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The time-area fishing closure impacts on fish stock; Qiantang River before and after a four-month fishing closure

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Abstract

Fishing closures, commonly used to manage fisheries' catch, involve temporarily closing a body of water to particular fishing gears to control fishing effort and protect feeding and spawning areas. In recent years in Qiantang River of China, with the socio-economic development, protection of fish stock has become increasingly urgent. The year 2019 was the first year that Qiantang River was included in the unified fishing ban system for the south of Yangtze River basin. Here, fish captures and hydroacoustic surveys were carried out in the research area of Qiantang River in order to present comparative descriptions of the dominant fish species, the temporal changes of fish size, density, biomass, and distribution affected by the four-month fishing closure in 2019. The results showed that *Pseudobrama simoni* (Bleeker, 1864) was the most dominant species both before and after the closure by using the traditional capture method. The mean target strength (TS) of overall fish after closure was –50.28 ± 0.19 dB, which was lower than that before, resulting in a significantly shorter derived mean length (13.42 ± 0.74 cm). The mean fish density and calculated biomass after closure were both significantly higher than that before it. More than 50% of fish species were distributed in the water of 5–20 m depth after the closure, which likely occurred in water deeper than 20 m before. Meanwhile, fewer outliers were found in different depth categories after closure. It is concluded that the four-month closure in 2019 had a positive effect on fish size, density, and biomass, leading to protection of pelagic fishes and a more even distribution of fish.

Keywords

capture, fishing closure, fish resource, hydroacoustics, Qiantang River

Introduction

Given the increased use of modern fishing devices, many marine and freshwater fish resources are intensively exploited, resulting in rapid declines in some fish stock, affecting national economies, local communities' socio-economic well-being, and even their protein saecurity (Tang and Chen 2004; Branch et al. 2011). Subsequently, as a frequently used tool to control fishing effort and protect feeding and spawning areas, time-area fishing closure measure has been taken into account by governments of many countries. The effect of this measure has been assessed on fishing strategies regarding the fishing mode, variations in the population structure of a particular fish, incidental megafauna catches, and social well-being impacts (Britton 2014; Escalle et al. 2016; O'Farrell et al. 2016), but more rarely, on overall fish stock.

With the improvement of instrument performance and the development of computer software, the hydroacoustic method has increasingly become one of the main methods for fishery stock assessments due to its advantage of a rapid, economic and extensive coverage of the water cross-section at distances large enough not to affect fish behavior (Simmonds and MacLennan 2005), and now has been widely used in many bodies of water (Hale et al. 2008; Pavlov et al. 2010; Gerasimov et al. 2019; Guo et al. 2019).

In China, overfishing has also become one of the most serious problems in inland waters, as well as in oceans, and time-area fishing closure measures have been implemented since 2002. However, there has been no published assessment of overall fish stock following a closure in any rivers. Qiantang River is the largest river in Zhejiang province with a basin area of about 55 000 km^2. Except for drinking, it also has functions of power generation, flood control, irrigation, and tourism. The river was historically rich in fish resources, and fish harvests date back several centuries, the highest take was recorded in 1960 with 5318.2 tones. Although harvest strategies incorporating seasonal bans and restricted fishing grounds have been conducted several years before 2019, which were mainly conducted in different tributaries of the river, the effects were not ideal due to inconsistency. The year 2019 was the first year that Qiantang River was included in the unified fishing ban system for the south of Yangtze River basin. Subsequently, all captures except recreational fishing should be banned in the main channel of Qiantang River from 1 March through 30 June every year in the future. So, what happened to fish stock after a four-month fishing closure in 2019?

Here, based on the data obtained from field fish collections and hydroacoustic surveys before and after the implementation of fishing closure in the main channel of Qiantang River, we compared the distribution of species in the research area, identified the dominant species, and evaluated changes in the fish size, density, biomass, and distribution. Our findings will present a description of characteristics of the temporal change effected by the closure and provide a scientific basis for the protection of fish stock in the river.

