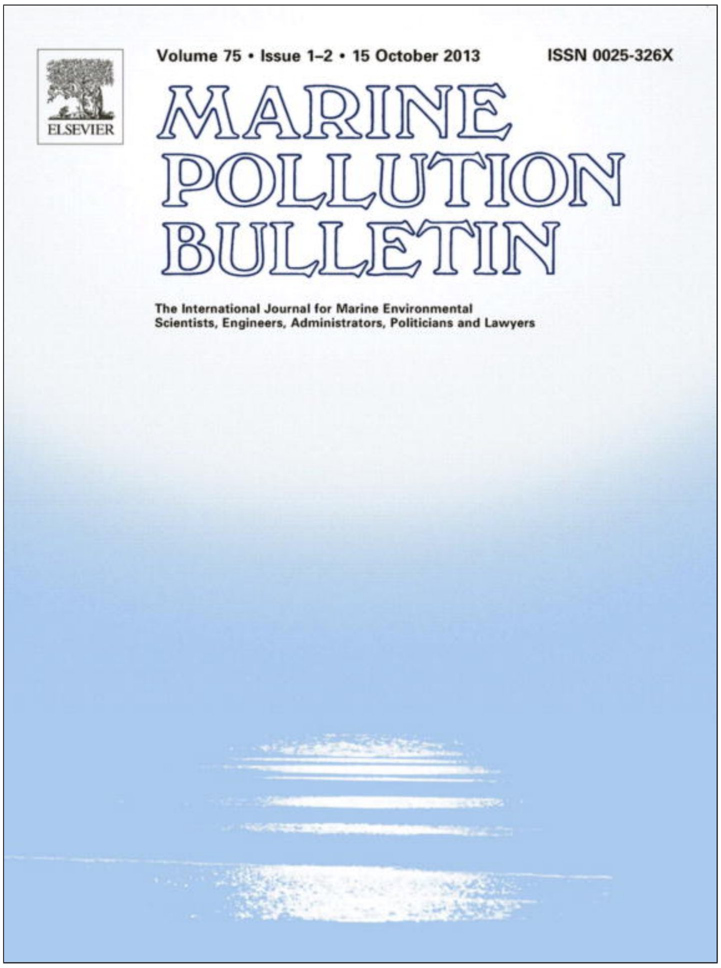
Volume 75 • Issue 1–2 • 15 October 2013
ISSN 0025-326X
ELSEVIER
MARINE POLLUTION BULLETIN
The International Journal for Marine Environmental Scientists, Engineers, Administrators, Politicians and Lawyers

Marine Pollution Bulletin 75 (2013) 53–61

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Assessing the benthic ecological status in the stressed coastal waters of Yantai, Yellow Sea, using AMBI and M-AMBI

Baoquan Li[a,*], Quanchao Wang[a,b], Bingjun Li[c]

[a] Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, Yantai 264003, China
[b] University of Chinese Academy of Sciences, Beijing 10039, China
[c] Ocean School of Yantai University, Yantai 264005, China

ARTICLE INFO

Keywords:
Benthos
Water analysis
Marine environment
Marine aquaculture
Benthic ecological status

ABSTRACT

The coastal waters around Yantai have been subjected to a variety of anthropogenic pressures over the last two decades. To assess the current benthic ecological health and the recovery process of the benthic ecosystem, four surveys were conducted in 2010 and 2011. The AMBI and M-AMBI were applied to assess the benthic ecological status. The ecological status of the Sishili Bay and Taozi Bay was "moderate" to "good" at most sampling stations during four surveys, but some stations were degraded due to pollution and eutrophication induced by human activities. The ecological status improved after removal of the marine raft culture and minimizing the amount of waste water discharged into the coastal waters of Yantai. The AMBI and M-AMBI could be used as suitable bio-indicator indices to assess the benthic ecological status of coastal waters in Yantai, Shandong Province.

1. Introduction

The Yellow Sea was once the most productive fishing grounds in Chinese waters, providing a huge amount of marine food before the 1980s; however, due to the intensive human activities, such as, the aquaculture, sewage discharge and land reclamation, the ecological health of the marine ecosystem was degraded greatly, especially along the coastal water zone where most human activities occurred (Tang, 2004; Wang et al., 1995; Liu D. et al., 2009). Yantai is located in the northern Yellow Sea, with a history of over 60 years of marine raft culture in the coastal waters, from seaweed *Laminaria japonica* and Asian kelp *Undaria pinnatifida* to scallop *Chlamys farreri*, *Argopecten irradians*, and mussel *Mytilus edulis* farming. The farming area in Sishili Bay was once up to 2450 ha, of which the farming area for scallop, mussel and seaweed was 800 ha, 400 ha and 250 ha, respectively (Wan, 2012; Gao et al., 2011). The scallop culture duration normally lasts for 1–2 years, and harvest time was at the end of October each year.

Over the last two decades, the rapid economic growth coupled with increased population have imposed unpredictable deleterious impacts on the coastal marine ecosystem around Yantai, especially in Sishili Bay (SB) and Taozi Bay (TB), e.g., aquaculture, wastewater discharge and shipping cargo throughput (Yantai Statistics Bureau, 2001–2009). Large quantities of nutrients caused by sewage discharge and aquaculture have been discharged into the SB and TB, including 150 tonnes of total phosphorus (TP) and 1910 tonnes of total nitrogen (TN) each year (Liu et al., 2006). The deterioration of this marine ecosystem was also confirmed by the increased occurrence of red tides and jellyfish blooms (Dong et al., 2010).

In order to assess ecosystem status and health, several integrative approaches have been developed involving biological (Borja et al., 2000, 2009a, 2011), chemical (Borja et al., 2004b; Tueros et al., 2008), and physio-chemical components (Bald et al., 2005). Of all the biological elements used to evaluate water bodies, e.g., phytoplankton, zooplankton, benthos, algae, phanerogams, fishes, macrobenthos have been more extensively used as a biological indicator in the assessment of ecosystem health (Borja and Tunberg, 2011), due to their rapid response to anthropogenic and natural stress and unique community characteristics, including relatively sedentary, long life span, different species composition with different tolerances to stress, and an important role of bioturbation and bioirrigation (Pearson and Rosenberg, 1978; Dauer, 1993; Borja et al., 2000; Lohrer et al., 2004).

To establish the ecological quality of European coasts, Borja et al. (2000) proposed the AZTI's Marine Biotic Index (AMBI), especially for areas under anthropogenic disturbances. Based on different tolerances and sensitivity to an anthropogenic stress gradient, macrobenthic species were classified into five ecological groups (EG) (Borja et al., 2000). Up to now, AMBI has proved to be an efficient biotic index in detecting degradation of habitat quality and is commonly used in different water bodies of the Atlantic Ocean, Baltic Sea, Mediterranean Sea, North Sea, Norwegian Sea, and the

* Corresponding author. Address: Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences, 17th Chunhui Road, Laishan District, 264003 Yantai, China. Tel./fax: +86 535 2109112.
E-mail address: bqli@yic.ac.cn (B. Li).

0025-326X/$ - see front matter
http://dx.doi.org/10.1016/j.marpolbul.2013.08.007

Bohai Sea (Muxika et al., 2005; Cai et al., 2012). However, due to the complexity of benthic communities and diversity of benthic gradients, the AMBI was not always consistent with some environmental parameters related to pollution under some conditions (Muxika et al., 2005). In order to overcome this potential weakness and to minimize some misclassification problems when assessing the ecological status by AMBI, the Multivariate AZTI Marine Biotic Index (M-AMBI) was proposed by Muxika et al. (2007), which integrates the Shannon's diversity, richness and AMBI into a factor analysis multivariate approach to assess the ecological status.

