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Evaluation of the Environmental Impact of Artificial Habitat on Seawater Quality in Tahe Bay, Lvshun

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Abstract

Artificial reefs and Seaweed enhancement floating rafts (abbreviated as floating rafts) are two main facilities for habitat creation in marine ranching. To understand the effects of artificial reefs, floating rafts, and artificial reef and floating raft combination (referred to as reef + raft) on the marine environment, a survey of the marine environment of The Bay Marine Ranch in Lvshun was conducted from 2021 to 2022, and Dissolved Inorganic Nitrogen (DIN), Dissolved Inorganic Phosphorus (DIP), Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), petroleum, Suspended solids and Heavy metals (including Cu, Pb, Zn, Cd, Hg, As), etc. The dynamic changes of the indicators and the fuzzy membership function of the indicators were determined according to the seawater quality standards, the indicator weights were determined by using the analytic hierarchy process, and the fuzzy comprehensive evaluation values of the three artificial habitats were calculated. The results show that all seawater quality indicators in September 2021, March 2022 and November 2022 meet the Class I Seawater Quality Standard (GB3097—1997) and are suitable for marine fishing waters. In April 2022, the survey indicators of the waters of Tahe Bay in Lvshun were all in line with Class II Seawater Quality Standard (GB3097—1997), except one station where the suspended matter was of Class III Seawater Quality Standard (GB3097—1997), which was suitable for mariculture waters. In 2021, artificial reefs, floating rafts, reef+raft on the quality of the human living environment: artificial reefs =reef +raft > floating rafts; the degree of impact on the marine biological habitat: reef + raft >artificial reefs > floating rafts; the degree of influence of artificial reefs, floating rafts, reef + raft on human living environment quality in 2022: reef+raft >floating rafts>artificial reefs; the degree of influence on the habitat of marine organisms: reef+raft >artificial reefs> floating rafts.

Keywords

Marine ranching, Artificial habitats, Impacts, Water quality environment

The degradation of marine habitats and loss of functions at the end of the 20th century led to a sharp decline in the variety and quantity of biological resources. Governments around the world have taken measures to try to prevent further habitat destruction to restore habitats and increase biological resources at the local level in order to achieve sustainable use of fisheries resources [1]. The offshore of China has also suffered from the deterioration of marine ecology, frequent diseases of cultured organisms, and a decline in seafood quality due to habitat destruction and marine environmental pollution [2]. Marine ranching is playing an increasingly important role in improving the ecological environment of the sea. However, how to optimize the ecological function of the sea under the concept of "ecological priority and land-sea integration", and efficiently use the physical space of the sea is an urgent problem [3]. Artificial reefs and enrichment floating rafts are currently the main facilities for habitat creation in marine ranching. The extent to which habitat creation affects the marine ecosystem is a common concern in the field of marine fisheries environment in China. The habitats created by various marine ranching facilities such as artificial reefs, floating rafts, and their combinations exist in the waters of Tahe Bay in Lvshun, Dalian city, which is an important marine cultivation waters in Dalian. The floating rafts are the main breeding facilities for algae such as *Undaria pinnatifida Suringar*, and the artificial reefs are the main breeding facilities for sea cucumbers, abalone and reef-type fish. In this study, based on the marine environment field survey data from 2021-2022, the fuzzy integrated evaluation method was applied to assess the impact of different habitats on the marine environment, hoping to benefit the high-quality development of marine ranching.

1. Materials and Methods

1.1 Data sources

The data of this study came from the sea area of Tahe Bay Marine Ranch. The Bay is located in the sea near the village of Guojiagou on South Road in Lvshun, Dalian City, Liaoning Province in China. Based on the actual marine fishery production in Tahe Bay, four types of waters, including artificial reefs area, floating rafts area, combined reef and raft (hereinafter referred to as reef+raft) area and controlled area, were selected as the target areas for this study (Figure 1). Four voyages of marine environmental surveys were carried out in September 2021 and March, April, and November 2022. As data from only two stations (floating rafts, reef + raft) were available in March and April 2022, the data from September 2021 and November 2022 were mainly used to analyse the impact of different artificial habitats on the environment. The distribution of the sampling sites within the study area is shown in Figure 1. The habitats at the four sampling sites were the artificial reefs area (S1), reef+raft area (S2), floating rafts area (S3) and controlled area (S4). The environmental survey of seawater quality was carried out according to the Marine Survey Specification (GB/T:12763.9-2007) [4]. Considering the ecological effects of artificial habitat facilities [5], the survey factors used for the analysis of this paper include inorganic nitrogen (DIN), inorganic phosphorus (DIP), dissolved oxygen (DO), chemical oxygen demand (COD), petroleum, suspended solids and heavy metals (Pb, Cd, Cu, Zn, Hg, As) in a total of 12 items. Seawater chemical environmental monitoring indicators, methods, and basis are shown in Table 1. Different habitat creation has different effects on the marine ecological environment, so according to the water chemical characteristics of the study area using the national "seawater quality standards": GB3097-1997 [6], seawater quality standards are divided into a total of four categories of evaluation criteria are shown in Table 2, so as to determine the level of water quality.

