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Current water pollution status at an important wintering site of the black-faced spoonbill *Platalea minor* in Xinghua Bay, south China

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ABSTRACT: Xinghua Bay is one of the largest wintering sites of the black-faced spoonbill *Platalea minor* in mainland China. The ecosystem of Xinghua Bay has shown a deteriorating trend with the increasing pressure of economic development in recent decades. To understand the current conservation status of the wintering spoonbills in Xinghua Bay, we collected water samples along the coast of Xinghua Bay and important spoonbill habitats during the wintering period to analyze the pollution degree of 7 target heavy metals and organics. The Nemerow pollution index (NPI), heavy metal pollution index (HPI) and contamination degree (CD) were used to assess the heavy metal pollution levels. The ecological risk index of a target heavy metal (E_f^i) and potential ecological risk index of all target heavy metals (RI) were used to assess the ecological risk of heavy metals levels in Xinghua Bay. Positive matrix factorization (PMF) was used to determine the sources of heavy metals in coastal waters with the EPA PMF5.0 model. The results showed that there was moderate to very heavy pollution by heavy metals and moderate associated ecological risks in Xinghua Bay, in which Hg and Cd were the major heavy metal pollution sources, and the level of organic pollution was of serious concern. The use of fertilizers for cultured shellfish and aquaculture in and around the bay were the major cause of the excessive nitrogen and phosphorus levels, and factories surrounding Xinghua Bay were the major sources of heavy metals and organic pollution. We propose conservation measures to increase black-faced spoonbill population and enhance its habitats.

KEY WORDS: Black-faced spoonbill · Heavy metal · Organics · Water pollution · Xinghua Bay

1. INTRODUCTION

The Endangered black-faced spoonbill *Platalea minor* (BirdLife International 2023) is distributed along the coastal fringes and archipelagos of East Asia, and mainly overwinters on the east coastline from Jiangsu Province to Hainan Island on mainland China, Macao, Hong Kong and Taiwan, as well as in Vietnam, Japan and South Korea, while it mainly breeds along the west coasts of North Korea and South Korea, with a small breeding population in the Liaoning Province in Northeast China and the Russian Far East (Chen et al. 2021, BirdLife International 2023). The black-faced spoonbill (hereafter 'spoonbill') population comprised fewer than 300 individuals in the 1980s (Collar et al. 1996), but with the strengthening of local government protection policies such as establishing protected areas and prohibiting coastal development, the population reached 6633 spoonbills in 2023 (Yu et al. 2023).

Xinghua Bay, located on the coast of Fujian Province in southern China, is an important habitat for migratory birds on the East Asian–Australasian Flyway. The total wetland area of Xinghua Bay is approximately

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61 300 ha, including 49 700 ha of natural wetland and 11 600 ha of artificial wetland (Li 2018). The wetland attracts many waterfowl as a resting place during migration, and is one of the most important wintering sites for the spoonbills in mainland China (Jin et al. 2008, 2009). Xinghua Bay is located between Fuqing and Putian in Fujian Province; the Jiangjing farm in Fuqing (5° 32′ 1.16″ N, 119° 24′ 3.64″ E) and Chigang farm in Putian (25° 28′ 31.76″ N, 119° 11′ 10.21″ E) are the major habitats for the wintering spoonbills, and the surrounding wetlands, such as the Jiangyin Peninsula in Fuqing, contain only a few individuals that can be found occasionally (Jin et al. 2009, Li 2018). Based on the surveys of the Hong Kong Bird Watching Society in recent years, the number of the wintering spoonbills in Xinghua Bay has stabilized at more than 100 individuals, reaching 323 at its peak and accounting for approximately 5% of the global wintering population, which is one of the largest wintering sites of the spoonbills in mainland China (Yu et al. 2023).

In recent decades, the ecosystem of Xinghua Bay has shown a trend towards habitat deterioration with the increasing pressure of economic development. Firstly, it is affected by industrial and agricultural wastewater and domestic sewage, the concentrations of nitrogen and phosphorus in waters are high, and the self-purification ability of seawater is poor, causing fish and shrimp resources to decline (Jin et al. 2010). Secondly, the wetland area of Xinghua Bay has been decreasing continuously with human development and construction activities; native vegetation such as *Kandelia candel* and *Phragmites communis* is degraded because of habitat fragmentation, and the habitats of hydrobionts and waterfowl have also been greatly reduced (Zhang et al. 2020, Lv 2021). Thirdly, mudflats have been gradually drying out, and aquaculture ponds have been converted into marine fishing, thermal discharge from coastal power plants (Cheng et al. 2013, Zhang et al. 2019). According to data published on the East Asian–Australasian Flyway Partnership website (https://www.eaaflyway.net/black-faced-spoonbill-working-group/), the population of wintering spoonbills in Xinghua Bay has shown a downwards trend in recent years (Fig. S1 in the Supplement at www.int-res.com/articles/suppl/n053p499_supp.pdf), which could be related to the increased economic development and factory construction in the local area.

