Ocean and Coastal Management 169 (2019) 37–49

Contents lists available at ScienceDirect

Ocean and Coastal Management

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

Effects of environmental factors on benthic species in a coastal wetland by redundancy analysis

Ho Wen Chen[a,*], Hui Chen Lin[b], Yen Hsun Chuang[a], Chu Ting Sun[a], Wei Yea Chen[a], Chang Yi Kao[a]

[a] Department of Environmental Science and Engineering, Tung-Hai University, Taichung, Taiwan
[b] Department of Life Science, Tung-Hai University, Taichung, Taiwan

ARTICLE INFO

Keywords:
Multivariate analysis
Coastal wetland management
Environmental factor
Causal analysis
Benthic species
Habitat environment
Ecological management

ABSTRACT

To elucidate the effects of environmental factors on the richness and diversity of benthic species, this study investigates the hydrology, water quality and physicochemical conditions of the soil around a coastal wetland in Central Taiwan. Samples were extracted monthly from 20 sites around the coastal wetland for one year and analyzed by redundancy analysis (RDA). The outcomes of this study reveal that the environmental parameters of the habitat govern different patterns of benthic species in wetlands. The properties of soil influence the pattern of benthic species, which has been changing in the study area owing to human activities, such as land reclamation, the building of bulwarks and the emission of pollution. The results reveal that heavy pollution loading near the local area with animal husbandry also reduced the richness and diversity of benthos. Principal Component Analysis (PCA) is used to identify all relevant environmental factors to explain the impact of economic and environmental behaviors on the distribution of benthic species. The PCA results demonstrate that short-term and long-term pollution differently influence patterns of benthic species.

1. Introduction

Various energy and material interchanges occur in coastal wetlands, which are located at the interchanges among rivers, land, the atmosphere and the ocean. Rivers periodically carry abundant nutrients into coastal wetlands, establishing a highly productive ecosystem. Coastal wetlands not only support productive ecosystems, but also perform functions that support cultural, societal, and economic activities, including water purification, flood regulation, germplasm conservation, recreation, and education (Benyamine et al., 2004; Copeland, 2010; Mitsch, 2005; Pereira and Cooper, 2006). Abundant nurseries for aquatic organisms in wetlands provide foraging and breeding habitats for waterbirds (Beck et al., 2001; Granadeiro et al., 2007) and support stable and diverse ecosystems. However, urbanization and industrialization have in recent decades caused the rapid disappearance of coastal wetlands owing to the great demand for land and the undervaluing of wetlands (Bateman et al., 2011; Halpern et al., 2008). Coastal wetland losses and heavy pollution loading from inland areas have severely damaged the ecosystem of the coastal wetlands and disturbed the material and energy flows in them (Yen and Chen, 2001). The ultimate result is outright loss of wetland habitat (Coleman et al., 2008) and chain reactions that detrimentally affect wetland protection and coastal sustainability (Zedler and Kercher, 2005).

Sustainable wetland management is interdisciplinary and an enormous challenge for decision-makers. For conservation purposes, the natural and man-made factors that influence species diversity within a wetland must be urgently understood (Pechmann et al., 1989). Numerous studies have addressed habitat status, species diversity and their relationships (Aung and Koike, 2015; Goutte et al., 2015; Guisan and Zimmermann, 2000; Redhead et al., 2016; Thomas et al., 2016), and discussed the effects of environmental factors, external pressures and their dynamics on wetlands. Large-scale climatic patterns, landscape changes, and pollution loading are believed to be critical in determining the potential distributions of species in wetlands (Hamza et al., 2015; Hartmann et al., 2015; Margiotta et al., 2016; Sullivan et al., 2015). In fact, a decision-maker must identify the factors that affect the patterns of species in a wetland for the purpose of sustainable development in a wetland system, and the ways in which both habitat and human factors affect local species diversity must be elucidated.

Understanding the spatial features of a habitat, human factors, communities of species and their interactions within a wetland is particularly important in planning conservation strategies (Brambilla et al.,

* Corresponding author. Tel.: +886 4 23590121x33636; fax: +886 4 23594276.
E-mail address: hwchen@thu.edu.tw (H.W. Chen).

https://doi.org/10.1016/j.ocecoaman.2018.12.003
Received 1 March 2018; Received in revised form 30 October 2018; Accepted 6 December 2018
Available online 13 December 2018
0964-5691/

2012). However, facing a complex environmental system, decision-makers have a serious challenge in extracting useful information or/and knowledge from large bodies of monitoring data (Finlayson and Mitchell, 1999). Therefore, the use of various mathematical methods, such as multivariate analysis and geostatistics, have been proposed to characterize habitats, reveal environmental changes, and establish relationships among environmental factors (Bhattacharya et al., 2015; Carreno et al., 2008; Lopez-Flores et al., 2014; Wingard and Lorenz, 2014).

Redundancy analysis (RDA) has been successfully used in TRY many environmental studies (Lv et al., 2015; Shangguan et al., 2016; Song et al., 2016). Gabarron et al. (2018) studied the impact of tailing ponds as a source of metals and arsenic on urban soils and road dust in towns and identified the physicochemical properties that are associated with the potential mobility of metals in each type of sampled material. Song et al. (2016) focus on combining the temporal variations of heavy metals in soil and rice grain between 2006 and 2011 with socio-environmental parameters, meanwhile, providing an interpretation of the variations in heavy metal concentrations in rice paddy soils. The RDA results indicated that close relationship between economic and social development and the accumulation of Zn in paddy soils by RDA.

RDA can identify correlations among sampling sites (Afifi and Clark, 2003; McArdle and Anderson, 2001), environmental conditions and outcomes, this method is extensively used to analyze environmental and biological systems (Badgley and Fox, 2000; Legorburu et al., 2013; Yergeau et al., 2009; Zhao et al., 2010). In this study, an integrated and systematic method is utilized to investigate wetland resource management. Principal Component Analysis (PCA) is used to elucidate the regional environmental characteristics (Dong et al., 2007). With technical concerns, engineers and scientists will try to understand the relationships between the patterns of benthic species and environmental factors in detail. From the viewpoints of the public and policy makers, a comprehensive and conceptual expression may be more important for communicating with them. PCA can not only able to reduce the dimensions of data, but also identify the latent environmental factors to meet the need of the public and policy makers. Therefore, to assess wetland status and its implications for conservation and management, PCA and RDA approaches are combined to identify the direction and strength of the relationship between species richness and the intensity of human activities. The proposed combined analysis enables the effects of environmental factors on habitat features in a wetland to be quantitatively analyzed, and supports a relational analysis of factors that dominate the pattern of benthic species. Using the results of the proposed approach, decision makers can understand not only the relationships between habitat status and the pattern of benthic species, but also the effect of external environmental pressures, such as pollution loading, on the habitats and the distribution of benthic species in a wetland.

2. Material and methods

2.1. Background and data collection

The study area (Fig. 1) is located at the coastal area of Changhua County in central Taiwan. The study area of 21,152 ha consists of all wetlands and Chang bin industrial park; it includes 26 km of coastline. The long coastal strip is a typical mudflat wetland, which provides an important habitat for crabs, benthos and migratory shorebirds. The great biodiversity has attracted the attention of the tourism industry, environmental educators and ecologists. Agriculture and aquaculture have for a long time been the main industries that support the local economy. However, the habitat in the study area has been severely threatened by pollution coastal engineering, drifting sand, river hydrology and the landization of tidal flats. (Wang et al., 2012).

To assess the effects of river pollution on the habitats and the distribution of benthic species within a wetland, a total of 26 environmental parameters were measured by following the national standards such as NIEA W455.51C, NIEA W510.54B, NIEA W210.58A, NIEA W420.50B, NIEA W417.50T, NIEA W417.50T, NIEA W448.51B, NIEA W427.53B, NIEA W320.52A, NIEA W320.52A from December 2013 to December 2014 at 20 sampling sites close to the estuaries of rivers and drains, as displayed in Fig. 1. Table 1 and Table 2 present the mean and variation of measured data. As shown in Table 1, three sets of parameters concerning the physico-chemical properties of the waterbody, soil features, and the concentrations of heavy metals in soil, were evaluated. The physio-chemical properties were hydrological and water quality parameters, and revealed tidal changes in the wetlands, pollution loading and river flow from the upstream catchments. The soil feature describe the environment of the habitat of the benthic species. The heavy metal parameters are used to quantify the threats of these metals to benthic species. Table 3 presents the surveyed benthic species within the study area. Changes in physio-chemical variables can be considered as causing a short-term disturbance to benthic species. Therefore, in the data analysis herein, the means of physio-chemical variables are used as independent variables and the sum of the quantity of all observed benthic species is taken as the dependent variable.

2.2. Richness and diversity of benthic species calculation

To understand the diversity and richness of benthic species in this study area, formula of diversity was shown in (1) (Shannon and Wiener, 1963) and formula of richness was shown in (2) (Margalef, 1951)

$$D = \sum ((n_i/N)\ln(n_i/N)) \tag{1}$$

$$R = (S - 1)/\ln(N) \tag{2}$$

where,

D: diversity of benthic species
n_i: ratio of population of ith benthic species to total population of all species
N: total population across all species
R: richness of species
S: number of species

2.3. Data and correlation analysis

To achieve the planning goals, there are three multivariate statistical methods including correlation analysis (CA), principal component analysis (PCA) and redundancy analysis (RDA) are utilized in this study. Firstly, correlation analysis was performed to explore the correlations among dependent and independent variables. The values of correlation coefficient in this study are used to define the collinearity of variables. The variables will be screen out if there are highly correlative to others. In this study, the exclusion criterion is set as correlation coefficient is larger than 0.9. In order to recognize the comprehensive impact of environmental variables to benthic species, PCA is utilized to define the latent factors (Jolliffe, 2002) in order to characterize the special features of the wetland system of interest (Chen et al., 2007). Finally, RDA is used to identify relationships among individual variables in different categories, in which RDA is a widely used multivariate analytical method that consisted of iterative correspondence analysis ordination and multiple regressions (Afifi and Clark, 2003; McArdle and Anderson, 2001). Before implementing the PCA and RDA processes, analyzed data are normalized based on Euclidean distance (Legendre and Gallagher, 2001; Warton et al., 2012).

