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Baseline for ostracod-based northwestern Pacific and Indo-Pacific shallow-marine paleoenvironmental reconstructions: ecological modeling of species distributions

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Abstract:

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

Key words: Autoecology, Distribution modeling, Indicator species, Ostracoda, Paleoenvironmental reconstruction, Proxy.

Key points

1. We provide a robust baseline for ostracod (microscopic Arthropods) based paleoenvironmental reconstructions from Quaternary and Anthropocene marginal marine sediments.

2. The studied species have wide distributions over the tropics and extratropics of the northwestern Pacific and Indo-Pacific.

3. Ecological modeling established reliable indicator ostracod species for paleoenvironmental reconstructions.

1. Introduction

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

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

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

2. Study area

Hong Kong is situated at the southeastern corner of the Pearl River (Zhujiang) Delta, and has an area of 2500 km^2 (Fig. 1), at 22° 12.021' to 22° 33.817' N latitude, 113° 53.388' to 114° 26.920' E longitude. It is an ideal location to study natural and/or anthropogenic impacts on benthic communities due to its complex hydrology and long history of human influence. Western Hong Kong is affected by input from the Pearl River, particularly during the summer heavy rainfall (Morton & Wu, 1975), when salinity of the surface waters is strongly influenced by rainfall. Eastern Hong Kong waters are mainly marine and derived from the South China Sea. As one of the most urbanized coastal areas in the world, human activities, including rapid industrialization, sewage discharge, trawling, dredging and land reclamation have led 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 & Sandhu, 2000; Shin, 1977; Tanner et al., 2000).

3. Materials and Methods

3.1. Samples and laboratory procedure

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

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

3.2 Environmental Variables

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

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.

The best-fitting models were selected based on Akaike's Information Criterion (AICc) for small sample size, in which the lower score indicates the better model support considering both goodness-of-fit and model complexity (Anderson & Burnham, 2002). Akaike weights were used to summarize proportional support for all candidate models (Anderson et al., 2000) (Table 2). We considered parameter estimates averaged over models, proportional to the support that each model received (Anderson et al., 2000) (Table 3). This approach accounts for the uncertainty in model selection and thus leads to appropriately broader confidence intervals than obtained by relying only on the single, best-supported model. The relative importance of various predictor variables was measured by the sum of Akaike weights of models 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 coefficients associated with it (Hendrickx et al., 2004). Thus, we used $GVIF^{1/2df}$ to make GVIF values comparable among those with different Df. VIF >20 is usually 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, adjusted $R^2 > 0.8$ indicates a strong correlation of variables (Hoffman, 2015). In all datasets, summer temperature (ST) and water depth (D) were highly correlated ($R^2=0.8217$), and the GVIFs of ST and Cu are >20, indicating that these correlations may influence regression results. Thus, we re-ran the linear regression modeling 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*.

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

5. Results and discussions

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

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

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

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

Relative abundance of *B. bisanensis* s.l. was significantly correlated with water depth (negative) (Tables 2 and 3) and this species prefers shallower environments (Figs. 2 and 4). In Chinese and Japanese coastal areas, *B. bisanensis* s.l. is abundant in brackish water (salinity: 20–30) at depths less than 10 m (Ikeya & Shiozaki, 1993; Irizuki et al., 2006; Zhao et al., 1986). Our results confirm its preference for shallow depths. *Bicornucythere bisanensis* is tolerant of anthropogenic 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 significant relation between relative abundance and metal concentration, productivity, or dissolved oxygen. Possibly, the more dominant presence of *S. impressa* and *N. delicata,* that are neither dominant or distributed throughout most of Japan, could explain this difference. These species may have a higher tolerance than *B. bisanensis* s.l. Another explanation may be that different morphotypes have different ecological preferences (Abe, 1988), and only Form A is known to be tolerant to eutrophication and bottom-water oxygen depletion (Irizuki et al., 2011; Irizuki et al., 2015a; 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).

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

Relative abundance of *N. bicarinata* was correlated with productivity (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; Yasuhara et al., 2005). We found *N. bicarinata* to be sensitive to eutrophication, prefering lower productivity (Figures 2, 4). This species is know from marginal marine environments around Japan and the East and South China Seas (Fig. 7).

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

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

Relative abundance of *L. malayensis* was correlated with dissolved oxygen (negative) and mud content (negative) (Tables 2 and 3). *Loxoconcha malayensis* is a typical tropical species known from the Indo-Pacific and the South China Sea (Fig. 7). We did not find a correlation to temperature, likely due to the small range of variation of bottom water temperatures in Hong Kong (winter temperature: 19.10–21.49°C). This species prefers coarse sediments and is resistant to low oxygen content (Table 2 and 3), as seen by its abundance in Victoria Harbour (Figs. 2 and 4).

Relative abundance of *N. elongata* was correlated only with turbidity (positive) (Tables 2 and 3). *Neosinocythere elongata* occurs along the entire coast of China (Fig. 7) in marginal marine, especially estuarine, environments shallower than 20 m (Dong et al., 2012; Hou & Gou, 2007; Liu et al., 2013; Liu et al., 2017; Zhao & Whatley, 1993) and is known from the Indo-Pacific region (Fig. 7). Our modeling results and previous studies indicate consistently that *N. elongata* prefers shallow, turbid waters like Deep Bay and the Pearl River Estuary (Figs 2 and 6).

Relative abundance of *S. roesmani* was correlated with Pb (negative) (Tables 2 and 3), thus it was sensitive to metal pollution (but note the significant autocorrelation with the modeling result of this genus) and absent in areas with high metal concentrations, e.g., Tolo and Victoria Harbours (Fig. 3, 6). This species occurs in the East and South China Seas and the Indo-Pacific region (Dewi, 1997; Mostafawi, 1992; Whatley & Zhao, 1988a) (Fig. 7).

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

Relative abundance of *A. goujoni* was correlated with salinity (positive) (Tables 2 and 3). It occurs not only in Mirs Bay where the salinity is higher, but also in Deep Bay and North Western Waters where the salinity is lower than in other areas (Figs 2 and 6). The Deep Bay and North Western Waters are shallow and have relatively low oxygen content. The modeling result of this species shows a marginally insignificant but negative relationship to oxygen content and water depth with moderately high relative importance (Table 3). We explain this inconsistency by considering their preference of higher salinity and shallow water depths, and also their resistance to low oxygen conditions, but further research is needed to know their autoecology with better confidence. *Alocopocythere goujoni* is known from the South China Sea and the Indo-Pacific (Fig. 7).