To better protect waterfowl, especially spoonbills, the Xinghua Bay Waterbird Provincial Nature Reserve of Fuqing (25° 26′ 17.30′–25° 31′ 34.28′ N, 119° 20′ 39.36′–119° 27′ 24.82′ E) was established in January 2023. The total area of the nature reserve is 7518.36 ha, including a core area of 2282.66 ha and an experimental area of 5235.70 ha. However, we believe that it is not enough to strengthen protection only by establishing the nature reserve, as habitats are deteriorating due to local economic development, and the current conservation state of the spoonbill's wintering site must be investigated completely. In particular, many factories have been established around Xinghua Bay in recent years, and the degree of pollution from industrial production and the use of chemical fertilizer in spoonbill habitats is unclear. We collected water samples along the coast of Xinghua Bay and in important spoonbill habitats during the wintering period in January 2023 and analyzed the pollution level and sources of heavy metals and organics in the waters to provide conservation suggestions for protecting wintering spoonbills and their habitats in Xinghua Bay.

2. MATERIALS AND METHODS

2.1. Sample collection

We surveyed the types and distributions of factories around Xinghua Bay (Table S1, Fig. S2) and asked the local wildlife management department about the current status of important habitats for the wintering spoonbills during 15–17 August 2022. Then, according to the distribution of factories around Xinghua Bay and the activities of the wintering spoonbills, we divided the sample collection sites into 3 categories, including sewage outlet (2 samples), spoonbill habitat (11 samples) and Xinghua Bay coast (32 samples); additionally, a total of 45 water samples were collected in Xinghua Bay from 5 to 11 January 2023 (Table S2; Fig. 1).

Sewage outlet sites (A and B) were centralized sewage outlets for factories located north of the Xinghua Bay Waterbird Provincial Nature Reserve of Fuqing. Sewage from surrounding factories flowed into Xinghua Bay from the sewage outlets after being uniformly treated by a local sewage-treatment plant. We collected treated surface water samples at Sites A and B.

Spoonbill habitat sites were located as follows: the spoonbills were mainly active in the intertidal zone in Xinghua Bay and also fed on surrounding aquaculture ponds, so we collected surface water samples from 11 habitats (Sites a–k) where the wintering spoonbills were often found.

Xinghua Bay coast sites were located using Zeqi saltern as the starting point and Mulan River estuary