RDA yields directional indices of the shared variance between two data sets, which can be regarded as predictive of the other (Vandenwollenberg, 1977). The advantages and disadvantages of redundancy analysis relative to other related multivariate analytical techniques such as canonical correlations and multivariate multiple regression, have been discussed extensively in the literature. (Lambert

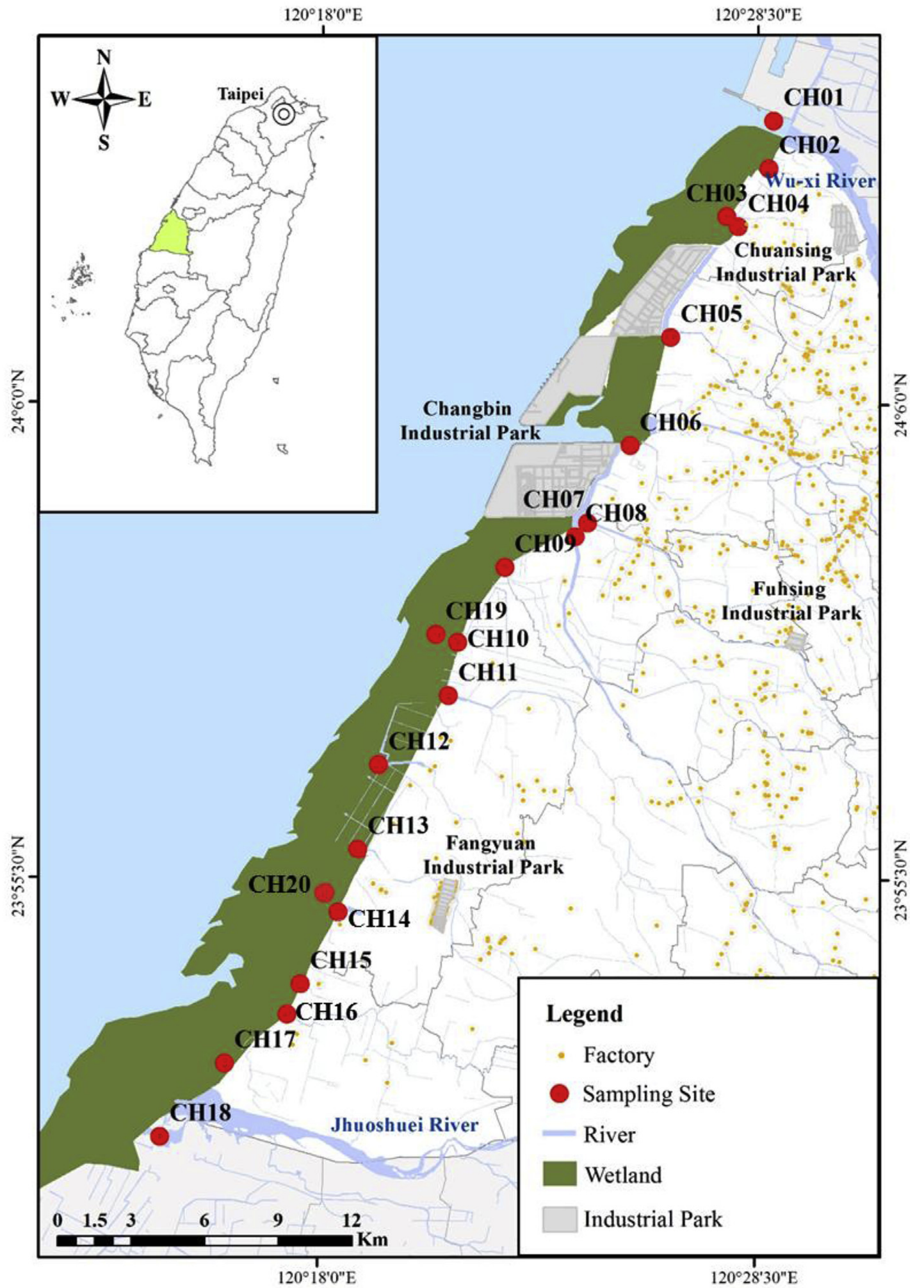

Fig. 1. The distribution of environmental monitoring sites.

et al., 1988). Since the method can identify relationships among sampling sites, environmental conditions and outcomes, it has been widely applied in relation to environmental and ecological issues (Badgley and Fox, 2000; Boucher and Debroas, 2009; Lami et al., 2009; Legorburu et al., 2013; Obolewski et al., 2010; Sole et al., 2008; Straskrabova et al., 2009; Yergeau et al., 2009; Zhao et al., 2010). To identify the key environmental factors that affect the distribution of benthic species within the study region, grouped parameters, including the physiochemical properties of the waterbody, soil features and the concentrations of heavy metals, are used as the independent variables in the RDA, whereas the quantity of benthic species are considered to the dependent variables. All RDA tests were conducted using Canoco® software for Windows 4.5, and the graphics were generated in CanoDraw for Windows 4.1® (ter Braak and Smilauer, 2002).

3. Result

3.1. Environmental characteristics of study area

Tables 1–3 present the monitoring results. A total of 26 environmental parameters were measured at each sampling site. At some sites, such as CH1, CH16, CH17 and CH20, high concentrations of suspension solid (SS) suggest severe solid erosion and pollution emission upstream. High pollution loadings are observed in estuaries around drainage outlets, especially at sites CH14 and CH15, where a number of *Mac ban* are present. Tables 1 and 2 also reveal that the oxidation-reduction potential of soil environment at sites CH7, CH13 and CH20 is lower than at other sites, favoring the motion of heavy metals and changing the pattern of pollutants in the soil. Notably, high concentrations of Zn were detected close to Changbin industrial park. Table 3 demonstrates that the diversity of benthic species at site CH14, CH15 and CH19 is less than at other sites. The species *Mac ban* dominates sites CH14 and CH15

Table 1
Environmental conditions of average in study area (2013.11–2014.11).

Parameters		Sites																			
		CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10	CH11	CH12	CH13	CH14	CH15	CH16	CH17	CH18	CH19	CH20
Phy-chemical properties of waterbody	[a]Temp.(°C)	23.63	24.09	25.12	24.35	24.60	24.0	25.50	24.94	25.97	26.62	26.06	24.83	25.95	25.36	24.58	24.13	25.11	25.89	26.69	26.44
	pH	7.70	7.60	7.81	7.83	7.50	7.63	7.74	7.73	7.60	8.20	7.61	7.80	7.42	7.59	7.60	7.71	7.80	7.79	7.62	7.82
	[b]EC (mS/cm)	35.96	2.11	5.87	2.41	16.33	31.10	20.38	16.68	22.12	44.86	32.26	42.08	17.43	6.88	6.96	22.88	45.38	26.72	48.54	48.76
	[c]DO (mg/L)	6.70	6.08	7.05	5.58	5.45	5.60	4.67	5.92	4.40	5.31	5.09	4.81	4.40	4.55	3.35	4.61	5.51	6.74	6.11	6.24
	[d]BOD (mg/L)	2.52	2.98	24.10	6.18	2.52	2.52	4.30	6.18	3.14	4.10	3.34	4.28	5.62	42.26	38.10	5.02	2.56	5.96	1.42	2.08
	[e]SS(mg/L)	748.04	60.88	157.40	153.40	75.02	195.34	97.66	201.84	95.16	79.44	177.34	119.02	113.30	190.84	116.20	740.36	587.44	242.36	55.46	551.40
	[f]KN(mg/L)	0.69	4.87	6.16	3.63	2.94	2.37	5.23	7.31	4.21	0.53	6.08	0.18	4.94	16.51	18.96	5.12	0.23	0.84	0.21	0.33
	NH_3-N (mg/L)	1.37	3.21	2.94	2.94	2.42	2.23	5.64	7.37	4.80	2.65	7.25	1.74	5.25	13.38	16.00	6.36	1.35	0.57	0.65	1.73
	NO_2-N (mg/L)	0.21	0.25	0.23	0.28	0.27	0.23	0.11	0.20	0.35	0.25	0.13	0.12	0.14	0.02	0.01	0.08	0.11	0.03	0.08	0.09
	NO_3-N (mg/L)	1.44	3.30	1.32	1.87	1.79	0.91	0.57	0.78	0.83	0.89	0.60	0.57	0.64	0.71	0.93	0.50	0.50	0.76	0.75	0.73
	[g]TP (mg/L)	0.58	1.15	1.28	1.09	0.90	0.88	0.79	0.94	0.56	0.31	1.23	0.46	1.24	1.86	2.15	0.90	0.45	0.99	0.18	0.34
	[h]TR(m)	–	0.73	–	–	0.62	–	1.60	–	–	–	1.66	1.41	1.40	–	–	1.71	–	0.44	1.49	1.46
	[i]TIT (min)	–	175.6	–	–	153.6	–	315.2	–	–	–	381.6	268.0	296.4	–	–	343.2	–	185.5	317.2	315.2
	[j]FV(m/min)	–	9.71	–	–	9.34	–	10.52	–	–	–	9.44	10.57	9.78	–	–	13.00	–	9.55	9.55	13.00
	[k]FR (m^3/min)	–	197.87	–	–	710.61	–	1157.70	–	–	–	276.83	427.23	307.49	–	–	545.54	–	785.93	729.79	545.54
Soil features	[l]pHs	7.67	7.56	7.54	7.60	7.60	7.42	7.63	7.56	7.49	7.54	7.57	7.57	7.48	7.75	7.46	7.22	7.56	7.69	7.70	7.79
	[m]Eh	120.20	96.80	31.00	131.00	75.20	49.40	−33.20	26.00	46.80	29.60	4.40	67.00	−3.80	67.80	23.60	23.60	1.20	127.60	132.40	−3.00
	[n]Sand (g/Kg)	67.82	73.92	57.13	49.90	73.16	47.35	41.28	40.54	77.52	56.30	59.97	71.12	40.02	10.90	9.07	10.66	46.44	53.34	83.30	72.01
	[o]Silt (g/Kg)	22.55	17.50	30.57	36.68	15.84	39.42	46.49	49.17	14.99	34.35	24.74	16.21	41.62	64.25	69.47	66.79	41.21	34.95	7.90	16.62
	[p]Clay (g/Kg)	9.63	8.57	12.29	13.42	11.00	13.23	12.23	10.29	7.49	9.35	15.29	12.67	18.36	24.84	21.46	22.55	12.35	11.72	8.80	11.37
Heavy metals	Cr (mg/Kg)	46.18	48.19	90.74	51.04	101.93	155.30	152.21	143.91	56.27	56.59	51.43	44.76	63.53	59.28	61.94	63.83	47.30	50.34	73.82	40.13
	Ni(mg/Kg)	64.15	87.67	108.41	84.16	103.14	114.08	99.86	122.18	104.47	106.40	97.35	90.73	106.28	105.79	114.28	99.97	94.67	99.67	84.59	96.31
	Cu(mg/Kg)	16.24	18.28	29.75	22.68	77.07	112.93	52.81	58.51	13.63	19.27	19.39	13.86	32.98	27.19	28.75	27.83	18.91	16.83	8.94	12.15
	Cd (mg/Kg)	2.92	1.93	2.41	0.68	1.55	3.56	4.23	4.22	3.88	4.76	4.77	2.99	5.19	5.71	6.33	5.90	2.69	4.82	2.66	2.26
	Zn (mg/Kg)	59.07	71.72	194.18	64.81	96.30	132.86	164.41	189.62	62.94	65.65	62.82	54.23	86.55	66.42	69.32	69.82	40.60	49.82	79.53	37.39
	Pb(mg/Kg)	43.05	40.48	47.98	39.33	51.82	61.24	342.26	58.33	51.12	40.01	37.62	35.25	47.49	52.99	58.20	55.07	53.79	45.37	36.42	43.97

