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Factors influencing tropical Island freshwater fishes: species, status, threats and conservation in Hainan Island

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Abstract – Hainan Island is located within the Indo-Burma global biodiversity hotspot, however, the freshwater fish fauna on this island is poorly understood. Based on field investigations and literature review, we compiled a list of 154 freshwater fish species (138 native and 16 non-native) belonging to 10 orders, 31 families and 104 genera found on Hainan Island. Of these, 31 species are endemic to China. The native freshwater fish fauna in Hainan Island is affiliated to South China sub-region of the Oriental Region. Current knowledge suggests that overexploitation, water pollution, flow modification, habitat degradation, and non-native species have severely reduced the freshwater fish biodiversity in Hainan Island. To protect freshwater fish biodiversity and fisheries in Hainan Island, some new measures should be adopted and current measures better enforced. This study constitutes an important resource for conservation management of freshwater fishes in Hainan Island.

Keywords: Biodiversity / conservation / freshwater fish / tropical Island / species diversity

Résumé – Facteurs influençant les poissons d'eau douce des îles tropicales: espèces, situation, menaces et conservation dans l'île de Hainan. L'île de Hainan est située dans le point névralgique de la biodiversité mondiale de l'Indo-Birmanie, mais la faune piscicole d'eau douce de cette île est mal connue. D'après les investigations sur le terrain et l'analyse documentaire, nous avons compilé une liste de 154 espèces de poissons d'eau douce (138 espèces indigènes et 16 espèces non indigènes) appartenant à 10 ordres, 31 familles et 104 genres trouvés sur l'île de Hainan. Parmi elles, 31 espèces sont endémiques en Chine. La faune indigène des poissons d'eau douce de l'île de Hainan est affiliée à la sous-région de la Chine du Sud de la Région Orientale. Les connaissances actuelles suggèrent que la surexploitation, la pollution de l'eau, la modification des débits, la dégradation de l'habitat et les espèces non indigènes ont sérieusement réduit la biodiversité des poissons d'eau douce de l'île Hainan. Afin de protéger la biodiversité des poissons d'eau douce et les pêcheries de l'île de Hainan, de nouvelles mesures devraient être adoptées et les mesures actuelles mieux appliquées. Cette étude constitue une source importante pour la gestion de la conservation des poissons d'eau douce dans l'île de Hainan.

Mots-clés : Biodiversité / conservation / poissons d'eau douce / île tropicale / diversité des espèces / diversité spécifique

1 Introduction

Freshwater ecosystems are considered to be some of the Earth's most important hotspots for biodiversity (Strayer and

Dudgeon, 2010). However, these ecosystems are also recognized as some of the most endangered on the planet (Gleick, 2003; Dudgeon *et al.*, 2006), because the extinction risks are significantly greater than those in terrestrial and marine ecosystems (Ricciardi and Rasmussen, 1999; Abell, 2002). Especially, freshwater fish received widespread attention owing to its high diversity and endemism in the

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world (Olden *et al.*, 2010). However, the researches about the conservation of freshwater fishes are very scarce (Strayer and Dudgeon, 2010).

China is one of the countries with the greatest freshwater fish diversity (Xing *et al.*, 2016). However, most studies on Chinese freshwater fishes focus on fish diversity of only a few large rivers, for example the Yangtze River (Fu *et al.*, 2003) and Mekong River (Kang *et al.*, 2009). This bias, towards these larger rivers, is likely due to the presence of important research institutions in these regions, such as the Institute of Hydrobiology in Wuhan – centrally placed for the Yangtze River. Whilst the focus of attention and resources on these larger rivers undoubtedly contributes towards a far more complete understanding of their assemblages and functioning, it also means that some regions with high freshwater fish diversity are not studied sufficiently, for example, Hainan Island.

Hainan Island is the second largest Island of China, and is situated in the southernmost part of the country. It is also a biodiversity hotspot (Myers *et al.*, 2000; Sodhi *et al.*, 2001), as a great number of studies, focused on terrestrial plants (Zhang, 2001), birds (Chen, 2008), aquatic plants (Wang *et al.*, 2008) and mammals (Chen, 2009) have shown. Whilst research has been conducted on the Southeastern distributional patterns of East Asian freshwater fish (Zakaria-Ismail, 1994; Yap, 2002), there is little information available specifically on the freshwater fishes Hainan Island.

The objectives of the present study were: (1) to compile an up-to-date inventory of the freshwater fish fauna of Hainan Island; (2) to review the main threats to freshwater fish biodiversity; and (3) to review recommendations for fish biodiversity conservation.

2 Materials and methods

2.1 Study area

Hainan Island is located in the northern part of the South China Sea (18°10'–20°10'N, 108°37'–111°03'E), and is separated from Chinese mainland by the narrow Qiongzhou straits (Fig. 1). With an area of about 33 900 km², Hainan Island is the second largest Island in China, just after Taiwan Island. The land area of Hainan Island accounts for only 0.35% of China's land area, but accounts for 42.5% of the total tropical land area of China (Pearl River Fisheries Research Institute, 1989).

Hainan Island is oval-shaped, with an approximately 45° orientation and measures 260 km from northeast to southwest and 180 km from southeast to northwest. The Island has a staircase-like topographic structure, descending step by step from towering mountains to flat tablelands (mesas) and plains at its periphery. Mountains and hills account for 38.7% of area of the total land area, with the mountains mainly distributed in the southern part of the central island and the hills mainly located in the central and northwestern parts of the Island. The mesas and coastal terraces, surrounding the mountains and hills, account for approximately 49.5% of the land area of the Island. The island is surrounded by a coastal plain, which accounts for about 11.2% of the total land area. The elevation of most Hainan Island's mountains is between 500–800 m, with only few mountains over 1500 m. Wuzhishan Mountain is the highest mountain (1876 m) and is located at the center of the

island. Yinggeling Mountain is the second highest mountain (1811 m) and is located northwest of Wuzhishan Mountain. Yajiadaling Mountain is the third highest mountain (1519 m) and is located in the west.

