fishes

Article

Catch Efficiency of Multi-Mesh Trammel Nets for Sampling Freshwater Fishes

Zhaohai Cheng [1,2,†], Lei Gao [1,†], Lixiong Yu [1], Xinbin Duan [1], Fengyue Zhu [1], Huiwu Tian [1], Daqing Chen [1] and Mingdian Liu [1,*]

[1] National Agricultural Science Observing and Experimental Station of Chongqing, Fishery Resources and Environmental Science Experimental Station of the Upper-Middle Reaches of Yangtze River, Ministry of Agriculture and Rural Affairs, Yangtze River Fisheries Research Institute, Chinese Academy of Fishery Science, Wuhan 430223, China; chengzhaohai@hbpu.edu.cn (Z.C.); gaolei@yfi.ac.cn (L.G.); yulixiong@yfi.ac.cn (L.Y.); duan@yfi.ac.cn (X.D.); zhufy@yfi.ac.cn (F.Z.); tianhw@yfi.ac.cn (H.T.); chdq@yfi.ac.cn (D.C.)

[2] School of Environmental Science and Engineering, Hubei Polytechnic University, Huangshi 435003, China

* Correspondence: liumd@yfi.ac.cn

† These authors contributed equally to this work.

Abstract: A multi-mesh trammel net has been developed and used for sampling freshwater fishes. However, little is known about the catch efficiency of the net. This research investigated the catch efficiency of a multi-mesh trammel net (nominal mesh size; 10.0, 30.0, 50.0, and 70.0 mm) for fish sampling in the Yangtze River of China. Catch composition and factors affecting catch per unit effort based on fish number ($CPUE_N$), weight ($CPUE_W$), and species number ($CPUE_S$) were analyzed. The results showed that the net was capable of capturing a wide range of fish sizes (total length, 5.5 to 121.0 cm) and species (n = 50). Increasing soak time from 9.4 to 24.0 h resulted in a decrease in $CPUE_N$ and $CPUE_W$ while a longer soak time increased $CPUE_S$. $CPUE_N$, $CPUE_W$, and $CPUE_S$ varied significantly with fishing locations. The net provides a potential complement to the current fish sampling techniques used in freshwater ecosystems (e.g., large rivers, lakes, and reservoirs). The findings of this research help to improve our understanding of the catch efficiency of the multi-mesh trammel net and provides insight into better designs for gears and methods for sampling diverse fish sizes and species.

Keywords: catch efficiency; CPUE; multi-mesh trammel net; fish sampling; freshwater fishes

Key Contribution: 1. Catch efficiency of multi-mesh trammel nets for sampling freshwater fishes were analyzed. 2. Catch per unit effort based on fish number ($CPUE_N$), weight ($CPUE_W$), and species number ($CPUE_S$) of the net did not vary significantly with soak time (9.4–24.0 h) while they changed significantly with fishing locations.

Citation: Cheng, Z.; Gao, L.; Yu, L.; Duan, X.; Zhu, F.; Tian, H.; Chen, D.; Liu, M. Catch Efficiency of Multi-Mesh Trammel Nets for Sampling Freshwater Fishes. *Fishes* **2023**, *8*, 464. https://doi.org/10.3390/fishes8090464

Academic Editors: Xiaobo Lou, Daisuke Kitazawa, Junbo Zhang and Chenxing Yang

Received: 22 August 2023
Revised: 13 September 2023
Accepted: 14 September 2023
Published: 16 September 2023

1. Introduction

The Yangtze River, with a length of over 6300 km, is the longest river in Asia and the third-longest in the world. Capture fisheries in the river were important sources of subsistence and commercial income for many people living along the river [1]. The fisheries in the 1950s provided more than 50% of inland fish production in China [2].

However, the Yangtze River fisheries have suffered a severe decline in recent years, primarily due to a combination of factors such as overfishing, habitat destruction, pollution, and the construction of dams [1]. This has resulted in a near-collapse of the fisheries in the Yangtze River Basin, which affected the livelihoods of people depending on the fisheries. And it has led to adverse impacts on the biodiversity conservation of the Yangtze River [3].

China has implemented several measures to address the issues and conserve biodiversity in the Yangtze River [4]. Fish sampling or monitoring projects are important for managing the sustainability of fish resources. Fish sampling or monitoring involves collecting data on fish populations, including fish size, age, distribution, and diversity. Data collected from such activities provide valuable information on the condition and dynamics of fish populations and their habitats. And information obtained via sampling or monitoring can be used to assess the effectiveness of management measures or policies and help policymakers to determine if the measures should be adjusted over time [5].

Many fish sampling or monitoring methods have been used in freshwater environments [6–8]. These methods include netting, electrofishing, acoustic survey, and environmental DNA [8,9]. Each method has its own advantages and disadvantages, and no method fits all fish sizes and species [10]. Choosing proper sampling methods suitable for specific waters is therefore essential for obtaining reliable and accurate data on fish populations and their habitats.

Among these methods, trammel or gillnets nets are commonly used in freshwater fish sampling due to their ease of operation and cost-effectiveness [11,12]. Trammel nets and gillnets have similar designs and fishing mechanisms [13]. Both types of nets consist of netting panels suspended vertically in the water column, with fish becoming wedged, gilled, or tangled as they encounter the net. However, there are also differences between the nets, such as the number of netting layers and the mesh size. These differences can affect the selectivity and efficiency of each net for different fish species and sizes [14,15]. Traditional gillnets are generally composed of one netting layer and contain only one mesh size. The design makes gillnets catch a narrow range of fish sizes and species. However, in large water bodies such as the Yangtze River, a wide range of fish species and sizes exist, making single-mesh gillnets an inadequate sampling method. The trammel net can be an alternative sampling method to traditional gillnets. The net is made of one inner and two outer netting layers, with the inner layer having a smaller mesh size than the outer ones. The inner layer is designed to trap or entangle fish while the two outer layers serve as a pocket preventing fish from escaping [13]. This design contributes to catching a wide range of fish sizes and species and obtaining a representative sample of fish populations.

The catch efficiency of trammel nets is influenced by many factors, including mesh size, net length, soak time, and set location [16,17]. Losanes et al. [18] found that the catch efficiency of trammel nets varied with soak time; however, another study showed that the catch efficiency was not significantly affected by soak time [19]. Mesh size affects the size of fish captured; small mesh sizes tend to catch smaller fish while larger mesh sizes are more effective for capturing larger fish [20]. Net length is also a critical factor that influences catch efficiency, with longer nets generally resulting in higher catch rates [19]. To obtain reliable and accurate information on fish populations, it is important to consider these factors when using trammel nets for fish sampling.

Joining trammel nets with multiple mesh sizes can be an effective method of sampling various fish sizes and species [21]. A multi-mesh trammel net has been developed for sampling freshwater fishes in the Yangtze River of China [22]. The net is composed of five trammel net panels with different mesh sizes of an inner netting layer. The multi-mesh trammel net has been used for freshwater fish sampling and monitoring in China, especially in the Yangtze River [22]. However, little is known about the catch performance of the net. Evaluating the catch efficiency of the sampling net is therefore necessary for understanding information on fish populations.

The objective of this research was to investigate the catch efficiency of the multi-mesh trammel net for fish sampling and to evaluate factors affecting the catch efficiency. The net was tested at different locations along the Yangtze River of China. Catch efficiency was quantified as catch per unit effort (CPUE); catch composition and distribution were analyzed. It was hoped that the findings of this research would improve our understanding of the catch efficiency of the multi-mesh trammel net as a sampling gear and provide insight into better designs for gears and methods for freshwater fish sampling.

2. Materials and Methods

2.1. Fishing Trials and Gear Specification

Fishing trials were conducted in the middle section of the Yangtze River. The fishing locations covered eight typical sampling sites along the river (Figure 1). Each sampling site covered an area 10 km upstream and downstream. The research was carried out onboard a fishing boat Zhongke Yu 512 (overall length l4 m) from 14 May to 28 November 2022. The fishing operation was conducted by professional fishers following fish sampling and monitoring procedures [22].