Notes:
[a] Temp.: Temperature.
[b] EC: Conductivity.
[c] DO: Dissolved oxygen.
[d] BOD: Biochemical oxygen demand.
[e] SS: Suspension Solid.
[f] KN: Kjeldahl nitrogen.
[g] TP: Total phosphorus.
[h] TR: Tidal range.
[i] TIT: Tidal inundation time.
[j] FV: Velocity of flow.
[k] FR: Flow rate.
[l] pHs: soil pH.
[m] Eh: Redox potential.
[n] Sand: The percentage of sand.
[o] Silt: The percentage of silt.
[p] Clay: The percentage of clay.

Table 2
Environmental conditions of standard deviation in study area (2013.11–2014.11).

Parameters		Sites																			
		CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10	CH11	CH12	CH13	CH14	CH15	CH16	CH17	CH18	CH19	CH20
Phy-chemical properties of waterbody	[a]Temp.(°C)	5.99	6.38	9.17	8.00	6.86	6.80	5.13	6.48	4.77	5.36	6.83	6.09	5.22	5.76	5.19	5.60	6.59	6.58	6.45	5.21
	pH	0.43	0.15	0.56	0.26	0.18	0.32	0.09	0.22	0.33	0.26	0.30	0.19	0.34	0.29	0.33	0.30	0.45	0.99	0.88	0.38
	[b]EC (mS/cm)	10.72	1.39	5.53	1.45	10.18	10.71	12.63	14.60	14.66	8.72	6.56	4.09	16.13	3.72	4.40	11.49	3.40	17.53	2.30	2.32
	[c]DO (mg/L)	1.83	1.67	1.38	1.42	0.97	0.71	0.61	1.55	1.56	1.86	1.37	1.72	0.82	1.81	0.83	0.97	1.65	2.61	0.61	0.39
	[d]BOD (mg/L)	1.91	0.74	25.27	3.35	1.27	1.77	6.22	5.11	3.25	4.48	2.31	2.65	4.85	22.02	28.72	6.27	1.59	8.89	0.83	2.54
	[e]SS(mg/L)	1161.15	10.16	139.34	133.96	55.81	183.18	54.56	135.74	69.91	45.72	203.00	71.82	79.14	161.09	301.16	602.32	252.07	83.71	30.90	508.37
	[f]KN(mg/L)	0.81	1.48	1.82	2.98	2.25	2.38	3.19	4.37	3.60	3.38	2.58	1.42	3.99	8.27	7.25	2.43	1.46	0.75	0.46	2.90
	NH_3-N (mg/L)	0.86	1.48	3.88	1.16	1.17	2.32	4.16	6.28	4.97	2.66	2.13	0.03	3.01	8.32	8.23	2.76	0.08	0.98	0.26	0.16
	NO_2-N (mg/L)	0.10	0.07	0.11	0.14	0.17	0.11	0.04	0.10	0.18	0.29	0.06	0.10	0.15	0.01	0.03	0.06	0.16	0.04	0.11	0.08
	NO_3-N (mg/L)	0.96	0.99	0.86	0.99	0.83	0.40	0.31	0.51	0.35	0.43	0.48	0.43	0.51	0.62	0.89	0.42	0.24	0.79	0.44	0.24
	[g]TP (mg/L)	0.42	0.51	0.59	0.73	0.83	0.63	0.55	0.65	0.35	0.19	0.93	0.24	0.81	1.30	1.08	0.43	0.37	1.54	0.18	0.35
	[h]TR(m)	–	0.42	–	–	0.37	–	0.44	–	–	–	0.53	0.21	0.21	–	–	0.23	–	0.32	0.36	0.15
	[i]TIT (min)	–	54.64	–	–	55.61	–	37.52	–	–	–	35.84	37.24	29.65	–	–	43.02	–	119.18	64.37	23.48
	[j]FV(m/min)	–	5.27	–	–	3.70	–	5.59	–	–	–	5.85	5.46	5.37	–	–	4.37	–	4.36	3.44	5.37
	[k]FR (m^3/min)	–	247.48	–	–	344.60	–	1188.18	–	–	–	296.49	324.05	507.03	–	–	572.79	–	521.87	193.17	507.03
Soil features	[l]pHs	0.35	0.36	0.65	0.34	0.52	0.30	0.27	0.37	0.32	0.67	0.26	0.42	0.37	0.19	0.45	0.63	0.25	0.66	0.39	0.51
	[m]Eh	66.41	52.72	76.34	98.73	48.19	89.42	133.77	141.91	99.65	89.75	93.77	116.66	106.55	62.07	62.00	54.41	89.12	50.75	49.92	100.98
	[n]Sand (g/Kg)	11.40	21.36	20.94	27.36	8.62	26.73	22.88	26.34	6.95	12.35	8.23	7.55	25.82	5.56	3.15	2.88	22.21	24.76	21.90	14.78
	[o]Silt (g/Kg)	2.69	5.71	4.07	5.34	4.16	6.80	6.46	4.67	2.98	5.03	7.28	5.34	7.53	3.46	7.97	6.89	3.23	5.85	5.93	4.09
Heavy metals	[p]Clay (g/Kg)	11.11	18.57	19.86	26.75	5.29	23.36	20.15	28.15	7.37	11.89	15.08	4.01	21.31	8.72	10.49	7.49	19.98	20.27	18.67	11.30
	Cr (mg/Kg)	13.42	19.97	4.10	16.79	23.52	42.47	72.90	70.02	2.23	3.11	3.23	7.22	5.81	5.17	6.50	12.41	9.56	1.26	64.08	9.09
	Ni(mg/Kg)	23.52	31.63	17.74	36.68	3.07	4.64	24.18	8.68	8.57	0.30	0.21	2.96	16.52	0.98	16.87	18.49	5.94	2.70	0.70	13.43
	Cu(mg/Kg)	5.37	15.80	1.53	14.27	31.46	40.90	21.85	33.89	1.61	0.53	0.14	3.82	0.86	1.19	0.56	2.04	9.97	0.30	3.84	6.40
	Cd (mg/Kg)	2.18	1.24	1.23	0.97	0.13	1.69	2.69	2.60	1.71	0.34	0.45	2.53	0.30	0.60	0.52	0.47	3.81	0.34	3.77	3.20
	Zn (mg/Kg)	83.00	100.87	71.42	91.09	123.52	187.33	231.94	267.59	88.67	92.85	88.84	76.69	122.40	93.93	98.03	98.74	57.42	70.45	112.48	52.88
	Pb(mg/Kg)	7.99	12.27	0.77	1.70	1.31	16.23	404.81	15.66	14.48	0.16	0.08	4.35	6.45	5.36	8.24	2.42	8.87	5.91	0.79	5.72

Notes:
[a] Temp.: Temperature.
[b] EC: Conductivity.
[c] DO: Dissolved oxygen.
[d] BOD: Biochemical oxygen demand.
[e] SS: Suspension Solid.
[f] KN: Kjeldahl nitrogen.
[g] TP: Total phosphorus.
[h] TR: Tidal range.
[i] TIT: Tidal inundation time.
[j] FV: Velocity of flow.
[k] FR: Flow rate.
[l] pHs: soil pH.
[m] Eh: Redox potential.
[n] Sand: The percentage of sand.
[o] Silt: The percentage of silt.
[p] Clay: The percentage of clay.

Table 3
Sum of benthos species (2013.11–2014.11).

Parameters (unit)		Sites																			
		CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8	CH9	CH10	CH11	CH12	CH13	CH14	CH15	CH16	CH17	CH18	CH19	CH20
Benthos	*Laternula anatine*(N)	89	14	0	90	0	36	232	159	55	114	74	0	4	0	0	1	113	19	0	1
	Uca borealis(N)	1	12	5	5	0	0	0	0	5	5	4	5	0	0	0	0	0	0	0	5
	Uca formosensis(N)	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	4	14	0	0
	Helice formosensis(N)	1	3	11	1	4	0	0	1	1	0	1	1	0	0	0	0	3	19	0	0
	Sanguinolaria diphos (N)	3	0	20	2	0	1	85	92	0	0	13	1	0	0	0	0	1	0	0	1
	Nereis(N)	27	1	3	3	6	3	15	3	3	2	0	0	0	2	0	8	1	2	0	1
	Metaplax elegans(N)	59	0	0	3	0	4	0	19	0	0	3	0	2	0	0	25	0	4	0	0
	Exopalaemon orientis (N)	36	43	10	38	9	10	1	13	4	17	62	3	2	136	38	22	615	696	0	0
	Scopimera longidactyla (N)	0	0	0	0	184	0	0	0	0	5	0	22	0	0	0	0	0	0	7	0
	Ilyoplax tansuiensis(N)	1	0	1	0	0	0	102	47	0	0	2	0	0	0	1	0	30	0	0	0
	Uca lacteal(N)	291	123	28	127	130	0	43	66	47	103	263	102	228	3	0	0	160	17	0	22
	Mictyris brevidactylus (N)	0	0	25	0	0	0	0	0	66	1	1	35	0	0	0	0	0	0	17	0
	Mac ban(N)	74	83	79	162	116	453	38	68	25	146	75	95	25	319	546	577	41	130	0	549
	Amphio(N)	0	15	0	1	1	2	447	67	3	0	0	0	0	0	0	0	0	0	0	0
	Uca arc(N)	20	27	234	105	24	13	69	40	1	3	6	10	10	0	0	0	30	90	0	1
	Rae pul(N)	0	0	0	2	0	3	3	13	0	8	8	0	0	0	0	10	1	0	0	0
	Aus edu(N)	0	0	0	0	0	0	0	0	0	0	1	7	0	0	0	0	1	0	0	3
	Sco bit(N)	0	30	0	0	1	0	0	0	25	0	4	0	0	0	0	0	0	0	320	0

Table 4
Correlation coefficient of environmental parameters.

