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Remote Sensing Assessment of Ecological Effects of Marine Ranching in the Eastern Guangdong Waters, China

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Abstract

This study aims to assess ecological effects of the construction of marine ranching in the eastern Guangdong waters. Variations in sea surface temperature (SST), chlorophyll a concentration (Chl-a), catch per unit effort (CPUE), biodiversity, biomass and density of benthos were compared during the pre- (August in 2011) and post- (August in 2013) marine ranching. These were based on satellite remote sensing and survey data. Results showed that the ratio of Nitrogen (N): Phosphorus (P) was closed to 16, Chl-a increased from 7.5 - 12.3 $mg \cdot m^{-3}$ to 10.4 - 16.2 $mg \cdot m^{-3}$, and CPUE increased from 2.1 - 5.5 $kg \cdot h^{-1}$ to 5.8 - 14.5 $kg \cdot h^{-1}$. The species number of fish, crustaceans, cephalopods and shellfish increased by 25, 3, 2 and 3 respectively. *Shannon-Wiener* biodiversity index of fish, crustaceans, cephalopods and shellfish increased by 0.5, 0.4, 0.1 and 1.0 respectively. Both biomass and density of benthos increased also. The construction of marine ranching in the eastern Guangdong had restored the habitat to some extent, and played positive effects in the conservation and proliferation of fishery resources in local area.

Keywords

Marine Ranching, Ecological Effects, Remote Sensing, Eastern Guangdong Waters, China

1. Introduction

Zhelin Bay marine ranching, located in eastern Guangdong Province, China, has a surface area of 68 to 70 km^2. It is one of the 12 important bays in Guangdong Province and one of the 18 important marine aquaculture areas along the coasts of China [**Figure 1**]. However, the fish stock in this area has declined dramatically in recent years due to overfishing, pollution and habit destruction (Zhou et al., 2011; Shu et al., 2016). Therefore, there is an urgent need to improve the marine ecological environment, and to conserve and proliferate the fishery resources of Zhelin Bay.

Marine ranchings are created by installing artificial structures such as artificial reefs in the coastal waters, providing shelter, feeding, spawning, and nursery grounds for marine life. Previous studies about the ecological impact of marine ranchings mainly focused on the on-site investigation of marine environment (Huang et al., 2017), and the comparative analysis of the community structure of biological and fishery resources (Chen., 2014; Liao et al., 2013; Becker et al., 2017; Li et al., 2011; Chen et al., 2016; Zhang et al., 2009). Spatially, the levels of nitrogen and phosphorus decrease from nearshore to offshore waters of Zhelin Bay (Peng et al., 2014), and the fishery population grows in summer (4.35 $kg \cdot km^{-2}$) and shrinks in winter (2.31 $kg \cdot km^{-2}$) (Yuan et al., 2017). The benthic community in this area is primarily composed of mollusks, arthropods and annelids (Shu et al., 2015). All these studies have clarified the current situation of marine life and environment of Zhelin Bay. However, the ecological impact of marine ranchings needs to be investigated using a variety of technical means.

Satellite remote sensing makes it possible to acquire long-term, large-scale and near-real-time sea surface data, and thus has been widely applied in fishery resource assessment (Yu et al., 2017), fishery environmental monitoring and other fields (Yu et al., 2010; Song et al., 2016; Yu et al., 2018). In our previous study, we analyzed the ecological impact of the artificial reefs in Daya Bay based on long-term remote sensing data (Yu et al., 2014). Zhelin Bay marine ranching is a typical ranching for fishery resource conservation in the South China Sea. In the present study, we assessed the ecological impact of Zhelin Bay marine ranching based on the changes in the ecological environment and resources before and after it was established, to provide a scientific basis for the planning, establishment and assessment of marine ranchings.