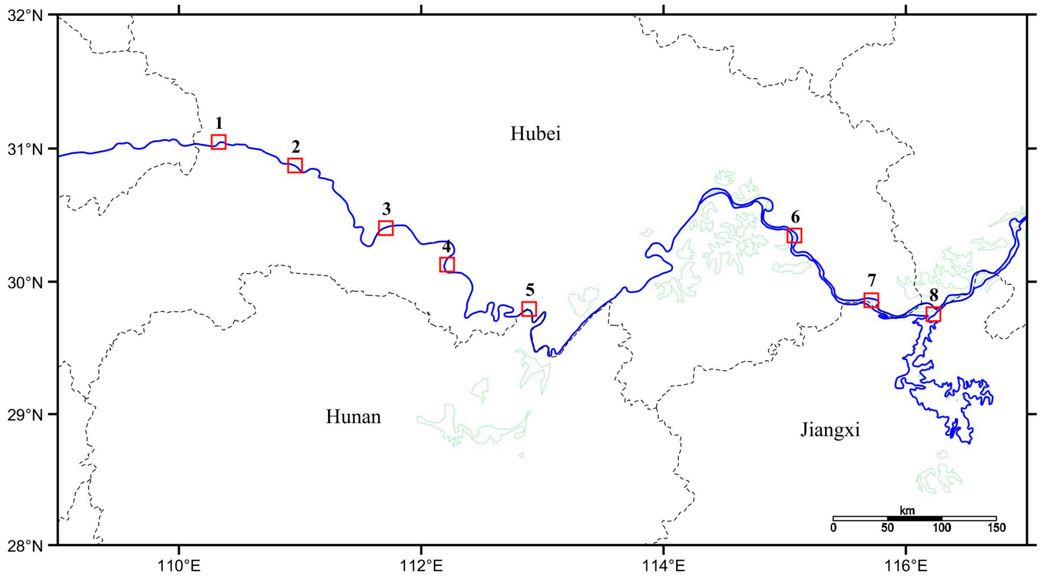

Figure 1. Map of the fishing locations along the Yangtze River. Red boxes indicate fishing locations 1–8.

Multi-mesh trammel nets with the same design were used for all the fishing trials (Figure 2). Each multi-mesh trammel net was 200.0 m long (float line) and 1.8 m high (skirt line), and was composed of four trammel net panels with different inner mesh sizes. Each panel was 50 m long and 1.8 m high. The four panels were sewn together in sequential order of mesh size (bar length): 10.0, 30.0, 50.0, and 70.0 mm. The inner mesh was made of monofilament nylon with diameters ranging from 0.011 to 0.025 mm. The inner nettings were covered with two layers of outer netting panels with the same design. The nominal mesh size of the outer netting was 500.0 mm; the diameter of the mesh twine (monofilament nylon) was 0.30 mm. To facilitate net deployment, relocation, and retrieving operation, a hauling line with a marker buoy was attached to the float line of the net.

At each fishing location, the nets were set on the bottom (depth > 2 m) with an anchor at either end. The end with small mesh was set near the shore while the big-mesh end was set in relatively deep water. Each net was deployed perpendicular to the river shore. The nets were set in the afternoon and retrieved the next morning. The soak time varied between 9.4 and 24.0 h depending on the weather conditions. For each haul, we recorded the date, soak time, and location coordinates. The nets were visually inspected prior to deploying to ensure that the netting was not twisted or entangled. The netting with severe damage was replaced, and the catch from that haul was not recorded.

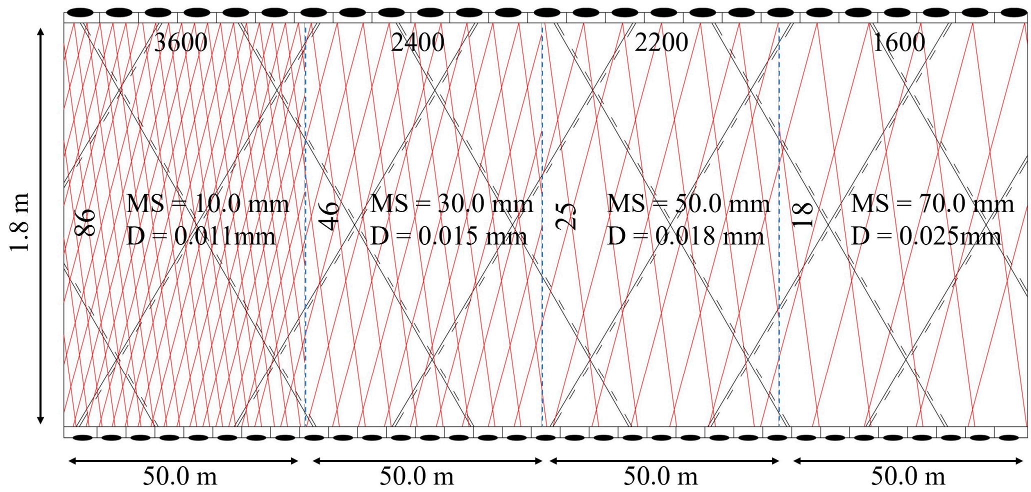

Figure 2. Schematic diagram of the multi-mesh trammel net. The whole net consisted of four separate trammel nets of different mesh sizes and the four nets were sewn together in a sequential order. (Black ellipses at the top represent the floats while the ones at the bottom represent the lead weight; red lines indicate the inner mesh netting; black slash lines indicate the outer mesh netting; the blue dot line represents the skirt line; MS is the mesh size of inner netting panels; D is the diameter of inner netting twine.)

2.2. Catch Sampling

Catch sampling and data recording were conducted onboard the boat. For each fishing trial, the catch from the multi-mesh trammel nets were identified and sorted by species. The number of the catch species was recorded. The individual number of each species was counted. All the individuals were weighed to the nearest 0.1 g, and the total length of each individual was measured to the nearest 0.1 cm. When the catch number of a species was large, a random subsample of 30 individuals of the species was applied. Shellfish species (e.g., freshwater turtles) were counted and weighed while the data were not included for further analysis.

2.3. Data Analysis

The effects of soak time, fishing locations, and dates on the catch efficiency of the multi-mesh trammel net were analyzed. Catch efficiency based on the catch per unit effort (CPUE) of the multi-mesh trammel net was estimated. CPUE was expressed as the number of fish individuals ($CPUE_N$), number of fish species ($CPUE_S$), and total weight ($CPUE_W$) of fish caught by the net. All data analyses were performed using R software (version 4.2.3) [23]; therefore, all references to "packages" in this context pertain to data packages that are incorporated within R. The dependent variables were continuous, and the independent variables were of mixed data types, including continuous and categorical variables. Generalized Linear Mixed Models (GLMM) were used. GLMMs can manage data that are unbalanced, incorporating random and fixed predictors [24]. In the following analyses, the predictor variables were soak time (Soaktime; fixed, continuous), fishing locations (Location; fixed, categorical), and fishing date (Date; random, categorical).

The dependent variables of $CPUE_N$ and $CPUE_S$ (Equations (1) and (2)) were count data (discrete). Therefore, the data were initially fit with a Poisson-distributed model with the glmer function, and dispersion was estimated with the DHARMa package [25]. If equidispersion was determined, then the analysis continued with the Poisson-distributed model. If overdispersion was observed, then the model was fit with a negative binomial model with the glmer function. In this case, the overdispersion parameter of the Poisson model significantly exceeded one; therefore, the negative binomial error structure was used and was found to be a better fit. The lme4 R package version 1.1-17 [26] was used for fitting the models.

$$\begin{gathered} CPUE_{Nij} \sim NB(\mu_{ij}) \\ E(CPUE_{Nij}) = \mu_{ij} \\ Log(\mu_{ij}) = Soaktime + Location_i + Date_j \\ Date_i \sim N(0, \sigma^2) \end{gathered} \tag{1}$$

$$\begin{gathered} CPUE_{Sij} \sim NB(\mu_{ij}) \\ E(CPUE_{Sij}) = \mu_{ij} \\ Log(\mu_{ij}) = Soaktime + Location_i + Date_j \\ Date_i \sim N(0, \sigma^2) \end{gathered} \tag{2}$$

where Date is assumed to be normally distributed with mean 0 and variance σ^2.