	Temp	pHw	EC	DO	BOD	SS	**NH_3-N**	KN	**NO_2-N**	**NO_3-N**	TP	pHs	Eh	Sand	Clay	Silt	TR	TIT	FV	FR
[a]Temp	1																			
pHw	.112	1																		
[b]EC	.211	-.030	1																	
[c]DO	.088	.408**	-.010	1																
[d]BOD	-.047	.233	-.253	.003	1															
[e]SS	-.125	.112	.132	.046	-.048	1														
NH_3-N	.004	.005	-.313*	-.364**	.225	.261	1													
[f]KN	-.143	-.160	-.574**	-.363**	.301*	-.071	.669**	1												
NO_2-N	-.195	-.069	-.395**	-.030	.048	-.202	.134	.257	1											
NO_3-N	-.335*	-.390**	-.313*	.023	-.104	-.202	-.084	.127	.315*	1										
[g]TP	-.220	.341*	-.420**	.201	.489**	.171	.473**	.425**	.182	-.075	1									
[l]pHs	.111	.329*	.159	.394**	-.023	.012	-.108	-.291*	.055	-.287*	.218	1								
[m]Eh	-.047	-.016	-.047	.146	.059	-.005	-.235	-.080	-.024	.101	.043	.138	1							
[n]Sand	.189	-.016	.258	.307*	-.291*	-.384**	-.362**	-.388**	.103	.168	-.244	.216	.308*	1						
[p]Clay	-.011	-.011	.004	-.262	.188	.246	.310*	.208	.039	-.148	.115	-.071	-.155	-.615**	1					
[o]Silt	-.197	.065	-.308*	-.290*	.272	.335*	.335*	.387**	-.100	-.157	.227	-.256	-.326*	-.969**	.480**	1				
[h]TR	.281*	.004	.345*	-.330*	-.114	.190	.177	-.079	-.310*	-.421**	-.299*	-.054	-.279*	-.162	.155	.123	1			
[i]TIT	.382**	.004	.374**	-.268	-.179	.134	.096	-.147	-.364**	-.371**	-.359*	-.056	-.126	-.166	.234	.124	.881**	1		
[j]FV	-.054	-.035	-.026	.038	.071	.141	.021	-.065	-.037	.020	.110	.085	-.341*	-.091	.006	.048	.249	.074	1	
[k]FR	-.109	-.055	-.258	.028	.144	-.012	.053	.163	.040	.052	.107	-.085	-.155	-.195	-.052	.253	-.180	-.211	.015	1

Notes: *: significant level = 0.05 (Two-tailed), **: significant level = 0.01 (Two-tailed).

[a] Temp.: Temperature.
[b] EC: Conductivity.
[c] DO: Dissolved oxygen.
[d] BOD: Biochemical oxygen demand.
[e] SS: Suspension Solid.
[f] KN: Kjeldahl nitrogen.
[g] TP: Total phosphorus.
[h] TR: Tidal range.
[i] TIT: Tidal inundation time.
[j] FV: Velocity of flow.
[k] FR: Flow rate.
[l] pHs: soil pH.
[m] Eh: Redox potential.
[n] Sand: The percentage of sand.
[o] Silt: The percentage of silt.
[p] Clay: The percentage of clay.

Table 5
The result of species factors screening by PCA.

Parameter	The impact of short-term pollution (F_1)	The impact of long-term pollution (F_2)	Chemical environment of water (F_3)	Physical property of sediment (F_4)	Chemical property of sediment (F_5)	The river's flow (F_6)
[f]KN	**.846**	-.093	-.265	.054	-.037	-.103
NH_3-N	**.776**	.158	-.074	.269	.123	.110
[b]EC	**-.636**	.420	.016	.114	-.030	.216
[g]TP	**.612**	-.280	.537	.230	.022	-.067
[d]BOD	**.490**	.002	.296	.116	-.121	-.378
[i]TIT	-.123	**.817**	-.201	.173	.119	.190
[h]TR	-.056	**.784**	-.181	.178	.331	.187
NO_3-N	-.005	**-.675**	-.412	-.205	.051	.087
[a]Temp.	-.007	**.670**	.144	-.379	-.072	-.007
NO_2-N	.435	**-.451**	-.033	-.281	.119	.305
pH	.078	.187	**.756**	.058	-.052	-.107
[l]pHs	-.097	.028	**.702**	-.085	.062	.297
[c]DO	-.317	-.261	**.692**	-.161	-.001	-.093
[e]SS	-.117	.001	.153	**.795**	.094	.094
[n]Sand	-.366	-.105	.153	**-.707**	-.128	.332
[o]Clay	.298	.184	-.124	**.611**	-.025	.051
[j]FV	-.040	-.042	.119	.091	**.833**	.046
[m]Eh	-.118	-.206	.132	-.031	**-.734**	.217
[k]FR	0.73	-.165	-.051	-.041	.148	**-.785**
Variance of Explained (%)	15.362	15.258	12.405	10.707	7.708	6.750
Cumulative explained variance	15.362	30.619	43.024	53.731	61.439	68.189

Notes:
[a] Temp.: Temperature.
[b] EC: Conductivity.
[c] DO: Dissolved oxygen.
[d] BOD: Biochemical oxygen demand.
[e] SS: Suspension Solid.
[f] KN: Kjeldahl nitrogen.
[g] TP: Total phosphorus.
[h] TR: Tidal range.
[i] TIT: Tidal inundation time.
[j] FV: Velocity of flow.
[k] FR: Flow rate.
[l] pHs: soil pH.
[m] Eh: Redox potential.
[n] Sand: The percentage of sand.
[o] Clay: The percentage of clay.

where high concentrations of Kjeldahl nitrogen were measured, whereas *Sco bit* dominates site CH19 in which is a high proportion of sandy soil with high conductivity, as shown in Table 1.

Table 4 shows the level of significance for each correlation coefficient. When significance is not strong (< 0.01), the variables are assumed not to be correlated so the correlation coefficient is considered to be zero. The variable screened out from CA must have high correlation coefficient and strong significance. To understand the correlation among variables, Table 4 demonstrate that the sand has high collinearity with silt. Since the silt is also high correlative with clay, silt is removed from CA and sand is retained. Thus, the sand is used herein as representative. Because of insufficient budget, some environmental variables were not measured (shown in Table 1). To elucidate the impact of all environmental variables to the patterns of benthic species, data for CH2, CH5, CH7, CH11, CH12, CH13, CH16, CH18, CH19 and CH20 are used in a database using which the PCA procedure is carried out. To identify the latent environmental features in the study area, Table 5 presents six environmental factors that were identified by PCA, which together explain 68.19% of the total variance in the data set. The first factor (F_1), comprising the concentrations of Kjeldahl nitrogen (KN), NH_3-N, conductivity, the concentration of total phosphorus (TP) and biochemical oxygen demand (BOD), explains 15.63% of the total variance. Factor 1 depends strongly on the concentrations of reduced organic compounds such as KN and NH_3-N and is believed to be correlated significantly with short-term human activities like farming and discharging pollutants. The second factor (F_2) comprises tidal inundation time, temperature, tidal range, and the concentrations of NO_2-N and NO_3-N, and it explains about 15.26% of the total variance. The environmental variables that are related to factor F_2 capture the hydraulic conditions of wetlands and long-term pollution. With regard to the nitrogen cycle, organic nitrogen is converted to NH_3N via remineralization and NH_3N is converted to NO_2-N and NO_3-N by nitrification under aerobic conditions (Brandes et al., 2007). For this reason, F_1 and F_2 as called "short-term pollution" and "long-term pollution", respectively, on account of the pollutant components of factor 1 and factor 2 in Table 4 and the required reaction time of nitrogen compounds. Factor F_3 comprises the concentration of dissolved oxygen (DO), soil pH (pHs) and pH of the water in the wetlands, which dominate the chemical environment therein. DO is an important and widely used index of water quality. It can be used not only to study the emission loading of a pollution source, but also to determine the water quality of a water body. Based on the PCA results in this study, DO is used to represent the water quality of the water body in the wetland system.

Table 5 also indicates that the concentration of SS in the waterbody and the sand and clay contents in the mudflats are important environmental factors combined as factor F_4 because they influence the characteristics of the habitat and the patterns of benthic organisms. Minor parameters, such as the rate and velocity of river flow close to local estuaries and the redox potential of the waterbody, are grouped as factors F_5 and F_6, which explain 7.71% and 6.75% of the total variance, respectively. Fig. 2 shows the difference among 10 sites for latent

