



Freshwater fishes of China: species richness, endemism, threatened species and conservation

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ABSTRACT

Aim To compile an inventory of freshwater fish species in China, and to investigate these data to determine spatial patterns in species richness, endemism and threatened species for the purpose of facilitating conservation.

Location China

Methods Literature, databases and fish collections were examined to create an inventory database of freshwater fishes of China. This list was analysed to determine species richness, endemism and threatened species. SPSS and ORIGIN software were used to determine relationships between these three parameters across the area and length of river basins. Coefficients of fish diversity for each major river were calculated using the Gleason Index.

Results Chinese freshwater fish fauna is comprised of 1323 species; the majority of species belong to Cypriniformes and Cyprinidae. Of 877 species endemic to China, 161 of 199 threatened species are endemic, with most classified as 'endangered' (85 species) or 'vulnerable' (70). Species endemism and the number of threatened species correlate positively with species richness. River basin area and length have no direct bearing on either species richness or endemism. The Pearl River was identified as the most species-rich system. It also has the most endemic and threatened fish species.

Main conclusions China's vast size, variable geography and climate influence patterns in species diversity and endemism. Its freshwater fish fauna is rich and largely endemic and a significant number of these endemic species are threatened. Dam construction, water pollution, overfishing and invasive species pose threats to native biodiversity. National assessment of threatened species is urgently needed. The Yangtze, Yellow and Pearl rivers require prioritized national protection. Environmental effects of development require serious consideration and, potentially, proactive conservation efforts and mitigation. Development on international rivers needs to consider environmental policies of all countries owning spans of the systems, particularly the wishes and concerns of nations with lower spans of a system.

Keywords

China, conservation, endemism, freshwater fish, species diversity.

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INTRODUCTION

China is both the world's most populous country and the fourth largest country by area. It is also one of 17 mega-diversity countries (Mittermeier *et al.*, 1997). More than 33,000 vascular plants (López-Pujol *et al.*, 2006) and 6100 vertebrate species – including 673 mammals (about 12% of

the total number of mammal species known; Jiang *et al.*, 2015), 1329 birds (13%; MacKinnon & Phillipps, 2000), 435 amphibians (11%; Zhang, 1999) and 464 reptiles (5%; Uetz & Hošek, 2014) – occur within its borders. Many of these species are endemic and many are also threatened.

Despite global analyses concluding China has exceptional riverine fish diversity and endemism (Tedesco *et al.*, 2012;

Tisseuil *et al.*, 2013), the lack of an up-to-date inventory of current patterns is a significant problem and complicates conservation potential. Commencing with the seminal work of the *Index Piscium Sinensium* (Chu, 1931), many subsequent texts are now obsolete or are written in Chinese and, as a result, have little global impact. Many regional reviews have been published, such as those for the Yangtze basin (Fu *et al.*, 2003), Pearl River (Chen *et al.*, 1986) and Upper Mekong River (Kang *et al.*, 2009). Although biogeographic patterns in fish distribution throughout China were recently appraised by Kang *et al.* (2014), their data were incomplete. Broad-scale analyses and syntheses of patterns in the diversity and distribution of freshwater fishes in China are otherwise limited (Fu *et al.*, 2003).

Freshwater biodiversity faces a global crisis, with some of the world's most species-rich, threatened and valuable fish lineages afforded no legal protection (Abell *et al.*, 2011). A variety of fishery, hydropower and navigation activities exploit China's extensive freshwaters resources, and each has some effects on native biodiversity. Although threats to freshwater systems from hydroelectric use (dams), pollution and habitat degradation have been extensively documented (Dudgeon, 2000, 2011), little remediation has been undertaken and, as a consequence, many endemic and iconic fish species are now endangered (EN) or at high risk of extinction.

We provide the most comprehensive account of the diversity, distribution and conservation status of freshwater fishes throughout China to-date. Our faunal inventory and associated database can be used to analyse patterns in distribution of species richness, endemism and the current conservation status of species. A key goal is to improve efforts in the conservation and management of fishes throughout China. This inventory will also benefit those evaluating zoogeographic relationships between freshwater fishes throughout greater Asia.

METHODS

Our inventory of native freshwater fishes (Appendix S1) has been collated based on review of ichthyological literature published from 1758 to 2014, including 101 books (92 in Chinese) and 1279 journal articles (721 in Chinese). This was supplemented with data from FishBase (Froese & Pauly, 2014); Fish Database of Taiwan (Shao, 2015); Catalogue of Fishes (Eschmeyer, 2015); and collections of the Chinese Academy of Sciences including Institute of Zoology, Institute of Hydrobiology, and Kunming Institute of Zoology and Beijing Natural History Museum.

To minimize error in our data, and to ensure accuracy and comprehensive coverage, we enlisted the services of expert colleagues to critique our species inventory (see Acknowledgements). We also personally examined various type materials in above collections in China, the United States (California Academy of Sciences) and the UK (British Museum of Natural History) in addition to our extensive review of the literature.

Species distributions were determined from the literature, collections and database sources. We recognize endemic species on two levels: China's endemic species refer to those taxa whose natural distribution is restricted to Chinese geographical boundaries; endemic riverine species refers to fishes which are exclusively distributed in one of the major river basins, such as the Yangtze, Yellow or Pearl. Threatened species were determined using several databases or Red Lists (Appendix S2). Analyses of relationships between species richness and river basin area and length were derived from hydrographic data from Lu & Fu (2010).

Data on species richness and endemic species of freshwater fishes in the major river basins of the world were downloaded from Fish-SPRICH database (Brosse *et al.*, 2013), and complemented by related literature.

