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4	Baseline for ostracod-based northwestern Pacific and Indo-Pacific shallow-
5	marine paleoenvironmental reconstructions: ecological modeling of species
6	distributions
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- 28 Abstract:

29 Fossil ostracods have been widely used for Quaternary paleoenvironmental 30 reconstructions especially in marginally marine environments (e.g. for water depth, 31 temperature, salinity, oxygen levels, pollution). But our knowledge of the autoecology 32 of indicator species, the base of paleoenvironmental reconstructions, remains limited 33 and commonly lacks robust statistical support and comprehensive comparison with 34 environmental data. We analysed marginally marine ostracod taxa at 52 sites in Hong 35 Kong for which comprehensive environmental data are available. We applied linear 36 regression models to reveal relationships between species distribution and 37 environmental factors, and identified indicator species of environmental parameters. 38 For example, Sinocytheridea impressa and Neomonoceratina delicata indicate 39 botttom-water hypoxia - eutrophication, and heavy-metal pollution - increased 40 turbidity, respectively. Many taxa are widespread throughout the northwestern Pacific 41 - Indo-Pacific regions, including temperate (South China Sea to Japan and Russia), 42 subtropical (i.e., Indo-Pacific to the East China Sea), and tropical (i.e., Indo-Pacific 43 and South China Sea) taxa. With statistical support from ecological modeling and 44 comprehensive environmental data, These results provide a robust baseline for 45 ostracod-based Quaternary-Anthropocene paleoenvironmental reconstructions in the 46 tropic-extratopic northwestern Pacific and Indo-Pacific.

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48 Key words: Autoecology, Distribution modeling, Indicator species, Ostracoda,

- 49 Paleoenvironmental reconstruction, Proxy.
- 50





51 Key points

- 52 1. We provide a robust baseline for ostracod (microscopic Arthropods) based
- paleoenvironmental reconstructions from Quaternary and Anthropocene marginalmarine sediments.
- 55 2. The studied species have wide distributions over the tropics and extratropics of the
- 56 northwestern Pacific and Indo-Pacific.
- 57 3. Ecological modeling established reliable indicator ostracod species for58 paleoenvironmental reconstructions.
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62 1. Introduction

Because of their small size, high abundance and excellent fossil record, fossil 63 64 ostracods (microcrustaceans), have been widely used to reconstruct Quaternary 65 environmental conditions including water-depth, salinity, temperature, oxygen, and 66 pollution, especially in marginal marine sediments (Boomer & Eisenhauer, 2002; Cronin, 2015; Frenzel & Boomer, 2005; Horne et al., 2012; Ruiz et al., 2005). In the 67 68 northwestern Pacific and Indo-Pacific there are numerous, widely distributed deltas 69 (Woodroffe et al., 2006) hosting accumulated Holocene marine sediments. Many 70 studies have reconstructed the depositional environments of these sediments (Alberti 71 et al., 2013; Dong et al., 2012; Irizuki et al., 2015b; Tanaka et al., 2011; Yasuhara & 72 Seto, 2006; Yasuhara et al., 2005; Zhou et al., 2015). Due to high sedimentation rates 73 (> 1 cm per year), fossil ostracods allow high-resolution reconstructions of human-74 induced environmental changes (pollution, eutrophication, bottom oxygen depletion) 75 over the past century (Irizuki et al., 2011; Yasuhara et al., 2003).





77 Many have evaluated the autoecology of indicator species as the basis for the 78 paleoenvironmental reconstructions (Hazel, 1988; Irizuki et al., 2003; Ozawa et al., 79 2004; Stepanova et al., 2003; Wang et al., 1988; Yasuhara & Seto, 2006; Zhao, 1984; 80 Zhao & Wang, 1988a, 1988b). Yet these studies tend to focus on only one or few 81 targeted environmental factor(s) and lack rigorous statistical evaluation, particularly 82 statistical modeling, a common approach in contemporary ecology. This is probably 83 due to the facts that comprehensive environmental dataset are often unavailable and 84 an ecological modeling approach (especially regression modeling and model selection) 85 has not been common in the field of micropaleontology.

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87 Hong Kong is an ideal location for the marine ecological modeling approach 88 valid for the northwestern Pacific and Indo-Pacific, because of its extensive and 89 intensive marine environmental monitoring program, which provides robust datasets 90 for ecological modeling and its subtropical location, where tropical and temperate 91 species coexist, which allows investigations of species with different latitudinal and 92 geographical distributions. We employed regression modeling of Hong Kong 93 shallow-marine ostracod species to show statistical relationships between species 94 abundance, distribution and environmental factors. This study allows the autoecology 95 and statistical evaluation of common tropical and extratropical species, providing a 96 baseline for ostracod-based shallow-marine paleoenvironmental reconstructions of the 97 northwestern Pacific and Indo-Pacific regions.

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99 2. Study area





100 Hong Kong is situated at the southeastern corner of the Pearl River (Zhujiang) Delta, and has an area of 2500 km² (Fig. 1), at 22° 12.021' to 22° 33.817' N latitude, 113° 101 102 53.388' to 114° 26.920' E longitude. It is an ideal location to study natural and/or 103 anthropogenic impacts on benthic communities due to its complex hydrology and 104 long history of human influence. Western Hong Kong is affected by input from the 105 Pearl River, particularly during the summer heavy rainfall (Morton & Wu, 1975), 106 when salinity of the surface waters is strongly influenced by rainfall. Eastern Hong 107 Kong waters are mainly marine and derived from the South China Sea. As one of the 108 most urbanized coastal areas in the world, human activities, including rapid 109 industrialization, sewage discharge, trawling, dredging and land reclamation have led 110 to a deteriorated marine benthic ecosystem (Blackmore, 1998; Hodgkiss & Yim, 1995; Hong et al., 2017; Hu et al., 2008; Morton, 1996; Morton & Blackmore, 2001; Owen 111 112 & Sandhu, 2000; Shin, 1977; Tanner et al., 2000).

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114 **3. Materials and Methods**

115 **3.1. Samples and laboratory procedure**

116 In January and July of 2011 we used a Van Veen Grab to collect 100 ml of sediment 117 from the uppermost cm of the sea floor from 52 sites in Hong Kong marine waters 118 (Fig. 1; Supplement A), 41 of which are in open waters and 11 in typhoon shelter sites. 119 Typhoon shelters are semi-enclosed areas of water designed to protect moored vessels 120 in extreme weather (Environmental Protection Department, 2011). All sites are 121 included in the Hong Kong EPD marine water and sediment quality monitoring 122 program, which has been conducted monthly since 1986 (for water) and biannually 123 (for sediment), providing comprehensive environmental data for all stations (see 124 below).