Relative abundance of *H. orientalis* was correlated with water depth (positive) (Tables 2 and 3; but note the significant autocorrelation with the modeling result of this genus), and it is more abundant in deeper waters including southern Mirs Bay (Fig. 5). *Hemikrithe orientalis* is known from depths of 20–50 m in the South China Sea (Zhao & Wang, 1988a), and reported from tropical Indo-Pacific marginal marine environments (Fig. 7). Our regression modeling consistently shows a positive relationship between the relative abundance and winter temperatures, with moderately high relative importance, although the correlation is marginally insignificant (Table 3).

Relative abundance of *L. epeterseni* was correlated with water depth (positive) and turbidity (negative) (Tables 2 and 3), and its occurs in the southern and eastern, deeper and less turbid parts of Hong Kong waters, but the trend is not very clear (Figs 2 and 6). This species is also known from the deeper parts of Osaka Bay, Japan (Yasuhara & Irizuki, 2001) and from marginal marine environments around Japan (Ishizaki, 1968), the East China Sea (Yang et al., 1982), and the South China Sea (Cao, 1998) (Fig. 7). This species is reported as *Loxoconcha modesta* in Hou & Gou (2007), and also has been misidentified as *Loxoconcha viva* and *Loxoconcha sinensis*

(Hou & Gou, 2007). Ishizaki (1968) described *Loxoconcha laeta* and *Loxoconcha modesta* but in our opinion, these are the females and males of the same species. Ishizaki (1981) gave the new species names *Loxoconcha epetersenі* and *Loxoconcha tosamodesta* for *Loxoconcha laeta* and *Loxoconcha modesta*, respectively, because these names were junior homonyms. Since *Loxoconcha laeta* (= *epeterseni*) appears earlier than *Loxoconcha modesta* (=*tosamodesta*) in the original description (Ishizaki, 1968), we use the name *Loxoconcha epeterseni* for this species.

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

The relative abundance of the cosmopolitan *Neonesidea* spp. was correlated with dissolved oxygen (positive), as expected for a phytal species (Smith & Kamiya, 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.

The relative abundance of the cosmopolitan phytal (Irizuki et al., 2008; Sato & Kamiya, 2007; Yasuhara et al., 2002) *Xestoleberis* spp. was correlated with turbidity (negative), mud content (negative), and dissolved oxygen (positive) (Table 2 and 3; Fig. 6). The taxon's habitats including clear water, coarse sediment, and high oxygen content are reflected in our modeling.

Summary

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

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Captions

Fig. 1 Locality map showing the 52 sampling sites across Hong Kong, including 41 open water sites (blue dots) and 11 typhoon shelter sites (red open dots). From west to east, DS: Deep Bay; NS: North Western waters; SS: Southern waters; VS: Victoria Harbour; ES: Eastern Buffer; JS: Junk Bay; TS: Tolo Harbour; PS: Port Shelter; MS: Mirs Bay.

Fig. 2 Spatial distribution of environmental parameters in Hong Kong. Mean surface-water chlorophyll-a concentration; water depth; summer (June to September) bottom-water dissolved oxygen content; mean bottom-water salinity; mean turbidity; mean summer (June to September) bottom-water temperature; mean winter (November to February) bottom-water temperature; and mean mud content. All are averaged values of the data obtained during 1986–2013 (Table 1).

Fig. 3 Spatial distribution of environmental parameters in Hong Kong. Mean copper (Cu) concentration, mean lead (Pb) concentration, and mean zinc (Zn) concentration in surface sediments. All are averaged values of the data obtained during 1986–2013 (Table 1).

Fig. 4. Spatial distribution of the relative abundance of *Sinocytheridea impressa*, *Neomonoceratina delicata*, *Bicornucythere bisanensis* s.l., *Pistocythereis bradyi*, *Nipponocythere bicarinata*, *Spinileberis quadriaculeata*, *Keijella kloempritensis*, and *Loxoconcha malayensis* in Hong Kong. See Figure 1 for sampling stations.

Fig. 5. Spatial distribution of the relative abundance of *Neosinocythere elongata*, *Stigmatocythere roesmani*, *Phlyctocythere japonica*, *Alocopocythere goujoni*,

Hemikrithe orientalis, *Loxoconcha epeterseni*, *Hemicytheridea reticulata* and *Neonesidea* spp. in Hong Kong. See Figure 1 for sampling stations.

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

Fig. 7. Geographical distributions of the 18 taxa in the northwestern Pacific and Indo-Pacific regions, including *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., and *Xestoleberis* spp. The following references were used mainly to determine the geographical distributions of the species: Al Jumaily and Al-Sheikhly (1999); Dewi (1997); Dong et al. (2012); Fauzielly et al. (2013); Hong et al. (2017); Hou and Gou (2007); Hussain et al. (2004); Hussain et al. (2010); Hussain and Mohan (2000, 2001); Irizuki et al. (2006); Irizuki et al. (2009); Iwatani et al. (2014); Jie et al. (2013); Li (1985); Mostafawi (1992); Nishath et al. (2017); Noraswana et al. (2014); Pugliese et al. (2006); Schornikov et al. (2014); Tanaka et al. (2009); Tanaka et al. (2011); Wang et al. (1988); Wang and Zhang (1987); Wang and Zhao (1985); Zhao (1984); Zhao and Wang (1988a, 1988b, 1990); Zhao and Whatley (1993); Zhou et al. (2015).

Table 1. Summary of marine water/sediment parameters. Note: 1. Summer: June, July, August and September. 2. Winter: November, December, January and February.

