

Environmental impact assessment of oilfield upgrades in Bohai Sea

Ruihui Chen¹, Yanna Xiong^{1,4}, Jiao Li³ and Xianbo Li^{2,5}

¹ Engineering Research Center of Groundwater Pollution Control and Remediation, Ministry of Education, College of Water Sciences, Beijing Normal University, No 19, Xijiekouwai Street, Beijing, 100875, China;

² Business School, Beijing Normal University, No 19, Xijiekouwai Street, Beijing, 100875, China;

³ Environmental Engineering Center, Chinese Research Academy of Environmental Sciences, No 8, Dayangfang, Beijing, 100012, China;

⁴ Solid Waste and Chemicals Management Centre, Ministry of Environmental Protection, Beijing, 100035, China.

⁵ lixb@bnu.edu.cn

Abstract. This paper designed 65 environmental monitoring sites to collect samples and analyze for better evaluating the environmental impact generated by cuttings, mud, produced water with oil and oil pollutions that produced during the upgrading in the Bohai Sea where the oil field 34-1 upgraded. Collecting samples include ocean water, marine life and sediments and test items involve PH, dissolved oxygen (DO), salinity, chemical oxygen demand (COD), phosphate, organic carbon, sulfide, inorganic nitrogen, petroleum, copper (Cu), lead (Pb), zinc (Zn), cadmium (Cd), total chromium (Cr), total mercury (Hg) and arsenic (As). Meanwhile sample sites collect and analyze the abundance and diversity of marine plants and elaborated the environmental impact caused by upgrading renovation project from the aspects of sea water, marine life and marine sediments. Through analysis and comparison we found that seawater quality conform the III seawater quality standards, the excessive rate of Cu is 10%, the average diversity index of marine life is 2.34 and evenness is 0.68. Influence range of marine sediments and pollutants of production is within 2.68km and basically has no serious impact in the surrounding sea area. It's worth nothing that reconstruction project has the risk of oil spilling and protective measures must be prepared.

1. Introduction

The Bohai Sea, also called Bohai or Bo Hai, is a semi-enclosed marginal sea of the northwestern Pacific Ocean on the northern of China. It is connected to the Yellow Sea on its east by the Bohai Strait. Bohai Sea is an important productive area in northern China, which buried abundant fuel resources such as oil and natural gas. In order to enhance the development and utilization of oil and natural gas in this area, Tianjin branch of China National Offshore Oil Corporation (CNOOC) upgraded the oilfield 34-1, which had produced many years in the Bohai Sea area. Upgrade renovation project produced much additional pollution such as cuttings, mud, produced water with oil and oil pollutions.



2. Materials and methods

2.1. Study area

The oilfield of BZ34-1 locate in southern area of Bohai Sea, 119°27'-119°37'E and 38°06'-38°10'N. Location diagram is as shown in figure 1. Average sea water depth among the oilfield is about 20.5m. The oilfield of BZ34-1 is away from oilfield of BZ34-2/4 about 3km in the south, oilfield of BZ25-1 about 35km in the northwest and oilfield of BZ28-1 about 22km in the northeast. The sea area of BZ34-1 situate low latitude area and belong to tropical marine climate with possess frequently active typhoon, high temperature, high humidity and heavy rain [1].

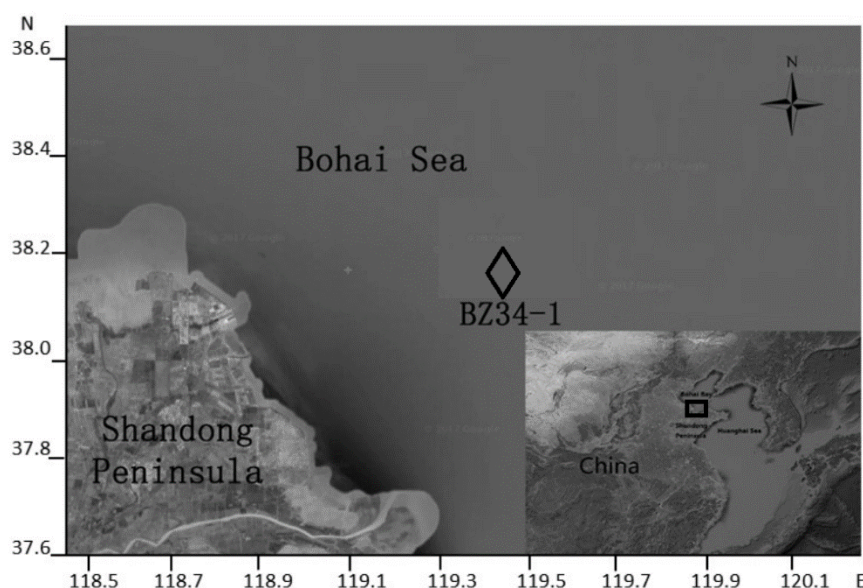


Figure 1. Map of the study area.