The aims of the present study were: (i) to assess the benthic ecological health of the Yantai coastal waters at the ecosystem level, and to test the recovery process based on the effect of removing the raft culture, using AMBI and M-AMBI; (ii) to test the adaptability of these two indices in coastal waters of Yantai by linking the AMBI, M-AMBI with environmental factors, especially the trace metals in the sediment; and (iii) to establish a suitable Chinese species assignation to EG.

The AMBI was firstly adopted to assess the benthic quality of intertidal zones of Bohai Sea in China at 2012 (Cai et al., 2012). Whereas, this is the first time that such methods have been applied to assess the ecological status in coastal waters of Yantai, Shandong Province by linking the AMBI, M-AMBI with environmental factors. Sishili Bay is a typical temperate coastal bay with a temperature range of 23.3–27.4 °C in summer and 2.5–3.5 °C in winter (Liu et al., 2012), and Yantai is also a typical city with rapid industrialization and intensification of coastal uses continue in the north of China. Moreover, it is urgent to set a useful biological indicator in the assessment of ecosystem health to meet the needs of management of Chinese government. Hopefully an important criterion will be set up for assessing the ecological status of coastal water of many similar cities in China from the research of this paper.

2. Material and methods

2.1. Study area

Considering the different kinds of anthropogenic disturbance on macrobenthos, up to 24 stations were selected to study the macrobenthos in the SB and TB, covering the outlet of Jiahe River, the biggest river that runs into the coastal waters; the sewage outfall near Zhifu Island, the Yantai Harbor and the marine raft culture zone. 14 stations were assessed in April 2010, 14 stations in August 2010, 21 stations in October 2010, and 19 stations in March 2011 (Fig. 1).

To improve the ecosystem health, the Fisheries and Oceans Bureau of Yantai minimized the amount of waste water discharged from some pollutant point sources since 2009, especially some chemical plants. And, to achieve a better landscape for tourism along the coastal zone of Sishili Bay, the Yantai government gradually removed most of the raft culture in Sishili Bay at the early of 2010, whereas, permitted the aquaculture in Taozi Bay. Thus, the different stress from aquaculture on ecosystem health between Sishili Bay and Taozi Bay provide two ideal sampling sites for comparison.

2.2. Sampling methods and procedure

Two separate replicate sediment samples were collected by a 0.05 m^2 box-corer grab at every station; the sediments were then sieved through a mesh with 0.5 mm aperture to obtain the macrobenthic organisms. The macrobenthic samples were preserved in 80% ethanol until laboratory identification to the lowest possible taxonomic level, then counted and weighted using a 0.01 g precision electric balance to get the number and wet weight. Sediment samples were also collected to measure trace elements (Pb, Cr, Co, Ni, Cu, Zn, A, Cd). The sediment trace element contents were analyzed by inductively coupled plasma mass spectrometry (ICP-MS) (Perkin-Elmer, USA). To obtain a complete digestion of sediment, firstly, 0.1–0.2 g dried sediment was homogenized by grindingwith mortar and pestle, and then sieved through a 200-meshes sieve. The sized sample was digested in an acid mixture of HF(5 ml), HNO3(3 ml) and HClO4(1 ml) in a sealed PTFE vessel for 12 h at 140 °C. Secondly, the extracts was dissolved in HNO3 solution (50%) at 150 °C, and lastly diluted to 50 ml with ultrapure water.

2.3. Statistical analysis

Macrofauna data were analyzed using several univariate indices: species richness, Shannon index (H'), AMBI (Borja et al., 2000), and M-AMBI (Muxika et al., 2007), which were all computed by using the AMBI program (version 5.0) freely available online at http://ambi.azti.es, and on the basis of the AMBI guidelines (Borja and Muxika, 2005). Based on Borja and Tunberg (2011), the threshold values for the M-AMBI conditions are as follows: 'high' quality > 0.77; 'good' = 0.53–0.77; 'moderate' = 0.38–0.53; 'poor' = 0.20–0.38; and 'bad' < 0.20. According to the guidelines for the use of AMBI (Borja and Muxika, 2005), all of the non-benthic invertebrate taxa (fish and megafauna) were removed.

To evaluate the hypotheses that (i) different kinds of anthropogenic disturbance would impose different stresses on macrobenthos, and (ii) the benthic ecological status and health would recover in 1 year after some control measures implemented by local government, the results of AMBI and M-AMBI of 7 stations that are common to all 4 sampling events were tested by the analysis of variance (ANOVA) and Kruskal–Wallis ANOVA analysis in the case of heterogeneity of variance. The 7 common stations in all 4 sampling events suffered from different kinds of anthropogenic activities, e.g., stations 1, 2, 3 (outside of Taozi Bay with less anthropogenic stress), 4 (near to the waste water discharge point with pollution stress), 9, 11 (near to the raft culture zone with mariculture stress), and 28 (at the Dagujia River Mouth with waste water discharge stress). All statistical analyses were performed using the software PASW Statistics 18.

2.4. Species assignation

According to the species-list of V. March 2012 (included in the package of software AMBI program version 5.0), most of the species were assigned. Some Chinese local species were based on our own knowledge (expert opinion).

3. Results

3.1. Abiotic parameters

According to Chinese Marine Sediment Quality Standard GB 18668-2002 (National Standard of the People's Republic of China GB 18668-2002, was issued by General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China at March 10 2012), the marine sediment of Class I quality can be used for marine fishery, natural reserve areas, natural preservation zones for rare and endangered animals, marine culture zones, bathing beaches, direct body contact marine sports and industrial water area related to marine foods; Class II can be used for normal industrial water and coastal scenic areas. Most of the trace metals in the sediment of all sampling stations qualified as superior Class I, indicating that the sediment quality of the Yantai coastal area was generally good (Table 1).

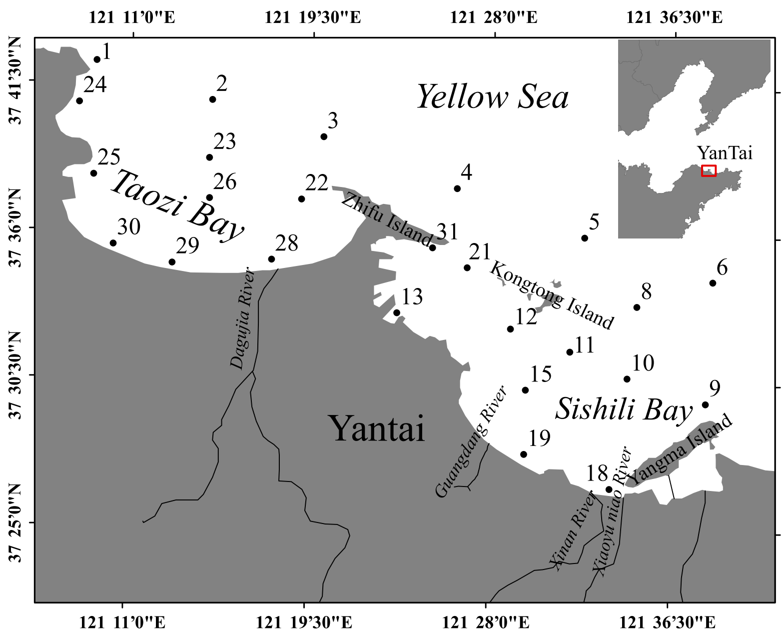

Fig. 1. Study area and locations of sampling stations in coastal waters of Yantai.

