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Safeguarding Free-Flowing Rivers: The Global Extent of Free-Flowing Rivers in Protected Areas

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Abstract: Approximately one-third of long rivers remain free-flowing, and rivers face a range of ongoing and future threats. In response, there is a heightened call for actions to reverse the freshwater biodiversity crisis, including through formal global targets for protection. The Aichi Biodiversity Targets called for the protection of 17% of inland water areas by 2020. Here, we examine the levels and spatial patterns of protection for a specific type of inland water area—rivers designated as free-flowing. Out of a global total of 11.7 million kilometers of rivers, 1.9 million kilometers (16%) are within protected areas and 10.1 million kilometers are classified as free-flowing, with 1.7 million kilometers of the free-flowing kilometers (17%) within protected areas. Thus, at the global level, the proportion of rivers in protected areas is just below the Aichi Target, and the proportion of free-flowing rivers within protected areas equals that target. However, the extent of protection varies widely across river basins, countries, and continents, and many of these geographic units have a level of protection far lower than the target. Further, high discharge mainstem rivers tend to have lower extent of protection. We conclude by reviewing the limitations of measuring river protection by the proportion of river kilometers within protected areas and describe a range of mechanisms that can provide more effective protection. We also propose a set of recommendations for a more comprehensive quantification of global river protection.

Keywords: free-flowing rivers; freshwater biodiversity conservation; protected areas; river protection

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1. Introduction

Rivers provide a broad range of benefits to people and support diverse and productive ecosystems [1]. However, river systems have experienced high levels of alteration and degradation by various economic activities—for example, only one-third of long rivers remain free-flowing [2]—with steep declines in both populations of freshwater species and ecosystem services [3]. Further, rivers face a range of ongoing and future threats, including dam construction, water extraction, overfishing, and pollution [4,5]. Due to these ongoing declines and future threats, there is a heightened call for investment and action to halt and reverse the freshwater biodiversity crisis, including through formal global targets for protection [6]. The Aichi Biodiversity Targets, under the Convention on Biological Diversity, called for the protection of 17% of inland water areas by 2020 [7]. Recent studies suggest that the world may be close to, or has already surpassed, that level of protection [8–10]. However, an emphasis on a single metric of protection with an arbitrary numerical level as an overarching global target (e.g., 17% of inland water areas under protection) risks overlooking finer-scale values or processes that should underpin global conservation goals [11]. In this paper, we examine the levels and spatial patterns of protection for a specific type of inland water area—rivers that are designated as free-flowing (sensu Grill and others [2])—to provide some greater resolution and insights on the extent of inland waters that are protected.

Free-flowing rivers (FFRs) are defined as those "where ecosystem functions and services are largely unaffected by changes to the fluvial connectivity, allowing unobstructed movement and exchange of water, energy, material, and species within the river system and with surrounding landscapes" (p. 216, [2]). Free-flowing rivers are identified by an index (the Connectivity Status Index or CSI) measuring the level of connectivity across four dimensions: lateral, longitudinal, vertical (connectivity with groundwater), and temporal (connectivity based on flow patterns over time). Grill and others [2] found that just over one-third of rivers longer than 1000 km can be considered free-flowing and dams were the primary driver of the loss of free-flowing status for rivers, due to both fragmentation of longitudinal connectivity and the alteration of flow patterns.

Rivers support a range of processes that maintain ecosystems and provide value to people [1]. For example, rivers sustain some of the world's most productive freshwater fisheries, providing food and livelihoods to hundreds of millions of people [12]. Rivers also deliver the sediment needed to maintain deltas, which are home to more than 500 million people and are among the most productive agricultural regions in the world [13].

Free-flowing rivers are particularly important for maintaining many of these values [14]. Migratory fish are an important component of many fisheries, including fish that require long-distance migrations between the ocean and rivers (e.g., anadromous fish such as salmon) and within river systems (e.g., fish that make long-distance migrations within the Amazon, Irrawaddy, and Mekong). Dams can disrupt these migrations, as demonstrated by the widespread decline in salmon populations from dammed rivers [15]. A global index of migratory fish populations reported a 76% decline since 1970 [16]. Dams also capture sediment and reduce its delivery to downstream floodplains, deltas, and near-shore marine environments. Nearly a quarter of global annual sediment flux is deposited within reservoirs and, in some river systems, such as the Nile, nearly all sediment is trapped behind dams [17]. As a result, several deltas with dense human populations are experiencing an accelerated loss of land, subsidence, and saltwater intrusion. A loss of river connectivity has also contributed to the decline of freshwater species and populations, as measured by the Living Planet Index and the International Union for Conservation of Nature's (IUCN's) Red List [3].

Loss of river connectivity, and associated impacts on species, ecosystems, and their services to people, are projected to continue. For example, Zarfl and others [5] mapped over 3600 hydropower dams around the world that are in some stage of planning or construction. If all of these dams were developed, they would fragment the majority of the remaining long free-flowing rivers in temperate and tropical river regions. Projected increases of hydropower to meet climate targets, such as within energy forecasts in reports by the Intergovernmental Panel on Climate Change (IPCC), would require an increase in global hydropower capacity 50 to 100% greater than the aggregate capacity of dams identified by Zarfl and others [5]; the level of hydropower development required to meet these climate targets would alter and fragment hundreds of thousands of kilometers of rivers worldwide [18].

To address both past losses and future risks, governments have committed to increasing the protection of inland water areas. Target 11 of the Aichi Targets states that "by 2020, at least 17% of inland water areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through systems of protected areas and other effective area-based conservation measures." Juffe-Bignoli and others [10] found that 20.7% of inland water areas—including lakes, wetlands, and rivers—are within protected areas, while, using somewhat different categories of inland waters, Bastin and others [8] found that 15 to 16.4% of inland waters were within protected areas. Focusing specifically on rivers, Abell and others [9] reported that 16% of global river length was found within protected area boundaries (referred to as "local protection").

Although these estimates suggest that the world has already achieved, or is close to achieving, the 17% global target, these assessments highlight the variability among countries and regions, with some countries far above the target and some well below [8,9]. Further, Juffe-Bignoli and others [11] emphasize that the proportional protection level (17%) of Target 11 can receive too much attention and that, in fact, the target is far more comprehensive than just an area goal. The target describes that the protection should be in the form of "ecologically representative and well-connected systems", encompassing "especially areas of particular importance for biodiversity and ecosystem services". Juffe-Bignoli and others [11] recommend a range of actions aimed at fulfilling the more comprehensive objectives of Target 11 and recommend how to better measure progress toward those objectives. Additionally, targets are currently under revision and Target 11 will be revised and updated in the post-2020 framework of the Convention on Biological Diversity (CBD). The current version of the proposed target focused on protection aims to "protect and conserve, through a well-connected and effective system of protected areas and other effective area-based conservation measures, at least 30% of the planet, with the focus on areas particularly important for biodiversity" by 2030.

Free-flowing rivers represent a specific category of inland waters and, by definition, these rivers are well-connected and provide the conditions that are more likely to allow species to persist into the future, particularly in a changing climate. Therefore, an assessment of the proportion and distribution of free-flowing rivers within protected areas will provide some further insights into progress toward the more comprehensive objectives of Target 11, beyond the inclusion of 17% of inland waters within protected areas. Here we quantify the length of rivers, and free-flowing rivers specifically, that are within the boundaries of protected areas. There are some limitations to defining those rivers that occur within protected areas as "protected", including the fact that protected areas are often defined by, and managed primarily for, terrestrial resources and may not actually protect rivers from major impacts, such as damming [19]. In this paper, we explore some of these limitations with case studies.

Further, we acknowledge that protected areas are just one mechanism for river protection, and it is the mechanism quantified by the various studies cited here [8–10]. However, there are other mechanisms to protect rivers, including river-specific policies, such as the Wild and Scenic Rivers Act in the United States or the Salmon Rivers of Norway [20–22]. These types of policies can provide strong protections for rivers, but these mechanisms are not always included in global databases of protected areas. Perry and others [21], in this special issue, review the global extent of these river-specific policies. Further, there are water management or water allocation policies, such as Environmental Water Reserves in Mexico, that are officially focused on volumes of water, not rivers per se, but that function as de facto river protections [23,24]. Thus, a more comprehensive assessment of the extent of global protection for free-flowing rivers will need to consider these other categories that are not quantified in this paper.

