remote sensing

MDPI

Article

Fishery Resource Evaluation with Hydroacoustic and Remote Sensing in Yangjiang Coastal Waters in Summer

Xiaoqing Yin [1,2], Dingtian Yang [1,3,4,*], Linhong Zhao [1,2], Rong Zhong [1,2] and Ranran Du [5]

[1] State Key Laboratory of Tropical Marine Environment, South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou 511458, China
[2] University of Chinese Academy of Sciences, Beijing 100049, China
[3] Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou), Guangzhou 511458, China
[4] Sanya Institute of Ocean Eco-Environmental Engineering, Sanya 572000, China
[5] Guangzhou Marine Geological Survey, Guangzhou 510075, China
* Correspondence: dtyang@scsio.ac.cn

Abstract: Yangjiang coastal waters provide vital spawning grounds, feeding grounds, and nursery areas for many commercial fish species. It is important to understand the spatial distribution of fish for the management, development, and protection of fishery resources. In this study, an acoustic survey was conducted from 29 July to 5 June 2021. Meanwhile, remote sensing data were collected, including sea surface temperature (SST), chlorophyll concentration (Chla), sea surface salinity (SSS), and sea surface temperature anomaly (SSTA). The spatial distribution of density and biomass of fish was analyzed based on acoustic survey data using the geostatistical method. Combining with remote sensing data, we explored the relation between fish density and the environment based on the GAMs model. The results showed that fish are mainly small individuals. The horizontal distri-bution of fish density had a characteristic of high nearshore and low offshore. In the vertical direc-tion, fish are mainly distributed in surface-middle layers in shallow waters (<10 m) and in middle-bottom layers in deeper waters (>10 m), respectively. The deviance explained in the optimal GAM model was 59.2%. SST, Chla, SSS, and longitude were significant factors influencing fish density distribu-tion with a contribution of 35.3%, 11.8%, 6.5%, and 5.6%, respectively. This study can pro-vide a scientific foundation and data support for rational developing and protecting fishery re-sources in Yangjiang coastal waters.

Keywords: Yangjiang coastal waters; fishery resources; geostatistics; GAMs; remote sensing

Citation: Yin, X.; Yang, D.; Zhao, L.; Zhong, R.; Du, R. Fishery Resource Evaluation with Hydroacoustic and Remote Sensing in Yangjiang Coastal Waters in Summer. *Remote Sens.* **2023**, *15*, 543. https://doi.org/10.3390/rs15030543

Academic Editors: Luis González Vilas, Jesus Torres Palenzuela and Laura González García

Received: 18 November 2022
Revised: 11 January 2023
Accepted: 14 January 2023
Published: 17 January 2023

1. Introduction

Coastal waters not only have high primary production and abundant fish resources, but also provide spawning ground, feeding ground, and nursery areas for commercial fish species [1]. However, fish in coastal zones are facing habitat destruction and fragmentation [2,3], declining resources [4,5], and less diversity [6], on account of several factors, including overfishing [7,8], marine pollution, aquaculture [9], and climate change [10,11]. Effective and accurate monitoring and assessment of fish resources are conducive to sustainable development, utilization, and conservation of fishery resources. Hydroacoustics is an important method for studying fish populations, which could provide fishery infor-mation about the size, abundance, biomass, and spatial distribution of fish [12–17]. When compared with traditional sampling methods, the technology has the advantages of being fast and efficient, having high accuracy, and inflicting no damage on fishery resources [18–20]. With advances in technology, hydroacoustic has been widely used to assess and manage fisheries in the ocean [21–26].

However, the abundance and biomass of fish, obtained from acoustic data, are cross-section data. To obtain continuous distribution data of fish abundance and biomass, in-terpolation is an option. The distribution of organisms and natural variables usually has various spatial heterogeneities and autocorrelations [27–29]. Classical statistical methods do not consider this. On the other hand, geostatistical interpolation methods are built on the spatial autocorrelation of observed data and the spatial variability of natural phenom-ena. The theoretical basis and tool for geostatistics [30] are the regionalized variable theory and variance function. Fish abundance or biomass coming from hydroacoustics, com-bined with the geostatistical method, was regarded as the best option to simulate species distribution or spatial dependence of biomass and environmental factors [31–36].

The environment influences the distribution of fish [37]. Satellite remote sensing is an essential tool for studying the ocean [38], providing a huge amount of marine data, including biotic (chlorophyll, fluorescence, primary productivity, etc.) and abiotic (currents, eddies, water temperature, winds, waves, sea surface height, transparency, etc.), with the advantages of rapid, large-scale, long-time, and synchronous observation and easy acquisition [39,40]. Knowledge of the relationship between these environmental data and fishery data (catch, survey, etc.) is the foundation for assessing fishery resources and predicting variations in fishing grounds. Some research hold that fisheries have a com-plex, nonlinear, and nonadditive relation with the environment [41,42]. The generalized additive models (GAMs), proposed by Hastie [43], are powerful tools for dealing with the nonlinear relation between biological population and environmental variables. Based on this model, some exports and scholars have made a lot of research on the relationship between fish and the environment [44–51].

Yangjiang coastal waters have excellent water quality and well-developed aquaculture. However, with the development of seaside industries and aquaculture, the ecologi-cal environment of coastal waters has been facing challenges [52,53]. Based on the Guang-dong Provincial Marine Environment Bulletin, water quality in Yangjiang coastal waters has been declining in recent years; for example, in Haitou Bay and the southern waters of Dongping Fishing Port, the seawater quality standard has dropped from Level I in 2015 to Level IV in 2017 [54]. According to the Guangdong Provincial Offshore Wind Power Development Plan (2017–2030) (revised), several offshore windfarms will be built in Yangjiang coastal waters, which will often have impacts on the marine environment and marine fishery resources [55–57]. Habitat degradation has also been found in Hailing Bay [58]. Variations in the marine environment can affect fishery resources. However, few studies on fish have been made in this region. Zhang et al. [59] investigated the species, quantity, and distribution of fish larvae and eggs in 1998. Jia et al. [60] studied the conditi-on of fishery resources in Hailing bay and Zhenhai bay.

In this paper, the specific objectives were (1) to analyze the spatial distribution of fish density and biomass using the geostatistical method; (2) to investigate the relation be-tween fish density distribution and the environment. This is the first time that hydroa-coustics was used to investigate fishery resources in Yangjiang coastal waters. This study not only provides a scientific basis for fishery management in Yangjiang coastal waters but also provides fundamental data for the fishery big data platform in the future.

2. Data and Methods

2.1. Study Area

Yangjiang coastal waters, situated on the northern South China Sea, have a bathymetric range of 0–22 m (Figure 1). The climate is subtropical oceanic monsoon with high temperatures; rainy summers; and mild, variably rainy winters. The mean annual temperature is 22.5 °C; the mean annual precipitation is 2200 mm; the tide is an irregular sem-idiurnal tide, and the tidal mean annual difference is 1.57 m [53]. There are several rivers entering the sea, such as Moyang River, Nalong River, and Shouchang River. Superior natural conditions and diverse habitats such as estuaries, harbors, mudflats, and mangroves provide ideal places for economic animals such as fish, shrimp, and crabs to fish breed and grow. According to the results of the investigation of Jia et al. [60], the dominant fish species were mainly *Thrissa kammalensis*, *Stolephorus commersoni*, *Sardinella zunasi*, *Carangoides kalla*, and *Thrissa dussumieri* in the study area, and their proportion was 82.35% of the total catch.

These fish species are all warm-water small pelagic fishes and usually inhabit middle and upper water layers. Due to overfishing, these small pelagic fish have become the dominant species in many offshore regions [61–64]. These small pe-lagic fishes are coastal fish [65–67] with obvious seasonal migration characteristics: in spring and summer, they migrate to shallow coastal waters for spawning, baiting, growth, and development, and in autumn and winter, they migrate to the offshore sea for over- wintering.

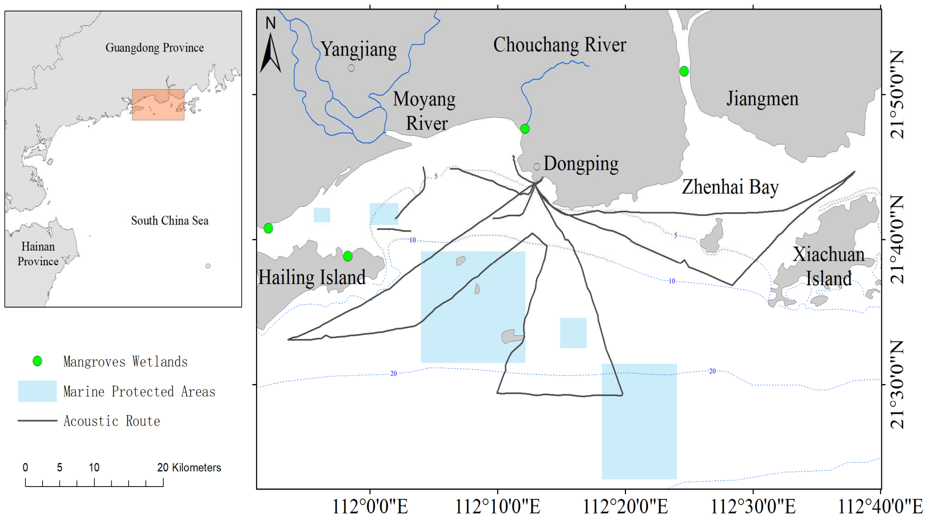

Figure 1. Location of the study area, which was highlighted in orange. These light blue areas are marine protected areas, and the green points represent mangrove wetlands.

