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Fish species abundance and distribution in Wuyishan National Nature Reserve, Jiangxi Province, China

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Keywords: Freshwater fish, composition, distribution, conservation, mountain streams, Wuyishan National Nature Reserve

Abstract

Wuyishan National Nature Reserve is located in the northwest of the Wuyi Mountain Range in northeastern Jiangxi Province. The fish fauna of mountain streams in the nature reserve was investigated seasonally from June 2015 to May 2016. A total of 2 505 samples were collected and classified into 7 families and 16 species. None of those collected in the nature reserve were alien species. Overall, 9 species (56.3% of the total number of fish species collected) were found to be endemic to China. The dominant species were *Pseudogastromyzon fasciatus* (IRI, 48.23%) and *Onychostoma barbatulum* (IRI, 46.39%); the common species were *Acrossocheilus parallens* (IRI, 9.76%), *Formosania stigmata* (IRI, 4.32%) and *Zacco platypus* (IRI, 1.15%). There were negative correlations between altitude and total number of species (S), altitude and Margalef index (D), and altitude and Shannon-Wiener index (H). Current threats to the conservation of fish species in the nature reserve were reviewed and management solutions were suggested.

Profile

Protected area

Wuyishan National Nature Reserve

Mountain range

Wuyi Mountains

Country

China

Introduction

Jiangxi Province, which covers almost 166 900 km^2 in total, is located in the south of China and lies between 24° 29' 14"–30° 04' 41" N and 113° 34' 36"–118° 28' 36" E (Figure 2). The north is relatively flat, while the other sides are surrounded by mountains. The main rivers in the province are the Ganjiang, Xinjiang, Fuhe, Raohe and Xiuhe, which flow into Poyang Lake and then drain into the Yangtze. Poyang Lake, the largest freshwater lake in China, its five affluents and the Yangtze together form a complete riverine-lacustrine network. With its complex river-lake ecosystem, Jiangxi Province provides good fish resources (Yin et al. 2017). According to previous studies, of a total of 220 recorded freshwater fish species throughout Jiangxi Province, 131 species (59.5%) are believed to be endemic, many of them being present in the mountainous regions (Huang et al. 2013). Protected areas such as nature reserves could play an important role in the conservation of freshwater fish species within Jiangxi Province, but there is a need to better identify the conservation value of these areas in relation to the biogeographical diversity of fish and the factors impacting on fish communities (Hu et al. 2014).

Worldwide, freshwater fish are the most diverse of all vertebrate groups, but they are also the most threatened group of vertebrates after amphibians (Moyle & Leidy 1992; Bruton 1995; Duncan & Lockwood 2001). Most mountain streams in the Wuyishan National Nature Reserve (WNNR) are shallow, and the hydrology of most headwater streams has been modified by farming and irrigation of the surrounding land. Recently, numerous anthropogenic disturbances, such as clear-cuts, small dams, road construction, fires and mining, have triggered physico-chemical alterations in the mountain streams (Liu & Fang 2001).

Figure 1 – Grand canyon in the Wuyishan National Nature Reserve, Jiangxi Province. © M.Hu

There have been several notable surveys of the flora and fauna within the nature reserve (Ding 1996; Hu & Liu 2008; Tao et al. 2008; Zhang et al. 2008; Cheng et al. 2009, 2011, 2012, 2013, 2015; Yuan et al. 2012; Lei et al. 2013; Xu et al. 2014; Wang et al. 2015a,b; Mao et al. 2016; Wu et al. 2016). However, so far there have been no studies on the distribution and abundance of fish species in the nature reserve. The aims of the present study are: (1) to characterize the species composition of the fish fauna and their distribution in the nature reserve; (2) to review the main threats to fish biodiversity, and (3) to establish some recommendations for the conservation of the fish fauna.