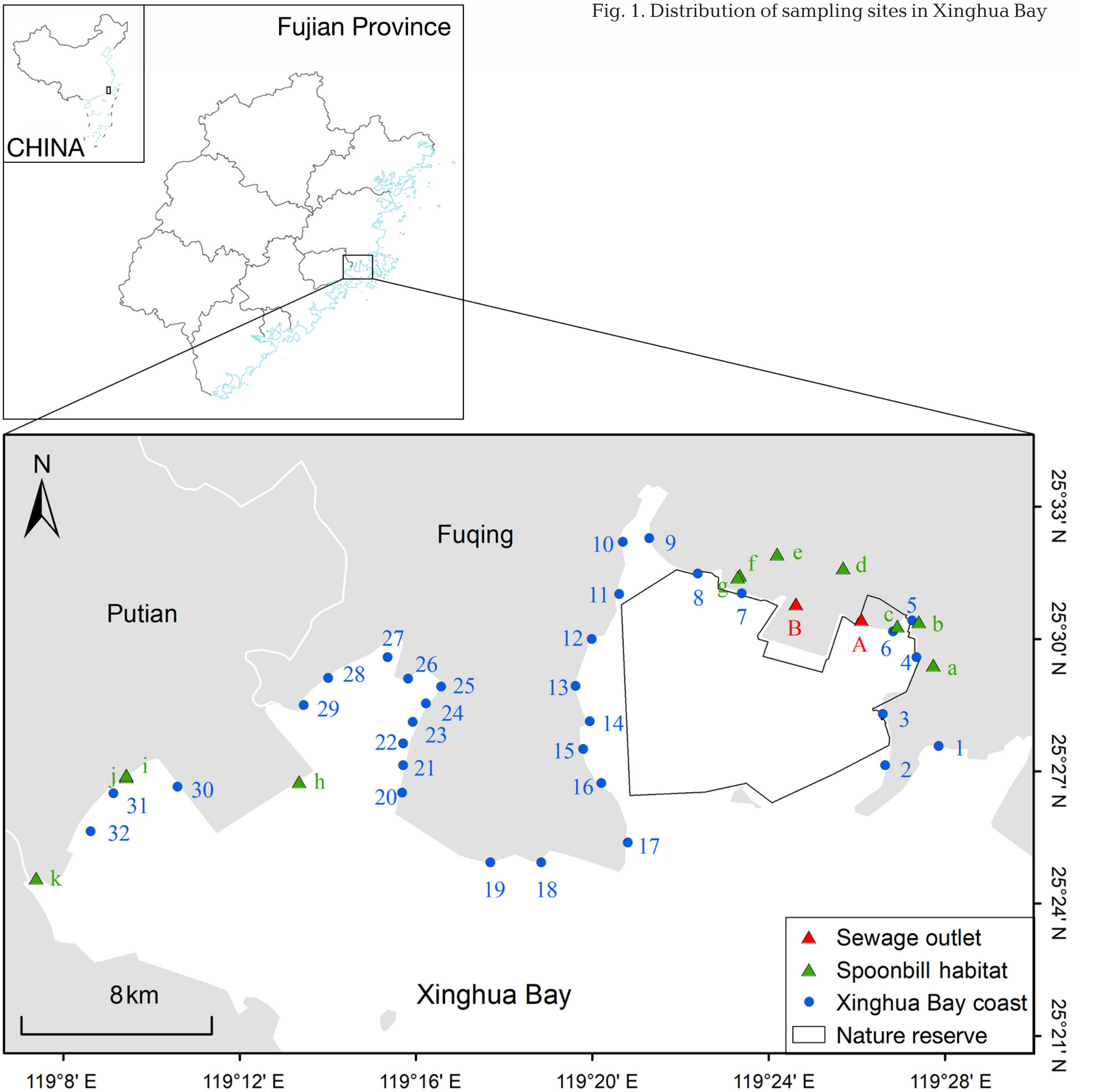

Fig. 1. Distribution of sampling sites in Xinghua Bay

as the end point, and the collection was carried out every 2 to 4 km along Xinghua Bay according to the actual situation of the surrounding coast in the field. A total of 32 surface water samples (Sites 1–32) were collected during low tide in Xinghua Bay.

Water samples (500 ml) were collected and stored in clean plastic bottles at −20°C. The concentrations of 7 typical heavy metals, including copper (Cu), zinc (Zn), chromium (Cr), cadmium (Cd), lead (Pb), mercury (Hg) and arsenic (As), and some water quality parameters which could reflect the degree of organic pollution, including dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), dissolved inorganic nitrogen (DIN), reactive phosphate (PO_4^{3-}-P), total nitrogen (TN) and total phosphorus (TP), were detected according to the methods in AQSIQ & SAC (2007) (Table S3).

2.2. Pollution assessment of heavy metals

The Nemerow pollution index (NPI), heavy metal pollution index (HPI) and contamination degree (CD)

Table 1. Pollution indices and their classification standards. NPI: Nemerow pollution index; HPI: heavy metal pollution index; CD: contamination degree

NPI classification standard; pollution level	HPI classification standard; pollution level	CD classification standard; pollution level
NPI < 1; none	HPI < 15; low	CD < 6; low
1 ≤ NPI < 2.5; low	15 ≤ HPI ≤ 30; moderate	6 ≤ CD <12; moderate
2.5 ≤ NPI < 7; moderate	30 < HPI ≤ 100; considerable	12 < CD < 24; considerable
NPI ≥ 7; heavy	HPI > 100; heavy	CD ≥ 24; very heavy

were used to assess the pollution level of heavy metals from all samples. Eqs. (1), (2) and (3) were used to calculate NPI (Liu et al. 2015, Wu et al. 2020), HPI (Mohan et al. 1996, Qu et al. 2018. Wu et al. 2020) and CD (Sharifi et al. 2016) as follows:

$$\mathrm{NPI} = \sqrt{\frac{\left(\frac{1}{n}\sum_{i=1}^{n}\frac{C_i}{C_0^i}\right)^2 + \left(\frac{C_i}{C_0^i}\right)^2_{\max}}{2}} \quad (1)$$

$$\mathrm{HPI} = \frac{\Sigma_{i=1}^{n}\left(\frac{C_i}{C_0^i}\times 100 \times \frac{k}{C_0^i}\right)}{\Sigma_{i=1}^{n}\frac{k}{C_0^i}} \quad (2)$$

$$\mathrm{CD} = \sum_{i=1}^{n}\frac{C_i}{C_0^i} \quad (3)$$

where n is the number of target heavy metals, C_i is the measured concentration of target heavy metal i, C_0^i is the highest assessment standard concentration of the target heavy metal in water and k is a proportionality constant. The value of k was set as 1 (Wanda et al. 2012), and C_0^i was set as the class I level as defined in MEE (1998), which targeted the sea fishery, sea nature reserves and rare and endangered sea life conservation district (Table S3).

