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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 marginal marine environments (e.g. for water depth, temperature, salinity, oxygen levels, pollution). But our knowledge of indicator species autoecology, the base of paleoenvironmental reconstructions, remains limited and commonly lacks robust statistical support and comprehensive comparison with environmental data. We analysed marginal 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 for 18 common taxa (mainly species, a few genera) in our Hong Kong dataset, and identified indicator species of environmental parameters. For example, *Sinocytheridea impressa*, widely distributed euryhaline species throughout the East and South China Seas and the Indo-Pacific, indicates eutrophication and botttom-water hypoxia. *Neomonoceratina delicata*, widely known species from nearshore and estuarine environments in the East and South China Seas, and the Indo-Pacific, indicates heavy-metal pollution and increased turbidity. The 18 taxa used for this study are widely distributed geographically and divided into Widespread (throughout the northwestern Pacific and Indo-Pacific regions), Temperate [South China Sea to Russia (Sea of Japan coast) and Japan], Subtropical (Indo-Pacific to the East China Sea), Tropical (Indo-Pacific and South China Sea), and Globally Distributed Groups. 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 tropical–extratropical northwestern Pacific and Indo-Pacific widely.

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

Key points

1. We provide a robust baseline for ostracod-based (microscopic Arthropods) 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 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 the high-resolution reconstruction of human-induced environmental changes (pollution, eutrophication, bottom oxygen depletion) over the past century (Irizuki et al., 2011; Irizuki et al., 2015a; Irizuki et al., 2018; Yasuhara et al., 2003; Yasuhara et al., 2007).

Many have evaluated the autoecology of ostracod indicator species as the basis for 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 a 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 fact that comprehensive environmental datasets are often unavailable and an ecological modeling approach (especially regression modeling and model selection) has not been common in this field of micropaleontology.

Hong Kong constitutes an ideal location for a marine ecological modeling approach in the northwestern Pacific and Indo-Pacific regions because of extensive and intensive marine environmental monitoring program and subtropical location where tropical and temperate species coexist. This program provides robust datasets for ecological modeling, and the subtropical location allows the investigation of species with different latitudinal and geographical distributions. We employed regression modeling of Hong Kong shallow-marine ostracod species to show

100 statistical relationships between species abundance, distribution and environmental
101 factors. This study allows the autoecology and statistical evaluation of common
102 tropical and extratropical species, providing a baseline for ostracod-based shallow-
103 marine paleoenvironmental reconstructions of the northwestern Pacific and Indo-
104 Pacific regions.
105
106 **2. Study area**
107 Hong Kong is situated at the southeastern corner of the Pearl River (Zhujiang) Delta,
108 and has an area of 2500 km^2 (Fig. 1), at 22° 12.021' to 22° 33.817' N latitude, 113°
109 53.388' to 114° 26.920' E longitude. It is an ideal location to study natural and/or
110 anthropogenic impacts on benthic communities due to its complex hydrology and
111 long history of human influence. Western Hong Kong is affected by input from the
112 Pearl River, particularly during the summer heavy rainfall (Morton & Wu, 1975),
113 when surface water salinity is strongly influenced by rainfall. Eastern Hong Kong
114 waters are mainly marine and derived from the South China Sea. As one of the most
115 urbanized coastal areas in the world, human activities including rapid industrialization,
116 sewage discharge, trawling, dredging and land reclamation have led to a deteriorated
117 marine benthic ecosystem (Blackmore, 1998; Hodgkiss & Yim, 1995; Hong et al.,
118 2017; Hu et al., 2008; Morton, 1996; Morton & Blackmore, 2001; Owen & Sandhu,
119 2000; Shin, 1977; Tanner et al., 2000).
120
121 **3. Materials and Methods**
122 **3.1. Samples and laboratory procedure**
123 In January and July of 2011 we used a Van Veen Grab to collect 100 ml of sediment
124 from the uppermost centimeter 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).

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 are mostly early instar juveniles that are often not preserved (because their shells are usually thin and delicate) or difficult to identify (see Yasuhara et al., 2009 and Yasuhara et al., 2017 for more details). 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; Irizuki et al., 2015a; Irizuki et al., 2018; 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

175 that included the variables in question (Brunham & Anderson, 2002).

