

Article

Trophic Structure of Fish Community in Artificial Reef Ecosystem Based on Body Mass Using Stable Isotope

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Abstract: Artificial reefs are widely recognized for their role in improving the ecological environment and creating protected habitats for marine organisms, ultimately enhancing biodiversity within the food web and fisheries resources. This study utilizes stable isotopes to analyze fish samples ranging from 3.4 to 1067 g in body mass, collected within the artificial reef area of Haizhou Bay. The objective is to determine if the $\delta^{15}\text{N}$ -based fish body mass acts as a driving factor in shaping the food web structure. The results showed a certain level of overlap among all trophic guilds, suggesting that most trophic guilds within this region share similar living environments and feeding habits. The multiple linear regression showed a slight increasing trend between $\delta^{15}\text{N}$ values and body mass. Furthermore, the predator–prey mass ratio (PPMR) was calculated to be 430:1 based on the $\delta^{15}\text{N}$ –body mass relationship. This implies that larger reef fish within this artificial reef ecosystem tend to have higher $\delta^{15}\text{N}$ values compared to smaller fish, indicating a shorter food chain in this ecosystem. In summary, this analysis provides valuable insights into the fish community structure within artificial reef ecosystems. Therefore, it is recommended that future studies focus on further characterizing the fish community structure using body mass information.

Keywords: stable isotope; fish community; artificial reef; body mass; predator–prey mass ratio



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1. Introduction

Artificial reefs are human-engineered structures deployed in the ocean to mimic the roles and advantages of natural coral reefs, including facilitating ecosystem restoration and enhancing habitat complexity [1–3]. These reefs play a significant role in enhancing adjacent environmental ecology and creating favorable habitats for marine life, supporting fish growth, reproduction, and protection from predators. Additionally, they contribute to biodiversity and resource abundance within the food web, benefiting fisheries [4–8]. The food webs of artificial reef ecosystems are crucial as they improve nutrient availability and promote biological productivity [7,8]. Generally, fish within these food webs are classified into specific trophic guilds [9–13]. However, it is important to recognize that many reef fish species exhibit trophic plasticity, feeding across different trophic levels, which is often overlooked (e.g., Robertson, 1982 [14]; Chen, 2002 [15]; Mouillot et al., 2014 [16]). This oversight has resulted in a lack of precise information on the food web dynamics of artificial reefs.

Research on diet and trophic position (TP) has traditionally involved the analysis of gut content composition and quantity. However, this method has certain limitations, such as the extensive workload and time required for conducting such studies. Additionally, it only provides insights into organisms' short-term diet [17,18]. The utilization of a stable carbon isotope ($\delta^{13}\text{C}$) and nitrogen isotope ($\delta^{15}\text{N}$) has emerged as an important approach for studying the trophic structure, feeding habits, and biodiversity of marine fish communities [19]. The $\delta^{13}\text{C}$ exhibits low values in organisms and allows for the differentiation of source diets from various areas. The $\delta^{15}\text{N}$ changes at a rate of approximately 3‰, with each higher level in the consumer hierarchy assisting in determining the trophic position of organisms [20–23]. By combining the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, it is possible to elucidate trophic ecology and species interactions within the marine food web and identify the utilization of key potential feeding sources [24–26].

In aquatic ecosystems, it is generally observed that larger individuals tend to feed at higher TPs compared to smaller individuals. This can be attributed to either diet shifts or ontogenetic processes [27–29]. However, various factors such as variation in feeding habits, seasonal effects, and human interference can lead to some large fish feeding at lower TPs [28,30]. Additionally, the TPs of certain species, like herbivores, may remain relatively constant regardless of body mass [31,32]. Alvarez-Filip et al. (2011) [33] propose that coral reef environments with greater structural complexity support a large proportion of fish with small size, which significantly shapes the functionality and stability of these ecosystems. However, research on the feeding ecology of fish based on body mass in artificial reef ecosystems is currently limited. Therefore, further exploration is needed to determine if artificial reefs possess similar functioning that supports their role as natural reefs.

The relationship between body mass and TP can serve as a reliable predictor, while size-based approaches offer a means of characterizing food web structures, particularly in highly diverse ecosystems with intricate trophic pathways [34]. To deepen our understanding of predator–prey dynamics and changes in community trophic composition, studying the correlation between TP and body mass at a community level is crucial [27,35,36]. The predator–prey mass ratio (PPMR) provides insights into spatiotemporal variations in the food web and enables a quick estimation of important parameters used to characterize ecosystem functioning [37–39]. Considering the diverse sources of primary productivity and the range of trophic guilds present, artificial reef ecosystems may exhibit smaller PPMRs and shorter food chains. However, there is currently a lack of studies investigating the $\delta^{15}\text{N}$ –body mass relationships and PPMR in artificial reef ecosystems. As a result, crucial insights into food web ecology remain unexplored.

