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Current status and diversity of fish resources in the Pinglu Canal Century Project

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Abstract: [Objective] The channel straightening project of the Pinglu Canal has fragmented the river course, compromising the integrity of original river course and causing ecosystem patchiness. Understanding the current status of fish resources and the characteristics of their diversity is crucial for the ecological management of the Pinglu Canal. [Methods] During the spring and autumn in 2021 and 2022, a survey of fish resources and species diversity in the Pinglu Canal was conducted using multi-mesh gill nets. A total of 125 fish species were collected, belonging to 10 orders, 34 families, and 89 genera. [Results] The result showed that the Pinglu Canal contained three nationally protected Class II species, two endemic species of the Qinjiang River, three anadromous/migratory species, and eight invasive species, accounting for 2.4%, 1.6%, 2.4%, and 6.4% of the total species, respectively. The fish community primarily consisted of mid-and bottom-dwelling, adhesive-egg-laying, and omnivorous species. The Shannon-Wiener, Simpson, Margalef, and Pielou indices of the fish community in the Pinglu Canal ranged from 2.347 to 2.757, 0.081 to 0.151, 3.493 to 4.382, and 0.812 to 0.892, respectively. These indices showed relatively uniform distribution across different river reaches. [Conclusion] The result indicate that the fish community structure in the Pinglu Canal is relatively uniform. The reach from the Yujiang River to the Shaping River shows higher stability, while other river reaches experience moderate or severe disturbances. This study provides supplementary baseline data on the fish community structure in the Pinglu Canal and explores the potential impact of inter-basin connectivity on fish resources, aiming to provide a scientific basis for habitat restoration assessments after the channel straightening project.

Keywords: Pinglu Canal Project; inter-basin connectivity; fish resources; community structure; biodiversity; influencing factors

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平陆运河世纪工程鱼类资源现状及多样性研究

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摘　要：【目的】平陆运河裁弯取直工程对河道形成切割效应，破坏了原有河道的完整性，使河道生态系统景观斑块化，了解鱼类资源状况及多样性特征对平陆运河的生态治理至关重要。【方法】2021—2022 年春季和秋季，采用多网目复合刺网调查的方式对平陆运河鱼类资源和物种多样性展开调查。渔获物调查共采集鱼类 125 种，隶属于 10 目 34 科 89 属。【结果】结果显示：平陆运河国家二级重点保护野生动物 3 种，钦江特有鱼类 2 种，江海洄游鱼类有 3 种，外来物种 8 种，分别占总种类数的 2.4%，1.6%，2.4%，6.4%，鱼类群落以中下层、产黏性卵、杂食性鱼类为主。平陆运河鱼类群落的 Shannon-Wiener 指数、Simpson 指数、Margalef 指数、Pielou 指数变化范围分别为 2.347～2.757、0.081～0.151、3.493～4.382、0.812～0.892，各指数在不同江段分布较为均匀。【结论】结果表明：平陆运河鱼类群落结构较为均匀，郁江江段至沙坪河江段鱼类群落结构稳定性相对较高，其余江段鱼类群落结构均受到中度干扰或严重干扰。为本研究补充了平陆运河鱼类群落结构的基础数据，探讨了水系连通后对鱼类资源可能造成的影响，以期为截弯取直后生境修复评估提供科学依据。

关键词：平陆运河工程；跨流域连通；鱼类资源；群落结构；生物多样性；影响因素

0　Introduction

The Pinglu Canal is a strategically significant waterway in Guangxi Province, beginning at the Pingtang estuary in Nanning and flowing along the Shaping River to Qinzhou. It acts as a vital connector between the Xijiang and Qinjiang River systems[1-2]. Its upstream section links to the Xijiang Shipping Line, facilitating navigation in multiple directions: westward to Nanjing via Yongjiang, eastward to Guangdong and Hong Kong via Yujiang, northward to Guizhou via Qianjiang, Hongshui River, or Liujiang, and southward to Qinzhou[3-7].

As part of the canal's development, 57 bend-straightening projects are planned, modifying 39.5% of the river's natural length[8]. While these changes improve navigability, they disrupt the river's continuity and fragment its ecosystem[9-10]. Construction activities further threaten aquatic life by burying and destroying habitats, causing significant mortality among aquatic organisms, with only a few survivors likely to endure[11].

Fish play a vital role in aquatic ecosystems, contributing to material cycling, energy flow, and information transfer, and they serve as key indicators of river health. Research on the status and diversity of riverine fish resources is a critical focus of ecological studies both locally and globally. The development of the Pinglu Canal is expected to have significant impacts on aquatic organisms due to activities such as river excavation, dredging, widening, terminal construction, material deposition, sediment disposal, and elevated water levels during operation. Surveys estimate that approximately 7, 138.05 tons of aquatic organisms will be lost during construction. Additionally, construction activities, including channel dredging, reef clearing, junction construction, and bank protection, are projected to adversely affect fish eggs and larvae, posing a serious threat to their survival[12].

The waterway extends approximately 135 kilometers and is divided into five sections: the Shaping River, the watershed, the Qinjiang River, Qinjiang entering

Haikou, and offshore entering Haikou. Due to construction techniques, cofferdam challenges, waste disposal requirements, and geological conditions, certain sections will require extensive dredging. This activity is expected to directly result in the loss of approximately 1 233.61 tons of fish and around 1.29 million fish larvae, with an estimated economic impact of 63 million yuan. Additionally, the alteration of the water system, including the closure of the former river in Qinjiang, may significantly disrupt the existing aquatic ecosystem. Such disruptions could affect the composition of aquatic organisms and reduce the genetic diversity of local indigenous fish species[13].

The construction of the Pinglu Canal has increased water volume, enhancing the river's dilution capacity and self-purification ability. These improvements provide essential conditions for effective watershed water environment management and support the development of a comprehensive ecological system. This system integrates soil and water conservation, water source protection, and ecological purification. Additionally, the canal's development contributes to environmental beautification, climate regulation, and the optimization of ecological conditions in the surrounding areas.

During the initial stages of the Pinglu Canal construction, limited understanding of the existing fishery resources and ecological conditions in the construction zones posed challenges. This knowledge gap hindered the availability of baseline data essential for evaluating the construction's ecological impacts. To address this issue, this study aims to comprehensively assess the status of fishery resources in the Pinglu Canal and identify habitat restoration needs following the straightening project. The analysis focuses on fish species composition, ecological types, population dominance, biodiversity, and community structure stability. Using diversity indices and abundance/biomass comparison (ABC) curves, the study evaluates data collected from environmental and fishery resource surveys conducted from 2021 to 2022. The findings contribute to the foundational understanding of fish communities in this river segment and provide a scientific basis for fishery resource management, biodiversity assessment, and critical habitat restoration.

1 Materials and Methods

1.1 Investigation Methods

The Pinglu Canal project, guided by the strategic construction plan of "connecting rivers to the sea, integrated planning, single-phase completion, and systematic operation," officially commenced on August 28, 2022. By the end of May 2024, the project had achieved a cumulative investment of 32.9 billion yuan, representing 45.2% of the total estimated budget. A total of 203 million cubic meters of excavation and earthworks had been completed, accounting for 63% of the planned volume[14]. The construction has progressed in a safe, efficient, and orderly manner.

