Research Article

Contaminants and heavy metals along the mangrove area of Dongzhai Harbor, China: distribution and assessment

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Abstract

In recent decades, higher-place shrimp ponds are prevalent in coastal areas of developing countries. However, shrimp aquaculture has a growing negative impact on mangrove wetland ecosystems. Mangroves located in Dongzhai harbor are under threat continuously of this commercialization. Therefore, a comprehensive analysis of contaminants and heavy metals is necessary for Dongzhai harbor, considering the mangrove area was declined and ecological services offered to the coastal communities with an insight for future restoration activities. In this study, pond effluents (Total Nitrogen (TN), Ammonia Nitrogen (AN), Total phosphorus (TP), Chemical Oxygen Demond (COD)) and heavy metals (Cd, Cu, Pb, Zn) were monitored in Dongzhai harbor yearly between 2013 and 2017. The results showed that the contents of Cd, Cu, Pb, and Zn were far lower than the standards. However, the main contaminants were organic matter and nitrogen. Maximum values of COD and TN were 26.10 $mg \cdot L^{-1}$ and 1.34 $mg \cdot L^{-1}$, respectively in 2017. Single factor index, Nemerow's pollution index, and Trophic level index revealed that the heavily polluted areas were Tashi and Sanjiang town.

Keywords Dongzhai harbor · Pollution monitoring · Analysis and assessment · Mangrove

1 Introduction

Mangroves are tropical and subtropical highly productive coastal ecosystems, which are found within the intertidal areas [1, 2]. Mangroves can provide numerous food, wood, medicine, fuel and other goods or services, which is absolutely important to human and society [3, 4]. In addition to providing numerous avian and aquatic species with suitable habitats, mangrove wetland ecosystems can protect coastal areas from tsunamis, hurricanes, tropical cyclones, and other natural disasters [3, 5]. Despite the well understood significance of mangroves, during the past semi-century, the mangroves began to die in large numbers and the ecosystems faced serious threats, especially in the developing countries [6]. There are a lot of deforestation and degradation in the mangroves because of the pressure of land use competition. Brackish aquaculture, salt production, and agriculture are the man-made causes of mangrove loss [7, 8]. Additionally, global warming, tropical cyclones, tsunamis, and other natural disturbances have contributed to mangrove loss [9, 10]. However, mangrove ecosystems are more resilient to natural disturbances than to human-induced disturbances.

In recent years, the increasing demand for shrimp around the world led to an explosive expansion of shrimp farming, especially in tropical coastal areas [11, 12]. However, shrimp aquaculture has a growing negative impact on mangrove wetland ecosystems. A large portion of shrimp feed added to the shrimp pond cannot be completely transformed into biomass, which can

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be responsible for excess primary productivity, and even causes eutrophication of water bodies [11, 13]. Therefore, temporal and spatial assessment of contaminants in shrimp farming areas is necessary to protect the mangrove ecosystems.

The Dongzhai harbor is a representative zone with a thirty-year history of mariculture in China. It is also the main area of mangrove distribution in China. In this area, shrimp farms use the higher-place pond. This is a kind of aquaculture pond, which is built above the high tide line [14]. In the process of shrimp farming, the aquaculture water in the pond needs to be raised by the power so that the breeding process is unaffected by the tide. Because the bottom of the pond is higher than the sea level, it can easily discharge the organic pollutants such as the residual bait and the shrimp feces. This factor can control the water quality in ponds easily and increase the success rate of shrimp culture [15]. This farming method has brought huge economic benefits to local residents. However, the development of coastal shrimp farming has caused serious pollution. Mangrove area was threatened and declined throughout the Dongzhai harbor, which was decreased nearly 11% from 1990 to 2010 (the Bureau of Statistics of Hainan Province, http:// www.stats.hainan.gov.cn/) [16]. Furthermore, the annual growth rate of the degraded area of mangroves was 66.4% from 2010 to 2013 in Dongzhai harbor. The major mangrove wood-boring isopod was *Sphaeroma terebrans*. The mangrove were damaged by borers, which was distributed in the coastal areas suffering serious anthropogenic disturbance and contamination. Shrimp culture made the water eutrophic, which could provide *S. Terebrans* with sufficient food [15, 17, 18]. Hence, the pollution indicators (Total Nitrogen, Ammonia Nitrogen, Total Phosphorus, Chemical Oxygen Demand) related to aquaculture wastewater were monitored. Based on monitoring indicators, the study compared the monitored concentrations of pollutants in the water with the standard values, to determine the pollution exceeding multiples based on Single factor index, and analyzed pollution stress by Nemerow's pollution index (NPI) and determined eutrophication by Trophic level index (TLI). Additionally, heavy metal pollution is a serious threat to the marine ecological environment due to its high toxicity, non-degradability, and bioaccumulation. Marine sediment is a large reservoir for heavy metals, thus monitoring heavy metals in the coastal areas is considered as an approbatory approach for environmental assessment [19, 20]. In recent years, urbanization of surrounding cities and the construction of shrimp ponds increase the potential risk of heavy metals to seafood security and ecological environment in Dongzhai harbor. Thus, whether the ecological environment in Dongzhai harbor is polluted by heavy metals needs to be investigated.

Even though, aquaculture contamination in Dongzhai harbor has been reported, the mangrove habitats have not been comprehensively evaluated. Whether the environment of Dongzhai harbor is polluted by aquaculture wastewater needs to be investigated so as to assess their potential risk to the mangrove ecosystem. The study was designated to examine the pollution status, spatiotemporal variation, pollution sources and potential risks of pollution indicators in coastal water (TN, AN, TP, COD_{Mn}) and sediment (Cd, Cu, Pb, Zn, pH), via analyzing the monitoring data in Dongzhai harbor of Hainan yearly, 2013–2017. Single factor index, Nemerow's pollution index, and Trophic level index were used to analyze the contamination of mangrove areas.

2 Material and methods

2.1 Study area

Hainan is located in the south of China. With a tropical monsoon climate, an extensive coastline, the vast water resources, the annual warmed, the abundant rainfall and numerous intertidal bay areas, Hainan provides suitable environmental conditions for mangrove growth. Hainan Island belongs to a tropical monsoon marine climate which has the following features: distinct seasons, no extreme hotness in summer, no extreme coldness in winter, slight annual temperature differences, and high annual average temperature. With a wide range of tropical plants, flowers, fruits, and herbs, Hainan is one of the largest tropical gene banks in Asia [21, 22].