In this study, five trophic guilds of 21 fish species in marine protected areas (MPAs) dominated by artificial reefs of Haizhou Bay (Jiangsu, China) were investigated, and the characteristics of the $\delta^{13}\text{C}$, $\delta^{15}\text{N}$ and TPs of the most relevant trophic guilds were explored. We aimed to determine the isotopic niches for trophic guilds to assess the potential $\delta^{15}\text{N}$ –body mass relationship and PPMR. This study will further help us to understand the food web structure of artificial reefs and can supplement the knowledge of the trophic structure of the fish community of the artificial reef ecosystem when corresponding policies and measures for the artificial reef construction need to be formulated and performed.

2. Materials and Methods

2.1. Study Area

Haizhou Bay is a semi-open harbor with Lianyungang city to the west and the Yellow Sea to the east. The sea area is approximately 877 km² in size and mainly composed of sandy and muddy sediment [40]. Since 2003, the local government has established MPAs for fragmented habitat recovery and fishery resource protection [4,41,42]. The main types of artificial reefs are concrete, metal and rubber. The climate and hydrology of this region are greatly influenced by the mainland, and most fishing areas are controlled by coastal currents. The tidal current is mainly a rotating flow, with a velocity of 0.4–0.65 m/s and a depth range between 10 and 15 m.

2.2. Fish Collection and Pretreatment

All samples were collected during three sampling campaigns in the artificial reef area of Haizhou Bay in 2020 and 2021, with sites ranging from 34°52.849' to 34°56.117' N and 119°13.641' to 119°33.778' E (Figure 1). During these surveys, a winged single-bag bottom trawl (15 m × 4 m × 8 m, mesh size: 1 cm × 1 cm) was used, with an average towing time of 30 min and a ship speed of 2.3 kn. All fish were divided into five trophic guilds (omnivores, planktivores, piscivores, carnivores, and benthivores) (Table 1), and data on the body length ($L_{SIA} \pm 0.1$ cm) and body mass ($W_{SIA} \pm 0.1$ cm) of the selected fish were recorded in the laboratory (Appendix A). The data were subjected to logarithmic conversion to eliminate the influence of the phylogeny. The fish dorsal muscles were collected and washed with distilled water, and then freeze-dried at −44 °C for 24 h for isotope analysis.

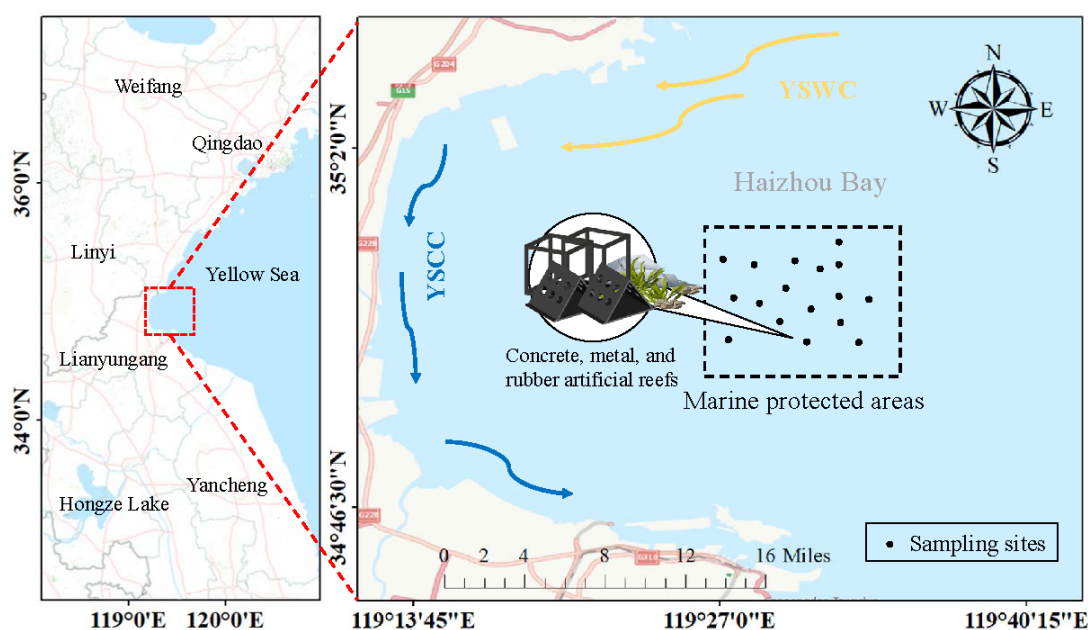


Figure 1. Sampling location in artificial reef area of Haizhou Bay. YSWC: Yellow Sea Warm Current, YSCC: Yellow Sea Coastal Current.

Table 1. The description of each trophic guild of fish.