Table 1
Trace metals analyzed in the sediment of some stations sampled in April 2010 (unit: mg/kg).

Station	Pb	Cr	Co	Ni	Cu	Zn	As	Cd
2	4.49	11.60	2.44	6.75	4.60	14.99	2.27	0.029
3	3.52	9.32	2.18	6.06	3.78	12.58	1.92	0.027
4	4.28	13.71	2.37	7.02	4.58	14.53	2.16	0.043
5	3.73	9.18	2.21	5.71	4.02	12.90	2.10	0.027
6	3.80	8.16	2.16	5.54	3.92	12.58	1.98	0.025
8	3.41	7.69	1.91	5.30	3.53	11.30	1.77	0.030
9	3.34	9.16	2.01	5.07	3.76	11.33	1.94	0.028
11	3.20	9.36	1.76	5.16	3.27	10.49	1.49	0.036
24	3.19	8.08	1.96	4.91	3.37	11.56	1.64	0.030
29	2.68	7.56	1.76	3.51	1.95	8.07	2.38	0.014

3.2. AMBI

By using the species-list of March 2012 and expert opinion, of all the 72 taxa identified in April 2010, 18 (25.0%) were not initially assigned to any ecological group. After assignment, 10 (13.8%) remained unassigned. In August 2010, 21 (25.0%) from 84 taxa identified were not initially assigned to any ecological group, and 10 (11.9%) remained unassigned after assignment. In October 2010, 33 (29.2%) from 113 taxa identified were not initially assigned to any ecological groups, and 14 (12.3%) still remained unassigned after assignment. In March 2011, 33 (32.7%) from 101 taxa identified were not initially assigned to any ecological groups, and 13 (12.9%) still remained unassigned after assignment.

In April 2010, the mean AMBI values of 14 sampling stations ranged from 1.08 to 2.63, with 2 (14.3%) undisturbed stations and 12 (85.7%) slightly disturbed stations, which implied that the benthic environment had suffered slight impacts from human activities (Table 2). The biodiversity index was not high, from 1.58 to 4.25, and richness from 3 to 29, which also indicated that the macrobenthos community had been disturbed by some environmental factors and human activities. Apart from station 29 with the high percentage of taxa that were not assigned, the results of AMBI at most of stations were acceptable.

In August 2010, the mean AMBI values for the 14 sampling stations ranged from 1.45 to 2.86, and all stations were slightly disturbed. The diversity ranged from 0.77 to 3.62, and richness from 3 to 27, which also indicated that the macrobenthos community had been disturbed by some environmental factors and human activities. Because the percentages of not-assigned species in most of stations were less than 20%, the results of AMBI were considered acceptable.

In October 2010, the mean AMBI values of 21 sampling stations ranged from 0.81 to 3.90, with 3 (14.3%) undisturbed stations, 16 (76.2%) slightly disturbed stations and 2 (9.5%) moderately disturbed stations, implying that the benthic environment suffered disturbance in the study area (Table 2).

In March 2011, the mean AMBI values for the 19 sampling stations ranged from 1.12 to 4.15, with 1 (5.3%) undisturbed station, 16 (76.6%) slightly disturbed stations and 2 (10.5%) moderately disturbed stations. The diversity ranged from 0.76 to 4.07, and richness from 6 to 36, also indicating that the macrobenthos community had been disturbed by some environmental factors and human activities. Because the percentages of not-assigned species in all of stations were less than 20%, the results of AMBI were considered acceptable (Table 2).

When taking into account the 7 stations (1,2,3,4,9,11,28) that are common to all 4 sampling events, the AMBI values among 7 common stations in four surveys were statistically significantly different (Krushal–Wallis ANOVA, Chi-sq = 12.33, $p = 0.055 < 0.1$), which confirms the hypothesis that different kinds of anthropogenic disturbance imposed different stresses on the macrobenthos community. Also, the AMBI values of the 7 common stations across the four surveys were also statistically significantly different (Krushal–Wallis ANOVA, Chi-sq = 155.02, $p = 0.075 < 0.1$), which indicated that the benthic ecological status and health had changed in 1 year after some control measures were implemented by the local government.

3.3. M-AMBI

M-AMBI reference conditions were set for the Yantai coastal water by the lowest AMBI value and highest diversity H' and richness S from the area, then increased by 15% of highest diversity and richness S, e.g., AMBI = 0, diversity = 4.89 and richness = 41. Bad status values were: AMBI = 6, diversity and richness = 0.

Table 2
Results of AMBI and biodiversity of macrobenthos from SB and TB in four surveys.

