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Status and habitat preferences for endemic inhabitants of fiddler crab *Uca formosensis* in Hsiang-Shan wetland, Taiwan

Shao-Wei Liao · Wen-Liang Chang · Shih-Wei Lin

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Abstract This article reports on soil samples collected from Hsiang-Shan wetland, Taiwan. Canonical discriminant analysis (CDA) was applied to identify an existing habitat type's scheme by identifying the physico-chemical properties of sediment in Hsiang-Shan wetland. The three constructed discriminant functions (CDFs) showed a marked contribution by most of the discriminant variables, and the recognition capacities in these three CDFs were 49.5, 32.8 and 17.7%. Our study revealed that the most important latent factors in Hsiang-Shan wetland are soil texture-caused factor, ocean current-caused factor, nutrient-caused factor, and the redox reaction-caused factor. And the most sensitivity parameters in this habitat followed the descending order: OBD, EC, Eh, sand, TN, porosity, STP, silt, VCP and pH. And the inhabited sediment properties for *U. formosensis* in terms of soil texture are sand, silt, and clay (34.05, 29.72, and 32.35%, respectively): that is clay loam soil. We also found that *U. formosensis* preferred to inhabit the upper intertidal zone, spending 8.41% of the time submerged. Vegetation coverage on the ground was less than 2.20%, showing that it preferred to live in a bare intertidal habitat. Concerning nest choosing, excavating burrows is more difficult when a high soil penetration force is required, and in this study the soil penetration force for 20 cm was found to be is 45.98 N/cm^2. The results will be helpful in developing a methodology for use by the government in refining its management programs.

Keywords Canonical discriminant analysis · Sediment properties · Taiwan · *Uca formosensis*

Introduction

Crabs play important structural and functional roles in the food web and may serve as indicators of ecological health, particularly in small sub-estuaries where conditions may be strongly linked to watershed and local factors (King et al. 2005). The shade of mangrove vegetation, particularly at higher shore levels during neap tides, ameliorates the harsh physical conditions caused by high temperatures and high evaporation rates (Shih et al. 1999). This can affect the distribution (Macnae 1968) and thermoregulatory behaviour (Smith and Miller 1973) of *Uca*, and of other tropical mangrove invertebrates (Macnae 1968; McGuinness 1994).

S.-W. Liao (✉)
Department of Environmental Resources Management,
Tajen University,
20 Wei-Hsin Road, Yen-Pu,
Pingtung, Taiwan 10907, Republic of China
e-mail: swliao@mail.tajen.edu.tw

W.-L. Chang · S.-W. Lin
Department of Bioenvironmental Systems Engineering,
National Taiwan University,
Taipei, Taiwan 10106, Republic of China

The physical structure of vegetation is likely to be important to animals that inhabit burrows. *Uca pugnax* (Smith) preferentially burrows close to underground parts of the cordgrass *Spartina alterniflora* (L.) in low salt marsh habitats, to gain structural support for its burrows (Bertness and Miller 1984). Crab burrows can increase the aeration of soil, redox conditions, and decomposition of organic litter, thereby affecting plant distribution. However, Nomann and Pennings (1998) and Nobbs (2003) found no evidence that plants support *Uca* burrows in high salt marsh habitats, and the number of *Uca* burrows was greater under suspended shadecloth that provided refuge from predators in clearings. Croll and McClintock (2000) revealed no significant differences between open and vegetation-covered areas of the marshes that might influence choice of burrow location. Ribeiro et al. (2005) demonstrated that the spatial heterogeneity of environmental factors (sediment thickness, sediment torque and organic matter content) can be translated to a spatial heterogeneity in the distribution of fiddler crabs. Factors that control the density of adult crabs may include spatial variations in the organic matter content of the sediment, given that crabs feed on organic matter adhering to sediment particles (Weissburg 1992), and in the suitability of the sediment for excavation and supporting the crab burrows (Bertness and Miller 1984). Consequently variations in habitat quality and resource availability can affect the distribution and growth of *Uca*.

Taiwan has ten species of fiddler crab, accounting for one-eighth of all the species in the world. The fiddler crab *Uca formosensis* Rathbun, 1921, is one of only a few Taiwanese endemic and endangered species of marine crabs known from Taiwan Island, and was first found in 1918 at Lukang, Taiwan by Moichiro Maki. This species is poorly known except for its morphological characters (Shih et al. 1999). Takahasi (1934a,b; 1935) noted that *U. formosensis* lived in muddy beaches with clay-like mud and ‘vegetation,’ and that it showed pronounced aggressiveness. A chimney of *U. formosensis* is built by the male, the burrow which probably widens the shaft and, more importantly, deepens the burrow so that it reaches the water table, thus providing a moist chamber in which the female can incubate her eggs (Shih et al. 2005). Previous reports of this species are almost wholly taxonomic, and in those that include ecological and/or distribution information, the data are too brief or too approximate, especially regarding environmental information. *U. formosensis* is gradually disappearing from Taiwan because of degradation of habitats and human stressors. However, the habitats of *U. formosensis* in Hai-Shan-Ku, Shen-Kang, and Chi-Ku, Taiwan are under pressure from overgrowth of mangroves (e.g. *Kandelia candel*), because mangroves can change habitat substrates, and from the development of industrial parks and landfills (Shih et al. 1999). Regarding the restoration of *U. formosensis*, it is important to understand its ecological habitats, especially in terms of sediment properties.

Understanding the natural history of *U. formosensis* is important in the conservation of this endemic and endangered species, as most of its habitat is under threat. The objectives of this study were therefore to:

1. Analyze sediment physico-chemical factors from Hsiang-Shan wetland,
2. Apply CDA to identify an existing habitat type’s scheme by sediment properties,
3. Interpret the most important latent factors,
4. Quantify suitable soil properties for *U. formosensis*, and
5. Combine these constructed canonical discriminant functions (CDFs) with sediment data, which could feasibly help to conserve a suitable habitat for *U. formosensis*. Ultimately, we sought to delineate the optimal living habitat for *U. formosensis* growth in Hsiang-Shan wetland and to identify the underlying mechanism producing the growth environment. This is the first study in Taiwan based on such an approach, and the results could be useful in providing a methodology for the government in refining its management program.