2. Materials and Methods

2.1. Study Area and Methods

Zhelin Bay marine ranching was built near Nan'ao Island in eastern Guangdong waters in 2010, with a total surface area of 2.067×10^4 hm^2, including shellfish area, seaweed area, net-cage area, stock enhancement area, and artificial reef areas. The areas were given in **Figure 1**. There are many shapes of artificial reef and net-cage. Here, rectangles were used to mark them. The shellfish area was 519.99 hm^2, dominated by *Paphia undulata, Musculus senhousia* and *Potamocorbula rubromuscula*. The seaweed area was 333.33 hm^2, dominated by *Asparagus schoberioides* and seaweed. The net-cage area was 200 hm^2. In addition, 7.20×10^6 fish, 1.4×10^8 tails of shrimps and 9.6823×10^7 m^3 of artificial reef were put into the stock enhancement area (Peng et al., 2014).

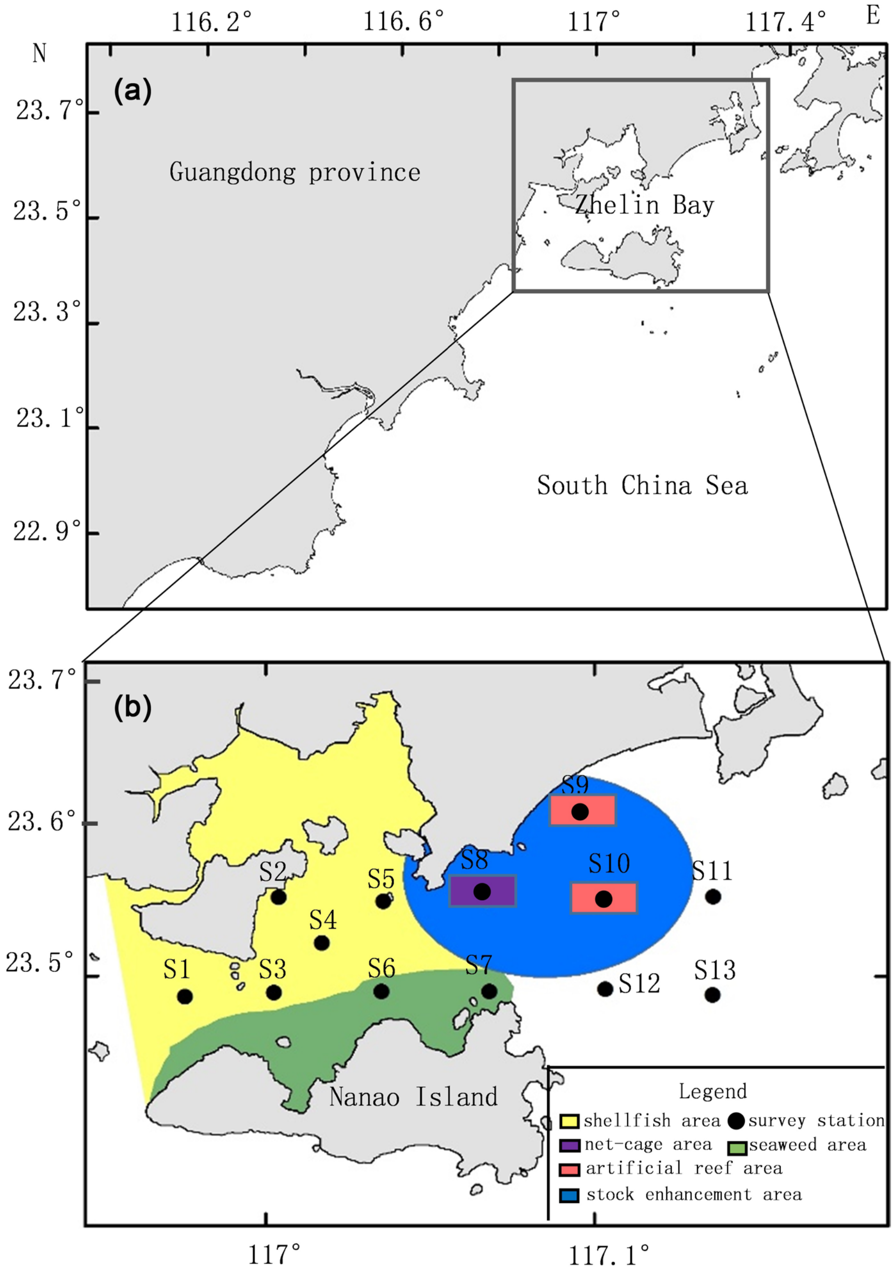

Figure 1. Study area and locations of surveyed stations.

