: Cyprinidae) from southern Gabon. Journal of Fish Biology. https://doi.org/10.1111/jfb.13995

Moran, E. F., Lopez, M. C., Moore, N., Müller, N., & Hyndman, D. (2018). Sustainable hydropower in the 21st century. Proceedings of the National Academy of Sciences, 115, 201809426.

Murphy, C. A., Taylor, G., Pierce, T., Arismendi, I., & Johnson, S. L. (2019). Short-term reservoir draining to stream bed for juvenile salmon passage and non-native fish removal. Ecohydrology, 12 (6), e2096. https://doi.org/10.1002/eco.2096

O’Connor, J. E., Duda, J. J., & Grant, G. E. (2015). 1,000 dams down and counting. Science, 348, 496–497.

Phillips, S. J. (2005). A brief tutorial on Maxent. AT&T Research. Retrieved from http://www.cs.princeton.edu/~schapire/maxent/tutorial/tutorial.doc

Rex, W., Foster, V., Lyon, K., Bucknall, J., & Liden, R. (2014). Supporting hydropower: An overview of the World Bank Group’s engagement. Washington, DC: World Bank Group.

Rich, M., Sullivan, J. P., & Hopkins, C. D. (2017). Rediscovery and description of Paramormyrops sphekedus (Sauvage, 1879) and a new cryptic Paramormyrops (Mormyridae: Ostegocephaliformes) from the Ogooué River of Gabon using morphometrics, DNA sequencing and electrophysiology. Zoological Journal of the Linnean Society, 180, 613–646.

Rosenberg, D. (2000). Global-scale environmental effects of hydrological alterations: Introduction. Bioscience, 50, 746–751.
Scott, C. A., Pierce, S., Pasqualetti, M., Jones, A., Montz, B., & Hoover, J. (2011). Policy and institutional dimensions of the water-energy nexus. *Energy Policy, 39*, 6622–6630.

Shawky, M., Moussa, A., Hassan, Q. K., & El-Sheimy, N. (2019). Pixel-based geometric assessment of channel networks/orders derived from global spaceborne digital elevation models. *Remote Sensing, 11*(3), 235.

Sullivan, J. P., Lavoué, S., & Hopkins, C. D. (2016). *Cryptomyrus*: A new genus of Mormyridae (Teleostei, Osteoglossomorpha) with two new species from Gabon, West-Central Africa. *ZooKeys, 561*, 117–150.

Thieme, M., Lehner, B., Abell, R., Hamilton, S. K., Kellndorfer, J., Powell, G., & Riveros, J. C. (2007). Freshwater conservation planning in data-poor areas: An example from a remote Amazonian basin (Madre de Dios River, Peru and Bolivia). *Biological Conservation, 135*, 500–517.

Tilt, B., Braun, Y., & He, D. (2009). Social impacts of large dam projects: A comparison of international case studies and implications for best practice. *Journal of Environmental Management, 90*, 249–257.

Vauchel, P., Santini, W., Guyot, J., Moquet, J., Martinez, J., Espinoza, J., … Ronchail, J. (2017). A reassessment of the suspended sediment load in the Madeira River basin from the Andes of Peru and Bolivia to the Amazon River in Brazil, based on 10 years of data from the HYBAM monitoring programme. *Journal of Hydrology, 553*, 35–48.

Welcomme, R., Winemiller, K., & Cowx, I. (2006). Fish environmental guilds as a tool for assessment of ecological condition of rivers. *River Research and Applications, 22*, 377–396.

Winemiller, K. B., McIntyre, P., Castello, L., Fluet-Chouinard, E., Giarrizzo, T., Nam, S., … Sáenz, L. (2016). Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. *Science, 351*, 128–129.

Zarfl, C., Lumsdon, A. E., Berlekamp, J., Tydecks, L., & Tockner, K. (2014). A global boom in hydropower dam construction. *Aquatic Science, 77*, 161–170.

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