125 Sediments were wet-sieved over a 63 µm mesh sieve and air dried or oven-126 dried at 40 °C. The residue was dry-sieved over a 150 µm mesh sieve, and ostracod 127 specimens larger than 150 µm were picked; smaller individuals were not included to 128 avoid problems of identification in small, early instar juveniles. In samples containing 129 fewer than 200 specimens, we picked all individuals. If there were more than 200 130 specimens, we picked ostracods from a split. We identified each counted specimen to 131 species level when possible. We considered both an entire carapace or a single valve 132 as one individual for counting.

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134 **3.2 Environmental Variables**

135 We selected parameters from the EPD monitoring program (Table 1) for our 136 regression modeling (see below), including surface productivity (Chlorophyll-a, Chl; 137 Fig. 2), water depth (D; Fig. 2), bottom water dissolved oxygen (DO; Fig. 2), bottom 138 water salinity (Sal; Fig. 2), turbidity (Tur; Fig. 2), summer bottom water temperature 139 (ST - June to September average; Fig. 2), winter bottom water temperature (WT -140 November to Feburary average; Fig. 2), mud content (MD; Fig. 2), and heavy metal 141 concentration (Cu, Zn, and Pb; Fig. 3). These parameters are known to control 142 ostracod faunal properties (Cronin, 2015; Cronin & Vann, 2003; Hazel, 1988; Ikeya 143 & Shiozaki, 1993; Irizuki et al., 2005; Ruiz et al., 2005; Yasuhara et al., 2007; 144 Yasuhara et al., 2012b). We used averages over the entire monitoring period (1986-145 2011), because the ostracods in this study were mostly dead shells, thus the samples 146 should be considered time averaged. Bottom water DO is the average of the summer 147 season (June-September), due to the likely importance of summer bottom water 148 oxygen depletion.

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150 **4. Regression modeling**

Multiple linear regression modeling was used to determine the relationship between common ostracod species (relative abundance of each species) and environmental parameters (Supplement B). All environmental parameters were log-transformed and zero centered. Salinity outliers (salinity <25: DS2 and DS3) and samples with low abundance (<50 specimens: ES5, MS7, VS21, VS5 & VS6) were removed from the models.

157 The best-fitting models were selected based on Akaike's Information Criterion 158 (AICc) for small sample size, in which the lower score indicates the better model 159 support considering both goodness-of-fit and model complexity (Anderson & 160 Burnham, 2002). Akaike weights were used to summarize proportional support for all candidate models (Anderson et al., 2000) (Table 2). We considered parameter 161 162 estimates averaged over models, proportional to the support that each model received 163 (Anderson et al., 2000) (Table 3). This approach accounts for the uncertainty in model 164 selection and thus leads to appropriately broader confidence intervals than obtained 165 by relying only on the single, best-supported model. The relative importance of 166 various predictor variables was measured by the sum of Akaike weights of models 167 that included the variables in question (Brunham & Anderson, 2002).

We explored linear dependencies by computing variance inflation factors (VIF) (Legendre & Legendre, 1998) and pairwise correlations between predictor variables to assess whether multicollinearity was likely to influence regression results (Yasuhara et al., 2012b). The degree of freedom is more than one for the geographic region variable (see below), thus we computed generalized variance inflation factors (GVIF). For continuous variables, GVIF (Table 4) is the same as VIF, but for categorical variables, GVIF has degrees of freedom (Df) equal to the number of





175 coefficients associated with it (Hendrickx et al., 2004). Thus, we used GVIF^{1/2df} to 176 make GVIF values comparable among those with different Df. VIF >20 is usually 177 indicative of high collinearity (Legendre & Legendre, 1998). Thus we calculated an equivalent threshold of 4.47 (equal to $\sqrt{20}$) for GVIF^{1/2df} to assess conlinearity. Also, 178 adjusted $R^2 > 0.8$ indicates a strong correlation of variables (Hoffman, 2015). In all 179 180 datasets, summer temperature (ST) and water depth (D) were highly correlated 181 $(R^2=0.8217)$, and the GVIFs of ST and Cu are >20, indicating that these correlations 182 may influence regression results. Thus, we re-ran the linear regression modeling 183 without ST and Cu. The new GVIFs of all variables were under 4.47 (Table 4).

We considered the degree of spatial autocorrelation in model residuals by the calculation of Moran's *I* index for the five best models. The neighborhood size was set as 2, 5, 10, 20 and 50 km. We found significant spatial autocorrelation in model residuals for many cases, thus we forced the geographic region variable (R) (Water Control Zones defined by EPD) to be included in all models. After this treatment, spatial autocorrelation was detected only in a few models for *Propontocypris* spp., *Stigmatocythere roesmani*, and *Hemikrithe orientalis*.

191 The multiple linear regression model analyses were implemented in R 192 programming language (R Core Team, 2016). We used 'M_UMI_N' (Bartoń, 2013) for 193 model averaging and 'SPDEP' (Bivand & Piras, 2015) to measure spatial 194 autocorrelation.

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196 5. Results and discussions

197 The comprehensive ostracod dataset for the 52 sites and the environmental variables 198 enabled us to elucidate distribution patterns of common ostracod taxa and their related 199 environmental factor(s). We identified 151 species belonging to 76 genera





200 (Supplement A). Among them, 18 common taxa (mainly species, a few genera) of 201 Sinocytheridea impressa, Neomonoceratina delicata, Propontocypris spp., 202 Pistocythereis bradyi, Bicornucythere bisanensis s.l., Keijella kloempritensis, 203 Nipponocythere bicarinata, Spinileberis quadriaculeata, Xestoleberis spp., 204 Loxoconcha malayensis, Neonesidea spp., Neosinocythere elongata, Stigmatocythere 205 roesmani, Phlyctocythere japonica, Alocopocythere goujoni, Hemikrithe orientalis, 206 Loxoconcha epeterseni and Hemicytheridea reticulata (Supplement B) were used for 207 regression modelling, and their relative abundances (to the total ostracod abundance in a sample) show a significant relation with environmental parameters. The best three 208 209 regression models are presented in Table 2 and the model-averaged parameter 210 estimates in Table 3.

Relative abundance of S. impressa [=Sinocytheridea latiovata; see Whatley 211 212 and Zhao (1988a)] was strongly correlated with salinity (negative), dissolved oxygen 213 (negative), mud content (positive) and productivity (positive) (Tables 2 and 3). The 214 species is noticeably dominant in areas characterized by a muddy bottom including 215 northern Mirs Bay, Port Shelter and coastal Southern Waters (Fig. 4). This species is 216 also abundant in Tolo Harbour, an area known for its summer hypoxia and 217 eutrophication (Hu et al., 2001; Sin & Chau, 1992). These results are consistent with 218 previous studies indicating that S. impressa is dominant in low salinity, nutrient-rich 219 and turbid estuaries (Irizuki et al., 2005; Tanaka et al., 2011), but we did not see a 220 significant relation with turbidity (Tables 2 and 3). S. impressa is known as a 221 euryhaline species widely distributed throughout the East and South China Seas 222 [abundant in water depths of <20 m; Whatley and Zhao (1988a)], and the Indo-Pacific 223 (Fig. 7).