The key components of the project include channel regulation, hub structures, and river-crossing constructions. The canal begins at the Pingtang River estuary, traverses the watershed, passes through Luwu Town, and flows southward along the Qinjiang River into the northern bay of Qinzhou Port. Along its route, it intersects ecologically sensitive areas, including the Xijin National Wetland Park in Hengxian, Guangxi, and designated drinking water source protection zones.

The impact assessment focuses on the aquatic ecological environment across three primary sections. From the Yujiang River estuary to the Shaping River, the Jiuzhou River section, and from Qinjiang Luwu to the Shanmu River. Historically, the fish fauna in this region has been classified into five complexes: tropical plain, river plain, Indo-Chinese mountain, Upper Tertiary, and northern plain fish complexes. Excluding eight introduced and three migratory species, the area supports 108 freshwater species, with the tropical plain and river plain complexes accounting for 82.4% of the total[15].

From 2021 to 2022, this study established six sampling sites along three river sections of the Pinglu Canal straightening project, designated as S1 to S6: S1 and S2 for the Yujiang River estuary to Shaping section, S3 and S4 for the Jiuzhoujiang section, and S5 and S6 for the Qinjiang Luwu to Shanmujiang section, as shown in Figure 1. Fish resource surveys were conducted biannually, in spring (April to June) and autumn (October to November). The survey methods followed the *Standards for Reservoir Fishery Resource Survey*

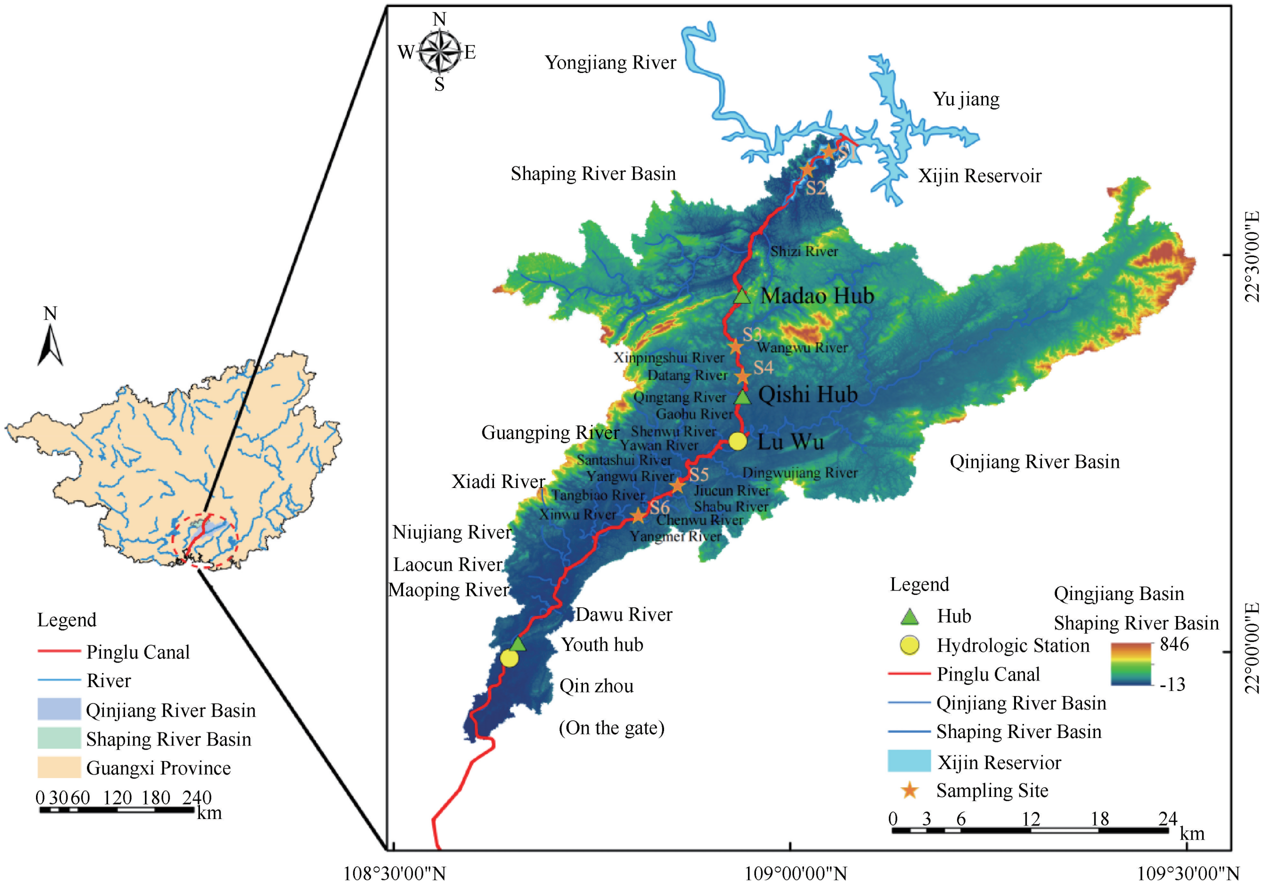

Fig. 1 Distribution of fish survey sites in Pinglu Canal

图 1 平陆运河鱼类调查站点分布

(SL 167-96) and the *Manual for Inland Water Resource Survey*.

At each survey site, fish samples were collected, and basic biological data—total length (mm), body length (mm), and weight (g)—were recorded before release. Specimens that died were preserved with records of the collection location, date, and vessel used. Unknown species were measured, fixed in 10% formalin, labeled with capture details, and taken to the laboratory for identification.

1.2 Data analysis

1.2.1 *Classification of Fish Ecological Types*

Based on historical data[16-17] and an analysis of fish characteristics in the survey area, such as habitat preferences, spawning types, and dietary habits—fish species were ecologically classified to better understand their roles within the Pinglu Canal ecosystem. Habitat preferences were grouped into three categories: species inhabiting the upper and middle water column, those occupying the middle and lower water column, and bottom-dwelling species that live and feed near the substrate. Spawning types included pelagic eggs, which float freely in the water; drifting eggs, carried by currents; weakly adhesive and adhesive eggs, which attach to substrates with varying strength; strongly adhesive eggs, firmly attached to surfaces; and demersal eggs, which sink and develop on the bottom. Dietary habits were classified into herbivorous fish, which feed primarily on plant material; filter-feeding fish, which extract small organisms or particles from water; omnivorous fish, which consume both plant and animal matter; and carnivorous fish, which primarily prey on other animals.

This ecological classification provides a structured framework for understanding fish species interactions and roles within the Pinglu Canal. It also aids in assessing construction impacts and supports the development of targeted habitat restoration and fishery management strategies.