Rivers in Hainan Island mostly originate from the central mountainous area, forming a radiating river system. There are 154 rivers flowing into the sea. The Nandu River, Wanquan River, and Changhua River are the largest rivers in Hainan Island, the basin area of these three rivers accounts for about 47% of the area of Hainan Island (Zeng and Zeng, 1989). Most rivers in Hainan Island are characterized by a short course (less than 350 km), high gradient, and fast flow. In wet season, the water levels of most rivers change rapidly. The wet season flood runoff accounts for over 80% of the total annual runoff. In dry season, some rivers dry out completely.

The coastline of Hainan Island is 1823 km in length and consists mainly of lagoons, harbors, mangroves, coral reefs, and estuaries. During 50 years of coastal development, the area of mangrove and coral reef have been reduced by 50% and 55.5%, respectively, while the length of shore reef has decreased by 59.1% (Zou *et al.*, 1999).

The climate of Hainan Island is tropical maritime and is dominated by monsoons, in April and October, with predominant northeasterly winds in winter (from November to March) and southwesterly winds in summer (from May to September). Annual average temperature varies geographically, from 22.8 °C to 25.8 °C (16–4 °C in January and 28–9 °C in August). The annual average precipitation is from 961 mm to 2439 mm, mainly concentrated from May to October, when the southwesterly winds dominate.

2.2 Sources of information

Both field investigations and literature review were used for collecting data of freshwater fish species in Hainan Island. Over ten ichthyological surveys were conducted on Hainan Island in different seasons between 2000 and 2016. We searched for literature that contained the following combination of words: “Hainan” and “freshwater fish” or “freshwater ichthyo” in the title, abstract, or keywords from the Thomson institute for scientific information (ISI, <http://www.isiknowledge.com>) and CNKI (<http://www.cnki.net>). We also collected information from some Chinese books, such as *The Freshwater and Estuaries Fishes of Hainan Island* (Pearl River Fisheries Research Institute, 1989). Based on our investigations and literature review, we compiled a preliminary list of the fish species of Hainan Island. To avoid confusion caused by synonyms and changes of common names, we identified the valid Latin names of every species in Catalog of Fishes database (<https://www.calacademy.org/scientists/projects/catalog-of-fishes>), which covers more than 61 700 fish species and subspecies with authoritative references. The present study compiled a preliminary inventory of freshwater fishes for Hainan Island (Tab. 1).

3 Fish biodiversity and conservation

There have been over 1300 freshwater fish species listed in China (Xing *et al.*, 2016). The present study revealed that a total

Fig. 1. The location and main water resources in Hainan Island.

of 154 freshwater fish species (138 native and 16 non-native species), belonging to 10 orders, 31 families and 104 genera are found on Hainan Island. Of these 138 native freshwater fish species and subspecies – belonging to nine orders, 26 families and 90 genera (Tab. 1) – 32 are endemic to China. Cyprinidae and Gobiidae are the most species-rich and endemic species-rich families, accounting for 47.9% and 14.8% of total native species and 53.1% and 18.8% of the total endemic species of Hainan Island, respectively. More specifically, one Balitoridae (*Plesio-*

myzon baotingensis), one Cobitidae (*Cobitis baishagensis*), six Cyprinidae (*Acrossocheilus kedai*, *Barbodes semifasciolatus*, *Folifer hainanensis*, *Garra hainanensis*, *Opsariichthys hainanensis*, and *Squalidus minor*), One Nemacheilidae (*Traccatichthys zispi*), and five Gobiidae (*Ctenogobius punctatus*, *Rhinogobius changjiangensis*, *R. linshuiensis*, *R. nandujianensis*, *R. wangchuangensis*) are endemic to Hainan Island. These 14 endemic species are the most important wild species and are worthy to be protected. In summary, Hainan Island,

Table 1. The list of freshwater fishes in Hainan Island.