Trophic Guild	Description
Omnivore	Complex diet resources (e.g., animal carcasses, debris)
Planktivore	A filter feeder, mainly feeds on zooplankton and phytoplankton
Piscivore	Feed on vertebrates, especially fish
Benthivore	Mainly feed on invertebrates in the sediments
Carnivore	Mainly feed on invertebrates in the water

2.3. Stable Isotope Analysis

Stable isotope analysis was carried out in the isotope analysis laboratory of the Third Institute of Oceanology, Ministry of Natural Resources, in Xiamen, China. The ratios of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ were determined by using a Vario Isotope Cube–Isoprime element analyzer. The $\delta^{15}\text{N}$ is expressed relative to that of N_2 in the air, while the $\delta^{13}\text{C}$ is expressed relative to that of the Vienna Pee Dee Belemnite (VPDB) standard. The result is expressed in the form of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ (mean $\pm$ SD), which is calculated according to the following formula.

$$\delta X = \left[\left(\frac{\lambda_{\text{sample}}}{\lambda_{\text{standard}}} - 1 \right) \right] \times 10^3 \quad (1)$$

where X is ^{13}C or ^{15}N and λ is the $^{13}\text{C}/^{12}\text{C}$ or $^{15}\text{N}/^{14}\text{N}$ ratio, respectively.

The analytical accuracies of the $\delta^{13}\text{C}$, $\delta^{15}\text{N}$, %C and %N are 0.1‰, 0.2‰, 4‰ and 1‰, respectively (Appendix B). There is no need to extract lipids from single samples because the effect of lipids on the isotope values was small, with a C/N ratio less than 3.7 [43,44].

2.4. Trophic Guild Analysis

Layman's metrics could reflect the trophic structure among fish communities, of which the total area (TA) was used to analyze the trophic diversity of trophic guilds [28,45]. The standard ellipse area corrected (SEA_C) for small sample size and SEA_B were selected to measure the isotopic niches of the different trophic guilds using the SIBER package [28]. Because of the information in the dataset, the Bayesian method was used for the posterior estimation of SEA_B 20,000 times, and a 95% confidence interval (CI) was provided. If the 95% CIs did not overlap, significant differences were considered to exist among the SEA_B values of different trophic guilds [46].

2.5. The $\delta^{15}\text{N}$ –Body Mass Relationship

The relationship between stable isotope values and body mass across species was analyzed using linear regression, which compared the average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ for each species with the maximum body mass (M_{max}). To minimize the risk of comparing different life stages, fishes were compared at a fixed percentage of their maximum body mass (specifically, $\geq 55\% M_{\text{max}}$) [47,48]. This standardization of body mass enhances the accuracy of the results, as fish species exhibit different body masses at various life history stages.

For each species, a linear regression relationship between the $\delta^{15}\text{N}$ and $\log_2 M$ was generated. The slope and intercept of this regression were then employed to calculate the $\delta^{15}\text{N}$ values for individuals of the same species across different body masses. The $\delta^{15}\text{N}$ – $\log_2 M$ relationship for all species was established using multiple linear regression. To derive the community-level relationship between the $\delta^{15}\text{N}$ and $\log_2 B$ (where B is used to differentiate this community analysis from the species-level analysis), the average weighted $\delta^{15}\text{N}$ value for each $\log_2 B$ class was computed using the following two formulas [49]:

$$r_i = M_i / \sum_{i=1}^n M_i \quad (2)$$

$$\delta^{15}\text{N}_j = \sum_{i=1}^n \delta^{15}\text{N}_i \times r_i \quad (3)$$

r_i is the mass ratio (r) of each individual (i) in each $\log_2 B$ class, n is the total number of individuals in the $\log_2 B$ class, and $\delta^{15}\text{N}_j$ is the product of r_i and the average weighted $\delta^{15}\text{N}$ of $\log_2 B$ of each j class in the whole community. The $\delta^{15}\text{N}_i$ was calculated using the linear $\delta^{15}\text{N}$ – $\log_2 M$ relationship at the species level if there was a significant correlation, but it was calculated as the average $\delta^{15}\text{N}$ of the species if there was no significant correlation.