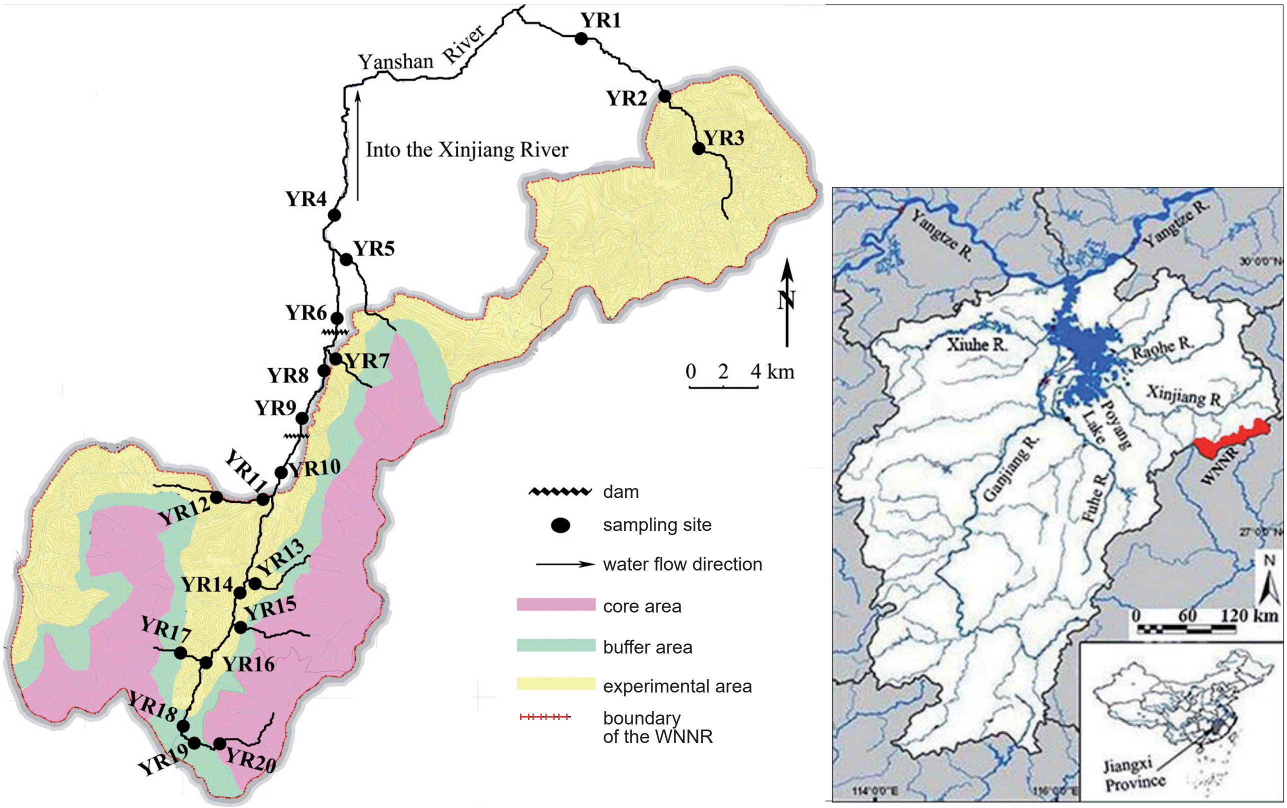

Figure 2 – Maps showing the locations of the WNNR (in red) and the sampling sites.

Materials and Methods

Study area

The WNNR (between 27° 48' 11"–28° 00' 35" N and 117° 39' 30"–117° 55' 47" E; total area: 160.07 km^2; highest altitude: 2 157.7 m) is located in the northwest of the Wuyi Mountain Range in northeastern Jiangxi Province (Figure 2). The nature reserve presents a humid subtropical climate and belongs to the forest ecological nature reserve for the conservation of mid-subtropical broad-leaved evergreen forest, and rare animals and plants. The annual average precipitation is about 2 600 mm, annual average temperature is about 14 °C, and forest coverage rate is up to 92.7% (Liu & Fang 2001). Most mountain streams in the nature reserve flow into the Yanshan River, which drains into the Xinjiang (Figure 2).