224 Relative abundance of N. delicata (=Neomonoceratina crispata; see Hou & 225 Gou, 2007) is significantly correlated with Zn (positive), salinity (positive) and 226 turbidity (positive) (Tables 2 and 3). N. delicata is a nearshore species, abundant at 227 depths less than 30 m, at relatively high salinities (>30; Zhao and Wang, 1988). N. 228 delicata prefers higher salinity waters in Hong Kong (Figs. 2 and 4; Tables 2 and 3), 229 and is likely tolerant to human-induced environmental stress such as pollution and 230 eutrophication, in view of its positive correlation with Zn and turbidity. This species 231 is widely known from nearshore and estuary environments in the East and South 232 China Seas, and the Indo-Pacific (Fig. 7).

233 Relative abundance of B. bisanensis s.l. was significantly correlated with 234 water depth (negative) (Tables 2 and 3) and this species prefers shallower 235 environments (Figs. 2 and 4). In Chinese and Japanese coastal areas, B. bisanensis s.l. 236 is abundant in brackish water (salinity: 20-30) at depths less than 10 m (Ikeya & 237 Shiozaki, 1993; Irizuki et al., 2006; Zhao et al., 1986). Our results confirm its 238 preference for shallow depths. Bicornucythere bisanensis is tolerant of anthropogenic 239 impacts, especially eutrophication and the resulting bottom water hypoxia in Japan (Irizuki et al., 2003; Yasuhara et al., 2003; Yasuhara et al., 2012a). We did not see a 240 241 significant relation between relative abundance and metal concentration, productivity, 242 or dissolved oxygen. Possibly, the more dominant presence of S. impressa and N. 243 delicata, that are neither dominant or distributed throughout most of Japan, could 244 explain this difference. These species may have a higher tolerance than B. bisanensis 245 s.l. Another explanation may be that different morphotypes have different ecological 246 preferences (Abe, 1988), and only Form A is known to be tolerant to eutrophication 247 and bottom-water oxygen depletion (Irizuki et al., 2011; Irizuki et al., 2015a; 248 Yasuhara & Yamazaki, 2005; Yasuhara et al., 2007). Form A is less abundant in





Hong Kong, and due to the difficulty of identification of juveniles, we did not divide *B. bisanensis* into morphotypes. *B. bisanensis* s.l. is widely distributed throughout
marginal marine environments around Japan and Russia, and the East and South
China Seas (Fig. 7).

253 Relative abundance of *P. bradyi* was highly correlated with salinity (positive), 254 water depth (negative) and Pb (negative) (Tables 2 and 3). This indicates the species 255 prefers relatively shallow environments with high salinity (Figs. 2 and 4). In the Pearl 256 River Delta and shallow South China Sea (Fig. 7), P. bradyi is dominant along the 257 inner continental shelf at water depths <100 m (mostly common between 10-50 m), 258 and at salinities from 30-40 (Li, 1985; Zhao & Wang, 1990; Zhao et al., 1986). 259 Pistocythereis bradyi is a typical middle muddy bay species in Japan (Irizuki et al., 260 2006; Yasuhara & Irizuki, 2001; Yasuhara & Seto, 2006), and known from open bays 261 such as Gamagyang Bay in Korea (Abe, 1988) and Malacca Strait (Whatley & Zhao, 262 1988b). In these studies, P. bradyi prefers relatively high salinity and deeper water in 263 the inner continental shelf (Tables 2 and 3). Our data agree as to the preference for 264 high salinity, but we find shallower depths, inconsistent with the literature. Maybe 265 salinity is more important than depth, but the restricted depth range of our sites (\leq 35 266 m) may also be a reason for this inconsistency. Our results indicate that P. bradyi is 267 sensitive to metal pollution. This species is widely distributed throughout the 268 marginally marine environments of Japan, the East and South China Seas, and the 269 Indo-Pacific (Fig. 7).

270 Relative abundance of *N. bicarinata* was correlated with productivity
271 (negative) (Tables 2 and 3). This is a typical middle bay species in Japan (Irizuki et al.,
2006), abundant on muddy substrates at water depths > 10 m (Yasuhara & Seto, 2006;
273 Yasuhara et al., 2005). We found *N. bicarinata* to be sensitive to eutrophication.





274 prefering lower productivity (Figures 2, 4). This species is know from marginal

275 marine environments around Japan and the East and South China Seas (Fig. 7).

276 Relative abundance of S. *quadriaculeata* is correlated to productivity (positive) 277 and turbidity (negative). This is a typical inner muddy bay species in Japan (Irizuki et 278 al., 2006), which prefers silty substrates in brackish waters, at salinities from 20–30, 279 and water depths of 2–7 m (Ikeya and Shiozaki, 1993). This study shows a preference 280 for waters with higher productivity but relatively low turbidity (Tables 2 and 3), so 281 that the species is abundant in Tolo Harbour (higher productivity, lower turbidity) but 282 not in Deep Bay (higher turbidity) (Figs. 2 and 4). Spinileberis quadriaculeata is not 283 tolerant to seasonal anoxia or oxygen depletion (0-1 mg/L) in Uranouchi Bay, Japan 284 (Irizuki et al., 2008), but we do not find a significant correlation with dissolved 285 oxygen content, probably due to the relatively high bottom-water oxygen content 286 (2.96-6.84 mg/L) in Hong Kong (Fig. 2; Supplement B). S. quadriaculeata is widely 287 distributed in marginally marine environments around Japan and Russia, and the East 288 and South China Seas (Fig. 7).

289 Relative abundance of K. kloempritensis was correlated only with water depth 290 (positive) (Fig. 4; Tables 2 and 3). Keijella kloempritensis is widely known from the 291 tropical Indo-Pacific region, and abundant along the inner continental-shelf of the 292 South and East China Seas (Fig. 7), at water depths range from 20-50 m and salinity 293 is close to normal marine (Zhao & Wang, 1990). Our modelling results are consistent 294 with this showing a preference for relatively deeper water in this study (Tables 2 and 295 3). Thus, this species is probably useful for reconstructing past sea-level changes in 296 the broad tropical and subtropical Indo-Pacific and northwestern Pacific regions.