Materials and methods

Site description

Hsiang-Shan wetland is a salty marsh in northern Taiwan, located west of the Hsiang-Shan flood plain (120°53′E, 24°45′N, Fig. 1) and suburban Hsin-Chu city (which has the most rapidly increasing population and economic production in Taiwan, hence the name Taiwan’s Silica Valley). The total area of the site is around 1,600 ha, and it is bordered by the Wu-Ming

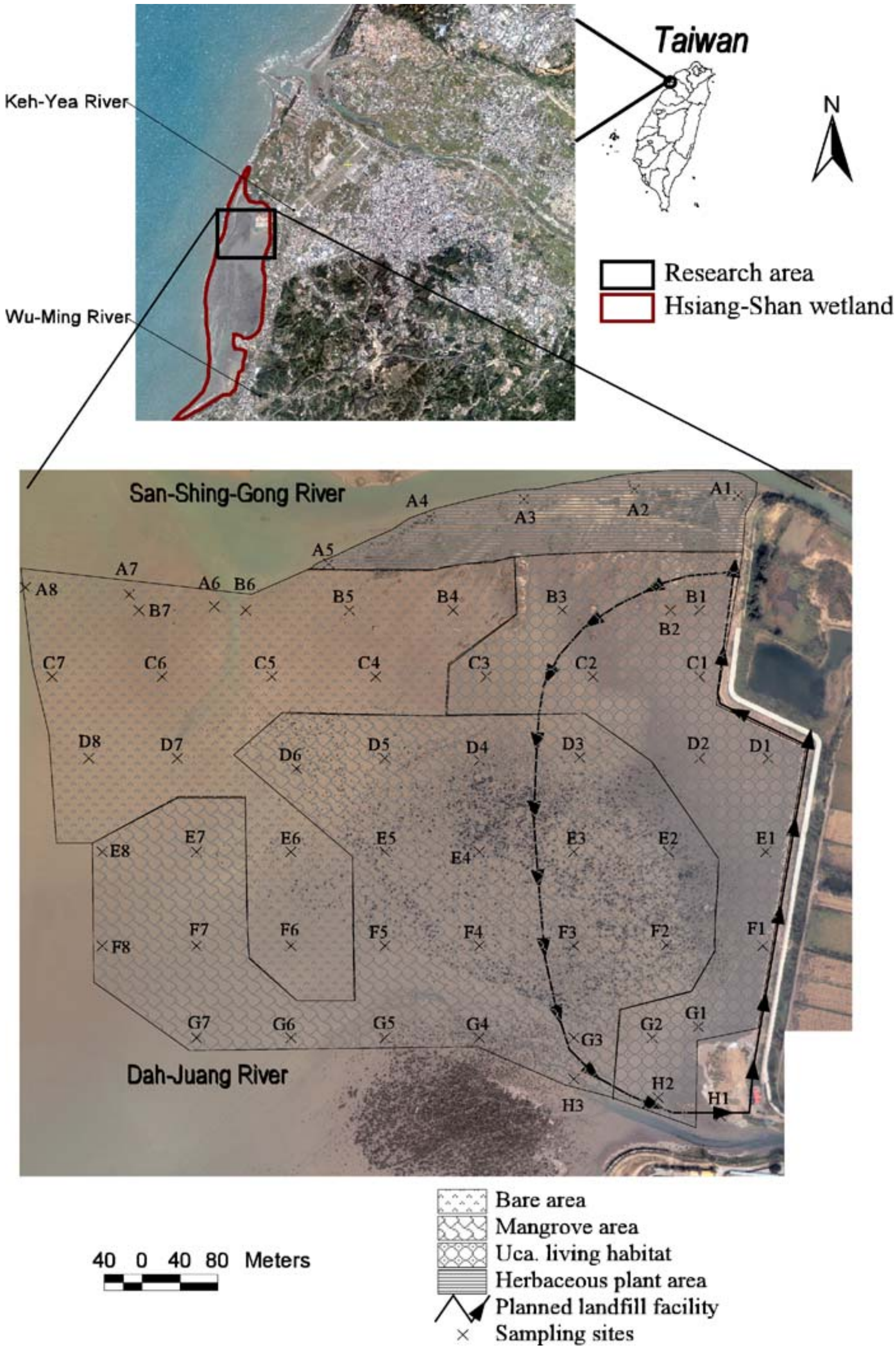

Fig. 1 Soil sampling sites in Hsiang-Shan wetland, Taiwan

River to the south and Keh-Yea River to the north, a boundary of 10 km along the seashore and 2 km width. The study area is in a zone with a subtropical climate and is exposed to sunshine throughout the year, except on an average of 28.9°C rainy days in the summer. The southwest monsoon influences the rainfall. Therefore, seasonal variations strongly affect the bay area ecosystem. It is the biggest seashore wetland in northern Taiwan and was constructed as a Seashore Wildlife Conservation Area by the Council of Agriculture. According to investigations by the Wildbird Society of Hsin-Chu, there are 274 genera of birds and more than 50% resident bird appear in Taiwan, and 43 genera of crabs, with the greatest abundance and diversity of fiddler crabs in Taiwan. Also, it is an essential route for winter migrant birds flying from Siberia to Australian. The Conferences of the Ramsar Convention held in 1996 officially named this area as a ring of the East Asia Water Bird Conservation Net. The area approaching the jetty shoal still shows traces of Taiwanese endemic *U. formosensis*. But mangrove has spread around the jetty shoal, in an area about 300 m long and 500 m wide. The predominant crabs in this area are *Uca arcuata*, *Uca lactea*, *Helice wuana*, *Macrophthalmus banzai* and a few *Scopimera longidactyla*, *Scopimera bitympana*, *Myctyris brevidactylus*, and Family Grapsidae. Crab activity has gradually decreased on the sand dunes on the southern side of San-Shing-Gong River. This should worsen the ecohabitat. The primary sources of pollution in Hsiang-Shan wetland included domestic and municipal wastewater from Hsin-Chu city and industrial wastewater from Hsin-Chu Science Industrial Park. The building of the sewage disposal facility by Hsin-Chu City Administration will worsen the habitat of the endangered crabs.