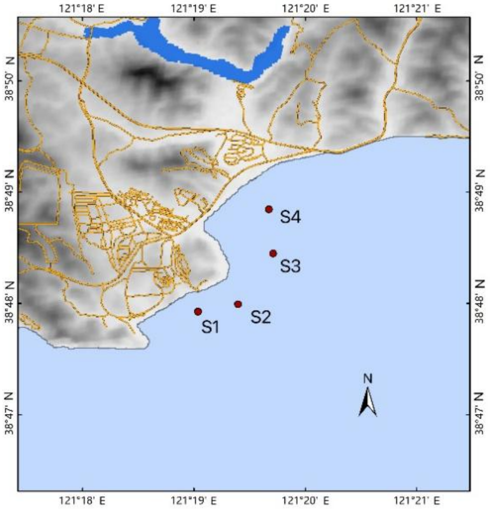

Figure 1. Distribution of water quality survey stations in Tahe Bay.

1.2 Evaluation methods

The evaluation of the environmental impact of artificial habitats on seawater quality mainly includes two main aspects. The first is to evaluate the impact on the environmental quality of human life as the evaluation objective, to evaluate the important impact of seawater quality environment on human production and life and physical and mental health and other human habitat environmental quality. i.e. the seawater quality conforms to the Chinese national seawater quality standard "Seawater Quality Standard" (GB3097-1997); The second is to evaluate the impact on the marine habitat environment, i.e. the seawater quality is suitable for the reproduction and growth and development of marine organisms. Studies have shown that within a certain range, the increase in the content of nutrient salts and heavy metals plays a role in promoting the growth of phytoplankton and marine organisms [7, 8]. Therefore, this study evaluates the impact of artificial habitats on the seawater quality environment from the above two aspects.

Table 1. Evaluation criteria

Water Quality Indicators	Seawater Quality Standards (GB3097-1997) /mg·L^{-1}			
	I	II	III	IV
DIP≤	0.015	0.03	0.03	0.045
DIN≤	0.2	0.3	0.4	0.5
COD≤	2	3	4	5
petroleum≤	0.05	0.05	0.3	0.5
DO≤	6	5	4	3
Suspended solids≤	10	10	100	100
Cu≤	0.005	0.01	0.05	0.05
Pb≤	0.001	0.005	0.01	0.05
Zn≤	0.02	0.05	0.1	0.5
Cd≤	0.001	0.005	0.01	0.01
Hg≤	0.00005	0.0002	0.0002	0.0005
As≤	0.02	0.03	0.05	0.05

1.2.1 Establish the fuzzy membership function of the evaluation index

In this paper, 12 investigation factors such as inorganic nitrogen (DIN), dissolved oxygen (DO), chemical oxygen demand (COD), dissolved inorganic phosphorus (DIP), petroleum, heavy metals (Pb, Cd, Cu, Zn, Hg, As), and suspended matter in water were selected as evaluated indicators. The fuzzy affiliation functions of evaluated indicators (DIN, DIP, DO, COD and Petroleums, etc.) were established by the threshold parabolic standardization method, in which DIN, DIP, COD, petroleum, suspended matter and heavy metal indicators were established by the partial small size and DO by the partial large size threshold parabolic standardization method, respectively (Table 2). The basic equations for partial small (also known as inverse or cost-based indicators, the smaller the better) and partial large (also known as positive or benefit-based indicators, the larger the better) are as follows:

(1) A function of the standardization of biased small (the smaller the better) evaluated indicators.

$$\begin{cases} 1 & x_i < x_{min} \\ y_i = \left(\frac{x_{max} - x_i}{x_{max} - x_{min}}\right)^k & x_{min} \ll x_i \ll x_{max} \\ 0 & x_i > x_{max} \end{cases}$$

(2) A function of the standardization of biased large (the larger the better) evaluated indicators.

$$\begin{cases} 0 & x_i < x_{min} \\ y_i = \left(\frac{x_i - x_{min}}{x_{max} - x_{min}}\right)^k & x_{min} \ll x_i \ll x_{max} \\ 1 & x_i > x_{max} \end{cases}$$

x_i is the measured value of the ith evaluation index ($i \in \mathrm{I}$). x_{max}, x_{min}, denote the maximum and minimum values of the ith evaluation index, respectively, and y_i is the standard value of each level.