176 We explored linear dependencies by computing variance inflation factors (VIF)
177 (Legendre & Legendre, 1998) and pairwise correlations between predictor variables
178 to assess whether multicollinearity was likely to influence regression results
179 (Yasuhara et al., 2012b). The degree of freedom is more than one for the geographic
180 region variable (see below), thus we computed generalized variance inflation factors
181 (GVIF). For continuous variables, GVIF (Table 4) is the same as VIF, but for
182 categorical variables, GVIF has degrees of freedom (Df) equal to the number of
183 coefficients associated with it (Hendrickx et al., 2004). Thus, we used $GVIF^{1/2df}$ to
184 make GVIF values comparable among those with different Df. VIF >20 is usually
185 indicative of high collinearity (Legendre & Legendre, 1998). Thus we calculated an
186 equivalent threshold of 4.47 (equal to $\sqrt{20}$) for $GVIF^{1/2df}$ to assess conlinearity. Also,
187 adjusted R^2 >0.8 indicates a strong correlation of variables (Hoffman, 2015). In all
188 datasets, summer temperature (ST) and copper (Cu) were highly correlated
189 (R^2=0.8217), and the GVIFs of ST and Cu are >20, indicating that these correlations
190 may influence regression results. Thus, we re-ran the linear regression modeling
191 without ST and Cu. The new GVIFs of all variables were under 4.47 (Table 4).

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

199 The multiple linear regression model analyses were implemented in R

200 programming language (R Core Team, 2016). We used 'M_UMI_N' (Bartoń, 2013) for
201 model averaging and 'SPDEP' (Bivand & Piras, 2015) to measure spatial
202 autocorrelation.
203
204 **5. Results and discussions**
205 The comprehensive ostracod dataset for the 52 sites and the environmental variables
206 enabled us to elucidate distribution patterns of common ostracod taxa and their related
207 environmental factor(s). We identified 151 species belonging to 76 genera
208 (Supplement A). Among them, 18 common taxa (mainly species, a few genera) of
209 *Pistocythereis bradyi*, *Bicornucythere bisanensis* s.l., *Nipponocythere bicarinata*,
210 *Spinileberis quadriaculeata*, *Phlyctocythere japonica*, *Loxoconcha epeterseni*,
211 *Sinocytheridea impressa, Neomonoceratina delicata*, *Keijella kloempritensis*,
212 *Neosinocythere elongata*, *Stigmatocythere roesmani*, *Hemicytheridea reticulata*
213 *Loxoconcha malayensis*, *Alocopocythere goujoni*, *Hemikrithe orientalis*,
214 *Propontocypris* spp., *Neonesidea* spp. and *Xestoleberis* spp. (Supplement B) were
215 used for regression modelling, and their relative abundances (to the total ostracod
216 abundance in a sample) show a significant relation with environmental parameters.
217 The best three regression models are presented in Table 2 and the model-averaged
218 parameter estimates in Table 3. A small percentage of specimens of phytal genera
219 (e.g., *Xestoleberis* spp., *Neonesidea* spp.) were contained in each sample, which are
220 basically allochthonous specimens in bottom sediments transported from surrounding
221 phytal environments. The value of allochthonous species to environmental
222 interpretation is limited, however most ostracod specimens in each sample are
223 composed of benthic, muddy sediment dwellers which are considered autochthonous.
224

225 Ostracods were divided into four groups based on their geographic
226 distributions, including Widespread Group; Temperate Group; Subtropical Group;
227 and Tropical Group; and Globally distributed Group (Fig. 4).
228
229
230 **a. Widespread Group**
231 Only one species *Pistocythereis bradyi* constitutes Widespread Group.
232 *Pistocythereis bradyi* is widely distributed throughout the marginal marine
233 environments of Japan, the East and South China Seas, and the Indo-Pacific (Fig. 4).
234 Relative abundance of *P. bradyi* was highly correlated with salinity (positive), water
235 depth (negative) and Pb (negative) (Tables 2 and 3). This indicates the species prefers
236 relatively shallow environments with high salinity (Figs. 2 and 5). In the Pearl River
237 Delta and shallow South China Sea (Fig. 4), *P. bradyi* is dominant along the inner
238 continental shelf at water depths <100 m (mostly common between 10–50 m), and at
239 salinities from 30–40 (Li, 1985; Zhao & Wang, 1990; Zhao et al., 1986).
240 *Pistocythereis bradyi* is a typical middle muddy bay species in Japan (Irizuki et al.,
241 2006; Yasuhara & Irizuki, 2001; Yasuhara & Seto, 2006), and known from open bays
242 such as Gamagyang Bay in Korea (Abe, 1988) and Malacca Strait (Whatley & Zhao,
243 1988b). In these studies, *P. bradyi* prefers relatively high salinity and deeper water in
244 the inner continental shelf (Tables 2 and 3). Our data agree as to the preference for
245 high salinity, but inconsistent with the literature regarding shallower water depths.
246 Salinity may be more important than depth, but the restricted depth range of our sites
247 (≤35 m) may also be a reason for this inconsistency. Our results indicate that *P.*
248 *bradyi* is sensitive to metal pollution.
249
250 **b. Temperate Group**