Dongzhai Harbor is located in the northeast of Hainan Province (19°51′ ~ 20°1 N, 110°32′ ~ 110°37′ E), which is belonging to the Qiongzhou Strait (Fig. 1). Mangrove preserved in DongZhai harbor is the largest coastal forest in China and a treasure house of species and genes with 16 families and 32 species of mangrove plants, 204 species of birds, 115 species of mollusks, 119 species of fish, 70 species of crabs, and 40 species of shrimps [23]. In 2010, the total mangrove area of Dongzhai harbor was about 1578.2 ha and the mangrove species mainly include *Rhizophora stylosa, Avicennia marina, Sonneratia apetala, Sonneratia caseolaris, Kandelia candel, Bruguiera sexangula,* and *Ceriops tagal* [24].

2.2 Sampling

The study conducted a thorough investigation of water and sediment pollution in Dongzhai harbor, Hainan. The sampling range is located in the west and south of Dongzhai harbor, which is the main distribution area of mangroves and shrimp ponds in Hainan. The fifteen points

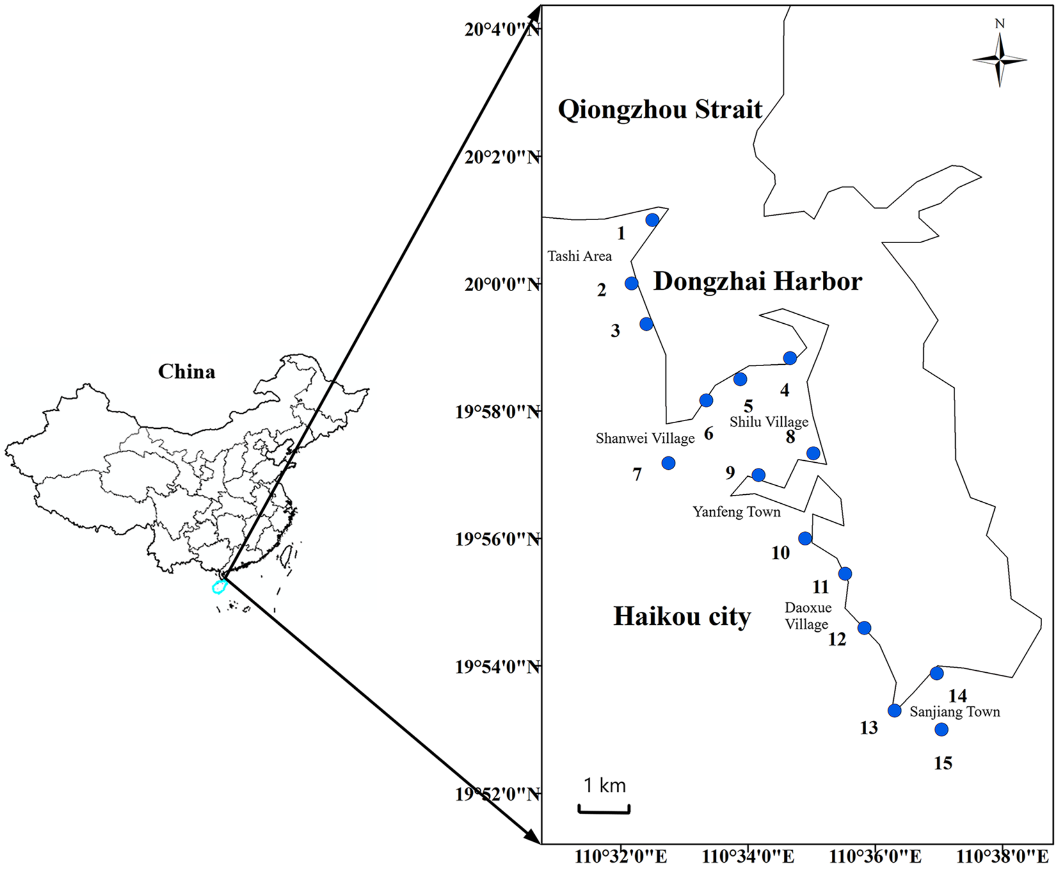

Fig. 1 Maps of the study area. Map of China, including the entire Hainan province and Dongzhai harbor. Blue circle symbols (1–15) represent sampling stations that were investigated during February and August yearly from 2013 to 2017

were separately located at six sampling areas. According to the location of the pollution source and the actual topography, these points are all located 25–30 m away from shrimp ponds and 1–2 m away from mangroves. Circumstances around sampling points, for example, the density of mangroves, topography of intertidal zone, and the number of shrimp ponds are similar in the same area. Fifteen sampling points were set up along Dongzhai harbor (Fig. 1) during the monitoring process.

Sample collection was launched in February and August (dry and wet season) from 2013 to 2017, which had the average temperatures of 18.8 °C and 28.1 oC, respectively and total precipitation of 30.6 mm and 171.9 mm, respectively. The samples were collected in low tide period, which could assess the anthropogenic effects. Due to high tide, the seawater dilution effect would affect the monitoring results. Water samples for chemical measurements were collected and preserved in printed polyethylene bottles with sulfuric acid (to pH 2.0) [25]. The polyethylene bottles were stored at 4 °C in the dark temperature controlled containers while in transit to the laboratory on the same day, which was carried out seven days or less after sampling. All the chemical analyses were done according to standard methods (American Public Health Association (APHA), 1992). At each sampling point, sediment samples were collected by stripping the surface sediment from 2 to 3 cm with a sampling shovel firstly and then using polyvinyl chloride core samplers (about 500 g weight, 20 cm depth). Every sample was transferred into a prelabeled clean plastic bag and the transportation was same as water sample [26].

For water samples, COD_{Mn} was determined by acidic potassium permanganate titration. Concentrations of TN and TP were determined by persulfate digestion. The concentration of AN was determined by Nessler's reagent colorimetric method. For sediment samples, the metal content was obtained through acid digestion (HNO_3:$HClO_4$:HF = 5:4:1, in volume) and the contents of Cd, Cu, Pb, and Zn were determined by Inductively Coupled Plasma Mass Spectrometry (ICP-MS, PerkinElmer NexION 350X, USA). The pH value of sediment was determined by the extraction method with 0.01 mol/L calcium chloride solution (ISO 10390:2005) Figs. 2 and 3.