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

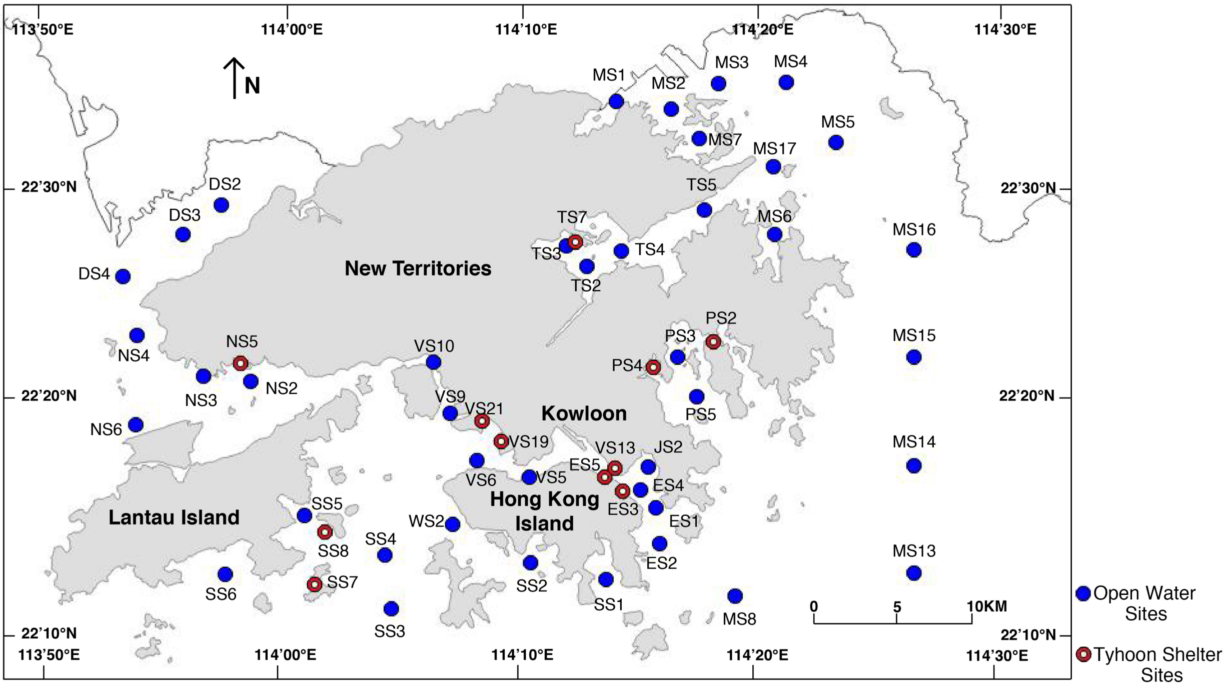
Table 3. Model-averaged parameter estimates and CIs of the relative abundance of common species, including *Sinocytheridea impressa*, *Neomonoceratina delicata*, *Propontocypris* spp., *Pistocythereis bradyi*, *Bicornucythere bisanensis* s.l., *Keijella kloempritensis*, *Nipponocythere bicarinata*, *Spinileberis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

Table 4. GVIF value for Environmental Variables. Df, degree of freedom; R, region. Other abbreviations are found in Table 1.

Table 5. Summary of autoecology for common ostracod taxa. Chl: Chlorophyll-a; D: Water Depth; DO: Dissolved Oxygen; MD: Mud Content; Sal: Salinity; Tur: Turbidity; WT: Winter Temperature; Pb: Lead; Zn: Zinc; R: Region.

Supplement A. Ostracod faunal list.

Supplement B. Dataset used for the regression modeling.


113'50°E
114'00°E
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114'30°E
22'30°N
22'20°N
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N
New Territories
Kowloon
Hong Kong Island
Lantau Island
MS1
MS2
MS3
MS4
MS5
MS7
MS17
MS6
MS16
MS15
MS14
MS13
MS8
TS5
TS7
TS3
TS4
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NS3
NS2
NS6
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WS2
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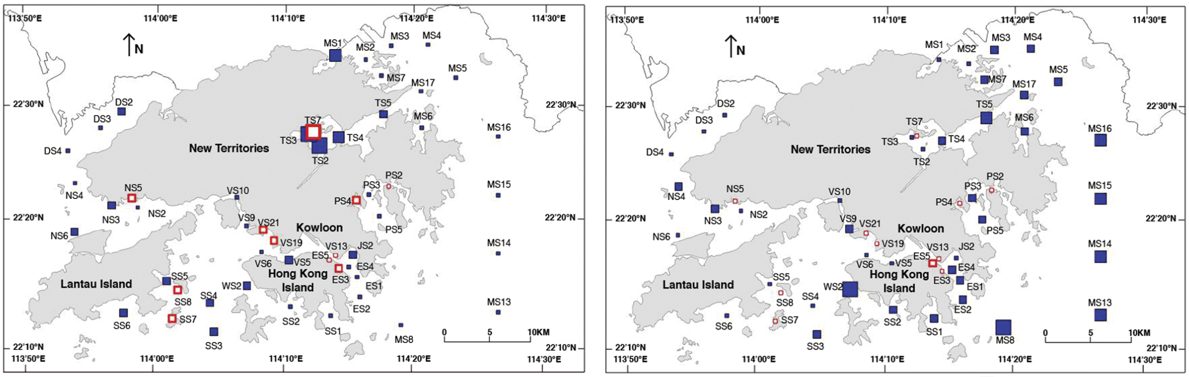
● Open Water Sites
◉ Tyhoon Shelter Sites

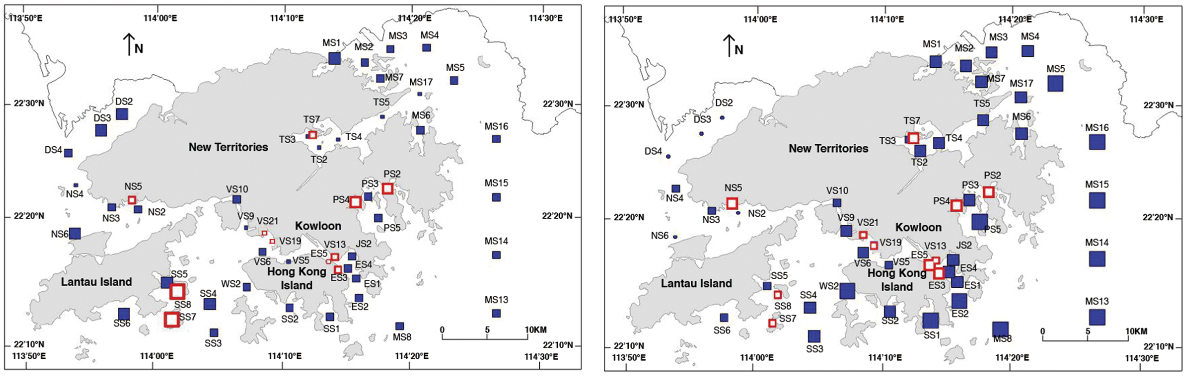
Fig. 1

Biogeosciences Discuss., https://doi.org/10.5194/bg-2018-405
Manuscript under review for journal Biogeosciences
Discussion started: 15 October 2018