The relationships between the NPI (Liu et al. 2015), HPI (Qu et al. 2018), CD (Sharifi et al., 2016) and pollution levels are shown in Table 1.

2.3. Ecological risk assessment of heavy metals

The ecological risk index of a target heavy metal (E_f^i) and potential ecological risk index of all target heavy metals (RI) were used to assess the ecological risk of heavy metals in all samples. Equations for calculating E_f^i (4) and RI (5) are presented below (Häkanson, 1980):

$$E_f^i = T_i \times \left(C_i / C_0^i\right) \quad (4)$$

$$\mathrm{RI} = \sum_{i=1}^{n} E_f^i \quad (5)$$

where T_i is the potential ecological risk coefficient of a target heavy metal. The values of T_i for the target heavy metals Cu, Zn, Cr, Cd, Pb, Hg and As were 5, 1, 2, 30, 5, 40 and 10, respectively (Häkanson 1980). The ranking criteria for ecological risk is shown in Table 2.

2.4. Data analysis

After a normal distribution and equal variance test, a t-test was used to analyze the differences in heavy metals and water quality parameter concentrations in the samples between the habitats of the wintering spoonbills and the Xinghua Bay coast. Pearson correlation analysis was used to determine the potential relationship between heavy metals and the water quality parameters of the Xinghua Bay coast samples (Harikrishnan et al. 2017, Wu et al. 2020). All analyses were comducted in SPSS 22.0.

Positive matrix factorization (PMF) was used to determine the source apportionment of heavy metals in coastal waters with the EPA PMF5.0 model, a multivariate factor analysis receptor model that deconstructed the sample data into factor contribution and factor profile to identify the factor profile and quantitatively calculate the factor contribution of the sam-

Table 2. Häkanson classification for ecological risk (E_f^i) and potential ecological risk index (RI). E_f^i: ecological risk index of a target heavy metal; RI: potential ecological risk index of all target heavy metals

E_f^i	Ecological risk level	RI	Ecological risk level
$E_f^i < 40$	Low	RI < 150	Low
$40 \le E_f^i < 80$	Moderate	150 ≤ RI < 300	Moderate
$80 \le E_f^i < 160$	Considerable	300 ≤ RI < 600	Considerable
$160 \le E_f^i < 320$	Heavy	RI ≥ 600	Very heavy
$E_f^i \ge 320$	Very heavy		

ple (Norris & Duvall 2014). Sample concentration and uncertainty associated with the sample data were used in PMF, and the uncertainty (Unc) was calculated using Eq. (6) when C_i was more than the standard deviation (SD)

$$\text{Unc} = 0.1 \times C_i + \frac{\text{SD}}{3} \quad (6)$$

otherwise, C_i was substituted with SD/2, and Unc was calculated using Eq. (7) as follows (Wang et al. 2016; Goswami & Kalamdhad 2023):

$$\text{Unc} = \frac{5}{6} \times \text{SD} \quad (7)$$

3. RESULTS

3.1. Heavy metals and water quality parameters

The concentrations of all detected heavy metals and water quality parameters from sewage outlet waters were within the measured concentration range of the Xinghua Bay coast and spoonbill habitat (Table 3; Fig. S3). Further analysis showed that DO (t = −2.395, df = 41, p = 0.021) from the Xinghua Bay coast was significantly higher and TN (t = 2.383, df = 41, p = 0.022) was significantly lower than in the spoonbill habitat, while there were no significant differences among the remaining elements between the spoonbill habitat and Xinghua Bay coast. This suggested that the waters along the Xinghua Bay coast and surrounding habitat of the wintering spoonbills could be connected, and the nitrogen may come from aquaculture ponds, which were the habitat of the wintering spoonbills.

Among the 45 sampling sites, except for Zn, Cr and As, which met the class I level according to MEE (1998), the measured concentration of Cu was 2.207 to 4.996 times, Pb was 2.434 to 8.460 times, Hg was 1.340 to 2.887 times, COD was 60.333 to 109.933 times, BOD was 49.333 to 98.000 times and DIN was 177.743 to 299.333 times that of the class I highest assessment standard values in all sampling sites (Fig. S3). Cd in 73.333% of sampling sites was 1.022 to 2.443 times, DO in 71.111% of sampling sites was 0.298 to 0.998 times, and PO_4^{3-}-P in 75.556% of sampling sites was 1.013 to 7.675 times that of the class I highest assessment standard values (Fig. S3).

These results showed that Cu, Cd, Pb, Hg, DO, COD, BOD, DIN and PO_4^{3-}-P pollution existed surrounding Xinghua Bay, especially COD, BOD and DIN, which showed very heavy pollution.