1.2.2 Determining the weight of evaluated indicators

When applying multiple evaluated indicators to evaluate the environment of marine ranching, each indicator should be assigned a different weight due to the varying importance of the various evaluated indicators. Using the three-scale analytic hierarchy process [10] (Table 4) to establish the evaluated indicator weight is shown in (Table 5).

Table 2. The membership function of the index evaluation criteria and its data source

Index	Affiliation functions	Data source
DIN/mg · L^{-1}	$\begin{cases} 1 & x < 0.2 \\ \frac{0.3-x}{0.3-0.2} & 0.2 \le x \le 0.3 \\ 0 & x > 0.3 \end{cases}$	According to China Seawater Quality Standards (GB3097-1997), China Water quality standard for fisheries (GB11607-89) and the classification criteria of seawater trophic levels in the literature [9] (Table 2).
DIP/mg · L^{-1}	$\begin{cases} 1 & x < 0.03 \\ \frac{0.045-x}{0.045-0.03} & 0.03 \le x \le 0.045 \\ 0 & x > 0.045 \end{cases}$	According to the Seawater Quality Standards (GB3097-1997), Water quality standard for fisheries (GB11607-89) and the classification criteria of seawater trophic levels in the literature [9] (Table 2).
DO/mg · L^{-1}	$\begin{cases} 0 & x < 5 \\ \left(\frac{x-5}{6-5}\right)^{0.11} & 5 \le x \le 6 \\ 1 & x > 6 \end{cases}$	According to the Seawater Quality Standards (GB3097-1997), Water quality standard for fisheries (GB11607-89), DO value of 5.01-6 mg L^{-1} when the evaluation value ≥ 0.60.
COD/ mg · L^{-1}	$\begin{cases} 1 & x < 2 \\ \left(\frac{3-x}{3-2}\right)^{0.11} & 2 \le x \le 3 \\ & x > 3 \end{cases}$	According to the Seawater Quality Standards (GB3097-1997), Water quality standard for fisheries (GB11607-89), COD in the range of 2 to 2.99 mg L^{-1}, the evaluation value ≥ 0.60.
petroleum/ mg · L^{-1}	$\begin{cases} 1 & x = 0 \\ \left(\frac{0.05-x}{0.05-0}\right)^{0.074} & 0 \le x \le 0.05 \\ 0 & x > 0.05 \end{cases}$	According to the Seawater Quality Standards (GB3097-1997), Water quality standard for fisheries (GB11607-89), petroleums in 0 ~ 0.04995 mg L^{-1} when the evaluation value ≥ 0.60.
Suspended solids/mg · L^{-1}	$\begin{cases} 1 & x = 0 \\ \left(\frac{10-x}{10-0}\right)^{0.074} & 0 < x \le 10 \\ 0 & x > 10 \end{cases}$	According to the Seawater Quality Standards (GB3097-1997), Water quality standard for fisheries (GB11607-89), Suspended solids in 0~9.99 mg L^{-1} when the evaluation value ≥ 0.60.
Hg, Cd, Pb, Cu, Zn, As/mg · L^{-1}	$\begin{cases} 1 & x = 0 \\ \left(\frac{a-x}{a}\right)^{k} & 0 < x \le a \\ 0 & x > a \end{cases}$	According to the Seawater Quality Standards (GB3097-1997), Water quality standard for fisheries (GB11607-89), where the a-values of Hg, Cd, Pb, Cu, Zn, As and sulfide are: 0.0005, 0.005, 0.05, 0.01, 0.1 and 0.050, respectively, and the unit of a-value is mg L-1; k-value is 0.074. k-value is determined based on the assurance that the a-value of the evaluation index is reduced by 1‰, and the evaluation value ≈ 0.60.

Table 3. The nutrition level of sea water [9]

Level	Trophic level	DIN/mg · L^{-1}	DIP/mg · L^{-1}
I	Poor nutrition	＜0.2	＜0.03
II	Moderate nutrition	0.2～0.3	0.03～0.045
III	Nutrient-rich	＞0.3	＞0.045
IV$_{P}$	Phosphorus limits moderate nutrition	＜0.2	
V$_{P}$	Phosphorus moderately limits potential eutrophication	0.2～0.3	
VI$_{P}$	Phosphorus limits potential eutrophication	＞0.3	
IV$_{N}$	Nitrogen restriction moderate nutrition		＜0.03
V$_{N}$	Nitrogen moderately limits potential eutrophication		0.03～0.045
VI$_{N}$	Nitrogen restriction is potentially eutrophic		＞0.045

Table 4. The means of 0～2 bid

Scale	Meaning
0	Compared with the two elements, the latter (j) is more important than the former (i).
1	Compared to the two elements, both are equally important
2	Compared with the two elements, the former (i) is more important than the latter (j).