Study sites

Twenty sampling sites were established on mountain streams in the WNNR (Figure 2), based on the representative habitat types present and accessibility during the study period. At each sampling site, the GPS position and altitude (*AL*) were recorded using a Garmin GPS map 76Cx; water temperature (*WT*) and dissolved oxygen (*DO*) were measured using a hand-held YSI multi-meter.

Fish survey

Samples were made at the twenty sites in the WNNR from June 2015 to May 2016, one being taken at each site during each of the four seasons. All the stations were characterized by shallow water depths, narrow channel widths, and relatively fast water currents flowing over boulder substrate. At each site, samples were collected using an electrofishing device consisting of two copper electrodes on wooden handles, powered by a 500-watt portable AC generator. Stunned fish were collected using dip nets or caught by hand. A cast net (mesh 5 mm × 5 mm; $\pi \times 0.6^2$ m = 1.13 m^2) was also used within shallow pools of the stream system to collect fish. Approximately 100 m of stream segment, typically comprising pool, run and riffle habitats, were sampled at each site. Specimens that could not be identified in the field were fixed in 10% formalin solution for accurate taxonomic verification. The unfixed, live fish were released at the sampling sites. All specimens were identified according to Zhu (1995), Chen (1998), Chu et al. (1999) and Yue (2000).

Data analyses

An index of relative importance (*IRI*) based on number percentage, weight percentage and frequency of occurrence combined was determined to measure fish dominance in catches. This index was calculated as follows (Liu et al. 2017):

$$IRI_i = (\%N_i + \%W_i) \times \%F_i$$

where $\%N_i$ and $\%W_i$ are the percentage number and percentage weight respectively of species i in the total catches, and $\%F_i$ is the occurrence frequency of

Table 1 – Characteristics of survey sites on the Yanshan River.