Sampling and analyzing soil

Grid sampling was undertaken at low tide in August 2004. The sampling area was divided into a 7×8 grid by a rectangular grid method. Each grid had an area of 10,000 m^2 and sampling stations were defined along a 100×100 m segment of shoreline, which was large enough to fully characterize local-scale habitats and to include heterogeneous shoreline segments. Random and triplicate samples with plant genera recognition in the meantime were taken from each grid, and then 22 physical–chemical variables were analyzed in the field and laboratory (Hillel 1998). There were a total of 56 sampling stations; thus, a 56×22 data matrix was generated.

Subsurface soil within 30 cm was sampled and stored in sturdy, tightly sealed plastic bags in an icebox, and analyzed as soon as possible. Soil samples were pretreated and air-dried outdoors at about 25−30°C, and ground using a wooden pestle, and then passed through a 2-mm sieve. Penetration resistance of the ground at 10 cm (P(10)) and 20 cm (P(20)) was measured with a penetrometer (Eijkelkamp). Soil texture, which is a manifestation of the component proportions of sand, silt, and clay, was determined by a buoyancy hydrometer method (ASTM 1994). Total organic carbon (TOC) was determined by weight loss (% of dry weight) on ignition (500°C for 6 h) (Brower et al. 1998). pH, redox value (Eh) and electrical conductivity (EC) of soil samples were measured in a 1:1 (w/w) soil/distilled water suspension with a pH meter, redox meter (WTW pH-320/Set-2) and EC meter (WTW LF 320/Set), respectively. Soil porosity was determined by dividing the void volume of soil by the total soil volume. Soil bulk density (BD: or apparent specific gravity) was determined by dividing the dried solid weight by the total soil volume; thus, onsite bulk density (OBD) was also calculated. Concentrations of Cu, Zn, Pb, Ni, Cd, and Cr were analyzed by ICP-AES (ICP LIBERTY II) using an ultrasonic nebulizer. All samples were filtered using 0.45-μm cellulose acetate filters, and acidified to pH 2 with nitric acid in the laboratory. The minimum detection limits were found to be 1.2, 1.1, 3.1, 2.3, 1.2, and 1.1 ìg/kg, respectively. Total nitrogen (TN) was analyzed by the molybdate blue method after digestion in nitric acid and perchloric acid. All soil properties were measured in the laboratory (Hillel 1998). The vegetation coverage percentage (VCP) was used within a geographic information system to estimate the proportions of vegetation-covered area based on aerial photograph. Habitat submerged time percentage (STP) was calculated by observing variations of depth and time in every site on a period of tide and compared with sea level from the Central Weather Bureau.

Statistical methods

Environmental and ecological monitoring usually generates a large amount of data that can be difficult to analyze and interpret due to the complex interrelationship between variables. To extract meaningful information from such databases, multivariate techniques have been used successfully to aid the interpretation of complicated field measurements. Canonical discriminant analysis (CDA) is used to interpret the spatial distribution of bio-assemblages with various environmental parameters (Cruz-Castillo et al. 1994; Momen and Zehr 1998; Manzelli et al. 2005; Liao et al. 2006, 2007). CDA determines how a set of quantitative variables may differentiate several known classes and yields linear functions of quantitative variables that maximally separate two or more groups of individuals, while minimizing variation within groups (Rencher 1992). The approach also allows the relationships among the groups to be graphically represented by plotting the values of canonical scores of sample observations. Two main statistics explain the characteristics and structure of the CDFs:

(1) The total canonical structure coefficients (TCSC), which are correlation coefficients between individual variables and canonical scores (similar to variable loadings in factor analysis) and
(2) The total standardized canonical coefficients (TSCC), which are the multipliers of standardized independent variables that yield the standardized canonical scores

The validity and use of these two indices have been discussed, but controversies remain (Rencher 1992; Huberty 1994; Matthew et al. 1994; Cruz-Castillo et al. 1994; Momen and Zehr 1998). TSCC specify the joint effects of independent variables of a given CDF, so are more informative than TCSC (Rencher 1992). TSCC can be misleading when independent variables are related to each other (Cruz-Castillo et al. 1994). In this study, TCSC were used to interpret the CDFs because significant correlations obtained among some of the independent variables (Table 1), and TSCC were used to yield the CDFs.

In this study, spatial variations of sediment parameters in Hsiang-Shan wetland were calculated using a correlation matrix. Multivariate analysis of the sediment data set was conducted using a CDA approach. The sediment variables had different measurement units so CDA was applied to experimental data that had been standardized by z-scale transformation, to prevent misclassification, since the dimensionality of the data varied widely (Rencher 1992). By field visual reconnaissance four types of habitat in neighboring *U. formosensis* habitats were selected. It was assumed that the four types of habitat were strongly affected by these soil parameters. Stepwise multiple discriminant analysis was conducted to correlate the habitat types with the physical and chemical variables obtained from the soil samples. These data sets [soil properties: TOC (Total organic carbon), TN (Total nitrogen), P(10) (Penetration stress at 10 cm), P(20) (Penetration stress at 20 cm), % clay, % sand, % silt, EC (Electrical conductivity), pH, H^+, VCP (Vegetation coverage percentage), STP (Submerged time percentage), BD (Bulk density), Soil porosity, OBD (Onsite bulk density), Eh (Redox value), Cu (Copper), Zn (Zinc), Pb (Lead), Ni (Nickel), Cd (Cadmium), Cr (Chromium)] were divided into groups, according to different types of habitat that resulted from classification. The class variables consisted of four habitat classes were obtained by field visual reconnaissance. The calculation was performed using the STATISTICA package from StatSoft (2004).