To analyze the effects of Soaktime, Location, and Date on $CPUE_W$ (Equation (3)), a Gaussian error structure was used because the dependent variables were continuous.

$$\begin{gathered} CPUE_{Wij} \sim NB(\mu_{ij}) \\ E(CPUE_{Wij}) = \mu_{ij} \\ \mu_{ij} = Soaktime + Location_i + Date_j \\ Date_i \sim N(0, \sigma^2) \end{gathered} \tag{3}$$

where Date is the random variable representing the variability among fishing dates and was assumed to be normally distributed with mean 0 and variance σ^2.

To quantify the proportion of variance accounted for by both the fitted and random effects, conditional and marginal pseudo-R^2 values were calculated for each mixed effect model [27] using the MuMIn package [28]. In circumstances where the conditional and marginal pseudo-R^2 values for a model were equivalent, it was inferred that the incorporation of random effects did not significantly improve the model fit. Consequently, a Generalized Linear Model devoid of the random effect would have been deemed more suitable. The assessment of normality was visually performed using quantile–quantile plots. The process of model validation did not reveal any issues. To identify specific disparities within significant independent variables, post hoc testing utilizing the Tukey method was employed.

3. Results

3.1. Catch Composition and Distribution

A total of eighty-six deployments were conducted in spring (May), summer (June–August), and winter (October–December) of 2022. The soak time ranged from 9.4 to 24.0 h. A total of 8369 individuals consisting of 51 fish (n = 50) and shellfish (n = 1) species were caught. The total weight of the catch was around 1930.57 kg (Table 1). Eight of the 51 species were caught with only one individual. Two freshwater turtles (*Pelodiscus sinensis*) weighing 0.51 kg were caught during the study, but the data were not included for regression analysis (Table 2).

Table 1. Overview of the net deployments during the fishing trials. Both catch number and catch weight include fish and shellfish species. Location number corresponds to fishing locations marked in Figure 1.

Location	Deployment	Soak Time (h) (Min–Max)	Catch Number	Catch Weight (kg)
1	10	11.6–12.0	637	45.67
2	10	12.0–13.0	744	29.50
3	7	15.5–19.3	471	158.57
4	8	16.6–19.5	407	62.94
5	9	17.5–24.0	711	195.98
6	17	10.6–22.1	2393	441.64
7	17	9.4–17.6	470	211.45
8	8	23.5–24.0	2536	784.82

Table 2. Summary of fish and shellfish species caught during all the fishing trials.

Species	Total Weight (kg)	Total Number
Coilia brachygnathus	40.70	1208
Parabramis spp.	257.71	935
Pelteobagrus vachelli	80.67	789
Hemiculter spp.	10.09	696
Culter spp.	103.70	641
Pelteobagrus nitidus	9.62	616
Xenocypris argentea	64.59	615
Pseudobrama simoni	5.29	386
Megalobrama spp.	24.93	345
Saurogobio spp.	9.54	313
Leiocassis spp.	97.28	211
Squalidus argentatus	3.52	200
Rhodeus spp.	1.10	183
Erythroculter mongolicus	41.31	157
Pelteobagrus fulvidraco	8.53	135
Hypophthalmichthys molitrix	289.43	125
Coilia macrognathos	9.10	101
Aristichthys nobilis	565.22	99
Siniperca kneri	50.93	91
Pseudolaubuca sp.	1.73	84
Carassius auratus	20.07	80
Coreius heterodon	10.71	58
Hemibagrus macropterus	7.57	38
Hemibarbus spp.	4.89	32
Cyprinus carpio	54.46	28
Elopichthys bambusa	4.53	25
Siniperca scherzeri	6.86	22
Pseudobagrus spp.	0.70	21
Rhinogobio spp.	1.26	20
Acipenser spp.	85.48	19
Pelteobagrus eupogon	1.46	16
Silurus meridionalis	11.01	14
Sander lucioperca	0.35	11
Silurus asotus	7.39	11
Ctenopharyngodon idellus	19.36	7
Chanodichthys erythropterus	0.83	6
Spinibarbus sinensis	4.96	5
Squaliobarbus curriculus	1.88	5
Myxocyprinus asiaticus	4.42	4
Parabotia fasciata	0.12	4
Ochetobius elongatus	0.26	3
Pelodiscus sinensis	0.51	2
Sarcocheilichthys sinensis	0.11	2
Channa argus	0.23	1
Cirrhinus molitorella	0.46	1
Cyprinus carpio specularis	0.53	1
Misgurnus anguillicaudatus	0.0027	1
Mylopharyngodon piceus	4.25	1
Neosalanx taihuensis	0.0022	1
Paracanthobrama guichenoti	0.35	1
Plagionatrops microlepris	0.57	1

Figure 3 shows the length and weight distribution of all the fish caught. The total length of the fish caught ranged from 5.5 to 121.0 cm. Ninety percent of all the fish were below 35.5 cm. The individual weight varied between 2.1 and 13,000.0 g, and individuals less than 403.6 g accounted for more than 90% by number.