1.2.2 *Analysis of Dominant Species in the Community*

Based on the analysis of the percentage by weight and percentage by number of fish catches, the relative importance index (*IRI*) was used to determine the community membership types of species[18-21]: Dominant species, $IRI \geq 1\,000$; Subdominant species, $100 \leq IRI < 1\,000$; Companion species, $10 \leq IRI < 100$; Occasional species, $IRI < 10$. The formula for calculating *IRI* is as follows.

$$IRI = (N + W) \times F \times 10^4 \quad (1)$$

$$F = \frac{C}{Y} \quad (2)$$

In the formula, N is the percentage of individuals (proportion of total catch by number for each fish species); W is the percentage of weight (proportion of total catch weight contributed by each fish species); F is frequency (frequency of occurrence of a species per sampling effort); Y is the number of fishing surveys conducted; C is the count (number of times the species appears in the catch).

1.2.3 *Conservation Targets and Classification of Conservation Status*

Referring to data from sources such as *the China Red List of Endangered Animals*[22] and *China Biodiversity Red List*[23], the fish conservation targets in the survey area were compiled, and their conservation and endangerment statuses were classified.

1.2.4 *Conservation Targets and Classification of Conservation Status*

The diversity analysis in this study utilized the Shannon-Wiener Index[24], Simpson Index[25], Margalef Index[26], and Pielou Index[27] to analyze the biodiversity indices of fish in the Pinglu Canal. The formulas for each index are as follows.

(1) Shannon-Wiener Index

$$H = -\sum_{i=1}^{S} P_i \ln P_i \quad (3)$$

(2) Simpson Index

$$D = 1 - \sum_{i=1}^{S} P_i^2 \quad (4)$$

(3) Margalef Index

$$d = \frac{S - 1}{\ln N} \quad (5)$$

(4) Pielou Index

$$J = \frac{H}{\ln S} \quad (6)$$

In the formula, $P_i = n_i/N$, n_i is the number of individuals of species i; N is the total number of all types; S is the number of species; H is the Shannon-Wiener Index.

1.2.5 *Analysis of Community Structure Stability*

The community structure stability analysis was conducted using the abundance biomass comparison (ABC) curve method proposed by Warwick[28]. This method was applied to evaluate the stability of fish community structures at various survey stations. The W statistic is used as a measure derived from the ABC curve. The formula for calculating the W statistic is as follows.

$$W = \frac{\sum_{i=1}^{S}(B_i - A_i)}{[50(S-1)]} \quad (7)$$

In the formula, S is the number of species, B_i and A_i are the cumulative percentage of biomass and quantity corresponding to the number of species in the curve, respectively.

This method analyzes the stability of the community structure by evaluating the W statistic and comparing the distribution of the biomass dominance curve and the abundance dominance curve within the same coordinate system. The interpretation is as follows: When the fish community is in a stable state, the W value is positive, and the biomass dominance curve lies above the abundance dominance curve. When the fish community is moderately disturbed, the W value approaches zero, and the two curves are close to each other or intersect. When the fish community is severely disturbed, the W value is negative, and the biomass dominance curve lies below the abundance dominance curve[29].

2 Results

2.1 Fish Composition, Ecological Type, Dominant Species and Conservation Grade

2.1.1 *Fish Species Composition*

During the survey, 507 fish were collected, weighing a total of 949.86 kg and representing 125 species across 10 orders, 34 families, and 89 genera, as shown in Table 1. Cypriniformes was the most diverse order, with 78 species (62.4%), followed by Perciformes with 21 species (16.8%), Siluriformes with 14 species (11.2%), and Characiformes with one

Table 1 Fish species, distribution, and ecological types in Pinglu Canal

表 1 平陆运河鱼类的种类、分布和生态类型

Order	Family	Genus	Species	Ecological Type		
				Location	Spawning Type	Food Type
Anguilliformes	Anguillidae	Anguilla	*Anguilla japonica*	B	P	C
			Anguilla marmorata	B	P	C
Clupeiformes	Clupeidae	Hemiculter	*Clupanodon thrissa*	U	P	F
			Konosirus punctatus	U	P	O
	Engraulidae	Coilia	*Coilia grayi*	U	V	C
Salmoniformes	Salangidae	Salanx	*Leucosoma chinensis*	U	D	C
			Salanx cuvieri	U	D	C
Characiformes	Characidae	Colossoma	*Colossoma brachypomum*	L	P	O
Cypriniformes	Cobitidae	Cobitis	*Cobitis sinensis*	B	D	O
			Cobitis arenae	B	V	O
		Schistura	*Schistura fasciolatus*	B	V	O
		Misgurnus	*Misgurnus anguillicaudatus*	B	V	O
		Micronemacheilus	*Micronemacheilus pulcher*	B	V	O
	Botiidae	Botia	*Botia robusta*	B	S-P	O
			Botia pulchra	B	S-P	O
		Parabotia	*Parabotia fasciata Dabry*	B	S-P	O
	Cyprinidae	Zacco	*Zacco platypus*	U	D	O
		Opsariichthys	*Opsariichthys bidens*	U	D	C
		Nicholsicypris	*Nicholsicypris normalis*	B	V	O
		Rasbora	*Rasbora steineri*	B	V	O
		Mylopharyngodon	*Mylopharyngodon piceus*	L	S-P	C
		Luciobrama	*Luciobrama macrocephalus*	U	S-P	C
		Ctenopharyngodon	*Ctenopharyngodon idella*	L	S-P	H
		Squaliobarbus	*Squaliobarbus curriculus*	U	D	O
		Ochetobius	*Ochetobius elongatus*	U	S-P	O
		Elopichthys	*Elopichthys bambusa*	U	S-P	C
		Rasborinus	*Rasborinus lineatus*	U	V	H
			Rasborinus formosae	U	V	O
		Sinibrama	*Sinibrama macrops*	B	V	O
			Sinibrama melrosei	B	V	O
		Pogobrama	*Pogobrama barbatula*	B	V	O
		Ancherythroculter	*Ancherythroculter lini*	U	V	C
		Pseudolaubuca	*Pseudolaubuca sinensis*	U	V	O
			Pseudolaubuca engraulis	U	V	O
		Toxabramis	*Toxabramis houdemeri*	U	V	O
		Hemiculter	*Hemiculter leucisculus*	U	V	O
		Hemiculterella	*Hemiculterella wui*	U	V	O
		Pseudohemiculter	*Pseudohemiculter dispar*	U	V	O
		Culter	*Culter alburnus*	U	M-V	C
			Culterrecurviceps	U	M-V	C
			Culter mongolicusBasilewsky	U	M-V	C
		Parabramis	*Parabramis pekinensis*	L	S-P	H
		Megalobrama	*Megalobrama terminalis*	L	V	O
		Xenocyprioides	*Xenocyprioides parvulus*	L	S-V	O
		Xenocypris	*Xenocyprisargentea*	L	S-V	O
			Xenocypris davidi	L	S-V	O
		Hypophthalmichthys	*Hypophthalmichthys nobilis*	U	S-P	F
			Hypophthalmichthys molitrix	U	S-P	F
		Hemibarbus	*Hemibarbus labeo*	L	V	O
			Hemibarbus medius	L	V	O
			Hemibarbus maculatus	L	V	O
		Pseudorasbora	*Pseudorasbora parva*	L	V	O
		Sarcocheilichthys	*Sarcocheilichthys nigripinnis*	L	V	O