Materials and methods

Research area

The study area belongs to a section of the main channel of Qiantang River, an important fishing stretch of water for fishermen in Fuyang and Tonglu counties (Fig. 1). This area is located between 29°52.6′N and 30°3.4′N, and 119°45.8′E and 119°59.5′E with a length of 29.9 km from east to west, with an average water depth of 14 m, a water volume of 0.31 km^3, and a maximum water depth of 35 m.

Field collection

Two fish removals were conducted by the hired fishermen in the research area in July 2018 and July 2019. The research area was evenly divided into 4 fish sampling sections, and the fishes were caught by deploying ground bamboo cages and multipanel nylon gillnets with mesh sizes ranging from 1 to 8 cm in each sampling section. All fishes caught were humanely euthanized, counted, and identified. Each specimen was measured to the nearest 0.1 cm (total length, L) and weighed to the nearest 0.01 g (weight, W) simultaneously.

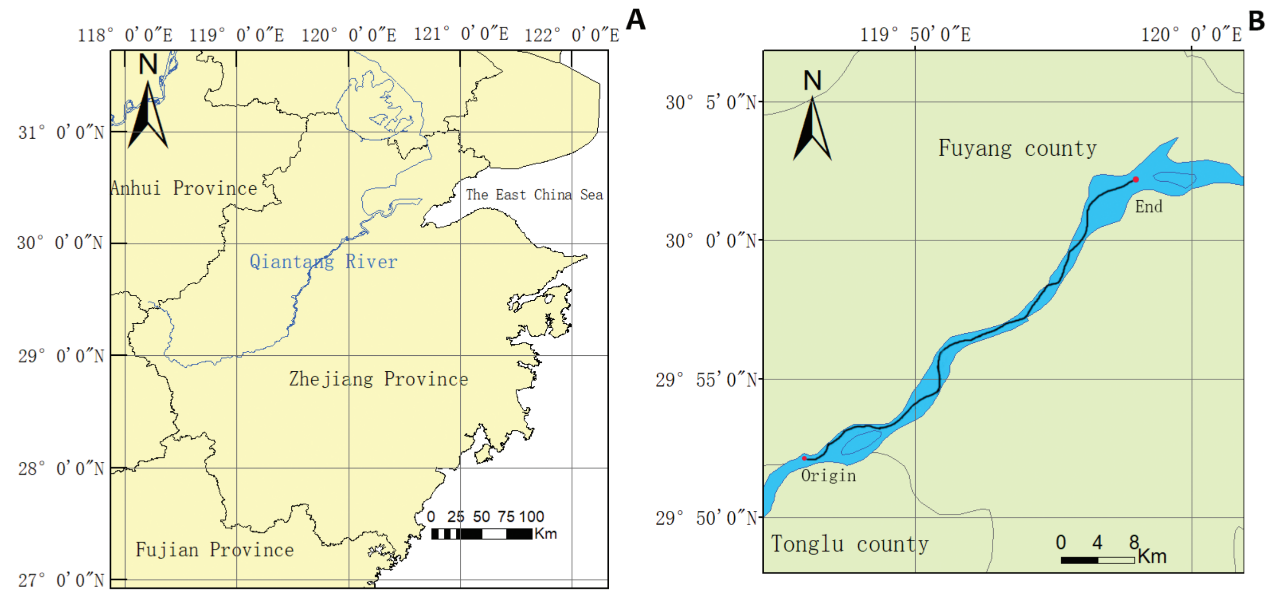

Figure 1. Location and hydroacoustic sampling transects in Qiantang River; (**A**) the location of Qiantang River in Zhejiang, China; (**B**) hydroacoustic sampling transects in Qiantang River.

The dominant species was assessed according to the formula of Pinkas et al. (1971):

$$IRI = (\%N + \%W) \times (\%FO)$$

where $\%N$ is the individual number of a certain species relative to the total number of fishes, $\%W$ is the weight of a certain species relative to the total weight of all fishes, and %FO is the frequency of occurrence of a certain species among the 4 fish sampling sections. According to the evaluation criterion of Zhang et al. (2016), the species is considered to be dominant when its IRI value is above 2000. For the most dominant fish species, the length–weight function,

$$W = aL^b$$

where W is the weight [g], L is the total length [cm], a is the intercept and b is the slope, was fitted with a simple linear regression model using log-transformed data.