Degrees of species richness are a function of the number of taxa in China compared to global totals within each family or order. Degrees of endemism and threatened species are measured relative to the number of China's endemic or threatened species over the total number of species within each family or order in China. Linear models between pairwise types of species richness, endemism and threatened species were fitted to determine relationships among three criteria. Logarithmic models (with 95% confidence limits) between species richness, endemism, threatened species, and the area and length of river basins were also fitted to determine relationships between diversity and river terrain. Two-sample *t*-tests between pairwise types of number of total, endemic and threatened species were performed. A coefficient of diversity for each major river basin was calculated using the Gleason Index $D = S/\ln A$ (A = basin area, S = total number of species) (Sun, 2001) to determine the degree of species richness in the main rivers. All statistical analyses were performed using SPSS 10.1 and ORIGIN 7.5.

RESULTS

Faunal richness

The fauna comprises 1323 species (3 lamprey and 1320 teleost fish), attributed to 283 genera, 42 families and 15 orders (Table 1). Primarily freshwater fish accounted for 1304 species and 19 were diadromous fish (14 anadromous and 5 catadromous species).

Three orders [Cypriniformes ($n = 1007$), Siluriformes ($n = 146$) and Perciformes ($n = 109$)] account for more than 95% of species (76.11%, 11.04% and 8.24%, respectively). The Cyprinidae ($n = 654$), Nemacheilidae ($n = 205$) and Balitoridae ($n = 91$) are the three most species-rich families, with 11 families containing more than 10 species. With 142 genera, the Cyprinidae has more than eight times the number of genera as the Nemacheilidae and Balitoridae (both 17, rank second). The ten most species-rich genera collectively contribute 400 species (30.23%) to the 1323 species recognized from the region (Table S1).

Table 1 Species richness, endemism and threatened species of China's freshwater fish.

Order	Family	Genus	Species	Total global species (Eschmeyer, 2014)	Degree of species richness (%)	Endemic species	Degree of endemism (%)	Threatened species	Degree of threatened species (%)
Petromyzontiformes	Petromyzontidae	2	3	42	7.14	0	0	2	66.67
Acipenseriformes	Acipenseridae	2	7	26	26.92	1	14.29	4	57.14
	Polyodontidae	1	1	2	50	1	100	1	100
Anguilliformes	Anguillidae	1	4	18	2.22	0	0	2	50
Clupeiformes	Clupeidae	1	1	194	0.52	0	0	1	100
	Engraulidae	1	1	147	0.68	0	0	0	0
Cypriniformes	Cyprinidae	142	654	2962	22.08	440	67.28	108	16.51
	Psilorhynchidae	1	1	24	4.17	0	0	1	100
	Cobitidae	12	54	246	21.95	39	72.22	1	1.85
	Balitoridae	17	91	231	39.39	78	85.71	5	5.49
	Nemacheilidae	17	205	632	32.44	179	87.32	8	3.9
	Gyrinocheilidae	1	1	3	33.33	0	0	1	100
	Catostomidae	1	1	83	1.2	1	100	1	100
Siluriformes	Bagridae	4	35	204	17.16	26	74.29	5	14.29
	Cranoglanididae	1	2	3	66.67	2	100	1	50
	Siluridae	4	15	96	15.63	5	33.33	4	26.67
	Schilbeidae	2	4	61	6.56	0	0	0	0
	Pangasiidae	2	5	28	17.86	0	0	2	40
	Amblycipitidae	2	11	36	30.56	11	100	3	27.27
	Akysidae	1	2	57	3.51	1	50	1	50
	Sisoridae	13	71	214	33.18	30	42.25	8	11.27
	Clariidae	1	1	120	0.83	0	0	0	0
Esociformes	Esocidae	1	2	7	28.57	0	0	0	0
Osmeriformes	Osmeridae	1	1	12	8.33	0	0	0	0
	Plecoglossidae	1	1	1	100	0	0	1	100
	Salangidae	4	6	18	33.33	3	50	0	0
Salmoniformes	Salmonidae	7	19	221	8.6	2	10.53	8	42.11
Gadiformes	Gadidae	1	1	23	4.35	0	0	0	0
Cyprinodontiformes	Cyprinodontidae	1	3	134	2.24	1	33.33	0	0
Gasterosteiformes	Gasterosteidae	2	2	19	10.53	0	0	0	0
Synbranchiformes	Synbranchidae	1	2	24	8.33	0	0	0	0
	Mastacembelidae	3	5	85	5.88	1	20	0	0
Scorpaeniformes	Cottidae	3	7	263	2.66	0	0	1	14.29
Perciformes	Serranidae	2	10	544	1.84	7	70	3	30
	Percidae	2	3	236	1.27	0	0	0	0
	Rhyacichthyidae	1	1	3	33.33	0	0	1	100
	Odontobutidae	5	8	23	34.78	5	62.5	4	50
	Eleotridae	5	8	171	4.68	0	0	1	12.5
	Gobiidae	10	62	1745	3.55	40	64.52	19	30.65
	Anabantidae	1	1	31	3.22	0	0	0	0
	Osphronemidae	2	4	130	3.08	2	50	1	25
	Channidae	1	7	35	20	2	28.57	1	14.29
Total	42	283	1323	9154		877		199	

Endemism

Two-thirds (877 species) of total species, represented by 173 genera, 22 families and 7 orders are endemic to China. Most of these taxa belong to the Cypriniformes ($n = 737$, 84.04% of total number of endemic species), followed by Siluriformes ($n = 75$, 8.55%) and Perciformes ($n = 56$, 6.39%)

(Table 1). Of these 173 genera, 90 are endemic to China and 43 of them are monotypic.

The 737 endemic Cypriniformes species account for 73.19% of the total number of species in this order, followed by Perciformes (51.38%) and Siluriformes (51.37%) (Fig. 1a). Species of four families (Catostomidae, Polyodontidae, Amblycipitidae and Cranoglanididae) are endemic to China.