Five species including *Bicornucythere bisanensis* s.l., *Nipponocythere bicarinata*, *Spinileberis quadriaculeata*, *Phlyctocythere japonica* and *Loxoconcha epeterseni* are distributed from Japan-Russian Coast to South China Sea.

Bicornucythere bisanensis s.l. is very common in most samples, the relative abundance of which was significantly correlated with water depth (negative) (Tables 2 and 3) and this species prefers shallower environments (Figs. 2 and 5). 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 this preference for shallow depths. In Japan, *Bicornucythere bisanensis* is tolerant of anthropogenic impacts, especially eutrophication and the resulting bottom water hypoxia (Irizuki et al., 2003; Irizuki et al., 2011; Irizuki et al., 2015a; Irizuki et al., 2018; Yasuhara et al., 2003; Yasuhara et al., 2007; 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; Irizuki et al., 2018; Yasuhara & Yamazaki, 2005; Yasuhara et al., 2007). Form A is less abundant in Hong Kong, and due to the difficulty of juvenile identification, we did not divide *B. bisanensis* into morphotypes. *Bicornucythere bisanensis* s.l. is widely distributed throughout marginal marine environments around Japan, Russia (Sea of Japan coast), and the East and South China Seas (Fig. 4).

276 Relative abundance of *N. bicarinata* correlated with productivity (negative)
277 (Tables 2 and 3). This is a typical middle bay species in Japan (Irizuki et al., 2006),
278 abundant on muddy substrates at water depths >10 m (Yasuhara & Seto, 2006;
279 Yasuhara et al., 2005). We found *N. bicarinata* to be sensitive to eutrophication,
280 prefering lower productivity (Figs 2 and 5). This species is know from marginal
281 marine environments around Japan and the East and South China Seas (Fig. 4).
282 Relative abundance of *S. quadriaculeata* correlated to productivity (positive),
283 and turbidity (negative) (Tables 2 and 3). This is a typical inner muddy bay species in
284 Japan (Irizuki et al., 2006), which prefers silty substrates in brackish waters, at
285 salinities from 20–30, and water depths of 2–7 m (Ikeya and Shiozaki, 1993). This
286 study shows a preference for waters with higher productivity but relatively low
287 turbidity (Tables 2 and 3), so that the species is abundant in Tolo Harbour (higher
288 productivity, lower turbidity) but not in Deep Bay (higher turbidity) (Figs. 2 and 5).
289 *Spinileberis quadriaculeata* is not tolerant to seasonal anoxia or oxygen depletion (0–
290 1 mg/L) in Uranouchi Bay, Japan (Irizuki et al., 2008), but we do not find a
291 significant correlation with dissolved oxygen content, probably due to the relatively
292 high bottom-water oxygen content (2.96–6.84 mg/L) in Hong Kong (Fig. 2;
293 Supplement B). *Spinileberis quadriaculeata* is widely distributed in marginal marine
294 environments around Japan, Russia (Sea of Japan coast), and the East and South
295 China Seas (Fig. 4).
296 Relative abundance of *P. japonica* correlated with water depth (positive)
297 (Tables 2 and 3). This species is known from relatively deeper waters (>40 m) in the
298 East China Sea (Ishizaki, 1981; Wang et al., 1988). At our sites, it has its greatest
299 abundance at the deeper southern sites (Fig. 5). *Phlyctocythere japonica* is distributed
300 around Japan (Yasuhara et al., 2002) and the East and South China Seas (Fig. 4).