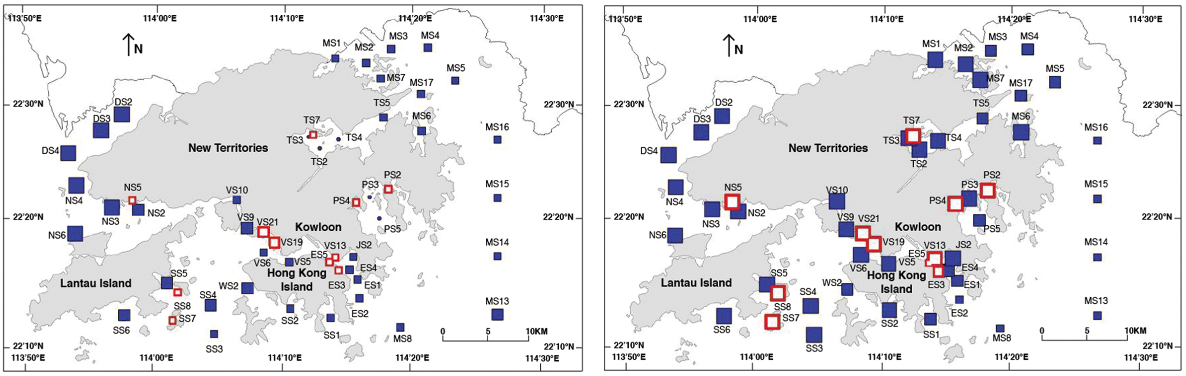
Chlorophyll-a (Chl) ▪1.0–4.0 ■4.1–8.0 ■8.1–12.0 ■>12.0μg/L

Water Depth(D) ▪1–10 ■11–20 ■21–30 ■>30m



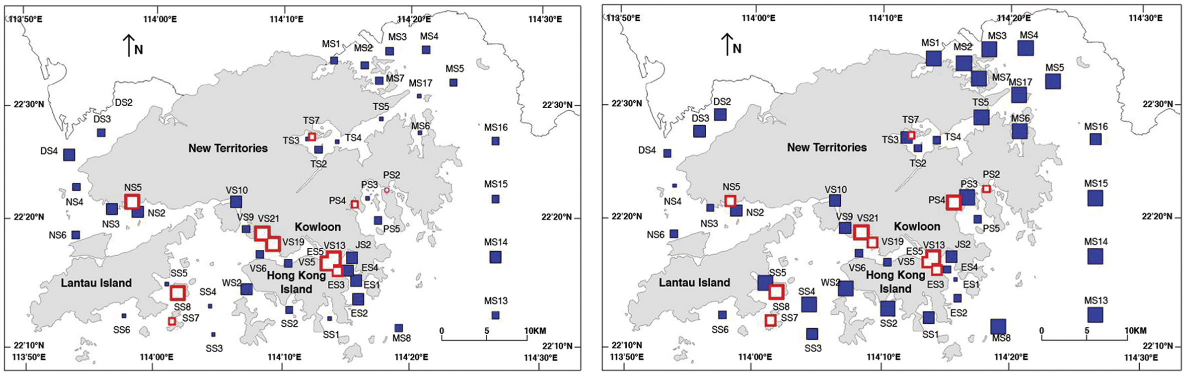
Dissolved Oxygen (DO) ▪2.95–4.00 ■4.01–5.00 ■5.01–6.00 ■>6.00mg/L

Salinity (Sal) ▪<30 ■30–31.5 ■31.6–33 ■>33psu



Turbidity (Tur) ▪0–5 ■5.1–10 ■10.1–15 ■>15NTU

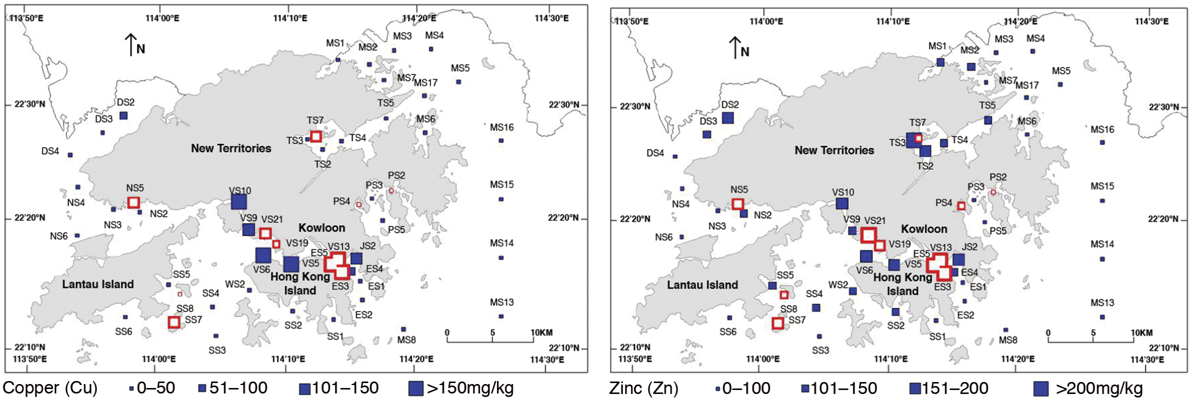
Summer Temperature (ST) ▪23–24 ■24.1–25 ■25.1–26 ■>26°C



Winter Temperature (WT) ▪19.0–19.5 ■19.51–20.0 ■20.01–20.5 ■>20.5

Mud Content (MD) ▪40–55 ■55.1–70 ■70.1–85 ■>85%w/w(<63μm)

Fig. 2


113°50'E
114°00'E
114°10'E
114°20'E
114°30'E
22°30'N
22°20'N
22°10'N
N
New Territories
Kowloon
Hong Kong Island
Lantau Island
MS1
MS2
MS3
MS4
MS5
MS6
MS7
MS8
MS13
MS14
MS15
MS16
MS17
DS2
DS3
DS4
TS2
TS3
TS4
TS5
TS7
PS2
PS3
PS4
PS5
NS2
NS3
NS4
NS5
NS6
VS5
VS6
VS9
VS10
VS13
VS19
VS21
ES1
ES2
ES3
ES4
ES5
JS2
WS2
SS1
SS2
SS3
SS4
SS5
SS6
SS7
SS8
0
5
10KM
Copper (Cu)
▪0–50
▪51–100
■101–150
■>150mg/kg
Zinc (Zn)
▪0–100
▪101–150
■151–200
■>200mg/kg