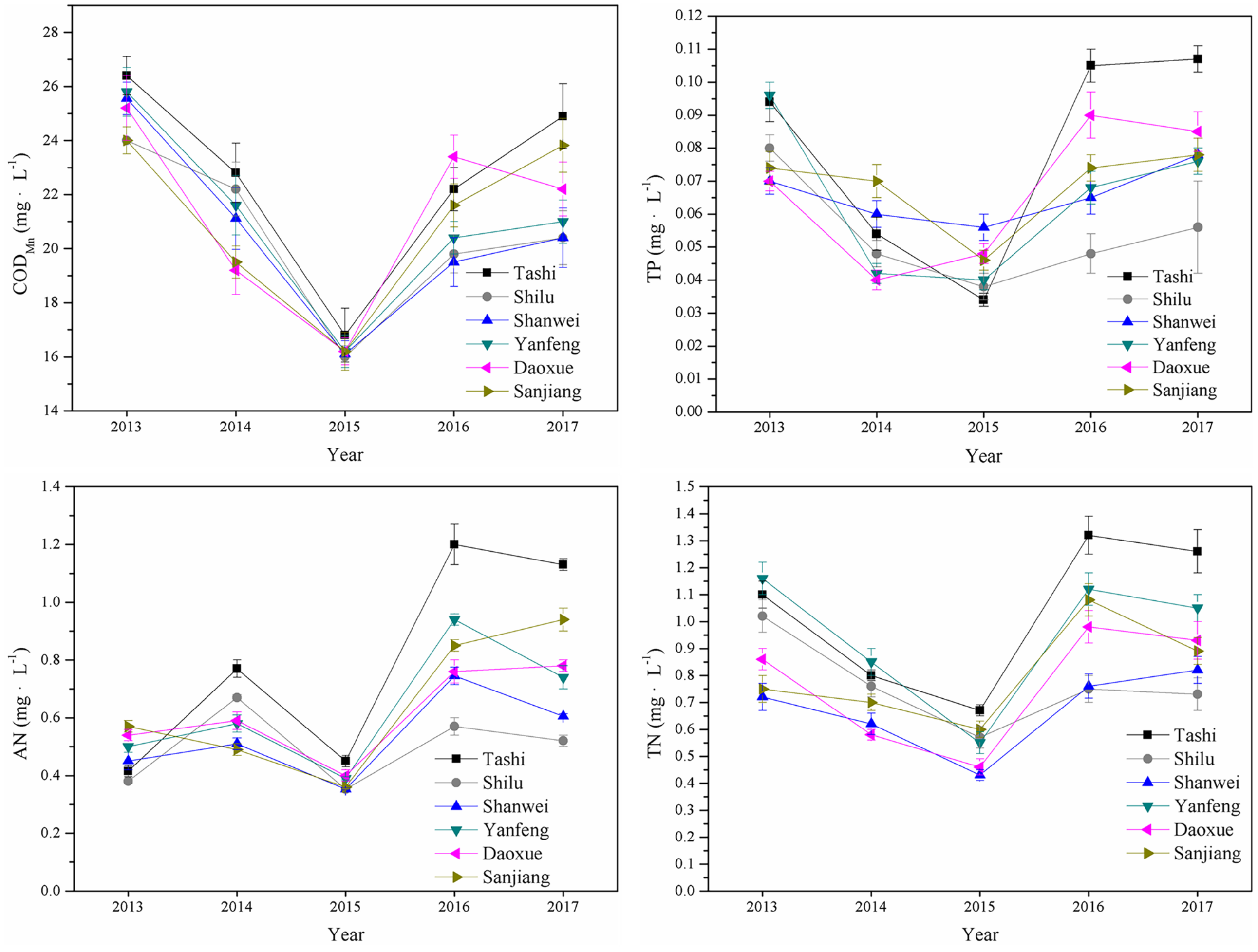

Fig. 2 Temporal variations in contents of COD$_{Mn}$, TP, TN and AN in water samples along the Weihai coast during February and August from 2013 to 2017. The data represent average values ± the standard deviation during different years; the bars represent the standard deviations of values from different stations in the study area of each year

Based on the monitoring data and ecological investigation of mangrove areas in Dongzhai harbor, the study used Single factor index, Nemerow's pollution index (NPI), and Trophic level index (TLI) to evaluate the pollution level of mangrove areas.

2.2.1 Single factor index

Single factor index is used to compare the measured concentration of pollutants with the environmental standard values to determine the pollution exceeding multiples. Currently, the single factor index of Dongzhai harbor is calculated using the following equation.

$$P_{i,j} = \frac{C_{i,j}}{S_i} \tag{1}$$

where $P_{i,\,j}$ is the Single factor index of pollutant i at the j sampling point, which means the exceeding standard multiple. $C_{i,j}$ represents the monitored concentration of the pollutant i at the j sampling point. S_i represents the standard concentration of the pollution factor i. In this study, S_i is the Environmental Quality Standard for Surface Water, China (Table 1).

Water quality requirements are divided into five classes according to its purpose for use and protection target.

Class I: mainly for source of water and national nature protection areas;

Class II: mainly for the first class protection areas for centralized potable water source, protection areas for rare fishes, spawn ground for fishes and shrimps, etc.