297 Relative abundance of *L. malayensis* was correlated with dissolved oxygen
298 (negative) and mud content (negative) (Tables 2 and 3). *Loxoconcha malayensis* is a





299	typical tropical species known from the Indo-Pacific and the South China Sea (Fig. 7).
300	We did not find a correlation to temperature, likely due to the small range of variation
301	of bottom water temperatures in Hong Kong (winter temperature: 19.10-21.49°C).
302	This species prefers coarse sediments and is resistant to low oxygen content (Table 2
303	and 3), as seen by its abundance in Victoria Harbour (Figs. 2 and 4).
304	Relative abundance of <i>N. elongata</i> was correlated only with turbidity (positive)
305	(Tables 2 and 3). Neosinocythere elongata occurs along the entire coast of China (Fig.
306	7) in marginal marine, especially estuarine, environments shallower than 20 m (Dong
307	et al., 2012; Hou & Gou, 2007; Liu et al., 2013; Liu et al., 2017; Zhao & Whatley,
308	1993) and is known from the Indo-Pacific region (Fig. 7). Our modeling results and
309	previous studies indicate consistently that N. elongata prefers shallow, turbid waters
310	like Deep Bay and the Pearl River Estuary (Figs 2 and 6).
311	Relative abundance of S. roesmani was correlated with Pb (negative) (Tables
312	2 and 3), thus it was sensitive to metal pollution (but note the significant
313	autocorrelation with the modeling result of this genus) and absent in areas with high
314	metal concentrations, e.g., Tolo and Victoria Harbours (Fig. 3, 6). This species occurs

315 in the East and South China Seas and the Indo-Pacific region (Dewi, 1997; Mostafawi,

316 1992; Whatley & Zhao, 1988a) (Fig. 7).

317 Relative abundance of *P. japonica* was correlated with water depth (positive) 318 (Tables 2 and 3). This species is known from relatively deeper waters (>40 m) in the 319 East China Sea (Ishizaki, 1981; Wang et al., 1988). At our sites, it has its greatest 320 abundance at the deeper southern sites (Fig. 5). Phlyctocythere japonica is distributed 321 around Japan (Yasuhara et al., 2002) and the East and South China Seas (Fig. 7). 322 Relative abundance of A. goujoni was correlated with salinity (positive)

323 (Tables 2 and 3). It occurs not only in Mirs Bay where the salinity is higher, but also





324 in Deep Bay and North Western Waters where the salinity is lower than in other areas 325 (Figs 2 and 6). The Deep Bay and North Western Waters are shallow and have 326 relatively low oxygen content. The modeling result of this species shows a marginally 327 insignificant but negative relationship to oxygen content and water depth with 328 moderately high relative importance (Table 3). We explain this inconsistency by 329 considering their preference of higher salinity and shallow water depths, and also their 330 resistance to low oxygen conditions, but further research is needed to know their 331 autoecology with better confidence. Alocopocythere goujoni is known from the South 332 China Sea and the Indo-Pacific (Fig. 7).

333 Relative abundance of *H. orientalis* was correlated with water depth (positive) 334 (Tables 2 and 3; but note the significant autocorrelation with the modeling result of 335 this genus), and it is more abundant in deeper waters including southern Mirs Bay 336 (Fig. 5). Hemikrithe orientalis is known from depths of 20-50 m in the South China 337 Sea (Zhao & Wang, 1988a), and reported from tropical Indo-Pacific marginal marine 338 environments (Fig. 7). Our regression modeling consistently shows a positive 339 relationship between the relative abundance and winter temperatures, with moderately high relative importance, although the correlation is marginally insignificant (Table 3). 340 341 Relative abundance of L. epeterseni was correlated with water depth (positive) 342 and turbidity (negative) (Tables 2 and 3), and its occurs in the southern and eastern, 343 deeper and less turbid parts of Hong Kong waters, but the trend is not very clear (Figs 344 2 and 6). This species is also known from the deeper parts of Osaka Bay, Japan 345 (Yasuhara & Irizuki, 2001) and from marginal marine environments around Japan 346 (Ishizaki, 1968), the East China Sea (Yang et al., 1982), and the South China Sea 347 (Cao, 1998) (Fig. 7). This species is reported as Loxoconcha modesta in Hou & Gou 348 (2007), and also has been misidentified as Loxoconcha viva and Loxoconcha sinensis





349 (Hou & Gou, 2007). Ishizaki (1968) described Loxoconcha laeta and Loxoconcha

350 *modesta* but in our opinion, these are the females and males of the same species.

351 Ishizaki (1981) gave the new species names *Loxoconcha epeterseni* and *Loxoconcha*

352 *tosamodesta* for *Loxoconcha laeta* and *Loxoconcha modesta*, respectively, because

353 these names were junior homonyms. Since *Loxoconcha laeta* (= *epeterseni*) appears

354 earlier than *Loxoconcha modesta* (=tosamodesta) in the original description (Ishizaki,

355 (1968), we use the name *Loxoconcha epeterseni* for this species.

356 Relative abundance of H. reticulata was correlated with Pb (negative) and 357 water depth (negative) (Tables 2 and 3). This species is abundant in Tolo Harbour 358 and the inner part of Mirs Bay (Fig. 5), at shallow depths, and is also consistently 359 found in very shallow waters from the Indo-Pacific (Zhao & Whatley, 1989). Their 360 metal-pollution sensitivity is contradictory because they occur in Tolo and Victora 361 Harbours, both polluted regions of Hong Kong, and further research is needed to 362 better understand these results (Figs 2 and 6). Hemicytheridea reticulata is distributed 363 in the East China Sea (Gu et al., 2017), the South China Sea, and the Indo-Pacific (Fig. 364 7).

365 (The relative abundance of the cosmopolitan *Neonesidea* spp. was correlated)
366 (with dissolved oxygen (positive), as expected for a phytal species) (Smith & Kamiya,
367 2002; Yamada, 2007) (Table 2 and 3; Fig 6).

The relative abundance of the cosmopolitan *Propontocypris* spp. was strongly correlated with productivity (negative) (Tables 2 and 3). This negative correlation with productivity (but note the significant autocorrelation with the modeling result of this genus) indicates that the genus prefers less eutrophic waters (Fig. 6). *Propontocypris* is a good swimmer (Maddocks, 1969), and thus may have an advantage in obtaining food in relatively food-limited environments.





<mark>374</mark>	The relative abundance of the cosmopolitan phytal (Irizuki et al., 2008; Sato &

- 375 Kamiya, 2007; Yasuhara et al., 2002) *Xestoleberis* spp. was correlated with turbidity
- 376 (negative), mud content (negative), and dissolved oxygen (positive) (Table 2 and 3;
- 377 Fig. 6). The taxon's habitats including clear water, coarse sediment, and high oxygen
- 378 content are reflected in our modeling.