3.2. Pollution levels and ecological risk assessment of heavy metals

Among the 3 indices, the HPI showed the most severe results, with very heavy pollution of heavy metals at all sampling sites, followed by the CD, which suggested that there was moderate (46.667%) to considerable (53.333%) heavy metal pollution at

Table 3. Statistical summary of heavy metals and water quality parameters in samples. There were only 2 samples at the sewage outlet (A and B), so the measured concentration was provided directly. DO: dissolved oxygen; COD: chemical oxygen demand; BOD: biological oxygen demand; DIN: dissolved inorganic nitrogen; PO_4^{3-}-P: reactive phosphate; TN: total nitrogen; TP: total phosphorus

	Cu (µg l^{-1})	Zn (µg l^{-1})	Cr (µg l^{-1})	Cd (µg l^{-1})	Pb (µg l^{-1})	Hg (µg l^{-1})	As (µg l^{-1})	DO (µg l^{-1})	COD (mg l^{-1})	BOD (mg l^{-1})	DIN (mg l^{-1})	PO_4^{3-}-P (mg l^{-1})	TN (mg l^{-1})	TP (mg l^{-1})
Spoonbill habitats														
Mean	18.673	5.238	9.331	1.720	4.599	0.114	0.116	3.948	169.370	75.273	48.164	0.054	0.249	0.109
SE	1.217	0.441	0.710	0.189	0.495	0.008	0.008	0.446	10.385	3.842	1.887	0.012	0.031	0.013
Min.	12.439	3.256	5.298	0.502	2.507	0.068	0.068	1.790	125.467	55.733	36.753	0.004	0.095	0.040
Max.	24.979	7.127	12.968	2.443	6.738	0.144	0.147	6.463	219.867	90.667	59.368	0.104	0.476	0.158
Xinghua Bay coast														
Mean	17.317	5.512	8.214	1.317	3.996	0.108	0.116	5.255	154.088	68.938	47.383	0.029	0.172	0.092
SE	0.744	0.218	0.391	0.125	0.251	0.005	0.005	0.281	4.266	2.728	1.153	0.004	0.016	0.004
Min.	11.037	3.277	5.298	0.148	2.434	0.067	0.067	2.273	120.667	49.333	35.549	0.007	0.013	0.052
Max.	24.741	7.923	12.450	2.443	8.460	0.144	0.164	8.247	203.600	98.000	59.867	0.115	0.357	0.127
Sewage outlet														
A	24.159	4.740	6.042	0.584	2.654	0.070	0.069	4.310	142.933	60.267	45.254	0.062	0.209	0.123
B	21.063	5.837	7.984	2.224	6.427	0.114	0.116	3.083	148.667	71.333	51.073	0.092	0.270	0.126

the sampling sites, and the NPI showed that most sampling sites (84.444%) had moderate heavy metal pollution (Fig. 2). In general, the heavy metal pollution assessments of waters at the sewage outlets, habitats and Xinghua Bay coast were similar and there was moderate to very heavy pollution surrounding Xinghua Bay.

Among the 45 sampling sites, 77.778% showed moderate potential ecological risk by analyzing the RI values (Fig. 3). Hg and Cd had moderate to considerable ecological risks, while other heavy metals had low ecological risks based on E_f^i values (Fig. 3). This suggested that most of the sampling sites surrounding Xinghua Bay had moderate ecological risks of heavy metals, and Hg and Cd were the major sources of heavy metal pollution.

3.3. Analysis of possible sources of heavy metals

Pearson correlation analysis showed that there was a significant positive correlation between Cr, Cd, Hg and As, indicating that these 4 heavy metals may have similar sources (Table 4). In addition, Cu with Cd ($p < 0.05$), Pb with Hg ($p < 0.05$) and As ($p < 0.01$), and COD with BOD ($p < 0.01$) were significantly positively correlated and As was significantly negatively correlated with TN ($p < 0.05$). These complex relationships suggested that multiple sources may affect the distribution of heavy metals on the Xinghua Bay coast.

PMF further highlighted 3 factors that impacted the sources of target heavy metals on the Xinghua Bay coast (Fig. 4). The contribution to factor 1 was shown by Zn and Cu, which mainly originate from the discharge of industrial and agricultural wastewater; factor 2 comprised Cd, Cu and Cr, which should originate from the discharge of industrial and agricultural wastewater and fuel combustion; and factor 3 comprised Pb, Hg and As, which should also originate from the discharge of industrial and agricultural wastewater and fuel combustion (Table S4).