2.2. Acoustic Data

We conducted an acoustic survey in Yangjiang Coastal waters during the day from 29 June to 5 July 2021. A split-beam BioSonic DT-X echosounder (frequency: 200 kHz, beam angle: 6.7°) was used to collect data. The transducer was fixed away from the ship engine. The transducer was oriented vertically and 0.8 m beneath the water surface. The Biosonics software Visual Acquisition was utilized for collecting acoustic echograms. Meanwhile, coordinates were perceived by GPS receivers. The main parameters are as follows: collection threshold was −130 dB; pulse duration was 0.4 ms.

Echo integration was used to calculate fish density. All data processing was carried out in the software Visual Analyzer 4.0. Analysis in Visual Analyzer followed the user guide [68]. Fish density (ρ) was calculated using the equation: $\rho = Sv/\sigma$. σ is the volume backscattering section and related to target strength (TS): $TS = 10\log(\sigma)$. Sv is the vol-ume backscattering strength (dB) and is as ten times the log of the sum of the gain-cor-rected reflected intensity samples (P), divided by the sum of the samples, times the system scaling constant (ρ_c): $Sv = 10\log(\rho_c * (\sum P/\sum samples))$. The bottom line was obtained by the bottom tracking algorithm. Then the bottom was transferred up 0.5 m to eliminate the interference of bottom noise. The echograms between 1.5 m below the transducer and the adjusted bottom line was processed. In order to shield the effect of other scatterers, such as plankton, etc., the target strength threshold was placed at –60 dB [69]. Single target analysis algorithms from the built-in software of Visual Analyzer were used to analyze acoustic data. Specific parameter settings are as follows: the minimum pulse coefficient is 0.75, the maximum pulse-back coefficient is 3, and the termination pulse width of –12 dB. Each analysis unit consists of 1200 pings, and the results of the analysis were including fish per unit area (*FPUA*), volume backscattering coefficient (*Sv*), fish per cubic meter (*FPCM*), backscattering cross section (σ), the starting coordinates, mean water depth, and *TS* distribution. Among them, *FPUA* and *FPCM* contain the following relationship: $FPUA = FPCM \times depth$.

2.3. Remote Sensing Data

Remote sensing data included sea surface temperature (SST), chlorophyll concentration (Chla), sea surface temperature anomaly (SSTA), and sea surface salinity (SSS). Among them, SST, Chla, and SSTA were collected from the Pacific fisheries science center of the National Oceanic and Atmospheric Administration (https://ocean-watch.pifsc.noaa.gov/ (accessed on 13 September 2022)). SST and SSTA data were from data products of the NOAA Coral Reef Watch Program, with a spatial resolution of 5 km and a temporal resolution of daily. Due to cloudy and rainy weather, multi-day data were not available, so Chla data from Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua data, with a spatial resolution of 4 km and a temporal resolution of 8 days were chosen. In order to be consistent with the resolution of acoustic data, ArcGIS was used to process the resolution of SST, Chla, and SSTA as 0.01° with the resample tool. SSS was downloaded from the Copernicus Marine Environment Management Service (http://marine.copernicus.eu (accessed on 13 September 2022)). The temporal and spatial resolution of SSS is daily and 1/12°, respectively. Remote sensing data of SST, Chla, SSTA, and SSS were extracted using MATLAB software in the study area.

2.4. Geostatistic Analysis

The variation function is defined as:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \quad (1)$$

In the formula, $\gamma(h)$ is semi-variance; h is lag distance, $z(x_i)$ is the observed value at sampled point x_i, $N(h)$ is the number of pairs separated by distance h [70]. The main specific process is as follows:

(1) Normality distribution test was performed. If the conduction of normal distribution was not satisfied, logarithmic, reciprocals, square roots, inverse square roots or Box-Cox transformations were available;
(2) Transformed data were modeled using the semi-variance function on the premise of isotropy. In general, there are 3 models: spherical, exponential, and Gaussian. The model is described by three parameters as follows [71]: (i) nugget, C_0, Y-axis inter-cept of the model; (ii) sill, $C_0 + C$, asymptote of the model; (iii) range, a, spatial de-pendence is apparent when the distance greater than the parameter;
(3) The parameters of residual sums of squares (RSS) and regression coefficient (r^2) are all important indicators that can reflect a fitting degree of model. The most suitable model had the highest r^2 and smallest RSS. Then, kriging interpolation was per-formed based on the final model;
(4) Verification of results. Cross-validation was adopted.

2.5. GAMs

In general, the equation of GAMs is as follows:

$$g(u_i) = \beta_0 + \sum_{i=1}^{n} f_i(x_i) + \varepsilon, \quad (2)$$

In the formula, $g(u_i)$ is a link function; u_i is response variable, and it represents FPUA in the paper; β_0, the intercept in y-axis; $f(x)$, a smooth function; x_i, the explana-tory variable, and it represents geographical and environmental factors in the paper (Table 1); ε, random error.

Table 1. The Description of environmental factors.

Variables	Units	Mean	Range	Description
SST	°C	29.65 ± 0.27	29.25–30.13	Sea surface temperature
Chlorophyll-a	mg/m^3	4.21 ± 2.20	0.37–10.53	Chlorophyll concentration
Salinity	psu	33.08 ± 0.45	31.90–33.51	Sea surface salinity
SSTA	°C	1.30 ± 0.25	0.89–1.72	Sea surface temperature anomaly
Depth	m	13.11 ± 4.82	5.86–22.3	Water depth

The collinearity between the environmental factors was tested by the variance inflation factor (VIF). If VIF > 10, the factor was removed [72]. With latitude, water depth, and sea surface temperature anomaly (SSTA) with larger VIF removed, the results are pre-sented in Table 2. Then, we adopted the stepwise method to add variables step by step (Table 3). The degree of model fitting is related to Akaike's information criterion (AIC) [73]. Finally, the model was selected when the value of AIC no longer decreased. These processes were performed with the software R.

Table 2. Collinearity analysis based on VIF.

Variables	VIF
Lon	1.051
SST	2.046
Chla	3.072
SSS	1.864

Table 3. Optimal model based on variables.

Model	AIC
log(FPUA + 1) ~ s(SST)	−50.442
log(FPUA + 1) ~ s(SST) + s(Chla)	−81.159
log(FPUA + 1) ~ s(SST) + s(Chla) + s(SSS)	−89.251
log(FPUA + 1) ~ s(SST) + s(Chla) + s(SSS) + s(Lon)	−104.401

3. Results

3.1. Size of Fish

The distribution of target strength (TS) was −58~−30 dB. The main range of TS was −58~−44 dB, which accounted for about 90.97% (Figure 2). On the basis of the formula of fish target strength and body length [74]: $TS = 19.1 \log 10(L) - 64.07$, the distribution range of body length of fish is about 2−11 cm, with a mean fish length of 5.24 cm, which indicates that fish are mainly small individuals in study areas.

Mean fish density was negatively correlated with water depth with a Pearson correlation coefficient of 0.63 (Figure 3a). Distribution of TS in different water depths showed a larger size of adult fish gathering in deeper water while juvenile fish were mainly distributed in shallow water (Figure 3b,c).

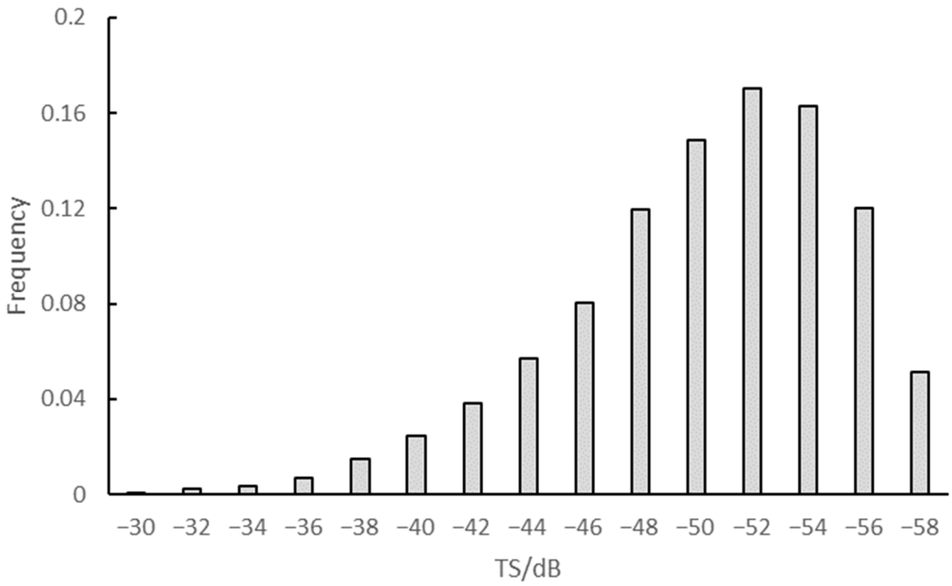

Figure 2. Distribution of Target Strength.