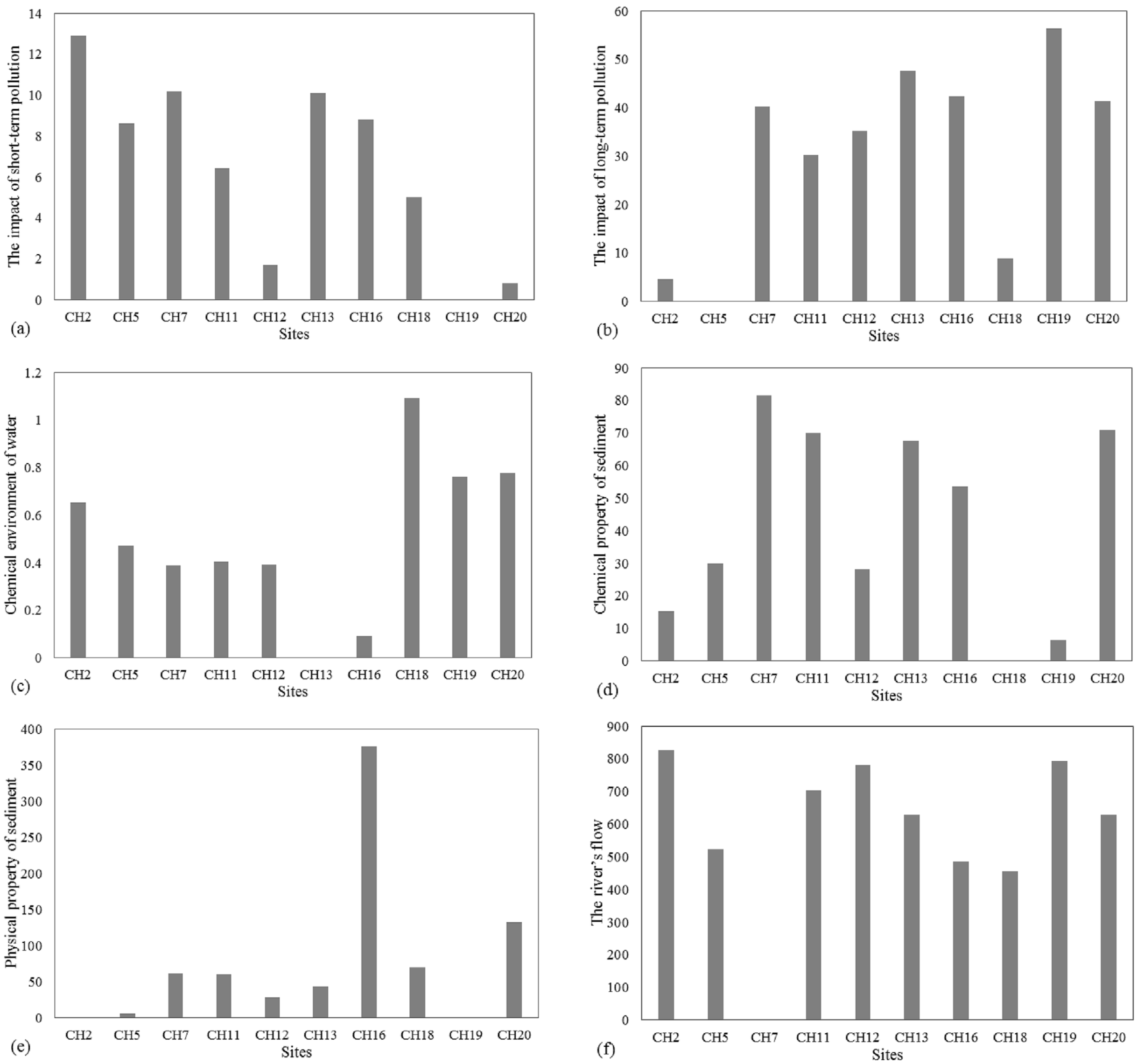

Fig. 2. Comparison of sites in each component by PCA

Fig. 2. Comparison of sites in each component by PCA.

environmental variable. CH2 has the highest short-term pollution, as shown in Fig. 2 (a). Comparing Fig. 2 (a) and 2 (b) indicates that CH19 has the least short-term pollution, but the highest long-term pollution. CH18, CH19 and CH20 have a high chemical environment of water in Fig. 2 (c); however, CH18 and CH19 have the lowest (Fig. 2 (d)). Fig. 2 (e) indicates that CH16 has high physical property of sediment. Fig. 2 (f) indicates that CH7 is more static than other sites. According to Fig. 2, chemical pollution of the environment, river's flow and the impact of long-term pollution are all highest in CH20, where the environmental impact is serious and enormously chemical reaction.

3.2. Effects of latent environmental characteristics on benthic species

RDA is performed to elucidate the effects of the above six environmental factors ($F_1 \sim F_6$) on the patterns of benthic organisms in the study areas. Species composition and biodiversity indicators, including richness and diversity, are used as the response variables in RDA and the individual and comprehensive effects of environmental factors on these response variables respectively. RDA biplot diagrams explain the relationships between latent environmental parameters and the patterns of the benthic organisms. In the diagrams, the monitoring sites are grouped into homogeneous categories with similar environmental characteristics, and arrows indicate the correlations among parameters: a longer arrow indicates that the corresponding parameter is more important; a small angle between two arrows indicates that the correlation between the two corresponding parameters is strong.

In Fig. 3, three groups of monitoring sites are identified. Group 1 is driven by hydraulic conditions and sediment composition (factors F_1, F_2, and F_5) and is rich in the species *Uca arc, Laternula anatine, Amphio, Ilyoplax tansuiensis, Uca lacteal* and *Sanguinolaria diphos*. Group 2, consisting of sites 2, 12 and 19, is driven by factor F_6 and is rich in *Mictyris brevidactylus, Sco bit, Aus edu* and *Uca borealis* as the main benthic species, indicating that a high flow velocity, a low flow rate and a low redox potential favor these benthic species. *Exopalaemon orientis, Mac ban, Metaplax elegans, Helice formosensis* and *Uca formosensis* are the dominant species in Group 3, where the habitat conditions are driven by two latent environmental features, which are the chemical environment of the waterbody (factor F_3) and the physical properties of the sediment (factor F_4). *Laternula anatine* and *Uca borealis* are dominated by factors F_1 and F_6, respectively. Factors F_2 and F_6 similarly

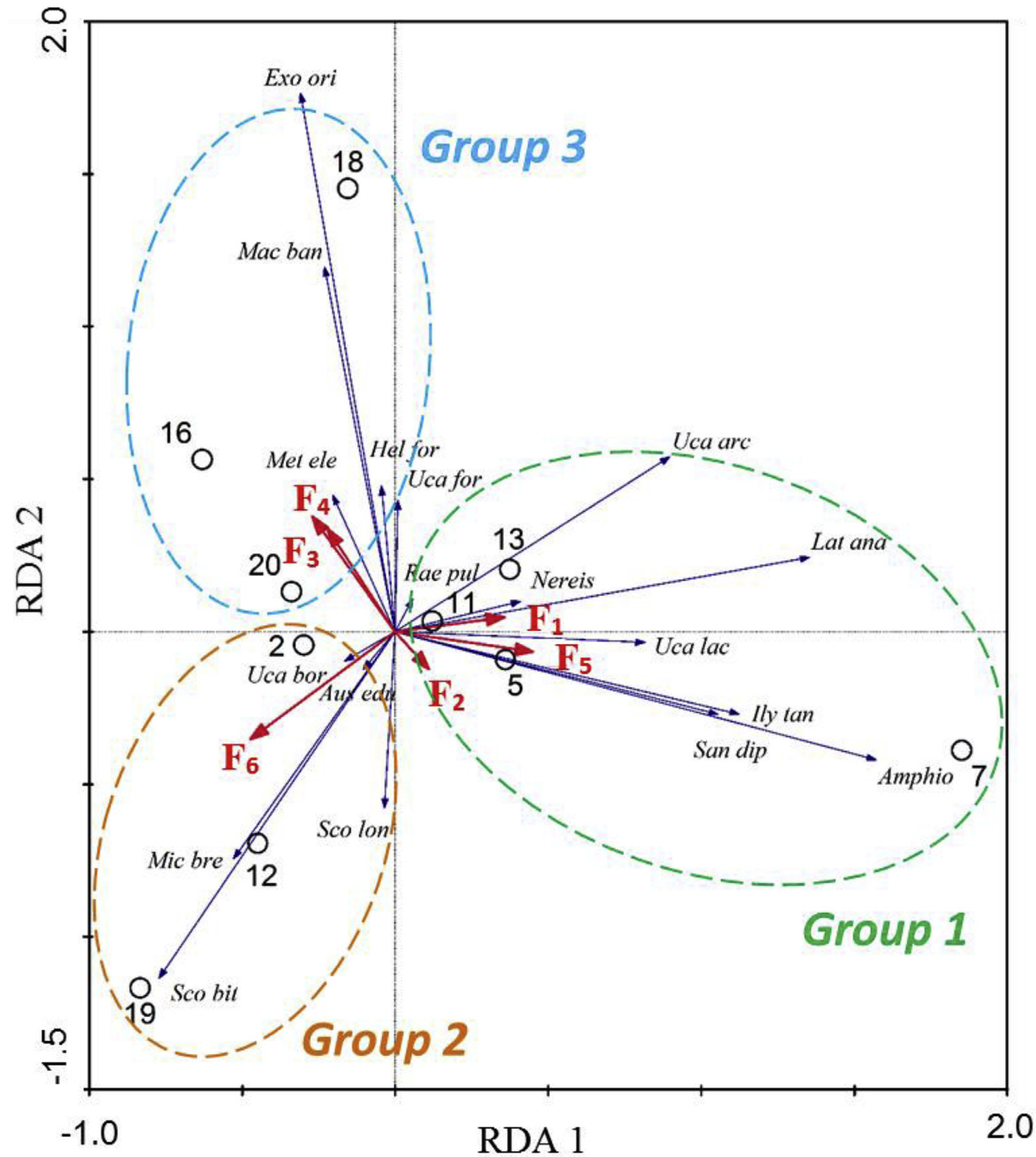

Fig. 3. The relationships between latent environmental features and benthic species.

influence *Scopimera longidactyla*.

3.3. Effects of environmental parameters on benthic species

To quantify the effects of parameters on the patterns of benthic species in the study area, advanced RDA is conducted. Fig. 4 plots the results of advanced RDA, which identifies four groups of sites. Sites 13, 14, 15 and 16 form Group 1, in which high concentrations of BOD, NH_3-N, and TP as well as a high percentage of clay are detected. The benthic species in this study favor such an environment. These four sites suffer from high pollution loading from Fangyuan Industrial Park (Urban and Rural Development Branch, 2014). At these four sites, some benthic species are significantly scarcer than others. Although site 13 has a high pollution loading like sites 14, 15 and 16, the high percentage of sand makes its benthic environment different. Group 2, with a high percentage of sand and a low percentage of silt, comprises sites 2, 3, 5, 9, 10, 11, 12, 19 and 20. The property of the benthic environment in Group 2 is negatively correlated with concentrations of organic pollutants such as BOD, NH_3-N, TP and SS, indicating that *Sco bit*, *Scopimera longidactyla*, *Mictyris brevidactylus* and *Uca borealis* prefer a cleaner benthic environment with a higher percentage of sand (Cooper et al., 2009). Soil characteristics are important in Groups 1, 2 and 4. Unlike those at sites in Group 1, benthic species such as *Metaplax elegans*, *Exopalaemon orientis*, *Uca formosensis* and *Mac ban* at the sites in Group 2 can tolerate light pollution loading. In contrast, chemical properties of the waterbody, rather than soil characteristics, dominate the habitat environment of the sites in Group 3. The abundance of most benthic species in Group 3 is positively correlated with the concentration of DO and pH, and negatively correlated with the concentrations of oxygen-consuming substances, such as BOD, NH_3-N, TP and KN. The environmental conditions around sites 4, 7 and 8 favor benthic species *Lat ana, Uca are, Uca lac, Amphio, San dip, Ily tan, Neres, Rae pul, Hel for*.