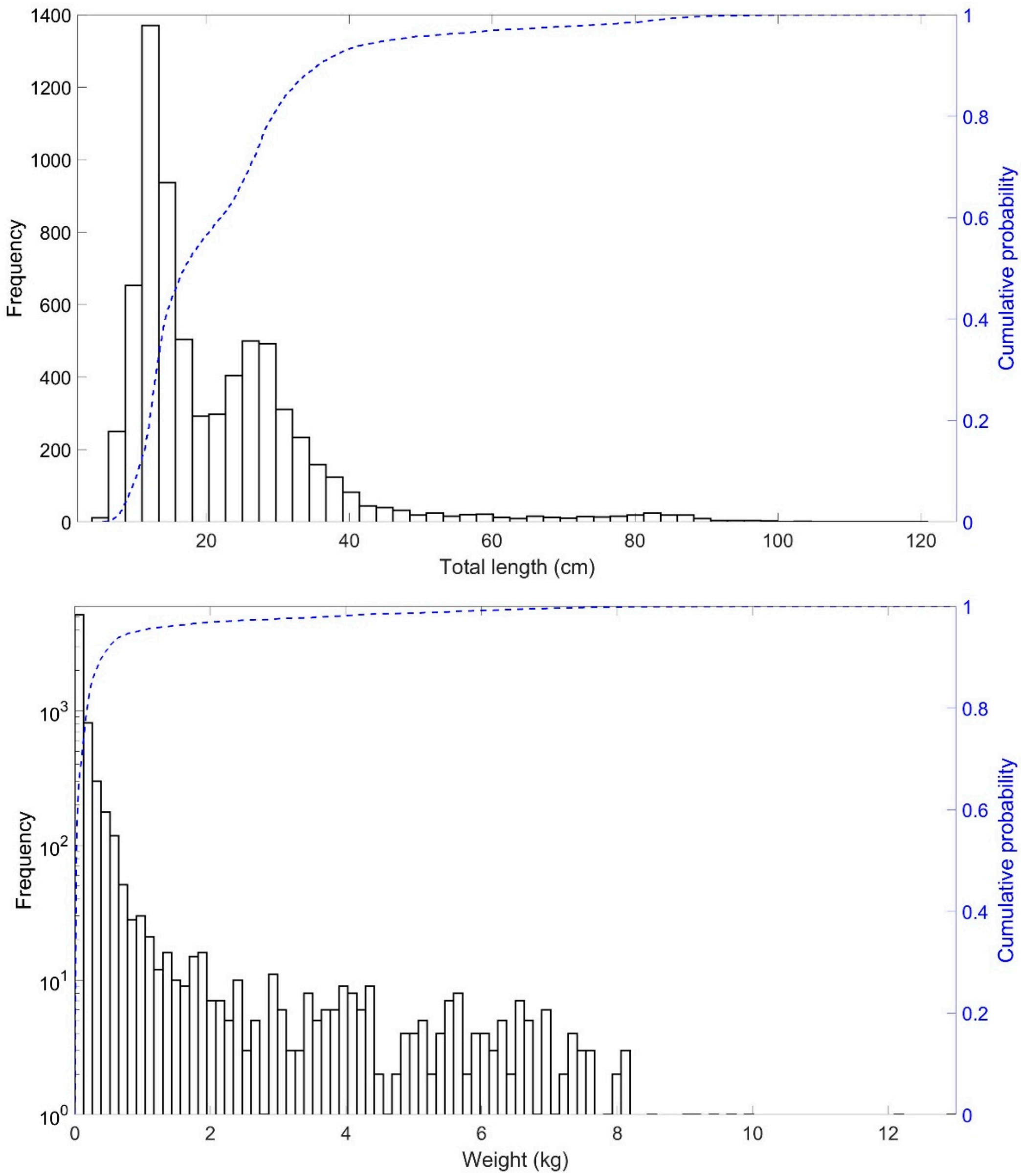

Figure 3. Length and weight distribution of all the fish caught. Dot lines show the cumulative probability curves.

3.2. Dominant Species

The most abundant species by number was Shortjaw tapertail anchovy (*Coilia brachygnathus*), accounting for 14.4% of the total catch while its total weight only accounted for 2.1% of the total catch (Table 2). The total length of Shortjaw tapertail ranged from 7.0 to 41.1 cm, and its weight ranged from 2.1 to 177.6 g. By weight, Bighead carp (*Aristichthys nobilis*) was the most abundant species, accounting for 29.3% by weight and 1.2% by number of the total catch. The total length of Bighead carp ranged from 33.4 to 98.0 cm, and the weight ranged from 400.6 to 12,100.0 g (Figure 4).

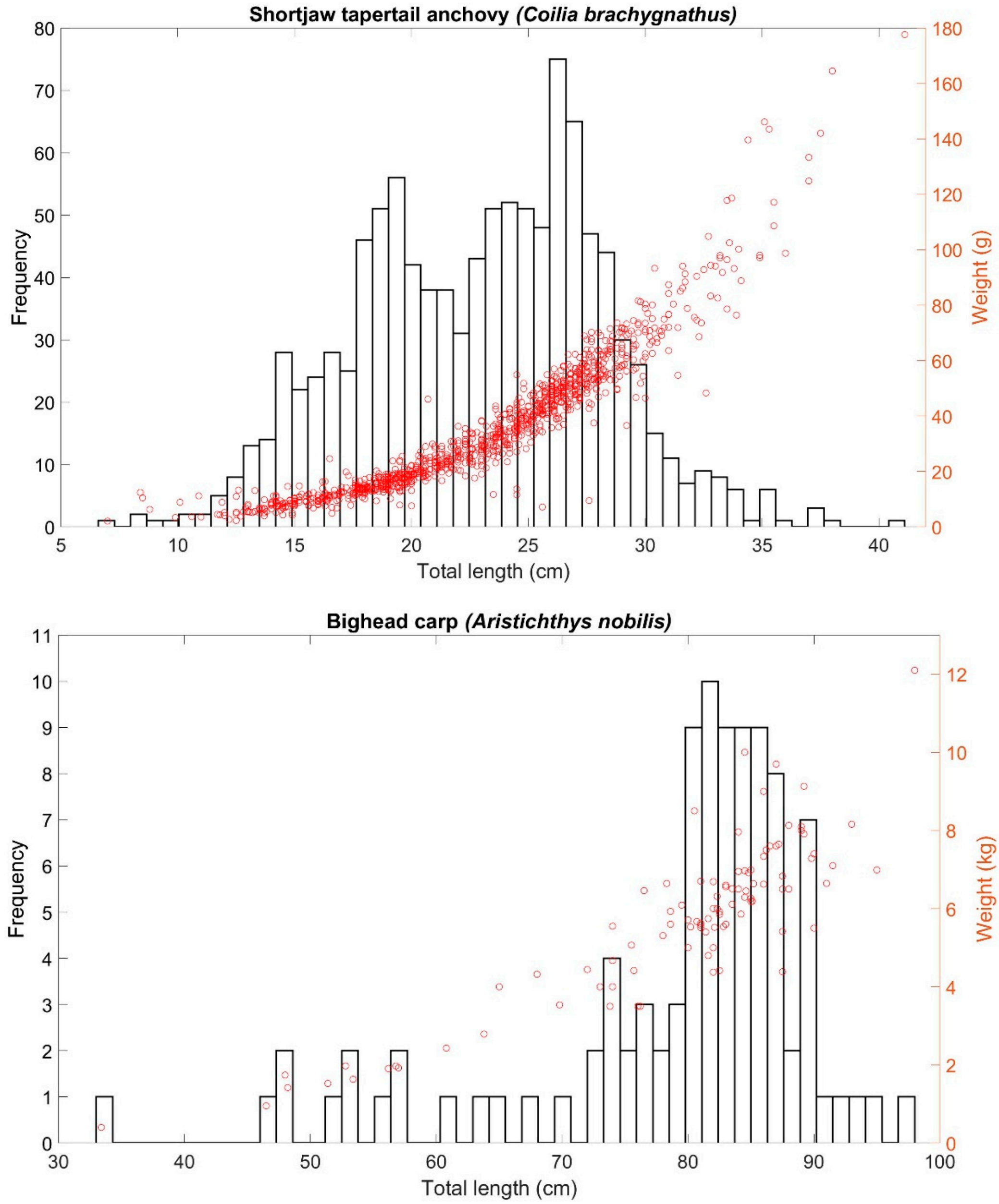

Figure 4. Length and weight distribution of the most abundant fish species—Shortjaw tapertail anchovy (*Coilia brachygnathus*) and Bighead carp (*Aristichthys nobilis*).

3.3. Catch Per Unit Effort of the Multi-Mesh Trammel Net

3.3.1. $CPUE_N$

A negative-binomial mixed model was fitted to estimate the effects of soak time and fishing locations on catch per unit effort ($CPUE_N$) of the multi-mesh trammel net (Table 3). The model included fishing dates (Date) as a random effect. The model's total explanatory power was substantial (conditional pseudo-R^2 = 0.87), and the part related to the fixed effects alone (marginal pseudo-R^2) was of 0.40. The effect of soak time (Soaktime) was statistically non-significant and negative ($\beta_1 = -0.034$, 95% CI = [−0.08, 0.009], $p = 0.123$); for a one-hour increase in soak time, the number of fish caught decreased by 3.3%. $CPUE_N$ varied significantly with fishing locations ($\chi^2 = 82.7$, df = 7, $p < 0.001$). Tukey post hoc analysis reveals the difference in $CPUE_N$ among fishing locations in Figure 5.