Table 5. Weights of evaluated indicators

Evaluated indicators/ mg · L^{-1}	Weight value (W_i)	Evaluated indicators/ mg · L^{-1}	Weight value (W_i)
DIN	0.131	Hg	0.028
DIP	0.215	Cd	0.028
COD	0.036	Pb	0.028
DO	0.083	Cu	0.028
Suspended solids	0.024	Zn	0.028
petroleum	0.344	As	0.028

1.2.3 Comprehensive evaluation

The comprehensive evaluation value of the marine environment of each station can be obtained from the equation $E=\sum_{i=1}^{n} w_i e_i$ (where w_i and e_i denote the weight of indicator i and the evaluation value of indicator i respectively). In this study, the fuzzy membership function of the evaluated indicators is used as the value of the evaluated indicators for the degree of impact on the quality of the human living environment, while the actual value of the evaluated indicators is used as the value of the evaluated indicators for the degree of impact on the habitat of marine organisms. The comprehensive evaluation value in both cases can be obtained by substituting the respective values of evaluated indicators into the evaluation equation ($E=\sum_{i=1}^{n} w_i e_i$).

2. Results

2.1 Dynamic characteristics of environmental indicators

The statistical results of the main environmental indicators of Tahe Bay from 2021 to 2022 are shown in Figure 2.

2.1.1 Characteristics of dynamic changes of DIN content

In September 2021, the content of DIN in Tahe Bay fluctuated between 0.011 and 0.019 mg/L (average of 0.143 mg/L). In March 2022, the content of DIN ranged from 0.538 to 0.202 mg/L (average of 0.081 mg/L). In November 2022, the content of DIN varied between 0.157 and 0.269 mg/L (average of 0.001 mg/L). In summary, it can be seen that the average content of DIN in Tahe Baydid not exceed the upper limit of 0.1 mg/L of the Class I of the Seawater Quality Standard (GB3097-1997). Overall, there is a decreasing trend in the interannual variation of the average DIN content [8]. The highest value of DIN content in 2021 was 0.269 μg/L, and the lowest value of DIN content appeared in 2022.

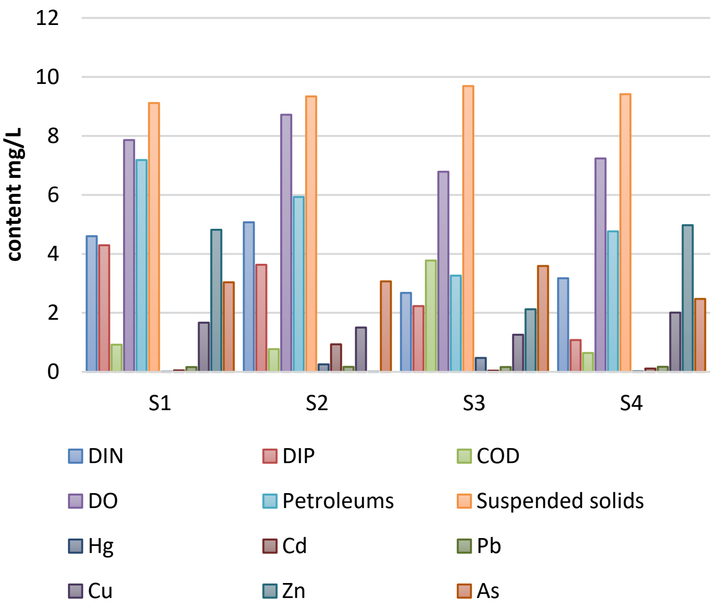

Figure 2. Statistical values of the content of main environmental indicators in Tahe Bay.

2.1.2 Characteristics of dynamic changes of DIP content

In September 2021, the range of DIP content in Tahe Bay varied between 0.003-0.008 mg/L (average of 0.004 mg/L). In March 2022, the DIP concentration ranged from 0.016 to 0.082 mg/L (average of 0.012 mg/L). In April 2022, the range of DIP content was 0.010-0.012 mg/L (average of 0.011mg/L). In November 2022, the content of DIP ranged from 0.0095 to 0.015μg/L (average of 0.013μg/L). In conclusion, it can be seen that the average content of DIP in Tahe Bay in September 2021, March 2022, September 2022 and November 2022 meets the requirements of Class I of the Seawater Quality Standards (GB3097-1997). Overall, from 2021 to 2022, the average content of DIP showed an upward trend followed by a downward trend. In 2021, the concentration of DIP peaked at 5.97 g/L; in 2022, it dropped substantially to 0.0095 g/L, the lowest value recorded.