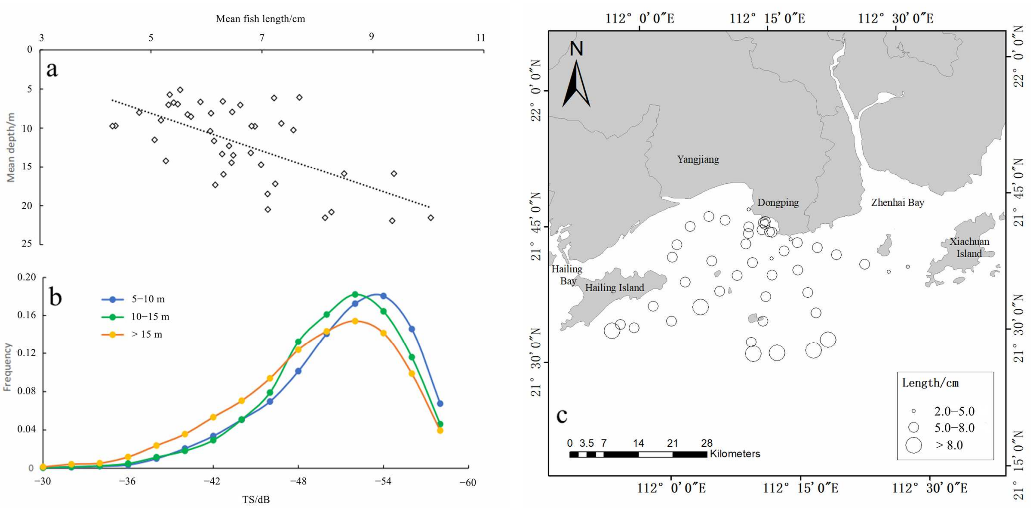

Figure 3. (**a**) Relationship between mean fish length and mean depth. (**b**) TS distribution in different water depth. (**c**) Spatial distribution of mean fish length in Yangjiang coastal waters.

3.2. Distribution of Fish Density and Biomass Based on Geostatistic

Fish density was expressed as fish per unit area (FPUA). Total backscattering cross sections (σ) in per unit volume can be quantified by volume backscattering coefficient (*Sv*). Thus, as a proxy of fish biomass [17], we use it to represent fish biomass in this paper.

As Table 4 shows, the optimal model for fish density and biomass are all exponential models. The nugget coefficient is an important indicator of the degree of spatial heterogeneity. The nugget coefficient of fish density was 0.273, while that of acoustic biomass was 0.498. This indicates that fish density and biomass all had moderate spatial auto-correlation.

The results of kriging interpolation and cross-validation are shown in Figure 4. Cross-validation results suggest that the fish density and acoustic biomass data predicted by the geostatistical model and the measured data that came from acoustic data had a regression coefficient of 0.63 and 0.61, respectively.

Table 4. Parameters of semi-variance function models.

Variable	Density			Biomass		
Model	Exponential	Spherical	Gaussian	Exponential	Spherical	Gaussian
Nugget (C_0)	0.0128	0.0048	0.0125	0.1213	0.0119	0.0301
Sill ($C_0 + C$)	0.0739	0.0729	0.0729	0.2436	0.1798	0.1802
Range (A)/m	5040	2820	2372.91	74,250	19,600	14,849.23
RSS	2.422×10^{-4}	3.423×10^{-4}	3.392×10^{-4}	3.67×10^{-3}	9.037×10^{-3}	8.994×10^{-3}
R^2	0.743	0.632	0.635	0.717	0.302	0.306
Nugget coefficient ($C_0/(C_0 + C)$)	0.273	0.066	0.171	0.498	0.066	0.167

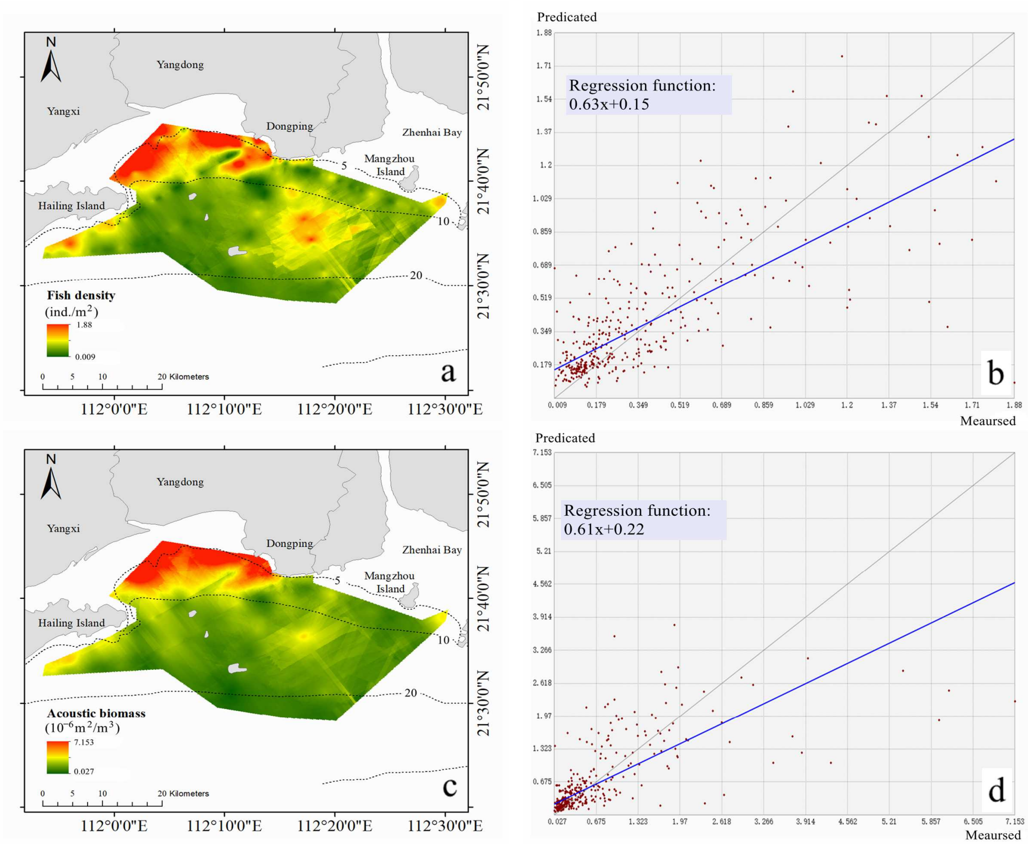

Figure 4. (**a**) Geostatistical interpolation result (density), (**b**) cross-validation (density), (**c**) geostatistical interpolation result (biomass), (**d**) cross-validation (biomass).

The range of fish density and acoustic biomass was 0.009–1.88 ind./m^2 and 0.027–7.153 10^{-6} m^2/m^3, with a mean value of 0.375 ind./m^2 and 0.638 × 10^{-6} m^2/m^3, respectively. The spatial distribution of acoustic biomass is similar to fish density. The distribution of fish density and biomass all had a characteristic of high nearshore and low offshore.

3.3. Vertical Fish Density Distribution

The parameter of FPCM was used to analyze the fish distribution vertically. Fish den-sity in shallow water areas (<10 m) is larger than that in deep water areas (>10 m) (Figure 5a). Water depth was stratified in units of 2 m. In the vertical direction, fish were mainly distributed in the surface and middle water layers when the water depth was less than 10 m (Figure 5b); fish were mainly distributed in middle and bottom water layers when the water depth was greater than 10 m (Figure 5c).

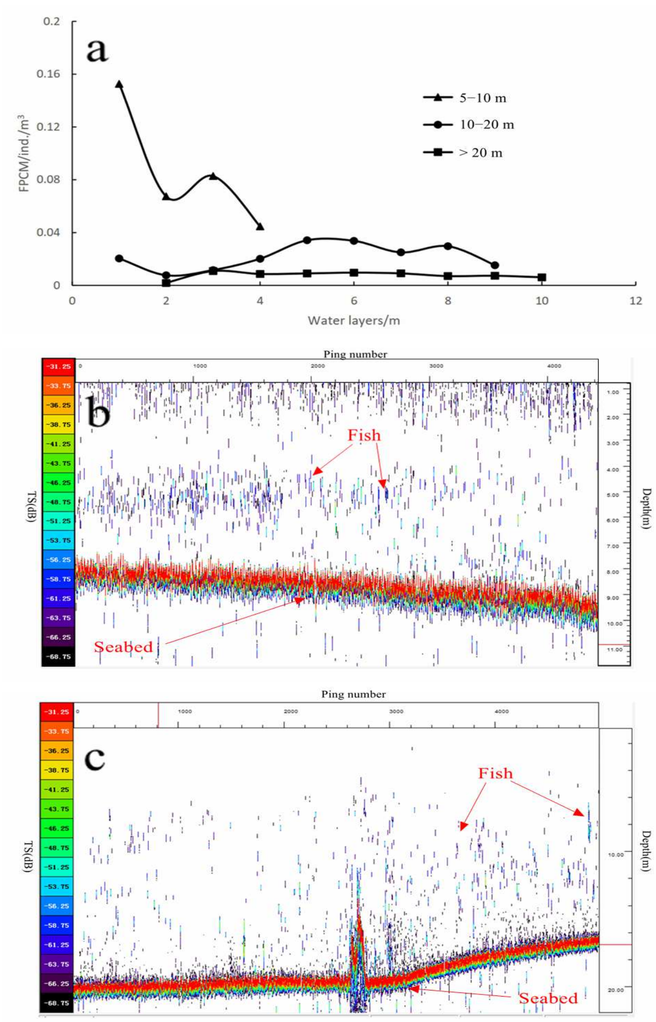

Figure 5. (**a**) Vertical distribution of fish density, (**b**) fish distribution in echogram (depth < 10 m), (**c**) fish distribution of in echogram (depth > 10 m). TS echograms are presented with a 40 log TVG.