In order to improve exploitation of oilfield BZ34-1, reverse the passive situation of low yield, promote the mining speed of oilfield BZ34-1, excavate potential ability of surplus crude oil reserves, CNOOC launch the first phase renovation project of BZ34-1. According to the engineering characteristics and the results of pollution source analysis, the main sources of pollution involve production water with oil, engine oil, domestic sewage and waste and production waste and so on. Main pollution factors are coliform bacteria, suspended solids, BOD₅, hard impurities and a small amount of oil. Thus the main environmental assessment contents are marine water, marine life and marine sediments on the basis of above contents.

2.2. Sample collection and analysis

For investigating the project's environmental quality situation, the CNOOC set up survey points as the figure 2 to inquire into sea water, marine life and marine sediments. Test items are heavy metals such as Hg, As, Cu, Pb, Zn, Cd, Cr, COD, DO and PH. As and Hg digested by HCl-HNO₃ and measured through Atomic Fluorescence Spectrometry, Cd and Pb digested by HNO₃-HF-HClO₄ and measured through Graphite Furnace Atomic Absorption Spectrophotometry, Cr determined by Flame atomic spectrophotometry, Cu determined by X fluorescence spectroscopy, organic nitrogen and COD by Spectrophotometer and other indexes by Multi-function portable detector [2].

Test and analysis results as follows: Table of water quality analysis, marine sediments and plankton which includes diversity, evenness and abundance. Specific information as table 1, table 2, table 3 and table 4.

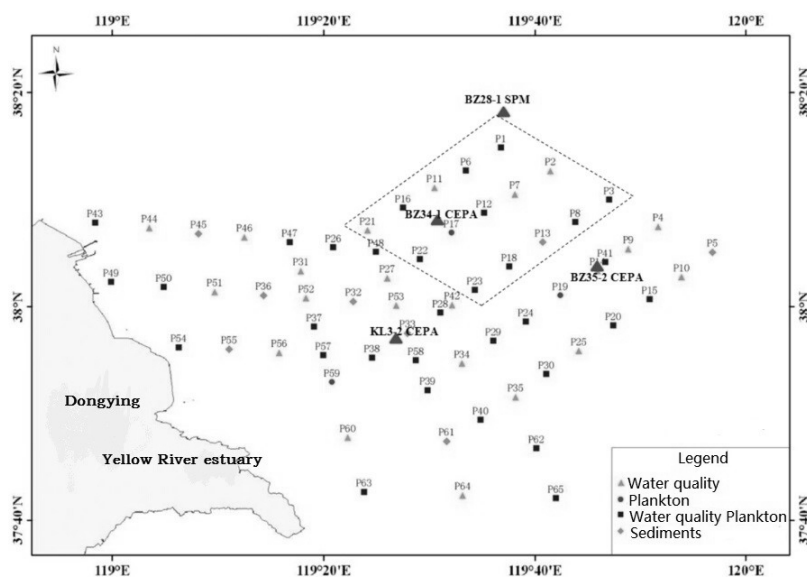


Figure 2. Map of survey points.

Table 1. Water quality survey statistics ($\mu\text{g/L}$)