Threatened species

Species considered to be threatened account for 15.04% of all species ($n = 199$), of which 125 (62.81% of total number of threatened species) belong to Cypriniformes, followed by Perciformes ($n = 30$; 15.08%), Siluriformes ($n = 24$; 12.06%), Salmoniformes ($n = 8$; 4.02%) and Acipenseriformes ($n = 5$; 2.51%). All species within seven families are threatened (Table 1). According to threat classification ranks, 35 species are considered critically endangered (CR), 85 EN and 70 vulnerable (VU). An additional five cyprinid species are considered extinct (EX) and a further four extinct in the wild (EW) (Table 2). The highest degrees of threatened species belong to the Petromyzontiformes, followed by Acipenseriformes, Clupeiformes and Anguilliformes. Despite Cypriniformes having the greatest number of threatened species, the proportion of these to the total number of species was the smallest of all groups considered (Fig. 1b).

Relationships among species richness, endemism and threatened species

Linear regression relationships between indices of endemic species (Y_{en}) and species richness (X_{tt}), threatened species (Y_{th}) to species richness (X_{tt}) and threatened species (Y_{th}) to endemic species richness (X_{en}) are as follows: $Y_{en} = 0.8205X_{tt} - 36.818$ ($R^2 = 0.9761$; $P < 0.0001$), $Y_{th} = 0.1249X_{tt} - 4.1045$ ($R^2 = 0.9697$; $P < 0.0001$) and $Y_{th} = 0.1498X_{en} + 1.6927$ ($R^2 = 0.9621$; $P < 0.0001$) (Fig 2a–c). Significant correlations exist between species richness and the number of endemic and the number of threatened species. The number of threatened species is also significantly correlated to the number of endemic species.

In total, 17 families contain threatened endemic species, with most threatened endemic taxa belonging to the Cyprinidae ($n = 100$). All threatened species within the

Polyodontidae, Cobitidae, Balitoridae, Nemacheilidae, Catostomidae, Bagridae, Cranoglanididae, Amblycipitidae, Akysidae and Serranidae are endemic in China (Table 3).

In relation to river basins of China

The majority of species occurred in 11 river basins with basin area exceeding 100,000 km². The total numbers of endemic and threatened species were compared (Table 4). Total species richness, endemic species richness and threatened species richness did not correlate significantly to river basin area or length.

The richest species diversity occurs in the Pearl, followed by the Yangtze and Lancangjiang (upper Mekong) rivers. These three rivers also had the highest number of threatened species. However, the Pearl, Yangtze and Yellow rivers contain most of China's endemic species. More than half of freshwater fishes from these three rivers are only found in China (74.68%, 75.59% and 56.69%, respectively). Relative to basin area, the Pearl River had the most species per 1000 km², followed by the Lancangjiang and Nuijiang (upper Salween) rivers. Only in the Pearl River did the number of species per 1000 km² exceed one. The Pearl, Lancangjiang and Yangtze rivers were the top three systems by numbers of endemic and threatened species by area and for the species richness index for all river systems (Table 4).

China has many international rivers. Lengths of the Yarlung Zangbo (upper Brahmaputra), Lancangjiang and Nuijiang all exceed 2000 km length in China. These rivers contain high species diversity and endemism of freshwater fishes. The Lancangjiang River is among the most diverse in terms of freshwater fish species, endemic species and threatened species per 1000 km² of basin area. Although the Yarlung Zangbo only has 41 freshwater fish taxa, 23 (56.10%) of them are only found in China (Table 4).

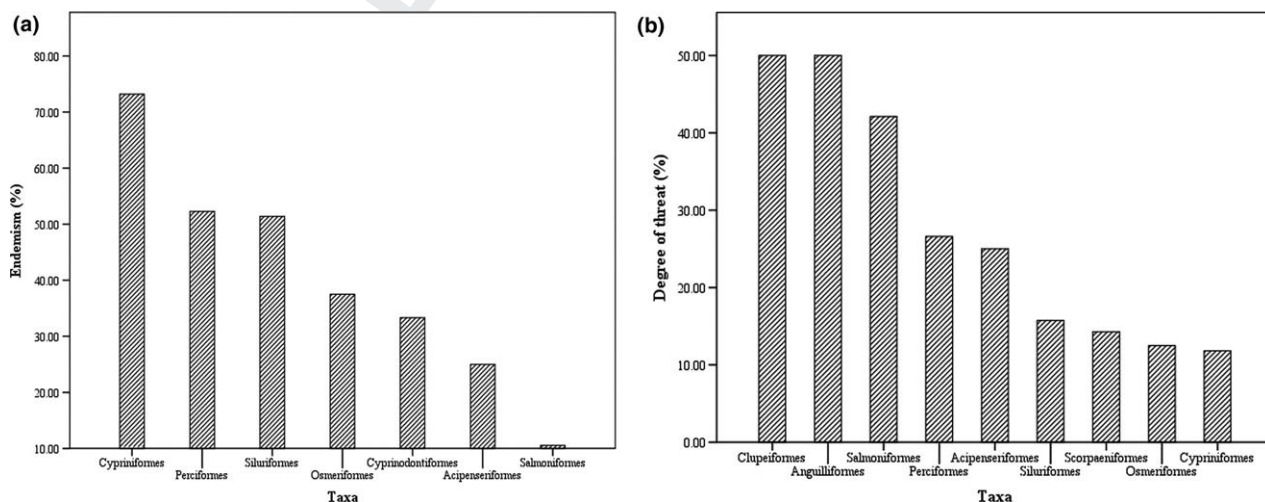


Figure 1 Degrees of endemism (a) and threatened species (b) by taxonomic order (excluding orders without endemic or threatened species).

Table 2 Total numbers of threatened freshwater fish species by family, and numbers (percentage) of fish in IUCN conservation status categories (EX, extinct; EW, extinct in the wild; CR, critically endangered; EN, endangered; VU, vulnerable).