No	Orders	Families	Latinname	Habitats	IUCN
1	Pleuronectiformes	Cynoglossidae	<i>Cynoglossus trigrammus</i> (Günther, 1862)	Coast	Least Concern
2	Synbranchiformes	Mastacembelidae	<i>Mastacembelus armatus</i> (Lacepède, 1800)	River	Least Concern
3		Synbranchidae	<i>Monopterus albus</i> (Zuiew, 1793)	Coast, river, lake, swamp, constructed wetlands	Least Concern
4	Cyprinodontiformes	Adrianichthyidae	<i>Oryzias curvinotus</i> (Nichols & Pope, 1927)	Coast, river, lake, swamp	Data Deficient
5			<i>Oryzias latipes</i> (Temminck & Schlegel, 1846)	Coast, river, lake, swamp	Least Concern
6		Poeciliidae	<i>Gambusia affinis</i> (Baird and Girard, 1853) ^a	Coast, river, lake, swamp, constructed wetlands	Least Concern
7			<i>Acheilognathus macropterus</i> (Bleeker, 1871)	River, lake, constructed wetlands	Data Deficient
8			<i>Acheilognathus tonkinensis</i> (Vaillant, 1892)	River, lake, constructed wetlands	Data Deficient
9			<i>Acrossocheilus ikedai</i> (Harada, 1943) ^{b c}	River, lake, constructed wetlands	Not Evaluated
10			<i>Acrossocheilus iridescens</i> (Nichols & Pope, 1927) ^b	River, lake, constructed wetlands	Data Deficient
11			<i>Aphyocypris arcus</i> (Lin, 1931) ^b	River, lake, constructed wetlands	Least Concern
12	Cypriniformes	Cyprinidae	<i>Aphyocypris normalis</i> (Nichols & Pope, 1927)	River	Not Evaluated
13			<i>Bangana discognathoides</i> (Nichols & Pope, 1927) ^b	River	Not Evaluated
14			<i>Barbodes semifasciolatus</i> (Günther, 1868) ^{b c}	River, lake, constructed wetlands	Least Concern
15			<i>Carassioideus acuminatus</i> (Richardson, 1846)	River, lake, constructed wetlands	Least Concern
16			<i>Carassius auratus</i> (Linnaeus, 1758)	River, lake, constructed wetlands	Least Concern
17			<i>Chanodichthys erythropterus</i> (Basilewsky, 1855)	River, lake, constructed wetlands	Least Concern
18			<i>Chanodichthys mongolicus mongolicus</i> (Basilewsky, 1855)	River, lake, constructed wetlands	Least Concern
19			<i>Chanodichthys recurviceps</i> (Richardson, 1846) ^b	River, lake, constructed wetlands	Least Concern
20			<i>Cirrhinus molitorella</i> (Valenciennes, 1844)	River, lake, constructed wetlands	Near Threatened
21			<i>Cyprinus acutidorsalis</i> (Chen & Hwang, 1977) ^b	Coast, river, lake	Not Evaluated
22			<i>Cyprinus carpio</i> (Linnaeus, 1758)	River, lake, constructed wetlands	Vulnerable
23			<i>Cyprinus rubrofasciatus</i> (Lacepède, 1803)	River, lake, constructed wetlands	Least Concern
24			<i>Folifer brevifilis</i> (Peters, 1881)	River, lake, constructed wetlands	Data Deficient
25			<i>Folifer hainanensis</i> (Wu, 1977) ^{b c}	River, lake, constructed wetlands	Endangered
26			<i>Garra hainanensis</i> (Chen & Zheng, 1983) ^{b c}	River	Not Evaluated
27			<i>Garra imberba</i> (Garman, 1912)	River	Data Deficient
28			<i>Garra orientalis</i> (Nichols, 1925) ^b	River	Least Concern
29			<i>Gobiobotia kollerii</i> (Bănărescu & Nalbant, 1966)	River	Data Deficient
30			<i>Hainania serrata</i> (Koller, 1927)	River	Vulnerable
31			<i>Hemibarbus labeo</i> (Pallas, 1776)	River	Not Evaluated
32			<i>Hemibarbus medius</i> (Yue, 1995)	River	Not Evaluated
33			<i>Hemiculter leuciscus</i> (Basilewsky, 1855)	River, lake, swamp, constructed wetlands	Least Concern
34			<i>Hypophthalmichthys harmandi</i> (Sauvage, 1884)	River, lake, constructed wetlands	Data Deficient
35			<i>Megalobrama terminalis</i> (Richardson, 1846)	River, lake, constructed wetlands	Not Evaluated
36			<i>Metzia formosae</i> (Oshima, 1920)	River, lake, constructed wetlands	Least Concern
37			<i>Metzia lineata</i> (Pellegrin, 1907)	River, lake, constructed wetlands	Least Concern
38			<i>Microphysogobio kachekensis</i> (Oshima, 1926)	River	Least Concern
39			<i>Microphysogobio labeoides</i> (Nichols & Pope, 1927)	River	Data Deficient
40			<i>Opsariichthys hainanensis</i> (Nichols & Pope, 1927) ^{b c}	River	Not Evaluated
41			<i>Osteochilus salsburyi</i> (Nichols & Pope, 1927)	River	Least Concern
42			<i>Osteochilus vittatus</i> (Valenciennes, 1842)	River	Least Concern

Table1. (continued).