Class III: mainly for the second class protection areas for centralized potable water source, protection areas for

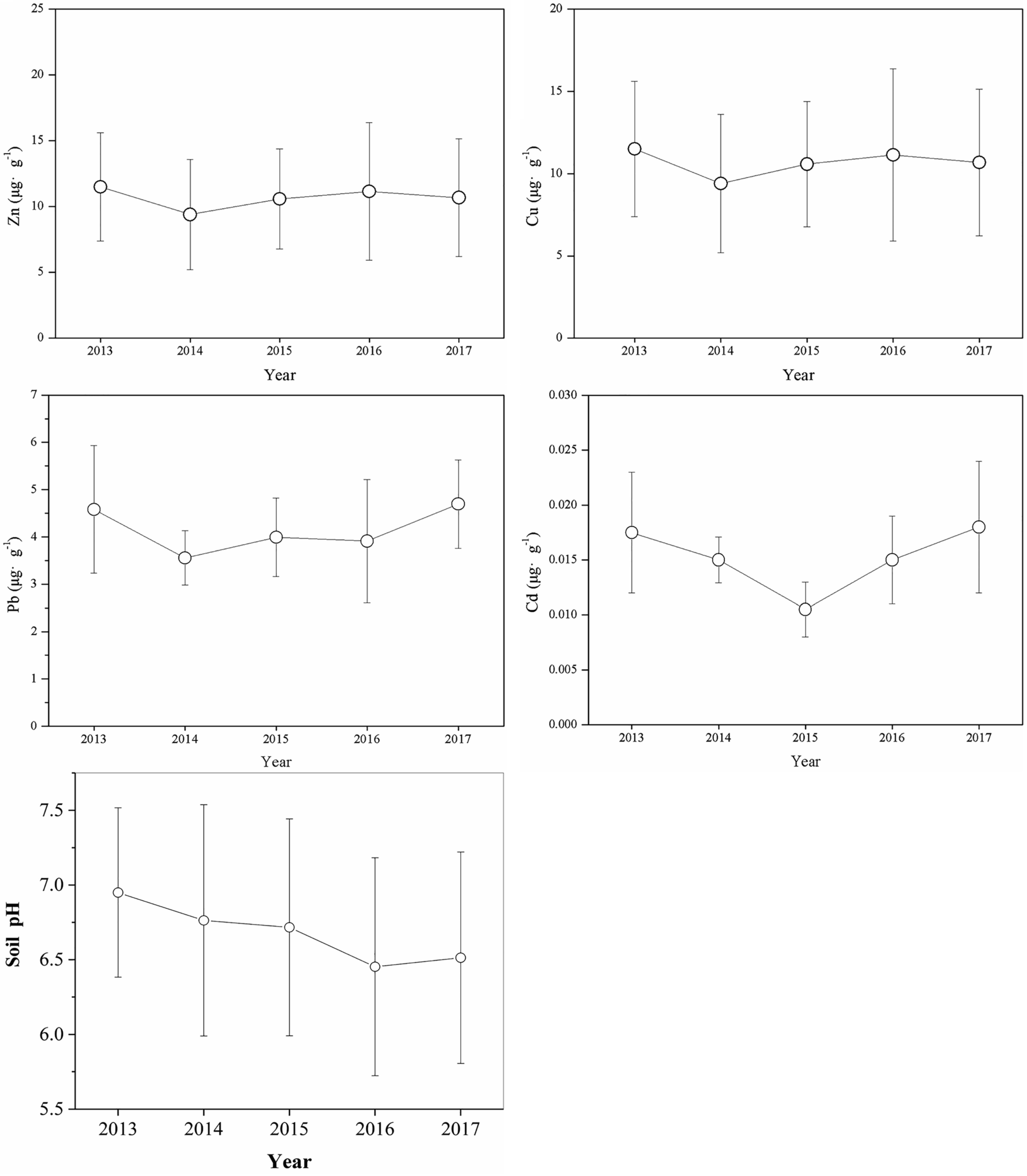

Fig. 3 Temporal variations in contents of Cu, Pb, Zn, Cd and pH in soil samples along the Weihai coast during February and August from 2013 to 2017. The data represent average values ± the standard deviation during different years; the bars represent the standard deviations of values from different stations in the study area of each year

general fish and shrimp overwintering field, migratory passage, aquaculture area and other fishery waters and swimming areas.

Class IV: mainly for general industrial water areas and entertainment water areas not directly touched by body.

Table 1 Environmental Quality Standard for Surface Water

Classification Standard value items	Class I	Class II	Class III	Class IV	Class V
Total phosphor ≤	0.02	0.1	0.2	0.3	0.4
Ammonia nitrogen ≤	0.15	0.5	1.0	1.5	2.0
Total nitrogen ≤	0.2	0.5	1.0	1.5	2.0
Permanganate index ≤	2	4	6	10	15

Class V: mainly for farmland water areas and water areas for general landscape requirement.

Mangrove wetland in Dongzhai harbor, Hainan is belong to the Class III standard.

2.2.2 Nemerow's pollution index (NPI)

Nemerow's pollution index (NPI) is representative of the comprehensive pollution index. It can directly and intuitively reflect the comprehensive water quality in the monitored area. It can not only highlight the influence of the heaviest pollution factors but also consider the other factors. Meanwhile, NPI avoids the influence of subjective factors in the weight coefficient during the weighting calculation [27]. Currently, the NPI of Dongzhai harbor is calculated using the following equation.

$$PI_j = \sqrt{\frac{\left(Max\frac{C_{i,j}}{S_i}\right)^2 + \left(\frac{1}{n}\sum_{i=1}^{n}\frac{C_{i,j}}{S_i}\right)^2}{2}} \tag{2}$$

where PI $_j$ is the Nemerow's pollution index at the j sampling point. $C_{i,j}$ represents the actual concentration of the pollutant i at the j sampling point. S_i represents the standard concentration of the pollution factor i. The obtained PI $_j$ was generally classified into five grades: PI $_j < 1$ indicates unpolluted for the assessed area, $1 <$ PI $_j < 2$ suggests the mild of contamination, $2 <$ PI $_j < 3$ indicates moderate pollution and PI $_j > 3$ represents severe pollution.