Site	salinity	pH	DO	COD	Inorganic nitrogen	Hg	Cu	Pb	Zn	Cd	Cr	Petroleum
P1	29.90	8.32	7580	584	220.00	0.03	1.75	1.65	12.20	0.17	2.37	48.20
P2	30.26	8.33	8110	544	217.00	0.04	2.19	1.68	15.00	0.09	2.38	59.30
P3	31.00	8.32	7710	288	129.00	0.04	1.93	1.38	16.60	0.11	2.73	33.50
P6	30.36	8.32	7550	600	295.00	0.03	2.20	1.54	15.20	0.12	2.54	47.80
P7	31.04	8.30	8500	624	219.00	0.04	2.32	1.07	16.20	0.14	2.41	35.40
P8	30.93	8.33	7650	768	132.00	0.05	1.88	1.08	15.20	0.17	2.35	47.10
P11	29.89	8.30	7460	704	327.00	0.04	1.89	1.74	9.43	0.13	3.01	38.90
P12	31.21	8.30	7890	616	295.00	0.04	2.20	2.00	11.00	0.13	2.55	94.60
P13	30.85	8.32	7600	552	116.00	0.04	2.37	1.49	12.40	0.17	1.85	26.00
P16	29.70	8.28	7550	584	326.00	0.04	1.68	1.55	16.10	0.15	1.92	44.00
P17	31.31	8.27	8000	680	304.00	0.03	1.86	1.65	9.03	0.10	1.68	71.40
P18	30.85	8.31	7380	832	126.00	0.04	2.15	2.05	17.80	0.15	1.96	32.50
P21	29.87	8.28	7490	704	330.00	0.04	2.18	1.76	17.50	0.11	2.74	48.20
P22	31.30	8.27	7890	744	325.00	0.03	1.56	1.69	19.10	0.18	2.31	37.80
P23	31.01	8.29	7620	752	140.00	0.04	1.90	1.25	15.50	0.12	2.36	16.70
Limit standard *	—	<8.5	>4000	$\leq$ 4000	$\leq$ 400	$\leq$ 2	$\leq$ 5	$\leq$ 10	$\leq$ 100	$\leq$ 10	$\leq$ 200	$\leq$ 300

*According to Sea water quality standards — (III) GB 3097-1997; — shows no standard

Table 2. Excessive statistical rate of water quality evaluation factor.

Evaluation factor	Exceeded number of sites	Excessive rate (%)	Maximum exceeded multiple
Petroleum	23	59	0.24
Active phosphate	20	51.3	2.73
Inorganic nitrogen	12	30.8	0.61
Zn	12	30.8	0.24

Table 3. Analysis results of surface sediments (*10⁻⁶g/g).

Site	Organic carbon	Hg	Cu	Pb	Zn	Cd	As	Complexes	Petroleum	S
P1	2810	0.0254	37.1	39.1	39.9	0.207	10.4	52.1	51.5	51.2
P3	1220	0.0293	14.4	11.1	23.9	0.116	6.7	17.2	34.3	39.5
P6	2200	0.0481	26.5	29.4	27.1	0.159	8.19	37.1	72	41.7
P8	1560	0.0445	11.9	11.7	27.3	0.116	7.02	23.4	19.6	40.9
P12	2490	0.0294	25.9	21.6	41.1	0.16	7.91	33.7	22.2	42
P13	2710	0.0468	26.7	20.8	29.7	0.178	9.21	34.9	64	54.6
P16	3360	0.0453	27.0	29.7	27.3	0.182	8.89	35.1	103	45.5
P18	1360	0.039	12.4	17.6	24.0	0.115	7.2	15.5	18.8	39.5
P22	1690	0.024	14.4	15.3	32.6	0.123	8.02	25.6	54.3	46.2
P23	2090	0.047	23.9	15.5	24.9	0.152	8.65	36.4	62	44.3
Min	1220	0.024	11.9	11.1	23.9	0.115	6.7	15.5	18.8	39.5
Max	3360	0.0481	37.1	39.1	41.0	0.207	10.4	52.1	103	54.6
Ave	2150	0.038	22.0	21.2	29.8	0.151	8.2	31.1	50.2	44.5
Ave										
Standard Index	1900	0.63	0.36	0.2	0.3	0.41	0.39	0.1	0.11	0.15
Limit standard*	4000	1.00	200.0	250.0	600.0	5.00	93.0	—	1500.0	—
≤										
Excessive rate (%)	0	0	10	0	0	0	0	0	0	0

*According to Marine sediment quality standards (III) GB 18668-2002; — shows no standard

According to survey results, the contents of PH, dissolved oxygen, phosphate, copper, zinc, cadmium, total chromium, arsenic, sulfide and volatile phenol in the sea water all meet I class seawater quality standard, about 20% samples excess in oil and the maximum exceeded multiple is 0.89, which correspond the III class seawater quality standard($\leq 0.30\text{mg/L}$), approximately 67% samples in the surface layer excess in Inorganic nitrogen and the maximum exceeded multiple is 0.65, which correspond the III class seawater quality standard($\leq 0.40\text{mg/L}$), 81% samples in the bottom excess in Cu and the maximum exceeded multiple is 1.51, which outside the V class seawater quality standard. Under the same conditions, seawater samples in South China Sea Oilfield in Sansha reach the standard in PH, dissolved oxygen, phosphate, copper, zinc, cadmium, total chromium, arsenic, sulfide and volatile phenol, oil content exceeded rate is 9%, whose maximum exceeded multiple is 0.35[3,4], Inorganic nitrogen are 5% and 0.21, which all not surpass III class seawater quality standard [5,6,7].

