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Fish assemblage structure in the Chishui River, a protected tributary of the Yangtze River

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ABSTRACT

Key-words: *Chishui River, fish distribution, environmental variables, canonical correspondence analysis (CCA), fish conservation*

This study aimed to characterize fish assemblage and evaluate environmental influence on fish distribution in the Chishui River, a protected tributary of the upper Yangtze River. Thirty-one sites regularly distributed in longitudinal profiles were sampled in April, 2007. Sixty-two fish species belonging to 3 orders, 8 families, and 52 genera were collected. Species richness and diversity significantly increased from upstream to downstream. Canonical correspondence analysis (CCA) highlighted five environmental variables (altitude, conductivity, dissolved oxygen, channel width and current velocity) significantly structuring fish assemblages in the Chishui River. Based on species distributions and fish-habitat relationships, conservation strategies were proposed for different reaches.

RÉSUMÉ

Structure des communautés piscicoles de la rivière Chishui, un affluent protégé du fleuve Yangtzé

Mots-clés : *rivière Chishui, distribution de poissons, variables environnementales, analyse canonique des correspondances (CCA), conservation piscicole*

Cette étude caractérise les communautés de poissons et évalue l'influence environnementale sur la distribution piscicole dans la rivière Chishui, un affluent protégé du fleuve Yangtzé. Trente-et-un sites régulièrement répartis sur le profil longitudinal ont été échantillonnés en avril 2007. Soixante-six espèces de poissons appartenant à 3 ordres, 8 familles et 52 genres ont été collectées. La richesse et la diversité spécifique augmentent significativement de l'amont vers l'aval. L'analyse canonique des correspondances (CCA) identifie cinq variables environnementales (altitude, conductivité, oxygène dissous, largeur du lit et vitesse du courant), structurant significativement les communautés de poissons dans la rivière Chishui. À partir des distributions spécifiques et des relations habitat-poisson, des stratégies de conservation sont proposées pour les différents biefs.

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INTRODUCTION

Fish assemblage is an important element in aquatic ecosystem. It provides a good biological indication for the quality of freshwater ecosystems since it is sensitive to a broad range of stressors (Karr, 1981; Oberdorff *et al.*, 2002). It has been widely reported that the distribution and abundance of fish species are strongly related to environmental factors (Tejerina-Garro *et al*., 1998; Brown, 2000). These factors include topographical characteristics (Platts, 1979), climate (Eaton and Scheller, 1996), hydrological regime (Poff and Allan, 1995), riparian land use (Lammert and Allan, 1999), and water physical-chemical variables such as dissolved oxygen and pH (Matthews and Hill, 1979). These abiotic parameters have short-term or long-term influences on the structure of fish assemblages (Gasith and Resh, 1999). Apart from abiotic factors, biotic factors such as predation and competition could also affect fish assemblages *via* direct and indirect mechanisms (Jackson *et al*., 2001).

Characterizing the factors that structure fish assemblages is useful for river management and fish preservation. Similar studies on fish-habitat relationships have been carried out in South America (*e.g.* Fialho *et al*., 2008), North America (*e.g.* Feyrer and Healey, 2003), Europe (*e.g.* Godinho *et al*., 2000) and Africa (*e.g.* Ibanez *et al*., 2007), but are still lacking for Asia (Shahnawaz *et al.*, 2010), and especially for China rivers.

With at least 286 fish species and subspecies distributing in the main channel and its affiliated tributaries, the upper Yangtze River is considered as a biodiversity hot spot for fish conservation (He *et al*., 2011). In the past decades, fish resources decreased dramatically and endemic species faced continuous threats. Dams, overfishing, pollution, deforestation, land erosion and other human activities were considered as main threats to fish biodiversity (Fu *et al*., 2003). The National Nature Reserve for rare and endemic fishes of the upper Yangtze River (NNRYR) was established in 2005 to protect fish resources. The protection zone included 353 km-long mainstream and some tributaries (the Chishui River; the river-mouth of the Minjiang River, the Tuojiang River, the Yuexi River, the Nanguang River, the Changning River and the Yongning River). Being the last undammed tributary of the upper Yangtze River, the Chishui River is an important part of the protection zone.

In this paper, we analysed the structure of fish assemblages in the Chishui River during April 2007. Our main objectives were: 1) to characterize the composition and spatial variation of fish assemblages, and 2) to identify the main environmental factors responsible for the variation in fish assemblages.

MATERIALS AND METHODS

> *STUDY AREA*

The Chishui River (27° 20′–28° 50′ N, 104° 45′–106° 51′ E) is the right tributary of the upper Yangtze River basin. It originates from the Wumeng Mountains in Yunnan province and flows for 437 km before joining the Yangtze River in Hejiang County of Sichuan Province, southwest of China. The river can be divided into three reaches as follows. The upstream reach with a length of 224.7 km extends from the source to Maotai Town in Guizhou Province. The midstream reach with a length of 158 km ranges from Maotai Town to Chishui City in Guizhou Province. Finally, the downstream reach extends from Chishui City to Hejiang County with a length of 54.3 km. The whole Chishui River was included in the study.