2.2.3 Trophic level index (TLI)

Trophic level index (TLI) is a comprehensive index that can characterize the eutrophication level of water bodies [28, 29]. Currently, the TLI of Dongzhai harbor is calculated using the following equations.

$$TLI\left(\sum\right) = \sum_{j=1}^{m} W_j \cdot TLI_j \tag{3}$$

$$W_j = \frac{r_{ij}^2}{\sum_{i=1}^{m} r_{ij}^2} \tag{4}$$

Table 2 Correlation coefficient of TLI

	TP	TN	COD_{Mn}
r_{ij}	0.84	0.82	0.83
r_{ij}^2	0.7056	0.6724	0.6889
W_j	0.34	0.33	0.33

where TLI $_j$ is the jth indicator with the corresponding weight W_j. According to the relationship between the reference chlorophyll *a* concentration and every indicator, the correlation coefficients of r_{ij} value were given in Table 2. The TLI of all the monitoring points was calculated from total phosphorus, total nitrogen and chemical oxygen demand. The formulas of each TLI indicator are given below:

$$\mathrm{TLI(TP)} = 10(9.436 + 1.624\ \ln(\mathrm{TP})) \tag{5}$$

$$\mathrm{TLI(TN)} = 10(5.453 + 1.694\ \ln(\mathrm{TN})) \tag{6}$$

$$\mathrm{TLI(COD)} = 10\left(0.109 + 2.661\ \ln\left(\mathrm{COD_{Mn}}\right)\right) \tag{7}$$

Equations 5, 6, and 7 are empirical regression equations based on a survey of eutrophication levels of water body in China, which based on the correlations between the index of the eutrophication and water quality parameters.

The obtained $TLI(\Sigma)$ was generally classified into five grades: $TLI(\Sigma) < 30$ indicates oligotropher for the assessed district, $30 < TLI(\Sigma) < 50$ suggests mesotropher of contamination, $50 < TLI(\Sigma) < 60$ indicates light eutropher, $60 < TLI(\Sigma) < 70$ indicates middle eutropher and $TLI(\Sigma) > 70$ represents hyper eutropher.

3 Results

In general, the variation trend of pollution contents in water samples declined from 2013 to 2015 and increased in the last two years. Among the pollutions, the concentrations of COD_{Mn} at all sampling points were higher than 15.00 mg·L^{-1} in five years, which were far beyond the national standard (GB3838-2002, China, Table 1). The content of COD_{Mn} in Tashi area was basically the highest in five years. The highest growth rate of COD_{Mn} from 2015 to 2017 was found in Tashi area and Sanjiang town, which were 48.21% and 47.04%, respectively. Since there are more shrimp ponds in these two areas, the mariculture produced more organic matter. The contents of TN and AN from 2013 to 2015 were in the range of 0.45–1.22 and 0.35–0.80 mg·L^{-1}, respectively. However, the content of TN had a rising trend since 2016. In particular, the contents of TN in Tashi area and Yanfeng town exceeded the standard limit of 1 mg·L^{-1} (GB3838-2002, China, Table 1). The maximum values of these two regions were 1.41 and 1.22 mg·L^{-1}, respectively, in 2016. Additionally, the content of TP had been always below the national standard limit of 0.2 mg·L^{-1}.

The contents of Zn, Cu, Pb and Cd were in the ranges of 8.72–24.66, 5.20–16.37, 2.61–5.93, 0.009–0.023 mg·Kg^{-1}, and with the means of 16.33, 10.64, 4.15, 0.015 mg·Kg^{-1}, respectively. Compared to the upper limits in Class I sediment category (Zn 100 mg·Kg^{-1}, Cu 35 mg·Kg^{-1}, Pb 60 mg·Kg^{-1}, Cd 0.5 mg·Kg^{-1}), derived from Environmental quality standard for sediment in the National Standard of China GB18668-2002), the contents of the four heavy metals in this study were far lower than the standard limits. The pH values of sediment samples showed a slow downward trend in the last five years and the minimum value was 5.63 in Tashi area in 2016. Since the use of disinfectants (hydrogen peroxide and chlorine dioxide) in shrimp farming and humus from dead mangroves, the average value of pH was less than 7.00 and weakly acidic.

On the basis of related monitoring data for five years, three kinds of pollution evaluation methods were used to analyze pollution situation and variation characteristics. Based on class III of Environmental quality standard for surface water (GB3838-2002, China, Table 2), the results of Single factor index (Fig. 4) showed that COD$_{Mn}$ was the most serious pollution, which was mostly 1 ~ 3 times over the standard. Among the sampling areas, the Single factor index of COD$_{Mn}$ in Tashi always exceeded 3.5, which was the most serious pollution region. Meanwhile, the results of three single factor indexes of TN, AN, and TP were basically less than 1, which meant the contents of TN, AN, and TP in the water were largely lower than the standard limits from 2013 to 2015. During this period, although the nitrogen contents of a few sampling points exceeded the standard, the single factor indexes were below 1.2. However, the indexes of TN and AN in the water body increased significantly from 2016. And the highest indexes of TN and AN in the most polluted area of Tashi were 1.32 and 1.02, respectively.

According to Nemerow's pollution index (NPI), the comprehensive pollution index variation map of mangrove wetland in Dongzhai harbor was shown in Fig. 5. Compared with the Single factor index, the NPI can more clearly and intuitively reflect the comprehensive quality of water in the monitoring areas. The NPI highlights the influence of the most serious pollution factors and takes into account the other factors at the same time. From Fig. 5, the pollution in the mangrove wetland of Dongzhai harbor showed a significant reduction from 2013 to 2015 and there was an increasing trend since 2016. In 2013, the number of highly polluted sampling points in Dongzhai harbor was 12. Apart from three sampling points in Sanjiang town, NPI of all the other sampling points exceeded 3. In 2015, the water quality was improved, 6 sampling points were moderately polluted, and the rest of the points were slightly polluted. However, the number of sampling points with moderate pollution reached 10 in 2016. The NPI of Tashi area was exceeded 3, and the NPI of Daoxue village and Sanjiang town exceeded 2 in 2017.

According to Trophic level index (TLI), the comprehensive trophic index variation map of mangrove wetland in Dongzhai harbor was shown in Fig. 6. The eutrophication of Dongzhai harbor had shown a trend from serious to mitigate and then began to deteriorate again. This change was basically the same as the variation trend of NPI in Fig. 5. In 2013, the number of hyper eutrophication sampling points in Dongzhai harbor was 10. In 2015, there were no hyper eutrophication sampling points and the middle eutrophication points were 5. However, the eutrophication of Dongzhai harbor was serious again since 2016. In 2017, the sampling points of hyper and middle eutrophication were 4 and 9, respectively. The areas with hyper eutrophication were Tashi area and Shanwei village.