Results and discussion

By field visual reconnaissance – 5 herbaceous plant sites, 22 mangrove sites, 15 bare area sites, and 14 *U. formosensis* living sites were chosen. Fifty-six homogeneous sites of habitats with 22 variables were used to create the canonical discriminant functions (CDFs). Thus CDA was applied to the normalized data matrix (56×22) in August 2004 to determine the CDFs that governed the observed responses. The class membership (for four types of habitat: bare area, mangrove area, *U. formosensis* living habitat, and herbaceous plant area) was less than the number of independent variables (22 soil parameters), so three CDFs were determined.

Construction the CDFs

A forward stepwise approach was applied to determine which variables could be incorporated in the model (StatSoft 2004). Thus, an *F*-test was conducted to identify the most discriminating variables. The process was terminated when the differences ceased to be significant. Table 2 shows that most of these discriminant variables were significant, according to Wilks' lambda test. (The programme showed highly significant discrimination when Wilks' Lambda=0.025; $F(45, 113)=6.25$; $p<0.0000$). The order of inclusion in the model, according to the *F*-test, was: STP, VCP, OBD, Cr, P(20), silt, Zn, sand, porosity, EC, TN, Cu, Pb, pH, and Eh. In these models, the main factors were the soil texture factor, the ocean factor, the nutrient factor, the anthropogenic living factor, and the environmental pollution factor. Accordingly, the habitats vary greatly by these factors. The main cause of these variations was the ocean current near the seashore, which was polluted by submerged landfill wastewater, municipal wastewater from Hsin-Chu city, and industrial wastewater from Hsin-Chu Science Industrial Park. The discriminatory capacity followed the order:

Table 1 Pairwise correlation coefficients between soil parameters of Hsiang-Shan wetland

	TOC	TN	P(10)	P(20)	Clay	Sand	Silt	EC	pH	H	VCP	STP	BD	Porosity	OBD	Eh	Cu	Zn	Pb	Ni	Cd	Cr
TOC	1.00																					
TN	**0.67**	1.00																				
P(10)	−0.21	−0.21	1.00																			
P(20)	−0.16	−0.20	**0.72**	1.00																		
Clay	**0.73**	**0.90**	−0.12	−0.15	1.00																	
Sand	**−0.70**	**−0.87**	0.23	0.22	**−0.93**	1.00																
Silt	**0.31**	**0.49**	−0.25	−0.21	**0.55**	**−0.61**	1.00															
EC	0.22	**0.33**	−0.17	−0.17	**0.39**	**−0.46**	**0.41**	1.00														
pH	**0.38**	**0.52**	−0.16	−0.04	**0.61**	**−0.64**	**0.45**	**0.26**	1.00													
H	**−0.34**	**−0.47**	0.23	0.09	**−0.56**	**0.58**	**−0.45**	−0.18	**−0.93**	1.00												
VCP	0.13	0.14	**−0.34**	**−0.30**	0.11	−0.13	0.12	−0.13	0.21	−0.22	1.00											
STP	−0.26	**−0.32**	−0.17	−0.01	**−0.39**	0.20	−0.07	−0.03	−0.07	0.06	−0.07	1.00										
BD	**−0.41**	**−0.59**	−0.07	0.03	**−0.56**	**0.59**	−0.22	−0.09	**−0.36**	**0.36**	−0.00	0.11	1.00									
Porosity	**0.75**	**0.88**	−0.21	−0.20	**0.91**	**−0.87**	**0.53**	0.23	**0.64**	**−0.58**	0.12	**−0.27**	**−0.50**	1.00								
OBD	**−0.52**	**−0.60**	0.11	0.12	**−0.70**	**0.73**	**−0.55**	**−0.60**	**−0.46**	**0.38**	−0.24	0.17	**0.35**	**−0.55**	1.00							
Eh	−0.11	−0.25	0.21	**0.30**	−0.25	**0.38**	**−0.32**	**−0.59**	−0.10	−0.01	**0.29**	−0.15	0.09	−0.23	**0.36**	1.00						
Cu	**0.27**	**0.35**	−0.09	−0.09	**0.39**	**−0.35**	0.14	0.19	**0.40**	**−0.34**	0.13	−0.19	−0.23	**0.36**	−0.26	0.02	1.00					
Zn	0.09	0.24	0.01	−0.15	0.19	−0.19	−0.20	−0.04	−0.00	−0.02	−0.05	−0.12	**−0.40**	0.20	0.10	0.02	0.02	1.00				
Pb	**0.51**	**0.67**	−0.04	−0.10	**0.72**	**−0.65**	**0.43**	**0.31**	**0.38**	**−0.35**	0.08	**−0.30**	**−0.31**	**0.58**	**−0.55**	−0.15	**0.32**	0.10	1.00			
Ni	**0.49**	**0.58**	−0.08	−0.20	**0.64**	**−0.57**	0.20	**0.34**	**0.31**	**−0.27**	**0.30**	**−0.33**	**−0.42**	**0.51**	**−0.54**	−0.03	**0.27**	0.20	**0.43**	1.00		
Cd	**0.47**	**0.67**	−0.10	−0.23	**0.67**	**−0.58**	0.25	**0.43**	**0.30**	−0.23	0.06	**−0.43**	**−0.44**	**0.62**	**−0.44**	−0.23	0.26	0.25	**0.33**	**0.75**	1.00	
Cr	0.26	**0.57**	−0.08	−0.21	**0.47**	**−0.48**	**0.37**	**0.41**	**0.27**	−0.19	0.12	−0.19	**−0.44**	**0.44**	**−0.37**	−0.10	0.26	0.21	**0.33**	**0.55**	**0.66**	1.00
Units	%	%	N/cm^2	N/cm^2	%	%	%	mS/cm			%	%	g/cm^3		g/cm^3	eV	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Mean	0.0069	0.0003	31.05	48.06	26.12	43.69	29.88	41.14	7.90	0.00	6.39	0.18	1.41	0.64	1.75	−57.99	0.08	0.09	0.24	0.18	0.07	0.06
Max	0.0140	0.001	76.67	126.13	46.52	87.06	54.81	65.60	8.45	0.00	38.40	0.34	1.55	1.30	2.15	−19.40	0.55	1.52	0.58	0.34	0.15	0.17
Min	0.0022	0.00	13.33	21.67	10.73	0.00	0.85	16.68	7.00	0.00	0.00	0.01	1.10	0.33	1.12	−74.20	0.00	0.02	0.00	0.07	0.02	0.01
Std	0.0028	0.0002	14.98	21.57	10.28	26.08	17.15	8.89	0.36	0.00	8.79	0.09	0.09	0.23	0.23	12.82	0.07	0.20	0.15	0.07	0.03	0.03