> *SAMPLING*

Thirty-one sites (13 in the upstream, 11 in the midstream and 7 in the downstream reaches, respectively) were sampled in an upstream direction with two electrofishing pass (by wading in shallow areas and from a boat in deeper areas) (Table I, Figure 1). Each sampling was conducted along about 200–500 m reach in the river and usually contain all kinds habitats

Table I
Locations and regional attributes of sampling sites in the Chishui River. Attribute: M means the site is located in the mainstream and T means the tributary of the Chishui River.

Tableau I
Localisation et attribut régional des sites échantillonnés dans la rivière Chishui. Attribut : M = le site est sur le cours principal et T = le site est sur un affluent de la rivière Chishui.

Site code	Site name	Latitude	Longitude	Altitude (m)	DM (km)	Attribute
1	YD	27°37′36"	105 °01′45"	1197	409.2	M
2	DH	27°46′36"	105°06′19"	990	378.3	T
3	PT	27°41′38"	105°17′57"	909	349.4	T
4	CY	27°47′35"	105°15′32"	855	368.9	T
5	XT	27°42′59"	105°18′46"	913	346.4	M
6	SL	27°45′11"	105°21′39"	672	339.2	M
7	XJ	27°44′53"	105°32′16"	602	315.3	M
8	DX	27°45′32"	105°32′08"	635	316.4	T
9	CZ	27°43′25"	105°35′01"	597	308.6	M
10	WT	27°43′21"	105°46′35"	515	279.4	M
11	SS	27°54′32"	105°42′41"	1008	304.1	T
12	QC	27°40′10"	105°55′23"	522	268.7	T
13	JC	27°46′50"	106°03′45"	485	244.1	M
14	MT	27°50′24"	106°21′10"	403	209.8	M
15	HM	28°12′25"	106°18′53"	382	180.1	M
16	EL	28°10′22"	106°25′03"	312	160.0	T
17	LH	28°08′52"	106°10′39"	393	166.4	M
18	YA	28°03′58"	105°54′40"	482	188.7	T
19	TC	28°16′44"	105°59′33"	276	120.9	M
20	YH	28°22′05"	105°55′53"	262	108.0	M
21	HS	28°27′18"	105°57′58"	246	95.5	M
22	BA	28°28′26"	105°49′13"	229	78.5	M
23	FX	28°31′01"	105°44′20"	220	68.2	T
24	DT	28°30′41"	105°40′44"	223	63.5	M
25	CS	28°34′33"	105°41′16"	219	54.5	M
26	CW	28°39′39"	105°45′13"	211	39.4	M
27	XS	28°42′55"	105°43′21"	206	27.8	M
28	MX	28°47′11"	105°46′35"	209	14.4	M
29	HK	28°48′10"	105°50′39"	198	0.0	M
30	GD	28°33′18"	106°05′04"	259	66.1	T
31	CH	28°41′23"	105°59′10"	220	46.9	T

(riffles, runs and pools). All sampled fishes were fixed in buffered formaldehyde (7%) and transported to the laboratory for counting and taxonomic determination (Wu, 1989; Chen, 1998; Chu *et al*., 1999; Yue, 2000). Fish data were expressed in a matrix as species abundance per hour by site.

Sixteen environmental factors were examined on each sampling site. Water temperature (WT, °C), dissolved oxygen (DO, $mg \cdot L^{-1}$), pH and conductivity ($\mu S \cdot cm^{-1}$) were recorded by a multi-parametric probe (WTW Multi 340i). Altitude (m) was recorded by an altimeter (Garmin GPS-76). Current velocity (CV, $m \cdot s^{-1}$) was measured using a flow-meter (LJD-10). Average water depth (WD, m) was calculated using a depth sounder (S48-1X). Average channel width (CW, m) was calculated by Leica CRF900. Substratum was divided into four types as sand, silt, cobble and boulder. The proportion (%) of each type was visually estimated. Distance from mouth (DM, km) was obtained from a digitized 1:50 000 scale map. Average annual data of rainfall (AR, mm), temperature (AT, °C) and sunlight (AS, hours) were gathered from the weather station nearby.