No	Orders	Families	Latinname	Habitats	IUCN
43			<i>Parabramis pekinensis</i> (Basilevsky, 1855)	River, lake, constructed wetlands	Not Evaluated
44			<i>Parazacco fasciatus</i> (Koller, 1927)	River	Least Concern
45			<i>Plagiognathops microlepis</i> (Bleeker, 1871)	River, lake, constructed wetlands	Least Concern
46			<i>Pseudogobio vaillanti</i> (Sauvage, 1878) ^b	River	Least Concern
47			<i>Pseudohemiculter dispar</i> (Peters, 1881)	River	Vulnerable
48			<i>Pseudohemiculter hainanensis</i> (Boulenger, 1900)	River	Least Concern
49			<i>Pseudorasbora parva</i> (Temminck & Schlegel, 1846)	River, lake, swamp, constructed wetlands	Least Concern
50			<i>Puntius semifasciolatus</i> (Günther, 1868)	River, lake, constructed wetlands	Least Concern
51			<i>Rasbora steineri</i> (Nichols & Pope, 1927)	River	Least Concern
52			<i>Rhodeus lighti</i> (Wu, 1931) ^b	River	Least Concern
53			<i>Rhodeus ocellatus ocellatus</i> (Kner, 1866)	River, lake, constructed wetlands	Least Concern
54			<i>Rhodeus spinalis</i> (Oshima, 1926)	River, lake, constructed wetlands	Data Deficient
55			<i>Sarcocheilichthys hainanensis</i> (Nichols & Pope, 1927)	River, lake, constructed wetlands	Least Concern
56			<i>Sarcocheilichthys nigripinnis nigripinnis</i> (Günther, 1873)	River, lake, constructed wetlands	Data Deficient
57			<i>Saurogobio immaculatus</i> (Koller, 1927)	River, lake, constructed wetlands	Not Evaluated
58			<i>Onychostoma gerlachi</i> (Peters, 1881)	River	Data Deficient
59			<i>Onychostoma leptura</i> (Boulenger, 1900)	River	Near Threatened
60			<i>Sinibrama affinis</i> (Vaillant, 1892)	River	Data Deficient
61			<i>Sinibrama melrosei</i> (Nichols & Pope, 1927) ^b	River, lake, constructed wetlands	Least Concern
62			<i>Spinibarbus denticulatus</i> (Oshima, 1926)	River, lake, constructed wetlands	Data Deficient
63			<i>Spinibarbus hollandi</i> (Oshima, 1919)	River	Least Concern
64			<i>Squalidus atromaculatus</i> (Nichols & Pope, 1927)	River	Data Deficient
65			<i>Squalidus minor</i> (Harada, 1943) ^{b c}	River	Least Concern
66			<i>Squalidus wolterstorffi</i> (Regan, 1908) ^b	River	Endangered
67			<i>Squaliobarbus curriculus</i> (Richardson, 1846)	River	Least Concern
68			<i>Toxabramis houdemeri</i> (Pellegrin, 1932)	River, lake, constructed wetlands	Data Deficient
69			<i>Xenocypris davidi</i> (Bleeker, 1871)	River, lake, constructed wetlands	Least Concern
70			<i>Xenocypris macrolepis</i> (Bleeker, 1871)	River, lake, constructed wetlands	Not Evaluated
71			<i>Zacco platypus</i> (Temminck & Schlegel, 1846)	River	Least Concern
72			<i>Ochetobius elongatus</i> (Kner, 1867) ^a	River, lake, constructed wetlands	Not Evaluated
73			<i>Mylopharyngodon piceus</i> (Richardson, 1846) ^a	River, lake, constructed wetlands	Least Concern
74			<i>Ctenopharyngodon idella</i> (Valenciennes, 1844) ^a	River, lake, constructed wetlands	Data Deficient
75			<i>Hypophthalmichthys molitrix</i> (Valenciennes, 1844) ^a	River, lake, constructed wetlands	Not Evaluated
76			<i>Hypophthalmichthys nobilis</i> (Richardson, 1845) ^{a b}	River, lake, constructed wetlands	Near Threatened
77			<i>Carassius cuvieri</i> (Temminck and Schlegel, 1846) ^a	River, lake, constructed wetlands	Data Deficient
78			<i>Currhinus mrigala</i> (Hamilton, 1822) ^a	River, lake, constructed wetlands	Not Evaluated
79			<i>Labeo rohita</i> (Hamilton, 1822) ^a	River, lake, constructed wetlands	Least Concern
80			<i>Balitora kwangsiensis</i> (Fang, 1930)	River, lake, constructed wetlands	Least Concern
81			<i>Beaufortia leveretti</i> (Nichols & Pope, 1927)	River	Least Concern
82			<i>Liniparhomaloptera disparis qiongzongensis</i> (Zheng & Chen, 1980) ^b	River	Data Deficient
83			<i>Plestiomyzon baotingensis</i> (Zheng & Chen, 1980) ^{b c}	River	Data Deficient
84			<i>Sinogastromyzon wui</i> (Fang, 1930) ^b	River	Vulnerable
85			<i>Yanmanenia hainanensis</i> (Chen & Zheng, 1980) ^b	River	Least Concern
		Balitoridae			Not Evaluated

Table1. (continued).