Acoustic surveys

Two hydroacoustic surveys were conducted on 17 July 2018 and 19 July 2019 by using a BioSonics split-beam DT-X echosounder (BioSonics, Seattle, WA, USA) with a 201 kHz transducer, an integrated GPS (Garmin 17xHVS, Garmin Ltd., Olathe, KS, USA) and a computer. Surveys were conducted during daylight sunshine, and the daily mean value of water temperature was 26.3°C and 23.5°C, respectively. A fishing boat was hired to help surveys at a speed of 2.0–2.5 m/s in a zig-zag route. During surveys, the transducer face was held 40–50 cm below the water surface. A standard BioSonices 36 mm tungsten carbide sphere was used to calibrate the transducer before each survey (Foote et al. 1987). The degree of coverage (D) was calculated for each survey according to the formula of Aglen (1983). Here, the degree of coverage was 6.14 and 6.36, respectively, which were both higher than 2, indicating the sampling error of density estimates to be less than 10% (Godlewska et al. 2009). The usage method of instruments was consistent with the scheme of Guo et al. (2019).

Acoustic data analysis

The hydroacoustic data were analyzed using BioSonics Visual Analyzer software 4.1 (BioSonics, Seattle, WA, USA), consistent with the scheme of Guo et al. (2019). The fish tracking parameters were set to values in Table 1. Only data between 1.5 m of the transducer and 0.5 m off the bottom were used in order to exclude dead zones. Fish density estimates were calculated by echo integration, defined as the summation of the volume backscattering strength (Sv) divided by the backscattering cross-section (σ_{bs}), derived from the mean echo intensity (target strength, TS) of individual fish. With set appropriate threshold (–60 dB) and manual corrected, data for each transect were cleared of noise (Zhou et al. 2016). The integration interval was set to 1200 pings.

Table 1. Parameter settings for the Bisonics Visual Analyzer.

Parameter	Setting
Echo threshold [dB]	–60
Tracking window [m]	1.79
Min detection range [m]	0
Max detection range [m]	50
Correlation factor	0.9
Pulse width factor	3
Min pulse width	0.75
Max plus width	3
Max ping gap	2

Calculation of fish size and biomass

Based on single echo detections (SED), the TS distributions were examined. The received echo signals were compensated depending on their range (R)[m] by the time-varied gain (TVG). A 40 log(R) TVG was applied to measurements of TS, whereas a 20 log(R) TVG was used to the measurements of Sv used when echo integration. Then, the mean value of TS (based on SED from –60 dB to –30 dB in 2 dB bins) was converted to mean length of tracked fish using the empirical formulas for TS–length relation (Foote 1998); mean length was converted to weight using the calculated length–weight function, $W = aL^b$, for the most dominant fish species; the weight was multiplied by the total density of transects; and the mean weight of the transects was then calculated as the mean biomass.

Statistical data analysis

Statistical analyses were performed using SPSS 16.0 and Excel 2007. Data are presented as mean ± standard error of the mean (SE). Prior to analysis, all data were tested for homogeneity (Levene's test). The nonparametric Kruskal–Wallis H test or one-way ANOVA were used to analyze the effects of fishing closure on mean TS, length, density, and biomass. To compare differences in fish density, water depths were divided into five intervals: 0–5 m, 5–10 m, 10–15 m, 15–20 m, 20–25 m, and >25 m. A two-way ANOVA was also performed to test the effects of water depth and fishing closure on fish densities. All tests were considered significant at a probability level of $P < 0.05$ (95% confidence). Box plot was performed in R 3.6.1 environment (R Development Core Team 2010).