Before (August 2011) and after (August 2013) Zhelin Bay marine ranching was established, nitrogen (N) and phosphorus (P) concentrations in water at each station were measured; and biomass, density and species number of benthos were determined by bottom trawl surveys. Bottom trawl survey is an important marine benthic investigation method, which not only pick up some of the larger individuals, but also collect some marine creatures living on the seabed (Zhang et al., 2017). The fishing vessel was 17.0 m long, 3.9 m wide. The power of main engine power was 88.2 KW, the perimeter of the mouth of the trawl net was 45.0 m, the size of mesh in the mouth was 45.0 cm, the size of mesh in the cod end was 2.5 cm, and the total length of the net was 25.0 m. The trawl was towed at 3.1 kn for 0.25 h once at each station. All investigations, analysis and identification were carried out following *The specification for Marine Monitoring* (GB17378-2007) and *The Specification for Oceanographic Survey—Marine Biological Survey* (GB12763.6-2007). The species of each captured individual was identified, their body weight was measured to the nearest 0.1. The body length of each fish and shrimp, and the width of each crab were also measured.

2.2. Data Analysis

2.2.1. Remote Sensing Data

The sea surface temperature (SST) and chlorophyll a (Chl-a) concentration in Zhelin Bay marine ranching in August 2011 (before the marine ranching was established) and August 2013 (after the marine ranching was established) were from NASA MODIS-Aqua Ocean Color Data (https://oceandata.sci.gsfc.nasa.gov/), with a temporal resolution of one day, and a spatial resolution of 4 km. MATLAB software were used to read the NC format, remove the invalid value and calculate the monthly average of SST and Chl-a. Kriging geostatistical interpolation (Wang, 1999) in the ArcGIS 10.2 software was used in the analysis and depicted the spatial distribution of SST and Chl-a.

2.2.2. Catch per Unit Effort (CPUE)

The catch per unit effort (CPUE, kg·h^{-1}) (Hilborn & Walters, 1992) was calculated using Formula (1) as follows,

$$\text{CPUE} = \frac{C}{t} \tag{1}$$

where C is total catch (including fish, crustaceans, cephalopods and shellfish) in kg, and t is time in h.

2.2.3. Density Distribution of CPUE

The Density distribution of CPUE (Parzen, 1962) indicates a set of CPUE data corresponding to the probability distribution of the density value, which is the trend of the data distribution of the CPUE. Suppose there are n CPUEs (X_1 to X_n), the frequency (ranging from 0 to 1 without units) of one CPUE was calculated using Formula (2) as follows,

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x - X_i}{h}\right) \tag{2}$$

where x is CPUE and k is the Kernel function (Zhang et al., 2013). In this study, the Gaussian distribution function was used, and h is the window width.

2.2.4. Shannon-Wiener (H’) Diversity Index (Wilson & Sheaves, 2001)

$$H' = -\sum\nolimits_{i=1}^{s} p_i \log_2 p_i \tag{3}$$

The H' indicates biological species diversity in community. The higher value of H' is, the more stable the community is. Where s is the total number of species captured at each station, and P_i is the ratio of the number of individuals of the i^{th} species to the total number of individuals of all species.

2.2.5. Benthos Density (ind·m⁻²)

$$\text{Benthos density} = n \cdot s^{-1} \quad (4)$$

where n is the number of benthos and s is the sampling area.

2.2.6. Redfield Ratio

Nitrogen and phosphorus are usually consumed at the Redfield N:P ratio of 16:1 by marine phytoplankton (Sun et al., 2006). So, An N:P ratio close to 16 indicates that the water quality is suitable for the growth of phytoplankton (Liu et al., 2008).