Table 1 (continued)

Order	Family	Genus	Species	Ecological Type		
				Location	Spawning Type	Food Type
		Squalidus	*Squalidus argentatus*	U	S-P	O
			Squalidus wolterstorffi	B	S-P	O
			Squalidus atromaculatus	B	S-P	O
		Microphysogobio	*Microphysogobio chinssuensis*	B	V	O
			Microphysogobio fukiensis	L	S-P	O
			Microphysogobio labeoides	L	S-P	O
			Microphysogobio tungtingensis	L	S-P	O
		Saurogobio	*Saurogobio dabryi*	L	S-P	O
		Acheilognathus	*Acheilognathus tonkinensis*	L	E	O
		Rhodeus	*Rhodeus spinalis*	L	E	O
			Rhodeus ocellatus	L	E	O
		Puntius	*Puntius semifasciolatus*	L	V	O
		Spinibarbus	*Spinibarbus denticulatus*	L	V	O
			Spinibarbus hollandi	L	V	O
		Onychostoma	*Onychostoma elongatum*	L	V	O
			Onychostoma barbatum	L	V	O
			Onychostonua leptura	L	V	O
			Onychostoma gerlachi	L	V	O
		Acrossocheilus	*Acrossocheilus iridescens longipinnis*	L	V	O
		Cirrhinus	*Cirrhinus molitorella*	L	V	O
		Ptychidio	*Ptychidio jordani*	B	V	O
		Osteochilus	*Osteochilus salsburyi*	L	V	O
		Garra	*Garra orientalis*	B	S-P	O
		Cyprinus	*Cyprinus acutidorsalis*	L	V	O
			Cyprinus carpio	L	V	O
			Cyprinus multitaeniata	L	V	O
		Setipinna	*Setipinna taty*	L	V	O
		Carassius	*Carassius auratus*	L	V	O
		Abbottina	*Abbottina rivularis*	B	V	O
		Gobiobotia	*Gobiobotia pappenheimi*	B	S-P	O
	Homalopteridae	Liniparhomaloptera	*Liniparhomaloptera disparis*	L	V	O
			Liniparhomaloptera disparis qiongzhonqensis	B	S-V	O
	Gastromyzontidae	Erromyzon	*Erromyzon sinensis*	L	V	O
Siluriformes	Siluridae	Silurus	*Silurus cochinchinensis*	B	S-V	C
			Silurus asotus	B	S-V	C
	Clariidae	Clarias	*Clarias fuscus*	B	S-V	O
			Clarias gariepinus	B	S-V	O
	Pangasidae	Sinopangasius	*Sinopangasius semicultratus*	B	V	C
	Ictaluridae	Ictalurus	*Ictalurus punctatus*	B	S-V	O
	Bagridae	Pelteobagrus	*Tachysurus fulvidraco*	B	S-V	C
			Pelteobagrus intermedius	B	S-V	C
			Pelteobagrus vachelli	B	S-V	C
		Cranoglanis	Cranoglanis bouderius	B	V	C
		Leiocassis	*Leiocassis crassilabris*	B	S-V	C
		Mystus	*Mystus guttatus*	B	S-V	C
	Sisoridae	Glyptothorax	*Glyptothorax fukiensis*	B	S-V	C
	Loricariidae	Hypostomus	*Hypostomus plecostomus*	B	S-V	O
Cyprinodontiformes	Poeciliidae	Gambusia	*Gambusia affinis*	U	E	O
	Adrianichthyidae	Oryzias	*Oryzias latipes*	U	E	O
Perciformes	Lateolabracidae	Lateolabrax	*Lateolabrax japonicus*	B	P	C
	Scombridae	Scomberomorus	*Scomberomorus niphonius*	B	S-V	O
	Serranidae	Coreoperca	*Coreoperca whiteheadiBoulenger*	B	P	C
		Siniperca	*Siniperca scherzeri*	L	P	C
			Siniperca kneri	L	P	C

Table 1 (continued)

Order	Family	Genus	Species	Ecological Type		
				Location	Spawning Type	Food Type
	Centrarchidae	Micropterus	*Micropterus salmoides*	L	V	C
	Cichlidae	Oreochromis	*Oreochromis mossambicus*	L	E	O
			Oreochromis niloticus	L	E	O
	Eleotridae	Bosttychus	*Bostrychus sinensis*	B	S-V	C
		Eleotris	*Eleotris oxycephala*	B	S-V	C
	Odontobutidae	Odontobutis	*Odontobutis sinensis*	B	S-V	C
	Gobiidae	Glossogobius	*Glossogobius giuris*	B	S-V	C
			Glossogobius olivaceus	B	S-V	C
		Rhinogobius	*Rhinogobius giurinus*	B	S-V	C
	Belontiidae	Macropodu	*Macropodus opercularis*	B	P	O
	Channidae	Channa	*Channa maculata*	B	P	C
			Channa asiatica	B	S-V	C
	Mastacembelidae	Mastacembelus	*Mastacembelus aculeatus*	B	V	O
			Mastacembelus armatus	B	V	O
	Synbranchidae	Monopterus	*Monopterus albus*	B	V	C
	Sciaenidae	Nibea	*Nibea albiflora*	L	P	C
Myliobatiformes	Rajidae	Dasyatis Rafinesque	*Dasyatis akajei*	B	E	O
Cichliformes	Cichlidae	Parachromis	*Parachromis managuensis*	B	V	C

Note: U. pelagic fish, L. lower fish, B. bottom fish, P. fish that produce floating eggs, S-P. fish that produce drifting eggs, M-V. fish that produce weakly sticky eggs, V. fish that produce sticky eggs, S-V. fish that produce strongly sticky eggs, D. fish that produce sunken eggs, E. Other spawning groups, C. Carnivorous fish, O. Omnivorous fish, F. The filter-feeding fish, H. Herbivorous fish

species (0.8%). Within Cypriniformes, the Cyprinidae family was the most dominant, comprising 67 species (53.6%), while the Cobitidae family accounted for 5 species (4%), as shown in Table 2.

The Qinjiang River featured two endemic species, *Xenocyprioides parvulus* and *Pogobrama barbatula*, while three anadromous species were identified: *Anguilla japonica*, *Anguilla marmorata*, and *Coilia grayi*. Eight non-native species were recorded, including *Colossoma brachypomum*, *Hypostomus plecostomus*, *Clarias gariepinus*, *Ictalurus punctatus*, *Gambusia affinis*, *Micropterus salmoides*, *Oreochromis mossambicus*, and *Oreochromis niloticus*. Notably, *Hypostomus plecostomus* was widely distributed across the Yujiang, Shaping, Jiuzhoujiang, and Qinjiang rivers.