2.1.3 Characteristics of dynamic changes of COD content

In September 2021, the COD content in Tahe Bay ranged from 0.4 to 1.04 mg/L (average of 0.508 mg/L). in March 2022, the COD content varied between 0.032 and 1.28 mg/L (average of 0.480 mg/L). in April 2022, the COD content ranged from 0.82 to 1.19 μg/L (average of 0.002 mg/L). in November 2022, the COD content ranged from 0.64 to 1.05 μg/L (average of 0.002 μg/L). In November 2022, the COD content ranged from 0.64 to 1.05 μg/L (average of 0.845 μg/L). the average COD content in seawater during 2021-2022 meets the first class in the Seawater Quality Standard (GB3097-1997). Overall, the average COD content has a cliff-jumping downward trend in 2021-2022. The highest value of 1.05 μg/L occurred in 2022 and the lowest value of 0.46 μg/L recorded in 2021.

2.1.4 Characteristics of dynamic changes in petroleum content

In September 2021, the petroleum content in Tahe Bayvaried between 6.50 and 14.30μg/L (average of 10.70μg/L). In March 2022, the petroleum content ranged from 1.76 to 7.50μg/L (average content 3.50μg/L). in April 2022, the petroleum content ranged from 11.60 to 14.40μg/L (average content 13.00μg/L). in November 2022, the petroleum content ranged from 0.02 to 0.03μg/L (average content 0.00μg/L). In November 2022, the petroleum content ranged from 0.02 to 0.03 μg/L (average 0.24 μg/L). The petroleum content in seawater during 2021-2022 continued to meet the first category of the Seawater Quality Standards (GB3097-1997). The aggregate analysis demonstrates that the average content of petroleum has an up-and-down trend. The highest value is 14.3μg/L and the lowest value is 6.5μg/L. The highest value of petroleum content in 2022 is 0.0268μg/L and the lowest value is 0.0178μg/L. The petroleum content in 2021-2022 shows an up-and-down fluctuation trend from S4 to S1.

2.1.5 Characteristics of dynamic changes of DO content

In September 2021, DO levels in Tahe Bay ranged from 5.81 to 6.81 mg/L (mean of 6.315 mg/L). In March 2022, DO levels fluctuated around 9.39 mg/L. In April 2022, DO levels ranged from 11.87 to 12.75 mg/L (mean of 12.31 mg/L). In November 2022, DO levels ranged from 7.6 to 8.43 mg/L (mean of 7.8625 mg/L). In November 2022, the DO content ranged from 7.6 to 8.43 mg/L (average of 7.8625 mg/L). In conclusion, it can be seen that the average concentration of D0 in Tahe Bay does not exceed the upper limit of 6mg/L set by the Seawater Quality Standard for Class I seawater quality, so the water quality is Class I. In general, the interannual variation in average DO content exhibits an oscillating upward and then downward trend.

2.1.6 Characteristics of dynamic changes of suspended solids content

In September 2021, the content of suspended solids in Tahe Bay ranged from 6.54 to 7.73 mg/L (average of 7.418 mg/L). in March 2022, the content of suspended solids fluctuated around 9.8 mg/L. in April 2022, the content of suspended solids ranged from 8.42 to 9.22 mg/L (average of 8.82 mg/L). in November 2022, the content of suspended solids ranged from 10.3 to 11.3 mg/L (average of 10.9 mg/L). In November 2022, the content of Suspended solids ranged from 10.3 to 11.3 mg/L (average of 10.9 mg/L). In summary, it can be seen that the average content of Suspended solids in Tahe Bay did not exceed the upper limit of 100 mg/L of Class II of Seawater Quality Standards (GB3097-1997), and the water quality level is Class II. In general, the interannual variation of the average content of Suspended solids showed an oscillating upward and then downward trend. the highest value of Suspended solids in 2021 was 7.73 mg/L and the lowest value was 6.54 mg/L. the highest value of Suspended solids in 2022 was 11.3 mg/L and the lowest value was 8.42 mg/L.