3. Results

3.1. Distribution of SST, Chl-a and CPUE during the Pre- and Post-Marine Ranching

After Zhelin Bay marine ranching was established, the SST, Chl-a and CPUE in water all increased, and varied in a wider range. Spatial overlay analysis showed that before the marine ranching was established (August 2011), SST fluctuated mainly from 27.1˚C to 28.9˚C, Chl-a fluctuated mainly from 2.7 to 12.1 mg·m^{-3}, and CPUE fluctuated mainly from 2.1 to 5.5 kg·h^{-1} [Figure 2(a)]. High CPUE was noticed mainly in the seaweed area and the net-cage area (S6, S7 and S8 stations), where SST ranged from 27.6˚C to 28.6˚C, and the Chl-a ranged from 7.5 to 12.3 mg·m^{-3} [Figure 2(a), Figure 2(c)]. After the marine ranching was established (August 2013), SST fluctuated mainly within the range from 28.1 to 29.6˚C,

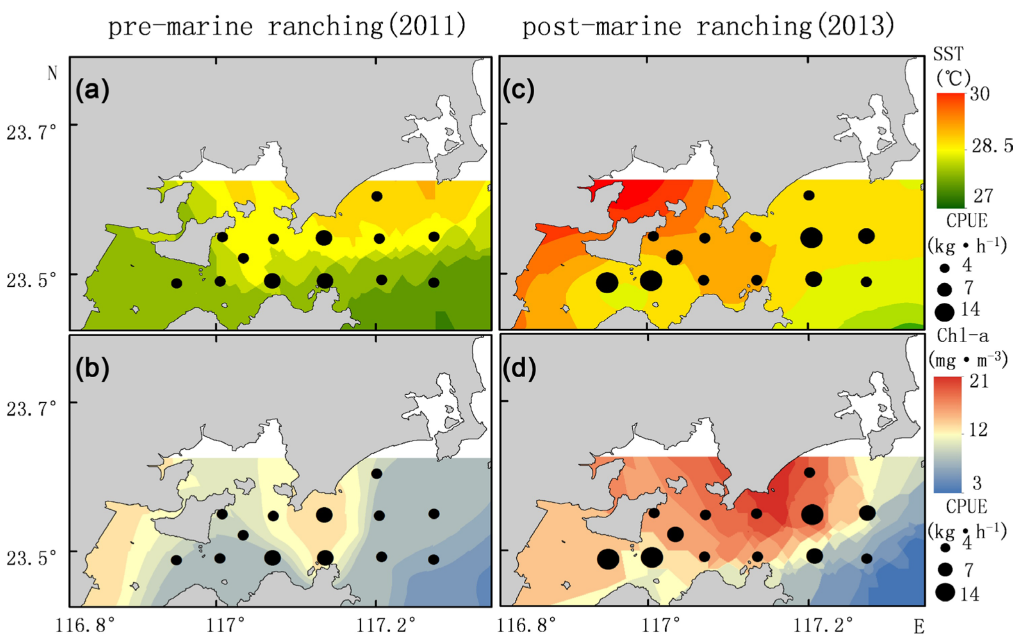

Figure 2. Spatial distribution of SST, Chl-a and CPUE during the pre- and post-marine ranching in Zhelin Bay.

Chl-a fluctuated within the range from 5.1 to 20.5 mg·m^{-3}, and CPUE ranged from 5.8 to 14.5 kg·h^{-1}. Results showed that high CPUE was observed mainly in the shellfish area and the artificial reef area (S1, S3 and S10 stations), where SST ranged from 28.8˚C to 29.4˚C, Chl-a ranged from 10.4 to 16.2 mg·m^{-3} [**Figure 2(b)**, **Figure 2(d)**]. Average SST was increased by 0.77˚C after the marine ranching was established, and chi-square test showed that the increase was extremely significant ($P = 0.001 < 0.01$); average Chl-a increased by 7.63 mg·m^{-3}, and chi-square test showed that the increase was also extremely significant ($P = 0.002 < 0.01$). In addition, high CPUE areas spatially expanded from seaweed area, net-cage area to shellfish area and artificial reef area. The average CPUE of Zhelin marine ranching after it was established was 1.9 times of that before it was established, and chi-square test showed that the increase in CPUE was insignificant ($P = 0.07 > 0.05$).