Site	Latitude	Longitude	AL [m]	WT [°C]	DO [mg·L^{-1}]	Habitat description
YR1	28°01′22″	117°50′29″	230	21.5±7.3	8.5±1.4	Slow-flowing, slightly turbid water with gravel and sandy substrates, partially shaded by riparian vegetation, slight disturbance
YR2	28°00′26″	117°52′38″	320	19.0±6.8	8.7±1.6	Slow-flowing, slightly turbid water with sandy and gravel substrates, shaded by riparian vegetation, slight disturbance
YR3	27°59′06″	117°54′09″	520	18.7±6.5	8.8±1.4	Fast-flowing, clear water with rocky substrate, shaded by forest canopy, no disturbance
YR4	27°57′47″	117°46′08″	395	18.9±6.9	8.0±1.9	Slow-flowing, slightly turbid water with sandy substrate, partially shaded by riparian vegetation, slight disturbance
YR5	27°57′09″	117°46′27″	430	19.4±6.7	8.8±1.5	Fast-flowing, slightly turbid water with gravel and rocky substrates, partially shaded by forest canopy, slight disturbance
YR6	27°56′10″	117°46′16″	450	17.9±5.4	8.6±1.5	Slow-flowing, slightly turbid water with rocky and gravel substrates, shaded by forest canopy and riparian vegetation, slight disturbance
YR7	27°55′57″	117°46′05″	515	18.5±6.0	9.0±1.1	Fast-flowing, slightly turbid water with gravel and rocky substrates, partially shaded by forest canopy, slight disturbance
YR8	27°55′36″	117°45′59″	500	18.3±6.2	8.6±1.2	Slow-flowing, clear water with gravel and rocky substrates, shaded by forest canopy and riparian vegetation, slight disturbance
YR9	27°54′13″	117°45′19″	612	19.2±6.7	8.2±1.9	Slow-flowing, slightly turbid with gravel and rocky substrates, shaded by forest canopy and riparian vegetation, slight disturbance
YR10	27°53′32″	117°44′59″	662	18.4±5.9	9.0±1.4	Slow-flowing, clear water with gravel and rocky substrates, shaded by forest canopy and riparian vegetation, slight disturbance
YR11	27°53′28″	117°44′47″	670	18.4±7.0	8.7±1.5	Slow-flowing, slightly turbid water with gravel and rocky substrates, shaded by riparian vegetation and forest canopy, slight disturbance
YR12	27°53′23″	117°44′11″	720	17.9±6.3	8.7±1.5	Fast flowing, clear water with rocky substrate, shaded by forest canopy, slight disturbance
YR13	27°52′05″	117°44′22″	770	17.8±5.9	8.9±1.3	Fast-flowing, clear water with rocky substrate, shaded by forest canopy, slight disturbance
YR14	27°51′57″	117°44′18″	800	18.1±5.9	8.6±1.6	Fast-flowing, clear water with gravel and rocky substrates, partially shaded by forest canopy, slight disturbance
YR15	27°51′17″	117°44′08″	835	18.0±5.9	8.8±1.2	Fast-flowing, clear water with rocky substrate, partially shaded by forest canopy, no disturbance
YR16	27°50′36″	117°43′34″	899	17.2±5.7	8.7±1.5	Fast-flowing, clear water with gravel and rocky substrates, partially shaded by forest canopy, no disturbance
YR17	27°50′37″	117°43′33″	900	16.7±5.4	9.0±1.2	Fast-flowing, clear water with gravel and rocky substrates, shaded by forest canopy, no disturbance
YR18	27°49′37″	117°43′06″	980	16.5±5.7	8.5±1.6	Fast-flowing, clear water with rocky substrate, shaded by forest canopy, no disturbance
YR19	27°49′14″	117°43′11″	1080	16.6±6.1	8.7±1.4	Fast-flowing, clear water with rocky substrate, shaded by forest canopy, no disturbance
YR20	27°49′06″	117°43′39″	1190	15.9±5.4	8.7±1.7	Fast-flowing, clear water with rocky substrate, shaded by forest canopy, no disturbance

species *i*. When IRI_i was more than 10%, it showed that the species *i* was dominant, while 1% < IRI_i < 10% meant that the species *i* was common.

The relative abundance of each species at each sampling site was estimated by:

$$P_{jk} = N_{jk} / N_k$$

where N_{jk} = the number of species *j* collected in site *k*, and N_k = the total numbers of all fish collected at site *k*.

The Margalef index (*D*) and Shannon-Wiener index (*H*) were used to calculate fish species richness for each site (Peet 1974; Magurran 1988):

$$D_k = (S_k - 1) / \ln N_k \text{ and } H_k = -\sum P_{jk} \ln P_{jk}$$

where S_k = the total numbers of species collected at site *k*.

With the development of computer technology, cluster analysis has begun to be used to study the community ecology, including fish species distribution (Yin et al. 2016). A dataset including all the species collected at each site was constructed. A similarity measure was conducted based on presence (1) or absence (0) of each species at each site (Huang et al. 2013). Pairwise similarities among all sites were computed in order to create a similarity coefficient matrix. The hierarchical cluster, furthest-neighbour method with squared Euclidean distance was used for cluster analysis based on the matrix. All analyses were performed using SPSS 13.0 software.

Results and discussion

Stream characteristics and physico-chemical parameters

Physico-chemical characteristics were similar across all studied sites in the WNNR. Most of the sampling sites were composed of sandy, gravel and rocky substrates. Shallow pools and riffles alternated in the segments studied. Most sites had clear water and were shaded by riparian vegetation or forest canopy. This appearance is typical of slightly disturbed mountain streams at higher altitudes (Table 1). The mean (± SE) water temperature was 18.1±6.2 °C. Water temperature ranged from 7.6 °C (site YR19 in winter) to 25.8 °C (site YR1 in summer). Site average dissolved oxygen was between 8.0 mg / L and 9.0 mg / L (mean ± SE, 8.7±1.3 mg / L). The high *DO* could be attributed to low water temperature and high water speed.