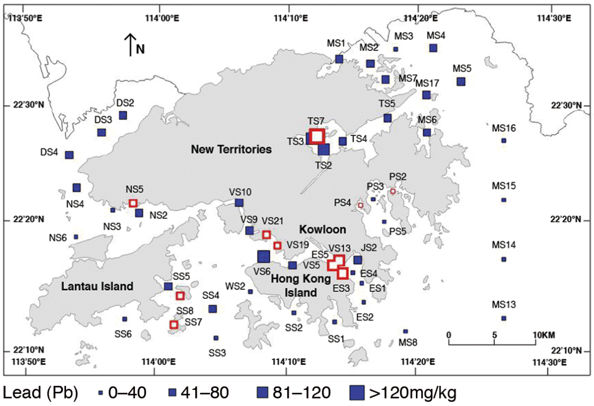
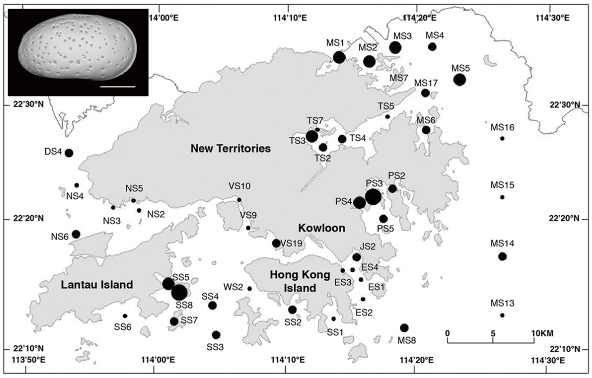
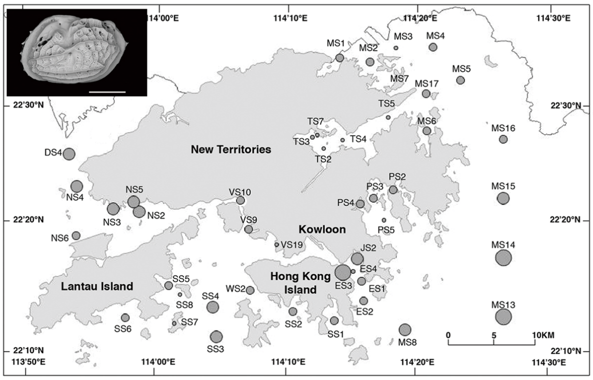

113°50'E
114°00'E
114°10'E
114°20'E
114°30'E
22°30'N
22°20'N
22°10'N
N
New Territories
Kowloon
Hong Kong Island
Lantau Island
0
5
10KM
Lead (Pb)
▪0–40
▪41–80
■81–120
■>120mg/kg

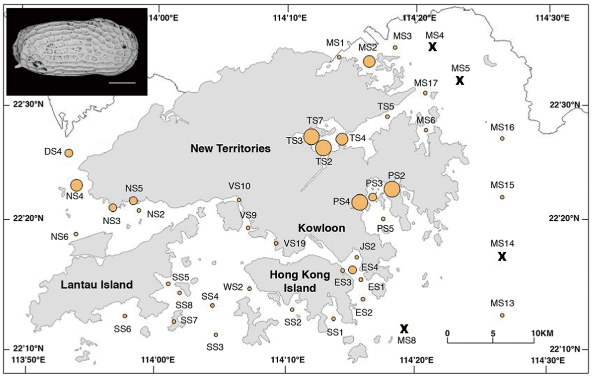
Fig. 3



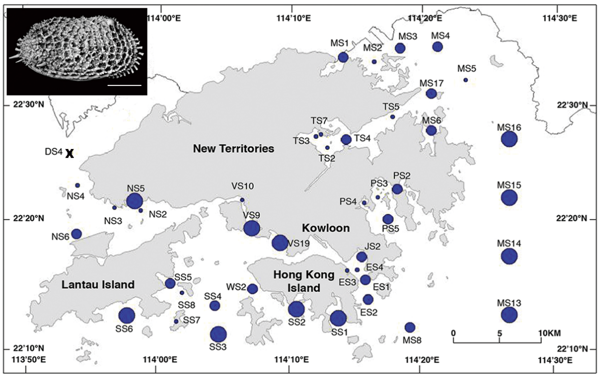
Sinocytheridea impressa 0< • ≤20% 20< ● ≤40% 40< ● ≤60% 60< ● ≤80%



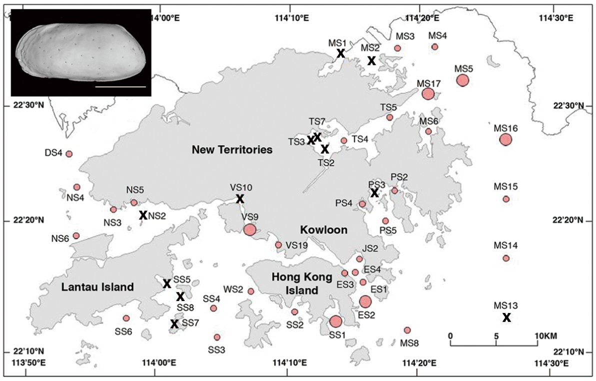
Neomonoceratina delicata 0< ◦ ≤10% 10< ● ≤20% 20< ● ≤30% 30%< ●



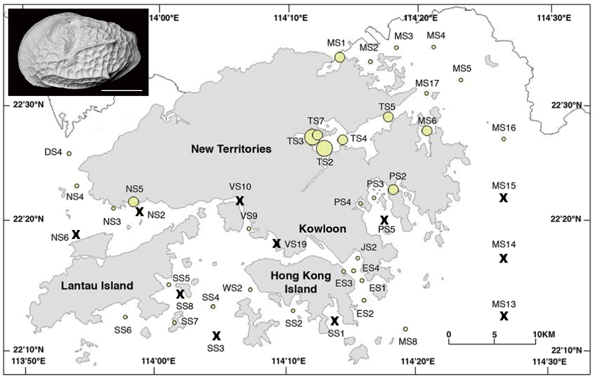
Bicornucythere bisanensis s.l. 0< ◦ ≤ 5% 5< ● ≤10% 10< ● ≤15% 15< ● ≤20% x absent



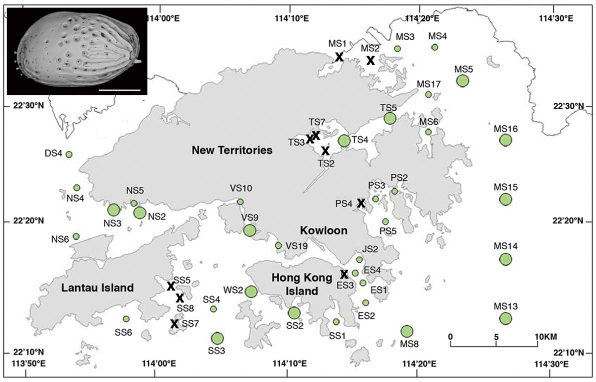
Pistocythereis bradyi 0< • ≤5% 5< ● ≤10% 10< ● ≤15% x absent