Orders	Families	Threatened species	EX	EW	CR	EN	VU
Petromyzontiformes	Petromyzontidae	2					2 (100)
Acipenseriformes	Acipenseridae	4				4 (100)	
	Polyodontidae	1			1 (100)		
Anguilliformes	Anguillidae	2				2 (100)	
Clupeiformes	Clupeidae	1				1 (100)	
	Engraulidae	0					
Cypriniformes	Cyprinidae	108	5 (4.81)	3 (2.88)	22 (20.37)	38 (35.19)	40 (37.04)
	Psilorhynchidae	1				1 (100)	
	Cobitidae	1					1 (100)
	Balitoridae	5			2 (66.67)	2 (40.00)	1 (20.00)
	Nemacheilidae	8			2 (25.00)		6 (75.00)
	Gyrinocheilidae	1				1 (100)	
	Catostomidae	1					1 (100)
Siluriformes	Bagridae	5			1 (20.00)	1 (20.00)	3 (60.00)
	Cranoglanididae	1					1 (100)
	Siluridae	4			1 (0.25)	2 (0.50)	1 (0.25)
	Schilbeidae	0					
	Pangasiidae	2			2 (100)		
	Amblycipitidae	3				2 (100)	1 (33.33)
	Akysidae	1			1 (100)		
	Sisoridae	8			3 (37.50)	5 (62.5)	
	Clariidae	0					
Esociformes	Esocidae	0					
Osmeriformes	Osmeridae	0					
	Plecoglossidae	1					1 (100)
	Salangidae	0					
Salmoniformes	Salmonidae	8		1 (12.50)		2 (25.00)	5 (62.50)
Gadiformes	Gadidae	0					
Cyprinodontiformes	Cyprinodontidae	0					
Gasterosteiformes	Gasterosteidae	0					
Synbranchiformes	Synbranchidae	0					
	Mastacembelidae	0					
Scorpaeniformes	Cottidae	1				1 (100)	
Perciformes	Serranidae	3					3 (100)
	Percidae	0					
	Rhyacichthyidae	1				1 (100)	
	Odontobutidae	4				2 (50.00)	2 (50.00)
	Eleotridae	1					1 (100)
	Gobiidae	19				19 (100)	
	Anabantidae	0					
	Osphronemidae	1				1 (100)	
	Channidae	1					1 (100)
Total		199	5	4	35	85	70

Comparison with freshwater fish diversity of major river basins of the world

Entire river basins of the Yangtze and Yellow, and more than 97% of the Pearl River are all inside the border of China. Therefore, the total number of freshwater fish and endemic species of these three rivers were compared to those in major rivers of the world. Although the Pearl River is far behind these major rivers in length and in basin area, its species richness can be ranked as the fourth greatest in the world

(Table 5). Compared to other rivers in the temperate zone (Amur, Lena, Ob and Mississippi), the Yangtze River has the greatest number of freshwater fishes.

The Pearl River has 243 species distributed exclusively in its basin, accounting for 52.15% of the total number of fish species present, which is the highest freshwater fish endemism rate in the world across rivers (Table 5). Although the Yangtze River cannot compare to the Pearl, with 175 endemic freshwater fishes, the proportion (41.08%) of endemic riverine species is higher than that of the Amazon and Mekong rivers.

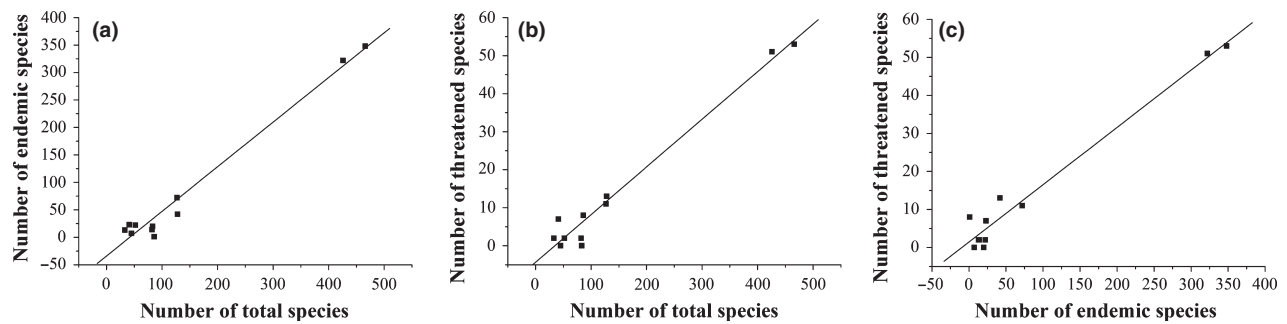


Figure 2 Linear regressions for numbers of endemic (a) and threatened (b) species to species richness, and threatened species to endemic species (c).

DISCUSSION

Faunal richness

Taxonomy is central to the understanding of biodiversity (Schlick-Steiner *et al.*, 2010), and accurate taxonomy is essential to making informed decision-making with regard to biogeographic patterns. The most recent account of diversity of freshwater fishes in China recognized 920 species (Kang *et al.*, 2014), considerably less than the 1323 species that we recognize despite the fact that our definitions of freshwater fishes were defined in the same way. Other databases have overestimated the number of taxa occurring in China based on uncritical acceptance of data. For example, FISHBASE (Froese & Pauly, 2014) reports 1614 species of freshwater fish in China. Accordingly, the number and identity of taxa we report differs from previous accounts.

The 1323 species of freshwater fish known from China represents about 9% of the total number of freshwater fish species world-wide [14,840 species from FISHBASE; Froese & Pauly (2014)] (although if FISHBASE overestimates true species richness, our figure is likely to be even greater). Undoubtedly, a varied topography with diverse aquatic habitats is the first reason for China's high species richness. China's terrain generally descends in three broad steps from west to east. The so-called first step is the Qinghai–Tibet Plateau, from which many rivers originate including the Yangtze, Yellow, Mekong (Lancangjiang), Salween (Nujiang) and Brahmaputra (Yarlung Zangbo) (Wang & Li, 2007). The first and third largest freshwater fish genera in China, *Triplophysa* and *Schizothorax*, both stem from the Plateau (Cao *et al.*, 1981). In fact, diversification and speciation of many other fish (e.g. the second largest genus *Sinocyclocheilus*) are also influenced by the uplift of the Qinghai–Tibet Plateau (Zhao & Zhang, 2009a).