3.4. Fish Density and Environmental Factors—GAM Model

The expression was as follows:

$$\log(FPUA + 1) \sim s(SST) + s(Chla) + s(SSS) + s(Lon), \quad (3)$$

Cumulation deviance explained by the optimal model for fish density is 59.2%. The contributions of factors affecting fish density are represented in Table 5. The results show that *SST* was the most influential factor and had a contribution of 35.3% (Table 5). Other factors successively are chlorophyll, *SSS*, and Longitude, with contributions of 11.8%, 5.6%, and 6.5%, respectively (Table 5). The F-test showed that all factors had a significant influence on fish density ($p < 0.01$).

SST had a maximum contribution of 35.3%. Fish density had a negative correlation with SST, and fish density declined with the increase of SST. In range of 29.25–29.45 °C and 29.45–30.13 °C, with the increase of SST, the confidence interval decreased and increased, respectively (Figure 6a). The contribution of chlorophyll was 11.8%. Fish densi-ty had a positive linear relation with chlorophyll density and increased with the increase of chlorophyll density in the range of 0.37–10.53 mg/m^3. When the range of chlorophyll density was 0.37–4 mg/m^3 and 4–10.53 mg/m^3, the confidence interval reduced and increased, respectively (Figure 6b). SSS had a contribution of 5.6%. In range of 31.9 to 32.4 PSU and 32.9 to 33.5 PSU, fish density declined with the increase of salinity; and in the field of 32.4 to 32.9 PSU, fish density increased with the increase of salinity. In range of 31.9

to 33 PSU, the confidence interval decreased. In the field of 33 to 33.5 PSU, the confidence interval first increased and then decreased (Figure 6c). The contribution of longitude was 6.5%. In range of 111.9°E to 112.2°E, fish density had a negative relation with longitude and decreased with the increase of longitude; in the range of 112.2°E–112.5°E, fish density was stable at a lower level. The confidence interval was reduced when the longitude was 111.9°E–112.1°E and increased when the longitude was 112.1°E–112.5°E (Figure 6d).

Table 5. The results of the optimal GAMs.

Variables	Edf	F	Accumulation of Deviance Explanation/%	Deviance Explanation of Each Factor/%	*p*
SST	2.266	24.499	35.3	35.3	9.23×10^{-11} ***
Chla	1.000	7.328	47.1	11.8	0.0077 **
SSS	6.284	5.444	52.7	5.6	1.34×10^{-5} ***
Longitude	2.466	5.795	59.2	6.5	7.68×10^{-4} ***

*** $p < 0.001$; ** $p < 0.01$.

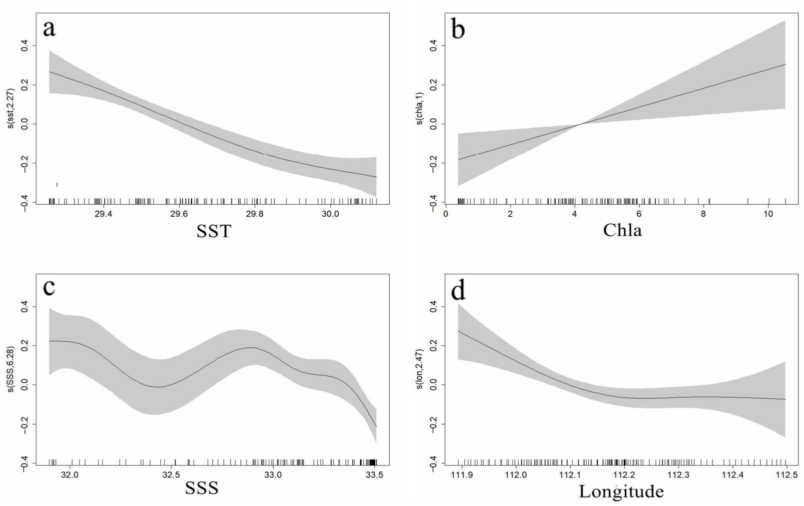

Figure 6. Effects of variables on fish density in the optimal model. (**a**) SST, (**b**) Chla, (**c**) SSS, (**d**) Longitude. s(x) is the spline smooth function in the *y*-axis, the values represent degree of freedom, and shaded areas indicate the 95% confidence interval.

4. Discussion

4.1. Size, Number and Distribution of Fish Resource

In this paper, we found that fish are mainly small individuals with a mean fish length of 5.24 cm in Yangjiang coastal waters. Several reasons account for the phenomenon. First, coastal waters are usually spawning and nursery areas of local and migratory fish. The breeding season for fish is usually in spring and summer. Second, according to the survey of Jia et al. [60], the dominant fish species were mainly small pelagic fish in shallow water. This phenomenon was also found in other regions. Fu et al. [75] also found that the mean fish length was 6.92 cm and the number of juvenile fish accounted for 85.86% in summer in coastal waters of northwest Beibu Gulf; Guo et al. [76] found that there were the largest mantissa density and smallest average individual quality of fish resource in Daya Bay as a result of small dominant fish species such as *Trachuurus japonicus*, *Culpanodon punctatus*, *Apogon lineatus*, and *leiognathus brevirostris*; Yan et al. [77] also found that the proportion of fish biomass with body weight less than 10 g reached 90.93% in summer in Huangmao Bay.

The distribution of fish density had a characteristic of high nearshore and low offshore. The increased number of juvenile fish in coastal waters is an important reason. In spring and summer, a large number of small pelagic fish migrate to shallow coastal waters for spawning. Higher productivity in coastal waters provides sufficient food for fish. Meanwhile, from May 1 to August 16 is the closed fishing season. Under these conditions, the number of adults and juvenile fish increases. Chen et al. [78] also pointed out that fish populations would grow rapidly under the conditions of no fishing pressure and rela-tively sufficient food.

In the vertical direction, we found that when the water depth < 10 m, fish was mainly distributed in the middle-surface water layers, and when the water depth > 10 m, fish were mainly distributed in middle-bottom water layers. First, shallow water has high pri-mary productivity and abundant food to attract fish to gather; second, fish in shallow water are mainly juvenile fish; third, predation pressure is less in shallow water. This phe-nomenon has also been found in the Yellow Sea [79] and the Pearl River Estuary [80].

The mean fish density in Yangjiang coastal waters in summer was 3.75×10^5 ind./km^2, which is larger than that in other regions in China (Table 6, Figure 7). First, bottom trawl was used in most studies. In general, fish at the bottom and near-bottom were investigated using bottom trawl, and fish in the whole water were investigated using hydroacoustics. Coupled with the selectivity of gear, bottom trawl may lead to an underestimation of fish density. Second, this may be related to perfect fishery protection measures and low fishing intensity. In order to protect marine organisms, several marine protected areas have been established. At the same time, recreational fishing and deep-sea fishing have been encour-aged to develop. These provide favorable conditions for the growth and reproduction of fisheries.

Table 6. Mean fish densities in coastal waters of China in summer.

Region	Time	Fish Density (10^5 ind./km^2)	Method	Source
Xinghua Bay	September 2008	0.582	Trawl	[81]
Min River Estuary	September 2008	1.588	Trawl	[81]
Dongshan Bay	August 2010	0.106	Trawl	[82]
Zhelin bay	August 2011	0.649	Hydroacoustic	[83]
Jiulong River Estuary	August 2013	0.571	Set and gill net	[84]
Qinzhou coastal waters	August 2016	1.248	Trawl	[85]
Zhejiang coastal waters	July 2015	2.055	Trawl	[86]
Lingshui Bay	August 2015	1.11	Hydroacoustic	[20]
Daya Bay	August 2015	1.066	Trawl	[76]
Sanmen Bay	June 2018	0.2888	Trawl	[87]
Oujiang estuary	August 2018	3.39	Trawl	[88]
Sansha Bay	July 2019	0.121	Set-net	[89]
Yangjiang coastal waters	July 2021	3.75	Hydroacoustic	This study