In addition, eight estuarine species were identified, including *Parachromis managuensis*, *Lateolabrax japonicus*, *Bostrychus sinensis*, *Glossogobius olivaceus*, *Salanx cuvieri*, *Glossogobius giuris*, and *Sinopangasius semicultratus*, primarily distributed in the downstream section near the Qinjiang Young Water Gate.

2.1.2 *Ecological Types of Fish*

The surveyed fish species were classified into three ecological types based on their habitat preferences. Bottom-dwelling species were the most abundant, including notable examples such as *Misgurnus anguillicaudatus*, *Liniparhomaloptera disparis qiongzhongensis*, *Silurus asotus*, *Pseudobagrus fulvidraco*, *Hemibagrus guttatus*, *Mastacembelus armatus*, and *Rhinogobius giurinus*, totaling 54 species (43.20%). Lower-layer species accounted for 43 species (34.40%), while surface and mid-water species were the least numerous, comprising 28 species (22.40%).

Reproductive characteristics revealed a dominance of species producing sticky eggs, with 54 species (43.20%), including *Coilia grayi*, *Micronemacheilus pulcher*, *Schistura fasciolatus*, *Misgurnus anguillicaudatus*, *Rasborinus lineatus*, *Sinibrama macrops*, *Culter alburnus*, *Culter mongolicus Basilewsky*, *Hemibarbus labeo*, *Pseudorasbora parva*, and *Mastacembelus aculeatus*. Fish producing sunken eggs ranked second, with 24 species (19.20%), followed by those producing drifting eggs (20 species, 16.00%), floating eggs (12 species, 9.60%), and strongly adhesive eggs (6 species, 4.80%). Other reproductive strategies, such as live-bearing, mouthbrooding, and utilizing mussels for egg protection, were observed in 8 species (6.40%).

In terms of dietary habits, omnivorous species were predominant, with 80 species (64.00%). Carnivorous species followed with 39 species (31.20%), while filter-

Table 2 Composition of fish species in Pinglu Canal

表 2 平陆运河鱼类种类组成

Order	Order species	Order percentage/%	Family	Family species	Family percentage/%
Anguilliformes	2	1. 6	Anguillidae	2	1. 6
Clupeiformes	3	2. 4	Clupeidae	2	1. 6
			Engraulidae	1	0. 8
Salmoniformes	2	1. 6	Salangidae	2	1. 6
Characiformes	1	0. 8	Characidae	1	0. 8
Cypriniformes	78	62. 4	Cobitidae	5	4. 0
			Botiidae	3	2. 4
			Cyprinidae	67	53. 6
			Homalopteridae	2	1. 6
			Gastromyzontidae	1	0. 8
Siluriformes	14	11. 2	Siluridae	2	1. 6
			Clariidae	2	1. 6
			Pangasidae	1	0. 8
			Ictaluridae	1	0. 8
			Bagridae	6	4. 8
			Sisoridae	1	0. 8
			Loricariidae	1	0. 8
Cyprinodontiformes	2	1. 6	Poeciliidae	1	0. 8
			Adrianichthyidae	1	0. 8
Perciformes	21	16. 8	Lateolabrax	1	0. 8
			Serranidae	3	2. 4
			Centrarchidae	1	0. 8
			Scombridae	1	0. 8
			Cichlidae	2	1. 6
			Eleotridae	2	1. 6
			Odontobutidae	1	0. 8
			Gobiidae	3	2. 4
			Belontiidae	1	0. 8
			Channidae	2	1. 6
			Mastacembelidae	2	1. 6
			Synbranchidae	1	0. 8
			Sciaenidae	1	0. 8
Cichliformes	1	0. 8	Cichlidae	1	0. 8
Myliobatiformes	1	0. 8	Rajidae	1	0. 8
Total	125	100. 00			

feeding and herbivorous species were least represented, each comprising 6 species (4. 80%).

2. 1. 3 *Dominant Species*

Dominant species were identified based on a Relative Importance Index (IRI) of 1 000 or higher. The analysis of the main fish compositions in the three river sections revealed distinct differences in dominant species across the sections. In the Yujiang River Estuary to Shaping River section, the dominant species were *Oreochromis niloticus*, *Cyprinus carpio*, *Hypophthalmichthys molitrix*, *Misgurnus anguillicaudatus*, and *Rhinogobius giurinus*. In the Jiuzhoujiang River section, the dominant species included *Hemiculter leucisculus*, *Misgurnus anguillicaudatus*, *Ancherythroculter lini*, *Oreochromis niloticus*, and *Hemibarbus maculatus*. In the Qinjiang River section from Luwu to Mushanba, the dominant species were *Oreochromis niloticus*, *Squaliobarbus curriculus*, and *Hemiculterella wui*. Overall, the dominant species in the Pinglu Canal primarily consisted of medium to small economically significant fish, such as *Oreochromis niloticus* and *Cyprinus carpio*.

2. 1. 4 *Protected Objects and Protection Levels*

The survey results show that among the 125 fish species collected, three are classified as national second-level protected wildlife: *Anguilla marmorata*, *Luciobrama macrocephalus*, and *Hemibagrus guttatus*, comprising 2. 4% of the total species. *Luciobrama macrocephalus* was recorded in the Yujiang River Estuary to Shaping River

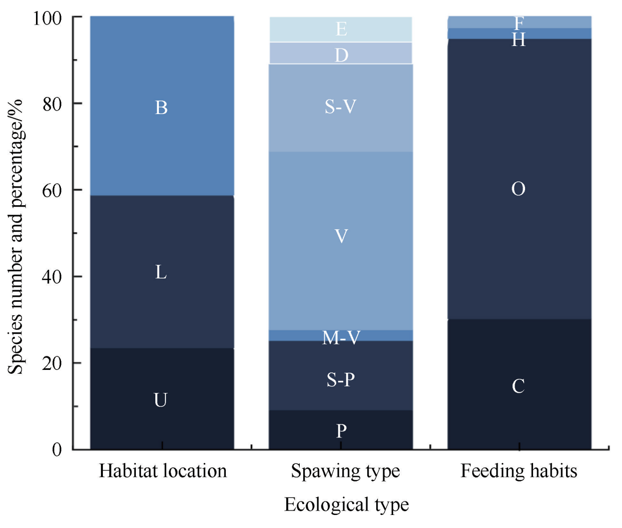

Fig. 2 Fish ecological types in Pinglu Canal

图 2 平陆运河鱼类的生态类型

section, while *Hemibagrus guttatus* was found across all three sections. *Anguilla marmorata* was observed in the Qinjiang Luwu to Shanmuba section. Six species were listed in the *Red Data Book of Endangered Animals in China*, including *Pogobrama barbatula*, *Xenocyprioides parvulus*, *Sinopangasius semicultratus*, *Ptychidio jordani*, *Anguilla marmorata*, and *Luciobrama macrocephalus*, which constitute 4.8% of the total species. Additionally, 23 species of nationally protected economically significant fish were identified, including *Ctenopharyngodon idella*, *Mylopharyngodon piceus*, *Squaliobarbus curriculus*, *Culter alburnus*, *Parabramis pekinensis*, *Hypophthalmichthys molitrix*, *Hypophthalmichthys nobilis*, *Spinibarbus denticulatus*, *Spinibarbus hollandi*, *Cirrhinus molitorella*, *Cyprinus carpio*, *Carassius auratus*, *Pseudobagrus fulvidraco*, *Monopterus cuchia*, *Siniperca kneri*, and *Channa maculata*, accounting for 18.4% of the total species , as shown in Table 3.