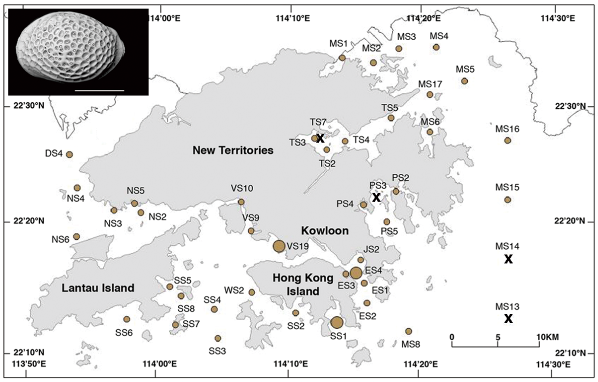
Nipponocythere bicarinata 0< ● ≤5% 5< ● ≤10% x absent



Spinileberis quadriaculeata 0< ◦ ≤5% 5< ● ≤10% 10%≤ ● x absent



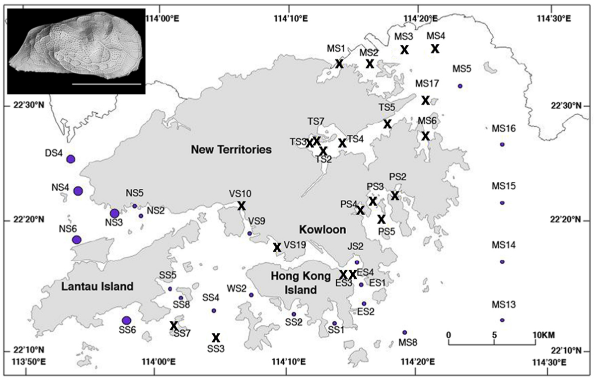
Keijella kloempritensis 0< ● ≤5% 5< ● ≤10% x absent



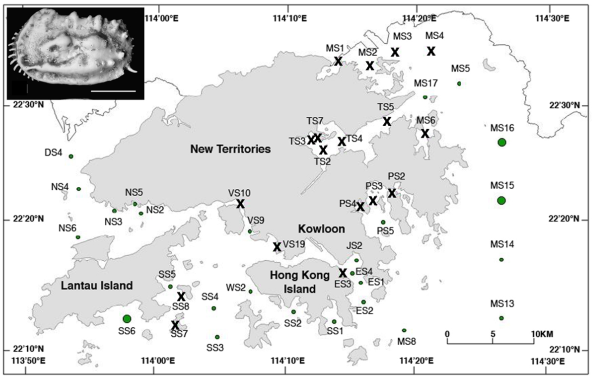
Loxoconcha malayensis 0< ● ≤5% 5< ● ≤10% x absent

Fig. 4

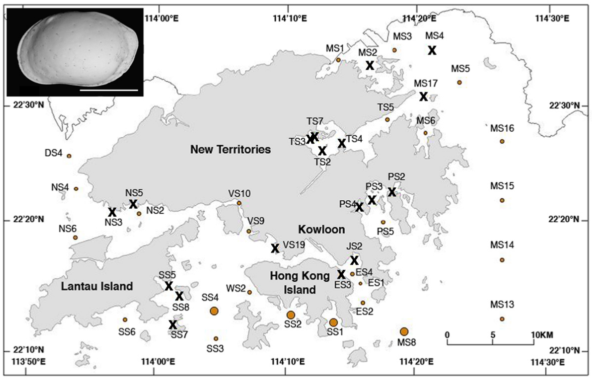
Biogeosciences Discuss., https://doi.org/10.5194/bg-2018-405
Manuscript under review for journal Biogeosciences
Discussion started: 15 October 2018



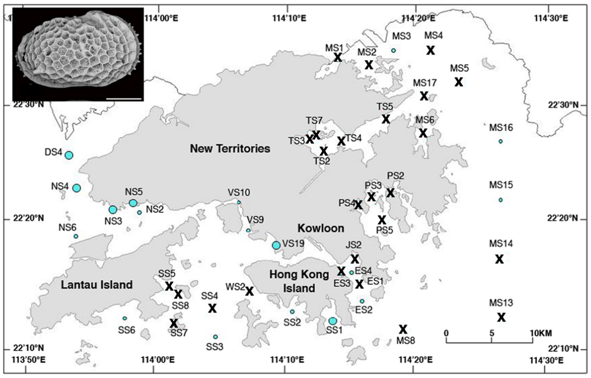
Neosinocythere elongata 0< • ≤5% 5< ● ≤10% x absent



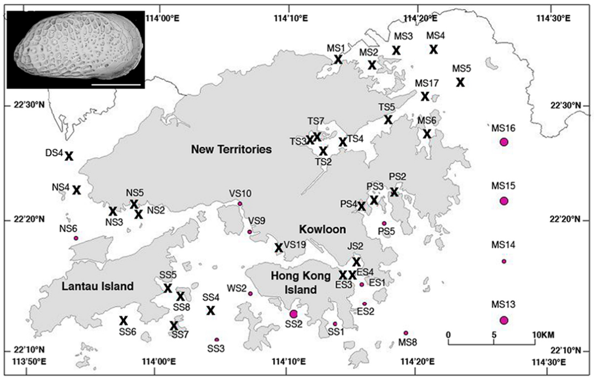
Stigmatocythere roesmani 0< • ≤4% 4< ● ≤8% x absent



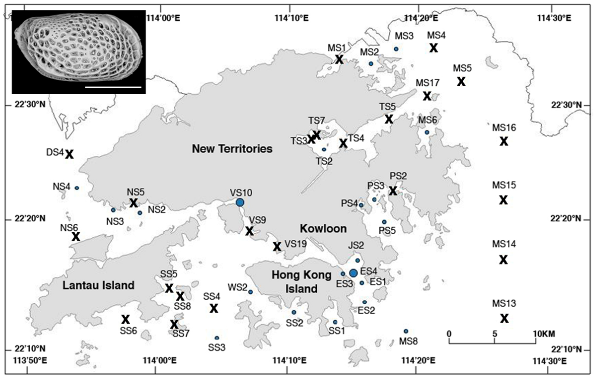
Phlyctocythere japonica 0< • ≤3.5% 3.5< ● ≤7% x absent