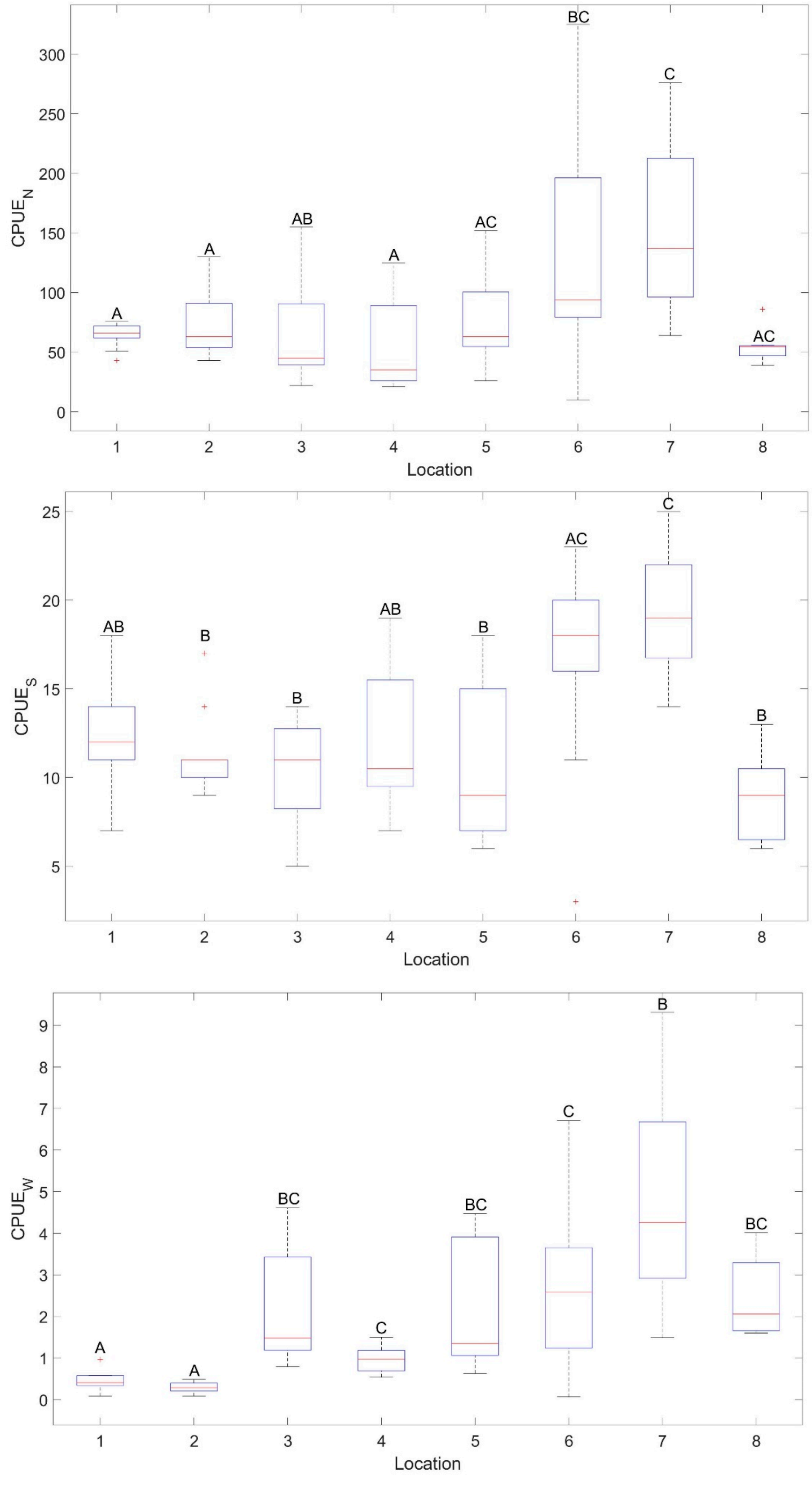

Figure 5. CPUE$_N$, CPUE$_S$, and CPUE$_W$ of the multi-mesh trammel net varying with fishing locations. For CPUE$_W$, the weight of the catch is in kg. Horizontal line within each box represents the median. Lower and upper hinges of the boxes represent the first and third quartiles, respectively. Lower and upper whiskers depict scores outside the interquartile range. Plus signs correspond to the outliers.

Table 3. Summarized regression results for the models presented in Equations (1)–(3). $CPUE_N$ represents catch per unit effort by counts. $CPUE_S$ is catch per unit effort by number of fish species. $CPUE_W$ is catch per unit effort by weight.

Dependent Variable	Marginal Pseudo-R^2	Conditional Pseudo-R^2	Random Variable	Fixed Variable	Estimate	Std. Error	*z*/*t* Value	*p*-Value
$CPUE_N$	0.397	0.870	Date	Intercept	4.384	0.329	13.311	<0.001
				Soaktime	−0.034	0.022	−1.544	0.123
				Location2	0.237	0.192	1.238	0.216
				Location3	0.258	0.252	1.022	0.307
				Location4	0.081	0.255	0.317	0.751
				Location5	0.639	0.293	2.182	0.029
				Location6	0.903	0.121	7.498	<0.001
				Location7	1.002	0.183	5.478	<0.001
				Location8	0.407	0.321	1.266	0.206
$CPUE_S$	0.489	0.489	Date	Intercept	2.470	0.154	16.005	<0.001
				Soaktime	0.003	0.011	0.250	0.803
				Location2	−0.068	0.129	−0.528	0.597
				Location3	−0.185	0.158	−1.17	0.241
				Location4	−0.009	0.154	−0.057	0.954
				Location5	−0.131	0.174	−0.755	0.450
				Location6	0.334	0.112	2.980	0.002
				Location7	0.454	0.107	4.253	<0.001
				Location8	−0.324	0.190	−1.706	0.088
$CPUE_W$	0.626	0.825	Date	Intercept	0.648	0.197	3.293	<0.001
				Soaktime	−0.009	0.013	−0.687	0.492
				Location2	−0.113	0.127	−0.886	0.376
				Location3	0.788	0.158	4.994	<0.001
				Location4	0.486	0.160	3.038	0.002
				Location5	0.796	0.185	4.294	<0.001
				Location6	0.736	0.099	7.436	<0.001
				Location7	1.083	0.117	9.239	<0.001
				Location8	0.934	0.202	4.622	<0.001

3.3.2. $CPUE_S$

The effects of soak time, fishing locations, and fishing date (random effect) on catch per unit effort based on number of catch species ($CPUE_S$) of the net that were estimated (Table 3). The model's explanatory power related to the fixed effects alone (marginal pseudo-R^2) was 0.49. Adding random effect to the model did not improve the model fitting (p = 0.980). The number of fish species caught increased by 0.26% for a one-hour increase in soak time while the increase was not statistically significant (β_1 = 0.003, 95% CI = [−0.02, 0.02], p = 0.803). $CPUE_S$ varied significantly with fishing locations (χ^2 = 67.8, df = 7, p < 0.001). The difference is presented in Figure 5.

3.3.3. $CPUE_W$

A linear mixed model was fitted to estimate the effects of soak time, fishing location, and fishing date on catch per unit effort by weight ($CPUE_W$) of the net (Table 3). The difference between the marginal pseudo-R2 (0.63) and the conditional pseudo-R2 (0.83) suggested that random effect (Date) improved the model fitting. For each one-hour increase in soak time, total catch weight (kg) decreased by 0.91% while the effect was not significant (β_1 = −0.009, 95% CI = [−0.04, 0.02], p = 0.492). Fishing location was a significant factor affecting $CPUE_W$ (χ^2 = 150.7, df = 7, p < 0.001); the variation in $CPUE_W$ with fishing locations is presented in Table 3 and Figure 5.

3.3.4. $CPUE_N$ for Shortjaw Tapertail Anchovy

In terms of catch number, Shortjaw tapertail anchovy was the most common species. Figure 6 shows $CPUE_N$ for this species varying among fishing locations. $CPUE_N$ varied significantly with fishing locations ($F(5, 54) = 4.83$, $p < 0.05$). A post hoc Tukey test showed that $CPUE_N$ at Locations 2, 4, and 8 was significantly lower than at Locations 1, 6, and 7. No significant differences were observed in $CPUE_N$ among Locations 1, 6, and 7, as well as among Locations 2, 4, and 8 (Figure 6).