Composition of fish species

A total of 2 505 specimens were collected and classified into 16 species and 7 families. Cyprinidae (6 species, 37.5% of the total numbers of fish species collected) was the dominant family, followed by Balitoridae (three species, 18.8%), Bagridae and Gobiidae (two species and 12.5% each), while Cobitidae, Siluri-

Table 2 – Composition and distribution of fish species in the WNNR, Jiangxi, China.

Family / species	Sampling sites																																								N [%]	W [%]	IRI [%]
	YR1		YR2		YR3		YR4		YR5		YR6		YR7		YR8		YR9		YR10		YR11		YR12		YR13		YR14		YR15		YR16		YR17		YR18		YR19		YR20				
	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W	N	W			
Cyprinidae																																											
Zacco platypus (Temminek & Schlegel, 1846)	1	8	14	66			140	749																																	6.19	6.59	1.15
Opsariichthys bidens (Günther, 1873)	5	9	8	68																																					0.52	0.62	0.07
Rhynchocypris oxycephalus (Sauvage & Dabry, 1874)									2	8					2	2			1	1											3	32	20	165	13	118					1.64	2.61	0.54
Gnathopogon imberbis (Sauvage & Dabry, 1874)*	5	16	3	26																																					0.32	0.34	0.03
Acrossocheilus parallens (Nichols, 1931)*					14	171			1	17			1	5	8	50	12	128	33	248	3	49			2	32	26	289	3	87	18	413	30	449	12	204	9	66			6.87	17.69	9.76
Onychostoma barbatulum (Pellegrin, 1908)*							1	2			12	121	21	164	37	155	27	189	85	767	29	316	52	483	63	592	89	698	15	94	42	483	49	409	47	477	60	358	2	70	25.19	43.09	46.39
Cobitidae																																											
Misgurnus anguillicaudatus (Cantor, 1842)	5	27	2	32																																					0.28	0.47	0.04
Balitoridae																																											
Vanmanenia stenosoma (Boulenger, 1901)*	4	17	3	15					1	12																															0.32	0.35	0.03
Formosania stigmata (Nichols, 1926)*					2	9			2	22	3	3	7	36			6	29	3	11	4	19	12	49	14	45	12	92	5	18	14	109	11	47	3	11	4	14	11	60	4.51	4.60	4.32
Pseudogastromyzon fasciatus (Sauvage, 1878)	2	14			2	18			5	10	5	8	45	140	17	54	69	104	240	450	63	144	51	86	199	287	210	285	52	86	113	239	43	151	115	268	36	85	17	32	51.26	19.72	48.23
Siluridae																																											
Silurus asotus (Linnaeus, 1758)	1	9																																							0.04	0.07	0.001
Bagridae																																											
Pseudobagrus ondon (Shaw, 1930)*	1	3	1	20			2	9	1	20																															0.20	0.42	0.03
Pseudobagrus truncatus (Regan, 1913)*			1	102																																					0.04	0.82	0.01
Amblycipitidae																																											
Liobagrus anguillicauda (Nichols, 1926)*			4	53															2	9	1	9									9	77	6	45	7	62					1.16	2.04	0.53
Gobiidae																																											
Rhinogobius giurinus (Rutter, 1897)	16	27							2	3							1	1	2	5																					0.84	0.29	0.09
Rhinogobius cliffordpopei (Nichols, 1925)*	12	24					1	6							2	4			1	2																					0.64	0.29	0.08

*Endemic to China (Huang et al. 2013; FishBase: www.fishbase.org). N: the number of specimens, W: the specimen weight (unit: g), N %: number percentage, W %: weight percentage, IRI %: index of relative importance.