2.1.7 Characteristics of dynamic changes of heavy metal content in seawater

From 2021 to 2022, the Cu concentration in Tahe Bay fluctuated between 1.98 and 3.49 g/L, and did not exceed the Class I of Seawater Quality Standards (GB3097-1997), so the water quality was Class I. The Pb concentration in Tahe Bay ranged from 0.15 to 0.345 g/L and did not exceed the Class I of the Seawater Quality Standards (GB3097-1997), indicating that the water quality was Class I. The Zn concentration in Tahe Bay ranged from 4.1 to 11.6 g/L and did not exceed Class I of the Seawater Quality Standards (GB3097-1997), indicating that the water quality was Class I. The Zn concentration in Tahe Bay ranged from 4.1 to 11.6 g/L and did not exceed Class I of the Seawater Quality Standards (GB3097-1997), indicating that the water quality was Class I. The Cd concentration ranged from 0.07 to 0.331 micrograms per liter and did not exceed Class I of the Seawater Quality Standards (GB3097-1997); thus, the water quality was Class I. The average Hg concentration in Tahe Bay ranged from 0.014 to 0.0362 g/L and did not exceed Class I of the Seawater Quality Standards (GB3097-1997), indicating that the water quality was Class I. The average level of arsenic in Tahe Bay ranged from 1.34 to 11.40 g/L and did not exceed Class I of the Seawater Quality Standards (GB3097-1997); therefore, the water quality is Class I. Thus, we can conclude that the heavy metal content in the marine environment of Tahe Bay meets the requirements of the first class of the Seawater Quality Standards (GB3097-1997).

2.2 The influence of different artificial habitats on seawater quality environment

This study evaluates the impact of the water quality environment on the quality of the human living environment and the habitat of marine organisms in order to analyze the impact of different artificial habitats on the marine water quality environment. Due to the fact that only two stations (floating raft and reef+floating raft) were operational in March and April 2022, only data from September 2021 and November 2022 were used to evaluate the impact of various artificial habitats on the seawater quality environment.

The evaluation values of each evaluated indicator were obtained by substituting the actual measured values of the evaluated indicators into the fuzzy membership function, and the fuzzy comprehensive evaluation values of the previous surveys were obtained by substituting the evaluation values of each evaluated indicator into the formula ($E = \sum_{i=1}^{n} w_i e_i$) (Table 6), which were used to evaluate the degree of impact of the water quality environment of different habitats on the quality of human living environment. The actual measured data of the evaluated indicators were substituted into the formula ($E = \sum_{i=1}^{n} w_i e_i$) to obtain the comprehensive evaluation values of the previous surveys, which were used to evaluate the degree of impact of the water quality environment of different habitats on the habitat of marine life (Table 6).

2.2.1 Impact on the quality of human living environment

In September 2021, the fuzzy evaluation values of the evaluated indicators ranged from 0.880-1.000; the fuzzy evaluation values of DIN, DIP, COD, Pb, Zn, Cd, Hg and As indicators were all 1.000, indicating that the environmental quality met the Class I of Seawater Quality Standard; The fuzzy evaluation value of DO indicator of 1.000 for artificial reefs, floating rafts and reef + raft, except for the control area of 0.977, indicates that the three artificial habitats may have improved the DO environment of the water column in autumn. The fuzzy evaluation value of Suspended solids ranged from 0.880 to 0.924, and the fuzzy evaluation value ranked artificial reefs> reef+raft> control> floating rafts; the fuzzy evaluation value of petroleum was between 0.975-0.990, the fuzzy evaluation value ranked reef+raft>artificial reefs=floating rafts>control; the fuzzy evaluation value of Cu 0.969-0.984, with fuzzy evaluation values ranked as artificial reefs> control >reef + raft > floating rafts; heavy metals combined fuzzy evaluation values between 0.995-0.997, with fuzzy evaluation values ranked as artificial reefs> floating rafts> reef + raft = control; and water quality combined fuzzy evaluation values between 0.987-0.994, with fuzzy evaluation values ranked as artificial reefs = reef +raft > floating rafts> control.