Marine biological survey results show that the variation range of chlorophyll a is (0.98~6.15) $\mu\text{g/L}$, while the variation range of marine primary productivity is (23.81~49.06) $\text{C}/(\text{m}^2 \cdot \text{d})$, whose

average value is 36.03mg².Cd/m². The variation range of diversity index (H) in phytoplankton and zooplankton are 0.92~2.49 and 0.26~1.59, and the evenness (J) are 0.28~0.73 and 0.13~0.61. The contents of organic carbon, total mercury, lead, zinc, cadmium, arsenic, total chromium, oil and sulfide in sediments all conform I class standard of <Quality standards for marine sediments> (GB 18668-2002). Copper content exceeded the standard and excessive rate is 10% [8]. Comparison with the results of bearing capacity of marine organisms in Cook Inlet studied by Rice, the variation range of diversity index (H) in phytoplankton and zooplankton and the evenness (J) in Cook Bay are all larger BZ34-1 area in Bohai Sea and the excessive rate is 17.19% [9]. Therefore we must pay close attention to the diversification of marine flora and fauna avoid ecological destruction.

Table 4. Results of Diversity, Evenness and Abundance about marine plants.

Site	Diversity index (H)	Evenness (J)	Abundance (D)
P1	1.72	0.57	0.45
P6	2.49	0.7	0.74
P8	2.19	0.73	0.48
P12	1.33	0.42	0.53
P13	1.31	0.4	0.54
P16	1.42	0.47	0.43
P18	1.94	0.58	0.57
P22	1.4	0.5	0.37
P23	0.92	0.28	0.54
Range	0.92 ~2.49	0.28 ~0.73	0.37 ~0.74
Ave	1.64	0.52	0.52

2.3. Chemical analysis and evaluation

Water quality evaluation factors consist 14 items: PH, dissolved oxygen, chemical oxygen demand, phosphate, inorganic nitrogen, petroleum, copper, lead, zinc, cadmium, total chromium, total mercury, arsenic and sulfide. Seawater quality assessment standards based on I class of seawater quality rating standards in the <Sea water quality standards> (GB3097-1997) [10]. Sediment deposits evaluation factors consist 10 items: organic carbon, petroleum, sulfide, total mercury, copper, lead, cadmium, zinc, chromium and arsenic and the quality assessment standards based on I class of marine sediments quality rating standards in the < Quality standards for marine sediment values>(GB18421-2001) [11]. The evaluation methods adopt the standard index method and the excessive standard method to evaluate and analyse above three types of marine environment.

3. Results and discussion

According to current understanding, the environmental pollution in the seawater, marine life and sediments of the Bohai Sea around oilfield BZ34-1 are mainly from three aspects: oil production water discharge, petroleum pollution and cuttings and mud, which brings high concentrations of contaminants and other pathways influencing their concentrations have relatively little impact compared with above three aspects. Now discussion and analysis as follows show the influence trend of three environments influenced by above three aspects.

3.1. Environmental assessment on pollutants on marine water

3.1.1. Environmental impact of oil production water discharge. Oil production water discharge 200m³/d waste water to Bohai Sea in BZ34-1 under normal circumstances, which oil concentration is 20mg/L and maximum number days of discharge is 15 days. The results show that petroleum background concentration is as high as 0.05mg/L, which has exceed the I class water quality standard at

the sea area of BZ34-1. The largest area of overtake III class is less than 0.057km^2 and the largest distance is less than 0.25km away from emission points at the situation of maximum wind power. While at the static wind situation, the largest area of overtake III class is less than 0.186km^2 , the largest distance is less than 0.35km away from emission points and the largest area of overtake IV class is less than 0.018km^2 .

3.1.2. Environmental impact of drill cuttings and mud. This project discharge non-oil cuttings about 3840m^3 (emission rate is $18\text{m}^3/\text{d}$) and non-oil mud 1200m^3 (maximum discharge rate is $35\text{m}^3/\text{h}$ at the final disposable discharge process). The results show that the effect of mud on water quality is measured on the surface and the area size of overtake I class water standard is 3.856km^2 . The farthest point of emission for overtake I class water is 2.3km and the time recovering to the I class water standard is 18.2h . Maximum area of overtake III and IV class water, which are 0.077km^2 and 0.037km^2 , are relative small compared with others. The map of surface mud diffusion envelope and the result of prediction of expansion field for drilling and mud are shown as figure 3, table 5 and table 6.