3.2. Variations in CPUE during the Pre- and Post-Marine Ranching

The frequency of fishery resources CPUE distributed more evenly after the marine ranching was established (August 2013). Before the marine ranching was established, the CPUE of Zhelin marine ranching ranged from 0 to 6 kg·h^{-1}, mostly from 2 to 6 kg·h^{-1}, and the highest CPUE density was 0.22 [**Figure 3**]. After the marine ranching was established, the CPUE of Zhelin marine ranching ranged from 0 to 15 kg·h^{-1}, mainly from 0 to 10 kg·h^{-1}, and the highest CPUE density was 0.11 [**Figure 3**].

3.3. Variations in Catches and Marine Environment during the Pre- and Post-Marine Ranching

The number of species and diversity index of each catch both increased after Zhelin Bay marine ranching was established. The number of captured fish species in the marine ranching increased from 38 in August 2011 to 63 in August 2013, the number of captured crustacean species increased from 39 to 42, the

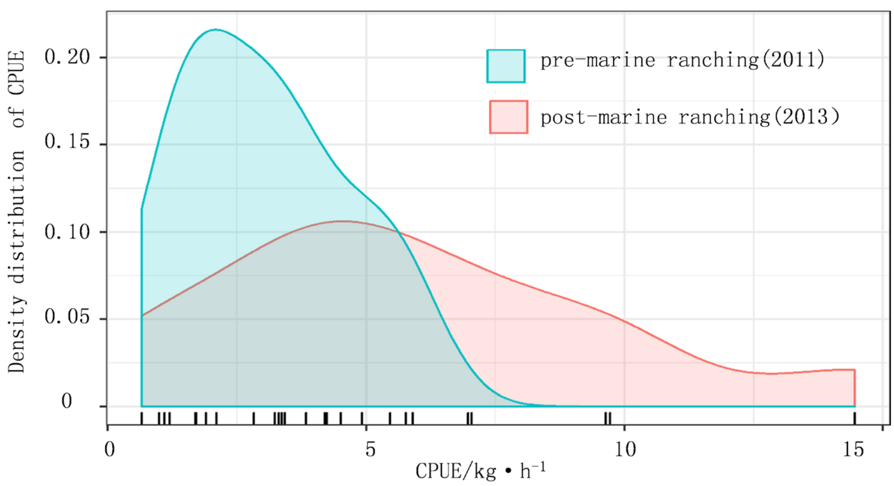

Figure 3. Variations in CPUE and CPUE density in the pre- and post-marine ranching in Zhelin Bay.

number of cephalopod species increased from 2 to 7, and the number of shellfish species increased from 3 to 6. The diversity index *H'* of fish in the marine ranching increased from 3.4 in August 2011 to 3.9 in August 2013, the *H'* of crustaceans increased from 3.8 to 4.2, the *H'* of cephalopods increased from 1.0 to 1.1, and the *H'* of shellfish increased from 0.6 to 1.6 [**Figure 4**].

The biomass and density of benthos in the marine ranching also increased after it was established. In August 2011, the biomass of benthos ranged mainly from 10 to 30 $g \cdot m^{-2}$, and the maximum value was 383.4 $g \cdot m^{-2}$, which was noticed in the shellfish bottoming area (Station S3), and the minimum value was 5.6 $g \cdot m^{-2}$, which appeared in the control area (Station S11). The density of benthos in the marine ranching ranged mainly from 70 to 150 $ind \cdot m^{-2}$, and the maximum value was 260 $ind \cdot m^{-2}$, which appeared in the shellfish area (Station S3), and the minimum value was 50 $ind \cdot m^{-2}$, which appeared in the shellfish area (Station S2). After Zhelin Bay marine ranching was established, the biomass of benthos ranged mainly from 40 to 200 $g \cdot m^{-2}$, and the maximum value increased to 400.3 $g \cdot m^{-2}$, which was noticed in the shellfish area (Station S5), and the minimum value increased to 20 $g \cdot m^{-2}$, which appeared in the control area (Station S12). The density of benthos ranged mainly from 100 to 300 $ind \cdot m^{-2}$, and the maximum value was 690 $ind \cdot m^{-2}$, which was observed in the shellfish area (Station S2), and the minimum value was 40 $ind \cdot m^{-2}$, which was noticed in the seaweed area (Station S6) [**Figure 5(a)**, **Figure 5(b)**].