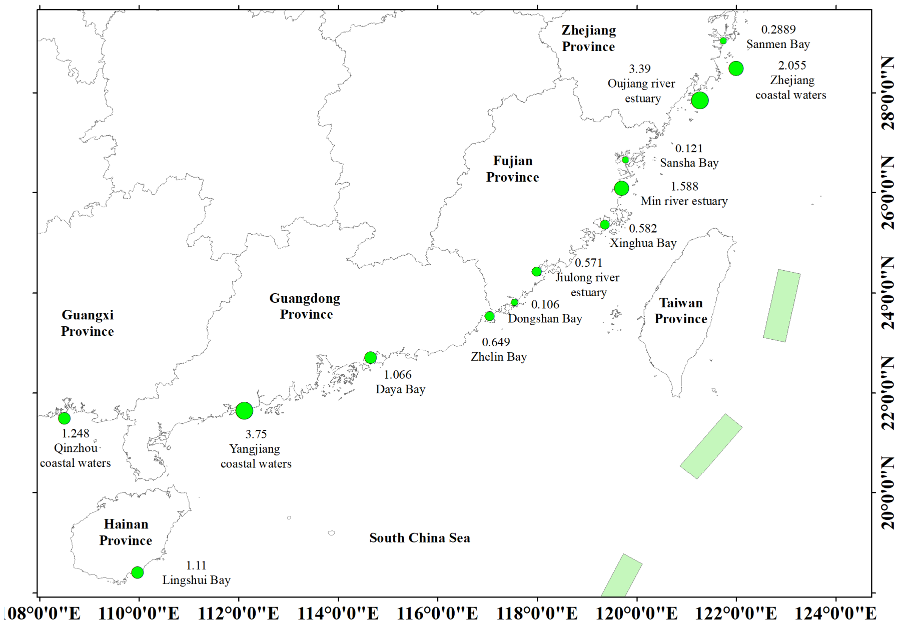

Figure 7. Mean fish densities in summer in different regions of China (Unit: 10^5 ind./m^2).

4.2. Relationship between Fish Density and Environmental Factors

For this article, GAMs results showed that SST, Chlorophyll, and SSS had significant impacts on fish density distribution. In these factors, SST was the most influential factor and had a contribution of 35.3%. We also found that fish density had a negative correlation with SST. With the increase in SST, fish density decreased. Water temperature not only affects the metabolism, growth, and reproduction of fish [90], but also affects fish activities (such as distribution and migration) [91]. In summer, fish are mainly warm-water and warm-temperature species offshore of the South China Sea [92]. Coastal waters have higher SST, which is not conducive to inhabitation for fish [78]. Temperature has also been viewed as the major factor influencing fish distribution in Maryland's coastal bays [93] and Zhoushan Islands [94].

Chlorophyll concentration was an important factor with a contribution of 11.8%. Fish density was positively associated with chlorophyll concentration. With the increase in chlorophyll concentration, fish density increased. Chlorophyll can reflect phytoplankton's biomass and can be used to estimate primary productivity [95]. Yangjiang has developed aquaculture in coastal waters. A large amount of nutrients salt from rivers carried, cage, and pond culture enter the bay, making plankton grow and multiply. Enough food and a suitable environment attract fish to gather. This is one of the reasons why fish density is high in coastal waters.

Sea surface salinity was also an important environmental factor with a contribution of 5.6%. This may be related to the presence of large numbers of juvenile fish in offshore waters. Compared with adult fish, juvenile fish are easily affected by salinity due to their incompletely developed organs [96]. Many studies have found that salinity is an import-ant factor affecting the distribution of larvae and juveniles [97–99]. Feng et al. [72] also found that salinity was an important factor influencing fish larvae density in western Guangdong water and the most suitable salinity range was 33.0–33.8 PSU. Fish density de-creased sharply when salinity is more than 33 PSU, this may be because that too-high salinity was not conducive to adult and juvenile fish. Salinity not only affects fish distribution [100], but also affects reproductive potential [101], species richness [102], community structure [103], and distribution pattern [104,105] of fish, especially in estuary.

4.3. Limitations and Prospects

In the study area, fish are mainly small pelagic fishes. In the daytime, fish are usually found close to the bottom [106], maybe in the dead zone; at night, fish usually leave the bottom and schools disaggregate [69,107,108]. In this paper, we only had acoustic survey data in the daytime. This may result in an underestimation of fish density. Meanwhile, the acoustic beam direction is vertical. In shallow water, small observation volume caused by the surface blind zone and the bottom dead zone [109] and fish avoidance caused by vessel noise [110] also led to an underestimation of fish density [111]. Thus, in order to estimate fish density accurately, in the future, we should add horizontal beam observation in shallow water and acoustic surveys at night.

Fish abundance is affected by a combination of physical factors (such as salinity, tem-perature, turbidity [112], dissolved oxygen [113–115], water depth [113], and chlorophyll [116]) and biotic factors (such as habitat [117], migration [118–120], and reproduction). The season is also an important factor [20,75,83], and fish density distribution and the influencing factors varied with it.

In this paper, we only analyzed the influence of several factors including SST, chlorophyll, and SSS on fish density in a short time. In the future, more environmental factors should be collected and considered to increase the accuracy of the model.

5. Conclusions

In this paper, we utilized acoustic data to analyze the spatial distribution of fish abundance and biomass using the geostatistical method. Then, the relationship between fish density and environmental factors was analyzed based on GAMs. The main conclusions can be drawn as follows:

(1) Fish are mainly small individuals in Yangjiang coastal waters in summer;
(2) The spatial distribution of fish density and acoustic biomass all had a characteristic of high nearshore and low offshore. Geostatistical analysis indicated that fish density and acoustic biomass had moderate spatial autocorrelation;
(3) In vertical direction, fish usually inhabit waters of upper-middle depth in shallow water areas (<10 m), and in deeper water areas (>10 m), fish usually inhabit waters in the middle and bottom;
(4) GAMs showed that SST, SSS, and longitude have a very significant correlation with fish density ($p < 0.001$), and chlorophyll has a significant correlation with fish density ($p < 0.01$).

Author Contributions: R.D. investigated; X.Y. investigated, processed and collected data, wrote the original draft manuscript; D.Y., R.Z. and L.Z. reviewed and edited the draft manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research is jointly supported by the National Key R&D Program of China (grant no. 2022YFC3104901), and Hainan Province Science and Technology Plan Sanya Yazhou Bay Science and Technology City Science and Technology Innovation Joint Project (grant no. 2021CXLH0014), and the Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou) (grant no. GML2019ZD0602).

Data Availability Statement: The datasets for this study are available from the corresponding author upon reasonable request.

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

References

1. Hutchings, L.; Beckley, L.E.; Griffiths, M.H.; Roberts, M.J.; Sundby, S.; Lingen, C. Spawning on the edge: Spawning grounds and nursery areas around the southern African coastline. *Mar. Freshw. Res.* **2002**, *53*, 307–318. [CrossRef]
2. Yu, J.; Chen, Z.; Xu, S. Land reclamation and its impact on fisheries resources in the Nansha wetland of Pearl River Estuary. *J. Fish. Sci. China* **2016**, *23*, 661–671.
3. Ding, X.; Shan, X.; Chen, Y.; Li, M.; Li, J.; Jin, X. Variations in fish habitat fragmentation caused by marine reclamation activities in the Bohai coastal region, China. *Ocean Coast. Manag.* **2020**, *184*, 105038. [CrossRef]
4. Yu, C.; Yu, C.; Zhang, F.; Ning, P. Fish species and quantity off southern Zhejiang East China Sea. *Oceanol. Limnol. Sin.* **2009**, *40*, 353–360.
5. Chen, Z.; Xu, S.; Qiu, Y. A retrospective analysis of fishery resources and ecosystem evolution in the Beibu Gulf. In Proceedings of the Annual Academic Conference of Chinese Aquatic Society, Nanchang, China, 9–10 September 2017.
6. Cheng, J.; Ding, F.; Li, S.; Yan, L.; Li, J.; Ling, Z. Changes of Fish Community Structure in the Coastal Zone of the Northern Part of East China Sea in Summer. *J. Nat. Res.* **2006**, *21*, 775–781.
7. Haimovici, M.; Cardoso, L.G. Long-term changes in the fisheries in the Patos Lagoon estuary and adjacent coastal waters in Southern Brazil. *Mar. Biol. Res.* **2017**, *13*, 135–150. [CrossRef]
8. Thykjaer, V.S.; Rodrigues, L.D.; Haimovici, M.; Cardoso, L.G. Long-term changes in fishery resources of an estuary in southwestern Atlantic according to local ecological knowledge. *Fish. Manag. Ecol.* **2020**, *27*, 185–199. [CrossRef]
9. Holmer, M. Environmental issues of fish farming in offshore waters: Perspectives, concerns and research needs. *Aquacult. Environ. Interact.* **2010**, *1*, 57–70. [CrossRef]
10. Brander, K.M. Global fish production and climate change. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 19709–19714. [CrossRef] [PubMed]
11. Allison, E.H.; Perry, A.L.; Badjeck, M.C.; Adger, W.N.; Brown, K.; Conway, D.; Halls, A.S.; Pilling, G.M.; Reynolds, J.D.; Andrew, N.L. Vulnerability of national economies to the impacts of climate change on fisheries. *Fish Fish.* **2009**, *10*, 173–196. [CrossRef]
12. Moose, P.H.; Throne, R.E.; Nelson, M.O. Hydroacoustics techniques for fishery resource assessment. *Mar. Technol. Soc. J.* **1971**, *5*, 35.
13. Thorne, R.E.; Hedgepeth, J.B.; Campos, J. Hydroacoustic observations of fish abundance and behavior around and artifical reef in costarica. *Bull. Mar. Sci.* **1989**, *44*, 1058–1064.
14. Stanley, D.R.; Wilson, C.A. Variation in the density and species composition of fishes associated with three petroleum platforms using dual beam hydroacoustics. *Fish. Res.* **2000**, *47*, 161–172. [CrossRef]
15. Godlewska, M.; Colon, M.; Doroszczyk, L.; Długoszewski, B.; Verges, C.; Guillard, J. Hydroacoustic measurements at two frequencies: 70 and 120 kHz consequences for fish stock estimation. *Fish. Res.* **2009**, *96*, 11–16. [CrossRef]