2. Materials and Methods

2.1. Hydrographic and Geographic Framework

For the river network, we used the HydroSHEDS database [25] at fifteen arc-second spatial resolution, or about 500 m pixel resolution at the equator. A river reach represents the smallest spatial element of the global network, while a river is considered an aggregation of river reaches that form a continuous flow path from the headwater source to the river outlet [2]. Rivers that are longer than 10 km and have a discharge larger than 1 cms at the most downstream reach were included. Those river reaches that are found in cold or hot deserts were omitted, according to existing physiographic maps, to exclude the uncertainty of small rivers [2]. In total, 2,267,400 river reaches were included in the analysis.

We used the classification of river reaches into Levels 1–7 (field ORD_FLOW in HydroRIVERS,) based on long-term average discharge (cubic meters/second), using logarithmic progression (Level 1 = >100,000, Level 2 = 10,000–100,000, Level 3 = 1000–10,000, Level 4 = 100–1000, Level 5 = 10–100, Level 6 =1–10, Level 7 =0.1–1). Rivers were also categorized by size, following classifications from Grill and others [2]: short (10–100 km), medium (100–500 km), long (500–1000 km), and very long (>1000 km).

For display of assessment results, we used HydroBASINS [26] for basin and continent boundaries and used the October 2020 United Nations Geospatial Information Section (UNGIS) for country boundaries [27]

2.2. Protected Areas and Extent of Rivers within Protected Areas

We used protected area data from the October 2020 World Database of Protected Areas (WDPA) [28]. Following guidance from IUCN and the United Nations Environment Programme-World Conservation Monitoring Centre (UNEP-WCMC) 2020, we included protected areas (PAs) with national, international, and regional status, and excluded PAs that are strictly marine or have a "proposed" or "not reported" status. The total extent of PAs represented 19.5 million km^2, or 13.2%, of the global land surface area, excluding Antarctica. Due to the recent exclusion of PAs for China in the publicly available WDPA, we used the January 2017 WDPA [29] to map PAs in China.

To determine river status, we used data from the global FFR assessment [2]. Whether a river is considered free-flowing or not is based on the Connectivity Status Index (CSI) of all river reaches within a river (see Grill and others for full methodology [2]). The CSI is based on six indicators that affect different aspects of a river's lateral, longitudinal, vertical, or temporal connectivity and ranges in value from 0% (i.e., no connectivity) to 100% (i.e., full connectivity). River reaches with a CSI of 95% or greater were considered to have good connectivity status and river reaches below 95% were considered impacted. If a river, including all of its river reaches, has a CSI of 95% or greater, the river is considered free-flowing. If all river reaches do not meet a CSI of 95%, the river is considered non-free-flowing.

To determine the percentage of river kilometers that falls within a PA, we overlaid data from the WDPA with the HydroSHEDS river reaches. For each river reach, we calculated the percentage of length that occurs within the boundaries of a PA. We then multiplied river reach length by percent within the PA to calculate the total length of the reach that falls within a PA.

Globally and by continent, we summarized the percentage of river kilometers that are free-flowing and then the percentage of free-flowing rivers' and all rivers' kilometers that are within PAs, for four river sizes based on river length (from short to very long). We also summarized the percentage of all rivers and free-flowing rivers that are within protected areas for the Reach Level groups, based on discharge. We summarized the percentage of free-flowing rivers' and all rivers' kilometers that are within PA by continent, country, and basin.

2.3. Case Studies on Limitations of Using Protected Area Boundaries to Define Protected FFR (Nepal and Brazil)

We conducted a case study using Nepal as an example of the impacts of how planned dams could, if built, cause rivers within PA boundaries to change from their current free-flowing status to non-free-flowing—from not only dams planned within PAs, but also those planned upstream or downstream of FFRs within PAs. We used the 285 dams in Nepal from Zarfl and others [5] and re-analyzed river connectivity status for Nepal's rivers—comparing the CSI of reaches from the FFR database (without the planned dams), and then as if the planned dams were built. We calculated the number of planned dams in PAs in Nepal and the number and length of rivers flowing through PAs that would change from free-flowing to not free-flowing. Note that the dams in the Zarfl database were identified as being within planning processes beyond the pre-feasibility stage; most of these potential dams in Nepal have at least initial licenses from the government (e.g., a survey license).

In addition, we focused on Brazil to calculate the extent of rivers that serve as the boundary of a protected area. We added a 1 km buffer to the PA boundaries and selected river reaches that fall within the 1 km buffer. To filter out river reaches crossing PA edges perpendicularly, we only included river reaches that were contiguous with at least one other river reach, belonging to the same river, within the buffer. Finally, we clipped the remaining river reaches to the buffer polygon to remove any river reaches that were not within the 1 km buffer. We then summed the total length of rivers that served as the boundaries of the protected areas.

3. Results

3.1. Protection at Global, Continent, Country, and Basin Scales

Out of a global total of 11.7 million kilometers of rivers, 1.9 million kilometers (16%) are within protected areas, and 10.1 million kilometers are classified as free-flowing, with 1.7 million kilometers of the FFR kilometers (17%) within protected areas. Thus, at the global level, the proportion of rivers in protected areas is just below the Aichi Target of 17% protection for inland waters, and the proportion of FFRs within protected areas equals that target. South America has the highest proportion of rivers within protected areas (28% of FFR kilometers and 27% of all river kilometers), whereas Asia has the lowest (11% of FFR kilometers and 10% of all river kilometers) (Table 1). The global extent of protection varies somewhat by the length of the river, with very long rivers having a somewhat lower proportion within protected areas compared to other categories of river length.

The extent of protection for free-flowing rivers varies widely between river basins, and within large river basins. Among the largest river basins, those with a high proportion of FFR kilometers within protected areas (>50%) include the Rhine, Danube, and Rufiji (Tanzania) basins. The Amazon, Orinoco, and Zambezi basins have greater than 30% of FFR kilometers in protected areas (Figure 1). Those with a low proportion of FFR kilometers in protected areas (<10%) include the Lena, Ob, and Volga (Russia), Parana and Magdalena (South America), Fraser, Mississippi, and Mackenzie (North America), Ganges, Indus, Salween, and Irrawaddy (Asia), Murray (Australia), and Niger (Africa) basins.

The extent of protection is also highly variable between countries (Figure 2). Of the largest 160 countries (by area), less than half (69) have reached a level of 17% of FFR kilometers in protected areas and more than one-third (62 countries) have less than 10% of FFR in protected areas (Figure 2a). Countries with more than 40% of FFR kilometers within protected areas include Venezuela, Namibia, Poland, Germany, Cambodia, and Nicaragua. Countries with less than 10% of FFR kilometers within protected areas include Angola, Sudan, Russia, Turkey, several countries from South Asia (India, Myanmar, Pakistan), Central Asia (Uzbekistan, Kyrgyzstan, Kazakhstan, Turkmenistan), and the Middle East and North Africa (Iran, Iraq, Egypt, Saudi Arabia, Algeria, Tunisia). The results are nearly identical when considering the proportion of all river kilometers that are in protected areas (Figure 2b) because the percentage of countries' protected FFR kilometers and the percentage of all protected river kilometers are highly correlated (correlation coefficient = 0.99).

This high correlation arises because, globally, most short rivers (95%) are classified as free-flowing and most (68%) global river kilometers are from short rivers. In contrast, only 9% of all global river kilometers come from long (>500 km) or very long (>1000 km) rivers, and about half of long rivers and only one-third of very long rivers are classified as free-flowing (Table 1). Because short rivers dominate total global length and most short rivers are free-flowing, at the scale of the world—or individual continents or countries—the proportion of all free-flowing rivers within protected areas is highly correlated to the proportion of all rivers within protected areas (e.g., the columns under "all rivers" in Table 1; Figure 2).

Across continents, short and medium rivers (representing 91% of all kilometers) show this high correlation but the correlation weakens with long and very long rivers (Table 1). For example, in Europe, 20% of kilometers of all long rivers are within protected areas, but only 7% of kilometers of long FFRs are in protected areas. North America has the opposite trend, with 24% of kilometers of long FFRs in protected areas and 15% of kilometers of all long rivers in protected areas.

Table 1. Organized by length of river and continent, percent of river kilometers that are free flowing and then percent of free-flowing rivers' and percent of all river kilometers that are within protected areas.