Surveys	Stations	I (%)	II (%)	III (%)	IV (%)	V (%)	Mean AMBI	Disturbance classification	Richness	Diversity	Not assigned (%)
April 2010											
	1	41.2	19.6	29.4	9.8	0	1.62	Slightly disturbed	23	3.98	7.3
	2	40	53.3	1.7	5	0	1.08	Undisturbed	16	3.52	1.6
	3	41.2	36.8	11.8	10.3	0	1.37	Slightly disturbed	24	4.16	1.4
	4	37.8	39.2	20.3	2.7	0	1.32	Slightly disturbed	25	3.97	0
	5	30	56.7	11.7	1.7	0	1.28	Slightly disturbed	26	3.9	0
	6	8.8	61.8	8.8	20.6	0	2.12	Slightly disturbed	11	2.97	0
	8	18.7	50.7	16	14.7	0	1.9	Slightly disturbed	22	3.76	0
	9	9.5	75.1	2.4	13	0	1.79	Slightly disturbed	20	1.63	0
	11	26	55	13	6	0	1.49	Slightly disturbed	21	3.14	1
	24	41.1	27.4	13.7	17.8	0	1.62	Slightly disturbed	29	4.25	8.8
	26	40	40	20	0	0	1.2	Undisturbed	4	1.92	0
	28	33.3	33.3	33.3	0	0	1.5	Slightly disturbed	3	1.58	0
	29	36.6	2.4	9.8	51.2	0	2.63	Slightly disturbed	11	2.8	26.8
	30	40.5	2.7	0	56.8	0	2.60	Slightly disturbed	8	2.34	2.6
August 2010											
	1	17.3	28.8	38.5	15.4	0	2.28	Slightly disturbed	15	3.25	0
	2	28.2	53.8	7.7	10.3	0	1.50	Slightly disturbed	15	3.62	0
	3	21.5	22.8	53.2	2.5	0	2.05	Slightly disturbed	16	2.99	0
	4	25.8	46.8	16.1	11.3	0	1.69	Slightly disturbed	17	3.61	1.6
	9	20	0	80	0	0	2.40	Slightly disturbed	3	1.38	28.6
	10	21.7	60.2	3.1	15	0	1.67	Slightly disturbed	27	2.61	1.3
	11	28.2	41.3	20.9	9.7	0	1.68	Slightly disturbed	33	3.62	3.3
	13	24.6	23.1	2.1	50.3	0	2.67	Slightly disturbed	14	1.92	0.5
	15	30.4	47.8	16.5	5.2	0	1.45	Slightly disturbed	20	2.84	0.9
	19	0.4	91.5	0	8.1	0	1.74	Slightly disturbed	9	0.77	0
	22	5.6	33.3	50	11.1	0	2.50	Slightly disturbed	8	2.39	5.3
	26	13.8	35.4	4.6	46.2	0	2.75	Slightly disturbed	12	2.3	1.5
	28	9.6	36.5	7.7	46.2	0	2.86	Slightly disturbed	14	2.66	7.1
	29	33.3	45.6	8.9	12.2	0	1.50	Slightly disturbed	9	2.41	1.1
October 2010											
	1	56.7	6.7	30	6.7	0	1.30	Slightly disturbed	14	3.25	3.2
	2	38.8	26.9	32.8	1.5	0	1.46	Slightly disturbed	17	3.23	2.9
	3	33.3	60	6.7	0	0	1.10	Undisturbed	11	3.15	6.3
	4	20	60	20	0	0	1.50	Slightly disturbed	4	1.92	0
	5	36.7	27.8	11.4	24.1	0	1.84	Slightly disturbed	28	4.1	4.8
	6	44.1	22	10.2	23.7	0	1.70	Slightly disturbed	17	3.74	0
	8	34.8	41.6	9	14.6	0	1.55	Slightly disturbed	26	4.08	6.3
	9	6.6	82.3	3.9	7.2	0	1.67	Slightly disturbed	14	1.79	1.1
	10	25.4	58.4	2.3	13.9	0	1.57	Slightly disturbed	22	2.62	1.1
	11	17.9	58.9	15.3	7.9	0	1.70	Slightly disturbed	25	2.9	1
	12	50	33.3	1.5	15.2	0	1.23	Slightly disturbed	21	3.72	1.5
	13	1.4	33.6	2.3	62.7	0	3.40	Moderately disturbed	20	2.01	0.9
	15	21.1	60.1	3.1	15.8	0	1.70	Slightly disturbed	25	2.58	0.4
	18	43.2	18.9	2.7	35.1	0	1.95	Slightly disturbed	15	2.94	0
	19	46.2	53.8	0	0	0	0.81	Undisturbed	7	2.5	7.1
	21	50.7	28.2	12.7	8.5	0	1.18	Undisturbed	21	3.79	0
	22	35	4.9	56.9	3.3	0	1.93	Slightly disturbed	12	1.81	0.8
	23	37.5	37.5	25	0	0	1.31	Slightly disturbed	7	2.73	11.1
	25	8	44	32	16	0	2.34	Slightly disturbed	13	3.29	0
	28	8	8	0	84	0	3.90	Moderately disturbed	9	1.4	5.7
	29	39.5	7.9	28.9	23.7	0	2.05	Slightly disturbed	16	3.3	26.9
March 2011											
	1	39.4	22.7	36.4	1.5	0	1.50	Slightly disturbed	19	3.37	7
	2	48.2	25	21.4	5.4	0	1.26	Slightly disturbed	25	4.06	8.9
	3	24.1	44.3	27.8	3.8	0	1.67	Slightly disturbed	21	3.68	8.1
	4	36.2	55.3	6.4	2.1	0	1.12	Undisturbed	15	3.42	9.6
	5	22.2	50.8	14.3	12.7	0	1.76	Slightly disturbed	19	3.5	7.4
	6	20	43.6	25.5	10.9	0	1.91	Slightly disturbed	23	4.07	19.1
	8	18.5	62.3	8	11.1	0	1.68	Slightly disturbed	29	3.97	6.9
	9	3.1	95.8	1.1	0	0	1.47	Slightly disturbed	12	0.76	0.3
	10	8.1	82.7	1.5	7.6	0	1.63	Slightly disturbed	16	1.45	0
	11	16.9	71	1.9	10.1	0	1.58	Slightly disturbed	21	2.25	1.4
	12	21.5	54.4	6.3	17.7	0	1.80	Slightly disturbed	19	3.22	2.5
	13	1.4	4.1	11	83.6	0	4.15	Moderately disturbed	10	2.1	1.4
	15	5.3	81.3	0.6	12.9	0	1.82	Slightly disturbed	12	1.48	0
	18	12	60	4	24	0	2.10	Slightly disturbed	8	2.22	0
	19	3.2	91.3	2.3	3.2	0	1.58	Slightly disturbed	17	0.94	0.5
	22	5.5	17.6	68.1	8.8	0	2.70	Slightly disturbed	16	2.09	2.2
	23	26.8	39.4	33.8	0	0	1.61	Slightly disturbed	16	3.1	6.6
	25	40.5	34.1	10.7	14.6	0	1.49	Slightly disturbed	36	4.03	2.4
	28	9.5	4.8	0	85.7	0	3.93	Moderately disturbed	6	1.3	4.5

In April 2010, 8 stations (57.1%) had 'good' ecological status (ES), and other 6 (42.9%) stations had 'moderate' ES. In August 2010, the benthic ecological health was almost same to that of April 2010 based on the M-AMBI, except for 2 stations with 'poor' ecological status (ES). Comparing April and August 2010, the benthic ecological health was slowly improving in October 2010, with most stations (71.4%) having 'good' ES, only 1 station (4.8%) with 'poor' ES. In March 2011, the benthic ecological health had one station with 'high' ES, 52.6% stations with 'good' ES, and 2 stations with 'poor' ES (Fig. 2).