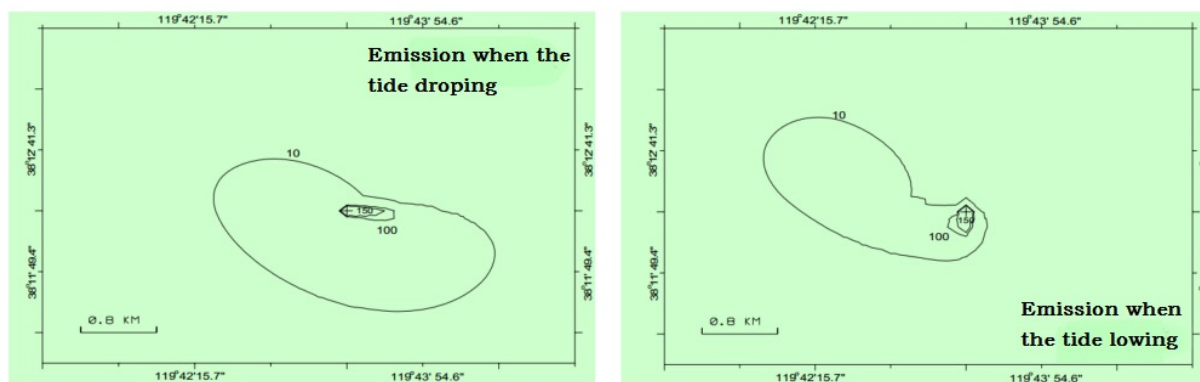


Figure 3. Maps of surface mud diffusion envelop.

Table 5. Results of prediction of expansion field for drilling and mud.

	the largest water quality	Maximum distance	Time restore to the
	area of over I class	away from emission points	I class water
surface layer	0.39km^2	0.61km	3.2h
Middle layer	0.15km^2	0.37km	3.5h
Bottom	0.06km^2	0.23km	2.3h

Table 6. Results of expansion field for drilling and mud.

Water standard	Sea area (km^2)	Maximum distance away from emission points (km)
over I	3.856	2.3
over II	0.642	0.675
over III	0.077	0.132
over IV	0.037	0.035

3.1.3. Environmental impact of domestic sewage discharging. This project discharge domestic sewage whose main pollution factors are coliforms, SS, BOD_5 and COD $29.4\text{m}^3/\text{d}$ ($10,731\text{m}^3/\text{a}$) approximately during the production run time and the domestic sewage discharge into the sea when the water reach the standard ($\text{COD} \leq 300\text{mg/L}$) after process with the sewage treatment plant. According to the results of

numerical simulation of domestic sewage discharge, sea area of COD exceeded incited by domestic sewage discharging is less than 0.003km^2 and maximum distance of emission is less than 50m. Thus conclusion can be got that domestic sewage emission will has a long-term local impact on the water quality around the discharge port.

3.2. Environmental assessment of pollutants on marine life

3.2.1. Toxicity of petroleum contaminants on marine life. Studies have shown that acute lethal effect caused by oil pollution is the most obvious harm to marine life, which kill creatures through oil film covering creatures or oil toxicity. Lethal effect concentration that oil pollution affect Bohai Sea biological organisms is $1\sim 100\text{mg/L}$ and Lethal concentration is $0.1\sim 1\text{mg/L}$. 96h TLm value that oil in Bohai Bay Oilfield influence 5 kinds of middle and upper fish is $1.22\sim 2.55\text{mg/L}$, 96h TLm value for 4 kinds shrimps is $0.87\sim 4.94\text{mg/L}$, 13 kinds of mollusks is $3.94\sim >10.58\text{mg/L}$ [12, 13]. Through the survey results we can find that 96h LC50 value for scales, yellowfin seabream and black bream larvae are 7.08, 9.12 and 5.89mg/L , for shrimp, monodon shrimp and Japanese shrimp are 4.09, 3.55 and 2.40mg/L , for emerald mussels, mussels, ripples and clams are 4.17, 6.76, 10.23 and $>32\text{mg/L}$. The oil concentration in the area is 0.0035mg/L , which has inhibitory effect on cell division for algae, reduce the growth rate of marine bivalves, initiate carcinogenic teratogenic and mutagenic effects. In general, it is benzene, toluene, and its derivatives in the oil that trigger seawater pollution in Bohai Sea.