4. DISCUSSION

In the present study, we found that there was moderate to very heavy pollution and moderate ecological risks of heavy metals surrounding Xinghua Bay, in which Hg and Cd were the major heavy metal pollution sources, and excessive COD and BOD indicated very high levels of organic pollution at sampling sites and spoonbill habitat on the Xinghua Bay coast. Moreover, concentrations of nitrogen and phosphorus were high, which shows that the current water pollution status in Xinghua Bay is a threat to the habitat of the wintering spoonbills.

The PMF results suggest that discharged industrial and agricultural wastewater and fuel combustion were potential sources of pollution in Xinghua Bay. Coastal cultured shellfish and fertilizer use are common in Xinghua Bay, and among the 32 sampling sites along the Xinghua Bay coast, 75% had cultured shellfish. This is related to the long history of cultured shellfish from the late Ming and early Qing dynasties and has become an important industry in the local area (Wang 2000). We also found that aquaculture ponds where the wintering spoonbills were often found were connected to Xinghua Bay through ditches, which suggests that the fertilizers used in the aquaculture ponds eventually flow into Xinghua Bay. The use of fertilizers generated heavy metals and was the main reason for the excessive nitrogen and phosphorus (Wang et al. 2018).

Through a field survey, we found that there were more than 50 factories around Xinghua Bay (Table S1), including a thermal power plant that burns fuels, in addition to others such as chemical, textile printing and dyeing, fertilizer production and glass factories, which could generate heavy metals and is highly likely to be related to the excessive concentrations of Cu, Cd, Pb and Hg (Table S4). These factories can also generate organics, sulfides, petroleum pollutants etc. (Gunka et al. 2019, Wang et al. 2020). The concentrations of COD and BOD were 50 to 100 times that of the class I highest assessment standard level, which showed excessive levels of organics, most likely from factory emissions. In addition, the lack of sulfides and petroleum pollutant detection, which are also indicators for measuring environmental pollution, was a limitation of our study.

As a piscivorous bird, habitat pollution from heavy metals, organics, nitrogen and phosphorus usually poses a risk to the spoonbill health (Vijver & Peijnenburg 2011, Canova et al. 2020). For example, Hg and Cd could be accumulated in egrets through the food chain, which would increase plasma enzyme activity, causing liver inflammation and also increasing the stress on other tissues such as kidneys and brain to the detriment of survival and reproductive success (Hoffman et al. 2009, Zaman et al. 2022). Further, excessive COD, BOD, nitrogen and phosphorus indicate that the waters have been experiencing eutrophication, which would reduce oxygen in the water, resulting in a decline in zooplankton and aquatic animal populations (Josué et al. 2019, He et al. 2022) and, ultimately, leading to a reduction in food resources