4. Discussion

Table 4 and Fig. 2 provide critical insights that can help managers screen out redundant variables and identify the relative importance of others. Effective data pre-processing can improve decision quality. Fig. 5 plots the relationships among the concentrations of heavy metals and the abundance of benthic species. It indicates that the soils around

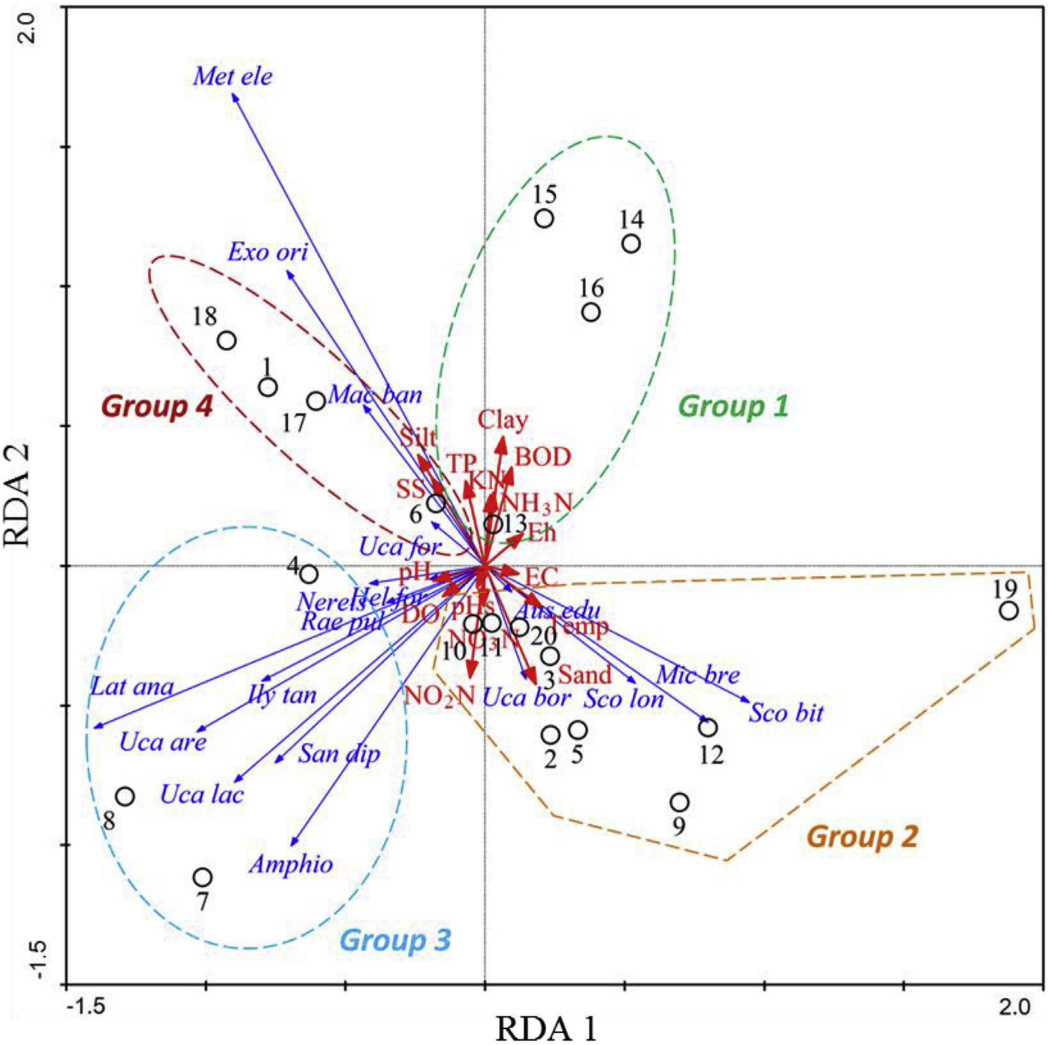

Fig. 4. The relationships between environmental parameters and benthic species.

sites 6, 7, 8 and 19 are rich in various heavy metals, because these sites are at the outlets of drains in industrial parks or areas that are dense with factories. The richness and diversity of benthic species are negatively correlated with the concentrations of heavy metals. However, some benthic species, such as *Laternula anatine*, *Sanguinolaria diphos*, *Nereis*, *Amphio*, *Ilyoplax tansuiensis* and *Rae pul*, can be found in environments with high concentrations of Pb, Zn, Cr and Cu. Notably, the concentration of Ni has a strong negative correlation with the abundance of most benthic species. Equations (1) and (2) below are used to evaluate the richness and diversity of benthic species at various sampling sites. Fig. 6 indicates that site 3 has a greater biological richness than other sites, and that the percentage of sand and the concentration of DO critically influence richness. Biological diversity at sites 2 and 7 exceeds that at other sites, and soil pH (pHs) and NO_3-N concentration are critical environmental parameters. Generally, the percentages of clay and silt in soil as well as organic pollution are negatively correlated with biological diversity and richness. The soil environment, including the percentage of sand and pH, influence biological diversity and richness.

This investigation classifies benthic species into Polychaete (Polych), Crustaceans (Crusta) and Shellfish and uses RDA to explain the effects of latent environmental characteristics on these three species. Fig. 7 indicates that the physical properties of sediment (F_4) are the most important factor in determining the abundance of Polych and Crusta. Short-term pollution and the chemical properties of the waterbody and the sediment dominate the growth of shellfish. Factors F_2 and F_6 are negatively correlated with the growth of benthos. The combination of RDA and PCA can provide enough information to enable decision-makers to identify the latent environmental features that dominate for a particular benthic species, enabling them to plan an efficient strategy for conserving targeted benthic species.

Taiwan is an island country with a high population density. More and more human activities, such as reclamation, industrialization, animal husbandry and coastal engineering, have been flushing to the coastal area and rapidly changing the coastal environment. Different species in the same habitat face different stresses in a changing environment (Chiang and Chang, 2018). In the last few decades, heavy metals emitted from industrial parks nearby the coastal area has been spread into marine environment and endanger the benthic species in the coastal wetland (Lin et al., 2013) and heavy environmental loading has caused habitat destruction and species extinction (Ju et al., 2017). Based on the results in Table 5, the environmental factors are divided into six categories. These six categories are associated with six driving forces of change of the state of a wetland environment. Factor F1 is associated with transient or temporary impacts of industry and animal husbandry. The habitat in the area near the drain of a polluted river, such as at sites 13 and site 11, is dominated by short-term pollution.

Decision-makers who seek to protect the habitat in these areas should prioritize the reduction of pollution. Sediment and river flow from upstream may also change the habitat of a wetland system,

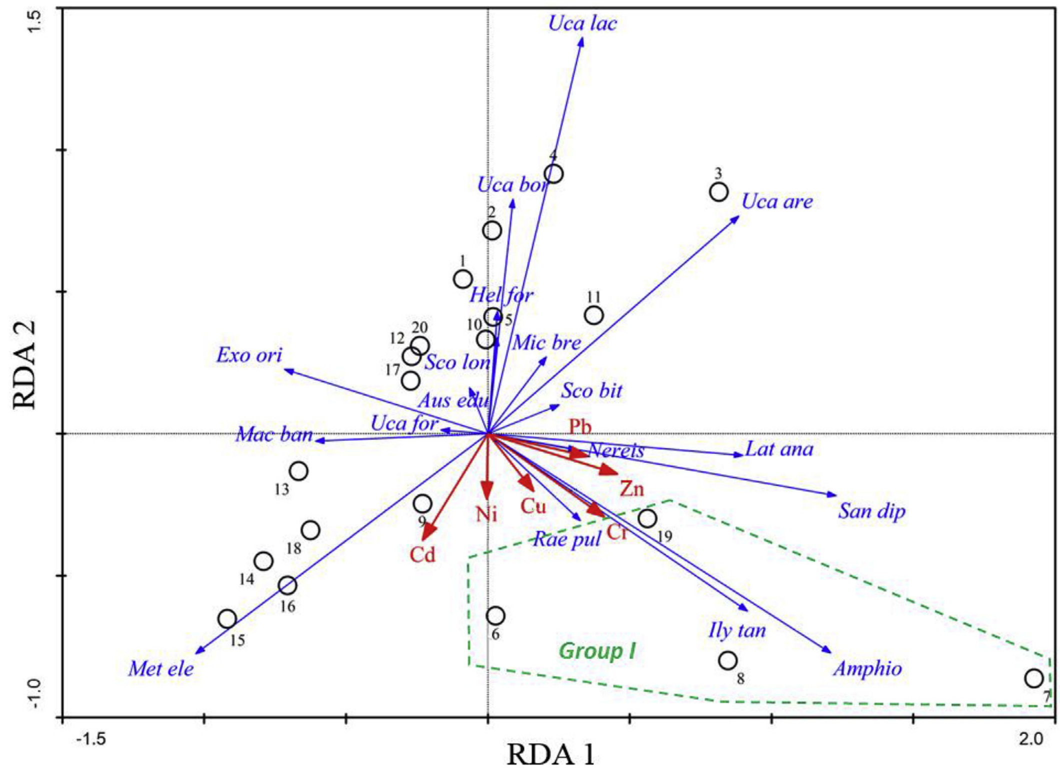

Fig. 5. The relationships between heavy metals and benthic species.