Both Palearctic (Acipenseridae, Salmonidae, Thymallidae, Catostomidae and the Cyprinid subfamily Leuciscinae) and Oriental (Gyrinocheilidae, Balitoridae and the Cyprinid subfamilies Barbinae and Labeoninae) freshwater fish faunas occur in China. The Orient is the second most species-rich realm among six major zoogeographic regions with about 3000 species (Berra, 2007). Palearctic taxa occur in northern

rivers such as the Heilongjiang, Haihe and Yellow river basins, whereas Oriental taxa are limited largely to southern rivers, such as the Pearl, Lancangjiang and Nujiang (Li, 1981). Intermixing of the two faunas can be clearly observed in eastern China.

China's freshwater fish fauna is dominated by cyprinid species. About 76.11% of the species belong to Cypriniformes, with about half of these to Cyprinidae (Table 1). The 1007 Cypriniformes species represent 24.03% of the global number of species in this order (4191, Eschmeyer, 2015); the 654 Cyprinidae species represent 22.08% of total global species count for this family (2962, Eschmeyer, 2015). Six of 11 families attributed to Cypriniformes (Van Der Laan *et al.*, 2014) occur in China, as do 11 of 13 recognized Cyprinidae subfamilies (Eschmeyer, 2015). Cyprinids are distributed throughout the China with the exception of a few lakes in North Tibet (Chen, 1998). Tremendous variation, both in morphology and genetics, as well as complex reproductive behaviour and life history, allow them to successfully occupy considerably divergent water bodies and niches.

Endemism

Two-thirds ($n = 877$) of freshwater fish species are now recognized as endemic to China. This figure is considerably greater than any other recent estimate [$n = 88$, De Silva *et al.* (2007); 124, Froese & Pauly (2014); and 613, Kang *et al.* (2014)]. Although no freshwater fish family is endemic to China, 82 genera are endemic and the highest levels of endemism occur in the most species-rich taxa: Cypriniformes and Cyprinidae. Such high levels of endemism pose unique challenges to the conservation of biodiversity.

Many endemic species occur in specific geographic or specialized habitats (Oberdorff *et al.*, 1999; De Silva *et al.*, 2007). More than 130 cavefish species, about one-third the total number of cavefish species in the world (Zhao *et al.*, 2011) and nearly 10% of all freshwater fish in China, are endemic to the country. The endemic *Sinocyclocheilus*, the most species-rich genus in Cyprinidae, contains 61 species which are limited to the karst area of southern China (Zhao & Zhang, 2009a; Zhao *et al.*, 2011). Most *Schizothorax*, the second most species-rich cyprinid genus in China, are

Table 3 Total numbers and percentages of threatened endemic species, and numbers and percentages in each conservation status category (EX, extinct; EW, extinct in the wild; CR, critically endangered; EN, endangered; VU, vulnerable).

Order	Family	Number of threatened endemic species	Proportion of endemism in threatened species (%)	EX	EW	CR	EN	VU
Petromyzontiformes	Petromyzontidae	0	0					
Acipenseriformes	Acipenseridae	1	25				1 (100)	
	Polyodontidae	1	100			1 (100)		
Anguilliformes	Anguillidae	0	0					
Clupeiformes	Clupeidae	0	0					
	Engraulidae	0	0					
Cypriniformes	Cyprinidae	100	92.59	5 (5.15)	3 (3.09)	19 (19.00)	38 (38.00)	36 (36.00)
	Psilorhynchidae	0	0					
	Cobitidae	1	100					1 (100)
	Balitoridae	5	100			2 (40.00)	2 (40.00)	1 (20.00)
	Nemacheilidae	8	100			2 (25.00)		6 (75.00)
	Gyrinocheilidae	0	0					
	Catostomidae	1	100					1 (100)
Siluriformes	Bagridae	5	100			1 (20.00)	1 (20.00)	3 (60.00)
	Cranoglanididae	1	100					1 (100)
	Siluridae	2	50				2 (100)	
	Schilbeidae	0	0					
	Pangasiidae	0	0					
	Amblycipitidae	3	100				2 (66.67)	1 (33.33)
	Akysidae	1	100			1 (100)		
	Sisoridae	6	75			1 (16.67)	5 (83.33)	
	Clariidae	0	0					
Esociformes	Esocidae	0	0					
Osmeriformes	Osmeridae	0	0					
	Plecoglossidae	0	0					
	Salangidae	0	0					
Salmoniformes	Salmonidae	2	25				2 (100)	
Gadiformes	Gadidae	0	0					
Cyprinodontiformes	Cyprinodontidae	0	0					
Gasterosteiformes	Gasterosteidae	0	0					
Synbranchiformes	Synbranchidae	0	0					
	Mastacembelidae	0	0					
Scorpaeniformes	Cottidae	0	0					
Perciformes	Serranidae	3	100					3 (100)
	Percidae	0	0					
	Rhyacichthyidae	0	0					
	Odontobutidae	3	75				2 (66.67)	1 (33.33)
	Eleotridae	0	0					
	Gobiidae	18	94.74				18 (100)	
	Anabantidae	0	0					
	Osphronemidae	0	0					
	Channidae	0	0					
Total		161		5	3	27	72	54

limited to the rivers and lakes in the Qinghai–Tibet Plateau, the highest ‘youngest’ land in the world (Chen, 1998). Some geological events also contributed to the formation of endemism. For example, the cold-water *Brachymystax tsinlingensis* is restricted to streams in the mid-Qinling Mountains, a consequence of the Last Glacial Maximum (Zhao & Zhang, 2009b; Xing *et al.*, 2015). This kind of species is particularly susceptible to environmental impact.