Bold values are significant at $P<0.05$.

Abbreviation: *P(10)* soil penetration force in 10-cm deep, *P(20)* soil penetration force in 20-cm deep, *VCP* vegetation coverage percentage, *STP* submerged time percentage, *BD* bulk density, *OBD* onsite bulk density, *Eh* oxidation–reduction potential, *STD* standard deviation.

Table 2 Outcomes of CDA determined by a forward stepwise method for the four habitats in Hsiang-Shan wetland

Discriminate variables	Wilks' lambda	*F*-remove	*p*-level	Mean (standard derivation) values of discriminate variables			
				H	M	B	U
OBD	0.039	7.451	0.000	1.99(0.09)	1.61(0.15)	1.96(0.13)	1.66(0.22)
STP	0.053	14.727	0.000	15.93(0.08)	20.95(0.07)	23.08(0.05)	8.41(0.08)
VCP	0.045	10.456	0.000	16.12(13.13)	10.40(9.49)	1.19(2.22)	2.20(3.06)
P(20)	0.033	4.161	0.012	69.07(39.73)	42.54(16.44)	51.11(17.74)	45.98(21.70)
Sand	0.031	3.075	0.039	56.01(23.05)	29.26(14.22)	69.73(19.24)	34.05(26.38)
Zn	0.031	3.227	0.033	0.08(0.02)	0.05(0.02)	0.04(0.02)	0.20(0.39)
Pb	0.028	1.460	0.241	0.14(0.07)	0.30(0.14)	0.16(0.09)	0.26(0.17)
Eh	0.027	1.292	0.291	−33.28(14.60)	−62.89(7.01)	−57.39(13.15)	−59.76(9.22)
Porosity	0.030	2.954	0.045	58.87(0.20)	70.42(0.14)	43.61(0.12)	75.65(0.29)
Silt	0.033	4.069	0.013	16.25(13.16)	41.22(8.95)	17.96(17.52)	29.72(16.70)
Cr	0.033	4.476	0.009	0.07(0.02)	0.07(0.04)	0.05(0.02)	0.08(0.04)
TN	0.028	1.685	0.186	2.06E−4 (1.69E−4)	4.04E−4 (2.26E−4)	1.01E−4 (8.57E−5)	4.05E−4 (2.75E−4)
EC	0.028	1.860	0.153	27.36(7.90)	45.36(6.77)	36.81(5.62)	44.09(8.51)
Cu	0.028	1.472	0.237	0.07(0.04)	0.10(0.11)	0.04(0.03)	0.08(0.04)
pH	0.027	1.383	0.263	8.08(0.18)	8.05(0.18)	7.61(0.45)	7.93(0.36)
Sampling number				5	22	15	14
TOC*	0.024	0.112	0.953	0.006(0.002)	0.008(0.003)	0.005(0.002)	0.008(0.003)
P(10)*	0.023	0.790	0.507	36.34(13.78)	24.86(11.93)	33.97(15.84)	35.78(16.76)
Clay*	0.024	0.252	0.859	22.09(7.60)	30.10(6.36)	15.81(5.33)	32.35(11.65)
H*	0.021	2.293	0.094	8.85E−9(3.79E−9)	9.69E−9(3.91E−9)	3.66E−8(2.92E−8)	1.72E−8(1.82E−8)
BD*	0.024	0.078	0.972	1.39(0.10)	1.39(0.06)	1.46(0.06)	1.38(0.14)
Ni*	0.024	0.316	0.814	0.19(0.07)	0.19(0.06)	0.13(0.04)	0.21(0.08)
Cd*	0.024	0.567	0.640	0.06(0.03)	0.06(0.02)	0.05(0.02)	0.09(0.03)

It showed highly significant discrimination when Wilk's Lambda=0.025; $F(45, 113)=6.25$; $p<0.0000$.

Note: the four habitats; *H* herbaceous plant area, *M* mangrove area, *B* bare area, and *U Uca formosensis* living habitat. (*): Indicating that discriminate variables had insignificance (didn't choose when Wilk's Lambda <0.025), and the value under the parentheses was standard deviation.

STP, VCP, OBD, Cr, P(20), silt, Zn, sand, and porosity; these represented the most important parameters in these models. OBD and soil porosity were deeply affected by soil texture; combined with silt and sand, we termed this 'soil texture factor.' STP and P(20) were termed 'ocean current factor.' Cr and Zn were termed 'anthropogenic living factor.' VCP represented the abundances of aquatic plants and could affect oxidation or reduction from plants roots, so was termed 'redox reaction factor.' Other variables not included in these models were: TOC, P(10), clay, $\lfloor H^+ \rfloor$, BD, Ni, and Cd; these variables had insignificant variance in these habitats.