379

380 Summary

381 Benthic ostracods from Hong Kong marginal marine waters studied here include 382 widespread (i.e., distributed throughout the northwestern Pacific - Indo-Pacific region: 383 one species), temperate (i.e., distributed from the South China Sea to Japan and 384 Russia: five species), subtropical (i.e., distributed from the Indo-Pacific to the East 385 China Sea: six species), and tropical (i.e., distributed in the Indo-Paficic and South 386 China Sea: three species) species and three globally distributed genera (Fig. 7). We 387 provide a robust baseline of autoecology for these common ostracod taxa based on rigorous statistical modeling using comprehensive environmental data. We 388 389 established reliable indicator forms for water depth, mud content, salinity, turbidity, 390 dissolved oxygen, heavy metal pollution (Pb and Zn) and eutrophication (chlorophyll-391 a) (Table 5). Thus our results are applicable for future ostracod-based 392 paleoenvironmental studies in a wide range of localities from the tropics to the 393 extratropics, and from the Indian Ocean to the northwestern Pacific. We established 394 pollution and eutrophication indicator species in tropical environments for the first 395 time. Anthropocene paleoenvironmental and paleoecological studies in the tropics are 396 urgently needed because (1) the tropics are seriously under-studied (Wilkinson et al., 397 2014; Yasuhara et al., 2012a), (2) tropical environments and ecosystems are 398 vulnerable and sensitive to human influences (Jackson et al., 2001; Pandolfi et al.,





- 2003), and (3) Indo-Pacific tropical environments have been seriously degraded by
 the human activity of rapidly developing countries (Bellwood et al., 2004; Jackson,
 2008; Knowlton & Jackson, 2008). Our results provide useful and reliable tools for
 tropical Anthropocene research in the broad Indo-Pacific region.
- 403

404 Acknowledgement

405 We thank the Environmental Protection Department of Hong Kong, especially K. 406 Yung, for support; L. Wong, C. Law, M. Lo, and the staff of the Electronic 407 Microscope Unit of the University of Hong Kong for their technical support; B. Lin, S. 408 Wang, R. Mak and V. Wang for helping sampling; P. Frenzel, M. Warne, E. Thomas, 409 O. Friedrich for valuable comments on an early version of the manuscript. The data 410 used are listed in the tables and supplements. The work described in this paper was 411 partially supported by the Environment and Conservation Fund of Hong Kong 412 (project code: 19/2012), the General Research Fund of the Research Grants Council of Hong Kong (project code: HKU 17303115), the Early Career Scheme of the 413 414 Research Grants Council of Hong Kong (project code: HKU 709413P), and the Seed 415 Funding Programme for Basic Research of the University of Hong Kong (project 416 codes: 201111159140, 201611159053) (to MY).

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419	References: Irizuki et al. (2006); Zhao and Wang (1988a, 1988b, 1990); Zhao and
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<mark>421</mark>	2007; Irizuki et al., 2009; Jie et al., 2013; Li, 1985; Tanaka et al., 2009; Wang & Zhao,
422	1985; Wang & Zhang, 1987; Zhao, 1984; Zhao & Wang, 1988b; Zhao & Whatley,





- 423 (1989; Zhou et al., 2015)(Noraswana et al., 2014)(Whatley & Zhao, 1988b)(Tanaka et
- 424 al., 2011)(Zhao & Whatley, 1993)(Pugliese et al., 2006)(Hussain et al., 2004; Nishath
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728 Captions

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730 Fig. 1 Locality map showing the 52 sampling sites across Hong Kong, including 41 731 open water sites (blue dots) and 11 typhoon shelter sites (red open dots). From west to 732 east, DS: Deep Bay; NS: North Western waters; SS: Southern waters; VS: Victoria 733 Harbour; ES: Eastern Buffer; JS: Junk Bay; TS: Tolo Harbour; PS: Port Shelter; MS: 734 Mirs Bay. 735 736 Fig. 2 Spatial distribution of environmental parameters in Hong Kong. Mean surface-737 water chlorophyll-a concentration; water depth; summer (June to September) bottom-738 water dissolved oxygen content; mean bottom-water salinity; mean turbidity; mean 739 summer (June to September) bottom-water temperature; mean winter (November to 740 February) bottom-water temperature; and mean mud content. All are averaged values 741 of the data obtained during 1986–2013 (Table 1). 742 743 Fig. 3 Spatial distribution of environmental parameters in Hong Kong. Mean copper 744 (Cu) concentration, mean lead (Pb) concentration, and mean zinc (Zn) concentration 745 in surface sediments. All are averaged values of the data obtained during 1986-2013 746 (Table 1). 747 748 Fig. 4. Spatial distribution of the relative abundance of Sinocytheridea impressa, 749 Neomonoceratina delicata, Bicornucythere bisanensis s.l., Pistocythereis bradyi, 750 Nipponocythere bicarinata, Spinileberis quadriaculeata, Keijella kloempritensis, and 751 Loxoconcha malayensis in Hong Kong. See Figure 1 for sampling stations. 752 753 Fig. 5. Spatial distribution of the relative abundance of Neosinocythere elongata, 754 Stigmatocythere roesmani, Phlyctocythere japonica, Alocopocythere goujoni,





755 Hemikrithe orientalis, Loxoconcha epeterseni, Hemicytheridea reticulata and

- *Neonesidea* spp. in Hong Kong. See Figure 1 for sampling stations.
- 757
- Fig. 6. Spatial distribution of the relative abundance of *Propontocypris* spp., and *Xestoleberis* spp. in Hong Kong. See Figure 1 for sampling stations.
- 760

761 Fig. 7. Geographical distributions of the 18 taxa in the northwestern Pacific and Indo-762 Pacific regions, including Sinocytheridea impressa, Neomonoceratina delicata, 763 Pistocythereis bradyi, Bicornucythere bisanensis s.l., Keijella kloempritensis, 764 Nipponocythere bicarinata, Spinileberis quadriaculeata, Loxoconcha malayensis, 765 Neosinocythere elongata, Stigmatocythere roesmani, Phlyctocythere japonica, 766 Alocopocythere goujoni, Hemikrithe orientalis, Loxoconcha epeterseni, 767 Hemicytheridea reticulata, Neonesidea spp., Propontocypris spp., and Xestoleberis 768 spp. The following references were used mainly to determine the geographical 769 distributions of the species: Al Jumaily and Al-Sheikhly (1999); Dewi (1997); Dong 770 et al. (2012); Fauzielly et al. (2013); Hong et al. (2017); Hou and Gou (2007); 771 Hussain et al. (2004); Hussain et al. (2010); Hussain and Mohan (2000, 2001); Irizuki 772 et al. (2006); Irizuki et al. (2009); Iwatani et al. (2014); Jie et al. (2013); Li (1985); 773 Mostafawi (1992); Nishath et al. (2017); Noraswana et al. (2014); Pugliese et al. 774 (2006); Schornikov et al. (2014); Tanaka et al. (2009); Tanaka et al. (2011); Wang et 775 al. (1988); Wang and Zhang (1987); Wang and Zhao (1985); Zhao (1984); Zhao and 776 Wang (1988a, 1988b, 1990); Zhao and Whatley (1993); Zhou et al. (2015).

777

778 Table 1. Summary of marine water/sediment parameters. Note: 1. Summer: June,

July, August and September. 2. Winter: November, December, January and February.