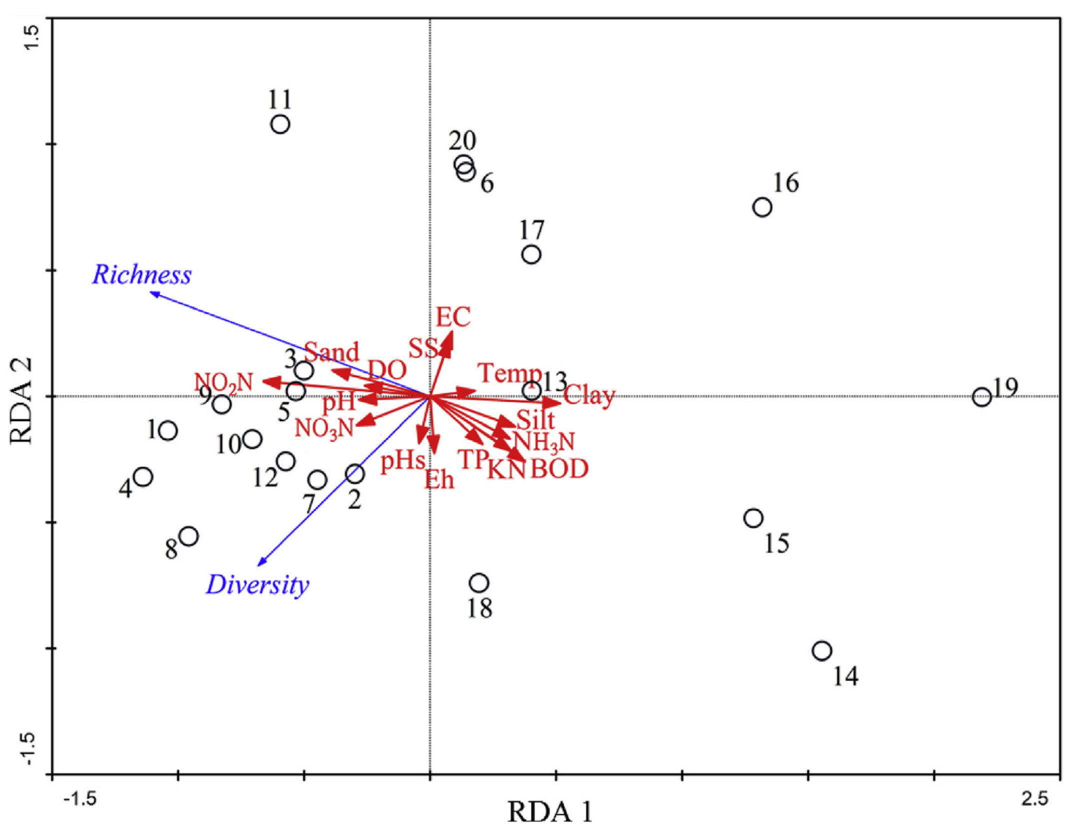

Fig. 6. The effects of environmental parameters on the richness and diversity of benthos.

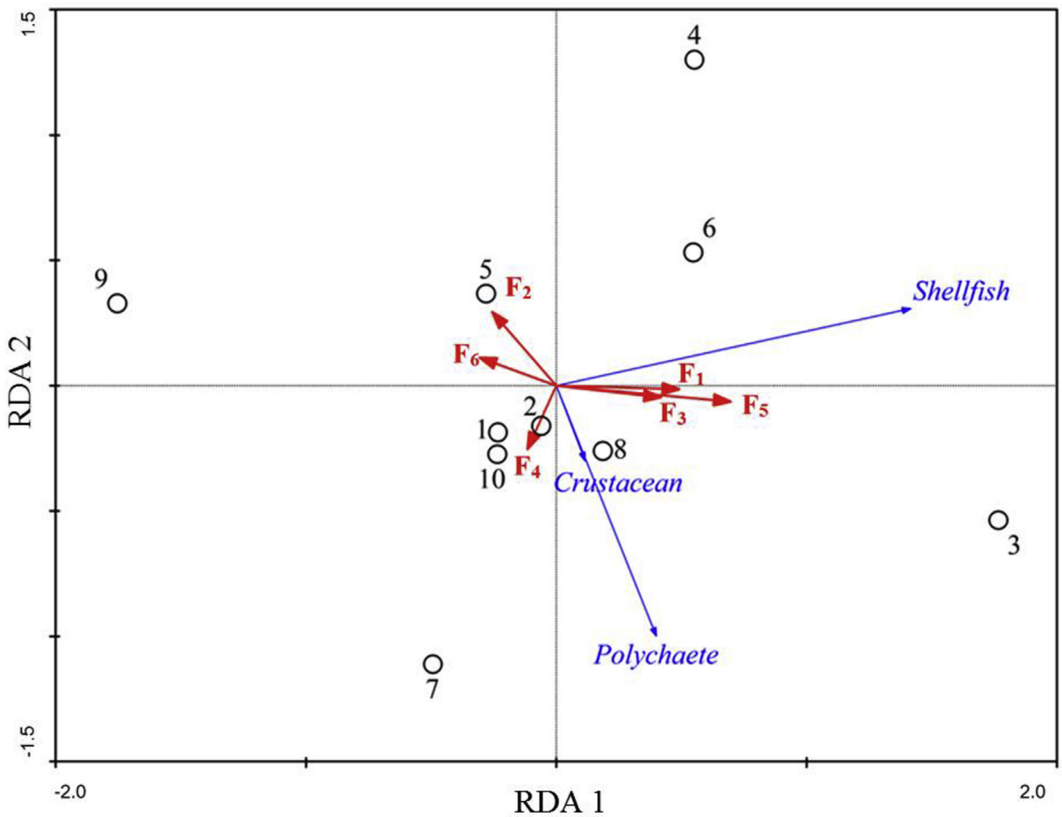

Fig. 7. The effects of latent environmental features on Polychaete, Crustaceans and Shellfish.

especially in areas (sites 12 and 19) with large tidal changes. According to the results in Table 2, the tidal range at site 20 is smaller than at site 12 or site 19. Although the site 20 has a positive relationship with tidal range, the chemical environment of the water plays a more important role than tidal range. Therefore, site 20 is categorized into group 3. Water blocking facilities, such as reservoirs and dams in the upstream reaches, can influence patterns of benthic species downstream. Therefore, decision-makers should consider the impact of river flow on benthic species when designing the ecological basis flow for rivers. Coastal engineering will change the ocean current and sediment along the coast. The results in this investigation that the substrate environment in a coastal wetland has an important role in determining the patterns of benthic species.

In the past decade, the balance among environmental protection, public use and socio-economic development has been upset in the case study area. To the extent reasonably possible, coastal engineering should avoid damaging the substrate environment (Chiau, 1998). Finally, pollution has long-term effects on the patterns of benthic species, and decision-makers consider them when developing a regional water quality protection plan.

5. Conclusions

Extracting information from monitoring data can help decision-makers determine the relationships between environmental characteristics and patterns of benthic species by RDA. The outcomes of this investigation indicate that the effects of environmental parameters on the habitat environment of wetlands are significant. The properties of soil importantly affect the pattern of benthic species, which have been changing in the study area owing to human activities, such as land reclamation, the construction of bulwarks and the emission of pollution. Analytical results indicate that the soil close to the Changbin industrial park, such as at sites 19 and 6, is rich in heavy metals, reducing the richness and diversity of benthic species. Heavy pollution loading at sites 13, 14, 15 and 16 has also reduced the richness and diversity of benthos there. Therefore, human activity changes the pattern of benthic species. Various methods such as the elimination of heavy metals and organic pollutants before emission may be worth developing to protect benthos in wetlands.

Acknowledgements

The authors would like to thank the Urban and Rural Development Branch, Construction and Planning Agency, Ministry of the Interior, Taiwan, for financially supporting this research under Contract No. UR-10228.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ocecoaman.2018.12.003.

References

Afifi, A.A., Clark, V., 2003. Computer-aided Multivariate Analysis, fourth ed. Chapman & Hall.

Aung, T., Koike, F., 2015. Identification of invasion status using a habitat invasibility assessment model: the case of Prosopis species in the dry zone of Myanmar. J. Arid Environ. 120, 87–94.

Badgley, C., Fox, D.L., 2000. Ecological biogeography of North American mammals: species density and ecological structure in relation to environmental gradients. J. Biogeogr. 27, 1437–1467.

Bateman, I.J., Mace, G.M., Fezzi, C., Atkinson, G., Turner, K., 2011. Economic analysis for ecosystem service assessments. Environ. Resour. Econ. 48, 177–218.

Beck, M.W., Heck, K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M., Halpern, B., Hays, C.G., Hoshino, K., Minello, T.J., Orth, R.J., Sheridan, P.F., Weinstein, M.R., 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51, 633–641.

Benyamine, M., Backstrom, M., Sanden, P., 2004. Multi-objective environmental management in constructed wetlands. Environ. Monit. Assess. 90, 171–185.