2.6. Predator–Prey Mass Ratio

The slope (b) of the TP– $\log_2 B$ relationship is obtained from the slope (s) of the $\delta^{15}\text{N}$ – $\log_2 B$ relationship, where $b = s/3.4$. The TP was calculated using the formula:

$$\text{TP} = \frac{\delta^{15}\text{N}_{\text{fish}} - \delta^{15}\text{N}_{\text{baseline}}}{\Delta\delta^{15}\text{N}} + \text{TP}_{\text{baseline}} \quad (4)$$

where $\Delta\delta^{15}\text{N}$ is the Trophic Enrichment Factor (TEF) and is assumed to be a constant equal to 3.4‰ (Post, 2002). If the activity range of *Sinonovacula constricta* ($\delta^{15}\text{N}_{\text{baseline}} = 7.5\text{‰}$; $\text{TP}_{\text{baseline}} = 2.0$) is small, the life cycle is long, and thus there is little isotope change ($n = 10$). Therefore, the PPMR is calculated as follows [39,50]:

$$\text{PPMR} = 2^{3.4/s} \quad (5)$$

To assess the uncertainty of PPMR, we conducted 10,000 simulations of independent s and $\Delta\delta^{15}\text{N}$ (mean and standard deviation of $3.4 \pm 1.0\text{‰}$; Post 2002) using a bivariate normal distribution ($\rho = 0$). This value was chosen based on our previous research in the same geographical area, which revealed that the difference in $\delta^{15}\text{N}$ values between juvenile and adult stages of *L. polyactis* and *C. lucidus* is remarkably close to 3.4‰ [51].

2.7. Tools for Analysis

All data were tested for normality and variance homogeneity, and the package SIAR was used in R (v. 4.4.1) [46,52,53]. Two-way ANOVA was used to perform the statistic tests in the $\delta^{13}\text{C}$ – $\delta^{15}\text{N}$ bi-plot. A linear regression was performed between the $\delta^{15}\text{N}$ and $\log_2 M$ to simulate values from a bivariate normal distribution. The Q–Q plots, standardized residual histograms, and the relationship between standardized residuals and fitted values were used to evaluate the assumptions of ordinary least-squares linear regression analysis. A generalized linear model (GLM) was used to test the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values between species. The Pearson correlation coefficient was used to evaluate the correlations between variables, and the Spearman correlation coefficient was used to analyze data that did not follow the bivariate normal distribution. All significance levels were set at $p = 0.05$, and all standard deviations are shown as $1 \pm \text{SE}$ unless otherwise stated.

3. Results

3.1. Isotopic Characteristics and Niche Analysis

A total of 21 species (192 individuals) from five trophic guilds were analyzed by the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$. The average $\delta^{13}\text{C}$ of all fish species was between $-20.51 \pm 0.44\text{‰}$ (*Pampus argenteus*) and $-16.41 \pm 0.31\text{‰}$ (*Platycephalus indicus*), and the average $\delta^{15}\text{N}$ was between $10.85 \pm 0.27\text{‰}$ (*Sardinella zunas*) and $14.47 \pm 1.25\text{‰}$ (*Tridentiger barbatus*). The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ between species showed significant differences (GLM, $p < 0.01$) (Figure 2A). The omnivores had the largest niche, covering those of almost all other trophic guilds, followed by the niches of carnivores, planktivores, and piscivores. The niche of the benthivore was the smallest (Figure 2B,C and Table 2).