Table 3 – Comparison of fish diversity among sites in the WNNR, Jiangxi, China.

Index	Sampling sites																			
	YR1	YR2	YR3	YR4	YR5	YR6	YR7	YR8	YR9	YR10	YR11	YR12	YR13	YR14	YR15	YR16	YR17	YR18	YR19	YR20
Total numbers of species (S)	10	8	3	4	7	3	4	5	5	8	5	3	4	4	4	6	6	6	4	3
Margalef index (D)	2.28	1.95	0.69	0.60	2.27	0.67	0.70	0.95	0.84	1.19	0.87	0.42	0.53	0.52	0.69	0.94	0.99	0.95	0.64	0.59
Shannon-Wiener index (H)	1.93	1.72	0.68	0.16	1.77	0.94	0.94	1.14	1.08	0.96	0.93	0.96	0.76	0.96	0.89	1.26	1.60	1.19	1.02	0.87

dae and Amblycipitidae were represented by one species each (Table 2).

Overall, 9 species (56.3% of the total numbers of fish species collected) that are endemic to China were found in the WNNR. Endemic fishes were classified into six families. The dominant family was Cyprinidae (three species), and the subdominant families were Balitoridae and Bagridae (two species each), while Amblycipitidae and Gobiidae were represented by one species each (Table 2).

The dominant species were *Pseudogastromyzon fasciatus* (*IRI*, 48.23%) and *Onychostoma barbatulum* (*IRI*, 46.39%); the common species were *Acrossocheilus parallens* (*IRI*, 9.76%), *Formosania stigmata* (*IRI*, 4.32%) and *Zacco platypus* (*IRI*, 1.15%). They were anatomically well adapted to live in fast-flowing currents with clear water and relatively high dissolved oxygen concentration. For instance, *Pseudogastromyzon fasciatus* and *Formosania stigmata* have a sucker structure under their bodies to keep them attached to the substrate in the boundary layer created by the water movement. Generally, they feed on algae growing on the rock, as well as detritus and insects.

Diversity analysis

In the composition of the main catches, the weight percentage of *Onychostoma barbatulum* was the largest (43.09% of the total weight), followed by *Pseudogastromyzon fasciatus*, *Acrossocheilus parallens*, *Zacco platypus* and *Formosania stigmata*, which accounted for 19.72%, 17.69%, 6.59% and 4.60% respectively. *Pseudogastromyzon fasciatus* was the most abundant, accounting for 51.26% of the total number of fish species, followed by *Onychostoma barbatulum*, *Acrossocheilus parallens*, *Zacco platypus* and *Formosania stigmata* (25.19%, 6.87%, 6.19% and 4.51% respectively) (Table 2).

Using the survey data, total numbers of species (S), Margalef index (D) and Shannon-Wiener index (H) were calculated for each sampling site (Table 3). The Margalef index and Shannon-Wiener index reflect the fish species richness and diversity. A high value for these indices is synonymous with greater fish diversity. The comparison of fish communities within the surveyed sites showed the highest fish diversity at site YR1 (Table 3). Moreover, there were negative correlations between altitude and total number of species, altitude and Margalef index, and altitude and Shannon-Wiener index (Figure 3).

Distribution and cluster analysis

The general distribution of fish species collected from the twenty sites is shown in Table 2. Four species (*Pseudogastromyzon fasciatus*, *Onychostoma barbatulum*, *Acrossocheilus parallens* and *Formosania stigmata*) appeared at more than 70% of the sites, two species (*Rhynchocypris oxycephalus and Liobagrus anguillicauda*) were recorded at 6 sites, while two species (*Silurus asotus* and *Pseudobagrus truncatus*) appeared only at one site. However, eight species (50% of the total numbers of fish species) were found at 2–4 sites.