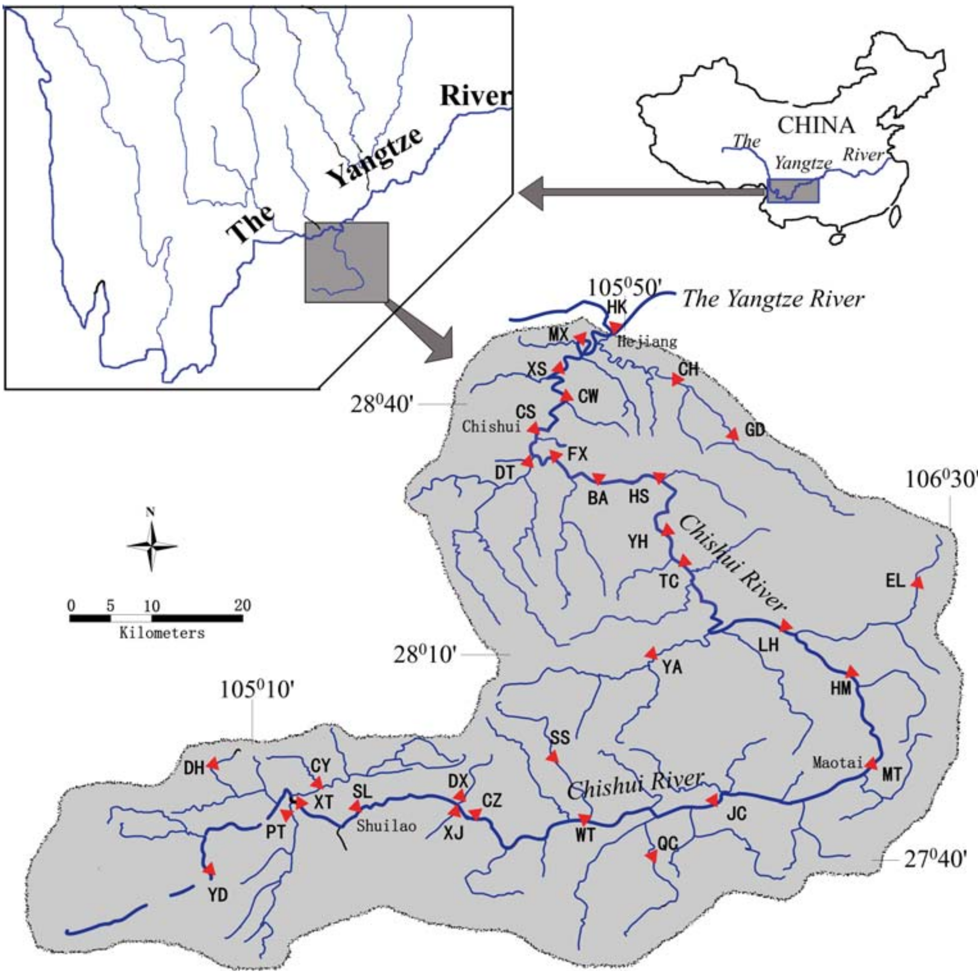

Figure 1
Sketch of 31 sampling sites (red triangles) in the Chishui River and its branch (blue line).

Figure 1
Localisation des 31 sites échantillonnés (triangles rouges) dans la rivière Chishui et ses affluents (ligne bleue).

> *DATA ANALYSIS*

Environmental and biological differences among the three reaches were tested using one-way analyses of variance (ANOVAs). These comparisons were carried out with Tukey's honestly significant difference (HSD) *post hoc* tests. In cases of persistent heteroscedasticity (results of Levene's test significant), we performed Games–Howell tests which do not assume equal variances between groups. All ANOVAs were made using SPSS statistical programs (version 13.0).

Canonical correspondence analysis (CCA) with Hill's scaling on inter-species distances was used to display the relationship between fish assemblage structure and the 16 environmental variables. According to the preliminary CCA, collinear environmental variables with high variance inflation factors (VIF > 20) were eliminated from further analyses. Stepwise forward selection with Monte Carlo test (999 permutations, $P < 0.05$) was used to select a minimum set of environmental variables that had significant and independent effects on fish distribution. Monte Carlo test (999 permutations, $P < 0.05$) was also used to determine the significance of each analysis under the null hypothesis that no relationship between fish and environmental variables existed. Two tests were performed: one based on the first CCA ordination axis and the other based on all canonical axes together.

Fish data were logarithmically transformed ($\log_{10}(x + 1)$), environmental variables that did not meet the normality assumption (Shapiro-Wilk test, $P < 0.05$) were transformed using natural logarithms. CCA analyses were performed using the software CANOCO for Windows 4.5 version (ter Braak and Smilauer, 2002).

RESULTS

> FISH ASSEMBLAGES

A total of 62 fish species, representing 52 genera, 8 families and 3 orders, were collected during the study period. Eighteen of them were endemic to the upper Yangtze River basin. Cypriniforms had the largest number of species (49 species), followed by Siluriforms (11 species) and Perciforms (2 species) (Table II). Cyprinidae was the most dominant family in species number, accounting for 66.1% of all species. *Squalidus argentatus, Zacco platypus*, *Pseudobagrus truncates, Spinibarbus sinensis, Opsariichthys bidens* and *Hemibarbus maculatus* were the most abundant species, accounting for 27.7% of all individuals captured during the sampling period. As shown in Table III, 5 species were common (occurrence $>$ 75%), 34 species were at a moderate common level (occurrence between 25% and 75%) and 23 species were scarce (occurrence $<$ 25%). Eight species occurred exclusively in the upstream reach, 1 in the midstream reach and 10 in the downstream reach, respectively. The downstream reach had the highest species richness and diversity per site (31 species, 4.29 bit), followed by the midstream reach (25 species, 4.06 bit) and the upstream reach (19 species, 3.52 bit). However, there were no significant differences in abundance among the three reaches (Table III).