Results

Fish biodiversity resulting from traditional capture method

In total, 47 and 44 fish species were identified before and after fishing closure respectively, both representing

9 orders and 14 families. *Pseudobrama simoni* (Bleeker, 1864) was found to be the most dominant species with the highest IRI values of 2965.31 and 2867.78, respectively, and the estimated length–weight relation (LWR) parameters *a* and *b* of this fish species were 0.0256 and 2.8117, respectively, indicating the LWR equation as:

$$W = 0.0256 \times L^{2.8117}$$
$$(R^2 = 0.957,\ n = 235).$$

However, subdominant species and common species were found to be changed. Three subdominant species were *Distoechodon tumirostris* Peters, 1881 (IRI = 1581.73), *Carassius auratus* (Linnaeus, 1758) (IRI = 1128.68), and *Squalidus argentatus* (Sauvage et Dabry de Thiersant, 1874) (IRI = 1091.01) before fishing closure, which changed to be *Coilia nasus* Temminck et Schlegel, 1846 (IRI = 1373.68), *Hypophthalmichthys molitrix* (Valenciennes, 1844) (IRI = 1106.22), and *Cyprinus carpio* Linnaeus, 1758 (IRI = 1003.29) after closure. Meanwhile, the first four common species, including *Tachysurus nitidus* (Sauvage et Dabry de Thiersant, 1874) (IRI = 991.73), *Cyprinus carpio* (IRI = 660.82), *Megalobrama terminalis* (Richardson, 1846) (IRI = 515.49), and *Hypophthalmichthys nobilis* (Richardson, 1845) (IRI = 500.08) changed to be *Tachysurus nitidus* (IRI = 953.76), *Carassius auratus* (IRI = 911.04), *Eleotris oxycephala* Temminck et Schlegel, 1845 (IRI = 753.00), and *Megalobrama terminalis* (IRI = 688.85) after closure, two species of which were different.

Fish size distribution

Results of the two hydroacoustic surveys showed a significant difference ($H_{2,\ 632}$ = 18.797, $P < 0.05$), with the mean TS before fishing closure (–49.17 ± 0.21 dB) greater than that after it (–50.28 ± 0.19). According to the formula, the derived mean lengths before and after closure were 15.26 ± 0.48 cm and 13.42 ± 0.74 cm, respectively, which also showed significant temporal differences (one-way ANOVA, $F_{1,\ 632}$ = 4.567, $P < 0.05$).

Echoes of more than –58 dB target strength were considered fish. The TS before and after the fishing ban both ranged from –58 dB to –34 dB. To compare differences in fish population sizes, fishes were divided into small-, mid-, and large-sized categories, based on their length (TS conversion). TS distributions varied between two surveys. Before closure, mid-sized fish of TS –50 to –38 dB (≈11–48 cm) accounted for 59.81% of the population, while small-sized fish under –50 dB accounted for 38.51% of all fish (Fig. 2). This was a little different from the results obtained after closure, of which mid-sized fish accounted for 58.86%, while small-sized fish 40.24% (Table 2).

Table 2. Proportional composition of fish populations before and after the fishing closure.

Size class [cm]	Before closure [%]	After closure [%]
Small-size (≈7–11)	38.51	40.24
Med-size (≈11–48)	59.81	58.86
Large-size (>48)	1.68	0.90

Fish density and biomass

Fish density after the fishing closure (3997.4 ± 466.89 fish/ha) was significantly greater than that before it (1716.4 ± 142.47 fish/ha) ($H_{2,\ 632}$ = 13.086, $P < 0.05$). The mean calculated biomass after closure (3238.1 ± 2543.9 kg/ha) was also significantly higher than that before closure (1282.2 ± 323.37 kg/ha) (one-way ANOVA, $F_{1,\ 632}$ = 3.673, $P < 0.05$).