After Zhelin Bay marine ranching was established, Chl a concentration increased at all stations. In August 2011, Chl a concentration ranged mainly from 2 to 6 $mg \cdot m^{-3}$, and the maximum value was 7.7 $mg \cdot m^{-3}$, which appeared in the shellfish area (Station S4), and the minimum value was 1.1 $mg \cdot m^{-3}$, which was noticed in the artificial reef area (Station S9). In August 2013, Chl a concentration ranged mainly from 5 to 15 $mg \cdot m^{-3}$, and the maximum value was 17.6 $mg \cdot m^{-3}$, which appeared in the shellfish area (Station S5), and the minimum value was 2.3 $mg \cdot m^{-3}$, which was observed in the shellfish area (Station S1) [**Figure 5(c)**].

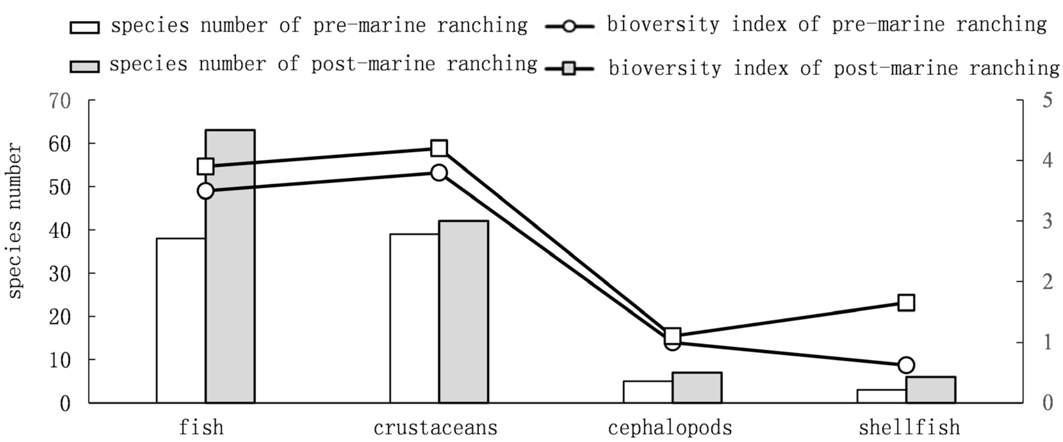

Figure 4. Variations in species number and biodiversity index of CPUE including fish, crustaceans, cephalopods and shellfish.