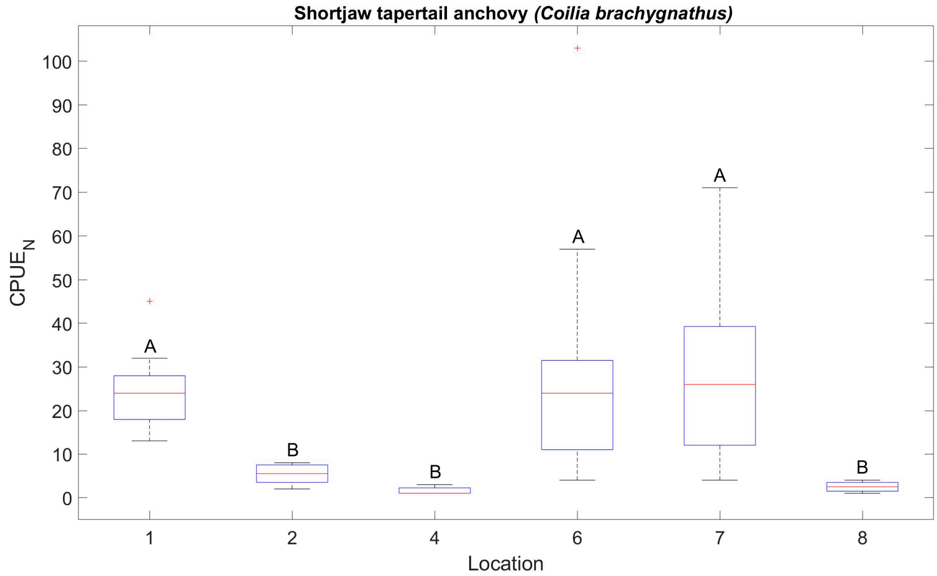

Figure 6. $CPUE_N$ for Shortjaw tapertail anchovy (*Coilia brachygnathus*) varying with fishing locations. Locations 3 and 5 are not presented in the figure because there was no catch of this species at the locations. Horizontal line within each box represents the median. Lower and upper hinges of the boxes represent the first and third quartiles, respectively. Lower and upper whiskers depict scores outside the interquartile range. Plus signs correspond to the outliers.

4. Discussion

This is the first comprehensive study to evaluate the catch efficiency of a multi-mesh trammel net for sampling freshwater fish in the Yangtze River of China. The results demonstrated that soak time (9.4–24.0 h) was not a significant factor affecting the CPUE of the net while the CPUE varied significantly with fishing locations. Fish captured by the net included 50 species ranging from 5.5 to 121.0 cm and weighed between 2.1 and 13,000.0 g. This research found that the net was effective for capturing a wide range of fish species and sizes, especially small individuals. The findings of this research contribute to our knowledge of the catch efficiency of the net as a sampling gear, and can be useful for researchers and practitioners interested in improving the efficiency and accuracy of fish sampling.

Catch distribution revealed that the net was effective for catching small fish; 90% of the catch were below 35.5 cm and weighed less than 403.6 g. This scenario could be analyzed from two perspectives. The number of small fish may be more than that of big ones in the Yangtze River; it was of higher likelihood for the small individuals to encounter the net. Another possible explanation is related to fish behavior [29]. Due to a combination of factors including the strength of netting materials and the strength of fish to break free from the nets [30,31], it was more difficult for small fish than large ones to escape from the net once they were caught.

The most abundant catch by number was Shortjaw tapertail anchovy. Based on the morphological characteristics of Shortjaw tapertail anchovy, it is assumed that its swimming capability and strength to break free from the net are weak [32–34]. In the middle and lower Yangtze River Basin, Shortjaw tapertail anchovy was one of the dominant species [35].

High abundance and morphological characteristics made it a species relatively easy to be captured and retained by the net.

By weight, bighead carp was the most abundant catch. The size of this species caught was relatively large; each individual was larger than 33.0 cm (body length) and weighed more than 400.0 g. Our results are consistent with previous research which found that trammel nets were effective at capturing adult bighead carp [36]. This indicates that the multi-mesh trammel net was also capable of catching large fish if available. A low rate of encounter with the net or low abundance of small fish of this species could lead to few small individuals being captured [37,38].

Many studies have investigated the effects of soak time on the catch efficiency of trammel nets or gillnets, whereas the results differ. Savina et al. [39] found that the catch efficiency of gillnets increased significantly with increasing soak time while another study reported that the catch efficiency decreased significantly with increasing soak time [17]. Losanes et al. [18] also found that the catch efficiency of trammel nets changed significantly with soak time. However, another research conducted by Acosta [19] suggested that the catch efficiency of gillnets did not change significantly with soak time. The findings are consistent with our results. The relationship between catch efficiency and soak time could be complex. Several possible factors account for the reason. A longer soak time could increase the possibility of fish encountering the net while it could also increase the likelihood of fish escaping. Captured small fish in the net may attract predators to accumulate in the net, which may affect the catch efficiency, decreasing the catch number or diversity [40]. These factors may interact with each other, making the effects of soak time on catch efficiency complex.

In this study, the fishing location was found to be a significant factor affecting catch efficiency. Research conducted in southern European waters yielded similar results, indicating that the catch efficiency of trammel nets varied with fishing locations [41]. Another study also demonstrated that the catchability of a gillnet changed considerably with fishing sites [42]. However, the fishing location is a factor consisting of uncontrollable variables. Biological factors such as fish abundance, mobility, distribution, and diversity varying across locations may lead to differences in catch efficiency. Environmental factors such as water current, clarity, temperature, etc. may interact with fish behavior and influence catch efficiency. The variables made the location factor difficult to predict even when using the same net and sampling protocols.

As demonstrated by previous studies, the net configuration was one of the factors influencing the catch efficiency of trammel nets or gillnets. The net dimensions, mesh and twine size, and hanging ratio can considerably affect the catch rate and species selectivity [13,43,44]. The color and material of the net can influence its visibility and detectability, thus affecting catch efficiency [15,45,46]. Additionally, the slackness of trammel nets affects catch efficiency [47–49]. The shape of the net in water can be affected by slackness; too much slackness can lead to net tangling, influencing its contact with fish and thus its catch efficiency. The effect of slackness may also be species- and size-specific, as certain species or sizes may be more prone to be retained in slack nets than others [Koike]. In this study, the factors discussed above were regarded as control variables; they were held constant throughout the research. Therefore, the catch efficiency of the multi-mesh trammel may change with the alternation of the configuration parameters discussed above.

The multi-mesh trammel net provides a potential alternative for the current methods of fish sampling in freshwater ecosystems (e.g., large rivers, lakes, and reservoirs). Various methods and techniques have been employed by researchers and fisheries managers to collect data on fish populations, behavior, and health [6–9]. Gillnets and trammel nets are commonly used in freshwater fish sampling. However, traditional gillnets or trammel nets are generally made of single-mesh-size netting (or inner netting layer); the selective nature of the nets cannot be ignored. These nets tend to retain certain fish species and sizes, which can lead to biased estimates of fish species composition and size structure [43]. The use of multi-mesh trammel nets has advantages over the use of single-mesh nets, especially in terms of species and size selectivity. Due to the multi-mesh nature, the multi-mesh nets can retain a broad range of fish sizes and species, which can provide a more comprehensive understanding of fish population. And multi-mesh trammel nets can improve sampling efficiency by capturing different sizes and species simultaneously. This is particularly beneficial for fish sampling where multiple sizes and species are targeted (e.g., in the Yangtze River). Compared to using other techniques, such as acoustic surveys, trawling, electrofishing, and environmental DNA, using multi-mesh trammel nets remains a relatively simple and easy way to sample fish in freshwater ecosystems. Additionally, the multi-mesh trammel net can be adapted to different research objectives and study sites by altering the mesh size combination and net configuration. This versatility also makes it a potential alternative for fish sampling methods in freshwater ecosystems.

5. Conclusions

The application of proper fish sampling methods is significant for the accurate assessment of fish stocks. However, no sampling method suites all fish species and sizes; better understanding of the efficiency of the methods helps improve the accuracy and reliability of data collection [10]. The results of this study contribute to our understanding of the catch efficiency of the multi-mesh trammel net. The net's ability to capture a wide range of fish species and sizes, coupled with its easy operation and relatively low cost, makes it a supplement to the existing fish sampling techniques in freshwater ecosystems. Further research could investigate the potential of the net for use in different aquatic environments and optimize the net design to fit different catch purposes.