Bhattacharya, B.D., Nayak, D.C., Sarkar, S.K., Biswas, S.N., Rakshit, D., Ahmed, M.K., 2015. Distribution of dissolved trace metals in coastal regions of Indian Sundarban mangrove wetland: a multivariate approach. J. Clean. Prod. 96, 233–243.
Boucher, D., Debroas, D., 2009. Impact of environmental factors on couplings between bacterial community composition and ectoenzymatic activities in a lacustrine ecosystem. FEMS Microbiol. Ecol. 70, 66–78.
Brambilla, M., Rizzolli, F., Pedrini, P., 2012. The effects of habitat and spatial features of wetland fragments on the abundance of two rallid species with different degrees of habitat specialization. Hous. Theor. Soc. 59, 279–285.
Brandes, J.A., Devol, A.H., Deutsch, C., 2007. New developments in the marine nitrogen cycle. Chem. Rev. 107, 577–589.
Carreno, M.F., Esteve, M.A., Martinez, J., Palazon, J.A., Pardo, M.T., 2008. Habitat changes in coastal wetlands associated to hydrological changes in the watershed. Estuar. Coast. Shelf Sci. 77, 475–483.
Chen, K.P., Jiao, J.J., Huang, J.M., Huang, R.Q., 2007. Multivariate statistical evaluation of trace elements in groundwater in a coastal area in Shenzhen, China. Environ. Pollut. 147, 771–780.
Chiang, Y.C., Chang, H.P., 2018. Cultural dimensions of risk perceptions: a case study on cross-strait driftage pollution in a coastal area of Taiwan. J. Environ. Manag. 206, 123–133.
Chiau, W.Y., 1998. Coastal zone management in Taiwan: a review. Ocean Coast Manag. 38, 119–132.
Coleman, J.M., Huh, O.K., Braud, D., 2008. Wetland loss in world deltas. J. Coast. Res. 24, 1–14.
Cooper, M., Uzarski, D., Burton, T., 2009. Benthic Invertebrate Fauna, Wetland Ecosystems.
Copeland, C., 2010. Wetlands: an Overview of Issues. University of Nebraska - Lincoln.
Dong, D.L., Wu, Q., Zhang, R., Song, Y.X., Chen, S.K., Li, P., Liu, S.Q., Bi, C.C., Lv, Z.Q., Huang, S.L., 2007. Environmental characteristics of groundwater: an application of PCA to water chemistry analysis in Yulin. J. China Inst. Min. Technol. 17, 73–77.
Finlayson, C., Mitchell, D., 1999. Australian wetlands: the monitoring challenge. Wetl. Ecol. Manag. 7, 105–112.
Gabarron, M., Faz, A., Acosta, J.A., 2018. Use of multivariable and redundancy analysis to assess the behavior of metals and arsenic in urban soil and road dust affected by metallic mining as a base for risk assessment. J. Environ. Manag. 206, 192–201.
Goutte, A., Cherel, Y., Churlaud, C., Ponthus, J.P., Masse, G., Bustamante, P., 2015. Trace elements in Antarctic fish species and the influence of foraging habitats and dietary habits on mercury levels. Sci. Total Environ. 538, 743–749.
Granadeiro, J.P., Santos, C.D., Dias, M.P., Palmeirim, J.M., 2007. Environmental factors drive habitat partitioning in birds feeding in intertidal flats: implications for conservation. Hydrobiologia 587, 291–302.
Guisan, A., Zimmermann, N.E., 2000. Predictive habitat distribution models in ecology. Ecol. Model. 135, 147–186.
Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., D'Agrosa, C., Bruno, J.F., Casey, K.S., Ebert, C., Fox, H.E., Fujita, R., Heinemann, D., Lenihan, H.S., Madin, E.M.P., Perry, M.T., Selig, E.R., Spalding, M., Steneck, R., Watson, R., 2008. A global map of human impact on marine ecosystems. Science 319, 948–952.
Hamza, F., Hammouda, A., Selmi, S., 2015. Species richness patterns of waterbirds wintering in the gulf of Gabes in relation to habitat and anthropogenic features. Estuar. Coast. Shelf Sci. 165, 254–260.
Hartmann, S.A., Segelbacher, G., Juina, M.E., Schaefer, H.M., 2015. Effects of habitat management can vary over time during the recovery of an endangered bird species. Biol. Conserv. 192, 154–160.
Jolliffe, I.T., 2002. Principal Component Analysis. Springer Series in Statistics.
Ju, Y.R., Chen, C.W., Chen, C.F., Chuang, X.Y., Dong, C.D., 2017. Assessment of heavy metals in aquaculture fishes collected from southwest coast of Taiwan and human consumption risk. Int. Biodeterior. Biodegrad. 124, 314–325.
Lambert, Z.V., Wildt, A.R., Durand, R.M., 1988. Redundancy analysis - an alternative to canonical correlation and multivariate multiple-regression in exploring interset associations. Psychol. Bull. 104, 282–289.
Lami, A., Musazzi, S., Marchetto, A., Buchaca, T., Kernan, M., Jeppesen, E., Guilizzoni, P., 2009. Sedimentary pigments in 308 alpine lakes and their relation to environmental gradients. Sediment. Pigments 62, 217–238.
Legendre, P., Gallagher, E.D., 2001. Ecologically meaningful transformations for ordination of species data. Oecologia 129, 271–280.
Legorburu, I., Rodriguez, J.G., Borja, A., Menchaca, I., Solaun, O., Valencia, V., Galparsoro, I., Larreta, J., 2013. Source characterization and spatio-temporal evolution of the metal pollution in the sediments of the Basque estuaries (Bay of Biscay). Mar. Pollut. Bull. 66, 25–38.
Lin, Y.C., Chang-Chien, G.P., Chiang, P.C., Chen, W.H., Lin, Y.C., 2013. Multivariate analysis of heavy metal contaminations in seawater, and sediments from a heavily industrialized harbor in Southern Taiwan. Mar. Pollut. Bull. 76, 266–275.
Lopez-Flores, R., Quintana, X.D., Romani, A.M., Baneras, L., Ruiz-Rueda, O., Compte, J., Green, A.J., Egozcue, J.J., 2014. A compositional analysis approach to phytoplankton composition in coastal Mediterranean wetlands: influence of salinity and nutrient availability. Estuar. Coast. Shelf Sci. 136, 72–81.
Lv, J.S., Liu, Y., Zhang, Z.L., Zhou, R.J., Zhu, Y.C., 2015. Distinguishing anthropogenic and natural sources of trace elements in soils undergoing recent 10-year rapid urbanization: a case of Donggang, Eastern China. Environ. Sci. Pollut. Res. 22, 10539–10550.
Margalef, R., 1951. Diversidad de especies en las comunidades naturales. PubInes. Inst. Biol. apl., Barcelona, pp. 59–72.
Margiotta, A.M., Shervette, V.R., Hadley, N.H., Plante, C.J., Wilber, D.H., 2016. Species-specific responses of resident crabs to vertical habitat complexity on intertidal oyster reefs. J. Exp. Mar. Biol. Ecol. 477, 7–13.
McArdle, B.H., Anderson, M.J., 2001. Fitting multivariate models to community data: a comment on distance-based redundancy analysis. Ecology 82, 290–297.
Mitsch, W.J., 2005. Wetland creation, restoration, and conservation: a wetland invitational at the Olentangy river wetland research park. Ecol. Eng. 24, 243–251.
Obolewski, K.T., Skorbilowicz, E., Skorbilowicz, M., Strzelczak, A., 2010. Influence of heavy metals contained in reed phragmites australis (cav.) trin. Ex steud. Inhabiting the vistula lagoon ON periphyton density. Fresenius Environ. Bull. 19, 340–347.
Pechmann, J.H., Scott, D.E., Gibbons, J.W., Semlitsch, R.D., 1989. Influence of wetland hydroperiod on diversity and abundance of metamorphosing juvenile amphibians. Wetl. Ecol. Manag. 1, 3–11.
Pereira, H.M., Cooper, H.D., 2006. Towards the global monitoring of biodiversity change. Trends Ecol. Evol. 21, 123–129.
Redhead, J.W., Fox, R., Brereton, T., Olivera, T.H., 2016. Assessing species' habitat associations from occurrence records, standardised monitoring data and expert opinion: a test with British butterflies. Ecol. Indicat. 62, 271–278.
Shangguan, Y.X., Wei, Y., Wang, L.Q., Hou, H., 2016. Sources and distribution of trace elements in soils near coal-related industries. Arch. Environ. Contam. Toxicol. 70, 439–451.
Shannon, C.E., Wiener, W., 1963. The Mathematical Theory of Communication. University of Illinois Press, Urbana.
Sole, M., Fetzer, I., Wennrich, R., Sridhar, K.R., Harms, H., Krauss, G., 2008. Aquatic hyphomycete communities as potential bioindicators for assessing anthropogenic stress. Sci. Total Environ. 389, 557–565.
Song, Q.J., Jabeen, S., Shamsi, I.H., Zhu, Z.Q., Liu, X.M., Brookes, P.C., 2016. Spatio-temporal variability of heavy metal concentrations in soil-rice system and its socio-environmental analysis. Int. J. Agric. Biol. 18, 403–411.
Straskrabova, V., Bertoni, R., Blazo, M., Callieri, C., Forsstrom, L., Fott, J., Kernan, M., Macek, M., Stuchlik, E., Tolotti, M., 2009. Structure of pelagic microbial assemblages in European mountain lakes during ice-free season. Adv. Limnol. 62, 19–53.
Sullivan, M.J.P., Newson, S.E., Pearce-Higgins, J.W., 2015. Using habitat-specific population trends to evaluate the consistency of the effect of species traits on bird population change. Biol. Conserv. 192, 343–352.
ter Braak, C.J., Smilauer, P., 2002. Canoco 4.5: reference manual and canodraw for Windows. In: User's Guide: Software Form Canonical Community Ordination (Version 4.5), (Microcomputer Power).
Thomas, J., El-Sheikh, M.A., Alfarhan, A.H., Alatar, A.A., Sivadasan, M., Basahi, M., Al-Obaid, S., Rajakrishnan, R., 2016. Impact of alien invasive species on habitats and species richness in Saudi Arabia. J. Arid Environ. 127, 53–65.
Urban and Rural Development Branch, C.a.P.A., 2014. Ministry of the interior. In: Ecological Survey and Environmental Monitoring Plan in Coastal Area of ChangHua.
Vandenwollenberg, A.L., 1977. Redundancy analysis an alternative for canonical correlation analysis. Psychometrika 42, 207–219.
Wang, T.Y., Huang, M.K., Li, H.C., Huang, C.N., 2012. Wetland kaleidoscope of Taiwan. In: C.a.P.A, Ministry of the Interior (Eds.), Urban AndRural Development Branch, (Hong, Chia. Hong).
Warton, D.I., Wright, S.T., Wang, Y., 2012. Distance-based multivariate analyses confound location and dispersion effects. Methods Ecol. Evol. 3, 89–101.
Wingard, G.L., Lorenz, J.J., 2014. Integrated conceptual ecological model and habitat indices for the southwest Florida coastal wetlands. Ecol. Indicat. 44, 92–107.
Yen, J., Chen, C.-Y., 2001. Allocation strategy analysis of water resources in South Taiwan. Water Resour. Manag. 15, 283–297.
Yergeau, E., Schoondermark-Stolk, S.A., Brodie, E.L., Dejean, S., DeSantis, T.Z., Goncalves, O., Piceno, Y.M., Andersen, G.L., Kowalchuk, G.A., 2009. Environmental microarray analyses of Antarctic soil microbial communities. ISME J. 3, 340–351.
Zedler, J.B., Kercher, S., 2005. Wetland resources: status, trends, ecosystem services, and restorability. Annu. Rev. Environ. Resour. 30, 39–74.
Zhao, Q., Weise, L., Li, P., Yang, K., Zhang, Y., Dong, D., Li, P., Li, X., 2010. Ageing behavior of phenanthrene and pyrene in soils: a study using sodium dodecylbenzenesulfonate extraction. J. Hazard. Mater. 183, 881–887.