	Short Rivers (<100 km)			Medium Rivers (100–500 km)			Long Rivers (500–1000 km)			Very Long Rivers (>1000 km)			All Rivers		
	% That Are FFR	FFR % Protected	All Rivers % Protected	% That Are FFR	FFR % Protected	All Rivers % Protected	% That Are FFR	FFR % Protected	All Rivers % Protected	% That Are FFR	FFR % Protected	All Rivers % Protected	% That Are FFR	FFR % Protected	All Rivers % Protected
Africa	98	16	16	86	16	16	71	16	16	44	15	18	90	16	16
Asia	92	11	10	75	11	10	55	12	10	29	7	9	83	11	10
Australia	98	13	13	88	12	12	67	10	9	54	18	15	94	13	13
Europe	92	16	16	61	13	17	29	7	20	11	11	18	78	15	17
North America	95	13	13	72	15	14	35	24	15	19	11	10	84	14	13
South America	98	29	28	83	25	23	64	29	24	48	22	19	92	28	27
World	95	17	17	77	16	15	54	17	16	33	14	14	87	17	16

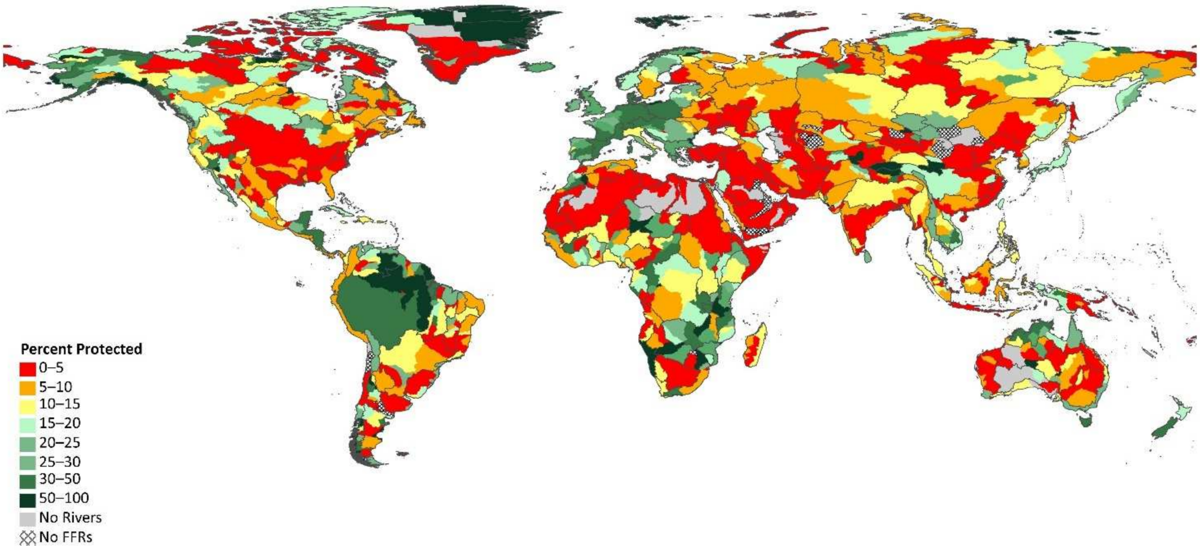
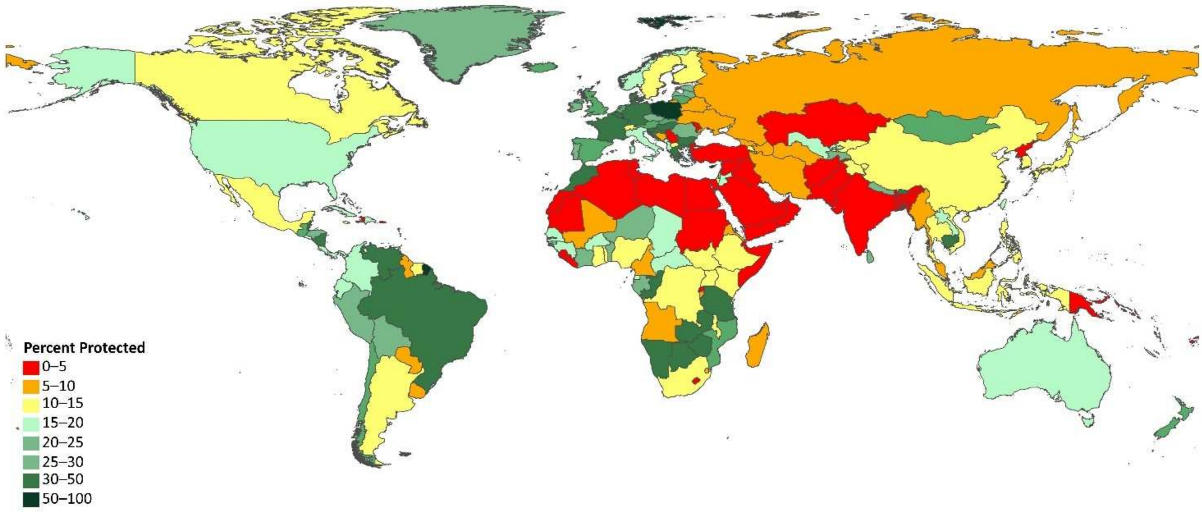


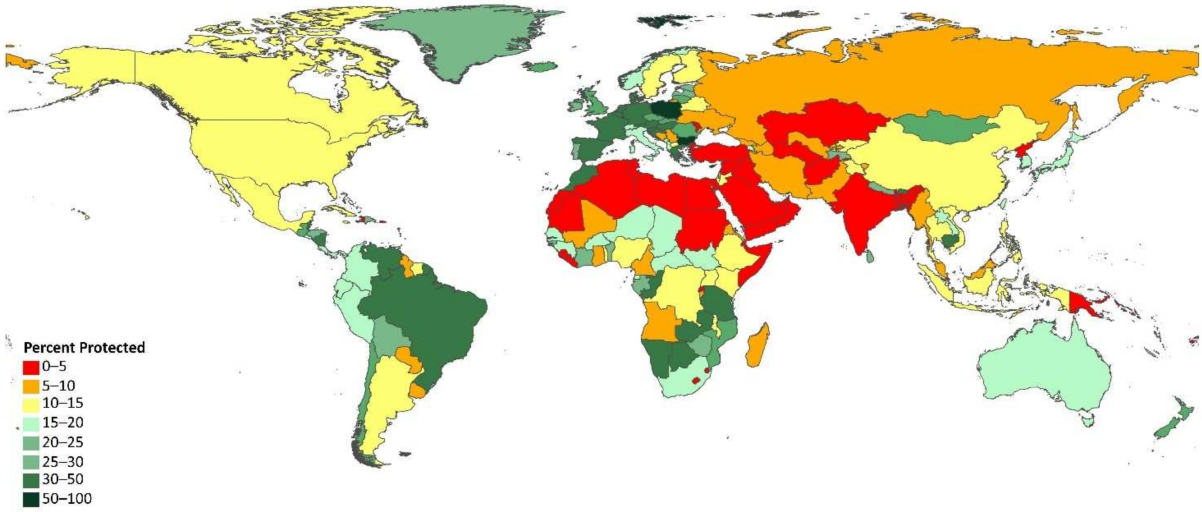
Figure 1. The percentage of free-flowing river kilometers that are within protected areas within major river basins (Level 4 basins, as defined by HydroSHEDS).

Because free-flowing rivers are a subset of all rivers, and the proportion of this subset varies across continents and river lengths (Table 1), we next compared the levels of protection between FFRs and non-FFR rivers for river lengths where the correlations between all rivers and FFRs are lower. In Africa, Australia, and South America, a high proportion of all long river kilometers are free-flowing (65–71%), whereas, in North America and Europe, approximately one-third of long rivers are free-flowing (Figure 3). In Africa and Australia, both FFRs and non-FFR rivers have similar proportions within protected areas (see percentages within the bars in Figure 3). For South America, North America, and Asia the proportion of long FFR kilometers in protected areas is about twice the proportion of non-FFR long rivers in protected areas. In contrast, only 7% of Europe's long FFR kilometers are in protected areas, whereas 25% of its long non-FFR kilometers are in protected areas. Most of Europe's long and very long FFRs are located in western Russia, and these have relatively low levels of protection; western Europe has more extensive protected areas, but the long rivers in these areas are not classified as free-flowing (note that the long and very long rivers of western Europe are generally not free-flowing, but their dark shading indicates high proportions within protected areas, and the cluster of long and very long FFRs in European Russia have relatively low levels of protection; Figure 4).