Table 3 shows the outcome of the chi-square test of the three CDFs (chi-squared statistic=39.21, $df=13$, $p<0.0002$). Canonical correlation coefficients (square root ratio of the between-group sum of squares to the total sum of the squares for a given CDF) exceeded 0.7 for every CDF. Eigenvalues (ratios of between-group sum of squares to within-group sum of squares for a given CDF) also exceeded 1 for every CDF. These three CDFs together explained for 100% (49.5, 32.8, and 17.7%) of the variance at the 56 sampling sites. The value of every discriminant variable was standardized to determine the relationship between the discriminant variables and functions. The standardized CDFs were obtained as follows:

$$\begin{aligned}\mathrm{CDF}_1 = {} & 1.12\ \mathrm{OBD} + 0.47\ \mathrm{STP} + 0.79\ \mathrm{VCP} \\ & + 0.69\ \mathrm{P}(20) - 1.02\ \mathrm{Sand} - 0.65\ \mathrm{Zn} \\ & + 0.09\ \mathrm{Pb} + 0.12\ \mathrm{Eh} - 0.75\ \mathrm{Porosity} \\ & - 0.34\ \mathrm{Silt} + 0.68\ \mathrm{Cr} - 0.11\ \mathrm{TN} \\ & - 0.53\ \mathrm{EC} - 0.07\ \mathrm{Cu} + 0.38\ \mathrm{pH}\end{aligned}$$

Table 3 Outcomes of total standardized canonical coefficients (TSCC) and total canonical structure coefficients (TCSC) between canonical discriminant functions (CDF_1, CDF_2, CDF_3) and discriminant variables

Discriminant variables	CDF_1		CDF_2		CDF_3	
	TSCC	TCSC	TSCC	TCSC	TSCC	TCSC
OBD	**1.115**	**0.400**	−0.121	**0.264**	−0.013	**−0.518**
STP	0.474	**0.212**	**−0.922**	**−0.415**	**−0.316**	**−0.336**
VCP	**0.794**	0.174	**−0.632**	**−0.195**	**0.603**	**0.484**
P(20)	**0.692**	0.159	−0.100	0.125	**0.358**	0.014
Sand	**−1.015**	**0.274**	0.028	0.168	**−1.000**	**−0.577**
Zn	−0.645	−0.096	0.097	0.161	0.144	0.093
Pb	0.092	−0.188	−0.387	−0.148	**−0.387**	0.231
Eh	0.124	**0.344**	0.342	**0.264**	**0.314**	0.175
Porosity	**−0.748**	**−0.217**	**1.040**	−0.005	−0.083	**0.469**
Silt	−0.339	**−0.211**	**−0.694**	**−0.309**	0.117	**0.341**
Cr	0.680	−0.073	**0.611**	0.027	0.076	0.263
TN	−0.109	**−0.220**	**−0.969**	−0.084	**−0.308**	**0.426**
EC	−0.534	**−0.369**	−0.199	**−0.224**	0.081	0.128
Cu	−0.065	−0.054	−0.443	−0.084	−0.002	0.226
pH	0.382	−0.030	0.198	−0.089	**0.270**	**0.498**
Chi-square value	168.409		96.755		39.207	
Canonical correlation coefficient	0.890		0.847		0.760	
Eigenvalue	3.830		2.542		1.367	
Cumulative variance explained	0.495		0.823		1.000	

Three CDFs accounted significantly amount of variation chi-squared statistic=39.21, *df*=13, $p<0.0002$.

$$\begin{aligned}\mathrm{CDF}_2 = {} & -0.12\ \mathrm{OBD} - 0.92\ \mathrm{STP} - 0.63\ \mathrm{VCP} \\ & - 0.10\ \mathrm{P(20)} + 0.03\ \mathrm{Sand} + 0.10\ \mathrm{Zn} \\ & - 0.39\ \mathrm{Pb} + 0.34\ \mathrm{Eh} + 1.04\ \mathrm{Porosity} \\ & - 0.69\ \mathrm{Silt} + 0.61\ \mathrm{Cr} - 0.97\ \mathrm{TN} \\ & - 0.20\ \mathrm{EC} - 0.44\ \mathrm{Cu} + 0.20\ \mathrm{pH}\end{aligned}$$

$$\begin{aligned}\mathrm{CDF}_3 = {} & -0.01\ \mathrm{OBD} - 0.32\ \mathrm{STP} + 0.60\ \mathrm{VCP} \\ & + 0.36\ \mathrm{P(20)} - 1.00\ \mathrm{Sand} - 0.14\ \mathrm{Zn} \\ & - 0.39\ \mathrm{Pb} + 0.31\ \mathrm{Eh} + 0.08\ \mathrm{Porosity} \\ & + 0.12\ \mathrm{Silt} + 0.08\ \mathrm{Cr} - 0.31\ \mathrm{TN} \\ & + 0.08\ \mathrm{EC} - 0.00\ \mathrm{Cu} + 0.27\ \mathrm{pH}\end{aligned}$$