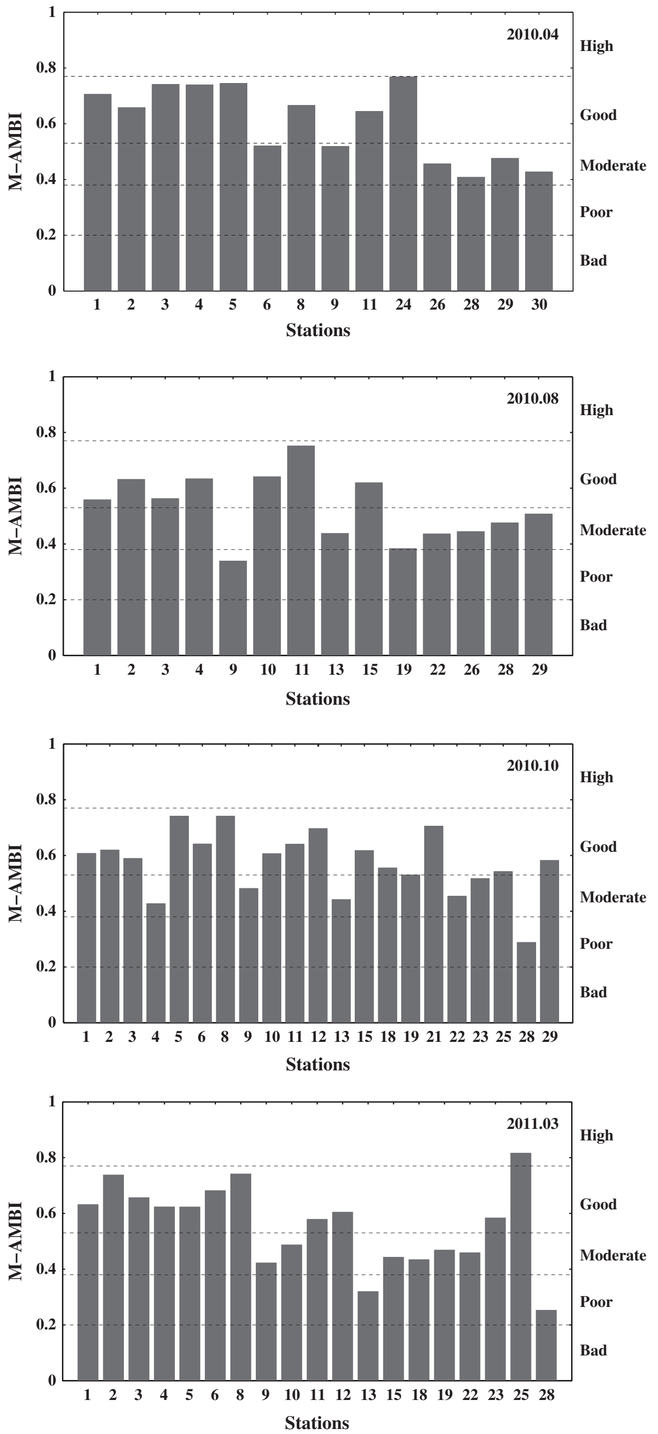

Fig. 2. M-AMBI values for coastal water of Yantai in April, August, October 2010 and March 2011.

When taking into account 7 common stations (1, 2, 3, 4, 9, 11, 28) to all 4 sampling events, the M-AMBI values among the 7 common stations in four surveys were statistically significantly different (Krushal–Wallis ANOVA, Chi-sq = 16.08, $p = 0.01 < 0.1$), again confirming the hypothesis that different kinds of anthropogenic disturbance imposed different stresses on the macrobenthos community. The M-AMBI values of the 7 common stations across the four surveys did not show statistically significant differences (Krushal–Wallis ANOVA, Chi-sq = 3.67, $p = 0.30 > 0.1$), which indicated that the benthic ecological status and health had not changed in 1 year.

4. Discussion

4.1. Ecological status of Yantai coastal waters and the stresses from anthropogenic activities

According to AMBI, the ecological status of the SB and TB was in the condition of "slightly disturbed" for most of sampling stations during the four surveys, while based on M-AMBI, the status conditions were "moderate" to "good". The interpretation of ecological status by using AMBI was relatively consistent with that of M-AMBI in Yantai coastal waters for most sampling stations. Station 28 with "poor" condition in October 2010 and March 2011 is near the Dagujia River estuary, where the effect of pollutants is the main disturbance source. As the second largest river of Yantai, the water quality of Dagujia River was in a relatively good condition over the past 20 years; it was also affected by the point pollution sources and agriculture non-point pollution sources (Li and Liu, 2007). Stations 9 and 19 are very close to the beach, where the tourism is the main disturbance source; Station 13 is just inside the harbor zone, which is disturbed by shipping activities, such as waterway dredging, waste waters, oil and trace metals (Wang et al., 1994; Di et al., 2013).

According to Chinese Sea Water Quality Standard (GB3097-1997) and Chinese Marine Sediment Quality Standard (GB 18668-2002), the seawater and sediment quality of most coastal areas in Yantai were qualified as Class I and Class II (Yantai Marine Environment Bulletin 2011 & 2011, in Chinese). The interpretations of ecological status indicated by the AMBI and M-AMBI matched well with the above mentioned bulletins and the results of good sediment quality conducted in April 2010. (Note: The sea water quality of Class I can be applied to the following purpose: marine fishery, natural reserve areas, natural preservation zone for rare and endangered animal; Class II for the purpose of marine culture zone, bathing beach, directly body contact marine sports and industrial water area related to marine food.) Due to the sediment characteristics of study area was almost homogeneous, with 78.6% of the sediment dominated by clay and silt (Di et al., 2013), the grain size of sediment at different sites should not have great effects on the spatial distribution of macrobenthos.

Coastal marine benthic communities are threatened by anthropogenic activities, and the rate of habitat degradation is considered alarming in many locations (Grey, 1997; Snelgrove et al., 1997). The spatial and temporal distributions of macrofaunal abundance and biomass can be influenced by different kinds of anthropogenic activities and environmental variables (DelValls et al., 1998; Magni et al., 2005, 2006). In the present study, AMBI and M-AMBI both indicated that different kinds of anthropogenic disturbance imposed different stresses on macrobenthos, but it remains hard to quantify the stress due to the complicated mutual relations and combined actions resulting from anthropogenic disturbance and environmental variables. On the whole, the stations outside of SB and TB with less anthropogenic stress (stations, 1, 2, 3, 5, 6, 8, 11) were in a relatively good ecological status, whereas, the stations inside the TB still with dense raft culture (stations, 9, 22, 26, 28, 29, 30) and station 13 inside the Yantai Harbor were in a poor to moderate ecological status.

At least five anthropogenic processes could affect the biodiversity and diversity across the sediment–water interface: global climate change, coastal-zone eutrophication, species introductions, mariculture, and bottom fishing (Smith et al., 2000). Bivalve aquaculture has multiple effects on local marine ecosystems, influencing both physical and biological factors, including local benthic effects (Forrest et al., 2009), all of which could directly or indirectly affect benthic assemblages. One of the most obvious effects of mariculture on benthic habitats is organic enrichment (Weston, 1990), which has similar effects to those resulting from organic loading and low oxygen stress induced by coastal eutrophication (Smith et al., 2000). In Sishili Bay, different human activities have impacted on the water quality and spatial distribution of benthic assemblages, including lantern net culture of bivalves in Shishili Bay affected the distribution of dissolved inorganic nitrogen (DIN) and soluble reactive phosphorus (SRP) (Wang et al., 2012); shipping, shellfish aquaculture farm and grain size affected the distribution of diatom and silicoflagellate fossils (Di et al., 2013), as well as different pollution source affected modern dinoflagellate cysts (Liu et al., 2012). In the present work, the ecological status of stations inside the TB (with dense raft culture) were all relatively poorer than the stations inside the SB (removal of raft culture), which was most likely due to the effects of aquaculture. The poor ecological status of station 13 (inside the Yantai Harbor) was probably related to bottom disturbance due to waterway dredging, which could alter the benthic biodiversity dramatically (Smith et al., 2000).

4.2. The reasons for the improving ES in coastal water of Yantai

In the 1990s, the quality of seawater around the coastal zone of Yantai was in a very poor condition (Liu Y. et al., 2009) and the environmental status in the sediment was also highly polluted (Lin et al., 1998). Since then, the ES of Yantai coastal waters has improved greatly, and the water quality was no longer showing an eutrophication status in 2006 (Liu Y. et al., 2009; Yantai Marine Environment Bulletin 2011 & 2011, in Chinese). According to statistical analysis, the AMBI and M-AMBI were not significantly different during the four surveys, which indicated that the ES in coastal water of Yantai were almost stable or even slowly improving from 2010 to 2011. Two main reasons could explain the slowly improving ES. The first one was the removal of raft culture in Sishili Bay. In the early of 2010, the Yantai government gradually removed most of the raft culture to achieve a better landscape for tourism along the coastal zone of Sishili Bay. Several studies had shown the negative impact on the environment from aquaculture, including the effects of waste products on benthic and planktonic communities (Primavera, 2006; Borja et al., 2009c), the spread of pests (Forrest et al., 2009), the effects of increased biodeposition (Canford et al., 2009) and functional value of coastal ecosystem (Godet et al., 2009). Although we could not get the quantitative assessment of the effect of removing raft culture upon the ES of coastal water in the present work, raft culture removal is certainly to be beneficial for water and benthic quality in this area in the long run. The second reason was minimizing the amount of waste water by some pollutant point source discharging into the coastal water. To improve the ecosystem health, the Fisheries and Oceans Bureau of Yantai minimized the amount of waste water discharged from some pollutant point sources since 2009, especially some chemical plants, which also contributed to the improving ES of coastal waters. So, the ecological status of water body and sediment were both in a relatively good condition, which meets the Class I and II according to Chinese Sea Water Quality Standard GB 3097-1997 (Bulletin of Yantai' s Environmental Status for the Year of 2010 & 2011).