Relation between water depth and fish density

More than 50% of fish species were found in the >20 m category before closure. While fish gradually moved towards the upper water layer, leading to the most distributed

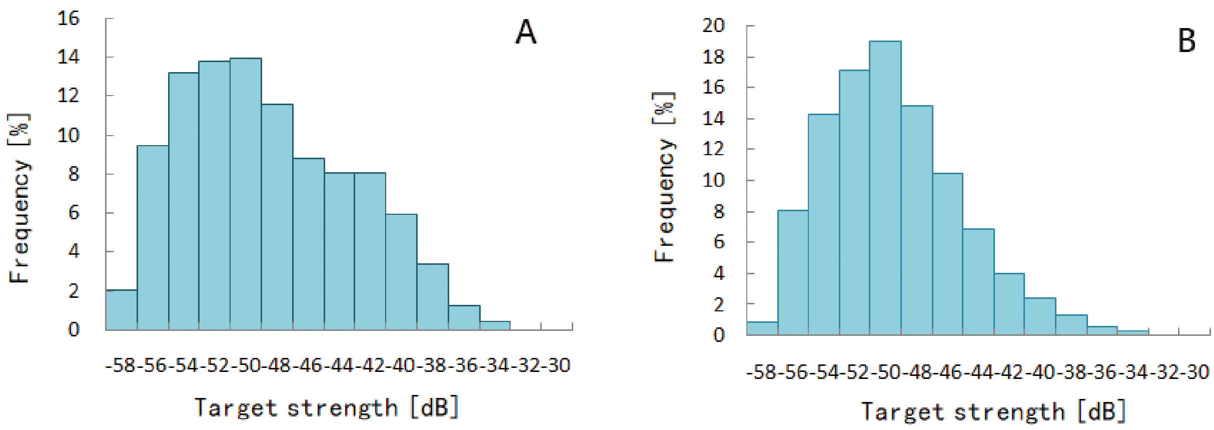

Figure 2. Frequency distribution of fish tracks detected by acoustic target strength (**A**) before and (**B**) after the closure of Qiantang River in Zhejiang, China.

layers of fish being located at 15–20 m, 5–10 m, and 10–15 m depth after closure, accounting for 24.95%, 20.44%, and 18.30% of the total fish in the research area, indicating a wider spread of fish (Table 3). However, the arithmetic means of density was not significantly affected by water depth ($F_{5,\,1850} = 1.855$, $P > 0.05$), but affected by the fishing closure ($F_{1,\,1850} = 6.571$, $P < 0.05$). As showed in Fig. 3, the medians of all transects in different depth categories after closure were all larger than those before closure, indicating a higher mean fish density after closure. Meanwhile, fewer outliers were found in six different depth categories after closure than before, indicating a more discrete density distribution of the fish before closure.

Table 3. Percentage of fish distributed in different depth categories before and after the fishing closure.

Depth category [m]	Before closure [%]	After closure [%]
0–5	3.19	3.48
5–10	6.79	20.44
10–15	17.36	18.30
15–20	18.69	24.95
20–25	21.55	17.59
>25	32.42	15.25

Discussion

Effects of time-area closure on fish stock

With a time-area closure, an area of water is closed to fishing with particular fishing gears during certain time periods. Originally, a time-area closure is commonly focusing on a single, target species and a single fishery (e.g., parrotfish, shrimp, tropical tuna) (Armsworth et al. 2011; O'Farrell et al. 2016), and now used to manage spatially and temporally acute bycatch problems (Goodyear 1999). The closures have been introduced to manage stocks of fish resources in many countries as well as other concurrent measures, e.g., restricting fishing gear, artificial propagation, and releasing (Torres-Irineo et al. 2011; Escalle et al. 2016). Tang and Chen (2004) confirmed that the timing of harvesting has a strong impact on the persistence of fish population, on the volume of mature fish stock, and on the maximum annual-sustainable yield. O'Farrell et al. (2016) found that the sex ratios of four parrotfish species—*Sparisoma viride* (Bonnaterre, 1788), *Sparisoma aurofrenatum* (Valenciennes, 1840), *Scarus vetula* Bloch et Schneider, 1801, and *Scarus taeniopterus* Lesson, 1829—recovered rapidly in Bermuda following a fishing closure, with male proportions equilibrated at values ranging from 0.36 to 0.54 within 3–4 years, similar to those reported at unfished sites in the region. Nevertheless, the consequences in terms of changes in fishing strategies and effort reallocation may not always be as expected (Hiddink et al. 2006; Torres-Irineo et al. 2011; Escalle et al. 2016). Thus, the optimal management of the time-area regulation, which has a direct relation to sustainable development, should receive much attention, to sustain fisheries at a good level of productivity and meet economic goals.