No	Orders	Families	Latinname	Habitats	IUCN
86			<i>Cobitis baishagensis</i> (Chen, Sui, Liang & Chen, 2015) ^{b c}	River	Not Evaluated
87		Cobitidae	<i>Cobitis sinensis</i> (Sauvage&Dabry de Thiersant, 1874)	River	Least Concern
88			<i>Misgurnus anguillicaudatus</i> (Cantor, 1842)	River, lake, constructed wetlands	Least Concern
89			<i>Schistura fasciolata</i> (Nichols & Pope, 1927)	River	Data Deficient
90		Nemacheilidae	<i>Traccatichthys pulcher</i> (Nichols & Pope, 1927)	River	Least Concern
91			<i>Traccatichthys zispi</i> (Prokofiev, 2004) ^{b c}	River	Not Evaluated
92			<i>Acentrogobius brevirostris</i> (Günther, 1861) ^b	Coast, river	Not Evaluated
93			<i>Awaous melanocephalus</i> (Bleeker, 1849)	Coast, river	Not Evaluated
94			<i>Awaous ocellaris</i> (Broussonet, 1782)	Coast	Least Concern
95			<i>Ctenogobius punctatus</i> (Oshima, 1926) ^{b c}	River, lake, constructed wetlands	Not Evaluated
96			<i>Glossogobius giurits</i> (Hamilton, 1822)	Coast	Least Concern
97			<i>Glossogobius olivaceus</i> (Temminck & Schlegel, 1845)	Coast	Least Concern
98			<i>Mugilogobius abei</i> (Jordan & Snyder, 1901)	Coast	Least Concern
99			<i>Oligolepis acutipennis</i> (Valenciennes 1837)	Coast	Data Deficient
100			<i>Rhinogobius brunneus</i> (Temminck & Schlegel, 1845)	River, lake, constructed wetlands	Data Deficient
101			<i>Rhinogobius changjiangensis</i> (Chen Miller Wu & Fang, 2002) ^{b c}	River, lake, constructed wetlands	Not Evaluated
102			<i>Rhinogobius duospilus</i> (Herre, 1935)	River, lake, constructed wetlands	Not Evaluated
103		Gobiidae	<i>Rhinogobius giurinus</i> (Rutter, 1897)	River, lake, constructed wetlands	Least Concern
104			<i>Rhinogobius leavelli</i> (Herre, 1935)	River, lake, constructed wetlands	Least Concern
105			<i>Rhinogobius linshuiensis</i> (Chen Miller Wu & Fang, 2002) ^{b c}	River, lake, constructed wetlands	Not Evaluated
106			<i>Rhinogobius nanduijiangensis</i> (Chen Miller Wu & Fang, 2002) ^{b c}	River, lake, constructed wetlands	Not Evaluated
107			<i>Rhinogobius wangchuangensis</i> (Chen Miller Wu & Fang, 2002) ^{b c}	River, lake, constructed wetlands	Not Evaluated
108			<i>Stenogobius genivittatus</i> (Valenciennes, 1837)	Coast	Least Concern
109		Perciformes	<i>Stenogobius ophthalmoporus</i> (Bleeker, 1853)	River, lake, constructed wetlands	Least Concern
110			<i>Siphodon multiquamus</i> (Wu & Ni, 1986)	Coast	Endangered
111			<i>Taenioides anguillaris</i> (Linnaeus, 1758)	Coast	Not Evaluated
112			<i>Taenioides cirratus</i> (Blyth, 1860)	Coast	Data Deficient
113		Ambassidae	<i>Ambassis gymnocephalus</i> (Lacepède, 1802)	Coast	Least Concern
114		Anabantidae	<i>Anabas textudineus</i> (Bloch, 1792)	Coast	Data Deficient
115			<i>Bostriochus sinensis</i> (Lacepède, 1801)	Coast	Least Concern
116			<i>Butis butis</i> (Hamilton, 1822)	Coast	Least Concern
117		Eleotridae	<i>Butis koilomatodon</i> (Bleeker, 1849)	Coast	Not Evaluated
118			<i>Eleotris acanthopoma</i> (Bleeker, 1853)	Coast	Least Concern
119			<i>Eleotris oxycephala</i> (Temminck & Schlegel, 1845)	Coast	Least Concern
120			<i>Channa argus</i> (Cantor, 1842)	River, lake, constructed wetlands	Not Evaluated
121			<i>Channa asiatica</i> (Linnaeus, 1758)	River, lake, constructed wetlands	Least Concern
122		Channidae	<i>Channa gachua</i> (Hamilton, 1822)	River, lake, constructed wetlands	Least Concern
123			<i>Channa maculata</i> (Lacepède, 1801)	River, lake, constructed wetlands	Least Concern
124		Percichthyidae	<i>Coreoperca whiteheadi</i> (Boulenger, 1900)	River	Least Concern
125			<i>Neodontobutis hainanensis</i> (Chen, 1985) ^b	River	Least Concern
126		Odontobutidae	<i>Odontobutis obscura</i> (Temminck & Schlegel, 1845)	River, lake, constructed wetlands	Vulnerable
127			<i>Sineleotris chalmersi</i> (Nichols & Pope, 1927)	River, lake, constructed wetlands	Not Evaluated

Table1. (continued).

No	Orders	Families	Latinname	Habitats	IUCN
128		Osphronemidae	<i>Macropodus opercularis</i> (Linnaeus, 1758)	River, constructed wetland	Least Concern
129		Percichthyidae	<i>Siniperca vietnamensis</i> (Mai, 1978)	River, lake, constructed wetlands	Data Deficient
130		Cichlidae	<i>Parachromis managuensis</i> (Gunther, 1867) ^a	River	Not Evaluated
131			<i>Oreochromis niloticus</i> (Linnaeus, 1758) ^a	River, lake, constructed wetlands	Not Evaluated
132	Anguilliformes	Anguillidae	<i>Anguilla japonica</i> (Temminck & Schlegel, 1846)	Coast, river, lake, constructed wetlands	Endangered
133		Chacidae	<i>Clarias fuscus</i> (Lacepède, 1803)	River, lake, constructed wetlands	Least Concern
134			<i>Cranoglanis boudierius</i> (Richardson, 1846) ^b	River	Vulnerable
135		Cranoglanididae	<i>Cranoglanis henrici</i> (Vaillant, 1893)	River	Least Concern
136			<i>Cranoglanis multiradiatus</i> (Koller, 1926)	River	Not Evaluated
137			<i>Glyptothorax fokienensis</i> (Rendahl, 1925) ^b	River	Least Concern
138		Sisoridae	<i>Glyptothorax hainanensis</i> (Nichols & Pope, 1927)	River	Not Evaluated
139			<i>Hemibagrus guttatus</i> (Lacepède, 1803)	River	Data Deficient
140			<i>Hemibagrus hainanensis</i> (Tchang, 1935)	River	Least Concern
141	Siluriformes	Bagridae	<i>Tachysurus intermedius</i> (Nichols & Pope, 1927)	River, lake, constructed wetlands	Least Concern
142			<i>Tachysurus vachellii</i> (Richardson, 1846)	River, lake, constructed wetlands	Data Deficient
143			<i>Tachysurus virgatus</i> (Oshima, 1926)	River, lake, constructed wetlands	Data Deficient
144			<i>Pterocryptis cochinchinensis</i> (Valenciennes, 1840)	River, lake, constructed wetlands	Least Concern
145		Siluridae	<i>Silurus asotus</i> (Linnaeus, 1758)	River, lake, constructed wetlands	Least Concern
146			<i>Clarias batrachus</i> (Linnaeus, 1758) ^a	River, lake, constructed wetlands	Least Concern
147		Clariidae	<i>Clarias gariepinus</i> (Burchell, 1822) ^a	River, lake, constructed wetlands	Least Concern
148		Loricariidae	<i>Hypostomus plecostomus</i> (Linnaeus, 1758) ^a	River, lake, constructed wetlands	Not Evaluated
149	Tetraodontiformes	Tetraodontidae	<i>Gastrophysus ocellatus</i> (Linnaeus, 1758)	Coast, river, lake, constructed wetlands	Not Evaluated
150		Polynemidae	<i>Eleutheronema tetradactylum</i> (Shaw, 1804)	Coast, river	Not Evaluated
151	Mugiliformes	Mugilidae	<i>Liza haematocheila</i> (Temminck & Schlegel, 1845)	Coast, river	Not Evaluated
152			<i>Mugil cephalus</i> (Linnaeus, 1758)	Coast, river	Not Evaluated
153			<i>Colossoma macropomum</i> (Cuvier, 1816) ^a	River, lake, constructed wetlands	Least Concern
154	Characiformes	Serrasalminidae	<i>Pygocentrus nattereri</i> (Kner, 1858) ^a	River, lake, constructed wetlands	Not Evaluated