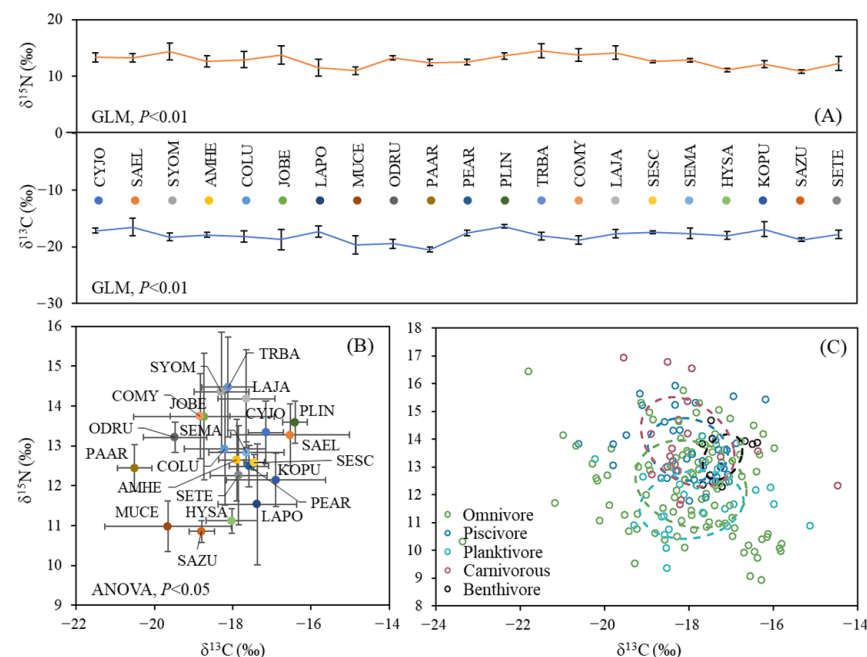


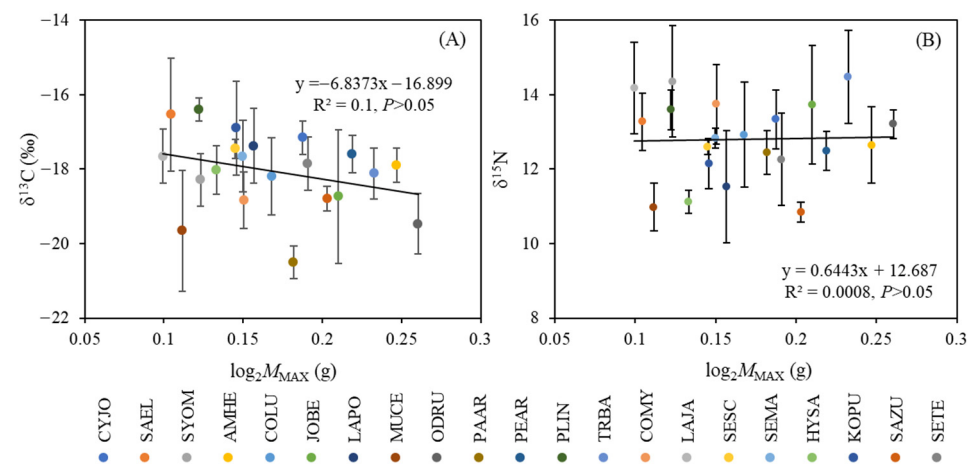
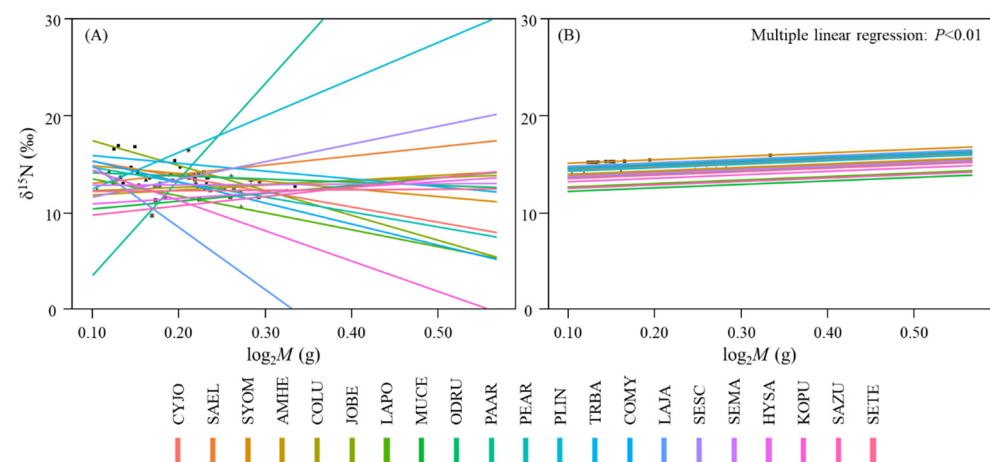
Figure 2. Comparison of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values (mean standard deviation) of all fish species (A) and standard ellipse diagram (B,C) of each trophic guild (distinguished by different colors). The codes are shown in Appendix A.

Table 2. Stable isotope TA and niche area ($\% ^2$) of each trophic guild (SEA_B (standard elliptic area) and SEA_C (estimated elliptic area)).

Trophic Guild	TA	SEA _B ($\% ^2$)	SEA _C ($\% ^2$)
Omnivore	41.71	6.46	6.51
Planktivore	16.85	4.70	4.90
Piscivore	11.40	3.35	3.45
Benthivore	1.91	1.15	1.28
Carnivorous	14.27	5.33	5.66

3.2. Relationship Between $\delta^{15}\text{N}$ and Body Mass at Species and Community Levels

There were statistically insignificant but very weak correlations between $\log_2 M_{\max}$ and the $\delta^{13}\text{C}$ ($R^2 = 0.1$, $p > 0.05$) and $\delta^{15}\text{N}$ ($R^2 = 0.01$, $p > 0.05$) among the different species (Figure 3). The $\delta^{15}\text{N}$ – $\log_2 M$ relationships of 11 species were positively correlated (e.g., for *Collichthys lucidus*), while those of 10 species were negatively correlated (e.g., for *Cynoglossus joyneri*) (Figure 4A). The multiple linear regression of the $\delta^{15}\text{N}$ – $\log_2 M$ relationship showed a very slight positive correlation with slope of 3.617 (Figure 4B), which reflects that the $\delta^{15}\text{N}$ value of species increased with increasing body mass at a community level.

**Figure 3.** Relationships between bulk $\delta^{15}\text{N}$ (A) and bulk $\delta^{13}\text{C}$ (B) (mean $\pm$ SD) and $\log_2 M_{\max}$ for all species (codes are shown in Appendix A). The average isotope values of individuals are greater than 55% of their $L_{\max}$.**Figure 4.** The $\delta^{15}\text{N}$ – $\log_2 M$ relationship of each species using linear regression (A) and multiple linear regression (B). The codes are shown in Appendix A.