Similarly to *P. japonica*, relative abundance of *L. epeterseni* correlated with water depth (positive), and turbidity (negative) (Tables 2 and 3). It occurs in the southern and eastern, deeper and less turbid regions of Hong Kong waters, but the trend is not very clear (Figs 2 and 5). This species is also known from the deeper parts of Osaka Bay (Yasuhara & Irizuki, 2001) and marginal marine environments around Japan (Ishizaki, 1968), the East China Sea (Yang et al., 1982), and the South China Sea (Cao, 1998) (Fig. 4). 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 these are the females and males of the same species (Ikeya et al., 2003). Ishizaki (1981) gave the new species names *Loxoconcha epeterseni* 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 (e.g., see Ikeya et al., 2003).

c. Subtropical Group

Six species including *Sinocytheridea impressa, Neomonoceratina delicata*, *Keijella kloempritensis*, *Neosinocythere elongata*, *Stigmatocythere roesmani* and *Hemicytheridea reticulata* are reported from the East China Sea to Indo-Pacific area.

Sinocytheridea impressa [=*Sinocytheridea latiovata*; see Whatley and Zhao (1988a)] is the most dominant species, the relative abundance of which was significantly correlated with salinity (negative), dissolved oxygen (negative), mud content (positive) and productivity (positive) (Tables 2 and 3). This species is

noticeably dominant in areas characterized by a muddy bottom including northern Mirs Bay, Port Shelter and coastal Southern Waters (Fig. 5). It 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). *Sinocytheridea 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. 4).

Neomonoceratina delicata (=*Neomonoceratina crispata*; see Hou & Gou, 2007) is very common in most of the samples, and the relative abundance significantly correlates with Zn (positive), salinity (positive) and turbidity (positive) (Tables 2 and 3). *Neomonoceratina delicata* is a nearshore species, abundant at depths less than 30 m, at relatively high salinities (>30; Zhao and Wang, 1988). It prefers the higher salinity waters in Hong Kong (Figs. 2 and 5; Tables 2 and 3) and in view of its positive correlation with Zn and turbidity, is likely tolerant to human-induced environmental stress such as pollution and eutrophication. This species is widely known from nearshore and estuarine environments in the East and South China Seas, and the Indo-Pacific (Fig. 4).

The relative abundance of *K. kloempritensis* correlated only with water depth (positive) (Fig. 6; Tables 2 and 3). Widely known from the tropical Indo-Pacific region, *K. kloempritensis* is abundant along the inner continental shelf of the South and East China Seas (Fig. 4), at water depths ranging from 20–50 m and salinity close to normal marine (Zhao & Wang, 1990). Our modelling results are consistent with this, showing a preference for the relatively deeper waters in our study (Tables 2 and

352 3). Thus, this species is probably useful for reconstructing past sea-level changes in
353 the broad tropical and subtropical Indo-Pacific and northwestern Pacific regions as a
354 deeper water indicator.

355 Relative abundance of *N. elongata* correlated only with turbidity (positive)
356 (Tables 2 and 3). This species occurs along the entire coast of China (Fig. 4) in
357 marginal marine, especially estuarine environments shallower than 20 m (Dong et al.,
358 2012; Hou & Gou, 2007; Liu et al., 2013; Liu et al., 2017; Zhao & Whatley, 1993)
359 (Fig. 4). Known from the Indo-Pacific region, our modeling results and previous
360 studies indicate consistently that *N. elongata* prefers shallow, turbid waters like Deep
361 Bay and the Pearl River Estuary (Figs 2 and 6).

362 The relative abundance of both *S. roesmani* and *H. reticulata* correlated with
363 Pb (negative) (Tables 2 and 3), thus they are sensitive to metal pollution (but note the
364 significant autocorrelation with the modeling result of *S. roesmani*) and absent in
365 areas with high metal concentrations, e.g., Tolo and Victoria Harbours (Fig. 3, 6).
366 Relative abundance of *H. reticulata* also correlated with water depth (negative)
367 (Tables 2 and 3). This species is abundant in Tolo Harbour and the inner part of Mirs
368 Bay (Fig. 6), at shallow depths, and is also consistently found in very shallow waters
369 from the Indo-Pacific (Zhao & Whatley, 1989). Their metal-pollution sensitivity is
370 contradictory because they occur in Tolo and Victora Harbours, both polluted regions
371 of Hong Kong, and further research is needed to better understand these results (Figs
372 2 and 6). They occur in the East and South China Seas and the Indo-Pacific region
373 (Fig. 4).