Interpretation and comparison a living habitat of *U. formosensis*

Four types of habitat were distinguished using the three CDFs. CDF_1 had the highest canonical coefficient (0.89) and were defined by five discriminant variables, whose canonical coefficients had high absolute values. These were OBD, sand, VCP, porosity, and P(20) (Table 3). Accordingly, CDF_1 comprised soil texture-caused factor, redox reaction-caused factor, and ocean current-caused factor. TCSC indicated that the variance of variables in CDF_1 followed the ascending order: silt, STP, porosity, TN, sand, Eh, EC, and OBD (Table 3). Silt and sand were strongly affected by OBD and porosity and were termed 'soil texture-caused factor.' STP and EC were strongly affected by tide and were termed 'ocean current-caused factor.' As well, TN nutrients can influence the production of organisms and thus influence the dissolved oxygen content. Table 2 shows the soil properties of the habitat of *U. formosensis*. OBD in herbaceous plant areas and bare areas was greater than in mangrove areas and *U. formosensis* living habitat areas. Also, STP was 8.41%, significantly smaller than in the other habitats, showing that *U. formosensis* prefers to inhabit the upper intertidal zone. Hsieh et al. (2004) compared the soil properties of *U. formosensis* habitats and mangroves, and found that *U. formosensis* is active on mudflats during low tide of the spring tide period, but remains hidden in burrows during the neap tide. STP was significantly greater in lower intertidal bare area than other habitats. The topography descended gradually from northeast to southwest, and we observed by visual reconnaissance in the field that the *U. formosensis* living habitat is submerged 2 days after the coming of the spring tide. Also, *U. formosensis* would dig deeper to avoid high temperatures and evaportranspiration at low tide. Shih et al. (2005) noted that chimney burrows of *U. formosensis* appeared on the mudflats of the high intertidal zone during the period of the neap tide in the warm season (March to October) in Taiwan. The location of *U. formosensis* can also be identified by the typical large chimneys built by males (and sometimes females) during neap tide periods in the reproductive season (Shih et al. 1999). The inhabited soil properties of *U. formosensis* in terms of soil texture were 34.05% sand, 29.72% silt, and 32.35% clay; thus, it prefers living in clay loam. The soil porosity of the *U. formosensis* living habitat (75.65%) was the highest of the four types of habitat. Takahasi (1935) also noted that *U. formosensis* lived in muddy beaches with clay mud. Shih et al. (1999) noted that most of *Uca*. spp. inhabited wide-open mudflats of the high intertidal zone without mangrove areas. The soil clay content in bare areas and herbaceous plant areas was smaller than that in mangrove areas and *U. formosensis* living habitats. Enhanced particle settlement in mangrove areas could reduce tidal flow and be conducive to a terrene landform. Soil EC was 44.09 ms/cm in *U. formosensis* living habitats, similar to that in mangrove areas. In summary, CDF_1 is the 'soil texture-caused factor,' 'ocean current-caused factor,' 'nutrient-caused factor,' and 'redox reaction-caused factor' based on TCSC. These factors can distinguish the four types of habitat and explained 49.5% of total variance of habitat sediment properties.

CDF_2 had a high canonical coefficient (0.85) and was defined by six discriminant variables, whose canonical coefficients had high absolute values. These were STP, VCP, porosity, silt, Cr, and TN (Table 3). Accordingly, CDF_2 comprised ocean current-caused factor, soil texture-caused factor, redox reaction-caused factor, and nutrient-caused factor. TCSC indicate that the variance of variables in CDF_2 followed the ascending order: VCP, EC, Eh, OBD, silt, and STP (Table 3). VCP is 2.20%, which can affect the redox status in *U. formosensis* living habitats. Also the value in *U. formosensis* living habitats and bare areas was significantly smaller than in mangrove and herbaceous plant areas. This showed that *U. formosensis* preferred bare intertidal habitats. Zucker (1981) and Salmon (1987) noted that greater vegetation obstructs the activity of fiddler crabs, and Shih et al. (1999) and Hsieh et al. (2004) inferred that the presence of mangrove was a survival stress for *U. formosensis.* In summary, CDF_2 is called the 'soil texture-caused factor,' 'ocean current-caused factor,' and 'redox reaction-caused factor' based on TCSC. These factors can distinguish these four types of habitat and explained 32.8% of the total variance of habitat sediment properties. CDF_3 had a high canonical coefficient (0.76) and was defined by eight discriminant variables, whose canonical coefficients had high absolute values. These were STP, silt, TN, porosity, VCP, pH, OBD, and sand (Table 3). Accordingly, CDF_3 comprised 'soil texture-caused factor,' 'ocean current-caused factor,' 'nutrient-caused factor,' and 'redox reaction-caused factor' based on TCSC, though the discriminant capacity was only 17.7% of the total variance.

Figures 2 and 3 represent scatterplots of the three CDFs, to distinguish the four types of habitat. It shows significant classification effects of sediment properties among *U. formosensis* living habitat and other habitats. From Fig. 2, CDF_1 shows that the greatest differences in sediment properties were between *U. formosensis* habitats and herbaceous plant areas. CDF_2 shows that the greatest differences in sediment properties were between *U. formosensis* habitats and mangrove areas. CDF_3 shows that the greatest differences in sediment properties were between *U. formosensis* living habitats and bare areas (Fig. 3).

Regarding the other important discriminant variables affecting *U. formosensis* habitats, Table 2 shows that P(20) in herbaceous plant areas was higher than in mangrove areas and *U. formosensis* living habitats. The comparatively higher OBD in herbaceous plant areas and bare areas was due to higher sand content, and this would cause a lower soil EC but better discharge and lower soil water content. This results in a hard substratum that is difficult for *U. formosensis* to excavate. Higher clay content and soil porosity would result in higher water retention capacity and enable easier excavation in mangrove areas and *U.*

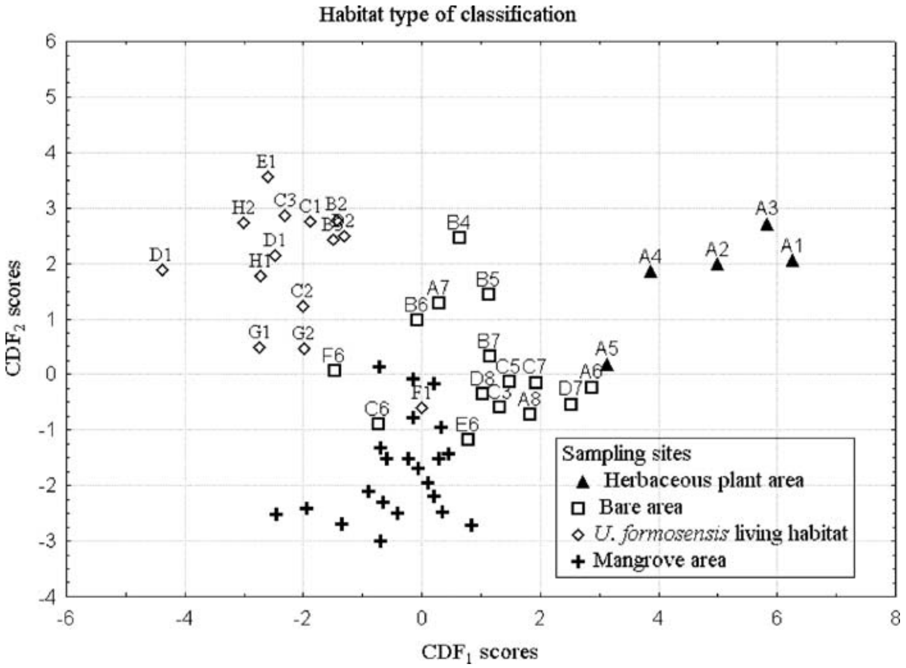

Fig. 2 Scatterplot of the first two canonical discriminant functions (CDF$_1$ and CDF$_2$) in Hsiang-Shan wetland