3.3. Estimation of PPMR

The estimation of PPMR can effectively indicate the length of the food chain. Based on the relationship between the $\delta^{15}\text{N}$ and $\log_2 B$, the regression equation was determined as $\delta^{15}\text{N} = 0.3886\log_2 B + 12.726$ ($R^2_{\text{adjusted}} = 0.12$, $p < 0.05$). This equation allowed us to calculate the mean PPMR for this study, which was determined to be 430: 1 (Table 3), using the slope value ($b = 0.3886$) derived from $\text{TP} - \log_2 B$.

Table 3. Average PPMR values for different communities obtained from the literature using an additive framework.

Community	PPMR Estimates		Reference
	Median	25th and 75th Quantiles	
Haizhou Bay	430:1		Present study
Central North Sea	104:1	42 to 75:1	Jennings et al. (2002a, b) [21,47]
Galician upwelling area	4500:1		Bode et al. (2003) [54]
Western Arabian Sea	7762:1		Al-Habsi et al. (2008) [49]
Puget Sound	4320:1	779 to 2.71×10^4 :1	Reum et al. (2015) [50]
Cantabrian Sea	2718:1		Romero-Romero et al. (2016) [34]
Cape Eleuthera	1047:1	250 to 4833:1	Zhu et al. (2019) [25]
Adriatic Sea	655:1		Zorica et al. (2021) [39]

4. Discussion

4.1. Trophic Dynamics of Species and Trophic Guilds

Exploring and understanding relationships between species within and across marine ecosystems poses a significant challenge. In our study, stable isotopic data analyzed at species and trophic guild levels did not reveal particularly noticeable differences in trophic ecology (Figure 2). However, carnivores, piscivores, and omnivores exhibited a consistent overlapped ellipse, suggesting potential resource overlap or shared environmental pressures. Conversely, planktivores and benthivores displayed less overlap, indicating varied reliance on distinct food sources or habitat preferences. These observations underscore the diverse ecological roles and resource utilization strategies among different trophic categories and provide a foundation for classifying the five trophic guilds examined in this study based on their distinct ecological characteristics. Moreover, omnivorous fish exhibited the largest TA value and niche, indicating a broader range of prey and a higher degree of trophic diversity. This trend has been observed in various regions, emphasizing the importance of maintaining high trophic diversity to enhance ecosystem stability, increase food resource utilization, and bolster resistance against external disturbances [55,56]. Additionally, the studied region is known to possess relatively abundant food resources [4,57,58]. As a result, some fish species may partly share dietary resources, leading to overlapping niches and interspecific competition [45,59], further highlighting the complex intraspecific and interspecific relationships within this ecosystem. The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of certain omnivorous species exhibit distinct differences from other trophic guilds. This significant variability observed within species reflects that there could be some differences in the living environment and feeding habits between these and other fishes. On the other hand, this indicates the presence of individual specialization within the food web, suggesting that different individuals of the same species consistently rely on distinct primary productivity sources in the food web [60]. For instance, in our study, *Mugil cephalus*, *Saurida elongata*, and *Johnius belangerii* displayed a wide range of $\delta^{13}\text{C}$ values. The underlying reasons behind this variation in food sources could be related to various environmental factors, such as current/tide direction and the availability of energy from primary productivity. Previous research has indicated that certain fish species selectively shift between habitats to obtain food carried by the tide, and different distributions in the fundamental carbon source (e.g., phytoplankton, macroalgae) are primarily responsible for their displacement due to active predation [61,62]. Additionally, other minor factors, such as reduced flow and increased

water depth, may negatively impact trophic diversity, potentially leading to changes in the food source [63].