^a Mean non-native freshwater fish species in Hainan Island.^b Mean freshwater fish species endemic to China.^c Mean freshwater fish species endemic to Hainan Island.

amounting for only 0.35% of total Chinese land area, contains 138 native freshwater fishes (about 10% of the Chinese total), with 38 species endemic to China and 14 species endemic to the island itself. Therefore, Hainan Island is very important for freshwater fish biodiversity conservation.

At the same time, there are 16 non-native freshwater fish species that occurred on Hainan Island (Tab. 1). Five freshwater fish species (*Ochetobius elongates*, *M. piceus*, *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, and *H. nobilis*) were trans located from other regions of China and another 11 fish species were introduced from other countries or regions. Some non-native species, such as Nile tilapia (*Oreochromis niloticus*) and mosquito fish (*Gambusia affinis*) have widely established feral populations in Hainan Island.

Conservation statuses of the freshwater fish species of Hainan Island have been listed in Table 1. Of the 138 native freshwater fish species, about 10% (12 species) are categorized as threatened according to IUCN Red List Criteria. These threatened fish species mainly occur in the streams of Hainan Island (Wang and Xie, 2004).

3.1 Habitats and fisheries

According to the Chinese State Administration of Forestry, the total area of wetlands on Hainan Island is 32×10^4 ha, of which 75.63% (24.2×10^4 ha) are natural and 24.37% (7.8×10^4 ha) are manmade (Jiang, 2015). The wetlands of Hainan Island include five types: coastal (including shallow sea, sea grass bed, coral reef, rocky coast, shingle foreshore, mudflat beach, mangrove, estuary, delta, and lagoon), river (permanent river and flood plain), lake, swamp, and constructed wetlands (reservoir, pond, canal, aquaculture pond, salt pans). All information about area and rate of different types of wetlands are listed in Table 2.

Although coast wetland are the most abundant of five types of wetlands on Hainan Island, only 29 freshwater fish species, some Gobiidae (such as *Awaous ocellaris*, *Glossogobius giuris*, *G. olivaceus* etc.) and estuarine fish (such as *Bostrychus sinensis*, *Butis butis* etc), occurred in coastal wetland. Rivers only accounted for 12% of total Hainan Island wetlands surface area, however, almost all freshwater fish (137 species) were found to inhabit riverine habitats. The area of freshwater lakes is very small, accounting for only 0.17% of total Hainan Island wetlands, and rivers connected most lakes in Hainan Island, thus, except for some native fish (such as Mastacembelidae, Balitoridae, and Cobitidae) only living in the rivers in the mountains, most fish species (80 species) that occurred in rivers were also found in lakes. Swamp is the least abundant wetland type, accounting for only 0.01% of total wetland area and hosting only six small fish species. The area of constructed wetlands is increasing rapidly and these wetland areas host many native and non-native freshwater fish species (native species including *Monopterus albus*, *Sinibrama affinis*, and *S. melrosei* and non-native species including *C. idella*, *H. molitrix*, *H. nobilis*, and *O. niloticus*), which were introduced to reservoirs and aquaculture ponds to increase fisheries productivity. Most fish species (78 species) occurring in lakes also occurred in constructed wetlands. In general, riverine habitats host the greatest diversity of freshwater fish species on Hainan Island and most fish species could live in multiple habitats. All information about the habitats of the fish of Hainan Island is listed in Table 1.

Table 2. The trait of Hainan Island wetlands.