374

375 **d. Tropical Group**

376 Three species including *Loxoconcha malayensis*, *Alocopocythere goujoni* and
377 *Hemikrithe orientalis* are distributed from the South China Sea to the Indo-Pacific.
378 Relative abundance of *L. malayensis* correlated with dissolved oxygen
379 (negative) and mud content (negative) (Tables 2 and 3). It is a typical tropical species
380 known from the Indo-Pacific and the South China Sea (Fig. 4). We did not find a
381 correlation with temperature, likely due to the small range of variation of bottom
382 water temperatures in Hong Kong (winter temperature: 19.10–21.49°C). This species
383 prefers coarse sediments and is resistant to low oxygen content (Table 2 and 3), as
384 seen by its abundance in Victoria Harbour (Figs. 2 and 6).
385 Relative abundance of both *A. goujoni* and *H. orientalis* correlated with
386 natural factors only. *Alocopocythere goujoni* correlated with salinity (positive)
387 (Tables 2 and 3) and occurs not only in Mirs Bay where the salinity is higher, but also
388 in Deep Bay and North Western Waters where the salinity is lower than in other areas
389 (Figs 2 and 6). The Deep Bay and North Western Waters are shallow and have
390 relatively low oxygen content. The modeling result of this species shows a marginally
391 insignificant but negative relationship to oxygen content and water depth with
392 moderately high relative importance (Table 3). We explain this inconsistency by
393 considering their preference for higher salinity and shallow water depths, and also
394 their resistance to low oxygen conditions, but further research is needed to know their
395 autoecology with better confidence. Relative abundance of *H. orientalis* correlated
396 with water depth (positive) (Tables 2 and 3; but note the significant autocorrelation
397 with the modeling result of this genus), and it is more abundant in deeper waters
398 including southern Mirs Bay (Fig. 6). It is known from depths of 20–50 m in the
399 South China Sea (Zhao & Wang, 1988a), and reported from tropical Indo-Pacific
400 marginal marine environments (Fig. 4). Our regression modeling consistently shows a

positive relationship between relative abundance and winter temperatures, with moderately high relative importance, although the correlation is marginally insignificant (Table 3).

e. Globally Distributed Group

Propontocypris is known as a cosmopolitan genus. The relative abundance of *Propontocypris* spp. significantly correlated with productivity (negative) (Tables 2 and 3). This negative correlation with productivity (but note a 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.

Phytal genera including *Neonesidea* spp. and *Xestoleberis* spp. have global distribution and are correlated with various environmental factors. The relative abundance of *Neonesidea* spp. correlated with dissolved oxygen (positive), as expected for a phytal species (Smith & Kamiya, 2002; Yamada, 2007) (Table 2 and 3; Fig 7). Similarly, phytal (Irizuki et al., 2008; Sato & Kamiya, 2007; Yasuhara et al., 2002) *Xestoleberis* spp. correlated with dissolved oxygen (positive), turbidity (negative) and mud content (negative) (Table 2 and 3; Fig. 7). This taxon's habitat preference including clear water, coarse sediment, and high oxygen content are reflected in our modeling. As mentioned above, the value of allochthonous phytal species to environmental interpretation is limited, but they broadly reflect adjacent phytal environments.

Summary

Benthic ostracods from Hong Kong marginal marine waters studied here include widespread (i.e., one species distributed throughout the northwestern Pacific—Indo-Pacific region), temperate (i.e., five species distributed from the South China Sea to Japan and Russia), subtropical (i.e., six species distributed from the Indo-Pacific to the East China Sea), and tropical (i.e., three species distributed in the Indo-Paficic and South China Sea) species and three globally distributed genera (Fig. 4). 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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792