The necessity of a time-area fishing closure in Qiantang River

In recent years in Qiantang River, with the socio-economic development, protection of fish stock has become increasingly serious. Although modern gears in the river are limited to gillnets, which are three-tiered with mesh sizes varying from 1 to 8 cm, the fishing mode results in indiscriminate harvesting of undersized and non-tar-

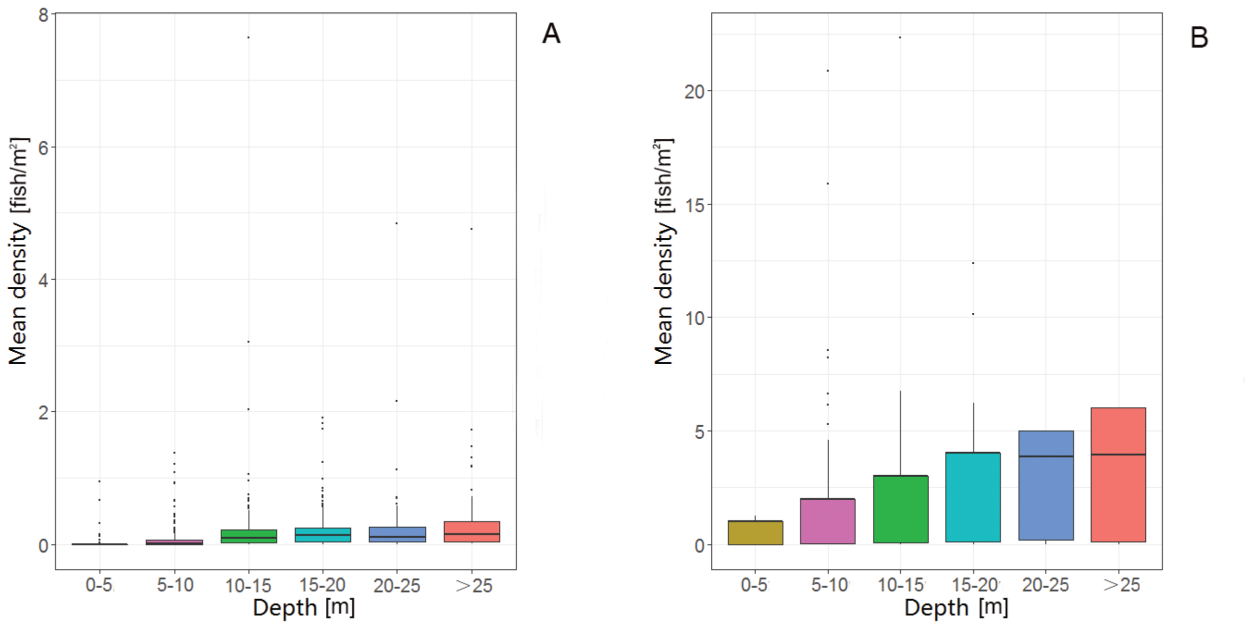

Figure 3. Acoustic mean fish density distribution at different water depth categories of Qiantang River in Zhejiang, China (**A**) before and (**B**) after the closure.

get species. The volume of fish stock in the river has declined, and the fish population structure is known to have changed. According to literature records, 136 fish species could be collected in this river in the late 1970s, receding to 122 species in 2018. Also, it has been found that some native fishes, e.g., *Acipenser sinensis* Gray, 1835, *Psephurus gladius* (Martens, 1862), *Tenualosa reevesii* (Richardson, 1846), and *Protosalanx hyalocranius* (Abbott, 1901), have disappeared and some alien ones, e.g., *Lepomis macrochirus* Rafinesque, 1819 and *Ictalurus punctatus* (Rafinesque, 1818), have become common. Thus, a fishing closure is conducive to the sustainable development of fishery in the river.