The cluster analysis demonstrated a division of the fish species at the twenty sites into two significantly different groups (Figure 4). Group A included sites YR1, YR2 and YR4. These three sites, located below 400 metres and shaded by riparian vegetation, were composed of sandy and gravel substrates with slow-flowing, slightly turbid water. Six species (*Zacco platypus*, *Opsariichthys bidens*, *Gnathopogon imberbis*, *Misgurnus anguillicaudatus*, *Silurus asotus* and *Pseudobagrus truncatus*) appeared only in this group of sites. Group B comprised the remaining seventeen sites. Located above 400 metres and shaded by forest canopy, these sites were composed of gravel and rocky substrates with fast-flowing, clear water. Three species (*Rhynchocypris oxycephalus*, *Acrossocheilus parallens* and *Formosania stigmata*) were found only at the sites of group B.

Factors favouring species abundance and endemism

The results of the present field studies in the WNNR showed that more than 7.2% of total fish species and 6.8% of total endemic species in Jiangxi Province (220 fish species and 131 endemic species; Huang et al. 2013) were collected or found to be distributed in the study area's mountain streams. The more abundant species or endemic species collected may be partially due to habitat stability and lack of disturbances, such as the introduction of exotic species. The riparian zones of streams in the WNNR were well forested, so that stream temperatures rarely reached 20 °C even during the summer, and dissolved oxygen levels were high at all sites, providing suitable environmental conditions for these fishes.

The index of relative importance (*IRI*) of *Rhynchocypris oxycephalus* was 0.54%. It was next only to the dominant species (*Pseudogastromyzon fasciatus* and *Onychostoma barbatulum*) and common species (*Acrossocheilus parallens*, *Formosania stigmata* and *Zacco platypus*). The presence of this representative cold-water species of the Holarctic Region in China, which is restricted to

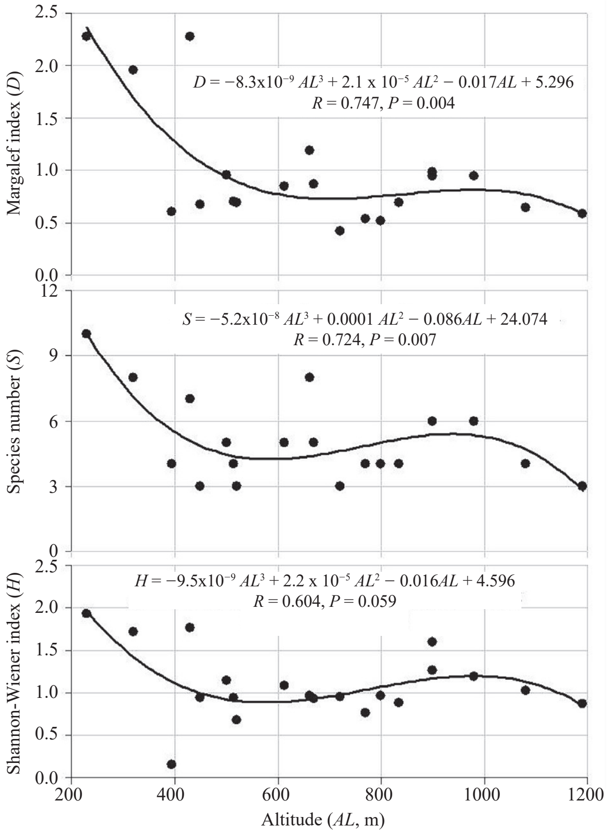

Figure 3 – Relationships between altitude (AL) and total number of species (S), altitude (AL) and Margalef index (D), and altitude (AL) and Shannon-Wiener index (H) at each site of the WNNR. Solid-line shows fitted trends between altitude and total number of species, altitude and Margalef index, and altitude and Shannon-Wiener index.