Relationships between species richness, endemism and threatened species

The total numbers of freshwater fish species, endemic and threatened species are significantly correlated. Positive linear relationships are apparent between the total number of species and the number of endemic species or threatened species (Fig. 2a,b), and between the number of endemic species and

Table 4 Hydrographic and biological features of major river basins in China (the top three in each in bold; hydrographic data from Lu & Fu, 2010).

River basin	Ocean system	Basin area in China ($\times 1000 \text{ km}^2$)	River length in China (km)	Average yearly runoff ($\times 10^8 \text{ m}^3$)	Number of species	Species per 1000 km^2	Species richness index (Gleason index)	Number of China's endemic species	China's endemic species per 1000 km^2	Number of threatened species	Threatened species per 1000 km^2
Yangtze	Pacific	1808	6397	9513	426	0.24	56.8	322	0.18	51	0.03
Heilongjiang	Pacific	902	2854	1166	88	0.1	12.93	1	0	10	0.01
Yellow	Pacific	795	5464	661.4	127	0.16	19.01	72	0.09	11	0.01
Pearl	Pacific	442.1	2214	3360	466	1.05	76.50	348	0.79	53	0.12
Huaihe	Pacific	269	1000	622.3	45	0.17	8.04	7	0.03	0	0
Haihe	Pacific	265	1090	211.6	83	0.31	14.88	20	0.08	0	0
Yarlung Zangbo	Indian	242	2057	1654	41	0.17	7.47	23	0.10	7	0.03
Tarim	Endorheic	236	2437	256.7	33	0.14	6.04	13	0.06	2	0.01
Liaohu	Pacific	221.1	1345	148	82	0.37	15.19	14	0.06	2	0.01
Lancangjiang	Pacific	167.4	2161	740	128	0.76	25	42	0.25	13	0.08
Nujiang	Indian	137	2013	689	52	0.38	10.6	22	0.16	2	0.01

the number of threatened species (Fig. 2c). As a general rule, the more species there are, the more endemic and threatened species there are likely to be (De Silva *et al.*, 2007; Lévêque *et al.*, 2008).

Fishes with specialized habitat requirements or limited distributions tend to be more sensitive to environmental change and degradation than those that are more widely distributed (Leprieur *et al.*, 2008). It follows that endemic species and those with relatively limited distributions will also be more VU. Therefore, it is not surprising that most species classified as 'threatened' in China are also endemic. In fact, 161 species considered threatened in China are endemic, comprising 80.90% of the total number of threatened species in the region (Table 3).

Patterns in major river basins

The Yangtze, Heilongjiang (Amur) and Yellow rivers are the three largest and longest in China (Table 4). Generally, rivers with large basins have more tributaries and diverse habitats than rivers with smaller basins. The Yangtze and Yellow rivers originates from glaciers on the Qinghai-Tibet Plateau and then flow eastward across China before entering the Pacific Ocean. Along their paths, they drop about 4500 m in altitude and are fed by many tributaries (622 exceeding 1000 km^2 basin area) (Lu & Fu, 2010). These waters are home to many freshwater fish species. Despite this, we found no statistically significant relationship between species richness and river basin area. Several other rivers, notably the Pearl (466 species) and Lancangjiang (128 species) in southern and south-western China, have exceptional species richness (Table 4). Rivers in southern and south-western China tend to have more species than those in northern and north-western China, regardless of basin area or river length.

The Pearl River has the highest species richness index and the most endemic Chinese species (also by area) of all rivers surveyed. This river consistently ranks among the top three in every parameter we measured (Table 4): (1) the entire basin is located in the subtropical zone; (2) the freshwater fish fauna belongs to the Oriental zoogeographical region (Wang *et al.*, 2007); (3) habitats are very diverse, especially with complex subterranean river systems, which are home to more than 100 cavefish species (Zhao *et al.*, 2011); (4) the basin was historically connected to the Yangtze River and Hainan Island (Zhao & Zhang, 2001; Wang *et al.*, 2007).

An underestimation of threatened species

A mere 15% of China's freshwater fish species are considered to be threatened based on official and semi-official evaluations. The number of threatened species in China has been seriously underestimated in previous published findings. In comparison, threatened freshwater fishes account for 38% and 41% of total number of species in Europe and the North America, respectively (Kottelat & Freyhof, 2007; Warren & Burr, 2014). Insufficient evaluation of threatened fish species

Table 5 Comparison of freshwater fish species richness and endemic species in major river basins of the world (the top three in each column in bold; hydrographic data from Roberts & Stewart (1976), Huh *et al.* (1998), Kouraev *et al.* (2004), Coynel *et al.* (2005), Sarkara *et al.* (2007), Abell *et al.* (2008), Lu & Fu (2010), Val & Almeida-Val (2012) and Liu *et al.* (2013); species and endemic species data from Fish-SPRICH).

River basin	Climatic region	River length (km)	Basin area ($\times 1000 \text{ km}^2$)	River length in China (km)	Number of species	Number of endemic species to river	Proportion of endemic species to river (%)	Total species in China
Nile	Tropical-subtropical	6825	3630	0	135	16	11.85	0
Amazon	Tropical	6400	1250	9	> 2500	810	32.4	0
Yangtze	Temperate	6397	1808	6397	426	175	41.08	426
Yellow	Temperate	5464	795	5464	127	30	23.62	127
Mekong	Tropical	4880	810	2161	890	202	22.7	128
Congo	Tropical	4650	3700	0	800	225	28.13	0
Amur	Temperate	4510	2050	2854	124	9	7.26	88
Lena	Temperate	4260	2450	0	40	0	0	0
Mississippi	Subtropical	3730	3200	0	267	18	6.74	0
Ob	Temperate	3680	2980	0	53	0	0	0
Ganges	Temperate	2800	980	0	301	54	17.94	0
Pearl	Subtropical	2214	442	2214	466	243	52.15	466