4.2. Relationship Between $\delta^{15}\text{N}$ and Body Mass

In this study, the relationship between the $\delta^{15}\text{N}$ and $\log_2 M$ for half of the fish species showed an increasing trend, meaning that they prey on higher-TP organisms with increasing body mass. This may be because an increase in mouth size, fitness level, and predation ability allows them to do so when they grow [36,64,65]. For trophic guilds showing negative correlations or high variation in the $\delta^{15}\text{N}$ – $\log_2 M$ relationship, the feeding habit may shift from high-value sources of primary productivity to different food types in the range of low or multiple pathways [21,28]. Several studies have shown that at an individual level, TPs significantly increase with body mass (e.g., Woodward et al., 2010 [66]; Gilljam et al., 2011 [67]). Robinson and Baum (2015) [68] found a positive correlation between the $\delta^{15}\text{N}$ and $\log_2 M$ for all individuals in two different trophic pathways (herbivore and carnivore). Zhu et al. (2019) [25] conducted analyses at both the species level and the whole-community level, revealing that differences among species are due to variations in the trophic pathways that sustain them. However, more data are necessary to fully understand how these trophic pathways influence the relationship. In this study, the $\delta^{15}\text{N}$ and $\log_2 B$ exhibited a very slight upward trend across species at the community level, suggesting that the TP tends to increase with increasing body mass, regardless of the trophic guild. This indicates that larger reef fish generally tend to feed on organisms at a higher TP in artificial reef ecosystems. Moreover, we observed weak relationships between the $\delta^{13}\text{C}$ and $\log_2 M_{\max}$, as well as the $\delta^{15}\text{N}$ and $\log_2 M_{\max}$. Despite the presence of large-sized omnivores and piscivores and small-sized benthivores and planktivores, the maximum body mass rarely constrains the trophic capabilities of species. Research by Graham and Zhu indicated that small-size-class biomass data from coral reefs are predominantly from herbivores, whereas large-size-class biomass data are mainly from omnivores and piscivores [25,35,48]. This result does not differ from those of this study and indicates that the ecological effect of clustering fish by artificial reefs may be similar to that of clustering fish by coral reefs. However, we should exercise caution before drawing a definitive conclusion, as this similarity may be influenced by the loss of habitat complexity and historical overfishing (e.g., the removal of certain trophic guilds of fish).

4.3. Food Chain Analysis Based on PPMR

The PPMR value estimated for this study (430: 1) differed significantly from the PPMR reported in other regions, such as the Western Arabian Sea (7762: 1 [49]), the Galician upwelling area (4500: 1 [54]), the Puget Sound (4320: 1 [50]), and the Cantabrian Sea (2718: 1 [34]). However, it was similar to the North Sea (104: 1 [21,47]) and the Adriatic Sea (655: 1 [39]). These observed differences can be attributed to the use of different TEF values (e.g., 2.5‰ and 3.4‰) and the broader or narrower range of TPs covered in their respective studies [39]. On the one hand, it was expected that there would be variations due to these factors. The TEF is a non-fixed parameter. While there are several options for its value, they generally fall within a relatively narrow range, typically between 2 and 4‰ [65]. Consequently, it is reasonable to assert that the impact of TEF variations is not likely to be markedly conspicuous. On the other hand, the slope derived from the $\delta^{15}\text{N}$ – $\log_2 B$ relationship reflects the extent of $\delta^{15}\text{N}$ variation with increasing body mass. A larger slope indicates a smaller $\delta^{15}\text{N}$ range and a shorter food chain, resulting in fewer TPs. In this study, the PPMR indicated that the food chain in the artificial reef area was relatively short compared to other aquatic systems. This suggests that the scale and stability of artificial reef ecosystems may be lower, with species occupying limited TPs within a narrow range. However, it is important to note that our PPMR data only represent the fish found in the artificial reef area. Further investigations are required to determine whether fish with higher TPs occur in the waters surrounding the artificial reef areas.

The current study has some limitations. On the one hand, all individuals are considered to have the same isotopic baseline, despite the expectation of significant isotopic differences among different ecosystem sources [69]. If consumers have significantly mixed diets, different baselines should be considered when estimating their TPs. This is why TPs for each species were not calculated in this study. On the other hand, for some species, the small sample size used for stable isotope analysis may lead to a higher or lower linear regression fitting effect than the true fitting effect and may therefore be inaccurate. In addition, the data collected in this study are not representative of all species in this area, and multiple net types should be used simultaneously (e.g., gill nets and cages) to compensate for the missing species and species in different periods of life history (juvenile or adult species) in the sampling survey in the future.

5. Conclusions

There is compelling evidence suggesting that artificial-reef fish have surpassed the boundary established by their corresponding trophic guilds. Additionally, the presently recognized trophic guilds are often oversimplified, thereby disregarding fish with mixed diets (e.g., certain carnivorous or piscivorous species that may belong to the omnivore category). Furthermore, the fish community within artificial reef ecosystems exhibits a distinct trophic structure. The findings highlight the pivotal role of body mass in shaping predator–prey dynamics and trophic pathways at the community level. Notably, this study identifies the first evidence of the relationship between the $\delta^{15}\text{N}$ and body mass among fish species in artificial reef ecosystems. However, such a relationship may not be universally applicable to all artificial reefs. In summary, our analysis offers novel insights into the structure of fish communities in artificial reef ecosystems. We recommend that future research further investigates the fish community structure by incorporating diverse information regarding body mass distribution.

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Institutional Review Board Statement: All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. The research was approved by the Shanghai Ocean University (SHOU) and the Lianyungang Marine and Fishery Bureau. No artificial reef, natural, and/or other habitats were disturbed during this research. All fish were killed by the Marine Survey Code. All samples were imported to the laboratory in SHOU under the Marine Survey Code.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author [Shuo Zhang], upon reasonable request.