4 Discussion

Mangroves located in Dongzhai harbor were polluted by non-point sources because of the shrimp culture. Based on satellite analysis and field investigation, by removing abandoned shrimp ponds, it was estimated that the area of shrimp ponds in Dongzhai harbor increased from about 1210 ha in 2009 to 1300 ha in 2017 within the 1.5 km buffer zone along the coastline [17]. The higher-place shrimp ponds needed a large amount of artificial feed for high-density aquaculture, but the amount of nutrients added to the pond was only a few could translate into the biomass of shrimp, most nutrients flow into the surrounding mangrove wetlands along with the discharge of aquaculture wastewater [30]. Therefore, nitrogen and organic matter from the wastewater caused pollution and eutrophication in Dongzhai harbor, which affected the mangrove ecosystem. For example, in the past two years, pollution and eutrophication of Tashi area, Shanwei village, and Sanjiang town had been serious, especially organic matter and nitrogen pollution in the water body. Meanwhile, during the process of studying pollutants in Dongzhai harbor, it was found that there was a continuous degradation of

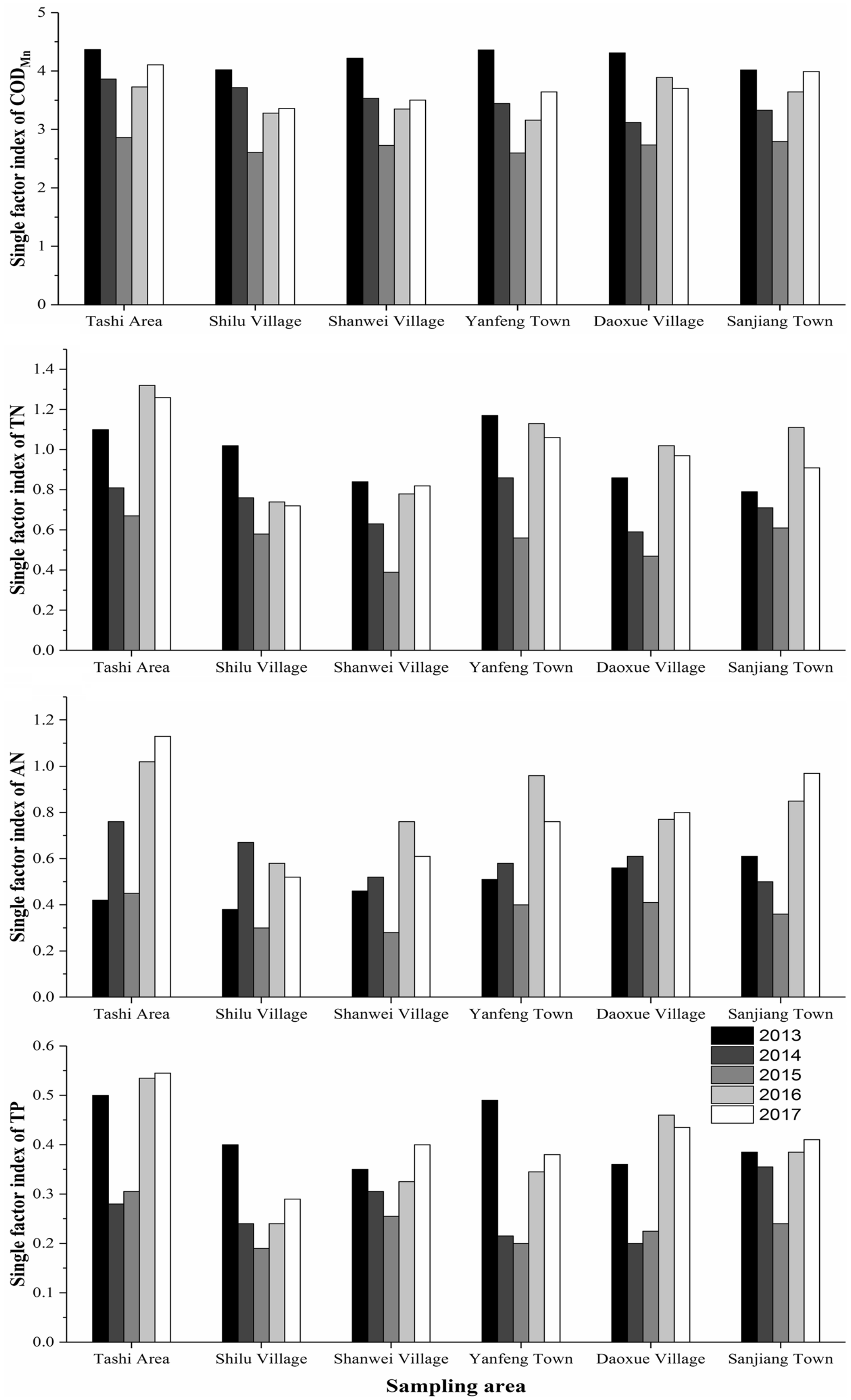

Fig. 4 Single factor indices of six regions from 2013 to 2017 (COD$_{Mn}$, TN, AN, TP)