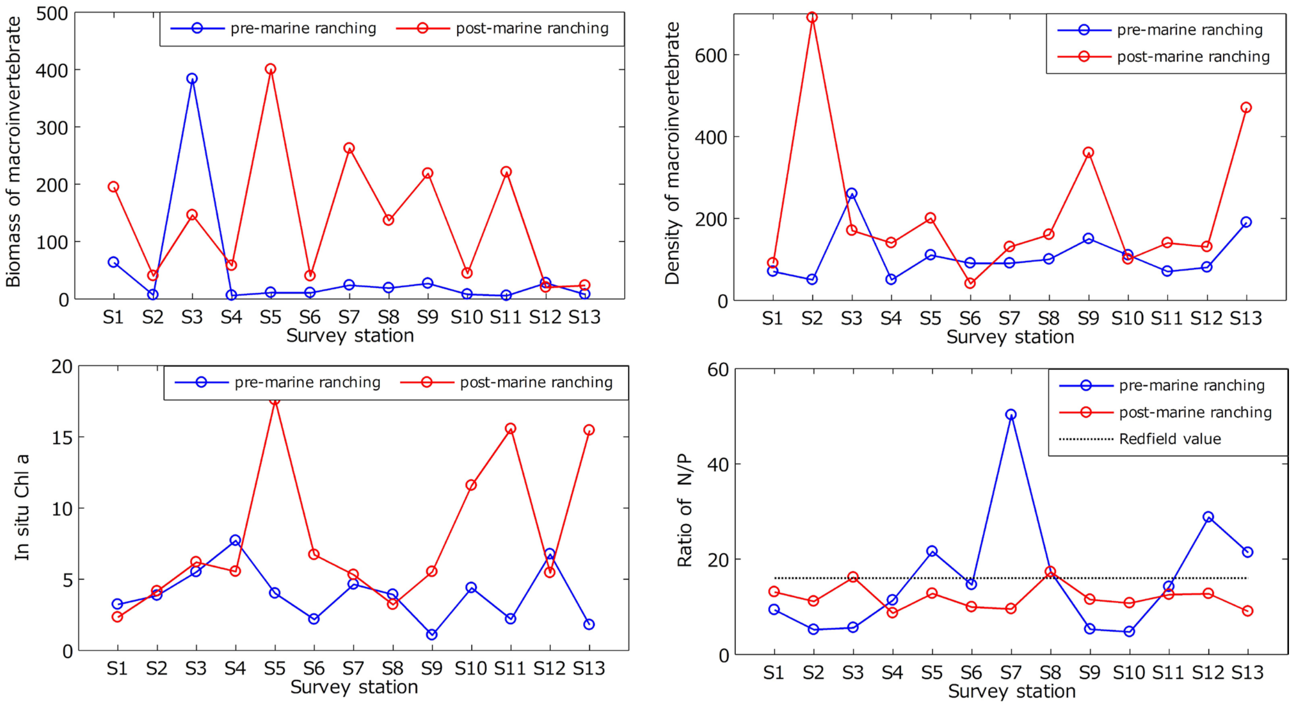

Figure 5. Changes in biomass and density of benthos, Chl a and nutrients before and after Zhelin Bay marine ranching was established: (a) Biomass of benthos; (b) Density of benthos; (c) Chl a concentration; (d) N:P ratio (the Dotted line indicates Redfield value of 16).

In August 2011, the ratio of nitrogen to phosphorus (N:P) in Zhelin Bay marine ranching ranged mainly from 5 to 50, and the stations with a Redfield value close to 16 were mainly distributed in the shellfish area, net-cage area and control area (S6, S8 and S11 stations). In August 2013, the N:P ratio in the marine ranching ranged mainly from 9 to 17, and there were seven stations with a Redfield value close to 16, mainly distributed in the shellfish area, seaweed area and control area (S1, S2, S3, S5, S7, S11 and S12 stations) [Figure 5(d)].

4. Discussion

4.1. Marine Ranching Improves Ecological Environment

The establishment of Zhelin Bay marine ranching alleviated eutrophication and increased Chlorophyll a concentration in marine coastal areas. Nutrients (nitrogen, phosphorus, *etc.*) concentration affects the growth of marine phytoplankton, and N:P ratio directly reflects the nutritional status of existing nitrogen and phosphorus in the waters. Four more stations with a N:P ratio close to the Redfield value 16:1 were noticed after the marine ranching was established. Water quality in the shellfish area, seaweed area and artificial reef area were significantly improved. Shellfish has a well-developed filter-feeding system, and extremely high water-filtering capacity. The large shellfish area of Zhelin Bay promotes the efficient use of carbon, nitrogen and phosphorus in water bodies to some extent (Fu, 2014). In addition, shellfish also has the ability to enhance seawater exchange, making nutrients more uniformly distributed and alleviating eutrophication in the sea (Chen et al., 2007). The seaweed area in Zhelin Bay was planted mainly with asparagus and seaweed, and large seaweed can absorb nutrients such as nitrogen and phosphorus, and purify water to some extent (Zou & Xia, 2011). The reef in the artificial reef area of Zhelin Bay improves water quality by changing the flow rate and direction of seawater and increasing attached biological biomass (Yu et al., 2015), and such ecological impact also spreads to the control area.

Chlorophyll a concentration is directly proportional to the level of nutrient salts (Zhang et al., 2008). Zhelin Bay underwent eutrophication before the marine ranching was established (Huang et al., 2005). Our results showed that after the marine ranching was established, the concentration of Chlorophyll a in the shellfish area, seaweed area, artificial reef area and control area of Zhelin Bay increased, which was consistent with previous studies (Wang et al., 2013; Liu et al., 1998; Chen et al., 2014). Seaweed areas can capture and storage carbon (Menendez et al., 2005), and artificial reef can change water flow, and thus to improve the primary productivity of marine ranching and the habitat of marine life, which lays a material foundation for the proliferation and conservation of fishery resources.