16. Lian, Y.; Huang, G.; Godlewska, M.; Cai, X.; Li, C.; Ye, S.; Liu, J.; Li, Z. Hydroacoustic estimates of fish biomass and spatial distributions in shallow lakes. *Chin. J. Oceanol. Limnol.* **2017**, *36*, 587–597. [CrossRef]
17. Jack, P.E.; Mohsin, A.A.; Mohamed, A.; Mark, W.; Jamie, H.; John, T.; Brad, E.; Ibrahim, A.M.; Mohannadi, M.; Lewis, L.V. Hydroacoustics to examine fish association with shallow offshore habitats in the Arabian Gulf. *Fish. Res.* **2018**, *199*, 127–136.
18. Guillard, J.; Vergès, C. The Repeatability of Fish Biomass and Size Distribution Estimates Obtained by Hydroacoustic Surveys Using Various Sampling Strategies and Statistical Analyses. *Int. Rev. Hydrobiol.* **2007**, *92*, 605–617. [CrossRef]
19. Zhou, L.; Zeng, L.; Fu, D.; Xu, P.; Zeng, S.; Tang, Q.; Chen, Q.; Chen, L.; Li, G. Fish density increases from the upper to lower parts of the Pearl River Delta, China, and is influenced by tide, chlorophyll-a, water transparency, and water depth. *Aquat. Ecol.* **2016**, *50*, 59–74. [CrossRef]
20. Li, B.; Chen, G.; Yu, J.; Wang, D.; Guo, Y.; Wang, Z. The acoustic survey of fisheries resources for various seasons in the mouth of Lingshui Bay of Hainan Island. *J. Fish. China* **2018**, *42*, 544–566.
21. Coombs, R.F.; Cordue, P.L. Evolution of a stock assessment tool acoustic surveys of Spawning Hoki (*Macruronus novaezelandiae*) off the west coast of South Island, Newzealand, 1985–1991. *N. Z. J. Mar. Freshw. Res.* **1995**, *29*, 175–194. [CrossRef]
22. Sala, A.; Fabi, G.; Manoukian, S. Vertical diel dynamic of fish assemblage associated with an artificial reef (Northern Adriatic Sea). *Sci. Mar.* **2007**, *71*, 355–364. [CrossRef]
23. Zhang, J.; Chen, Z.; Chen, G.; Zhang, P.; Qiu, Y.; Yao, Z. Hydroacoustic studies on the commercially important squid *Sthenoteuthis oualaniensis* in the South China Sea. *Fish. Res.* **2015**, *169*, 45–51. [CrossRef]
24. Zhang, J.; Chen, G.; Chen, Z.; Yu, J.; Fan, J.; Qiu, Y. Acoustic estimation of fishery resources in southern continental shelf of Nansha area. *S. China Fish. Sci.* **2015**, *11*, 1–10.
25. Lucca, B.M.; Warren, J.D. Fishery-independent observations of Atlantic menhaden abundance in the coastal waters south of New York. *Fish. Res.* **2019**, *218*, 229–236. [CrossRef]
26. Hamuna, B.; Pujiyatf, S.; Dimara, L.; Natief, N.M.N.; Alianto. Distribution and density of demersal fishes in Youtefa Bay, Papua, Indonesia: A study using hydroacoustic technology. *India J. Fish.* **2020**, *67*, 30–35. [CrossRef]
27. Fotheringham, A.S. "The Problem of Spatial Autocorrelation" and Local Spatial Statistics. *Geogr. Anal.* **2009**, *41*, 398–403. [CrossRef]
28. Liu, D.; Zhao, Q.; Guo, S.; Liu, P.; Xiong, L.; Yu, X.; Zou, H.; Zou, Y.; Wang, Z. Variability of spatial patterns of autocorrelation and heterogeneity embedded in precipitation. *Hydrol. Res.* **2019**, *50*, 215–230. [CrossRef]
29. Wu, Z.; Zhang, C.; Xue, Y.; Ji, Y.; Ren, Y.; Xu, B. Spatial heterogeneity of demersal fish in the offshore waters of Shandong. *Acta Oceanol. Sin.* **2022**, *44*, 21–28.
30. Matheron, G. Principles of Geostatistics. *Econ. Geol.* **1963**, *58*, 1246–1266. [CrossRef]
31. Jorge, P.; Rubén, R. Acoustic-geostatistical assessment and habitat–abundance relations of small pelagic fish from the Colombian Caribbean. *Fish. Res.* **2003**, *60*, 309–319.
32. Rubén, R.U.; Edwin, N. Biomass estimation from surveys with likelihood-based geostatistics. *ICES J. Mar. Sci.* **2007**, *64*, 1723–1734.
33. Stratis, G.; Dimitra, K. Mapping abundance distribution of small pelagic species applying hydroacoustics and Co-Kriging techniques. *Hydrobiologia* **2008**, *612*, 155–169.
34. Addis, P.; Secci, M.; Angioni, A.; Cau, A. Spatial distribution patterns and population structure of the sea urchin *Paracentrotus lividus* (Echinodermata: Echinoidea), in the coastal fishery of western Sardinia: A geostatistical analysis. *Sci. Mar.* **2012**, *76*, 733–740. [CrossRef]
35. Thorson, J.T.; Shelton, A.O.; Ward, E.J.; Skaug, H.J. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. *ICES J. Mar. Sci.* **2015**, *72*, 1297–1310. [CrossRef]
36. Castillo, R.; Aparco, L.L.C.; Grados, D.; Cornejo, R.; Guevara, R.; Csirke, A.J. Anchoveta (*Engraulis ringens*) Biomass in the Peruvian Marine Ecosystem Estimated by Various Hydroacoustic Methodologies during spring of 2019. *J. Mar. Biol. Oceanogr.* **2020**, *9*, 1000214.
37. Galaiduk, R.; Radford, B.; Case, M.; Bond, T.; Taylor, M.; Cooper, T.; Smith, L.; McLean, D. Regional patterns in demersal fish assemblages among subsea pipelines and natural habitats across north-west Australia. *Front. Mar. Sci.* **2022**, *9*, 979987. [CrossRef]
38. Fan, W.; Zhu, S.; Shen, J. An application of sattllite remote sensing-derived marine environmental factors to marine fisheries: A review. *Mar. Sci.* **2005**, *29*, 67–72.
39. Strong, J.A.; Elliott, M. The value of remote sensing techniques in supporting effective extrapolation across multiple marine spatial scales. *Mar. Pollut. Bull.* **2017**, *116*, 405–419. [CrossRef] [PubMed]
40. Zhang, X.; Li, Z.; Li, D.; He, Y. Marine Environment Distinctions and Change Law Based on eCongnition Remote Sensing Technology. *J. Coast. Res.* **2019**, *94*, 107–111. [CrossRef]
41. Stenseth, N.C.; Mysterud, A.; Ottersen, G.; Hurrell, J.W.; Chan, K.S.; Lima, M. Ecological Effects of Climate Fluctuations. *Science* **2002**, *297*, 1292–1296. [CrossRef] [PubMed]
42. DingsØr, G.E.; Ciannelli, L.; Chan, K.-S.; Ottersen, G.; Stenseth, N.C. Density dependence and density independence during the early life stages of four marine fish stocks. *Ecology* **2007**, *88*, 625–634. [CrossRef]
43. Hastie, T.; Robert, T. Generalized Additive Models: Some Applications. *J. Am. Stat. Assoc.* **1985**, *82*, 371–386. [CrossRef]
44. Gordon, S.; Emily, S.; Neal, W. Relating trends in walleye pollock (*Theragra chalcogramma*) abundance in the Bering Sea to environmental factors. *Can. J. Fish. Aquat. Sci.* **1995**, *52*, 369–380.