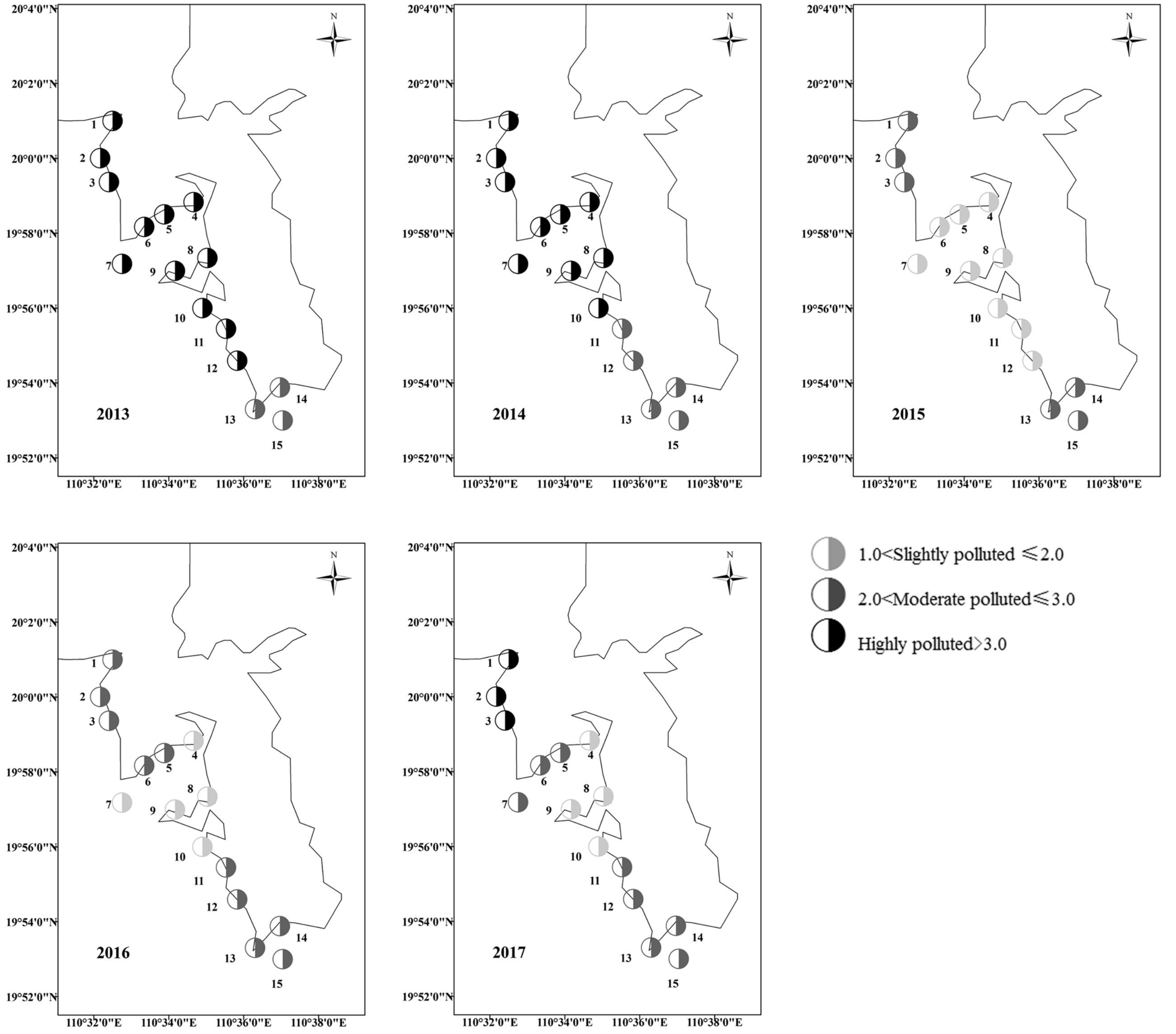

Fig. 5 Nemerow's pollution index for each sampling point along Dongzhai harbor from 2013 to 2017

mangroves. The mangrove was damaged by *S. terebrans*, which was distributed in the coastal areas suffering serious anthropogenic disturbance and contamination. For example, about 41 ha shrimp ponds are distributed around the Changning River (110°34′7.17" ~ 110°35′14.62" E, 19°56′53.96" ~ 19°57′21.19" N) and the area of mangrove degradation increased from 2.49 ha in 2013 to 7.62 ha in 2017 [17]. According to the monitoring data, Dongzhai harbor had no risk of heavy metal pollution in the past 5 years. This was because Hainan was the only area without industrial production in China and there were kelp culture in Dongzhai harbor. Due to kelp alga is one of the biosorption remediation technologies that has a strong removal effect of heavy metals in seawater [31], the kelp mariculture activities likely contributes, at least in part, to the lower metal contents in coastal sediments in Dongzhai harbor. Nevertheless, in view of seafood security and human health, continuous attention should be strengthened on the heavy metal pollution of Dongzhai harbor in the future.

Based on the monitoring indicators, the three water quality indexes basically showed the same trend of pollution variation, which was from serious to mitigate and then began to deteriorate again. According to the investigation for five consecutive years, a large outbreak of marine borers- *S. terebrans* occurred in the mangrove area of Dongzhai harbor in 2013, which caused the mangrove death. The reason for this outbreak was that eutrophic water would lead to the explosive growth of algae and plankton in the estuaries and mangrove wetlands. And