> ENVIRONMENTAL GRADIENTS

As shown in Table IV, environmental variables of the Chishui River displayed large variance along the upstream-downstream gradient. Altitude, channel width, water depth and distance from mouth varied significantly for the three reaches. Channel width and water depth increased with the decreasing altitude and distance from mouth. Water temperature in the upper reaches was relatively low (below 20 °C) and increased in a downstream direction, as well as conductivity. Dissolved oxygen was about 8 $mg \cdot L^{-1}$ in the whole river and peaked in the midstream reach. The water pH was slightly alkaline and showed no significantly difference among the three reaches. The proportion of substratum types differed among three reaches. The upper sites were dominated by cobble and sand, with less than 10% silt. The midstream reach had the highest boulder percentages and moderate sand. Silt significantly increased in a downstream direction. The climate of Chishui basin was warm and humid, meteorological factor except for annual temperature exhibited no significant difference among the three reaches.

> ENVIRONMENTAL INFLUENCES ON FISH DISTRIBUTION

The large variance inflation factors (VIF $>$ 20) of the preliminary CCA suggested redundancy among cobble, silt and water depth, and these variables were subsequently excluded from the environmental data set. The forward selection procedure showed that altitude, conductivity, dissolved oxygen, channel width and current velocity were the environmental variables that accounted for significant ($P < 0.05$) portions of the total variance in fish species composition. CCA with these five environmental variables produced an ordination in which all canonical axes were significant ($P = 0.001$). The eigenvalues for the first two axes were

Table II
Lists of 62 species, showing fish fauna and species code. Asterisks denote endemic species.

Tableau II
Liste des 62 espèces et codes des espèces. L'astérisque marque les espèces endémiques.

Species name	Species code
Cypriniforms	
Cyprinidae	
***Zacco platypus* (Temminck *et* Schlegel)**	Z.pla
***Opsariichthys bidens* Günther**	O.bid
***Ctenopharyngodon idellus* (Cuvier *et* Valenciennes)**	C.ide
***Squaliobarbus curriculus* (Richardson)**	S.cur
***Pseudolaubuca sinensis* Bleeker**	P.sin
Sinibrama taeniatus* (Nichols)	S.tae
Ancherythroculter kurematsui* (Kimura)	A.kur
Ancherythroculter nigrocauda* Yih *et* Woo	A.nig
Hemiculterella sauvagei* Warpachowski	H.sau
***Hemiculter leucisculus* (Basilewsky)**	H.leu
Hemiculter tchangi* Fang	H.tch
***Cultrichthys erythropterus* (Basilewsky)**	C.ery
***Culter alburnus* Basilewsky**	C.alb
***Culter mongolicus* (Basilewsky)**	C.mon
***Xenocypris davidi* Bleeker**	X.dav
***Pseudobrama simoni* (Bleeker)**	P.sim
***Hypophthalmichthys molitrix* (Cuvier *et* Valenciennes)**	H.mol
***Hemibarbus labeo* (Pallas)**	H.lab
***Hemibarbus maculatus* Bleeker**	H.mac
***Pseudorasbora parva* (Temminck *et* Schlegel)**	P.par
***Sarcocheilichthys nigripinnis* (Günther)**	S.nig
***Squalidus argentatus* (Sauvage *et* Dabry)**	S.arg
***Rhinogobio typus* Bleeker**	R.typ
***Abbottina rivularis* (Basilewsky)**	A.riv
***Saurogobio dabryi* Bleeker**	S.dab
***Gobiobotia filifer* (Garman)**	G.fil
***Rhodeus ocellatus* (Kner)**	R.oce
***Spinibarbus sinensis* (Bleeker)**	S.sin
Percocypris pingi* (Tchang)	P.pin
Acrossocheilus monticolus* (Günther)	A.mon
***Acrossocheilus yunnanensis* (Regan)**	A.yun
***Onychostoma sima* (Sauvage *et* Dabry)**	O.sim
Bangana rendahli* (Kimura)	B.ren
***Pseudogyrinocheilus procheilus* (Sauvage *et* Dabry)**	P.pro
Sinocrossocheilus labiata* Su,Yang *et* Cui	S.lab
***Garra pingi* (Tchang)**	G.pin
Schizothorax grahami* (Regan)	S.gra
Schizothorax kozlovi* Nikolsky	S.koz
Procypris rabaudi* (Tchang)	P.rab
***Cyprinus carpio* Linnaeus**	C.car
***Carassius auratus* (Linnaeus)**	C.aur
Cobitidae	
***Paracobitis variegatus* (Sauvage *et* Dabry)**	P.var
Paracobitis wujiangensis* Ding *et* Deng	P.wuj
Oreias dabryi* Sauvage	O.dab
Leptobotia elongata* (Bleeker)	L.elo
***Misgurnus anguillicaudatus* (Cantor)**	M.ang
Homalopteridae	
***Lepturichthys fimbriata* (Günther)**	L.fim
Sinogastromyzon sichangensis* Chang	S.sic
Sinogastromyzon szechuanensis* Fang	S.sze

Table II
Continued.