Globally, 8.1% of free-flowing short rivers have their entire length within protected areas, with South America having the greatest percentage (16.5%) and the other continents ranging from 3.1% of Europe's free-flowing short rivers to 6.7% of those in Africa that have their entire length in protected areas. For medium length rivers, this drops to 1.8% globally, with South America at 3.7% and the rest of the continents at approximately 2% (Africa, North America) or below 1.2% (Asia and Australia); Europe has 0.1% of its medium length rivers with their entire length in protected areas. Globally, there is a single long river with its entire length in protected areas: the Qumar River of China, which flows within two adjacent protected areas, Kekexili State and Sanjiangyuan National Nature Reserves.



(**a**)



(**b**)

Figure 2. (**a**) The percentage of all free-flowing river kilometers within protected areas, by country. (**b**) The percentage of all river kilometers within protected areas, by country. Note that the maps are nearly identical, reflecting the high correlation between levels of protection for rivers and free-flowing rivers. Although the United States shift colors between the two maps, that reflects a small difference between the percentage of river kilometers in protected areas (14%) and the percentage of FFR kilometers in protected areas (15%).

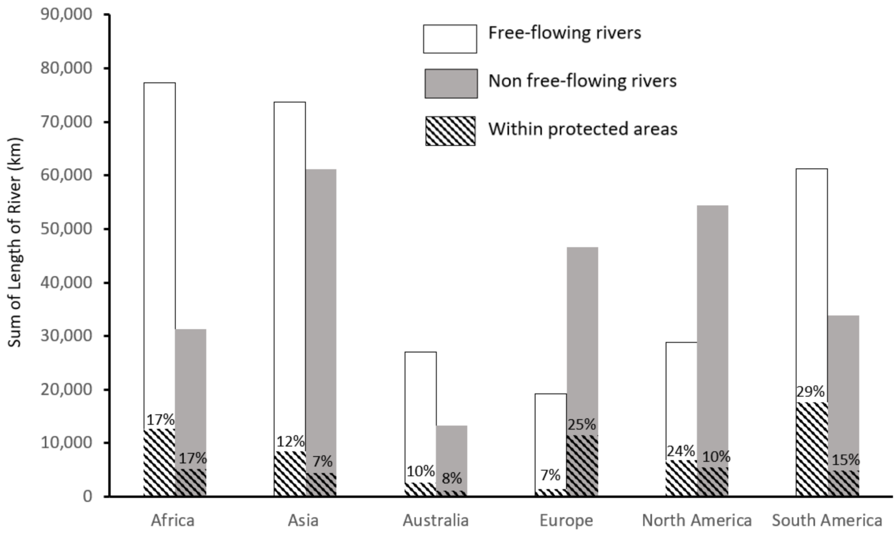


Figure 3. The extent of protection for long free-flowing rivers and long non-free-flowing rivers. Open bars are FFRs, and shaded bars are non-FFRs, and hatching indicates the proportion of each that is within the boundaries of protected areas, along with percentages above each hatched section. The majority of long rivers in Europe and North America are non-free-flowing (gray bars are higher than open bars), while the reverse is true for other continents.

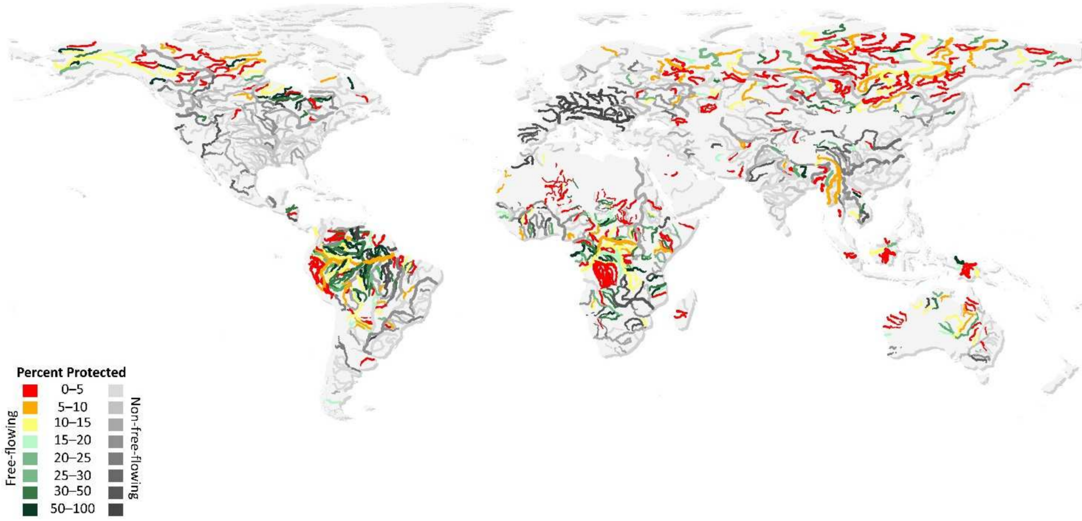


Figure 4. All the long (>500 km) and very long (>1000 km) rivers in the world with color (for free-flowing rivers) or grayscale shading (for non-free-flowing rivers), indicating the proportion of each river, by length, that is within a protected area.

3.2. Protection Based on Reach-Scale Discharge

In addition to analyzing patterns by river length, we also summarized the results by reach, with Reach Level reflecting mean annual discharge. Similar to how total river kilometers are dominated by short rivers, total river kilometers are also dominated by reaches with smaller discharges. For example, Reach Levels 6 and 7 (the smallest discharge) collectively represent 75% of all global river kilometers, whereas Reach Levels 1 and 2 collectively represent 0.2% of all global river kilometers. A high proportion of smaller (low discharge) reaches are classified as free-flowing, with 93% of Reach Level 7 kilometers classified as free-flowing, compared to approximately 40% of Reach Levels 2 and 3 (the only Reach Level 1 in the world is the lower 1300 kilometers of the Amazon, which is classified as free-flowing). For Reach Levels 6 and 7, the percentages of protection for kilometers within free-flowing reaches are highly correlated with the percentages of protection for kilometers in all reaches; the correlation becomes weaker for larger reach levels (e.g., see Europe, with 29% of all kilometers in Reach Level 3 within protected areas, compared to only 4% of kilometers of free-flowing Reach Level 3 within protected areas; Table 2).

Table 2. The percentage of all rivers and free-flowing rivers of each reach level that are within protected areas.

	Reach Level 7		Reach Level 6		Reach Level 5		Reach Level 4		Reach Level 3		Reach Levels 2 + 1	
	All	**FFR**	**All**	**FFR**	**All**	**FFR**	**All**	**FFR**	**All**	**FFR**	**All**	**FFR**
Africa	16%	16%	16%	16%	18%	17%	17%	16%	15%	14%	19%	19%
Asia	11%	11%	10%	11%	10%	11%	7%	7%	7%	8%	10%	15%
Australia	15%	14%	13%	13%	13%	13%	8%	7%	11%	13%		
Europe	15%	14%	16%	15%	19%	17%	22%	11%	29%	4%		
North America	12%	12%	14%	14%	15%	17%	13%	20%	10%	14%	7%	*
South America	26%	27%	27%	28%	26%	29%	27%	31%	20%	21%	17%	19%
Global	15%	16%	16%	17%	17%	18%	16%	18%	14%	15%	14%	18%

* North America has no reaches of Level 2 classified as free-flowing.

For reach levels with small discharge, the variability in the extent of protection of free-flowing kilometers in a country is largely explained by the extent of protection of a country's terrestrial area. For example, a country's proportion of FFR kilometers within protected areas for Reach Level 7 is highly correlated with the extent of the country's proportion of land within protected areas ($r^2 = 0.90$ for all countries). The ability for the percentage of land in protected areas to explain the percentage of protected FFRs is much weaker for reaches with higher discharge (e.g., $r^2 = 0.09$ for Reach Level 2; Figure 5).