Table 6. Evaluation results of seawater quality in Tahe Bay area

Time	Project	Evaluation value							
		S1(artificial reefs)		S2(reef+raft)		S3(floating rafts)		S4(controlled area)	
		Fuzzy evaluation val-	Actual value	Fuzzy evaluation values	Actual value	Fuzzy evaluation values	Actual value	Fuzzy evaluation values	Actual value
2021.09	DIN	0.131	0.018	0.131	0.021	0.131	0.016	0.131	0.019
	DIP	0.215	0.001	0.215	0	0.215	0.001	0.215	0
	COD	0.036	0.029	0.036	0.035	0.036	0.002	0.036	0.017
	DO	0.083	0.491	0.083	0.499	0.083	0.049	0.081	0.565
	Suspended solids	0.022	0.157	0.022	0.197	0.021	0.172	0.022	0.186
	Petroleums	0.339	0.005	0.340	0.003	0.339	0.002	0.336	0.003
	Cu	0.027	0.094	0.027	0.080	0.027	0.098	0.027	0.055
	Pb	0.028	0.009	0.028	0.010	0.028	0.006	0.028	0.008
	Zn	0.028	0.314	0.028	0.297	0.028	0.325	0.028	0.291
	Cd	0.028	0.007	0.028	0.009	0.028	0.008	0.028	0.008
	Hg	0.028	0.001	0.028	0.001	0.028	0.001	0.028	0.001
	As	0.028	0.094	0.028	0.038	0.028	0.051	0.028	0.045
	Nutrient	0.346	0.019	0.346	0.021	0.346	0.016	0.346	0.019
	heavy metal	0.166	0.519	0.166	0.435	0.166	0.489	0.166	0.408
	Comprehensive evaluation value	0.991	1.22	0.993	1.19	0.991	0.731	0.986	1.198
2022.11	DIN	0.131	0.035	0.131	0.005	0.131	0.021	0.131	0.037
	DIP	0.215	0.003	0.215	0.038	0.215	0.002	0.215	0.022
	COD	0.036	0.038	0.036	0.029	0.036	0.023	0.036	0.03
	DO	0.083	0.644	0.083	0.083	0.083	0.7	0.083	0.636
	Suspended solids	0.000	0.271	0.000	0.262	0.000	0.247	0.000	0.266
	Petroleums	0.333	0.009	0.327	0.006	0.325	0.008	0.327	0.009
	Cu	0.027	0.095	0.027	0.067	0.027	0.067	0.027	0.084
	Pb	0.028	0.005	0.028	0.006	0.028	0.004	0.028	0.005
	Zn	0.028	0.157	0.028	0.118	0.028	0.115	0.028	0.129
	Cd	0.028	0.002	0.028	0.002	0.028	0.002	0.028	0.002
	Hg	0.028	0	0.028	0	0.028	0	0.028	0
	As	0.027	0.319	0.028	0.227	0.028	0.185	0.027	0.137
	Nutrient	0.346	0.038	0.346	0.043	0.346	0.023	0.346	0.059
	heavy metal	0.166	0.578	0.166	0.42	0.166	0.373	0.165	0.357
	Comprehensive evaluation value	0.964	1.578	0.958	0.843	0.956	1.374	0.957	1.357

Remarks:

a) The fuzzy evaluation value is obtained by substituting the measured value of the evaluated indicator into the fuzzy membership function. The range of this value is between 0 and 1, the closer to 1 means that the indicator is better;

b) The fuzzy evaluation value of nutrients is obtained by formula $(0.131\cdot F_{DIN}+0.215\cdot F_{DIP})/(0.131+0.215)$, where F represents the fuzzy membership function value; The evaluation value of nutrient salt is obtained from the formula $(0.131\cdot C_{DIN}+0.215\cdot C_{DIP})/(0.131+0.215)$, where C represents the measured value;

c) The fuzzy evaluation value of heavy metals is obtained from $(0.028\cdot F_{Cu}+0.028\cdot F_{Pb}+0.028\cdot F_{Zn}+0.028\cdot F_{Cd}+0.028\cdot F_{Hg}+0.028\cdot F_{As})/(0.028\times 6)$, where F represents the fuzzy membership function value obtained; The measured evaluation value of heavy metals is obtained from $(0.028\cdot C_{Cu}+0.028\cdot C_{Pb}+0.028\cdot C_{Zn}+0.028\cdot C_{Cd}+0.028\cdot C_{Hg}+0.028\cdot C_{As})/(0.028\times 6)$, where C represents the measured value;

d) The comprehensive evaluation value is the sum of the fuzzy evaluation values (or measured values) of each indicator multiplied by its weight respectively.

In November 2022, the fuzzy evaluation values of the evaluated indicators ranged from 0.947-1.000; the fuzzy evaluation values of DIN, DIP, COD, DO, Pb, Zn, Cd and Hg indicators were all 1.000, indicating that the environmental quality met the first class seawater quality standard; the fuzzy evaluation values of suspended substances were all 0.000, which might be related to the heavier wind and waves at sea during the sampling period; the fuzzy evaluation values of petroleum was between 0.947-0.970, and the fuzzy evaluation value ranked reef + raft > floating rafts>artificial reefs = control; the fuzzy evaluation value of Cu is between 0.970-0.980, and the fuzzy evaluation value ranked reef + raft = floating rafts> control >artificial reefs; the comprehensive fuzzy evaluation value of heavy metals was between 0.992-0.995, and the fuzzy evaluation value ranked reef +raft = floating rafts> control = fish reefs; the comprehensive fuzzy evaluation value of water quality ranged from 0.957-0.966, with fuzzy evaluation values ranked as of reef + raft > floating rafts> control > reefs.