4.3. Species assignation

According to the newest version of species list March 2012, about 68–75% of the species collected in the four surveys were initially assigned to a specific ecological groups. Those species not on the list were assigned by the following approach, e.g., consulting references, same genus and expert opinion (Borja et al., 2008). However, some territorial and Chinese local species still could not be assigned to any ecological groups due to the lack of information. Based on the guidelines of AMBI (Borja and Muxika, 2005), 'when the percentage of taxa that are not assigned is high (>20%), the results should be evaluated with care, because there may be subsequent problems in the interpretation'. In the present study, only one station had the percentage of unassigned taxa over 20% in four surveys after species assignment. So, the results of AMBI should be acceptable, and could be used to proceed with the ecological status analysis.

4.4. Reference condition

The setting of the reference condition for a water body is very crucial for calculating M-AMBI (Muxika et al., 2007). Four options could be used to derive reference conditions: (i) comparison with an existing "pristine"/undisturbed site; (ii) historical data and information; (iii) models and (iv) expert judgment (see details in Borja et al., 2004a; Muxika et al., 2007; Forchino et al., 2011; Borja et al., 2012). However, it is impractical to find pristine/undisturbed sites worldwide with the increasing pressure on water bodies brought about by human activities. Also, because reference conditions can change naturally with ecoregion, water body type and habitat (Borja et al., 2009b), sometimes it is particularly difficult to set reference conditions. To set a rational reference condition, several approaches have been applied, e.g., M-AMBI default (lowest AMBI value and highest diversity H' and richness S from the area), using minimally disturbed sampling stations, literature, data-driven, knowledge driven and real reference stations (Forchino et al., 2011; Borja et al., 2012). The approach for setting the reference condition by selecting the highest richness and diversity values observed in their study and increased these by 10–15%, was considered to be reasonable (Borja et al., 2008; Paganelli et al., 2011).

This is the first assessment of the ES of the coastal water in Yantai by AMBI and M-AMBI. In the present study, due to the stress of human activities on the study region, we chose the highest value of diversity, richness of four surveys, then increased these value by 15%, as the reference conditions in the Yantai coastal water, e.g., AMBI = 0, H' = 3.5, S = 28 and the "worst" possible values were based on the following values: AMBI = 6, H' = 0, and S = 0, representing the conditions resulting from major human activities impact.

5. Conclusions

The benthic ecological health of the Yantai was assessed using AMBI and M-AMBI indices in this work. The following conclusions have been made:

(1). The AMBI and M-AMBI indicated that the ecological status of the Sishili Bay and Taozi Bay was"moderate" to "good" at most sampling stations during four surveys, but some stations were degraded due to pollution and eutrophication induced by human activities.

(2). The ecological status improved after removal of the marine raft culture and minimizing the amount of waste water discharged into the coastal waters of Yantai.

(3). AMBI and M-AMBI could be used as suitable bio-indicator indices to assess the benthic ecological status of coastal waters in Yantai, Shandong Province. This study also provides an important criterion for assessing the ecological status of coastal water of many similar cities in China.

Acknowledgments

This study was funded by the project of The National Natural Science Foundation of China (NSFC Nos. 40976086 & 41061130543) and the Technology Development Program of Shandong Province (2011GHY11525).

Appendix A

Species list and their ecological group assignation in coastal water of Yantai.

Group	Family	Species	Ecological group (EG)
Arthropoda	Calanticidae	*Smilium scorpio*	Not assigned
Arthropoda	Nymphonidae	*Nymphon* sp.	I
Chaetognatha	Sagittidae	*Aidanosagitta crassa*	I
Cnidaria	Actiniidae	*Anthopleura nigrescens*	Not assigned
Polychaeta	Ampharetidae	*Paramphicteis angustifolia*	II
Polychaeta	Ampharetidae	*Amphicteis scaphobranchiata*	I
Polychaeta	Ampharetidae	*Samytha gurjanovae*	I
Polychaeta	Amphinomidae	*Linopherus ambigua*	IV
Polychaeta	Cirratulidae	*Chaetozone setosa*	IV
Polychaeta	Cirratulidae	*Cirriformia chrysoderma*	IV
Polychaeta	Cirratulidae	*Tharyx multifilis*	IV
Polychaeta	Flabelligeridae	*Pherusa bengalensis*	I
Polychaeta	Glyceridae	*Glycera prashadi*	II
Polychaeta	Goniadidae	*Glycinde gurjanovae*	II
Polychaeta	Lumbrineridae	*Lumbrineris latreilli*	II
Polychaeta	Magelonidae	*Magelona cincta*	I
Polychaeta	Maldanidae	*Maldane sarsi*	I
Polychaeta	Maldanidae	*Asychis gotoi*	II
Polychaeta	Nephtyidae	*Inermonephtys inermis*	II
Polychaeta	Nephtyidae	*Nephtys caeca*	II
Polychaeta	Nephtyidae	*Nephtys californiensis*	II
Polychaeta	Nephtyidae	*Nephtys polybranchia*	II
Polychaeta	Nereididae	*Nereis heterocirrata*	III
Polychaeta	Nereididae	*Perinereis cultrifera*	III

Appendix A (*continued*)

Group	Family	Species	Ecological group (EG)
Polychaeta	Nereididae	*Perinereis nuntia*	III
Polychaeta	Nereididae	*Tambalagamia fauveli*	Not assigned
Polychaeta	Oenonidae	*Arabella iricolor*	I
Polychaeta	Onuphidae	*Epidiopatra hupferiana*	Not assigned
Polychaeta	Onuphidae	*Onuphis geophiliformis*	II
Polychaeta	Opheliidae	*Ophelina acuminata*	III
Polychaeta	Orbiniidae	*Naineris laevigata*	I
Polychaeta	Orbiniidae	*Scoloplos marsupialis*	I
Polychaeta	Oweniidae	*Owenia fusiformis*	II
Polychaeta	Paralacydoniidae	*Paralacydonia paradoxa*	II
Polychaeta	Paraonidae	*Aricidea fragilis*	I
Polychaeta	Phyllodocidae	*Eteone longa*	III
Polychaeta	Phyllodocidae	*Eumida tubiformis*	II
Polychaeta	Polynoidae	*Gattyana pohaiensis*	III
Polychaeta	Polynoidae	*Gaudichaudius cimex*	III
Polychaeta	Polynoidae	*Halosydnopsis pilosa*	Not assigned
Polychaeta	Polynoidae	*Lepidonotus* sp.	II
Polychaeta	Sabellidae	*Potamilla neglecta*	II
Polychaeta	Phyllodocidae	*Phyllodoce madeirensis*	II
Polychaeta	Serpulidae	*Salmacina dysteri*	Not assigned
Polychaeta	Sigalionidae	*Sthenolepis japonica*	I
Polychaeta	Spionidae	*Prionospio* sp.	Not assigned
Polychaeta	Spionidae	*Laonice cirrata*	III
Polychaeta	Spionidae	*Paraprionospio pinnata*	IV
Polychaeta	Spionidae	*Prionospio pygmaeus*	II
Polychaeta	Spionidae	*Prionospio queenslandica*	IV
Polychaeta	Spionidae	*Spiophanes bombyx*	III
Polychaeta	Sternaspidae	*Sternaspis scutata*	III
Polychaeta	Syllidae	*Ehlersia cornuta*	II
Polychaeta	Syllidae	*Typosyllis adamanteus*	II
Polychaeta	Terebellidae	*Amaeana occidentalis*	III
Polychaeta	Terebellidae	*Pista fasciata*	I
Polychaeta	Ampharetidae	*Phyllocomus hiltoni*	I
Polychaeta	Ampharetidae	*Amphicteis*	III