Tableau II
Suite.

Species name	Species code
Siluriforms	
Bagridae	
Pelteobagrus vachelli **(Richardson)**	P.vac
Pelteobagrus nitidus **(Sauvage *et* Dabry)**	P.nit
Leiocassis crassilabris **Günther**	L.cra
Pseudobagrus truncatus **(Regan)**	P.tru
Pseudobagrus emarginatus **(Regan)**	P.ema
Pseudobagrus pratti **(Günther)**	P.pra
Mystus macropterus **(Bleeker)**	M.mac
Siluridae	
Silurus asotus **Linnaeus**	S.aso
Silurus meridionalis **Chen**	S.mer
Sisoridae	
Glyptothorax fokiensis **(Rendahl)**	G.fok
Euchiloglanis davidi **(Sauvage)***	E.dav
Perciforms	
Serranidae	
Siniperca chuatsi **(Basilewsky)**	S.chu
Gobiidae	
Rhinogobius giurinus **(Rutter)**	R.giu

0.536 and 0.206, respectively. The species-environment correlations for the first two axes were 0.942 and 0.940, respectively. The first two axes accounted for 79.6% of the total variation explained by the environmental variables, of which 57.5% was contributed by the first axis and another 22.1% by the second. The intraset correlations between the environmental variables were examined to find out those variables most correlated with each of the axes. The first axis was correlated with altitude (0.94) and channel width (0.65). The second axis was most correlated with conductivity (–0.80), current velocity (–0.75) and dissolved oxygen (–0.63).

The CCA produced two biplots which showed the relationships between species, sites and environmental variables. From the site-environment biplot (Figure 2), all upstream sites had positive scores on axis 1 and clustered on the right half of the plot. Most sites in the midstream reach, except YA and MT, were clustered on the third quarter of the plot, with negative scores on axis 1 and axis 2. All sites in the lower reaches (except XS) were clustered in the second quarter of the plot. Three groups of species were discriminated by their location along the environmental gradient (Figure 3). The first group (*e.g.*, *Euchiloglanis davidi*, *Oreias dabryi*, *Schizothorax grahami*, *Schizothorax kozlovi* and *Acrossocheilus yunnanensis*) with positive scores on axis 1 was representative of upstream areas. These species were associated with high altitude and narrow channel. The second group, with negative scores on axis 1 and axis 2, was constituted by species like *Bangana rendahli*. This group was abundant in the midstream reach with rapid flow, high conductivity and dissolved oxygen. The third group (*e.g.*, *Pseudobrama simoni*, *Pseudorasbora parva*, *Sarcocheilichthys nigripinnis*, *Rhodeus ocellatus* and *Silurus meridionalis*) with negative scores on axis 1 and positive scores on axis 2 was representative of the downstream reach. This group was mainly related to wide channel, low altitude and low conductance.

DISCUSSION

> *FISH-HABITAT RELATIONSHIPS*

Significant relationships between environmental variables and fish assemblages were found in the Chishui River. Altitude was positively correlated with the first CCA axis and explained

Table III
Species occurrences for each sampling sites, superscript number indicates the species exclusively occurred in one reach (1, 2 and 3 represent upstream, midstream and downstream reaches, respectively). %RA *means relatively abundance for each species and* SR *means species richness for each sampling sites. See Table I for species and site code.*

Tableau III
Occurrence des espèces pour chaque site échantillonné, les nombres en exposant indiquent les espèces présentes dans un seul bief (1, 2 et 3 représentent les biefs amont, médian et aval, respectivement). %RA = abondance relative de chaque espèce et SR = richesse spécifique à chaque site.

Species	Occurrence																																%RA
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Sum	
Z.pla		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	30	5.76
O.bid		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	30	5.01
C.ide																				*	*	*			*				*	*		6	0.23
S.cur[3]																											*	*	*			3	0.06
P.sin																				*	*	*	*	*	*	*	*	*	*	*		11	1.2
S.tae																				*			*				*		*	*	*	6	0.25
A.kur																				*	*	*	*	*	*	*	*	*	*	*		11	0.97
A.nig[3]																												*	*			2	0.18
H.sau							*		*				*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	20	4.08
H.leu[3]																												*	*			2	0.21
H.tch																								*	*	*	*	*	*		*	7	1.24
C.ery[3]																									*			*	*			3	0.06
C.alb																				*	*		*	*		*	*	*	*	*		9	0.4
C.mon																		*	*	*	*	*	*	*	*	*	*	*	*	*	*	14	1.73
X.dav[3]																												*	*			2	0.52
P.sim[3]																												*	*	*	*	4	0.83
H.mol[3]																									*	*		*	*			4	0.11
H.lab						*	*	*	*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*			23	2.08
H.mac							*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	25	4.66

Table III
Continued.

Tableau III
Suite.