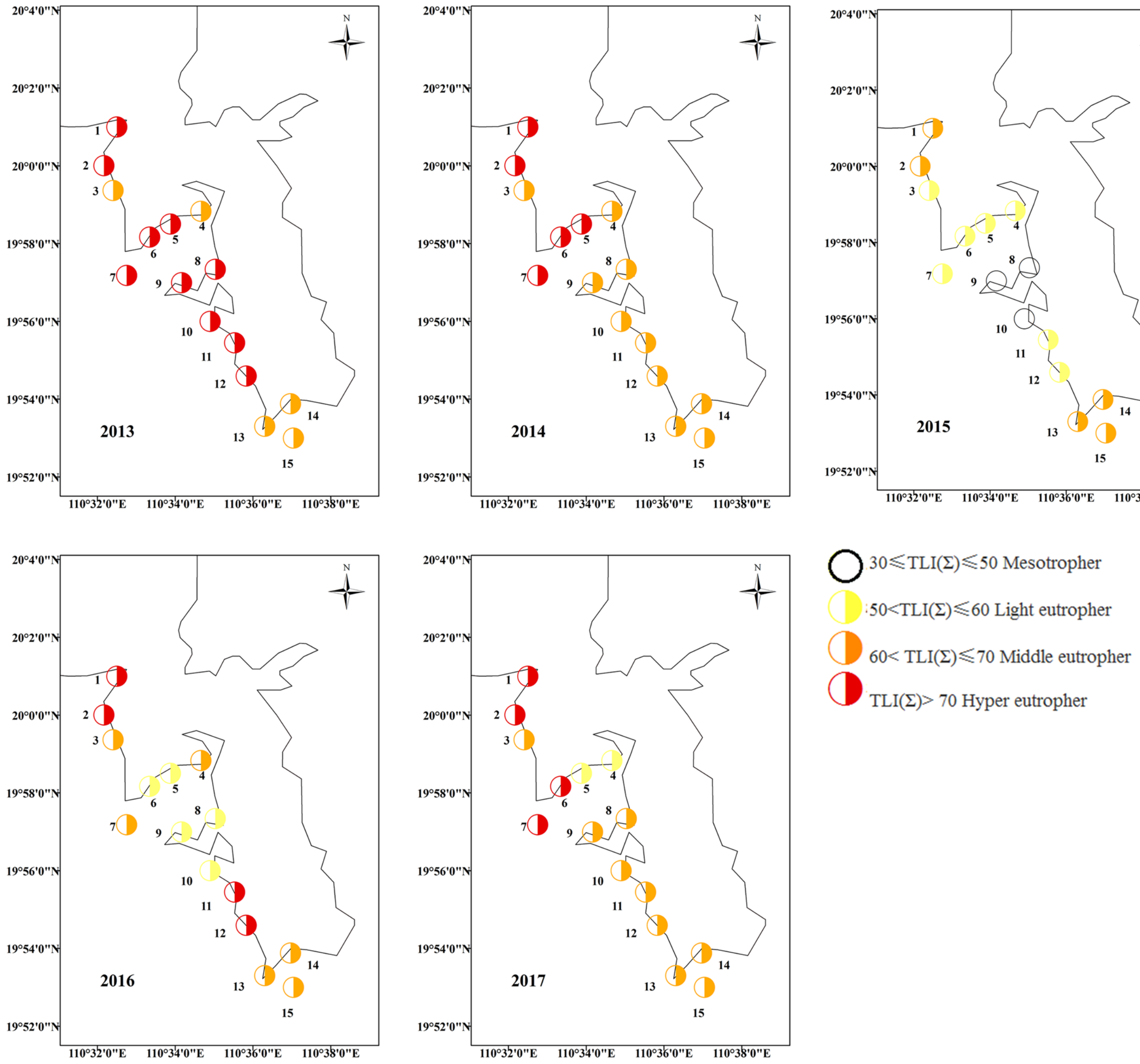

Fig. 6 Trophic level index for each sampling point along Dongzhai harbor from 2013 to 2017

plankton could provide rich food for the marine borers—*S. terebrans*, which would lead to a huge threat to mangroves [32, 33]. Thus, the Haikou Municipal Government implemented pollution control measures since January 2014 and these measures had reduced the pollution in 2015. For example, Daoxue village was one of the regions that had the most intensive implementation of contamination abatement strategies. Half of the shrimp ponds in Daoxue village were closed in early 2014 and we could find a significant reduction of pollution and eutrophication in this region. Moreover, Yanfeng town, as one of the seriously polluted towns, also began to implement strict pollution control measures in late 2014. Half of the shrimp ponds in Yanfeng town were closed. At the same time, livestock farms were relocated and a matching pipe network was set up for sewage discharge from some shrimp ponds. Therefore, the amelioration of pollution was the most obvious in Yanfeng Town. In contrast, due to Tashi area and Sanjiang town only closed about one-eighth of shrimp ponds, the decreases of pollution and eutrophication were not obvious in Tashi area. And in Sanjiang town, the ranges of NPI and TLI were always 2–3, 60–70, respectively, which were moderately polluted and middle eutropher in five years. Meanwhile, Shilu and Shanwei village also began to manage shrimp culture at the end of 2014, about one-sixth of the shrimp ponds were closed and relevant departments collected the domestic sewage discharged. And as a result, pollution in these two areas had been reduced. However, with the control of *S. terebrans* outbreak and the weakening of supervision, the number of higher-place shrimp ponds around the mangroves had been increasing since 2016. Therefore, in the last two years, the pollution and eutrophication in the mangrove area of Dongzhai harbor had been serious again. The eutrophication of Tashi and Sanjiang town was deteriorating. And the pollution of organic matter and nitrogen in the water body was particularly serious. Additionally, compared with the data of 2013 that *S. terebrans* outbreak suddenly when the area of serious pollution and eutrophication was over two-thirds, the relevant departments should take measures to control the serious water pollution since 2016.

Therefore, the solution to this cultural problem is one of the keys to the restoration of mangrove ecosystem in the future. One of the major challenges faced by shrimp farming is to overcome environmental concerns and improve economic efficiency by developing and implementing management strategies that reduce nutrient wastes. We could find some new approaches, which include the improvements of feed formulation and the management of effluent treatment systems. The management and recovery of mangroves in Dongzhai harbor should be more integrated, standardized and strict. A complete mangrove ecological monitoring system should be established to grasp the dynamic changes of mangrove wetlands and analyze the causes. Meanwhile, in order to protect the coastal ecological environment strictly, the residents in the ecologically sensitive areas could gradually migrate to another livable place. On the basis of the coastal area restoration, the modern marine pastures could be vigorously developed to replace the higher-place shrimp ponds. Relevant departments should establish a total quantity control system for the pollutants entering mangrove wetland and formulate comprehensive plans for the protection and utilization of coastal zones.

5 Conclusions

The mangrove wetland is a high-yield ecosystem in the coastal ecosystem. Although coastal residents know its importance, the mangrove wetland in Dongzhai harbor, Hainan has been seriously threatened in the past 30 years. Therefore, a comprehensive analysis of effluents and heavy metals is necessary for Dongzhai harbor, considering the mangrove declined and the ecological services offered to the coastal communities. According to the monitoring results, due to shrimp culture, the contents of organic matter and nitrogen in the water of Dongzhai harbor were exceeding the standard, which were 26.10 mg·L^{-1} and 1.34 mg·L^{-1}, respectively in 2017. The contents of the four heavy metals (Cu, Pb, Zn, Cd) were far lower than the standard limits during the past five years. On the basis of monitoring indicators, three water quality indexes basically showed the same trend of pollution variation, which showed a significant reduction from 2013 to 2015 and then there was an increasing trend since 2016. Single factor index, Nemerow's pollution index, and Trophic level index revealed that the heavily polluted areas were Tashi and Sanjiang town. Furthermore, since compared with the data of 2013, *S. terebrans* outbreak suddenly when the area of serious pollution and eutrophication was over two-thirds, there should be restoration activities to control the water pollution since 2016. The discharge of untreated aquaculture wastewater has brought tremendous pressure to the ecological environment of mangrove wetland in Dongzhai harbor. Hence, it is imperative to devise long-term management and conservation plans for the ecologically significant mangrove forests with a focus on sustainable livelihood.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest. Liu Jing and Myat Thiri have no conflict of interest.

Ethical approval statement This article does not contain any studies with human participants or animals performed by any of the authors. In this experiment, we did not collect any samples of human and animals.

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