2.2 Fish Diversity

The analysis reveals a high level of fish diversity in the Pinglu Canal. The Shannon-Wiener index ranged from 2.347 to 2.757, the Simpson index from 0.081 to 0.151, the Margalef richness index from 3.493 to 4.382, and the Pielou evenness index from 0.812 to 0.892. These results indicate a relatively even

Table 3 Conservation targets and protection classes of fish species in Pinglu Canal

表 3 平陆运河鱼类的保护对象及保护等级

Species	Endangered Category China's Red List of Biodiversity	Protection Class	Key protected fish in Pinglu Canal (Y/N)	Relative abundance
Pogobrama barbatula	EN		Y	–
Xenocyprioides parvulus	VN		Y	–
Sinopangasius semicultratus	VN		Y	–
Ptychidio jordani	CR		Y	–
Anguilla marmorata	EN	Ⅱ	Y	–
Luciobrama macrocephalus	CR	Ⅱ	Y	–
Hemibagrus guttatus		Ⅱ	Y	–
Mylopharyngodon piceus			Y	+
Ctenopharyngodon idella			Y	++
Squaliobarbus curriculus			Y	+
Culter alburnus			Y	+
Parabramis pekinensis			Y	+
Hypophthalmichthys molitrix			Y	+++
Aristichthys nobilis			Y	+++
Spinibarbus denticulatus			Y	+
Spinibarbus hollandi			Y	+
Cirrhinus molitorella			Y	++
Cyprinus carpio			Y	+++
Carassius auratus			Y	+++
Pseudobagrus fulvidraco			Y	+
Monopterus cuchia			Y	++
Siniperca kneri			Y	+
Channa maculata			Y	++

Note: CR: Critically Endangered, EN: Endangered, VU: Vulnerable. Relative abundance: "–" indicates rare; "+" indicates present; "++" indicates relatively abundant; "+++" indicates very abundant.

distribution of fish communities. Spatially, the Shannon-Wiener index peaked in the Jiuzhoujiang River section and was lowest in the Yujiang River Estuary to Shaping River section. Conversely, the Simpson index was highest in the Yujiang River Estuary to Shaping River section and lowest in the Jiuzhoujiang River section. The Margalef richness index was greatest in the Qinjiang Luwu to Shanmuba section and lowest in the Yujiang River Estuary to Shaping River section. The average Pielou index, exceeding 0.700, further underscores the even distribution of fish communities across the Pinglu Canal.

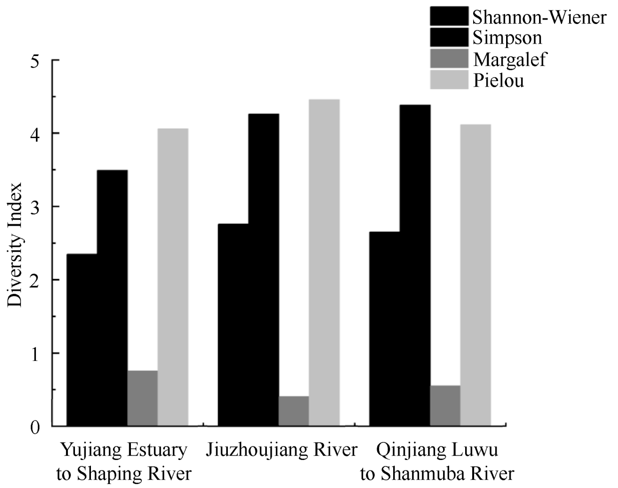

Fig. 3 Spatial variation of fish diversity indices at different cross-sections of Pinglu Canal

图 3 平陆运河不同断面鱼类多样性指数的空间变化

2.3 Stability of Fish Community

To evaluate the stability of fish communities in different sections of the Pinglu Canal, abundance/biomass comparison (ABC) curve analysis was conducted using catch data from each sampling site as shown in Figure 4. The results showed that in the Yujiang River Estuary to Shaping River section, the W value was greater than 0, with the biomass dominance curve positioned above the abundance dominance curve, and its starting point higher than that of the abundance curve. This indicates a relatively stable fish community structure in this section. In the Jiuzhoujiang River section, the W value was close to 0, and the biomass and abundance dominance curves were nearly overlapping, suggesting moderate disturbance to the community structure. Conversely, in the Qinjiang Luwu to Shanmujiang section, the W value was less than 0, with the biomass dominance curve positioned below the abundance dominance curve and intersecting at various points, reflecting severe disturbance to the fish community structure.

3 Discussion

3.1 Composition and Trends of Fish Species in Pinglu Canal

This study reveals that the fish community in the Pinglu Canal is predominantly composed of bottom-dwelling species, sticky egg spawners, and omnivorous fish. The gravel and sand substrate provides abundant food resources, creating favorable habitats for benthic species. However, a significant decline in species diversity was observed compared to historical records. In the past, the Qinjiang and Shaping River basins supported 152 species, with dominant species including *Parargyrops edita*, *Secutor ruconius*, *Saurida tumbil*, and *Sebastiscus marmoratus*[30]. The absence of some of these species in the current survey is likely attributed to the focus on construction areas along the Pinglu Canal.

Species listed in the *China Red Data Book*, such as

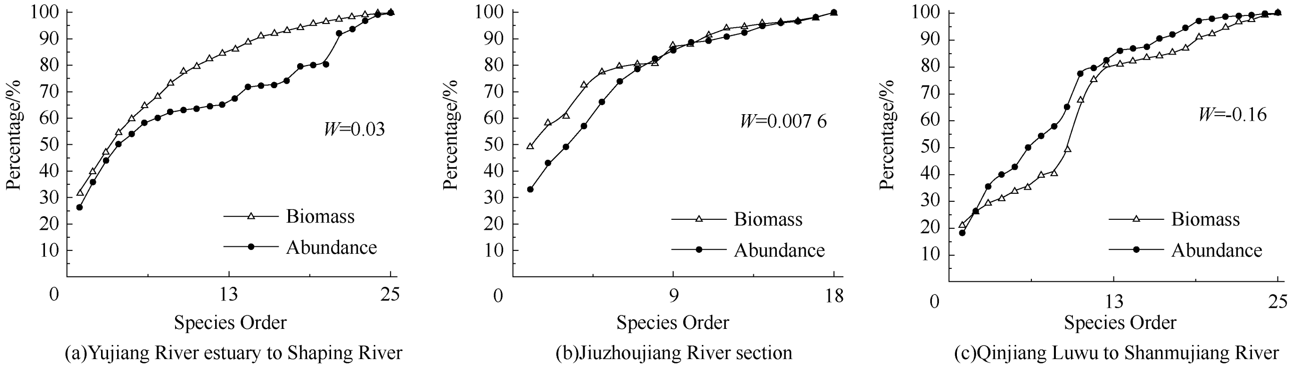

Fig. 4 Fish community abundance-biomass curves at different cross-sections of Pinglu Canal

图 4 平陆运河不同断面鱼类群落数量-生物量曲线

Pogobrama barbatula, *Xenocyprioides parvulus*, and *Sinopangasius semicultratus*, prefer small, clear-water habitats found in rivers and streams. Literature indicates that these species are likely distributed in the upper tributaries of the Qinjiang River, including the San Tashui and Xitun River basins. This survey confirmed their presence only in small water bodies near Qinjiang, consistent with previous records.