Effects of the fishing closure on fish biodiversity

In practice, the general closure period in Qiantang River included in the unified fishing ban system for the south of Yangtze River basin is from 1 March through 31 June, lasting for 4 months. It is confirmed that many economically important fish propagate at this time every year, and the aggregating behavior of breeding fish makes them more vulnerable to capture. Ley et al. (2002) found high diversity and productivity in tropical mangrove-dominated estuaries after closure. Here, the decline of three species after closure may be related to the contingency of fishing. Marks et al. (2015) also confirmed that total catch rates after the closure were significantly higher than before, differences in the size composition of species reflected both the increased survival of older fishes and higher recruitment success. Furthermore, we concluded that the conservation effect would be different for different fish. After a four-month fishing closure, the most dominant species remain unchanged. By contrast, the subdominant and common species changed to some extent. Different from small fishes (*Distoechodon tumirostris*, *Carassius auratus*, and *Squalidus argentatus*) contributing to subdominant species before closure, migratory species (*Coilia nasus*) and releasing species (*Hypophthalmichthys molitrix* and *Cyprinus carpio*) became the subdominant species after closure. Meanwhile, in addition to *Tachysurus nitidus* and *Megalobrama terminalis* remaining unchanged, the other two fishes of the first four common species changed. Thus, it seems that the presently reported fishing ban system could help migratory fish to propagate quickly, rather than being caught when spawning. At the same time, the fishing ban also led to a significant decrease of capture amount for releasing species during the closed period, resulting in a significant increase of abundance in the river.

Effects of the fishing closure on fish size, density, and biomass

It is accepted that such a closure can effectively protect fish spawning and hatching, and is also beneficial for the growth of fish larvae, to promote the natural supplement of fish resources and the self-restoration of the ecological environment in the waters (Tang and Chen 2004). Our results also confirmed this view by using the hydroacoustic method, which showed that the mean fish density and biomass after the closure were both significantly greater than that before it, while the derived mean length after the closure was lower than before. In detail, the mean length of fish decreased after the time-area ban, i.e., the proportions of small-sized fish increased (40.24% vs. 38.51%), while mid-sized (58.86% vs. 59.81%) and large-sized fish (0.90% vs. 1.68%) decreased in July 2019. The mean weight also showed the same trend. Reproduction protection during the closure could somewhat explain the reason. The 2019 fishing closure increased the survival of older fishes and most juvenile fishes, made them supplementary to the total population, increasing fish abundance and the small size composition of fish species.

Effects of the fishing closure on fish distribution

Fishing closure resulted in a change of fish distribution. It is accepted that time-area closures are often preferred for more mobile pelagic species (Hobday and Hartmann 2006; Grantham et al. 2008; Game et al. 2009), maybe due to their easy capture by gillnets with relatively fixed mesh size. In this study, a reduction of these pelagic fish stock, a more discrete size of uncaught fish, and a distribution in deeper water were disclosed before closure. For example, more than 50% of fish were concentrated in >20 m layer. However, after a four-month fishing closure, there was no significant difference in the distribution of water depth, with more than 50% of the fish distributed in 5–20 m layer. Thus, it seems that the fishing closure of 2019 protected the pelagic fish and made fish more evenly distributed.

Conclusion

The reasons for the time-area ban policy are biological, concerned with protecting and restoring fish stock, not only impacting catches of target species, but also non-target species that can be sold, and non-target species that do not have commercial value for fishermen (Chumchuen et al. 2016). Since 2019, a four-month fishing closure from 1 March through 31 June has been adopted in the main channel of Qiantang River of China every year, which has a great positive effect on fish size, density, and biomass, and makes fish more evenly distributed. Future continuous multi-year monitoring combining the traditional capture and hydroacoustic survey methods needs to be carried out, and more additional closure time may be needed except for the critical life stage of important endangered fish species, to realize the sustainable development of fish in the river.

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