780

781	Table 2. Best three regression models of the relative abundance of common species,
782	including Sinocytheridea impressa, Neomonoceratina delicata, Propontocypris spp.,
783	Pistocythereis bradyi, Bicornucythere bisanensis s.l., Keijella kloempritensis,
784	Nipponocythere bicarinata, Spinileberis quadriaculeata, Xestoleberis spp.,
785	Loxoconcha malayensis, Neonesidea spp., Neosinocythere elongata, Stigmatocythere
786	roesmani, Phlyctocythere japonica, Alocopocythere goujoni, Hemikrithe orientalis,
787	Loxoconcha epeterseni and Hemicytheridea reticulata. The table shows the
788	coefficient of each term, adjusted R ² , the Akaike information criterion corrected for
789	small sample size (AICc), and the Akaike weight (AW). Bold denotes significance at
790	P < 0.05. Overall P is < 0.05 in all models. R: region. Other abbreviations are found in
791	Table 1

792

793 Table 3. Model-averaged parameter estimates and CIs of the relative abundance of 794 common species, including Sinocytheridea impressa, Neomonoceratina delicata, 795 Propontocypris spp., Pistocythereis bradyi, Bicornucythere bisanensis s.l., Keijella 796 kloempritensis, Nipponocythere bicarinata, Spinileberis quadriaculeata, Xestoleberis 797 spp., Loxoconcha malayensis, Neonesidea spp., Neosinocythere elongata, 798 Stigmatocythere roesmani, Phlyctocythere japonica, Alocopocythere goujoni, 799 Hemikrithe orientalis, Loxoconcha epeterseni and Hemicytheridea reticulata. CIs, 800 confidence intervals; RI, relative importance (the sum of the Akaike weights of 801 models that include the variable in question; see Materials and Methods); R, region. 802 Other abbreviations are found in Table 1. Bold denotes CIs that exclude zero. For R, 803 coefficient, lower CI, and upper CI values shown are averages of those for geographic 804 regions.





805	
806	Table 4. GVIF value for Environmental Variables. Df, degree of freedom; R, region.
807	Other abbreviations are found in Table 1.
808	
809	Table 5. Summary of autoecology for common ostracod taxa. Chl: Chlorophyll-a; D:
810	Water Depth; DO: Dissolved Oxygen; MD: Mud Content; Sal: Salinity; Tur:
811	Turbidity; WT: Winter Temperature; Pb: Lead; Zn: Zinc; R: Region.
812	
813	
814	Supplement A. Ostracod faunal list.
815	
816	Supplement B. Dataset used for the regression modeling.

817















22'10°N 113'50°E











Lead (Pb) • 0-40 • 41-80 • 81-120 >120mg/kg























Fig. 4









Fig. 5













Fig. 7





Table 1.			
Parameter (Abbreviation)	Unit	Sampling Depth / Material	Season (AD. 1986-2013)
Chlorophyll-a (Chl)	μg/L	Surface water	All year
Water Depth (D)	m		All year
Dissolved Oxygen (DO)	mg/L	Bottom water	Summer ¹
Mud Content (MD)	%w/w (<63μm)	Bottom sediment	All year
Salinity (Sal)		Bottom water	All year
Turbidity (Tur)	NTU	Bottom water	All year
Summer Temperature (ST)	°C	Bottom water \bigvee	Summer ¹
Winter Temperature (WT)	°C	Bottom water	Winter ²
Copper (Cu)	mg/kg	Bottom sediment	All year
Lead (Pb)	mg/kg	Bottom sediment	All year
Zinc (Zn)	mg/kg	Bottom sediment	All year





Table 2.													
Model	Chl	D	DO	MD	Sal	Tur	WT	Pb	Zn	R	R^2	AICc	AW
Sinocythe	eridea in	npressi	7										
1	0.33		-1.47	0.75	-9.13					0.34	0.55	-37.29	0.27
2	0.41		-1.48		-8.75					0.37	0.50	-35.24	0.10
3			-1.12	0.94	-10.30					0.44	0.49	-34.78	0.08
Neomono	ceratina	a delica	ata										
1					3.77	0.34			0.41	-0.13	0.48	-82.57	0.29
2			0.43		5.02	0.31			0.39	-0.20	0.50	-81.21	0.15
3					3.47	0.33		-0.20	0.55	-0.12	0.48	-79.32	0.06
Proponto	<i>cypris</i> s	pp.											
1	-0.28			0.46						0.04	0.20	-72.47	0.15
2	-0.24									0.07	0.13	-71.74	0.10
3	-0.24			0.49			-2.46			0.02	0.22	-70.76	0.06
Pistocyth	ereis br	adyi											
1		-0.12			2.67			-0.21		-0.06	0.61	-163.64	0.52
2		-0.13			2.87	0.04		-0.20		-0.05	0.61	-159.79	0.08
3		-0.12	0.07		2.83			-0.21		-0.07	0.60	-159.42	0.06
Bicornucy	vthere b	isanen.	<i>sis</i> s.l.										
1		-0.09		-0.23						0.02	0.60	-137.80	0.12
2		-0.08								-0.01	0.56	-136.77	0.07
3				-0.29				0.18		0.00	0.58	-136.77	0.05
Keijella k	loempri	itensis											
1		0.06						-0.06		-0.02	0.56	-202.12	0.12
2		0.08								-0.02	0.53	-201.51	0.09
3		0.06		0.09				-0.08		-0.02	0.58	-200.86	0.06
Nipponoc	ythere l	bicarin	ata										
1	-0.07		-0.12							0.03	0.43	-200.57	0.11
2	-0.09									0.03	0.39	-200.38	0.10
3	-0.09	-0.03	-0.16							0.04	0.45	-199.30	0.06
Spinilebe	ris quad	lriacule	eata										
- 1	0.06					-0.09				-0.04	0.63	-183.88	0.10
2		-0.05								0.02	0.60	-182.94	0.06
3	0.08					-0.09	-0.75			-0.04	0.65	-182.66	0.05
Xestolebe	eris spp.												
1		0.04	0.15	-0.11		-0.08		0.05		-0.02	0.62	-225.55	0.09
2		0.03	0.15	-0.09		-0.09				-0.02	0.59	-225.29	0.08
3				-0.09		-0.06				0.00	0.52	-224.60	0.06