Species	Occurrence																															%RA
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Sum	
P.par		*					*																					*	*	*		5	0.25
S.nig[3]																												*	*			2	0.14
S.arg										*				*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	19	5.84
R.typ													*	*	*	*			*	*	*	*	*	*	*	*	*	*	*	*		16	3.94
A.riv													*			*														*		3	0.09
S.dab							*						*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	19	4.34
G.fil																				*							*					2	0.06
R.oce[3]																									*	*	*	*	*	*	*	7	1.09
S.sin					*	*	*		*	*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*	*	25	5.38
P.pin[1]		*	*	*		*						*																				5	0.14
A.mon													*	*	*	*		*	*	*	*	*	*	*	*		*	*			*	15	1.12
A.yun	*	*	*	*	*	*	*	*	*	*	*	*								*												13	3.46
O.sim		*	*	*	*	*	*	*	*	*	*	*	*	*	*				*	*	*	*	*	*	*	*	*	*				24	2.30
B.ren[2]																			*		*											2	0.06
P.pro	*	*	*	*	*	*	*	*	*	*	*	*	*		*	*		*	*													17	2.30
S.lab[1]	*			*		*						*																				4	0.38
G.pin		*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*						*	*			*					19	2.15
S.gra[1]	*	*	*	*	*	*	*	*	*	*		*																				11	1.20
S.koz[1]	*	*	*	*	*	*	*																									7	1.10
P.rab																				*	*	*	*	*	*	*	*	*	*			10	0.61
C.car											*		*	*	*			*		*	*	*	*	*	*	*	*	*	*	*	*	17	1.44
C.aur											*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	21	2.30
P.var[1]	*	*	*	*	*	*	*	*	*	*		*																				11	1.67
P.wuj							*											*												*		3	0.51

Table III
Continued.

Tableau III
Suite.

Species	Occurrence																															%RA
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Sum	
O.dab[1]	*	*	*	*	*	*																										6	1.69
L.elo			*	*		*			*	*			*	*	*				*	*							*					11	0.29
M.ang	*	*	*	*	*	*	*	*	*	*	*	*		*		*			*				*							*	*	18	1.62
L.fim			*	*									*	*								*					*		*			7	0.35
S.sic		*	*	*	*	*	*	*	*	*	*	*	*																			12	3.20
S.sze													*	*	*					*	*	*		*	*	*			*			10	0.58
P.vac										*	*	*	*	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*		20	2.77
P.nit										*	*		*			*			*	*	*	*	*	*	*	*	*	*	*	*	*	17	1.87
L.cra						*	*	*	*	*	*	*	*	*			*			*	*	*	*	*	*	*	*	*	*		*	21	1.92
P.tru					*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	27	5.72
P.ema													*		*	*	*	*	*	*					*	*	*	*				11	1.47
P.pra					*	*	*	*		*		*	*		*	*			*	*												11	0.38
M.mac										*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*			*	*	20	3.39
S.aso							*			*			*						*	*	*	*	*	*			*	*		*		12	0.54
S.mer[3]																											*			*		2	0.03
G.fok						*					*		*		*	*		*														6	0.20
E.dav[1]	*	*	*	*	*																											5	0.41
S.chu									*			*	*	*	*	*				*	*	*	*	*			*	*	*	*		15	1.90
R.giu																	*			*			*				*	*	*	*		7	0.25
SR	9	15	16	17	16	21	22	15	18	22	19	22	29	23	24	23	16	15	24	34	28	27	29	28	29	27	36	37	37	30	20		

Table IV
Mean values and standard errors of the environmental and biological variables. Asterisks showing significant difference among reaches in ANOVA (P < 0.05).

Tableau IV
Valeur moyenne et erreur standard des variables environnementales et biologiques. Les astérisques signalent les différences significatives entre biefs dans une ANOVA ($P < 0{,}05$).

	Upstream	Midstream	Downstream	*F*-ratio	*P*-value
Environmental data					
Altitude (m)*	735.9 ± 239.6	302.5 ± 88.7	217.4 ± 19.8	29.30	0.000
Water temperature (°C)*	15.4 ± 2.9	21.9 ± 2.4	23.2 ± 1.7	31.00	0.000
Conductivity ($\mu S \cdot cm^{-1}$)*	365.5 ± 28.6	383.4 ± 26.1	290.4 ± 38.4	21.19	0.000
Dissolved oxygen ($mg \cdot L^{-1}$)*	8.20 ± 0.26	8.66 ± 0.29	7.67 ± 0.94	13.23	0.000
pH	8.13 ± 0.46	7.77 ± 0.28	8.07 ± 0.24	2.93	0.070
Channel width (m)*	34.7 ± 14.5	44.3 ± 18.0	121.7 ± 35.7	39.88	0.000
Current velocity ($m \cdot s^{-1}$)*	0.91 ± 0.32	1.53 ± 0.28	0.79 ± 0.44	12.84	0.000
Water depth (m)*	0.7 ± 0.4	2.6 ± 1.2	4.8 ± 2.6	19.83	0.000
Boulder (%)*	15.2 ± 13.2	37.0 ± 6.7	7.1 ± 3.9	48.15	0.000
Cobble (%)*	42.9 ± 9.2	33.5 ± 8.2	20.7 ± 18.4	8.68	0.001
Sand (%)*	34.6 ± 6.6	33.5 ± 7.8	20.0 ± 8.2	10.05	0.001
Silt (%)*	8.2 ± 6.1	20.5 ± 6.9	35.7 ± 20.5	14.68	0.000
Distance from mouth (km)*	317.0 ± 54.2	123.0 ± 47.5	35.6 ± 23.1	99.29	0.000
Annual temperature (°C)*	15.1 ± 2.6	17.0 ± 1.9	17.9 ± 0.2	4.84	0.016
Annual rainfall (mm)	1085.8 ± 104.7	1157.2 ± 141.0	1104.6 ± 71.7	1.69	0.203
Annual sunlight (hours)	1154.1 ± 174.1	1227.0 ± 99.6	1214.0 ± 37.0	1.02	0.375
Biological data					
Species richness*	19 ± 5	25 ± 6	31 ± 6	11.54	0.000
Abundance ($ind \cdot h^{-1}$)	190 ± 58	218 ± 63	240 ± 92	1.32	0.283
Shannon-Wiener Index (bit)*	3.52 ± 0.53	4.06 ± 0.33	4.29 ± 0.34	8.93	0.001