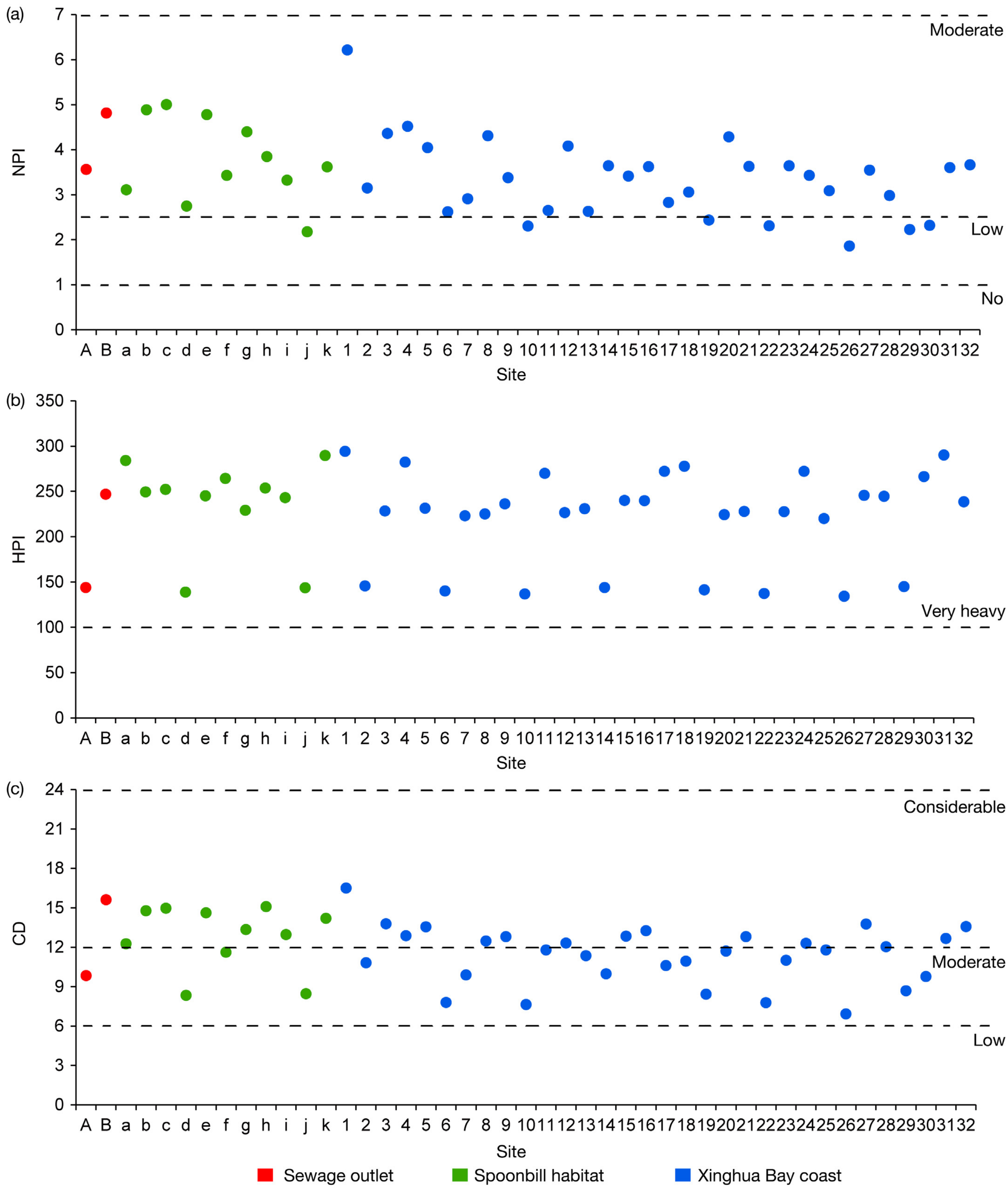

Fig. 2. Heavy metal pollution assessment with different pollution indexes. (a) NPI: Nemerow pollution index; (b) HPI: heavy metal pollution index; (c) CD: contamination degree

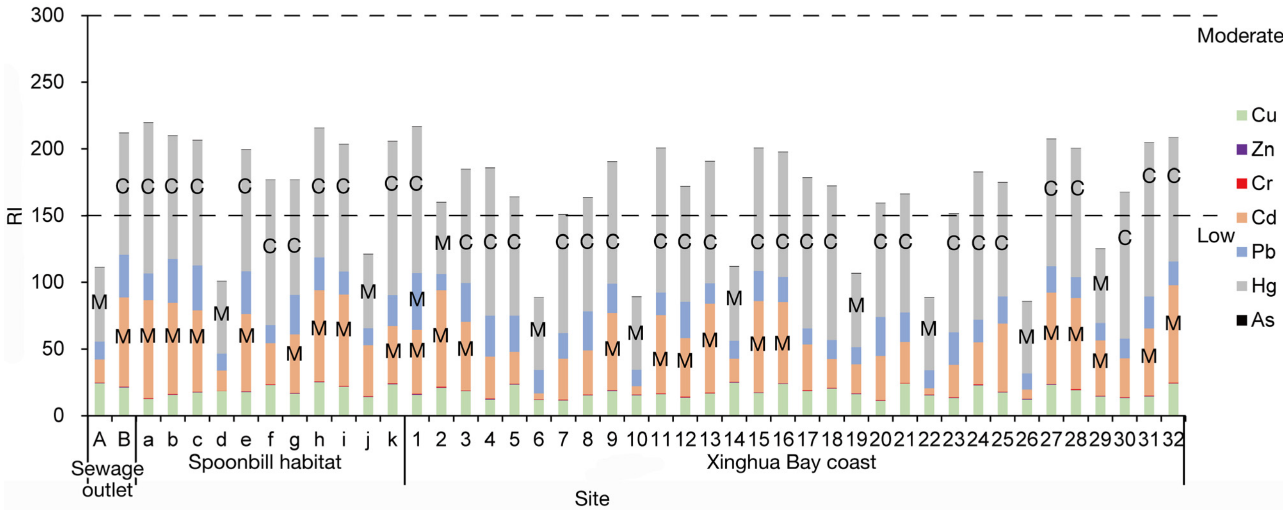

Fig. 3. Potential ecological risk assessment of heavy metals. Based on the RI (potential ecological risk index of all target heavy metals) ranking criterion, the 2 dotted lines represent low and moderate heavy metal pollution, respectively. Based on E_f^i (ecological risk index of a target heavy metal), M or C on the colored bar indicates moderate or considerable pollution of this heavy metal, respectively, and no letter indicates low pollution

Table 4. Pearson correlation coefficients between heavy metals and water quality parameters of the Xinghua Bay coast. Values in bold indicate significant differences; *p < 0.05, **p < 0.01