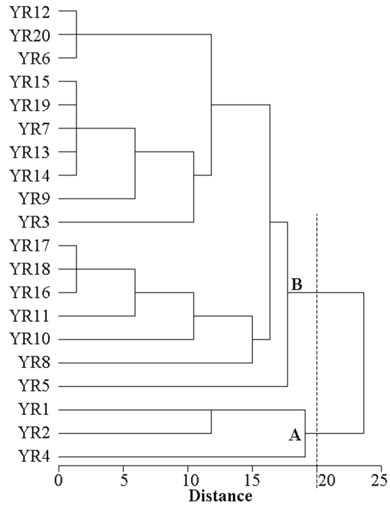

Figure 4 – Cluster analysis of fish species collected at the twenty sampling sites in the WNNR. (Group A: the three sites located below 400 metres; Group B: the seventeen sites located above 400 metres).

mountain streams in Jiangxi Province (except for the Xunwushui River and the south of Jiangxi Province), may be related to the effect of Quaternary glaciations (Zhang & Chen 1997). It has been suggested that the alternating Quaternary glacial and interglacial periods moved *Rhynchocypris oxycephalus* to the south, where the species survived in the small mountain streams where the water is cold (Huang et al. 2013).

Current threat and conservation

Changes in aquatic ecosystems can alter fish assemblages, and fish can be used as good indicators of ecological health for the conservation of streams and rivers (Suen & Herricks 2006; Pont et al. 2007; Linde-Arias et al. 2008). Fish biodiversity is facing numerous threats due to anthropogenic activities, including over-exploitation, water pollution, habitat alteration, introduced invasive species and climate change (Dudgeon et al. 2006; Allan & Castillo 2007). During recent decades, streams and rivers in China have been drastically modified because of agricultural activities, the increased need for drinking water supplies, and the construction of multi-purpose dams, artificial reservoirs, levees and weirs (Fu et al. 2003). Small and fast-flowing streams have often been transformed into wide slow-flowing streams. These factors have greatly reduced effective migration for those species moving between different stream habitats. This change would mean that the organisms become restricted to mountainous areas and are replaced by other species adapted to slow-flowing streams (Hu et al. 2009). Man-made modifications to the hydrology have had a serious negative impact on the biodiversity and fish resources of Jiangxi Province (Tang et al. 1993; Wang et al. 2004). In the WNNR, dams have been built on some mountain streams (Figure 2). Meanwhile the water has become polluted by domestic sewage and waste at sites YR4, YR6, YR7 and YR11. In addition, some people catch fish for food at site YR3 using rotenone or other poisons which are usually used to exterminate snails. This kind of fishing not only contributes to the reduction of fish biodiversity but is also harmful to human health. Thus relatively low fish diversity was present at these sampling sites (Table 3).

Globally, more than half of all accessible freshwater runoff is currently used by humans, and freshwater habitats are being subjected to unprecedented levels of human disturbance (Saunders et al. 2002). Increased water demand for irrigation, industrial and domestic use already threatens freshwater resources in many parts of the world (Szöllosi-Nagy et al. 1998). Protected areas are a major element in terrestrial conservation strategies, essential in preventing habitat loss or degradation, but few such areas have been created specifically for freshwater species and habitats (Saunders et al. 2002). To protect fish diversity and fish stocks more effectively, law enforcement should be strengthened, and fish sanctuaries and freshwater fish conversation areas should be established. Therefore, the primary objective for the successful conservation of the freshwater fish species richness in the WNNR must be to develop effective controls and management practices that enable life-cycle success, dispersal and population maintenance within stream systems. Effective fish passage facilities need to be improved in order to enhance the connectivity of streams for fish dispersal and migration. Fishing activities in the WNNR, especially using rotenone and other poisons, must be strictly prohibited. The conclusions of the present research agree with Jang et al.'s statement (2003) that the long-term management and conservation of the fish fauna of nature reserves and other protected areas in Jiangxi Province will require good bench-mark sites and a long-term monitoring protocol.

Acknowledgments

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