The proportion of protection for all river kilometers, all FFR kilometers, and kilometers of low-discharge reaches (e.g., Reach Level 7) are all highly correlated with each other and with the proportion of land that is within protected areas (correlation coefficients are all > 0.97; Table 3 and Figure 5). There is a relatively low correlation between these categories and the proportion of FFR kilometers of Reach Level 2 in protected areas (correlation coefficients are between 0.25 and 0.27; Table 3). In the 15 countries that have FFR kilometers of Reach Level 2, these tend to have lower levels of protection than the level of protection for land or overall river kilometers (Figure 5).

Table 3. For the 15 countries that encompass river reaches of the size of Reach Level 2, coefficients of correlation among the percentage of protection of land and the percentage of protection of various categories of rivers.

	All Rivers	**All FFR**	**Reach Level 7**	**Reach Level 2**
Land	0.99	0.99	0.99	0.25
All rivers		1.00	0.99	0.27
All FFR rivers			0.99	0.25
Reach Level 7				0.27

3.3. Case Studies on the Limitations of Using Protected Area Boundaries to Define Protected FFR

In Nepal, there are 5502 km of rivers in protected areas and currently, 99% of them (5453 km) are classified as free-flowing, reflecting that 97% of all river kilometers in Nepal are classified as free-flowing (25,454 km of FFRs out of a total 26,020 km in Nepal). There are 285 hydropower dams that have been proposed or are in some stage of planning in Nepal, with nearly a quarter of these (67) in protected areas. If the dams in the "planned hydropower dams" database were built, the extent of FFRs in Nepal would decline by one-third, with just over 17,000 km remaining free-flowing. As a result, over 2000 km of rivers in protected areas, representing portions of 65 rivers, would lose their free-flowing status, a 40% loss within protected areas. Of these rivers, 41 would lose their FFR status because of a new hydropower dam built inside of the protected area, while 24 rivers would lose their FFR status because of a dam built outside of the protected area boundaries, either up- or downstream (Figure 6).

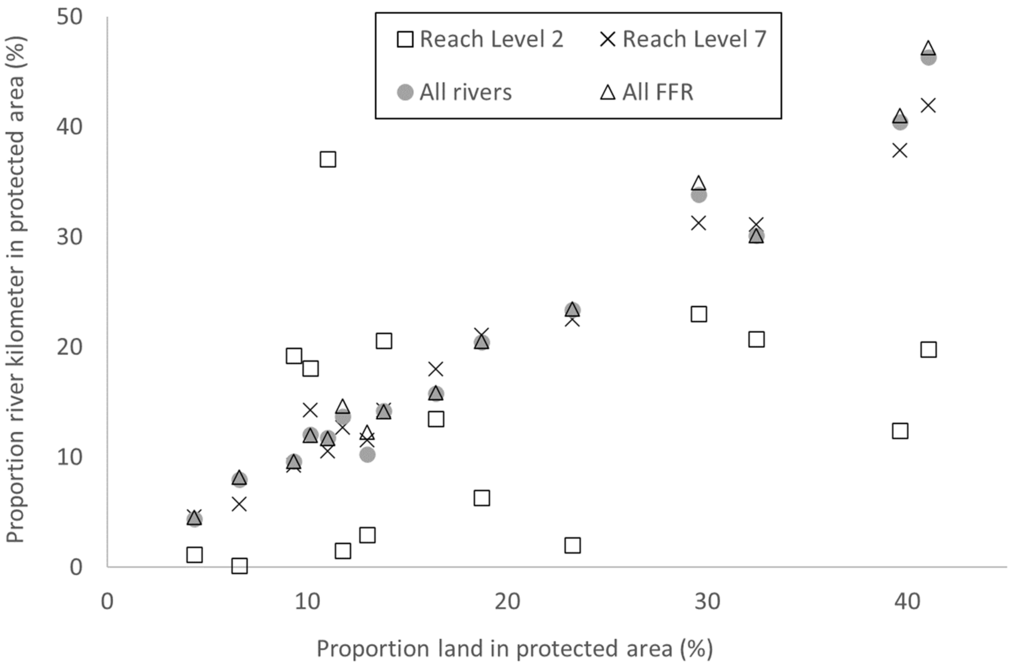


Figure 5. The proportion of land in protected areas compared to the proportion of river kilometers within protected areas for (1) reaches of Level 2 (squares); (2) reaches of Level 7 (X's); (3) all rivers (filled circles); and (4) all free-flowing rivers (triangles) for the 15 countries that have reaches of Level 2.

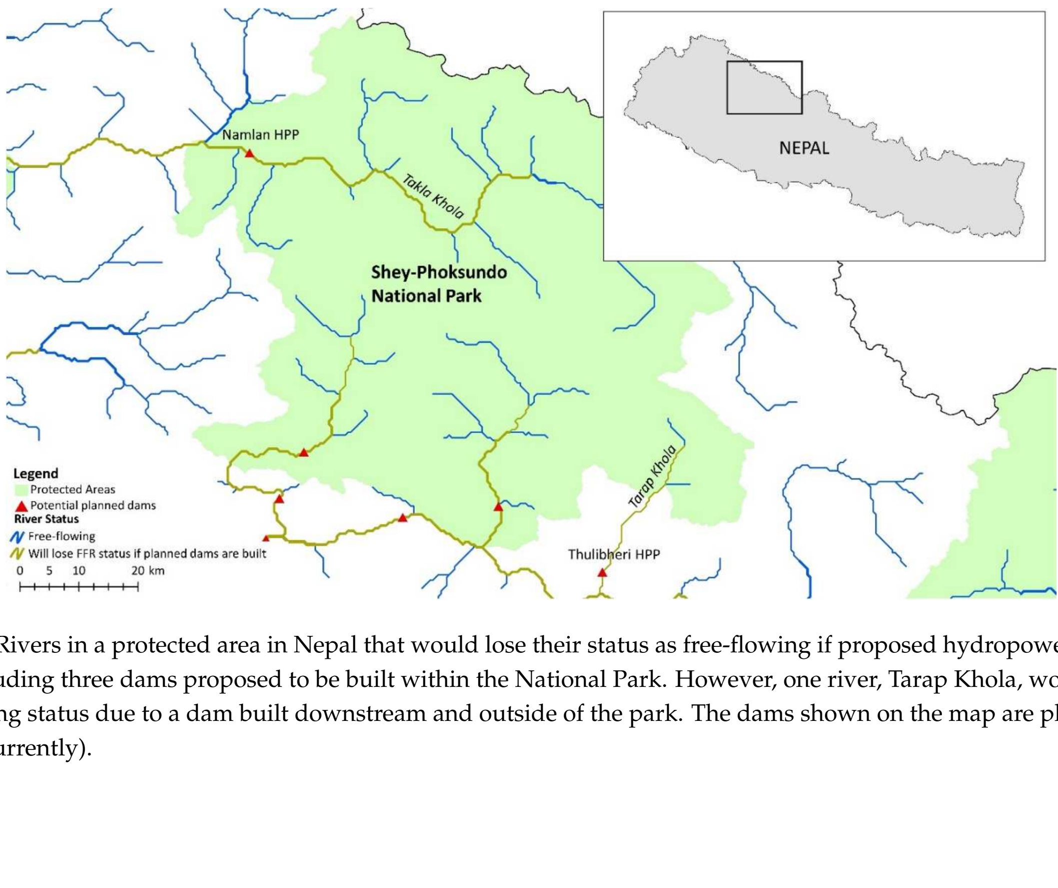


Figure 6. Rivers in a protected area in Nepal that would lose their status as free-flowing if proposed hydropower dams are built, including three dams proposed to be built within the National Park. However, one river, Tarap Khola, would lose its free-flowing status due to a dam built downstream and outside of the park. The dams shown on the map are planned (not existing currently).

In Brazil, rivers form nearly half (45%) of all protected area boundaries, with nearly 80,000 kilometers of river forming a boundary (nearly all of these kilometers are classified as free-flowing). Thus, approximately 10% of all river kilometers counted as being inside of a protected area are actually forming a boundary of a protected area (Figure 7).

Figure 7. The location of Iguaçu National Park in southern Brazil (top row of images); the yellow rectangle corresponds to the large image in the center. In that image, the forested area is the National Park and its eastern boundary is defined by the path of the Gonçalves Dias River (the horizontal red rectangle on the right corresponds to the photo in lower right), illustrating that rivers that serve as protected area boundaries can have very different land uses on the non-protected side of the river—in contrast to the Rio Floriano, which flows within the park (vertically oriented red rectangle on the left corresponds to the image in the lower left).