3.2.2. Toxicity of water for oil production on marine life. Oil production water contain great amount of non-hydrocarbon organic matter (most of them are carboxylates), aromatic hydrocarbons whose concentration is about $20\sim 40\text{mg/L}$, such as benzene, toluene and xylene, ammonia nitrogen and inorganic matter. The biological toxicity of production water related with the concentration of oil pollution. Experiments show that production water brought by this project generate value of 48h LC50 for *crassostrea gigas* is 5%, 24h LC50 for *salono gairderi* is 10% and 96h LC50 for *penaeus aztecus* and *psectiferus* is $3\%\sim 30\%$. In addition we find that fish are not as sensitive as invertebrates through comparative experiment.

3.2.3. 2Toxicity of drill cuttings and mud on marine life. The toxicity of drilling mud mainly depends on several chemical additives that account very few parts in the drilling mud such as barite, bentonite, chrome, trichlorite, sulfonated pitchene and diesel and so on. In the mud produced during the project, the value of 96h LC50 for 83% of them is larger than $100\ 000\text{mg/L}$, 96h LC50 for 89% is larger than 1000mg/L and for 95% is larger than 100mg/L . In the light of standards proposed by USA, which resolve the toxicity of mud to creatures, 83% of them is non-toxic. The mud material mainly contain Cr, Pb and Zn, but Cr store in the material with non-toxic form and others exist or adsorb in the solid particle, which is hard to dissolve and release and has not a serious impact on the biological under normal circumstances[14].

3.3. Environmental assessment of pollutants on marine sediment deposits

Cuttings and mud deposition on the seabed within a certain range after discharging and emissions, currents, water depth and other factors affect distribution area of cuttings and mud. Deposition radius distribute within 1000 meters and most in 200 meters. This project bring cuttings emissions 3840m^3 during the engineering period and the seabed area that covering the thickness of the sea is greater than 2cm is 0.19km^2 . The type of sediments in the coverage area has changed and organic matter content will increase in the sediments for cuttings emission. Thus may cause coverage affect for benthic organisms within 250m around the discharge port and lead to partial and short term influences for benthic organisms.

4. Concluding remarks and perspectives

According to the result of research and analysis for sea water, marine life and sediments and model simulation prediction, we find that environmental risk probability will not as high as before during the production time. It is worth nothing that the microbes in the seawater may convert and release the non-toxic material into noxious substance and real-time monitoring is important. The environmental risk will not occur under the basic protection and related measures conditions. It is important to use cleaning tools and recycling equipment during production and upgrading process soon after so as to reduce the oil spill risk to the least.

Reference

- [1] Yuan L, Han L, Bo W, Chen H, Gao W and Chen B 2017 *Mar. Pollut. Bull.* **118** L79
- [2] Zhang Y, Song J, Yuan H, Xu Y and He Z 2010 *Arch Environ Contam Toxicol* **59** L120
- [3] Qiao Y, Feng J, Cui S and Zhu L 2017 *Mar. Pollut. Bull.* **117** L222
- [4] Cao X and Chen C 2012 *Water Res.* **46** L1901
- [5] Liu W, Chen J, Lin X, Fan Y and Tao S 2007 *Environ. Pollut.* **146** L470
- [6] Liu X, Jiang X, Liu Q, Teng A and Xu W 2016 *Environ Earth Sci* **75** L364
- [7] Chen Y, Gao Y, Chen C, Liang J, Sun L, Zhen Y and Qiao L 2016 *Mar. Pollut. Bull.* **113** L362
- [8] Swart H, De V and Vosbeek M 1997 *Estuarine Coastal Shelf Sci.* **45** L123
- [9] Liu X, Meng R, Xing Q, Lou M, Chao H and Bing L 2015 *Ocean Coast. Manage.* **108** L140
- [10] Yu F, Li J, Cui S, Zhao Y, Feng Q and Chen G 2016 *Ocean Eng.* **124** L363
- [11] Chen H, Wang J, Chen J, Lin H and Lin C 2016 *Mar. Pollut. Bull.* **113** L132
- [12] Akhbarizadeh R, Moore F, Keshavarzi B and Moeinpour A 2017 *Environ. Pollut.* **220** L720
- [13] Wang Z, Hoekstra P, Burchard H, Ridderinkhof H, De H, and Stive M 2012 *Ocean Coast. Manage.* **68** L39
- [14] Hu L, Shi X, Bai Y, Qiao S, Li L, Yu Y, Yang G, Ma D and Guo Z 2016 *J. Mar. Sys.* **155** L50