4.2. Marine Ranching Increases CPUE and Species Diversity of Fishery Resources

After the marine ranching was established, CPEU and the biomass and density of benthos, as well as the species number and diversity of captured samples all increased. Fish are very sensitive to changes in water temperature, and suitable temperature is an important condition for fish aggregation (Hu et al., 2012). Remote sensing showed that after Zhelin Bay marine ranching was established, SST was more uniform in this area, and the Chl-a concentration and the primary productivity of the marine area increased, providing a suitable environment and sufficient bait for the growth and reproduction of marine organisms. As a result, CPUE in the Zhelin Bay area increased, and the distribution of CPUE density was more uniform. CPUE of the shellfish area, artificial reef area and control area increased significantly, due to increased Chl-a concentration in these areas. Sowing shellfish improved the primary productivity of the marine area to some extent (Nakamura & Kerciku, 2000). After Zhelin Bay marine ranching was established, the number of fish, crustaceans, cephalopods and shellfish species increased by 25, 3, 2 and 3, and their diversity index H' increased by 0.5, 0.4, 0.1, and 1.0, respectively; CPUE density increased, and varied in a wider range. All the results were consistent with the findings in Daya Bay and Zhangzi Island marine ranching (Chen et al., 2013; Chen et al., 2014). When an ocean current meets the artificial reef structure, deeper water must flow upward, and bring the nutrients to the surface layer, which provides food for plankton and increases the dissolved oxygen of the water body (Yu et al., 2015; Jiang et al., 2016; Liu et al., 2013). The artificial reefs also provide a shelter, spawning and nursery grounds for reef fish and other marine life (Cui et al., 2009; Charbonnel et al., 2002). This creates a chain reaction, whereby larger fish come to prey on the smaller ones, and population densities increase around the reefs. In addition, the increased range of CPUE density may be due to summer fishing moratorium. Zhelin Bay marine ranching provides a habit for marine life, and promotes the proliferation of fishery resources (Yu et al., 2018). The chi-square test showed that the increase in CPUE was not significant in the short period after the establishment of the marine ranching, so long-term data are needed to determine the effect of the marine ranching on the proliferation of fishery resources.

After Zhelin Bay marine ranching was established, both the biomass and density of benthos increased, and the increases in shellfish area, artificial reef area and contrast area were obvious, because the marine ranching provides a suitable environment for the propagation of benthic organisms (Zhang et al., 2008). Benthos live in the sediments of water bodies. Among them, shellfish can purify the substrate, create a good habitat for benthos, and promote the growth of benthos, increasing the biomass and density of benthos (Shentu et al., 2017). In addition, artificial reefs increase the biomass of attached organisms, which then attract more marine organisms that feed on them, increasing the species number and diversity of benthic organisms (Shu et al., 2015). In addition, the data also showed that the biomass and density of benthos at stations fluctuated to some extent. Some stations have a significant increase, while others changes slightly after the construction of marine ranching. On the one hand, it is because biomass and density of benthos are related to the depth of water (Cai et al., 2018). On the other hand, human activities such as the establishment of artificial reefs and the bottom sowing of shellfish disturbed benthic habitat. Although the ecosystem has the ability to recover from these events, the time required for each station is also different (Chen et al., 2016).

5. Conclusion

In this study, we assessed the ecological effects of marine ranching based on satellite remote sensing and in situ observation. Results showed that after the marine ranching was established, the marine areas with an N:P ratio closed to the Redfield value 16:1 expanded, and Chl-a concentration increased from 7.5 - 12.3 $mg \cdot m^{-3}$ to 10.4 - 16.2 $mg \cdot m^{-3}$, CPUE increased by 1.9 times, and the biomass and density of benthos also increased. These showed that the establishment of Zhelin Bay marine ranching contributes to the restoration of fish habitats, and promotes the proliferation and conservation of fishery resources, ecological environment improvement, resource proliferation and conservation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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