45. Niu, M.; LI, X.; Xu, Y. Effects of spatiotemporal and environmental factors on the fishing ground of *Trachurus murphyi* in Southeast Pacific Ocean based on generalized additive model. *Chin. J. Appl. Ecol.* **2010**, *21*, 1049–1055.
46. Tang, F.; Wu, Y.M.; Zhou, W.; Cui, X.; Fan, W.; Zhang, S. Study of marine environment and squid fishing fisheries in North Pacific Ocean based on remote sensing and GIS technology. In Proceeding of the 2nd International Conference on Energy and Environmental Protection (ICEEP 2013), Guilin, China, 20–21 April 2013.
47. Setiawati, M.D.; Sambah, A.B.; Miura, F.; Tanaka, T.; As-syakur, A.R. Characterization of bigeye tuna habitat in the Southern Waters off Java-Bali using remote sensing data. *Adv. Space Res.* **2015**, *55*, 732–746. [CrossRef]
48. Setiawati, M.D.; Tanaka, T. Utilization of Scatterplot Smoothers to Understand the Environmental Preference of Bigeye Tuna in the Southern Waters off Java-Bali: Satellite Remote Sensing Approach. *Fishes* **2017**, *2*, 2. [CrossRef]
49. Wang, J.; Chen, X.; Chen, Y. Projecting distributions of Argentine shortfin squid (*Illex argentinus*) in the Southwest Atlantic using a complex integrated model. *Acta Oceanol. Sin.* **2018**, *37*, 31–37. [CrossRef]
50. Wang, Y.; Yao, L.; Chen, P.; Yu, J.; Wu, Q. Environmental Influence on the Spatiotemporal Variability of Fishing Grounds in the Beibu Gulf, South China Sea. *J. Mar. Sci. Eng.* **2020**, *8*, 957. [CrossRef]
51. Mammel, M.; Naimullah, M.; Vayghan, A.H.; Hsu, J.; Lee, M.; Wu, J.; Wang, Y.; Lan, K. Variability in the Spatiotemporal Distribution Patterns of Greater Amberjack in Response to Environmental Factors in the Taiwan Strait Using Remote Sensing Data. *Remote Sens.* **2022**, *14*, 2932. [CrossRef]
52. Chen, Y.; Chen, Q. The present situation of the environmental protection of coastal waters in Yangjiang City and the countermesures for pollution prevention. *Guangdong Chem. Ind.* **2012**, *39*, 109.
53. Yangdong District People Government. *Planning of Aquaculture Tidal Flat in Yangdong District, Yangjiang (2018–2030)*; Yangdong District People Government: Yangjiang, China, 2019.
54. Yangjiang Municipal Environmental Protection Bureau. *Prevention and Control of Coastal Sea Pollution in Yangjiang City*; Yangjiang Municipal Environmental Protection Bureau: Yangjiang, China, 2019.
55. Thomsen, F.; Lüdemann, K.; Kafemann, R.; Piper, W. *Effects of Offshore Wind Farm Noise on Marine Mammals and Fish*; Cowrie Ltd.: Hamburg, Germany, 2006.
56. Wilhelmsson, D.; Malm, T.; Ohman, M.C. The influence of offshore wind power on demersal fish. *ICES J. Mar. Sci.* **2006**, *63*, 775–784. [CrossRef]
57. Berkel, J.V.; Burchard, H.; Christensen, A.; Mortensen, L.O.; Thomsen, F. The Effects of Offshore Wind Farms on Hydrodynamics and Implications for Fishes. *Oceanography* **2020**, *33*, 108–117. [CrossRef]
58. Mai, G.; Chen, Z.; Wang, X.; Xiao, Y.; Li, C. Spatial pattern of fish taxonomic diversity along coastal waters in northern South China Sea. *S. China Fish. Sci.* **2022**, *18*, 38–47.
59. Zhang, J.; Huang, Z. An investigation on fish eggs and larvae in sea area around planning Yangjiang neclear plant. *J. Trop. Oceanogr.* **2003**, *22*, 78–84.
60. Jia, X.; Li, C.; Chen, Z.; Wang, X. *Strategies for Managing Offshore Fishery Resources and Their Ecosystems in the Northern South China Sea*; Ocean Press: Beijing, China, 2012.
61. Wang, X.; Du, F.; Qiu, Y.; Li, C.; Li, D.; Jia, X. Variations of fish species diversity, faunal assemblage, and abundances in Daya Bay in 1980–2007. *J. Appl. Ecol.* **2010**, *21*, 2403–2410.
62. Sun, P.; Shan, X.; Wu, Q.; Chen, Y.; Jin, X. Seasonal variations in fish community structure in the Laizhou Bay and the Yellow River Estuary. *Acta Ecol. Sin.* **2014**, *34*, 367–376.
63. Liu, H.; Ye, Z.; Li, Z.; Hu, H.; Pang, Y.; Dou, S. The community structure of ichthyoplankton in the centural Yellow Sea in spring and summer. *Acta Ecol. Sin.* **2016**, *36*, 3775–3784.
64. Xie, Z.; Sun, D.; Liu, Y.; Lin, L.; Wang, T.; Xiao, Y.; Li, C. Preliminary analysis of nekton composition and diversity in Jiangmen waters, China. *S. China Fish. Sci.* **2018**, *14*, 21–28.
65. Yang, D.; Wu, G.; Sun, J. The investigation of pelagic eggs larvae and juveniles of fishes at the mouth of Changjiang River and adjacent areas. *Oceanol. Limnol. Sin.* **1990**, *21*, 346–355.
66. Ding, Y.; Xian, W. Temporal and spatial structure of Ichthyoplankton assembleges in the Yangtze Estuary during autumn. Period. *Ocean Univ. China* **2011**, *41*, 67–74.
67. Xiao, Y.; Wang, R.; Zheng, Y.; He, W. Species composition and abundance distribution of ichthyoplankton in the Pearl River Estuary. *J. Trop. Oceanogr.* **2013**, *32*, 80–87.
68. Biosonics. *User Guide: Visual Analyzer 4*; BioSonics, Inc.: Seattle, WA, USA, 2002.
69. Yin, X.; Yang, D.; Du, R. Fishery Resources Evaluation in Shantou Seas Based on Remote Sensing and Hydroacoustics. *Fishes* **2022**, *7*, 163. [CrossRef]
70. Wang, Z.; Johnson, D.A.; Rong, Y.; Wang, K. Grazing effects on soil characteristics and vegetation of grassland in northern China. *Solid Earth* **2016**, *7*, 55–65. [CrossRef]
71. Wang, A.; Wang, Q.; Li, J.; Yuan, G.; Albanese, S.; Petrik, A. Geo-statistical and multivariate analyses of potentially toxic elements' distribution in the soil of Hainan Island (China): A comparison between the topsoil and subsoil at a regional scale. *J. Geochem. Explor.* **2019**, *197*, 48–59. [CrossRef]
72. Feng, Y.; Yao, L.; Zhao, H.; Yu, J.; Lin, Z. Environmental Effects on the Spatiotemporal Variability of Fish Larvae in the Western Guangdong Waters, China. *J. Mar. Sci. Eng.* **2021**, *9*, 316. [CrossRef]