in China is the primary reason for underestimations. Although conservative, the most recent evaluation (based on IUCN, 2014 criteria) was carried out from 2000 to 2003 and published in 2009 (Wang & Xie, 2009). Unfortunately, the past decades of degradation were not accounted for in determining the conservation status of China's freshwater fishes. This is a long gap considering the rapid pace of development in China and may lead to potentially erroneous assumptions based on dated status assessments. The State Key of Protected Wild Animals List is regarded as the only official assessment with legal standing in China. However, the current version only includes 12 freshwater fishes, leaving much to be desired when considering real-time conservation management issues for dozens of additional taxa. Another key problem leading to the underestimation of threatened species is insufficient knowledge of basic natural history and population status data for most of freshwater fishes in China. As a result, many species have not been adequately assessed. A poor understanding of species richness and endemism among the freshwater fishes of China exists and the need for an up-to-date and inclusive revision is the primary justification for this effort. Moreover, past evaluations mostly relied on the experts' personal experiences and were not derived from a robust dataset. Another disconcerting trend is that experts, especially ones with substantial field observations and experiences, are becoming fewer and fewer with the de-emphasis of natural history and biogeography in the Chinese academic system and world-wide.

Major threats to China's freshwater fish

China remains one of the world's largest fish-producing countries. It contributes about 20% (2.30 million tons) of the global inland aquaculture production of about

11.60 million tons (2012 data; FAO, 2014). Nearly, all freshwater fish species, regardless of size, have been targeted for commercial fisheries with direct impacts to fish abundance and diversity (Xie & Chen, 1999). However, due to overfishing, many traditional fisheries have failed or are failing from pressures exerted through modern harvest activities. Some species have been relegated to the list of EN species or the Red Book as a result of intensive over-harvest. This process has happened in all major river systems of China, but especially in the Yangtze River. Chinese shad (*Tenualosa reevesii*), an anadromous fish, was widely distributed in the near seas of China. The species formerly form large schools when they swam upriver, exposing the species to easy harvest. The extraction of Chinese shad in the Yangtze and Xiajiang rivers peaked at 1575 tons in 1974. After that point, the production declined dramatically in a very short period of time. The Chinese shad has been extirpated from the Yangtze River since 1990. A single individual was caught in Jiangsu Province in 1998 (Liu *et al.*, 2002). Overfishing of spawning fish is the main force driving the decline of this fish stock (Yue & Chen, 1998). Also, overfishing can lead to the phenomenon of 'fishing down the food web', the successive removal of the larger elements of a multispecies fish assemblage and their replacement by smaller elements of the assemblage, which are typically at lower trophic levels (Allan *et al.*, 2005). Further, illegal fishing also inflicts considerable damage to freshwater fisheries. These activities are smaller in scale but wide-ranging. Electrofishing is widespread throughout China from North to South for short-term profit and as an efficient collecting method (Zhao *et al.*, 2015). Although it is forbidden by law, it remains a rampant activity and one that undermines fish populations across China.

China started to build dams and hydraulic structures in large scale dating back to the 1950s. From 1951 to 1977,

18,595 dams of different sizes were built, accounting for 53.4% of the total numbers of dams in the world (Pan & He, 2000). As a result, some migrating and estuarine fishes have disappeared in coastal rivers (Zhang & Zhao, 2013). Since 1990, huge dams have been constructed, including the Three Gorges Dam, the largest power station in the world. There is no doubt that these dams will have negative influences on the associated freshwater fish faunas. Chinese sturgeon (*Acipenser sinensis*) and Chinese paddlefish (*Psephurus gladius*) formerly played important roles in commercial fisheries throughout the upper Yangtze River. Historically, their large body sizes made them an ideal fishery species. From 1972 to 1980, the annual mean catch of Chinese sturgeon was 517 individuals, or 77,550 kg, for the entire Yangtze River (Wei *et al.*, 1997). This was before the closure of the Gezhouba Dam (the first dam on the Yangtze River) in 1981. As a consequence, the population has declined rapidly and commercial fishing was banned in 1983 (Wei *et al.*, 1997). Subsequently, Chinese sturgeon and Chinese paddle fish were listed as a class I species in the State Protected Animal List in 1988 (comparable to the giant panda). The paddle fish may even be EX, given none are known from surveys between 2006 and 2008 (Zhang *et al.*, 2009). Presently, largemouth bronze gudgeon (*Coreius guichenoti*), the elongate loach (*Leptobotia elongata*), and long-fin rhino gudgeon (*Rhinogobio ventralis*) (all distributed in the upper reaches of the Yangtze River) are facing a similar situation owing to the construction of several large dams ranked among the ten largest dams in the world.

With rapid economic development, water pollution is increasing in both rivers and lakes. In 2014, according to the China Environmental Situation Bulletin, released by Ministry of Environmental Protection of People's Republic of China, water quality did not satisfy the criteria for the general public and fishery use (at least Grade III) from 28.8% of monitoring sections of major rivers and 24 of 62 lakes or reservoirs. Freshwater environments suffer from three main types of pollution: industrial wastewater polluted with nitrates, phosphates and heavy metals; pesticides and fertilizer washed off of farmland by rain; and untreated sewage (Zhao *et al.*, 2015).