Class	Type	Area (hectare)	Rate (%)
Coast	Shallow sea	144695.05	45.21
	Sea glass bed	502.55	0.16
	Coral reef	5283.36	1.65
	Rocky coast	4355.27	1.36
	Shingle foreshore	26405.51	8.25
	Mudflat beach	992.55	0.31
	Mangrove	4736.05	1.48
	Estuary	6969.28	2.18
	Delta	22.82	0.01
	Lagoon	7704.32	2.41
River	Permanent river	35108.59	10.97
	Flood plain	4646.46	1.45
Lake	Freshwater lake	556.91	0.17
Swamp	Marshes	43.68	0.01
	Reservoirs and ponds	56738.18	17.73
Constructed wetlands	Canals	840.63	0.26
	Aquaculture ponds	15532.14	4.87
	Salt pans	4863.04	1.52

The coast is important to local residents of Hainan Island for commercial and recreational fishing. Many fish species (such as *Boleophthalmus pectinirostris*, *A. melanocephalus*, etc) occurring in coastal areas are important delicacies for local residents (CCTV 2014), however it is noteworthy that some Gobiidae (such as *Yongeichthys criniger*, *Acentrogobius caninus*, etc) occurring here are poisonous to humans. Several people die every year because of Gobiidae poisoning. Hainan Island's rivers are also important recreational fishing site. Many native and non-native fish species (native species, including *Aphyocypris arcus*, *A. normalis*, *Chanodichthys recurviceps* and non-native species, including *Carassius cuvieri*, *O. niloticus*, *Hypostomus plecostomus*, *Clarias batrachus* and *C. gariepinus*) are caught by residents. The area of freshwater lakes and swamps is very small in Hainan Island, hence the commercial and recreational fishing in these two wetland-types are very limited, especially in swamps, where few people go fishing. On Hainan Island, constructed wetlands are the most important commercial fishing sites. Many fish species (*M. piceus*, *C. idella*, *H. molitrix*, *H. nobilis*, *Cyprinus carpio*, *O. niloticus*, *C. auratus*, *Misgurnus anguillicaudatus*, *C. batrachus*, *C. gariepinus*, *Colossoma macropomum*, *Anguilla japonica*, *M. albus*) were introduced into constructed wetlands (aquaculture ponds) for aquaculture (Xiong *et al.*, 2015), especially since the 1990s, when Nile tilapia (*O. niloticus*) were introduced to Hainan Island for aquaculture (Wang *et al.*, 2015).

4 Threats to freshwater fish biodiversity

Freshwater ecosystems possess high levels of biodiversity and endemism. They cover less than 1% of the earth's surface, yet support over 10% of the species (Strayer and Dudgeon, 2010) and are regarded to be in a state of crisis

Fig. 2. The freshwater capture and percent of Hainan Island, red column mean production, black line mean rate.

(Vörösmarty *et al.*, 2010), with higher proportion of species threatened with extinction here than in their terrestrial and marine counterparts (Strayer and Dudgeon, 2010). The main threats to freshwater biodiversity include: overexploitation, water pollution, flow modification, habitat degradation, and non-native species (Dudgeon *et al.*, 2006).

Consistent with other regions of China, inland fisheries are an important threat to the freshwater fish of Hainan Island (Xing *et al.*, 2016). In 2014, the freshwater fisheries of Hainan harvested 22 073 tons, which is 15 times more than that of 26 years earlier. The freshwater fisheries accounting for 0.96% of the total freshwater fisheries harvest for the whole of China in 2014, which is four times greater than that of 26 years earlier (Fig. 2). Which shows that the exploitation pressure on freshwater fishes of Hainan Island has increased strikingly. Illegal fishing practices, such as electro fishing and poison fishing are widespread throughout Hainan Island and, despite strict penalties for perpetrators, remain pervasive and could cause dramatic declines in freshwater biodiversity (Zhao *et al.*, 2015).

In the past twenty years, water pollution has increased rapidly in China, along with rapid economic development (Qin *et al.*, 2013). Now, many rivers and reservoirs have been polluted by agriculture, industry, and rapid urbanization in Hainan Island (Zhao, 2015). Although the total industrial wastewater discharge has decreased by approximately 40% since twenty years ago (Zhang *et al.*, 2013), some rivers and reservoirs have been polluted by nonpoint sources of contaminants. Meanwhile, the number of fish species has decreased, caused by water quality degradation by nonpoint source pollution (Harding *et al.*, 1998) and lethal fish spill events, frequently occurring in some rivers of Hainan Island (CCTV, 2016).

Flow modification is one of the most critical threats to Chinese freshwater fish biodiversity (Fu *et al.*, 2003; Axing *et al.*, 2016). The spatial and temporal distribution of rainfall in Hainan Island is very uneven, with more than 80% of total rainfall between May and October. For more efficient and dependable water supplies, many hydrological infrastructures projects were undertaken between 1950 and 1980 in order to satisfy agricultural and hydropower demands. Today, over 2 000 reservoirs are distributed all over Hainan Island

(Pearl River Fisheries Research Institute, 1989). However, nearly 20% freshwater fish species (26 species) are migratory species in Hainan Island. The loss of river connectivity due to the construction of reservoirs inevitably leads to the decline of some migratory species populations (*e.g.* *A. japonica*). Meanwhile, the construction of reservoirs altered fast flowing streams to slow flows, causing declines of fish dependent upon these fast flowing stream habitats (*e.g.* *Glyptothorax fokiensis*).

Over a period of seventy years the human population of Hainan Island increased from 2.59 million to over 9 million, in 2015 (Statistical Bureau of Hainan Province, 2016). Because of economic development and intensive human impacts, many natural habitats have been degraded and fragmented (Liao *et al.*, 2009). A number of organisms (plants, amphibians, mammals and birds) have been threatened by habitat degradation on Hainan Island (Lei *et al.*, 2003; Xie *et al.*, 2007; Zhang *et al.*, 2010; Meng *et al.*, 2011). Research has shown that habitat degradation leads to loss of fish biodiversity in other regions (Kruk, 2007; Hermoso *et al.*, 2011), however little is known about the actual negative impacts on native freshwater fish caused by habitat degradation on Hainan Island.