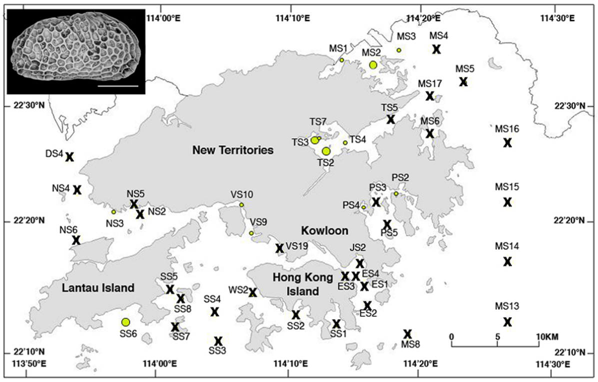
Alocopocythere goujoni 0< • ≤1.5% 1.5< ● ≤ 3% x absent



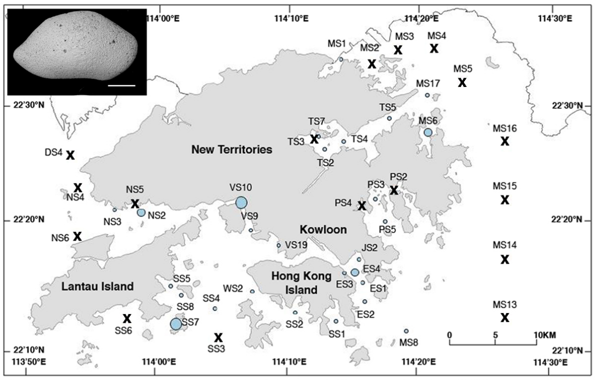
Hemikrithe orientalis 0< • ≤3% 3< ● ≤6% x absent



Loxoconcha epeterseni 0< • ≤3% 3< ● ≤6% x absent



Hemicytheridea reticulata 0< • ≤2% 2< ● ≤4% x absent



Neonesidea spp. 0< ◦ ≤ 5% 5< ○ ≤10% 10< ◯ ≤20% x absent

Fig. 5

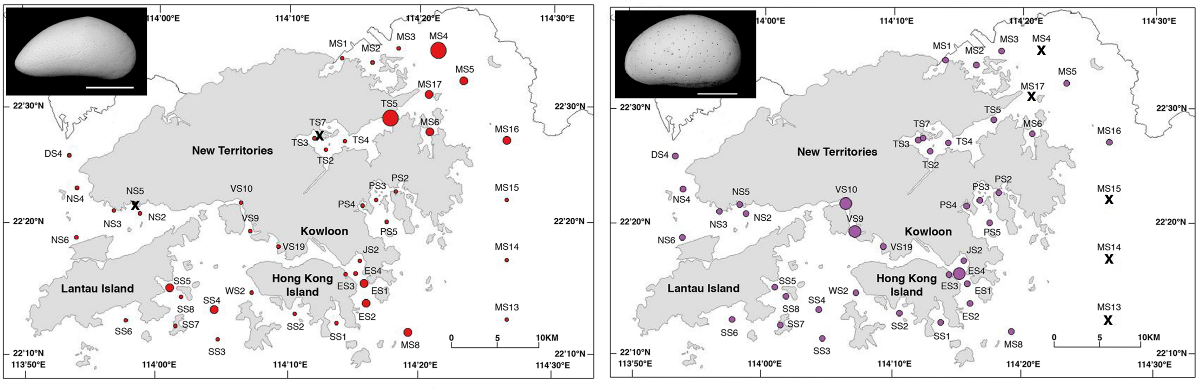

Propontocypris spp. 0< • ≤10% 10< ● ≤20% 20%< ● ≤60% x absent
Xestoleberis spp. 0< • ≤5% 5< ● ≤15% x absent
New Territories
Kowloon
Hong Kong Island
Lantau Island
114°00'E
114°10'E
114°20'E
114°30'E
113°50'E
22°30'N
22°20'N
22°10'N
0
5
10KM
MS1
MS2
MS3
MS4
MS5
MS6
MS8
MS13
MS14
MS15
MS16
MS17
TS2
TS3
TS4
TS5
TS7
PS2
PS3
PS4
PS5
DS4
NS2
NS3
NS4
NS5
NS6
VS9
VS10
VS19
JS2
ES1
ES2
ES3
ES4
WS2
SS1
SS2
SS3
SS4
SS5
SS6
SS7
SS8