In the past, threats from invasive species did not capture concern in China. To increase the output of aquaculture, China has introduced at least 140 aquatic animals, including 89 species of fishes (Hu *et al.*, 2006). Tilapias have become the dominant fish species in the natural waters in Hainan Island and are now common in Guangdong, Guangxi and Fujian Provinces. These species are directly responsible for native species loss and population collapse of native fishes in these areas (Zhao *et al.*, 2015). It is also common for the human-assisted invasion of native species, originally distributed in the east of China, into the aquatic systems of the West, such as topmouth gudgeon (*Pseudorasbora parva*). These invasions accompany the expansion of cultured fishes. For example, the fish fauna of Lake Qionghai, with many endemic species including *Cyprinus qionghaiensis* and

Anabarilius liui liui, has been replaced by introduced species such as topmouth gudgeon and Chinese false gudgeon (*Abutting rivularis*). Originally, the lake contained 30 native fish species but now contains only nine (as of 2011) (Zheng *et al.*, 2012).

Forming a conservation strategy the right way

First, an effort to protect freshwater fishes should be based on a comprehensive understanding of patterns of species richness across a large scale as well as patterns of endemism (Oberdorff *et al.*, 1999). This approach provides a platform for evaluation stemming from the current status of freshwater fishes. However, assessment of threatened species lags far behind the water quality assessment in China. Water quality assessment has accelerated due to recent economic development. There are many examples of fish species in China that have been impacted by economic development and others demonstrating the need for updated conservation status. One state protected animal, the Chinese sucker (*Myxocyprinus asiaticus*), the only catostomid species in China, was formerly recorded in the Yangtze and Minjiang rivers (in Fujian Province). The Minjiang population disappeared decades ago, possibly due to the impact of development on the aquatic ecosystem. A recent study by Wang & Xie (2009) suggested that the White Cloud Mountain minnow (*Tanichthys albonubes*) may be EW. Fortunately, this fish was rediscovered in Guangdong Province in 2003 (Yi *et al.*, 2004). Since then, many wild populations have been found in different localities including Hainan and Guangxi (Chan & Chen, 2009; Li & Li, 2011). Status information needs to be updated so that we can determine appropriate strategies for conservation management. Environmental evaluation of hydro-project construction is urgently needed. The data will undoubtedly illuminate the needs of many freshwater fishes in China. Therefore, we recommend a national-scale assessment of China's freshwater fishes, to be executed immediately. A mechanism for gathering new information and updating the status of species also needs to be present and should be led by the government. A system that responds to real-time threats is desirable (one that will respond to development such as dam construction in an appropriate window of time such that conservation actions may be enacted prior to construction).

Second, conservation of fishes in the Yangtze, Yellow and Pearl rivers is a high priority because they are all essentially within China. However, different rivers have different situations that need to be carefully considered on an individual basis. Today, China is promoting large-scale dam construction. Based on the Brief Report on the Comprehensive Utilization Planning of Yangtze River Basin approved by the State Council in 1990, nine, five and four hydropower stations will be established (or have already been built) on the upper, middle and lower reaches of the Jinshajiang River (the upper branch of the Yangtze), respectively. Rampant overfishing compounds problems for some species in these

drainage systems. Dam construction must be considered in the development of sound, data-based conservation strategies and regulations for fishery species. Enforcement of laws and regulations is necessary for the success of such efforts. Maintaining natural sections in main river channels, restocking EN species and completely banning all unsustainable fishing activities may relieve these pressures on the fish fauna of the Yangtze River. The Yellow River passes through a large arid area in North China. In the past century, intense water resource demands in the middle reaches of the river have led to low water availability in the lower part of the system. Strengthening fisheries management and optimizing the schedule of water resource extraction in the middle branch of the river will aid restoration of freshwater fauna in the Yellow River basin. The Pearl River has 243 endemic riverine species of 348 China's endemic species. More than half of them are cave-dwellers, accounting for 90% of Chinese cavefish species (Zhao *et al.*, 2011), and few are sufficiently studied to accurately assess their current conservation status. Most are likely threatened by habitat degradation, water pollution and over-harvesting. Even seemingly benign activities may threaten some species (Zhao *et al.*, 2011). In spite of these serious threats, few cavefish species are included in the Red List. Considering the Pearl River also has a diverse array of habitats, including subterranean water bodies, we feel that the number of endemic and threatened species in the system will likely exceed currently recognized levels. The number of recognized threatened species per 1000 km² in the Pearl is already more than three times that of the Yangtze River (Table 4). These considerations lead us to propose the Pearl River as a conservation priority.

Third, conservation of freshwater fish distributed in international rivers requires collaborative conservation and management planning among neighbouring countries. The Lancangjiang and Nujiang, two international rivers in south-western China, have high numbers of species relative to basin area (Table 4). Some fishes in the Mekong River make long-distance breeding migrations upstream (Dudgeon, 2000). Mainstream dams will block migration routes, resulting in population declines of trans-boundary migratory fishes such as giant Pangasius (*Pangasius sanit-wongsei*). The first Lancangjiang mainstream dam (Manwan Dam) was built in 1987. Since then, the local fish fauna has changed gradually. Nonetheless, 48% of the local species have disappeared in this area in 20 years – from 1987 to 2007 (Kang *et al.*, 2009). In addition to dam construction, overfishing and invasion of exotic species also contributed to the loss of native species (Kang *et al.*, 2009). Although threat factors to freshwater fishes in these international rivers are similar to those in the major rivers of China, conservation strategies may not be the same owing to differences in environmental law and regulations among neighbouring countries. China has suffered species loss and population collapse of freshwater fishes in the Yangtze and Yellow rivers. These lessons and experiences should be

shared with countries in the middle and lower Mekong to avoid them suffering the consequences of similar management mistakes. The headwaters of each trans-international river need strict protection as they serve as spots of high species diversity and contain unique habitats. In addition, effective conservation actions will be borne from close collaborations with countries containing lower reaches of trans-international river systems. We recommend that all countries sharing these international rivers should collaboratively build a mechanism to coordinate the development of water resource while protecting the entire aquatic fauna through shared benefits and responsibilities.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table S1 The 10 most speciose genera of freshwater fish in China.

Appendix S1 Definitions of freshwater fish in the present study.

Appendix S2 Databases or Red Lists were used to determine the species conservation status.

BIOSKETCHES

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