Model	Chl	D	DO	MD	Sal	Tur	WT	Pb	Zn	R	R^2	AICc	AW
Loxoconcha malayensis													
1		-0.03	-0.14	-0.12						0.03	0.55	-229.55	0.10
2	0.04		-0.13	-0.12						0.02	0.55	-229.42	0.09
3		-0.04	-0.14	-0.10				-0.04		0.03	0.57	-228.47	0.06
Neonesid	<i>ea</i> spp.												
1	-0.12			-0.25					0.19	0.05	0.28	-149.00	0.09
2	-0.11		0.33	-0.24			-1.13		0.20	0.05	0.31	-147.86	0.05
3			0.21							0.02	0.08	-147.40	0.04
Neosinoc	ythere e	longata	a										
1	-0.02					0.09				-0.03	0.76	-244.70	0.09
2				-0.06		0.08				-0.03	0.76	-244.42	0.08
3						0.09				-0.03	0.74	-244.15	0.07
Stigmatod	cythere i	roesma	ni										
1								-0.08		0.00	0.23	-225.23	0.07
2					0.36			-0.07		-0.02	0.25	-224.06	0.04
3			0.10		0.67			-0.07		0.30	0.30	-224.03	0.04
Phlyctocy	there ja	ponica											
1		0.04								0.00	0.28	-238.60	0.19
2		0.03			0.33					-0.02	0.30	-237.01	0.09
3		0.03						-0.02		0.00	0.27	-235.62	0.04
Alocopoc	ythere g	goujoni											
1	_	-			0.21					-0.04	0.68	-331.97	0.09
2		-0.01			0.28				-0.01	-0.04	0.71	-330.52	0.05
3		-0.01			0.27			-0.02		-0.04	0.71	-330.45	0.04
Hemikrith	he orien	talis											
1		0.03					0.46			0.00	0.19	-249.44	0.11
2		0.03	0.07							0.00	0.18	-248.67	0.07
3		0.04	0.06				0.42			0.00	0.23	-248.60	0.07
Loxoconc	ha epet	erseni											
1	*	0.03			-0.33	-0.03				0.01	0.49	-288.61	0.11
2	0.02	0.04		-0.04	-0.34	-0.04				0.00	0.56	-287.76	0.07
3	0.02	0.04			-0.34	-0.04				0.00	0.51	-287.31	0.06
Hemicyth	eridea 1	reticula	ta										
1		-0.03						-0.04		0.01	0.23	-270.79	0.14
2	0.02	-0.02						-0.04		0.01	0.26	-269.44	0.07
3	0.03							-0.03		0.00	0.19	-268.64	0.05





WT

Table 1	3.								
Term	RI	Coeffiencient	Lower CI	Upper CI	Term	RI	Coeffiencient	Lower CI	Upper CI
Sinocyt	heridea	ı impressa			Keijella	a kloemj	pritensis		
R	1.00	0.36	-0.09	0.81	R	1.00	-0.02	-0.09	0.04
Sal	0.99	-9.26	-14.61	-3.91	D	0.86	0.06	0.02	0.11
DO	0.91	-1.42	-2.48	-0.37	Pb	0.58	-0.08	-0.17	0.01
MD	0.75	0.82	0.07	1.57	Sal	0.35	0.68	-0.21	1.58
Chl	0.74	0.82	0.03	0.70	MD	0.25	0.08	-0.05	0.21
WT	0.20	0.82	-2.34	8.89	Tur	0.24	0.05	-0.03	0.14
Zn	0.13	0.82	-0.68	0.51	Chl	0.22	-0.04	-0.11	0.03
Tur	0.11	0.82	-0.61	0.30	Zn	0.17	0.02	-0.11	0.14
D	0.11	0.82	-0.29	0.41	WI	0.14	0.33	-0.55	1.22
Pb	0.10	0.82	-0.62	0.46	DO	0.11	0.03	-0.14	0.19
Neomo	nocerat	tina delicata	0.40	0.10	Nippon	ocyther	e bicarinata	0.04	0.00
K 7	1.00	-0.15	-0.42	0.12	K	1.00	0.02	-0.04	0.09
Zn	0.94	0.41	0.11	0.70	Cni	0.92	-0.08	-0.14	-0.02
Sal	0.93	4.00	1.00	/.13	DU	0.50	-0.14	-0.30	0.02
DO	0.84	0.33	0.00	1.00	D WT	0.30	-0.03	-0.08	0.02
DO	0.33	0.43	-0.17	0.20	W I Sol	0.23	-0.03	-0.08	0.02
PU MD	0.17	-0.18	-0.07	0.30	Sai	0.24	0.31	-0.55	1.50
D	0.14	0.23	-0.33	0.84	1ui 7n	0.19	-0.04	-0.11	0.04
D WT	0.11	-0.01	-0.22	2.60	ZII Ph	0.18	-0.04	-0.12	0.04
Chl	0.11	-0.80	-4.32	2.00	MD	0.13	-0.03	-0.11	0.00
-	0.09	0.00	-0.24	0.25		0.10	0.00	-0.15	0.15
Propon	tocypri:	s spp.	0.10	0.20	Spinile	beris qu	adriaculeata	0.10	0.07
K Chl	1.00	0.05	-0.19	0.30	K Tuu	0.00	-0.01	-0.10	0.07
	0.80	-0.26	-0.47	-0.04	Tur	0.00	-0.09	-0.1/	0.00
	0.58	0.50	-0.03	1.03		0.54	0.06	0.00	0.13
W I Dh	0.29	-2.00	-0.48	0.20	D WT	0.45	-0.03	-0.10	0.01
FU Sol	0.19	-0.18	-0.33	1.02	DO	0.32	-0.70	-1.82	0.31
	0.17	-1.48	-4.88	0.45	MD	0.19	0.10	-0.10	0.50
D0 7n	0.13	-0.27	-0.99	0.43	Ph	0.17	-0.07	-0.25	0.09
D	0.14	0.04	-0.17	0.41	7n	0.17	0.03	-0.09	0.15
Tur	0.15	0.04	-0.29	0.20	Sal	0.14	0.05	-1.03	1.26
D .		0.01	0.29	0.52	V		0.11	1.05	1.20
Pistocyi	1 00	o oc	0.15	0.04	D	<i>i oo</i>	op.	0.06	0.05
N Sal	1.00	-0.00	-0.13 1 53	3.88	к Tur	0.77	-0.01	-0.00	-0 01
D	1.00	-0.12	-0.19	-0.06	MD	0.66	-0.10	-0.12	0.00
Ph	0.97	-0.21	-0.32	-0.10	DO	0.63	0.13	0.00	0.26
Tur	0.12	0.04	-0.07	0.15	D	0.42	0.03	-0.01	0.07
Zn	0.11	-0.05	-0.23	0.13	Pb	0.33	0.04	-0.02	0.11
DO	0.10	0.06	-0.18	0.31	Sal	0.27	0.46	-0.24	1.15
WT	0.10	0.33	-0.98	1.64	WT	0.19	-0.37	-1.06	0.31
Chl	0.09	0.02	-0.08	0.11	Zn	0.14	0.00	-0.09	0.08
MD	0.08	-0.01	-0.20	0.18	Chl	0.10	0.00	-0.05	0.05
Ricorni	ucyther	e hisanensis s l			Loxoco	ncha m	alavensis		
R	1.00	0.01	-0.11	0.12	R	1.00	0.02	-0.02	0.06
MD	0.63	-0.26	-0.52	0.00	DO	0.87	-0.14	-0.25	-0.03
D	0.62	-0.08	-0.16	0.00	MD	0.85	-0.11	-0.20	-0.02
Pb	0.38	0.14	-0.05	0.33	D	0.48	-0.03	-0.06	0.00
DO	0.20	0.17	-0.15	0.48	Chl	0.40	0.03	-0.01	0.08
Chl	0.19	0.06	-0.07	0.19	Pb	0.29	-0.04	-0.10	0.02
Tur	0.19	0.07	-0.08	0.22	WT	0.26	0.41	-0.21	1.03
Zn	0.16	-0.01	-0.28	0.25	Zn	0.20	-0.03	-0.10	0.04
Sal	0.12	-0.02	-1.86	1.82	Sal	0.15	-0.26	-0.91	0.39
WT	0.10	0.06	-1.80	1.92	Tur	0.11	-0.01	-0.07	0.05