From the 1950s, many non-native fish were introduced to improve reservoir fisheries on Hainan Island, some of which, such as Nile tilapia (*O. niloticus*), are now abundant in a number of the reservoirs of Hainan Island. These non-native fish species play an important role for improving fisheries production and the economic development of Hainan Island. Based on the harvested quantities, tilapia, Black carp (*M. piceus*), Grass carp (*C. idella*), Silver carp (*H. molitrix*) and Bighead carp (*H. nobilis*) are the key non-native aquaculture fish groups in Hainan Island (Fig. 3a–d). The most dominant non-native aquaculture species are tilapia (Fig. 3d), which account for approximately 20% of the total harvest in China (unpublished data). Non-native freshwater species now constitute over 10% of the total freshwater fish species in Hainan Island (Tab. 1). These non-native fish species could lead to enormous negative impacts on native fisheries and biodiversity (Xiong *et al.*, 2015). For example, the increase of Nile tilapia in the rivers of South China has led to declines in the CPUE from native fish communities as well as declines in the number of native fish species caught (Gu *et al.*, 2015). Another prominent example is the mosquito fish (*G. affinis*), which could pose a grave threat to Chinese freshwater biodiversity (Yan *et al.*, 2009; Karraker *et al.*, 2010). Inevitably, these non-native species could harm freshwater biodiversity in Hainan Island, but there is currently a dearth of quantitative impact studies in the literature and this shortfall should be addressed, as a priority.

5 Conservation of freshwater fish biodiversity

Freshwater fish are considered as the second most threatened animal group, after amphibians (Bruton, 1995), however, freshwater fish are the most important animal group for freshwater aquaculture in both China and World (Wang *et al.*, 2015). Hence freshwater fish have conservation value, both for ecological and economic reasons.

Fig. 3. Annual aquaculture production of main freshwater fish species in Hainan Island.

Establishment of conservation areas is considered a foundation of biodiversity protection (Chape *et al.*, 2005; Naughton *et al.*, 2005). To date, there have been 50 nature reserves established for the conservation of tropical forests, mangroves, coral reefs, birds and karst cave ecosystems in Hainan Island, however there are no conservation areas for protection of freshwater biodiversity. Arguably, freshwater conservation areas and fish passages should be established on Hainan Island, particularly around mountain streams which provide habitat for threatened and endemic fish species, such as *P. baotingensis*, *S. minor* and *P. baotingensis*.

Illegal fishing remains pervasive on Hainan Island and efforts should be focused on enforcing the law, to prevent the perpetuation of such practices electrofishing, poison fishing, and some kinds of trap fishing are strictly prohibited according to Chinese Fisheries Law. The use of gillnets with greater than 5 cm mesh should also be enforced (Chen and Chen, 2010), as gillnets with smaller meshes-sizes are commonly used on Hainan Island. Some rare and endangered fishes should be artificially propagated and released. In 2010, the artificially propagated and released freshwater fishes reached 16 billion in China, a three-fold increase from ten years prior (Ministry of Agriculture, 2015). Although data on the precise number of freshwater fish artificially propagated and released in Hainan Island is lacking, most artificial propagation and release efforts occurred in the Yangtze River and Pearl River. Currently, most

artificially propagated and released species (like *C. auratus*, *C. carpio*, *Misgurnus anguillicaudatus*, *M. albus*, *Parabramis pekinensis*, *Tachysurus vachellii*) are used for fishery and aquaculture purposes. The key biological characteristics of many endemic and threatened fish species (e.g. *Cranoglanis boudierius*, *Neodontobutis hainanensis*, *P. baotingensis*) are still unknown, thus more studies should pay attention to life history traits and habitat requirements of the endemic and threatened fishes on Hainan Island.

The establishment of dams can lead to degradation of river habitat and impair the functionality of ecosystems (Dudgeon, 2000; Dudgeon *et al.*, 2006), especially for anadromous fish species (Xie, 2003). However, the density of dams in Hainan Island is higher than in other regions of China and other countries. A number of mitigation approaches (including flow release of dams, establishing passage of migratory fishes, etc.) should be implemented, to minimize negative impacts. Meanwhile, habitat restoration (especially aquatic plant restoration) should be considered, to provide diverse habitat for native freshwater fish (Collingsworth and Kohler, 2010). Although there is very high diversity of aquatic plants on the island (Wang *et al.*, 2008), intensive human activities could lead to decline and even extinction of aquatic plants, as in the rest of China. Thus, local government, citizens, and environmental organizations should pay more attention to the impacts of dams and carry out habitat restoration where necessary.

China is currently the most seriously threatened county by invasion of aquatic organisms (Xiong *et al.*, 2015; Wang *et al.*, 2016; Xiong *et al.*, 2017). Although little is known about the negative impacts of these non-native freshwater fishes in Hainan Island, these non-native fish species have caused great negative impacts in other regions of world (Pimentel *et al.*, 2000; Ribeiro and Leunda, 2012). Non-native freshwater fish could lead to declines of native endemic species by hybridization, competition for food and habitat, predation, and habitat and ecosystem alterations (Xiong *et al.*, 2015). Therefore, more research is needed on ecological and economic impacts of these non-native freshwater fishes in Hainan Island.

6 Conclusion

Based on the current study, Hainan Island contains a very high diversity of freshwater fish. At present, some factors (*e.g.* overexploitation, water pollution, flow modification, habitat degradation, and non-native species) have caused great negative impacts on native freshwater fishes. Therefore, effective protection and conservation of Hainan Island freshwater fish should be considered, including establishment of conservation areas, control of illegal fishing, development of sustainable fisheries, restoration of habitat, and the prevention of further non-native species introductions.

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