2.2.2 Impact on the habitat environment of marine organisms:

In September 2021, the comprehensive effect of nutrients was ranked as reef+raft>artificial reefs=control area>floating rafts; The comprehensive effect of heavy metals was ranked as artificial reefs>floating rafts>reef+raft>control area; The overall effect was ranked as artificial reefs>controlled area> reef+raft>floating rafts. In November 2022, the comprehensive effect of nutrients was ranked as reef+ raft>artificial reefs=controlled area>floating rafts; The comprehensive effect of heavy metals was ranked as artificial reefs>floating rafts>reef+raft>controlled area; The overall effect was ranked as artificial reefs>controlled area > reef + raft > floating rafts.

The reason may be that the sediments of the reef + raft area and the floating rafts area contain more algae proliferation and algae decay. The debris produced by decaying algae is decomposed by bacteria into nutrients, and the upwelling generated by artificial reefs transports the nutrients from the bottom to the surface. Therefore, the comprehensive evaluation value of nutrients in reef+ raft area is the highest. The lowest nutrient content in the floating raft sea area may be because algae absorb a large amount of nutrient salt, and the nutrient salt in the water body cannot replenish the nutrient salt in the bottom sediment to the middle and upper sea due to the lack of upwelling. The nutrient content in the control area is higher because the content of phytoplankton and algae in the control area is lower than that in the floating raft area. The density of algae in the floating raft area and the reef + raft area was high, which may be the reason for the relatively low concentration of heavy metals. Studies have shown that algae have a strong adsorption effect on heavy metals [11], and the heavy metal content in sea areas with high algae density is low. The low heavy metal content in the control area may be caused by a large number of algae floating to the control area caused by sea wind and waves a few days before sampling.

3. Discussion

(1) Artificial habitats have improved the marine water quality environment to some extent. Weiding Wang (2010) concluded that the construction of artificial reefs plays a positive role in improving and restoring marine ecology [12]; Yan Zhang et al. (2013) studied the characteristics of changes in seawater quality of artificial reefs in Laizhou Bay, Shandong Province [13]; and Pimao Chen et al. (2013) pointed out that using artificial reefs to improve the ecological environment of marine fishing grounds and enrichment areas is an effective measure for the sustainable development of coastal fisheries [14]. The results of the comprehensive evaluation of different habitat combinations on nutrient salts, heavy metals and overall were calculated and judged that the construction of fish reef areas improved the seawater quality in the Tahe Bay area of Lvshun to a certain extent. The results of the comprehensive evaluation in September 2021 were artificial reefs> controlled area>reef+raft > floating rafts; artificial reefs = reef+raft > floating rafts>controlled area. the comprehensive evaluation in November 2022. The results were artificial reefs = reef+raft > floating rafts> controlled area; reef+raft > floating rafts>controlled area>artificial reefs. The results were consistent with the findings of Xiaoping Jia (2003) [15], who showed that Artificial reefs and artificial reef and floating raft combinations had a greater impact on the marine ecological environment. Of these, the effects of the two habitat combinations, floating rafts and artificial reefs and floating rafts, on the marine ecosystem vary accordingly to the seasons. The results of this study on the extent of the impact of different artificial habitats on the marine environment can be used as a reference for the restoration of marine ecosystems by artificial habitats.

(2) Ecological benefit is a significant feature of marine ranching compared with traditional farming methods. The maximization of ecological benefits of marine ranching must be based on the maximization of ecological benefits formed by artificial measures [16]. This study evaluated artificial reefs, floating rafts, fish reef + raft three kinds of artificial habitat impact on the marine ecological environment. It is hoped that the results of this study can serve as a catalyst for the healthy and sustainable development of marine ranching.

(3) The fuzzy comprehensive evaluation method can objectively reflect the fuzziness and continuity of evaluated things, ensuring close connections between things [17]. In terms of water quality evaluation, the fuzzy comprehensive evaluation method applies membership functions to classify water quality levels, which can scientifically and objectively reflect the water quality status. From the actual situation of various indicators, the evaluation conclusion is basically consistent with the expert opinion.

Based on the comprehensive evaluation results, the sea area is gradually becoming polluted. This area is located in the nearshore shallow waters, close to the port, and the uncertainty of human activities may lead to unstable changes in nutrients in the waters, which brings a certain degree of contingency to the investigation results [18-23].

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