Term	RI	Coeffiencient	Lower CI	Upper CI	Term	RI	Coeffiencient	Lower CI	Upper CI		
Neones	<i>idea</i> sp	р.			Alocop	ocyther	e goujoni				
R	1.00	0.02	-0.09	0.13	R	1.00	-0.03	-0.05	-0.02		
DO	0.72	0.30	0.02	0.57	Sal	0.78	0.22	0.03	0.41		
Zn	0.58	0.15	-0.01	0.31	D	0.46	-0.01	-0.02	0.00		
MD	0.46	-0.23	-0.49	0.03	DO	0.43	-0.03	-0.07	0.01		
Chl	0.42	-0.09	-0.21	0.02	Pb	0.31	-0.01	-0.03	0.01		
WT	0.32	-1.13	-2.69	0.42	Zn	0.29	-0.01	-0.03	0.01		
Tur	0.24	-0.09	-0.22	0.05	WT	0.24	0.13	-0.08	0.33		
D	0.23	0.05	-0.04	0.15	Tur	0.18	0.01	-0.01	0.03		
Pb	0.17	0.05	-0.13	0.24	MD	0.14	-0.01	-0.04	0.02		
Sal	0.15	-0.60	-2.20	1.01	Chl	0.11	0.00	-0.01	0.01		
Neosino	ocyther	e elongata			Hemik	rithe ori	ientalis				
R	1.00	-0.03	-0.07	0.00	R	1.00	0.00	-0.04	0.03		
Tur	1.00	0.08	0.04	0.13	D	0.77	0.03	0.00	0.05		
MD	0.33	-0.05	-0.13	0.02	WT	0.46	0.43	-0.07	0.93		
Chl	0.30	-0.02	-0.05	0.01	DO	0.44	0.08	-0.02	0.17		
WT	0.26	-0.33	-0.85	0.18	Sal	0.30	0.37	-0.17	0.90		
Zn	0.21	-0.02	-0.06	0.02	Pb	0.22	-0.03	-0.08	0.02		
Pb	0.19	-0.02	-0.07	0.02	Tur	0.17	0.02	-0.03	0.07		
D	0.12	0.00	-0.03	0.03	Chl	0.14	-0.01	-0.05	0.03		
DO	0.12	-0.02	-0.11	0.07	Zn	0.11	0.00	-0.05	0.05		
Sal	0.10	0.04	-0.40	0.49	MD	0.10	-0.01	-0.08	0.07		
Stigmat	tocythe	re roesmani			Loxoconcha epeterseni						
R	1.00	-0.01	-0.07	0.05	R	1.00	0.00	-0.02	0.03		
Sal	0.61	0.62	-0.04	1.27	D	0.94	0.03	0.00	0.05		
Pb	0.61	-0.06	-0.12	0.00	Tur	0.76	-0.03	-0.06	0.00		
Tur	0.37	0.04	-0.01	0.10	Sal	0.53	-0.30	-0.62	0.02		
Zn	0.31	-0.05	-0.11	0.02	MD	0.38	-0.04	-0.08	0.01		
DO	0.31	0.09	-0.04	0.22	Chl	0.30	0.02	-0.01	0.04		
MD	0.23	-0.06	-0.16	0.04	DO	0.26	0.04	-0.02	0.10		
Chl	0.19	-0.02	-0.07	0.02	Pb	0.17	0.01	-0.02	0.05		
WT	0.19	0.35	-0.33	1.02	WT	0.13	-0.13	-0.48	0.22		
D	0.14	-0.01	-0.05	0.04	Zn	0.12	0.01	-0.03	0.04		
Phlycto	cythere	e japonica			Hemic	vtheride	a reticulata				
R	1.00	-0.01	-0.05	0.03	R	1.00	0.01	-0.02	0.03		
D	0.80	0.03	0.01	0.06	Pb	0.67	-0.04	-0.07	0.00		
Sal	0.42	0.46	-0.10	1.02	D	0.66	-0.02	-0.04	0.00		
Pb	0.21	-0.03	-0.08	0.03	Chl	0.49	0.03	0.00	0.05		
Zn	0.20	-0.02	-0.07	0.03	WT	0.24	-0.24	-0.64	0.16		
WT	0.15	0.22	-0.38	0.81	MD	0.23	-0.03	-0.09	0.02		
DO	0.14	0.03	-0.08	0.15	Zn	0.17	-0.01	-0.06	0.05		
Tur	0.12	0.00	-0.05	0.05	DO	0.13	0.02	-0.05	0.10		
Chl	0.12	0.00	-0.04	0.05	Tur	0.13	-0.01	-0.05	0.03		
MD	0.11	0.00	-0.09	0.08	Sal	0.11	-0.05	-0.43	0.34		





Table 4.			
Environmental Variables	GVIF	Df	GVIF ^{1/2Df}
Chl	7.40	1	2.72
D	6.41	1	2.53
DO	4.49	1	2.12
MD	3.72	1	1.93
Sal	9.43	1	3.07
Tur	6.67	1	2.58
Pb	9.98	1	3.16
Zn	10.05	1	3.17
WT	2.39	1	1.55
R	1266.30	9	1.49





Table 5										
Taxa	Chl	D	DO	MD	Sal	Tur	WT	Pb	Zn	R
Sinocytheridea impressa	+		-	+	-					
Neomonoceratina delicata					+	+			+	
Pistocythereis bradyi		-			+			-		
Bicornucythere bisanensis s.l.		-								
Keijella kloempritensis		+								
Nipponocythere bicarinata	-									
Spinileberis quadriaculeata	+					-				
Loxoconcha malayensis			-	-						
Neosinocythere elongata						+				
Stigmatocythere roesmani								-		
Phlyctocythere japonica		+								
Alocopocythere goujoni					+					
Hemikrithe orientalis		+								
Loxoconcha epeterseni		+				-				
Hemicytheridea reticulata		-						-		
Neonesidea spp.			+							
Propontocypris spp.	-									
Xestoleberis spp.			+	-		-				