4. Discussion

The global proportion of all river kilometers in protected areas is just below the 17% protection for inland waters expressed by Aichi Target 11, and the proportion of FFR kilometers within protected areas equals that target. However, the full text of Target 11 indicates that the protection should be implemented in a system that is "ecologically representative" (e.g., across river size and habitat types). Two main results in this analysis suggest that, even though the current global proportion of FFRs in protected areas has reached the 17% target, ecological representation is currently not achieved.

First, there is a wide variability of levels of protection across river basins, countries, and continents. Whole regions of the world, including North Africa and the Middle East, and South and Central Asia, have consistently low levels of protection (Figure 2). The distinct species, populations, and ecosystems that occur in rivers across these regions are therefore likely to be found in systems with far less protection than the 17% target. Similarly, large river basins across the world—ranging from the Niger (4%) to the Ob (7%), Salween (7%), Mackenzie (8.5%), and Parana (9.4%)—have very low levels of protection for rivers, and free-flowing rivers, across their basins.

Second, there are wide differences in protection for river reaches of different sizes, based on length or discharge. This is most apparent when looking at patterns within individual countries. There are 15 countries with reaches of the size of Reach Level 2 (very high discharge). In these countries, an average of 20% of all FFR kilometers are within protected areas. However, for kilometers within reaches of Level 2, that drops to an average of 13% (see Figure 5). That is, countries with large free-flowing rivers tend to have lower levels of protection for the high discharge mainstem reaches of those rivers than they do for the reaches and tributary rivers with lower discharge distributed throughout the basin upstream of those mainstem reaches. Species richness increases with discharge [30] and these mainstem, high discharge reaches often have distinct processes (e.g., long-duration connectivity to extensive floodplains) and distinct species, populations, and services shaped by those processes (e.g., the highly productive fisheries of mainstem rivers with extensive floodplains) Reach Levels 1, 2, and 3 comprise just under 200,000 kilometers globally—less than 2% of river kilometers in this study—yet they encompass much of the diversity, productivity, and cultural importance associated with rivers around the world. For example, these high discharge mainstem reaches (and associated floodplains) encompass the most productive freshwater fisheries in the world, including the Irrawaddy River and the lower Mekong River (Reach Levels 2 and 3). These high discharge mainstem reaches also include many of the most prominent examples of rivers important to cultures, such as the Victoria Falls on the Zambezi River, the Nile as it flows through the Valley of the Kings, and the site of the Kumbh Mela along the Ganges River, a spiritual event dubbed "the largest gathering of humans" on the planet [31]. Thus, an "ecologically representative" system that protects "especially areas of particular importance for biodiversity and ecosystem services" (not to mention cultural and social values) should ensure sufficient protection for these distinct ecosystems within river networks, and our results indicate that currently, these river types have lower protection than do rivers, or free-flowing rivers, overall.

The fact that these high discharge river reaches, by aggregate length, are a very small portion of the world's total river kilometers—yet they encompass resources and values that are among the most important among rivers—underscores the risk of placing too much emphasis on a simple metric and target, such as protecting 17% of rivers. Global targets could incorporate specific goals for various sizes of rivers, as well as striving to achieve geographic distribution.

The fact that short rivers or small discharge reaches represent the highest proportion of rivers in the world by length raises a similar point about tracking progress toward global targets. If a target for global river protection defines "river" as a general term to include a wide range of river sizes, then tracking the target will essentially track the status of small rivers. Further, the extent of small rivers will generally scale proportionally to the extent of land area. Thus, most countries that achieve 17% of land area within protected areas will also achieve approximately 17% of river kilometers under protection. And because most small rivers are classified as free-flowing, then the country will also have achieved approximately 17% protection of free-flowing rivers. That is, as long as one defines "river" to include a broad range of sizes, tracking the extent of land under protection will essentially also track the extent of rivers under protection. However, there is little relationship between a country's proportion of land protected and proportion of high discharge mainstem reaches rivers in protected areas, although these reaches have environmental and social values that are disproportionately high (e.g., species richness and fisheries) relative to their share of global river kilometers.

Designating protected areas that include rivers is one mechanism for protecting rivers. Other mechanisms include river-specific policies, such as the Wild and Scenic Rivers Act (USA) and National Salmon Rivers (Norway) [20,21]. The database (WDPA) used in this and other studies of river protection (e.g., [8,9]) includes some but not all of these areas and so this study potentially misses some length of river under protection. Higgins and others [22]) reviewed a set of policies, regulations, judicial actions, water and land rights, and community-based efforts that can provide protection to rivers but are often not included in the WDPA and thus in most global tracking of protection [22]. Further, water allocation mechanisms or other water-management policies can serve as de facto river protection policies. For example, the Environmental Water Reserves (EWR) in Mexico establish a monthly flow allocation for rivers. Proposed infrastructure, such as a dam, must demonstrate that its operation can be consistent with the monthly flows prescribed by the EWR. Rivers with EWRs that are close to natural flow levels functionally have a high level of protection, and proposals for hydropower dams were withdrawn from the San Pedro and Usumucinta rivers because they could not comply with the EWR [23]. In Mexico, a total of 44,000 kilometers of FFRs have EWR defined for them [24].

A more complete assessment of the extent of global protection of FFRs will need to include rivers in protected areas (e.g., this study), rivers protected by river-specific mechanisms not included in the WDPA, and rivers with water-management policies that function as de facto protection mechanisms. There is ongoing work to expand the assessment of types of protection and to map Other Effective Area-based Conservation Measures (OECM), such as EWR, in order to better account for the full range of interventions that support conservation goals. (An OECM is defined as a "geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity, with associated ecosystem functions and services and where applicable, cultural, spiritual, socio-economic, and other locally relevant values") [32].

A more comprehensive assessment should also consider some of the limitations of defining as "protected" those river reaches that are within the boundaries of protected areas. While in many countries national parks provide strict protection for rivers, including a prohibition on dam development and other activities that would degrade rivers, not all protected areas across the world actually protect rivers from major impacts, such as dam construction. Thieme and others [19] found that at least 1249 large dams are located within PAs and that 14% of planned geolocated hydropower dams (509 dams) are located within PAs. There are also several examples of where protected areas were altered (e.g., downsized or decommissioned) to allow dam construction [19,33].

In the Nepal case study in this paper, we found that the development of proposed hydropower dams would cause 40% of river kilometers in Nepal's protected areas to lose their FFR status, and much of that loss was from dams proposed to be built inside protected areas (note that it is not certain how many of these dams may actually get built, but they are within government planning documents and have generally received initial licenses). In general, the river-specific protection mechanisms, such as a Wild and Scenic designation, do not allow dam development on protected rivers.

As indicated by the case study in Brazil, rivers often form the boundary of a protected area, but many mapping methods (including in this paper's global assessment) would consider those rivers to be within, and thus protected by, the protected area. However, there may be distinct limitations for the degree of protection afforded to rivers that form boundaries, because one side of the river, and perhaps a portion of the river itself, may actually fall outside of the jurisdiction of the protected area and be subject to impacts from land-use or activities such as fishing (see Figure 7). This issue merits further investigation, both in terms of global mapping of rivers as protected area boundaries and studies of the management implications of rivers as boundaries.

Finally, this study focused on the protection of free-flowing rivers, a status that derives from characteristics across multiple spatial scales. The designation of a free-flowing river is based on the Connectivity Status Index (CSI) value for a given reach, which is influenced by both local conditions (e.g., floodplain development that constricts lateral connectivity) and conditions throughout the network, such as upstream flow alteration, up- and/or downstream fragmentation of longitudinal connectivity, and sediment dynamics. Using the CSI effectively highlights the limitations of classifying a free-flowing river as "protected" if it falls within the boundaries of a protected area; the CSI, and thus, the free-flowing status of a reach inside a protected area, also depends on the conditions outside of the formally "protected" reach [9,34]. The Nepal case study illustrates this, as dozens of rivers in Nepalese protected areas would lose their FFR status if proposed hydropower dams (planned outside of a protected area) were constructed up- or downstream of the protected area, affecting the rivers within protected areas by flow alteration or fragmentation of connectivity. In other words, a given protected area can be managed as effectively as possible, yet the rivers within it could lose their FFR status due to decisions and actions outside of the protected area. Note that river-specific mechanisms (e.g., designating a stretch of river as Wild and Scenic) generally also have this vulnerability, in that they do not necessarily prevent impacts, such as dam construction, from occurring downstream or on upstream tributaries, in ways that would compromise the free-flowing nature of the river that the mechanism is intended to protect.