significant directions of variance in species distributions. This result is similar to the one obtained by Edds (1993) who also noticed that altitude was the most important factor contributing to variation in fish assemblage in the Gandaki River. In the Chishui River, Schizothoracinae and Nemachilinae species which mainly appeared in the upper reaches at an altitude of 1000–1500 m are adapted to harsh environment of cold water and energy availability. On the other hand, some Cultrinae and Gobioninae species had a significant negative correlation with altitude and were mainly present in the lower sites. Hocutt and Stauffer (1975) suggested that species richness increases with both channel width and water depth. Large width and deep water lead to environmental stability and allow vertical and horizontal separation of microhabitat for fish species (Matthews, 1998). This phenomenon was in accordance with our findings. The downstream reach, characterized by wide channel and deep pools, was rich in phyto- and zooplanktonic community. Because of the increase in living space, habitat and food diversity, the number of fish species increased along an upstream-downstream gradient. Current velocity was another significant variable affecting the spatial pattern of fish species, which was negatively correlated with the second CCA axis. It turned out to be highest in the middle reaches, where the lotic species such as *Bangana rendahli* were typically abundant. In contrast, *Culter mongolicus* and *Squalidus argentatus* were abundant in the lower reaches, these lentic species commonly appear in lakes, ponds, pools and backwaters of large rivers in China (Chen, 1998). In addition, conductivity and dissolved oxygen survived in the forward selection procedure and acted as surrogates for axis 2, these two factors were also observed and influenced the fish communities in a tropical river (Araujo *et al.*, 2009). However, other expected factors such as substratum types and the meteorological factors were not significant in CCA, the former were due to their redundancy with altitude and were excluded by the variable selection procedure; the latter may be because the study area was relatively small that annual rainfall and sunlight exhibited no significant difference among the three reaches.

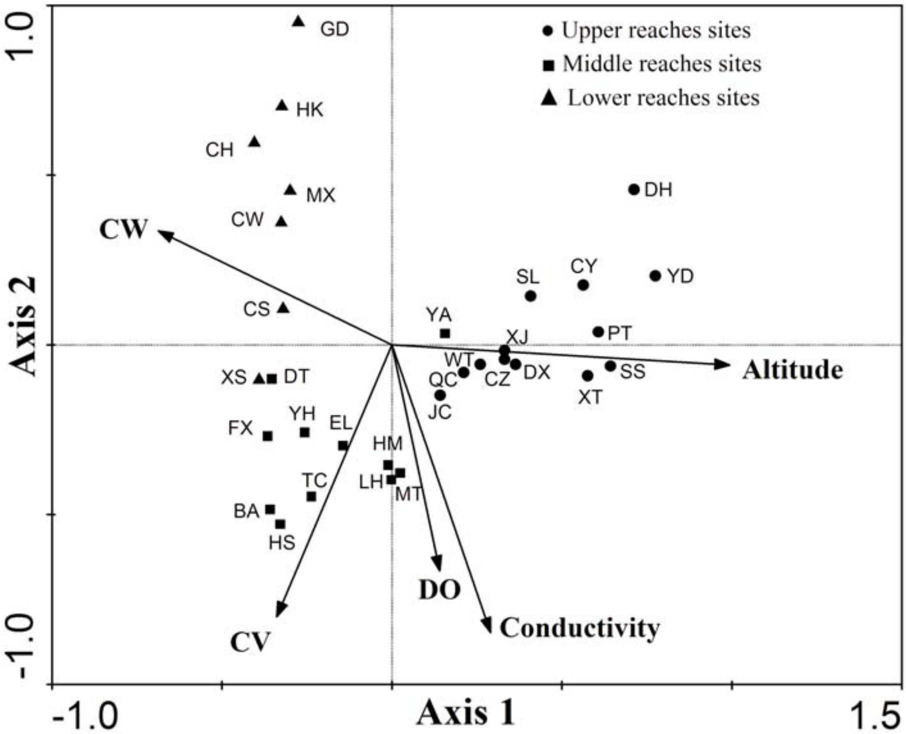

Figure 2
Canonical correspondence analysis ordination plots showing relationship between the distribution of sample sites and main environmental variables.