	Cu	Zn	Cr	Cd	Pb	Hg	As	DO	COD	BOD	DIN	PO_4^{3-}-P	TN	TP
Cu	1.000													
Zn	−0.197	1.000												
Cr	0.049	−0.335	1.000											
Cd	**0.357***	−0.309	**0.399***	1.000										
Pb	−0.176	−0.052	0.126	0.146	1.000									
Hg	0.110	−0.256	**0.662****	**0.385***	**0.401***	1.000								
As	0.057	−0.208	**0.609****	**0.363***	**0.554****	**0.934****	1.000							
DO	0.216	0.158	−0.299	−0.230	−0.024	−0.153	−0.098	1.000						
COD	−0.094	0.027	0.058	−0.015	−0.045	−0.172	−0.138	−0.263	1.000					
BOD	−0.013	0.074	0.235	0.220	0.025	0.026	−0.013	0.004	**0.479****	1.000				
DIN	−0.112	0.009	0.214	0.002	−0.200	0.162	0.168	−0.267	0.224	−0.022	1.000			
PO_4^{3-}-P	−0.087	0.046	0.140	0.131	0.249	−0.087	−0.055	−0.011	0.201	0.205	0.194	1.000		
TN	0.026	−0.062	0.021	0.038	−0.334	−0.300	**−0.397***	0.171	0.039	−0.005	0.048	0.037	1.000	
TP	0.342	−0.345	0.184	0.333	0.067	0.135	0.061	0.074	−0.070	−0.002	−0.309	0.172	0.134	1.000

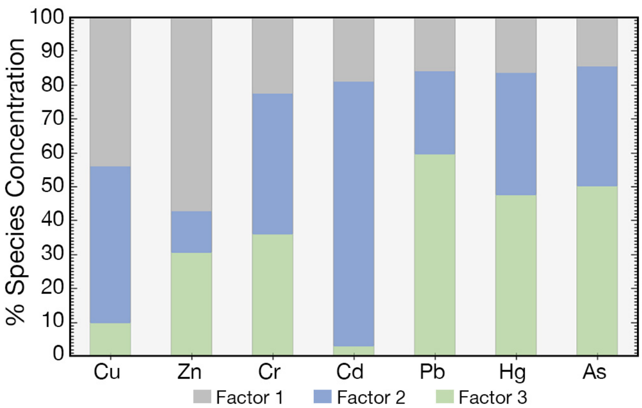

Fig. 4. Factor fingerprints of target heavy metals on the Xinghua Bay coast. The sources of the 7 heavy metals were modeled into 3 categories, i.e. Factor 1, Factor 2, Factor 3, based on the proportion of each heavy metal in each factor

available to the wintering spoonbills. In addition to aquaculture and factories, we found that mudflat reclamation and bridge and highway building have been developing in recent years, and may contribute to the population decline of the wintering spoonbills in Xinghua Bay. These engineering constructions have reduced mudflat areas and intensive human activities have disturbed the waterfowl habitat.

Based on the current status of water pollution in Xinghua Bay, we provide the following 4 recommendations. First, a new and effective scheme of aquaculture development along the coast of Xinghua Bay should be formulated to reduce the risk of heavy metal, organic, nitrogen and phosphorus pollution as soon as possible, as well as ensuring the healthy development of the aquaculture industry. Second, regular monitoring of the quality of waste water and gas generated by factories around Xinghua Bay should occur, and the pollution caused by waste-water discharge and exhaust gas deposition should be reduced to control the input of heavy metals and organics to Xinghua Bay. Third, gradual restoration of the damaged estuarine mudflat should be implemented, as well as protection of the existing coastal wetland vegetation and salt marsh beach in the intertidal zone around Xinghua Bay to reduce the impact on waterfowl, especially for the wintering spoonbills and their habitats. And fourth, communication should be strengthened between relevant local government departments, such as the forestry and grass bureau and environmental protection bureau, to monitor the ecosystem of Xinghua Bay, such as setting up water quality monitoring stations for regular monitoring of aquatic ecosystems to protect migratory bird habitats.

In summary, the local population decline of the wintering spoonbills in Xinghua Bay should attract the attention of the local wildlife management department, even though the global population has been increasing. Corresponding actions should be taken in a timely manner to solve the current water pollution problems, including the nitrogen and phosphorus pollution caused by aquaculture and the heavy metal and organic pollution generated by factory production. As an endangered bird that mainly breeds in coastal fringes of northern China and the Korean Peninsula and which migrates along the eastern coastline of China, the conservation of these sites also deserves international attention because of the loss and degradation of coastal wetlands (Ma et al. 2023); future research will be carried out to better protect this species.

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