This limitation of protected areas for fully protecting FFRs suggests that broader concepts—beyond inclusion within the boundaries of a protected area or river-specific protection mechanisms—are needed to determine the level of protection, or degree of vulnerability, of an FFR. Abell and others [9] began to explore this needed expansion, proposing the concepts of "local protection" for a given reach (i.e., what is mapped in this study) along with "comprehensive protection", which is a function of the extent of protection of the area of the upstream drainage area above the given reach. This concept could be expanded in a few ways. First, the comprehensive protection of Abell and others [9] focuses on upstream conditions, but an FFR is also vulnerable to changes that take place downstream (e.g., from a dam blocking fish migration in the upstream direction). Second, comprehensive protection (sensu [9]) is calculated as a function of the extent of the upstream area within protected areas (e.g., percentage of land area). However, this overlooks the specific network vulnerabilities of an FFR. A reach could have 90% of its upstream area under protection, but the unprotected 10% may allow the construction of a dam that would lower the reach's connectivity status value such that it loses its FFR status. Similarly, even with 100% of the upstream area in some form of protection, that protection may have been established for other resources, such as protecting forests, and may not prevent dam construction. Although maintaining natural vegetation is important for water quality in a downstream reach, the highest priority for protecting a downstream FFR may not be in protecting land cover but in ensuring the channel network remains connected. Thus, the concept of comprehensive protection should be expanded to include more than just the upstream extent of protected areas, but also the protection of key network characteristics, perhaps requiring a broad suite of protection mechanisms [22]. Policies that prohibit dam construction on certain tributaries, or on the downstream main river, may be more important for maintaining a given FFR than broad spatial coverage of protected areas over the upstream drainage (though that may be important for sediment and water quality). A comprehensive effort to track the extent of protection of FFRs should account for the distribution of various types of protection, ranging from protected land in the upstream drainage to policies that protect connectivity of the channel network at various scales (local, and up- and downstream).

5. Conclusions

At the global level, the proportion of rivers in protected areas is just below the Aichi Target of 17% protection for inland waters, and the proportion of FFRs within protected areas equals that target. However, the extent of protection varies widely across river basins, countries, and continents, and many of these geographic units have a level of protection far lower than the target. Further, large mainstem rivers tend to have a lower extent of protection.

In addition, there are limitations to considering as "protected" those FFRs, or rivers more generally, that are within the boundaries of protected areas. While protected areas in some countries prohibit dam construction and other harmful activities, many countries allow dam construction within protected areas—14% of geolocated planned hydropower dams globally are within protected areas—or, if not officially, enforcement is weak or boundaries can be changed to accommodate development [19]. Securing strong protection for a free-flowing river adds additional challenges, as FFR status is dependent on conditions of a channel network both up and downstream of a given reach and thus, designating a protected status for a specific reach of an FFR may not protect its free-flowing status from impacts outside the reach.

Protected areas are often established based primarily, or exclusively, on terrestrial resources and, consequently, often fall short of protecting rivers and their ecosystems and species, because they were not designed and/or are not managed to address the patterns and processes that structure and sustain natural aspects of rivers [35]. Given these limitations of protected areas, fully protecting free-flowing rivers will likely require a range of additional mechanisms not limited by protected area boundaries, whether that is a terrestrially defined PA, such as a national park, or a river-specific designation, such as Wild and Scenic. These mechanisms include legislation, administrative designations, regulations, acquisition of enforceable rights in land or water, judicial actions, and collective management of pooled resources that are directed at maintaining free-flowing rivers and are long-lasting. These mechanisms can focus on protecting connectivity as well as other key processes and resources, such as water quality and biota (reviewed in [22]).

This review of the limitations of using traditional protected areas to protect free-flowing rivers also suggests that methods to map, quantify, and track the extent of protected FFRs will also need to be more comprehensive. A more comprehensive method will encompass the following:

- Rivers within protected areas, with methods to track those rivers that serve as boundaries of protected areas, and thus, may lack the full protection of the relevant designation. Further refinement may include methods to account for how the strength of protections for rivers within protected areas varies across countries (see below).
- Rivers protected by river-specific mechanisms not included within the World Database on Protected Areas, such as rivers protected by the mechanisms reviewed by Perry and others [21].
- Rivers protected by water allocation or other water-management policies that serve as de facto river protection policies. Examples include Environmental Water Reserves in Mexico and instream flow standards, such as those of Connecticut (USA) [22,23].
- Across these types, quantify and track across geography and river sizes and types. The extent of river protection should be assessed across environmental and biogeographical patterns, such as river sizes [2] and types [36], and potentially stratified by Freshwater ecoregional Major Habitat Types [37] and biogeographic realms [38].
- Further categorize the extent of protected rivers by the strength of protection of different measures across geographies, such as whether dams are formally or informally allowed. Higgins and others [22] review additional ways to measure the strength

of protection policies, including the extent of protection for various river processes, whether protections are legally protected and enforceable, the duration of protection, and whether protections are sustained through local community norms if not under legal governance.

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References

1. Opperman, J.J.; Orr, S.; Baleta, H.; Garrick, D.; Goichot, M.; McCoy, A.; Morgan, A.; Schmitt, R.; Turley, L.; Vermeulen, A. Achieving Water Security's Full Goals through Better Integration of Rivers' Diverse and Distinct Values. *Water Secur.* **2020**, *10*, 100063. [CrossRef]
2. Grill, G.; Lehner, B.; Thieme, M.; Geenen, B.; Tickner, D.; Antonelli, F.; Babu, S.; Borrelli, P.; Cheng, L.; Crochetiere, H.; et al. Mapping the World's Free-Flowing Rivers. *Nature* **2019**, *569*, 215–221. [CrossRef]
3. WWF. *Living Planet Report 2020: Bending the Curve of Biodiversity Loss*; WWF: Gland, Switzerland, 2020.
4. Reid, A.J.; Carlson, A.K.; Creed, I.F.; Eliason, E.J.; Gell, P.A.; Johnson, P.T.J.; Kidd, K.A.; MacCormack, T.J.; Olden, J.D.; Ormerod, S.J.; et al. Emerging Threats and Persistent Conservation Challenges for Freshwater Biodiversity. *Biol. Rev.* **2019**, *94*, 849–873. [CrossRef] [PubMed]
5. Zarfl, C.; Lumsdon, A.E.; Berlekamp, J.; Tydecks, L.; Tockner, K. A Global Boom in Hydropower Dam Construction. *Aquat. Sci.* **2015**, *77*, 161–170. [CrossRef]
6. Tickner, D.; Opperman, J.J.; Abell, R.; Acreman, M.; Arthington, A.H.; Bunn, S.E.; Cooke, S.J.; Dalton, J.; Darwall, W.; Edwards, G.; et al. Bending the Curve of Global Freshwater Biodiversity Loss: An Emergency Recovery Plan. *BioScience* **2020**, *70*, 330–342. [CrossRef] [PubMed]
7. Secretariat of the Convention on Biological Diversity. Strategic Plan for Biodiversity 2011–2020, Including Aichi Biodiversity Targets. Available online: https://www.cbd.int/sp/ (accessed on 18 February 2021).
8. Bastin, L.; Gorelick, N.; Saura, S.; Bertzky, B.; Dubois, G.; Fortin, M.-J.; Pekel, J.-F. Inland Surface Waters in Protected Areas Globally: Current Coverage and 30-Year Trends. *PLoS ONE* **2019**, *14*, e0210496. [CrossRef]
9. Abell, R.; Lehner, B.; Thieme, M.; Linke, S. Looking Beyond the Fenceline: Assessing Protection Gaps for the World's Rivers. *Conserv. Lett.* **2017**, *10*, 384–394. [CrossRef]
10. Juffe-Bignoli, D.; Burgess, N.D.; Bingham, H.; Belle, E.; De Lima, M.; Deguignet, M.; Bertzky, B.; Milam, A.; Martinez-Lopez, J.; Lewis, E. *Protected Planet Report 2014*; UNEP-WCMC: Cambridge, UK, 2014; Volume 11.
11. Juffe-Bignoli, D.; Harrison, I.; Butchart, S.H.; Flitcroft, R.; Hermoso, V.; Jonas, H.; Lukasiewicz, A.; Thieme, M.; Turak, E.; Bingham, H.; et al. Achieving Aichi Biodiversity Target 11 to Improve the Performance of Protected Areas and Conserve Freshwater Biodiversity: Elements Needed to Meet a Global Target for Protected Areas. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **2016**, *26*, 133–151. [CrossRef]
12. McIntyre, P.B.; Reidy Liermann, C.A.; Revenga, C. Linking Freshwater Fishery Management to Global Food Security and Biodiversity Conservation. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 12880–12885. [CrossRef]
13. Syvitski, J.P.M. Deltas at Risk. *Sustain. Sci.* **2008**, *3*, 23–32. [CrossRef]
14. Auerbach, D.A.; Deisenroth, D.B.; McShane, R.R.; McCluney, K.E.; LeRoy Poff, N. Beyond the Concrete: Accounting for Ecosystem Services from Free-Flowing Rivers. *Ecosyst. Serv.* **2014**, *10*, 1–5. [CrossRef]
15. Nehlsen, W. Pacific Salmon Status and Trends—A Coastwide Perspective. In *Pacific Salmon & Their Ecosystems: Status and Future Options*; Stouder, D.J., Bisson, P.A., Naiman, R.J., Eds.; Springer: Boston, MA, USA, 1997; pp. 41–50. ISBN 978-1-4615-6375-4.
16. Deinet, S.; Scott-Gatty, K.; Rotton, H.; Twardek, W.; Marconi, V.; McRae, L.; Baumgartner, L.; Brink, K.; Claussen, J.; Cooke, S.; et al. *Living Planet Index for Migratory Freshwater Fish*; World Fish Migration Foundation: Groningen, The Netherlands, 2020.
17. Syvitski, J.P.M.; Kettner, A.J.; Overeem, I.; Hutton, E.W.H.; Hannon, M.T.; Brakenridge, G.R.; Day, J.; Vörösmarty, C.; Saito, Y.; Giosan, L.; et al. Sinking Deltas Due to Human Activities. *Nat. Geosci.* **2009**, *2*, 681–686. [CrossRef]
18. Opperman, J.; Hartmann, J.; Lambrides, M.; Carvallo, J.; Chapin, E.; Baruch-Mordo, S.; Eyler, B.; Goichot, M.; Harou, J.; Hepp, J. Connected and Flowing: A Renewable Future for Rivers, Climate, and People. *WWF*, 28 October 2020.