Figure 2
Graphique d'analyse canonique des correspondances montrant les relations entre la répartition des sites échantillonnés et les principales variables environnementales.

> CONSERVATION IMPLICATIONS

Our study showed that species composition varied significantly among the three reaches, thus, customized conservation strategies should be developed for different reaches.

The upstream reach is clearly discriminated from other reaches by the abundance of stenochoric species. High declivity affects fish movements, preventing recolonization of headwaters by species from lower reaches. Therefore, the upper reaches should be considered as an independent conservation unit to protect stenochoric species. These species adapted to low temperature and poor energy availability, typically exhibit slow growth, late maturity, and low fecundity. Thus, they are particularly vulnerable to fishing. Therefore, additional protection must be quickly made to protect this zone against fishing.

Although the midstream reach has moderate species richness and fewer narrow-distribution species, this zone is essential for fish spawning. Wu *et al*. (2010) reported that at least 34 species with different spawning strategies laid eggs throughout this region; some species laid drifting eggs in the middle channel while others produced adhesive eggs in backwater area near the bank. Unfortunately, this area is an important waterway route and suffers frequent channel regulations. Broadening and deepening the channel considerably homogenize the river form and slower water flow which will impact negatively the spawning habitats. Gravel mining which eliminates spawning areas for fish is another problem. Thus, more attention needs to be paid to canalization plans and gravel mining in this zone.

The downstream of the Chishui River supports the highest species richness. The fish composition in this area is similar to the contiguous mainstream of the Yangtze River; all species of this downstream reach also appear in the mainstream of the Yangtze River (Ding, 1994).

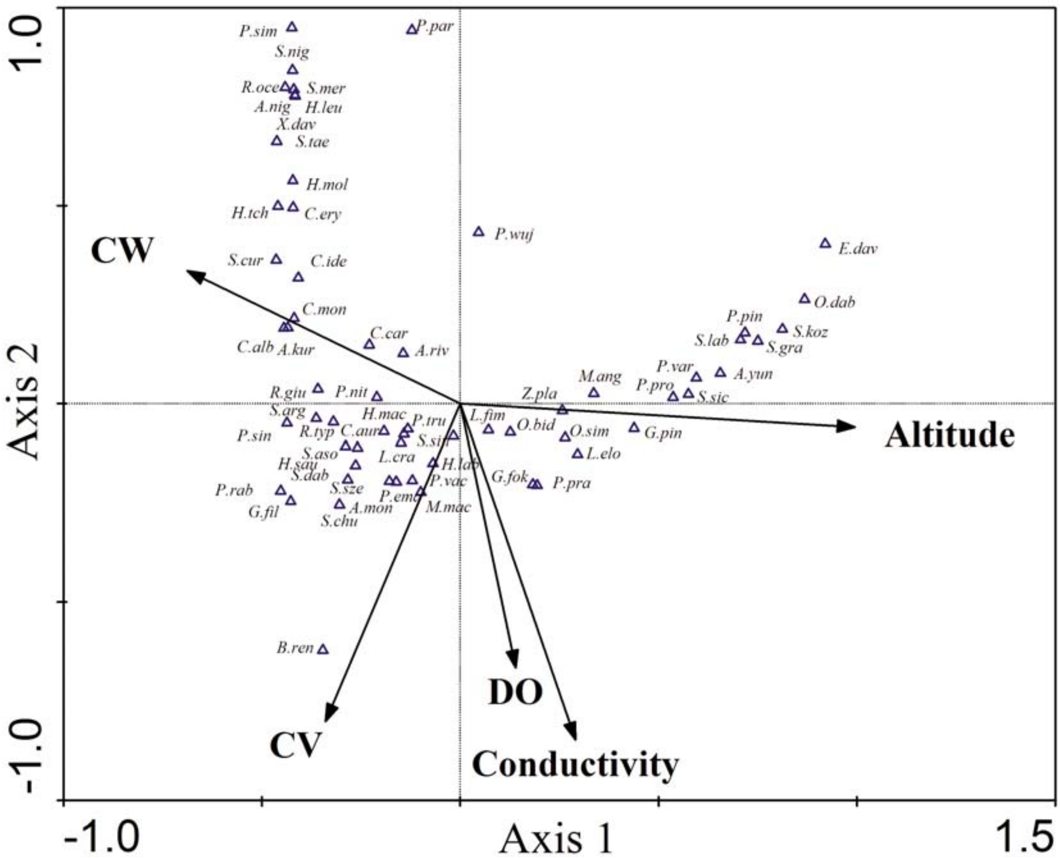

Figure 3
Species distribution in relation to significant environmental variables (see Table II for species code).

Figure 3
Distribution des espèces en relation avec les variables environnementales significatives (voir tableau II pour les codes d'espèce).

This zone can thus be considered as an important corridor for fish between the Chishui River and the Yangtze River.

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