The nationally protected species *Luciobrama macrocephalus*, typically found in open waters of rivers and lakes, was observed only in the Xijin Reservoir. This limited distribution likely results from human activities, barriers between rivers and lakes, and recent food shortages. These factors have fragmented the once-continuous river ecosystem into isolated units, disrupting migratory patterns and contributing to the decline in *Luciobrama macrocephalus* populations.

Over recent decades, the construction of the Pinglu Canal and associated hydropower development have fragmented habitats, causing significant changes to fish ecosystems. The catch is now dominated by lentic species, primarily resilient and widely distributed taxa, with a marked decline in fish resources over long distances. Among historically recorded migratory species, *Dasyatis akajei* has become landlocked, while *Anguilla marmorata* was captured only in the Luwu to Shanmuba section of the Qinjiang River. Furthermore, the population of *Leucosoma chinensis* has declined by over 90% since the construction of the Guiping shipping hub[31].

Rare and endemic species have also experienced sharp population declines or local extinction. Historically, the region supported numerous species adapted to swift currents; however, the reservoir-induced flooding of flowing river sections has destroyed critical habitats, severely restricting their living spaces and contributing to population declines.

The fish species composition in the Shaping and Qinjiang River Basins shows both similarities and distinctions. *Acipenser sinensis* was recorded only in the Shaping River Basin, while *Anguilla marmorata* appeared exclusively in the Qinjiang River Basin[32]. Of the eight exotic species identified, only *Hypostomus plecostomus* was present in both basins. Increased water connectivity raises the risk of exotic species invasion. *Acipenser sinensis* and *Tenualosa reevesii* have seen declining populations in the Yujiang and Qinjiang rivers. Enhanced water connectivity offers the potential for rediscovering protected species in the Pinglu Canal. However, structures like the youth sluice have restricted *Anguilla marmorata* to estuarine areas, such as Fangchenggang, limiting its upstream migration.

3.2 Characteristics of Fish Community Structure

Fish diversity is essential for evaluating ecosystem community structure and functioning. Commonly used diversity indices, such as the Shannon-Wiener, Simpson, Margalef, and Pielou indices, help assess the richness, complexity, and stability of fish species composition. Higher index values indicate a more diverse and stable community. In the Pinglu Canal, these indices are relatively high, reflecting rich fish diversity and community stability. According to Magurran's general range (1.500 ~ 3.500) for diversity indices[33], the Shannon-Wiener index in the Pinglu Canal sections ranges from 2.347 to 2.757, indicating moderate to relatively high diversity. The Jiuzhoujiang section stands out with its high diversity, thanks to its complex river environment, featuring diverse habitats such as shoals, pools, bends, and varied riverbed substrates (rocky outcrops, gravel, and sandy areas) along with both swift currents and calm bays, which support a diverse range of fish ecological groups.

The abundance-biomass comparison (ABC) curve, widely used to assess disturbance levels in marine benthic communities, has also been applied to evaluate the stability of inland fish communities. The analysis reveals that the average W value for the Yujiang River estuary to Shaping River section is greater than 0, with no curve crossings, suggesting a stable fish community structure. In contrast, the Jiuzhoujiang section and the Qinjiang Luwu to Shanmujiang section show crossings and W values less than 0, indicating varying levels of disturbance in these areas. Overall, disturbance levels decrease progressively along the Pinglu Canal, likely due to tributary confluences. As the canal connects water systems, hydrological conditions are returning to a more natural state, enhancing the ecosystem's self-regulatory capacity and reducing disturbances in fish communities[34]. However, the stability of fish community structure in the ShaPing River Basin may decrease, while stability in the Qinjiang River Basin is likely to improve.

3.3 Suggestions for Protecting Fish Resources in the Pinglu Canal Project

The Pinglu Canal project will create interconnected water bodies, impacting the integrity, connectivity, and biodiversity of existing aquatic ecosystems. Previous studies on similar water system connectivity projects suggest that such connectivity enhances water security and ecological quality by optimizing water distribution and improving the aquatic environment[29]. However, the varying chemical and ecological environments of connected surface waters can disrupt ecological balance, potentially harming the aquatic ecosystem.

There are notable differences in biological species between the Shapinghe and Qinjiang basins. The survey results reveal that a total of 125 fish species have been monitored in both basins, with 15 species common to both, including *Lencosoma chinensis*, *Opsariichthys bidens*, *Ochetobius elongatus*, *Rasborinus lineatus*, *Sinibrama melrosei*, *Hemiculter leucisculus*, *Parabramis pekinensis*, *Megalobrama terminalis*, *Aristichthys nobilis*, and *Hypophthalmichthys molitrix*, which together represent 12% of the total fish species.

With the completion of water transfer projects between the two basins, biological exchange has been facilitated, and migratory fish such as *Anguilla japonica* and *Coilia grayi* have been observed in the Jiuzhoujiang River. The operation of the Pinglu Canal will further accelerate this species exchange. Based on the survey results, the following recommendations are made.

(1) Adjust Stocking Species and Quantities: Based on the current fish resource status and the project's impacts, the species for release should include *Mylopharyngodon piceus*, *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, *Hypophthalmichthys nobilis*, *Konosirus punctatus*, *Spinibarbus hollandi*, and *Squaliobarbus curriculus*. Research should focus on breeding, scaling up releases, and evaluating ecological benefits.

(2) Install Fish Passage Facilities at Youth Dam: The Youth Dam, while addressing seawater intrusion, has disrupted migratory pathways for species like Anguilla japonica. Installing fish passage facilities for migratory species is recommended.

(3) Enhance Monitoring of Invasive Species: Invasive species such as *Colossoma brachypomum*, *Hypostomus plecostomus*, *Clarias gariepinus*, and others are encroaching on the niches of endemic species. It is crucial to strengthen monitoring and control the spread of invasive species in the Pinglu Canal, along with assessing risks and proposing effective control measures.

4 Conclusion

(1) This study establishes baseline data on the fishery resources of the Pinglu Canal, documenting 125 species across 10 orders, 34 families, and 89 genera, including three nationally protected species and six listed in the *Red Book of Endangered Species of China*.