Conflicts of Interest: The authors declare that they have no conflicts of interest.

Appendix A. Scientific Name, Code, Trophic Guild, Number (n), Sampling Length Range of the Stable Isotope (L_{SIA}), Mean $\delta^{13}C$ and $\delta^{15}N$ of Fishes in This Study

Scientific Name	Code	Trophic Guild	n	L_{SIA} (mm)	W_{SIA} (g)	$\delta^{13}C$	$\delta^{15}N$
<i>Cynoglossus joyneri</i>	CYJO	Benthivore	11	16.7–163	8.5–40.3	-17.16 ± 0.45	13.34 ± 0.79
<i>Saurida elongata</i>	SAEL	Carnivorous	3	208–360	74.0–760.3	-16.54 ± 1.52	13.28 ± 0.77
<i>Synechogobius ommaturus</i>	SYOM	Carnivorous	13	29.6–403	8.0–277.2	-18.29 ± 0.7	14.35 ± 1.5
<i>Amblychaeturichthys hexanema</i>	AMHE	Omnivore	6	11.7–112	11.6–16.6	-17.9 ± 0.45	12.65 ± 1.02
<i>Collichthys lucidus</i>	COLU	Omnivore	23	12.8–165	10.8–62.0	-18.2 ± 1.04	12.92 ± 1.41
<i>Johnius belangerii</i>	JOBE	Omnivore	4	9.7–140	10.7–27.1	-18.73 ± 1.8	13.73 ± 1.59
<i>Larimichthys polyactis</i>	LAPO	Omnivore	42	12.9–166	8.1–83.2	-17.37 ± 1	11.53 ± 1.51
<i>Mugil cephalus</i>	MUCE	Omnivore	8	27.4–362	26.7–497.2	-19.66 ± 1.62	10.98 ± 0.64
<i>Odontamblyopus rubicundus</i>	ODRU	Omnivore	3	17.3–125	4.2–14.3	-19.47 ± 0.82	13.21 ± 0.38
<i>Pampus argenteus</i>	PAAR	Omnivore	3	102–112	34.2–45.2	-20.51 ± 0.44	12.44 ± 0.59
<i>Pennahia argentata</i>	PEAR	Omnivore	6	9.6–12.1	12.1–23.7	-17.59 ± 0.5	12.49 ± 0.52
<i>Platycephalus indicus</i>	PLIN	Omnivore	7	22.5–32.3	116.0–290.5	-16.41 ± 0.31	13.59 ± 0.53
<i>Tridentiger barbatus</i>	TRBA	Omnivore	10	7.3–92	3.4–19.7	-18.12 ± 0.68	14.47 ± 1.25
<i>Conger myriaster</i>	COMY	Piscivore	11	32.9–1742	30.8–100.1	-18.83 ± 0.76	13.74 ± 1.07
<i>Lateolabrax japonicus</i>	LAJA	Piscivore	13	236–447	117.3–1067	-17.65 ± 0.73	14.18 ± 1.23
<i>Sebastes schlegelii</i>	SESC	Piscivore	4	10.9–14.3	56.5–118.9	-17.45 ± 0.26	12.59 ± 0.19
<i>Sebastes marmoratus</i>	SEMA	Piscivore	6	12.1–14.8	60.4–102.0	-17.65 ± 0.96	12.83 ± 0.26
<i>Hyporhamphus sajori</i>	HYSA	Planktivore	3	29.7–36.4	116.7–181.7	-18.03 ± 0.66	11.12 ± 0.31
<i>Konosirus punctatus</i>	KOPU	Planktivore	7	14.6–159	33.5–116.1	-16.9 ± 1.26	12.14 ± 0.67
<i>Sardinella zunas</i>	SAZU	Planktivore	3	12.3–13.2	20.8–30.4	-18.8 ± 0.33	10.85 ± 0.27
<i>Setipinna tenuifilis</i>	SETE	Planktivore	6	12.6–139	5.9–37.7	-17.85 ± 0.72	12.26 ± 1.24

Appendix B. Common Carbon and Nitrogen Isotope Certified Reference Material Identification Values

Standard Materials	$\delta^{13}C_{VPDB}/\%$	$w_{OC}/\%$	$\delta^{15}N_{Air}/\%$	$f_{15N}/\%$	$w_{TN}/\%$
GBW04407	−22.43				
GBW04408	−36.91				
USGS-40	−26.39	8.16	−4.50		
IAEA-N-1	-		0.43		10.5
IAEA-N-2	-		20.41		10.6
IAEA-311	-			2.05	10.6

Note: “-” indicates no corresponding value. VPDB: Vienna Pee Dee Belemnite; Air: N_2 in the Air. w_{OC} : Organic Carbon Mass Fraction; w_{TN} : Total Nitrogen Mass Fraction; f_{15N} : Nitrogen Isotope Abundance.

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