(*continued on next page*)

Appendix A (*continued*)

Group	Family	Species	Ecological group (EG)
		gunneri	
Polychaeta	Capitellidae	*Heteromastus filiformis*	IV
Polychaeta	Cirratulidae	*Cirratulus cirratus*	IV
Polychaeta	Cirratulidae	*Cirriformia tentaculata*	IV
Polychaeta	Glyceridae	*Glycera rouxi*	II
Polychaeta	Glyceridae	*Glycera onomichiensis*	II
Polychaeta	Hesionidae	*Oxydromus angustifrons*	II
Polychaeta	Lumbrineridae	*Lumbrineris tetraura*	II
Polychaeta	Nephtyidae	*Aglaophamus sinensis*	II
Polychaeta	Nereididae	*Platynereis bicanaliculata*	II
Polychaeta	Nereididae	*Nereis aibuhitensis*	III
Polychaeta	Onuphidae	*Diopatra bilobata*	I
Polychaeta	Opheliidae	*Armandia intermedia*	I
Polychaeta	Orbiniidae	*Haploscoloplos elongatus*	IV
Polychaeta	Phyllodocidae	*Phyllodoce papillosa*	II
Polychaeta	Pilargidae	*Sigambra bassi*	IV
Polychaeta	Poecilochaetidae	*Poecilochaetus serpens*	I
Polychaeta	Sabellidae	*Sabella spallanzanii*	I
Polychaeta	Sphaerodoridae	*Sphaerodoropsis* sp.	II
Polychaeta	Spionidae	*Aonides oxycephala*	III
Polychaeta	Spionidae	*Spiophanes bombyx*	III
Polychaeta	Terebellidae	*Artacama proboscidea*	I
Polychaeta	Terebellidae	*Pista cristata*	I
Polychaeta	Trichobranchidae	*Terebellides stroemii*	II
Mollusca	Cardiidae	*Clinocardium buelowi*	Not assigned
Mollusca	Cardiidae	*Fulvia mutica*	Not assigned
Mollusca	Columbellidae	*Mitrella bella*	I
Mollusca	Hiatellidae	*Hiatella orientalis*	I
Mollusca	Littorinidae	*Littorina brevicula*	II
Mollusca	Mactridae	*Mactra cygnus*	I
Mollusca	Mactridae	*Raetellops pulchella*	III
Mollusca	Mactridae	*Mactra chinensis*	I
Mollusca	Mactridae	*Mactra nipponica*	I
Mollusca	Mactridae	*Mactra* sp.	I
Mollusca	Mytilidae	*Idas japonicus*	Not assigned

Appendix A (*continued*)

Group	Family	Species	Ecological group (EG)
Mollusca	Naticidae	*Neverita didyma*	I
Mollusca	Nuculidae	*Nucula faba*	I
Mollusca	Philinidae	*Philine* sp.	II
Mollusca	Pholadidae	*Barnea* sp.	Not assigned
Mollusca	Psammobiidae	*Nuttallia olivacea*	Not assigned
Mollusca	Pyramidellidae	*Chemnclzia acosmia*	Not assigned
Mollusca	Pyramidellidae	*Odostomia sublirulata*	II

References

Bald, J., Borja, A., Muxika, I., Franco, J., Valencia, V., 2005. Assessing reference conditions and physic-chemical status according to the European Water Framework Directive: a case-study from the Basque country (Northern Spain). Mar. Pollut. Bull. 50, 1508–1522.

Borja, A., Muxika, I., 2005. Guidelines for the use of AMBI (AZTI's marine biotic index) in the assessment of the benthic ecological quality. Mar. Pollut. Bull. 50, 787–789.

Borja, A., Tunberg, B.G., 2011. Assessing benthic health in stressed subtropical estuaries, eastern Florida, USA using AMBI and M-AMBI. Ecol. Ind. 11, 295–303.

Borja, A., Franco, J., Pérez, V., 2000. A marine biotic index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. Mar. Pollut. Bull. 40 (2), 1100–1114.

Borja, A., Franco, J., Valencia, V., Bald, J., Muxika, I., Belzunce, M.J., Solaun, O., 2004a. Implementation of the European Water Framework Directive form the Basque country (north Spain): a methodological approach. Mar. Pollut. Bull. 48 (3–4), 209–218.

Borja, A., Valencia, V., Franco, J., Muxika, I., Bald, J., Belzunce, M.J., Solaun, O., 2004b. The water framework directive: water alone, or in association with sediment and biota, in determining quality standards? Mar. Pollut. Bull. 49, 8–11.

Borja, A., Dauer, D.M., Diaz, R., Llanso, R.J., Rodriguez, J.G., Schaffner, L., 2008. Assessing estuarine benthic quality conditions in Chesapeake Bay: a comparison of three indices. Ecol. Ind. 8, 395–403.

Borja, A., Bald, J., Franco, J., Larreta, J., Muxika, I., Revilla, M., Rodríguez, J.G., Solaun, O., Uriarte, A., Valencia, V., 2009a. Using multiple ecosystem components, in assessing ecological status in Spanish (Basque Country) Atlantic marine waters. Mar. Pollut. Bull. 59, 54–64.

Borja, A., Ranasinghe, A., Weisberg, S.B., 2009b. Assessing ecological integrity in marine waters, using multiple indices and ecosystem components: challenges for the future. Mar. Pollut. Bull. 59, 1–4.

Borja, Á., Rodríguez, J.G., Black, K., et al., 2009c. Assessing the suitability of a range of benthic indices in the evaluation of environmental impact of fin and shellfish aquaculture located in sites across Europe. Aquaculture 293, 231–240.

Borja, Á., Galparsoro, I., Irigoien, X., Iriondo, A., Menchaca, I., Muxika, I., Pascual, M., Quincoces, I., Revilla, M., Germán Rodríguez, J., Santurtún, M., Solaun, O., Uriarte, A., Valencia, V., Zorita, I., 2011. Implementation of the European marine strategy framework directive: a methodological approach for the assessment of environmental status, from the Basque Country (Bay of Biscay). Mar. Pollut. Bull. 62, 889–904.

Borja, Á., Dauer, D.M., Grémare, A., 2012. The importance of setting targets and reference conditions in assessing marine ecosystem quality. Ecol. Ind. 12, 1–7.

Cai, W., Liu, L., Meng, W., Zheng, B., 2012. The suitability of AMBI to benthic quality assessment on the intertidal zones of Bohai Sea. Acta Sci. Circumstantiae 32 (3), 992–1000 (In Chinese with English abstract).