Author Contributions: Conceptualization, Z.C., L.G. and M.L.; Data curation, Z.C.; Formal analysis, Z.C. and L.G.; Funding acquisition, L.G., L.Y., X.D., F.Z., H.T., D.C. and M.L.; Investigation, Z.C., L.G., L.Y., X.D., F.Z., H.T., D.C. and M.L.; Methodology, Z.C. and L.G.; Project administration, X.D. and D.C.; Resources, F.Z.; Software, Z.C., L.G. and H.T.; Supervision, X.D., D.C. and M.L.; Validation, Z.C. and L.G.; Visualization, Z.C.; Writing—original draft, Z.C.; Writing—review and editing, Z.C., L.G., L.Y., X.D., F.Z., H.T., D.C. and M.L. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the National Key R&D Program of China, grant number 2022YFC3202001; National Natural Science Foundation of China—Ministry of Water Resources of the People's Republic of China and China Three Gorges Corporation—Yangtze River Water Science Research Joint Fund Project, grant number U2240214; and Innovation Team Project of Chinese Academy of Fishery Sciences, grant number 2020TD09.

Institutional Review Board Statement: The animal study protocol was approved by the Institutional Review Board of Animal Experimental Ethical Inspection of Laboratory Animal Centre, Yangtze River Fisheries Research Institute, Chinese Academy of Fishery Sciences (protocol code YFI2022-mingdian-01; date of approval, 2 March 2022).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: We would like to thank many graduate students and staff from Yangtze River Fisheries Research Institute. Thanks are also extended to the crew of the boat Zhongke Yu 511.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zhang, H.; Kang, M.; Shen, L.; Wu, J.; Li, J.; Du, H.; Wang, C.; Yang, H.; Zhou, Q.; Liu, Z.; et al. Rapid Change in Yangtze Fisheries and Its Implications for Global Freshwater Ecosystem Management. *Fish Fish.* **2020**, *21*, 601–620. [CrossRef]
2. Jin, B.; Winemiller, K.O.; Ren, W.; Tickner, D.; Wei, X.; Guo, L.; Li, Q.; Zhang, H.; Pompeu, P.S.; Goichot, M.; et al. Basin-scale Approach Needed for Yangtze River Fisheries Restoration. *Fish Fish.* **2022**, *23*, 1009–1015. [CrossRef]
3. Zhang, Y. Freshwater Biodiversity Conservation in China: Progress in the Yangtze River Basin. *Aquat. Conserv.* **2022**, *32*, 1565–1570. [CrossRef]
4. Chen, T.; Wang, Y.; Gardner, C.; Wu, F. Threats and Protection Policies of the Aquatic Biodiversity in the Yangtze River. *J. Nat. Conserv.* **2020**, *58*, 125931. [CrossRef]

5. Lynch, A.J.; Cooke, S.J.; Beard, T.D., Jr.; Kao, Y.-C.; Lorenzen, K.; Song, A.M.; Allen, M.S.; Basher, Z.; Bunnell, D.B.; Camp, E.V.; et al. Grand Challenges in the Management and Conservation of North American Inland Fishes and Fisheries. *Fisheries* **2017**, *42*, 115–124. [CrossRef]
6. Casselman, J.M.; Penczak, T.; Carl, L.; Mann, R.H.; Holcik, J.; Woitowich, W.A. An evaluation of fish sampling methodologies for large river systems. *Pol. Arch. Hydrobiol.* **1990**, *37*, 521–551.
7. Portt, C.B.; Coker, G.A.; Ming, D.L.; Randall, R.G. A review of fish sampling methods commonly used in Canadian freshwater habitats. *Can. Tech. Rep. Fish. Aquat. Sci.* **2006**, 2604. Available online: https://publications.gc.ca/collections/collection_2012/mpo-dfo/Fs97-6-2604-eng.pdf (accessed on 8 February 2023).
8. Radinger, J.; Britton, J.R.; Carlson, S.M.; Magurran, A.E.; Alcaraz-Hernández, J.D.; Almodóvar, A.; Benejam, L.; Fernández-Delgado, C.; Nicola, G.G.; Oliva-Paterna, F.J.; et al. Effective Monitoring of Freshwater Fish. *Fish Fish.* **2019**, *20*, 729–747. [CrossRef]
9. Evans, N.T.; Lamberti, G.A. Freshwater Fisheries Assessment Using Environmental DNA: A Primer on the Method, Its Potential, and Shortcomings as a Conservation Tool. *Fish. Res.* **2018**, *197*, 60–66. [CrossRef]
10. Kubečka, J.; Godø, O.R.; Hickley, P.; Prchalová, M.; Říha, M.; Rudstam, L.; Welcomme, R. Fish Sampling with Active Methods. *Fish. Res.* **2012**, *123–124*, 1–3. [CrossRef]
11. Wanner, G.A.; Shuman, D.A.; Brown, M.L.; Willis, D.W. An Initial Assessment of Sampling Procedures for Juvenile Pallid Sturgeon in the Missouri River Downstream of Fort Randall Dam, South Dakota and Nebraska. *J. Appl. Ichthyol.* **2007**, *23*, 529–538. [CrossRef]
12. Argent, D.G.; Kimmel, W.G. Efficiency and Selectivity of Gill Nets for Assessing Fish Community Composition of Large Rivers. *N. Am. J. Fish. Manag.* **2005**, *25*, 1315–1320. [CrossRef]
13. He, P. Gillnets: Gear design, fishing performance and conservation challenges. *Mar. Technol. Soc. J.* **2006**, *40*, 12–19. [CrossRef]
14. Gray, C.A.; Jones, M.V.; Rotherham, D.; Broadhurst, M.K.; Johnson, D.D.; Barnes, L.M. Utility and efficiency of multi-mesh gill nets and trammel nets for sampling assemblages and populations of estuarine fish. *Mar. Freshw. Res.* **2005**, *56*, 1077–1088. [CrossRef]
15. Grimaldo, E.; Herrmann, B.; Su, B.; Føre, H.M.; Vollstad, J.; Olsen, L.; Larsen, R.B.; Tatone, I. Comparison of Fishing Efficiency between Biodegradable Gillnets and Conventional Nylon Gillnets. *Fish. Res.* **2019**, *213*, 67–74. [CrossRef]
16. Lloyd, J.A.; Mounsey, R.P. The potential of the trammel net as an alternative method for sampling fish on deep water reefs. *Fish. Res.* **1998**, *39*, 67–74. [CrossRef]
17. Rotherham, D.; Gray, C.A.; Broadhurst, M.K.; Johnson, D.D.; Barnes, L.M.; Jones, M.V. Sampling Estuarine Fish Using Multi-Mesh Gill Nets: Effects of Panel Length and Soak and Setting Times. *J. Exp. Mar. Bio. Ecol.* **2006**, *331*, 226–239. [CrossRef]
18. Losanes, L.P.; Matuda, K.; Fujimori, Y. Outdoor Tank Experiments on the Influence of Soaking Time on the Catch Efficiency of Gillnets and Entangling Nets. *Fish. Res.* **1992**, *15*, 217–227. [CrossRef]
19. Acosta, A.R. Soak Time and Net Length Effects on Catch Rate of Entangling Nets in Coral Reef Areas. *Fish. Res.* **1994**, *19*, 105–119. [CrossRef]
20. Saber, M.A.; El-Ganainy, A.A.; Shaaban, A.M.; Osman, H.M.; Ahmed, A.S. Trammel Net Size Selectivity and Determination of a Minimum Legal Size (MLS) for the Haffara Seabream, Rhabdosargus Haffara in the Gulf of Suez. *Egypt. J. Aquat. Res.* **2022**, *48*, 137–142. [CrossRef]
21. Beauchamp, D.A.; Parrish, D.L.; Whaley, R.A. *Coldwater Fish in Large Standing Waters*; Standard Methods for Sampling North American Freshwater Fishes; American Fisheries Society: Bethesda, MD, USA, 2009; pp. 97–117.
22. Chen, D. *The Handbook for Monitoring Acquatic Resources in the Yangtze River Basin*; China Agriculture Press: Beijing, China, 2021; pp. 33–42. (In Chinese)
23. Team, R.C. R: A Language and Environment for Statistical Computing. Available online: http://www.R-project.org (accessed on 8 February 2023).
24. Harrison, X.A.; Donaldson, L.; Correa-Cano, M.E.; Evans, J.; Fisher, D.N.; Goodwin, C.E.D.; Robinson, B.S.; Hodgson, D.J.; Inger, R. A Brief Introduction to Mixed Effects Modelling and Multi-Model Inference in Ecology. *PeerJ* **2018**, *6*, e4794. [CrossRef]
25. Hartig, F. DHARMa: Residual Diagnostics for Hierarchical (Multi-Level/Mixed) Regression Models [Online]. R Foundation for Statistical Computing, Vienna, Austria. Available online: https://cran.r-project.org/web/packages/DHARMa/vignettes/DHARMa.html (accessed on 8 February 2023).
26. Bates, D.; Mächler, M.; Bolker, B.; Walker, S. Fitting Linear Mixed-Effects Models Using Lme4. *J. Stat. Softw.* **2015**, *67*, 1–48. [CrossRef]
27. Nakagawa, S.; Schielzeth, H. A general and simple method for obtaining R2 from generalized linear mixed-effects models. *Methods Ecol. Evol.* **2012**, *4*, 133–142. [CrossRef]
28. Barton, K. Mu-MIn: Multi-Model Inference. R Package Version 0.12. 2/r18. 2009. Available online: http://R-Forge.R-project.org/projects/mumin/ (accessed on 8 February 2023).
29. He, P.; Pol, M. Fish behaviour near gillnets: Capture processes and influencing factors. In *Behaviour of Marine Fishes*; He, P., Ed.; Wiley-Blackwell: Ames, IA, USA, 2010; pp. 205–236.
30. Regier, H.A.; Robson, D.S. Selectivity of gill nets, especially to lake whitefish. *J. Fish. Res. Board Can.* **1966**, *23*, 423–454. [CrossRef]
31. Prchalová, M.; Mrkvička, T.; Peterka, J.; Čech, M.; Berec, L.; Kubečka, J. A Model of Gillnet Catch in Relation to the Catchable Biomass, Saturation, Soak Time and Sampling Period. *Fish. Res.* **2011**, *107*, 201–209. [CrossRef]