formosensis living habitats. The average height of *U. formosensis* chimneys is 9.2 cm (highest 14.0 cm) and its burrows are 10 cm to 1 m deep (Shih et al. 2005). Clay content is the most important factor in the construction of chimneys and burrows, and a high soil penetration force increases the difficultly of digging burrows. Croll and McClintock (2000) revealed no significant differences between opened and vegetation-covered areas of marshes that might influence choice of burrow location, besides particle constituents. *U. formosensis* preferred inhabiting areas with soil of a high clay content and moderate soil penetration force.

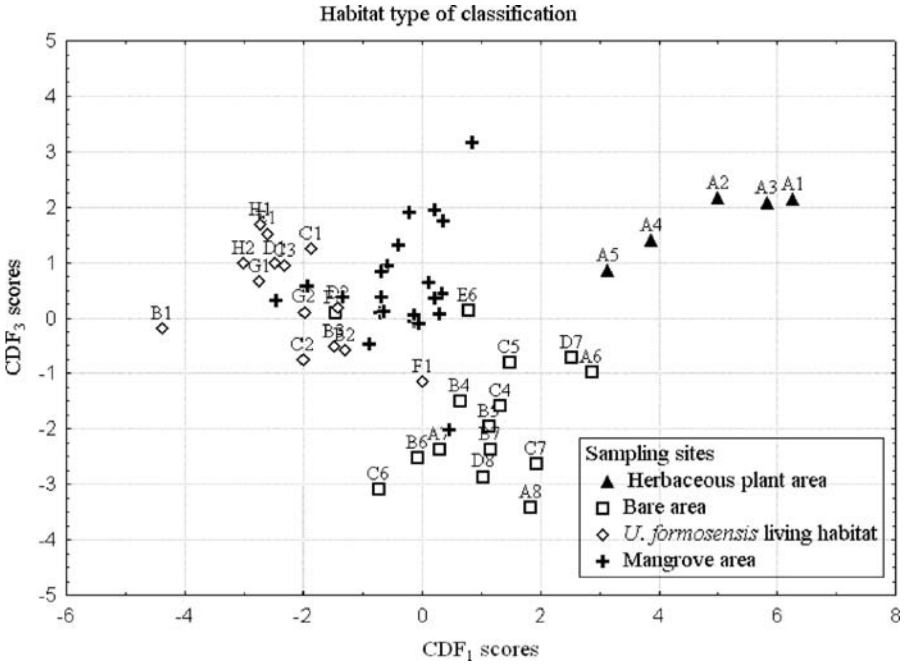

Fig. 3 Scatterplot of the second two canonical discriminant functions (CDF$_1$ and CDF$_3$) in Hsiang-Shan wetland

In mangrove areas, the dominant species *U. arcuata* is present in significantly greater numbers than *U. formosensis*. *U. arcuata* is found throughout eastern Asia. Controlling habitat characteristics, especially sediment properties to ensure stable living habitats, is the most important aspects of the conservation and restoration of *U. formosensis* habitats. Considering this study and previous research, we suggest keeping some areas of low-density herbaceous plants to assess the influence of herbaceous plants on *U. formosensis* in the future. In this habitat, the main water resources were tidal variation, the San-Shing-Gong River, and the Dah-Juang River. Changing hydrology and water quality will affect sedimentation and flushing in the mudflat area when the wastewater treatment facility is constructed. *U. formosensis* inhabits Hsiang-Shan wetland on the riverside of San-Shing-Gong River, but further investigation is necessary to confirm whether a similar habitat exists for conservation on the 10-km long seashore. Furthermore, studies of the abundance and distribution of *Uca* spp. will help in understanding the relationship between *Uca* spp. and sediment properties.

Conclusions

CDA was proven a useful tool for classifying types of habitat in the present study, which identified physical and chemical properties of sediment in Hsiang-Shan wetland, Taiwan. The method can be used to establish a feasible conceptual model of the relationships between soil properties and types of habitat. Furthermore, considering the three constructed linear discriminate functions, the main factor are soil texture-caused factor, ocean current-caused factor, nutrient-caused factor, and the redox reaction-caused factor. And the most significant variables in this habitat followed the descending order: OBD, EC, Eh, sand, TN, porosity, STP, silt, VCP and pH in the first three discriminant function. Controlling these discriminate variables will enable Hsiang-Shan wetland to be managed, and a biodiverse habitat to be created and supported. To conserve and restore a habitat for the endemic and endangered fiddler crab *U. formosensis,* we summarize the preferences living conditions as below.

1. The inhabited soil properties for *U. formosensis* in terms of soil texture were 34.05% sand, 29.72% silt, and 32.35% clay: that is, it preferred clay loam soil. The soil porosity of the *U. formosensis* living habitat (75.65%) was the highest among the four types of habitat.
2. STP was 8.41%, significantly lower than in the other habitats, showing that *U. formosensis* prefers the upper intertidal zone.
3. VCP was 2.20% in *U. formosensis* living habitats, similar to that in bare areas but significantly lower than that in mangrove and herbaceous plant areas. This shows that *U. formosensis* prefers bare intertidal habitats.
4. A high soil penetration force increases the difficultly of excavating burrows. In this study, P(20) was 45.98 N/cm^2.
5. Construction of wastewater treatment facilities on the mudflat habitats of *U. formosensis* must be avoided.

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