Canford, P.J., Hargrave, B.T., Foucette, L.I., 2009. Benthic organic enrichment from suspended mussel (*Mytilus edulis*) culture in Prince Edward Island, Canada. Aquaculture 292, 189–196.

Dauer, D.M., 1993. Biological criteria, environmental health and estuarine macrobenthic community structure. Mar. Pollut. Bull. 26 (5), 249–257.

DelValls, T.A., Conradi, M., Garcia-Adiego, E., et al., 1998. Analysis of macrobenthic community structure in relation to different environmental sources of contamination in two littoral ecosystems from the Gulf of Cádiz (SW Spain). Hydrobiologia 385, 59–70.

Di, B., Liu, D., Wang, Y., Dong, Z., Li, X., Shi, Y., 2013. Diatom and silicoflagellate assemblages in modern surface sediments associated with human activity: a case study in Sishili Bay, China. Ecol. Ind. 24, 23–30.

Dong, Z., Liu, D., Keesing, J.K., 2010. Jellyfish blooms in China: dominant species, causes and consequences. Mar. Pollut. Bull. 60, 954–963.

Forchino, A., Borja, A., Brambilla, F., Rodríguez, J.G., Muxika, I., Terova, G., Saroglia, M., 2011. Evaluating the influence of off-shore cage aquaculture on the benthic ecosystem in Aolhero Bay (Sardinia, Italy) using AMBI and M-AMBI. Ecol. Ind. 11, 1112–1122.

Forrest, B.M., Keeley, N.B., Hopkins, G.A., et al., 2009. Bivalve aquaculture in estuaries: review and synthesis of oyster cultivation effects. Aquaculture 298, 1–15.

Gao, H., Deng, Z., Sun, W., et al., 2011. Study on the relationship between ecological environmental pollution and red tide occurring in Sishili Bay, Yantai. Environ. Monit. China 27 (2), 50–101 (In Chinese with English abstract).

Godet, L., Toupoint, N., Fournier, J., et al., 2009. Clam farmers and oystercatchers: effects of the degradation of *Lanice conchilega* beds by shellfish farming on the spatial distribution of shorebirds. Mar. Pollut. Bull. 58, 589–595.

Grey, J.S., 1997. Marine biodiversity: pattern, threats and conservation needs. Biodivers. Conserv. 7, 153–175.

Liu, D., Keesing, J.K., Xing, Q., Shi, P., 2009. World's largest macroalgal bloom caused by expansion of seaweed aquaculture in China. Mar. Pollut. Bull. 58, 888–895.

Liu, D., Shi, Y., Di, B., Sun, Q., Wang, Y., Dong, Z., Shao, H., 2012. The impact of different pollution sources on modern dinoflagellate cysts in Sishili Bay, Yellow Sea, China. Mar. Micropaleontol. 84–85, 1–13.

Li, J., Liu, X., 2007. Water quality change and trend analysis of Dagujia River Basin in Yantai. Water Resour. Power 25 (6), 20–24 (In Chinese with English abstract).

Lin, R., Zhang, B., Song, X., Xie, W., Sun, D., 1998. Environmental status for the sediment near the Zhifu Bay area. Mar. Environ. Sci. 17 (4), 22–26.

Liu, Y., Liu, X., Xing, H., et al., 2006. Analysis of the water quality in the sea area of Sishili Bay of Yantai in 2003. Trans. Oceanol. Limnol. 3, 93–97 (in Chinese with English abstract).

Liu, Y., Ji, L., Guo, J., Qu, L., Yang, L., Ding, L., 2009. Space-time changing trends analysis of the water quality and eutrophication of Yantai nearby seas. Mar. Sci. Bull. 28 (2), 18–22 (In Chinese with English abstract).

Lohrer, A.M., Thrush, S.F., Gibbs, M.M., 2004. Bioturbator enhance ecosystem function through complex biogechemical interactions. Nature 43, 1092–1095.

Magni, P., Micheletti, S., Casu, D., et al., 2005. Relationships between chemical characteristics of sediments and macrofaunal communities in the Cabras lagoon (Western Mediterranean, Italy). Hydrobiologia 550, 105–119.

Magni, P., Como, S., Montani, S., et al., 2006. Interlinked temporal changes in environmental conditions, chemical characteristics of sediments and macrofaunal assemblages in an estuarine intertidal sandflat (Seto Inland Sea, Japan). Mar. Biol. 149, 1185–1197.

Muxika, I., Borja, A., Bonne, W., 2005. The suitability of the marine biotic index (AMBI) to new impact sources along European coasts. Ecol. Ind. 5, 19–31.

Muxika, I., Borja, A., Bald, J., 2007. Using historical data, expert judgment and multivariate analysis in assessing reference conditions and benthic ecological status, according to the European Water Framework Directive. Mar. Pollut. Bull. 55, 16–29.

Paganelli, D., Forni, G., Marchini, A., Mazziotti, C., Occhipinti-Ambrogi, A., 2011. Critical appraisal on the identification of reference conditions for the evaluation of ecological quality status along the Emilia-Romagna coast (Italy) using M-AMBI. Mar. Pollut. Bull. 62, 1725–1735.

Pearson, T., Rosenberg, R., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Annu. Rev. 16, 229–311.

Primavera, J.H., 2006. Overcoming the impacts of aquaculture on the coastal zone. Ocean Coast. Manage. 49, 531–545.

Smith, C.R., Austen, M.C., Boucher, G., et al., 2000. Global change and biodiversity of marine sediments: impacts and linkages across the sediment-water interface. Bioscience 50, 1108–1120.

Snelgrove, P.V.R., Blackburn, T.H., Hutchings, P.A., et al., 1997. The importance of marine sediment biodiversity in ecosystem processes. Ambio 26, 578–583.

Tang, Q., 2004. Study on Ecosystem Dynamics in Coastal Ocean. III, Atlas of the Resources and Environment in the East China Sea and the Yellow Sea Ecosystem. Science Press, Beijing, China, 398 p. (in Chinese, with English abstract).

Tueros, I., Rodríguez, J.G., Borja, A., Solaun, O., Valencia, V., Millán, E., 2008. Metal background levels in estuarine and coastal waters, for use in physic-chemical assessment within the European Water Framework Directive. Sci. Total Environ. 407, 40–52.

Wan, L., 2012. Research on seawater environment pollution of mariculture in Yantai Sishili Bay. J. Anhui. Agri. Sci. 40 (11), 6801–6803 (in Chinese, with English abstract).

Wang, X., Guo, Y., Sun, Y., 1994. Prediction of water quality in offshore area north of Yantai. J. Ocean Univ. Qingdao, 50–55, SI (in Chinese, with English abstracts).

Wang, X., Xu, Z., Zhou, X., 1995. Animal survey in Yantai inshores. Chinese J. Ecol. 14 (1), 6–10 (in Chinese, with English abstract).

Wang, Y., Liu, D., Dong, Z., Di, B., Shen, X., 2012. Temporal and spatial distribution of nutrients under the influence of human activities in Sishili Bay, northern Yellow Sea of China. Mar. Pollut. Bull. 64, 2708–2719.

Weston, D.P., 1990. Quantitative examination of macrobenthic community changes along an organic enrichment gradient. Mar. Ecol. Prog. Ser. 61, 233–244.