32. Reis, E.G.; Pawson, M.G. Fish Morphology and Estimating Selectivity by Gillnets. *Fish. Res.* **1999**, *39*, 263–273. [CrossRef]
33. Olin, M.; Kurkilahti, M.; Peitola, P.; Ruuhijärvi, J. The Effects of Fish Accumulation on the Catchability of Multimesh Gillnet. *Fish. Res.* **2004**, *68*, 135–147. [CrossRef]
34. Yimer, M.A.; Cao, L.; Shen, J.-Z.; Zhang, E. Age, Growth, Maturity and Mortality of the Tapetail Anchovy Coilia Brachygnathus (Engraulidae) in Lake Honghu, China. *J. Fish Biol.* **2023**, *2*, 1–12. [CrossRef]
35. Fang, D.; Yang, H.; Zhang, H.; Wu, J.; Wei, Q. Fish community structure and diversity in the middle reaches of the Yangtze River. *Shuichan Xuebao* **2023**, *47*, 154–170. (In Chinese)
36. Butler, S.E.; Freedman, J.A.; Diana, M.J.; Wahl, D.H. Evaluation of gears for sampling different life stages of asian carp. (presentation). In Proceedings of the 143rd Annual Meeting of the American Fisheries Society, Little Rock, AR, USA, 8–14 September 2013.
37. Harley, S.J.; Myers, R.A.; Dunn, A. Is Catch-per-Unit-Effort Proportional to Abundance? *Can. J. Fish. Aquat. Sci.* **2001**, *58*, 1760–1772. [CrossRef]
38. Olin, M.; Tiainen, J.; Kurkilahti, M.; Rask, M.; Lehtonen, H. An Evaluation of Gillnet CPUE as an Index of Perch Density in Small Forest Lakes. *Fish. Res.* **2016**, *173*, 20–25. [CrossRef]
39. Savina, E.; Krag, L.A.; Frandsen, R.P.; Madsen, N. Effect of Fisher's Soak Tactic on Catch Pattern in the Danish Gillnet Plaice Fishery. *Fish. Res.* **2017**, *196*, 56–65. [CrossRef]
40. Plumlee, J.D.; Roskar, G.; Craig, J.K.; Fodrie, F.J. Assessing the Catch Efficiency of Predators in the Presence of Prey Using Experimental Gillnets in a Temperate Estuary. *Fish. Res.* **2022**, *253*, 106383. [CrossRef]
41. Stergiou, K.I.; Moutopoulos, D.K.; Soriguer, M.C.; Puente, E.; Lino, P.G.; Zabala, C.; Monteiro, P.; Errazkin, L.A.; Erzini, K. Trammel net catch species composition, catch rates and métiers in Southern European waters: A Multivariate Approach. *Fish. Res.* **2006**, *79*, 170–182. [CrossRef]
42. Borgstrøm, R.; Bergum, K.; Børresen, T.E.; Svenning, M.A. Gillnet Catchability of Brown Trout Salmo Trutta Is Highly Dependent on Fish Size and Capture Site. *Fauna Norv.* **2019**, *39*, 30–38. [CrossRef]
43. Hamley, J.M. Review of Gillnet Selectivity. *J. Fish. Res. Board Can.* **1975**, *32*, 1943–1969. [CrossRef]
44. Gray, C.A.; Broadhurst, M.K.; Johnson, D.D.; Young, D.J. Influences of Hanging Ratio, Fishing Height, Twine Diameter and Material of Bottom-Set Gillnets on Catches of Dusky Flathead Platycephalus Fuscus and Non-Target Species in New South Wales, Australia. *Fish Sci.* **2005**, *71*, 1217–1228. [CrossRef]
45. Grimaldo, E.; Herrmann, B.; Jacques, N.; Vollstad, J.; Su, B. Effect of Mechanical Properties of Monofilament Twines on the Catch Efficiency of Biodegradable Gillnets. *PLoS ONE* **2020**, *15*, e0234224. [CrossRef]
46. Wanner, G.A.; Klumb, R.A.; Shuman, D.A.; Steffensen, K.D.; Stukel, S.; Utrup, N.J. Comparison of Green and White Mesh Trammel Nets and Gill Nets to Assess the Fish Community in a Large River. *N. Am. J. Fish. Manag.* **2010**, *30*, 12–25. [CrossRef]
47. Koike, A.; Matuda, K. Catching Efficiency of Trammel Net with Different Slacknesse and Mesh Sizes of Inner Net. *Nippon Suisan Gakkai Shi* **1988**, *54*, 221–227. [CrossRef]
48. Acosta, A.R.; Appeldoorn, R.S. Catching Efficiency and Selectivity of Gillnets and Trammel Nets in Coral Reefs from Southwestern Puerto Rico. *Fish Res.* **1995**, *22*, 175–196. [CrossRef]
49. Erzini, K.; Gonçalves, J.M.S.; Bentes, L.; Moutopoulos, D.K.; Casal, J.A.H.; Soriguer, M.C.; Puente, E.; Errazkin, L.A.; Stergiou, K.I. Size Selectivity of Trammel Nets in Southern European Small-Scale Fisheries. *Fish Res.* **2006**, *79*, 183–201. [CrossRef]