(2) The Shapinghe and Qinjiang basins share few fish species, and increased water system connectivity could alter habitats, facilitate species exchange, and heighten the risk of invasions.

(3) Pinglu Canal's fish diversity is generally moderate to rich, with the Jiuzhoujiang section showing particularly high diversity. However, the abundance-biomass comparison suggests some disturbance in the fish community structure in this section.

(4) Field investigations show desiccation and frequent human activities in some areas. The canal's operation is expected to improve aquatic conditions and provide better habitats for organisms.

References:

[1] TAN K, HUANG L, TAN K, et al. Metabarcoding analysis of potential HABs in the Maowei Sea, China: A baseline information for the "Pinglu Canal Waterway" mega-waterway project[J]. Estuarine, Coastal and Shelf Science, 2024, 301: 108752.

[2] XIAO Y, YANG S, LI W J, et al. Impact of channel deepening on the saltwater intrusion process in the Qinjiang River estuary, Southeast China[J]. Estuarine, Coastal and Shelf Science, 2024, 300: 108718.

[3] XIAO Y, LI D, YANG S, et al. Response of salt water intrusion to a huge navigation project construction in the Qinjiang River Estuary, Southeast China[J]. Journal of Coastal Conservation, 2024, 27(6): 69.

[4] OU J, TIAN Y, ZHANG Q, et al. Coupling UAV hyperspectral and LiDAR data for mangrove classification using XGBoost in China's Pinglu Canal Estuary[J]. Forests, 2023, 14(9): 1838.

[5] TIAN Y, HUANG H, ZHOU G, et al. Mangrove biodiversity

assessment using UAV LiDAR and hyperspectral data in China's Pinglu canal estuary[J]. Remote Sensing, 2023, 15(10): 2622.

[6] LIN K. On Promoting High-Quality Construction of the Strategic Project of Pinglu Canal in Guangxi [J]. Coastal Enterprises and Science & Technology 2023, 28(4): 14-20.

[7] JIANG M. The goal, task and action strategy of rule of law construction of Pinglu Canal of Century Project [J]. Journal of Beibu Guly University, 2023, 38(5): 64-71.

[8] LI D. Study on the Mechanism of Saltwater Intrusion and Mitigation Measures in the Pinglu Canal [D]. Chongqing: Chongqing Jiaotong University, 2023.

[9] FINNEGAN N, DIETRICH W. Episodic bedrock strath terrace formation due to meander migration and cutoff[J]. Geology, 2021, 39(2): 143-146.

[10] LI Z, WANG Z, PAN B. Formation mechanism and long-term evolution of oxbow lakes [J]. Journal of Sediment Research, 2012 (5): 16-25.

[11] LIU N, LI T, KUANG S. Ecological waterway assessment of Wuhan-Anqing reach of the Yangtze River[J]. Joumal of Peking University, 2021, 57(3): 489-495.

[12] FENG B, LI J, GONG H, et, al. Study on ecological damage characteristics and compensation standard of aquaculture project based on recovery capacity and impact cycle: A case study of the famous aquaculture area of Shuihutu in Xiangshan County [J]. Journal of Natural Resources, 2019, 34(4): 745-758.

[13] ZHU D, CHANG J. Evaluation on temporal and spatial changes of biological integrity for shallow lakes in the middle reach of the Yangtze River [J]. Acta Ecologica Sinca, 2004, 24(12): 2761-2767.

[14] LIU X, LIU Y, WANG S, et al. New canal construction and marine emissions strategy: a case of Pinglu[J]. Frontiers in Marine Science, 2024, 10: 1303879.

[15] YANG Q, YANG S. China's canal project threatens biodiversity[J]. Science, 2023, 381(6658): 612.

[16] HAN Y. Studies on fish species diversity and evolution trend in Lijiang River[J]. Journal of Hydroecology, 2010, 3(1): 22-28.

[17] LI D Y, LI R H, WU Z Q, et al. Species composition and diversity of fish in Dawangtan Reservoir in Nanning, Guangxi[J]. South China Fisheries Science, 2018, 14(2): 110-117.

[18] GABR M H, MAL A O. Trammel net fishing in Jeddah: species composition, relative importance, length-weight and length-girth relationships of major species[J]. International Journal of Fisheries and Aquatic Studies, 2018, 6(2): 305-313.

[19] LIAO H, PIERCE C L, LARSCHEID J G. Empirical assessment of indices of prey importance in the diets of predacious fish [J]. Transactions of the American Fisheries Society, 2001, 130(4): 583-591.

[20] FANG D, YANG H, ZHANG H, et al. Fish community structure and diversity in the middle reaches of the Yangtze River[J]. Journal of Fisheries of China, 2023, 47(2): 029311.

[21] LI X, ZHANG Q, DIAO Y, et al. Ecological flow considering hydrological season and habitat suitability for a variety of fish[J]. Ecological Modelling, 2024, 489: 110625.

[22] WANG S. Red Book of Endangered Animals in China (Mammals, Birds, Fishes, Amphibians and Reptiles) [M]. Beijing: Science Press, 1998.

[23] ZHANG E, CAO W. China Red List of Biodiversity: Vertebrates Volume 5 Freshwater Fishes (Upper and Lower Volumes) [M]. Beijing: Science Press, 2021.

[24] SHANNON C E, WEAVER W. The mathematical theory of communication[J]. Philosophical Review, 1949, 60(3): 144.

[25] SIMPSON E H. Measurement of diversity[J]. Nature, 1949, 163 (4148): 688.

[26] QUASTLER H. Information Theory in Biology[M]. Urbana, Illinois: University of Illinois Press, 1953.

[27] PIELOU E C. Ecological Diversity[M]. New York: Wiley, 1953.

[28] WARWICK R M, CLARKE K R. Relearning the ABC: taxonomic changes and abundance/biomass relationships in disturbed benthic communities[J]. Marine Biology, 1994, 118: 739-744.

[29] WARWICK R M. A new method for detecting pollution effects on marine macrobenthic communities[J]. Marine biology, 1986, 92: 557-562.

[30] ZHANG G, YANG C, LIU Y, et al. Pattern of fish community and its relationship with environmental factors in Fangchenggang (Qinzhou Coastal area of Beibu Gulf) [J]. South China Fisheries Science, 2022, 18(4): 20-33.

[31] TAN X, LI X, LEK S, et al. Annual dynamics of the abundance of fish larvae and its relationship with hydrological variation in the Pearl River[J]. Environmental Biology of Fishes, 2010, 88: 217-225.

[32] WANG D, ZHAO Y H, ZHANG C G, et al. Species diversity of wild freshwater fishes and sustainable utilization of the fish resource in Guangxi, China[J]. Acta Zootaxonomica Sinica, 2007, 32: 160-173.

[33] ALBERDI I, CAÑELLAS I, CONDES S. A long-scale biodiversity monitoring methodology for Spanish National Forest inventory. Application to Álava region[J]. Forest Systems, 2014, 23(1): 93-110.

[34] ZHANG H, JIN G, YU Y. Review of river basin water resource management in China[J]. Water, 2018, 10(4): 42.

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