19. Thieme, M.L.; Khrystenko, D.; Qin, S.; Kroner, R.E.G.; Lehner, B.; Pack, S.; Tockner, K.; Zarfl, C.; Shahbol, N.; Mascia, M.B. Dams and Protected Areas: Quantifying the Spatial and Temporal Extent of Global Dam Construction within Protected Areas. *Conserv. Lett.* **2020**, *13*, e12719. [CrossRef]
20. Moir, K.; Thieme, M.; Opperman, J.J. *Securing a Future That Flows: Case Studies of Protection Mechanisms of Rivers*; WWF; The Nature Conservancy: Washington, DC, USA, 2016.
21. Perry, D.; Harrison, I.; Hernandes, S.; Burnham, S.; Nichols, A. Global Analysis of Durable Policies for Free-Flowing River Protections. *Sustainability* **2021**, *13*, 2347. [CrossRef]
22. Higgins, J.; Zablocki, J.; Newsock, A.; Krolopp, A.; Tabas, P.; Salama, M. Durable Freshwater Protection: A Framework for Establishing and Maintaining Long-Term Protection for Freshwater Ecosystems and the Values They Sustain. *Sustainability* **2021**, *13*, 1950. [CrossRef]
23. Opperman, J.J.; Kendy, E.; Barrios, E. Securing Environmental Flows Through System Reoperation and Management: Lessons From Case Studies of Implementation. *Front. Environ. Sci.* **2019**, *7*. [CrossRef]
24. Salinas-Rodríguez, S.A.; Barba-Macías, E.; Infante Mata, D.; Nava-López, M.Z.; Neri-Flores, I.; Domínguez Varela, R.; González Mora, I.D. What Do Environmental Flows Mean for Long-Term Freshwater Ecosystems' Protection? Assessment of the Mexican Water Reserves for the Environment Program. *Sustainability* **2021**, *13*, 1240. [CrossRef]
25. Lehner, B.; Verdin, K.; Jarvis, A. New Global Hydrography Derived from Spaceborne Elevation Data. *Eos Trans. Am. Geophys. Union* **2008**, *89*, 93–94. [CrossRef]
26. Lehner, B.; Grill, G. Global River Hydrography and Network Routing: Baseline Data and New Approaches to Study the World's Large River Systems. *Hydrol. Process.* **2013**, *27*, 2171–2186. [CrossRef]
27. UNGIS. Global International Boundaries. 2020. Available online: https://www.un.org/geospatial/ (accessed on 3 March 2021).
28. UNEP-WCMC. Protected Areas Map of the World. October 2020. Available online: https://www.protectedplanet.net/en/resources/october-2020-update-of-the-wdpa (accessed on 3 March 2021).
29. UNEP-WCMC. Protected Areas Map of the World. January 2017. Available online: https://www.protectedplanet.net/en/resources/january-2017-update-of-the-wdpa (accessed on 3 March 2021).
30. Xenopoulos, M.A.; Lodge, D.M. Going with the Flow: Using Species–Discharge Relationships to Forecast Losses in Fish Biodiversity. *Ecology* **2006**, *87*, 1907–1914. [CrossRef]
31. Frayer, L. Welcome to the World's Largest Gathering of Humans. *National Public Radio*. 20 January 2019. Available online: https://www.npr.org/sections/goatsandsoda/2019/01/20/686482390/welcome-to-the-worlds-largest-gathering-of-humans (accessed on 1 March 2021).
32. IUCN; World Commission on Protected Areas (WCPA); Task Force on Other Effective Area-based Conservation Measures. *Recognising and Reporting Other Effective Area-Based Conservation Measures*; IUCN: Gland, Switzerland, 2019.
33. Pack, S.M.; Ferreira, M.N.; Krithivasan, R.; Murrow, J.; Bernard, E.; Mascia, M.B. Protected Area Downgrading, Downsizing, and Degazettement (PADDD) in the Amazon. *Biol. Conserv.* **2016**, *197*, 32–39. [CrossRef]
34. Thieme, M.L.; Rudulph, J.; Higgins, J.; Takats, J.A. Protected Areas and Freshwater Conservation: A Survey of Protected Area Managers in the Tennessee and Cumberland River Basins, USA. *J. Environ. Manag.* **2012**, *109*, 189–199. [CrossRef]
35. Leal, C.G.; Lennox, G.D.; Ferraz, S.F.B.; Ferreira, J.; Gardner, T.A.; Thomson, J.R.; Berenguer, E.; Lees, A.C.; Hughes, R.M.; Mac Nally, R.; et al. Integrated Terrestrial-Freshwater Planning Doubles Conservation of Tropical Aquatic Species. *Science* **2020**, *370*, 117–121. [CrossRef]
36. Dallaire, C.O.; Lehner, B.; Sayre, R.; Thieme, M. A Multidisciplinary Framework to Derive Global River Reach Classifications at High Spatial Resolution. *Environ. Res. Lett.* **2019**, *14*, 024003. [CrossRef]
37. Abell, R.; Thieme, M.L.; Revenga, C.; Bryer, M.; Kottelat, M.; Bogutskaya, N.; Coad, B.; Mandrak, N.; Balderas, S.C.; Bussing, W.; et al. Freshwater Ecoregions of the World: A New Map of Biogeographic Units for Freshwater Biodiversity Conservation. *BioScience* **2008**, *58*, 403–414. [CrossRef]
38. Holt, B.G.; Lessard, J.-P.; Borregaard, M.K.; Fritz, S.A.; Araújo, M.B.; Dimitrov, D.; Fabre, P.-H.; Graham, C.H.; Graves, G.R.; Jønsson, K.A.; et al. An Update of Wallace's Zoogeographic Regions of the World. *Science* **2013**, *339*, 74–78. [CrossRef] [PubMed]