Fig. 6

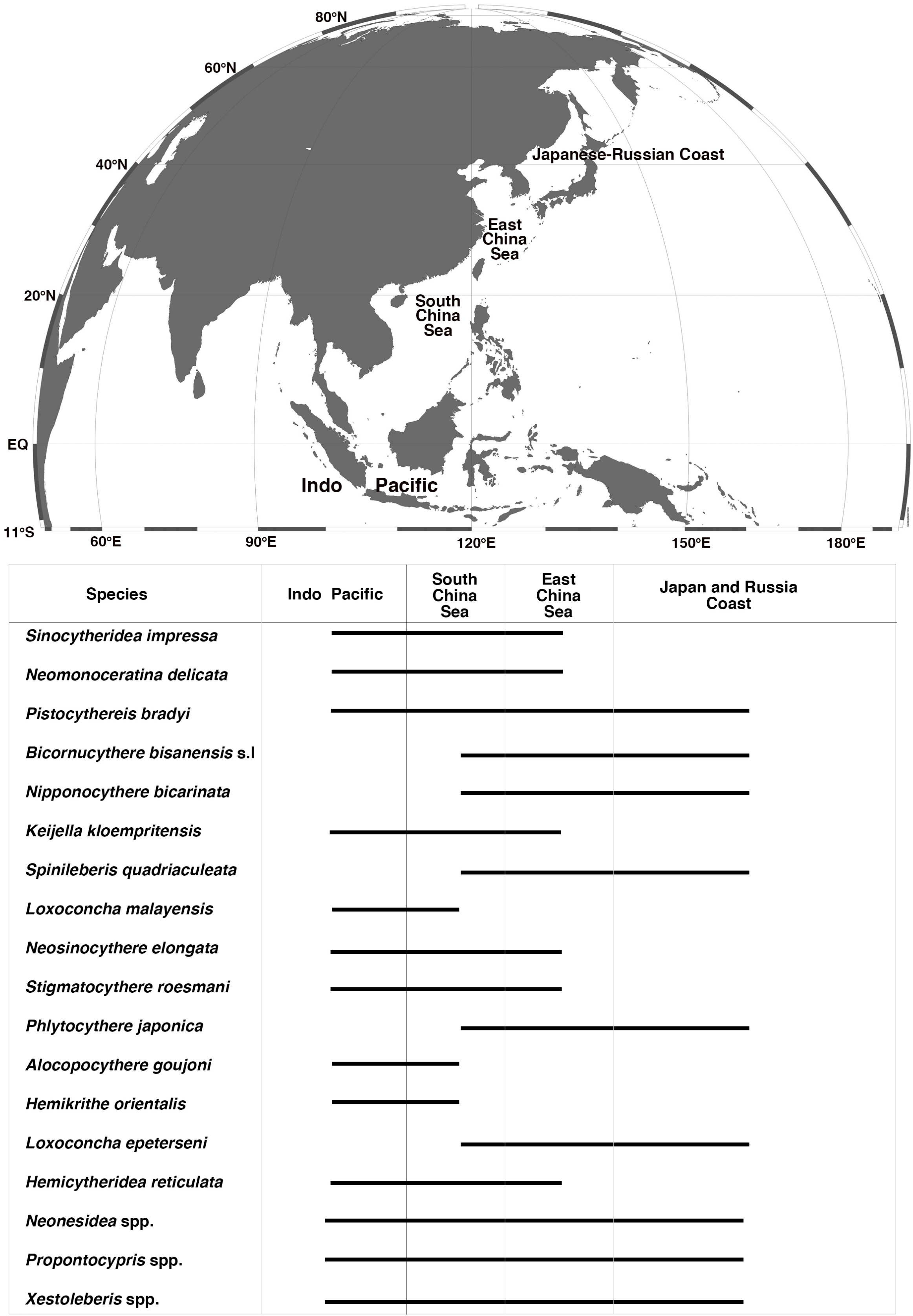

80°N
60°N
40°N
20°N
EQ
11°S
60°E
90°E
120°E
150°E
180°E
Japanese-Russian Coast
East China Sea
South China Sea
Indo
Pacific
Species
Indo
Pacific
South China Sea
East China Sea
Japan and Russia Coast
Sinocytheridea impressa
Neomonoceratina delicata
Pistocythereis bradyi
Bicornucythere bisanensis s.l
Nipponocythere bicarinata
Keijella kloempritensis
Spinileberis quadriaculeata
Loxoconcha malayensis
Neosinocythere elongata
Stigmatocythere roesmani
Phlytocythere japonica
Alocopocythere goujoni
Hemikrithe orientalis
Loxoconcha epeterseni
Hemicytheridea reticulata
Neonesidea spp.
Propontocypris spp.
Xestoleberis spp.

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	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
Sinocytheridea impressa													
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
Neomonoceratina delicata													
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
Propontocypris spp.													
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
Pistocythereis bradyi													
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
Bicornucythere bisanensis 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 kloempritensis													
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
Nipponocythere bicarinata													
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
Spinileberis quadriaculeata													
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
Xestoleberis 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
Neonesidea 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
Neosinocythere elongata													
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
Stigmatocythere roesmani													
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
Phlyctocythere japonica													
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
Alocopocythere 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
Hemikrithe orientalis													
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
Loxoconcha epeterseni													
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
Hemicytheridea reticulata													
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

Table 3.

Term	RI	Coeffiencient	Lower CI	Upper CI	Term	RI	Coeffiencient	Lower CI	Upper CI
Sinocytheridea impressa					***Keijella kloempritensis***				
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	WT	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
Neomonoceratina delicata					***Nipponocythere bicarinata***				
R	1.00	-0.15	-0.42	0.12	R	1.00	0.02	-0.04	0.09
Zn	**0.94**	**0.41**	**0.11**	**0.70**	**Chl**	**0.92**	**-0.08**	**-0.14**	**-0.02**
Sal	**0.93**	**4.06**	**1.00**	**7.13**	DO	0.50	-0.14	-0.30	0.02
Tur	**0.84**	**0.33**	**0.06**	**0.59**	D	0.30	-0.03	-0.08	0.02
DO	0.33	0.45	-0.17	1.06	WT	0.25	-0.03	-0.08	0.02
Pb	0.17	-0.18	-0.67	0.30	Sal	0.24	0.51	-0.35	1.36
MD	0.14	0.25	-0.33	0.84	Tur	0.19	-0.04	-0.11	0.04
D	0.11	-0.01	-0.22	0.20	Zn	0.18	-0.04	-0.12	0.04
WT	0.11	-0.86	-4.32	2.60	Pb	0.13	-0.03	-0.11	0.06
Chl	0.09	0.00	-0.24	0.23	MD	0.10	0.00	-0.13	0.13
***Propontocypris* spp.**					***Spinileberis quadriaculeata***				
R	1.00	0.05	-0.19	0.30	R		-0.01	-0.10	0.07
Chl	**0.80**	**-0.26**	**-0.47**	**-0.04**	**Tur**	**0.66**	**-0.09**	**-0.17**	**0.00**
MD	0.58	0.50	-0.03	1.03	**Chl**	**0.54**	**0.06**	**0.00**	**0.13**
WT	0.29	-2.60	-6.48	1.28	D	0.45	-0.05	-0.10	0.01
Pb	0.19	-0.18	-0.55	0.20	WT	0.32	-0.76	-1.82	0.31
Sal	0.17	-1.48	-4.88	1.92	DO	0.19	0.10	-0.10	0.30
DO	0.15	-0.27	-0.99	0.45	MD	0.17	-0.07	-0.23	0.09
Zn	0.14	-0.03	-0.48	0.41	Pb	0.17	-0.05	-0.16	0.07
D	0.13	0.04	-0.17	0.26	Zn	0.14	0.03	-0.09	0.15
Tur	0.10	0.01	-0.29	0.32	Sal	0.13	0.11	-1.03	1.26
Pistocythereis bradyi					***Xestoleberis* spp.**				
R	1.00	-0.06	-0.15	0.04	R	1.00	-0.01	-0.06	0.05
Sal	**1.00**	**2.71**	**1.53**	**3.88**	**Tur**	**0.77**	**-0.07**	**-0.12**	**-0.01**
D	**1.00**	**-0.12**	**-0.19**	**-0.06**	**MD**	**0.66**	**-0.10**	**-0.19**	**0.00**
Pb	**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
***Bicornucythere bisanensis* s.l.**					***Loxoconcha malayensis***				
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
***Neonesidea* spp.**					***Alocopocythere 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
Neosinocythere elongata					***Hemikrithe orientalis***				
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
Stigmatocythere 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
Phlyctocythere japonica					***Hemicytheridea 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	$\mathrm{GVIF}^{1/2\mathrm{Df}}$
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.			+	-		-				