73. Liu, S.; Liu, Y.; Alabia, I.D.; Tian, Y.; Ye, Z.; Yu, H.; Li, J.; Chen, J. Impact of Climate Change on Wintering Ground of Japanese Anchovy (*Engraulis japonicus*) Using Marine Geospatial Statistics. *Front. Mar. Sci.* **2020**, *7*, 604. [CrossRef]
74. Love, R.H. Target strength of an individual fish at any aspect. *J. Acoust. Soc. Am.* **1977**, *62*, 1397–1403. [CrossRef]
75. Fu, X.; Xu, Z.; Que, J.; Yan, T. Temporal-spatial Distribution Characíeristics of Fish Stocks in North-west Coastal Waters of Beibu Gulf. *Fish. Sci.* **2019**, *38*, 10–18.
76. Guo, J.; Chen, Z.; Xu, Y.; Xu, S.; Li, C. Tempo-Spatial Distribution Characteristics of Fish Resources in Daya Bay. *J. Ocean Univ. China* **2018**, *48*, 47–55.
77. Yan, L.; Tan, Y.; Yang, B.; Zhang, P.; Li, J.; Yang, L. Comparison on resources community of stow-net fishery before and after fishing off season in Huangmaohai Estuary. *S. China Fish. Sci.* **2016**, *12*, 1–8.
78. Chen, X. *Fishery Resources and Fisheries*, 2nd ed.; Ocean Press: Beijing, China, 2014; pp. 152–167.
79. Ma, Y.; Si, J. Study on monitoring of fish activity in the Yellow sea coastal water based on hydroacoustic technology. *Fish. Modern.* **2016**, *43*, 70–75.
80. Wang, T.; Huang, H.H.; Zhang, P.; Zhang, S.F.; Wu, F.X.; Liu, Q.X.; Liao, X.L.; Xie, B. Acoustic survey of fisheries resources and spatial distribution in Guishan wind farm area. *J. Fish. Sci. China* **2020**, *27*, 1496–1504.
81. Xu, Z. Comparison of fish density between the Minjiang Estuary and Xinghua Bay during spring and summer. *J. Fish. China* **2010**, *34*, 1395–1403.
82. Zhang, J.; Luo, Y.; Li, Y.; Gao, T.; Lin, L. Temporal and Spatial Distribution of Species Composition and Quantity of Nekton in Dongshan Bay and Adjacent Areas. *J. Ocean Univ. China* **2013**, *43*, 44–51.
83. Zhang, J.; Chen, P.; Fang, L.; Chen, G.; Li, X. Background acoustic estimation of fisheries resources in marine ranching area of Zhelin Bay-Nan'ao Island in the south China Sea. *J. Fish. Sci. China* **2015**, *39*, 1187–7798.
84. Gu, Y. Study on Fish Community and Resources in Jiulong River Estuary, Fujian. Master's Thesis, Jimei University, Xiamen, China, 2014.
85. Zhang, G.; Yang, C.; Sun, D.; Liu, Y.; Shan, B.; Zhao, Y.; Zhou, W. Seasonal variation of fish community in north central region of Beibu Gulf. *J. South Agric.* **2021**, *52*, 2861–2871.
86. Hu, C.; Zhang, Y.; Li, D.; Zhu, W.; Jiang, R.; Li, P.; Wang, Y.; Zhou, Y.; Zhang, H. Study on fish resources and community diversity during spring and summer in the coastal spawning ground of Zhejiang Proviance, China. *Acta Hydrobiol. Sin.* **2018**, *42*, 984–995.
87. Cai, M.; Xu, Z. Species composition and density of fishes in the Sanmen Bay. *J. Sci. Fish. Univ.* **2009**, *18*, 198–205.
88. Chen, W.; Ye, S.; Qin, S.; Fan, Q.; Chen, S.; Ni, Y.; Peng, X. Assessment of fish community structure and redundancy analysis of dominant species in the Oujiang River estuary. *J. Fish. Sci. China* **2021**, *28*, 1536–1547.
89. Liu, Y.; Ye, S.; Ma, C.; Zhuang, Z.; Xu, C.; Shen, C.; Cai, J.; Xie, S. Seasonal variations in species and the quantity of nekton in Sansha Bay. *Fujian Mar. Sci.* **2022**, *46*, 86–94.
90. Donelson, J.M.; Munday, P.L.; Mccormick, M.I.; Nilsson, G.E. Acclimation to predicted ocean warming through developmental plasticity in a tropical reef fish. *Glob. Chang. Biol.* **2011**, *17*, 1712–1719. [CrossRef]
91. Sims, D.W.; Wearmouth, V.J.; Genner, M.J.; Southward, A.J.; Hawkins, S.J. Low-temperature-driven early spawning migration of a temperate marine fish. *J. Anim. Ecol.* **2004**, *73*, 333–341. [CrossRef]
92. Fu, X. Distribution of Fish Populations and Structure of Fish Communities in the Coastal Waters of Northwest Beibu Gulfand Their Influential Factors. Master's Thesis, Shanghai Ocean University, Shanghai, China, 2018.
93. Love, J.W.; May, E.B. Relationships between fish assemblage structure and selected environmental factors in Maryland's coastal bays. *Northeast. Nat.* **2007**, *14*, 251–268. [CrossRef]
94. Yu, N.; Yu, C.; Xu, Y.; Chen, L.; Xu, H.; Wang, H.; Zhang, P.; Liu, K. The relationship between distribution of fish abundance and environmental factors in the outer waters of the Zhoushan Islands. *Acta Oceanolog. Sin.* **2020**, *42*, 80–91.
95. Eppley, R.W.; Stewart, E.; Abbott, M.R.; Heyman, U. Estimating Ocean primary production from satellite chlorophyll. Introduction to regional differences and statistics for the Southern California Bight. *J. Plankton Res.* **1985**, *7*, 57–70. [CrossRef]
96. Maryann, M.; Joseph, J.C.J. Osmoregulation in juvenile and adult white sturgeon, *Acipenser transmontanus*. *Environ. Biol. Fish.* **1985**, *14*, 23–30.
97. Wan, J.; Zeng, D.; Bian, X.; Ni, X. Species composition and abundance distribution pattern of ichthyoplankton and their relationship with environmental factors in the East China Sea ecosystem. *J. Fish. China* **2014**, *38*, 1375–1398.
98. Zou, M.; Chen, Y.; Song, X.; Li, S.; Zhong, J. Distribution and drift trend of Collichthys lucidus larvae and juveniles in the coastal waters of the southern Yellow Sea. *J. Fish. China* **2021**, *46*, 557–568.
99. Niu, M.; Zuo, T.; Wang, J.; Chen, R.; Zhang, J. Egg and larval distribution of *Liza haematochezia* and their relationship with environmental factors in the coastal waters of the Yellow River Estuary. *J. Fish. Sci. China* **2022**, *29*, 377–387.
100. Kim, J.Y.; Kim, J.I.; Choi, S.G.; Chun, Y.Y.; Choi, I. Factors Affecting the Wintering Habitat of Major Fishery Resources in Southwestern Korean Waters. *Ocean Sci. J.* **2007**, *42*, 41–48. [CrossRef]
101. Kim, J.Y.; Lee, S.K.; Kim, S.S.; Choi, M.S. Environmental factors affecting anchovy reproductive potential in the southern coastal waters of Korea. *Anim. Cells Syst.* **2013**, *17*, 133–140. [CrossRef]
102. Lappalainen, A.; Shurukhin, A.; Alekseev, G.; Rinne, J. Coastal fish communities along the northern coast of the Gulf of Finland, Baltic Sea: Responses to salinity and eutrophication. *Int. Rev. Hydrobiol.* **2000**, *85*, 687–696. [CrossRef]
103. Rodriguez-Climent, S.; Caiola, N.; Ibanez, C. Salinity as the main factor structuring small-bodied fish assemblages in hydrologically altered Mediterranean coastal lagoons. *Sci. Mar.* **2013**, *77*, 37–45.

104. Morin, B.; Hudon, C.; Whoriskey, F.G. Environmental- influences on seasonal distribution of coastal and estuarine fish assemblages at Wemindji, Eastern James Bay. *Environ. Biol. Fishes* **1992**, *35*, 219–229. [CrossRef]
105. Zhang, Y.; Xian, W.; Li, W. Fish assemblage structure in adjacent sea of Changjiang estuary in spring of 2004 and 2007 and its association with environmental factors. *Period. Ocean Univ. China* **2013**, *43*, 67–74.
106. Axenrot, T.; Didrikas, T.; Danielsson, C.; Hansson, S. Diel patterns in pelagic fish behaviour and distribution observed from a stationary, bottom-mounted, and upward-facing transducer. *ICES J. Mar. Sci.* **2004**, *61*, 2004. [CrossRef]
107. Fréon, P.; Gerlotto, F.; Soria, M. Diel variability of school structure with special reference to transition periods. *ICES J. Mar. Sci.* **1996**, *53*, 459–464. [CrossRef]
108. Gauthier, S.; Rose, G.A. Acoustic observation of diel vertical migration and shoaling behaviour in Atlantic redfishes. *J. Fish Biol.* **2005**, *61*, 1135–1153. [CrossRef]
109. Totland, A.; Johansen, G.O.; Godø, O.R.; Ona, E.; Torkelsen, T. Quantifying and reducing the surface blind zone and the seabed dead zone using new technology. *ICES J. Mar. Sci.* **2009**, *66*, 1370–1376. [CrossRef]
110. Robertis, A.D.; Handegard, N.O. Fish avoidance of research vessels and the efficacy of noise-reduced vessels: A review. *ICES J. Mar. Sci.* **2013**, *70*, 34–45. [CrossRef]
111. Knudsena, F.R.; Sægrov, H. Benefits from horizontal beaming during acoustic survey: Application to three Norwegian lakes. *Fish. Res.* **2002**, *56*, 205–211. [CrossRef]
112. Blaber, S.J.M.; Blaber, T.G. Factors affecting the distribution of juvenile estuarine and inshore fish. *J. Fish Biol.* **1980**, *17*, 143–162. [CrossRef]
113. Rakocinski, C.F.; Baltz, D.M.; Fleeger, J.W. Correspondence between environmental gradients and the community structure in Mississippi Sound as revealed by canonical correspondence analysis. *Mar. Ecol. Prog. Ser.* **1992**, *80*, 135–148. [CrossRef]
114. Fraser, T.H. Abundance, seasonality, community indices, trends and relationships with physicochemical factors of trawled fish in upper Charlotte Harbor, Florida. *Bull. Mar. Sci.* **1997**, *60*, 739–763.
115. Albaret, J.J.; Simier, M.; Darboe, F.S.; Ecoutin, J.M.; Raffray, J.; Morais, L.T. Fish diversity and distribution in the Gambia Estuary, West Africa, in relation to environmental variables. *Aquat. Living Resour.* **2004**, *17*, 35–46. [CrossRef]
116. Liu, Z.; Yang, L.; Yan, L.; Yuan, X.; Cheng, J. Fish assemblages and environmental interpretation in the northern Taiwan Strait and its adjacent waters in summer. *J. Fish. Sci. China* **2016**, *23*, 1399–1416.
117. Thorman, S. Physical factors affecting the abundance and species richness of fishes in the shallow waters of the southern Bothnian Sea (Sweden). *Estuar. Coast. Shelf Sci.* **1986**, *22*, 357–369. [CrossRef]
118. Smith, C.L.; Hill, A.E.; Foreman, M.G.; Peña, M.A. Horizontal transport of marine organisms resulting from interactions between diel vertical migration and tidal currents off the west coast of Vancouver Island. *Can. J. Fish. Aquat. Sci.* **2001**, *58*, 736–748. [CrossRef]
119. Rodríguez, J.M.; Hernández-León, S.; Barton, E.D. Vertical distribution of fish larvae in the Canaries-African coastal transition zone in summer. *Mar. Biol.* **2006**, *149*, 885–897. [CrossRef]
120. Wang, Z.; DiMarco, S.F.; Ingle, S.; Belabbassi, L.; Al-Kharusi, L.H. Seasonal and annual variability of vertically migrating scattering layers in the northern Arabian Sea. *Deep Sea Res. Part I Oceanogr. Res. Pap.* **2014**, *90*, 152–165. [CrossRef]