793

794 **Captions**

795

796 Fig. 1 Locality map showing the 52 sampling sites across Hong Kong, including 41
797 open water sites (blue dots) and 11 typhoon shelter sites (red open dots). From west to
798 east, DS: Deep Bay; NS: North Western waters; SS: Southern waters; VS: Victoria
799 Harbour; ES: Eastern Buffer; JS: Junk Bay; TS: Tolo Harbour; PS: Port Shelter; MS:
800 Mirs Bay.
801
802 Fig. 2 Spatial distribution of environmental parameters in Hong Kong. Mean surface-
803 water chlorophyll-a concentration; water depth; summer (June to September) bottom-
804 water dissolved oxygen content; mean bottom-water salinity; mean turbidity; mean
805 summer (June to September) bottom-water temperature; mean winter (November to
806 February) bottom-water temperature; and mean mud content. All are averaged values
807 of the data obtained during 1986–2013 (Table 1).
808
809 Fig. 3 Spatial distribution of environmental parameters in Hong Kong. Mean copper
810 (Cu) concentration, mean lead (Pb) concentration, and mean zinc (Zn) concentration
811 in surface sediments. All are averaged values of the data obtained during 1986–2013
812 (Table 1).
813
814 Fig. 4 Geographical distributions of the 18 taxa in the northwestern Pacific and Indo-
815 Pacific regions, including *Pistocythereis bradyi*, *Bicornucythere bisanensis* s.l.,
816 *Nipponocythere bicarinata*, *Spinileberis quadriaculeata*, *Phlyctocythere japonica*,
817 *Loxoconcha epeterseni*, *Sinocytheridea impressa, Neomonoceratina delicata*, *Keijella*
818 *kloempritensis*, *Neosinocythere elongata*, *Stigmatocythere roesmani*, *Hemicytheridea*
819 *reticulata Loxoconcha malayensis*, *Alocopocythere goujoni*, *Hemikrithe orientalis*,
820 *Propontocypris* spp*., Neonesidea* 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); Gu et al. (2017); 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). Note that *Sinocytheridea impressa* is know to be distributed in Japan, but their Japanese distribution is very limited in certain areas of the southern part of Japan (Iwasaki, 1992; Tanaka et al. 2019). Thus, we did not indicate their Japanese-Russian coast distribution in this figure.

Fig. 5 Spatial distribution of the relative abundance for *Pistocythereis bradyi*, *Bicornucythere bisanensis* s.l., *Nipponocythere bicarinata*, *Spinileberis quadriaculeata*, *Phlyctocythere japonica*, *Loxoconcha epeterseni*, *Sinocytheridea impressa,* and *Neomonoceratina delicata* in Hong Kong. See Figure 1 for sampling stations.

Fig. 6 Spatial distribution of the relative abundance for *Keijella kloempritensis*, *Neosinocythere elongata*, *Stigmatocythere roesmani*, *Hemicytheridea reticulata* *Loxoconcha malayensis*, *Alocopocythere goujoni*, *Hemikrithe orientalis*, and *Propontocypris* spp. in Hong Kong. See Figure 1 for sampling stations.

Fig. 7. Spatial distribution of the relative abundance for *Neonesidea* spp. and *Xestoleberis* spp. in Hong Kong. See Figure 1 for sampling stations.

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 *Pistocythereis bradyi*, *Bicornucythere bisanensis* s.l., *Nipponocythere bicarinata*, *Spinileberis quadriaculeata*, *Phlyctocythere japonica*, *Loxoconcha epeterseni*, *Sinocytheridea impressa, Neomonoceratina delicata*, *Keijella kloempritensis*, *Neosinocythere elongata*, *Stigmatocythere roesmani*, *Hemicytheridea reticulata Loxoconcha malayensis*, *Alocopocythere goujoni*, *Hemikrithe orientalis*, *Propontocypris* spp*., Neonesidea* spp. and *Xestoleberis* spp.. 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 for common species including *Pistocythereis bradyi*, *Bicornucythere bisanensis* s.l., *Nipponocythere bicarinata*, *Spinileberis quadriaculeata*, *Phlyctocythere japonica*, *Loxoconcha epeterseni*, *Sinocytheridea impressa, Neomonoceratina delicata*, *Keijella kloempritensis*, *Neosinocythere elongata*, *Stigmatocythere roesmani*, *Hemicytheridea reticulata Loxoconcha malayensis*, *Alocopocythere goujoni*, *Hemikrithe orientalis*,

Propontocypris spp., *Neonesidea* spp. and *Xestoleberis* spp.. 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. + and - marks indicate significant positive and negative corrlations, respectively.

Supplement A. Ostracod faunal list.

Supplement B. Dataset used for the regression modeling.

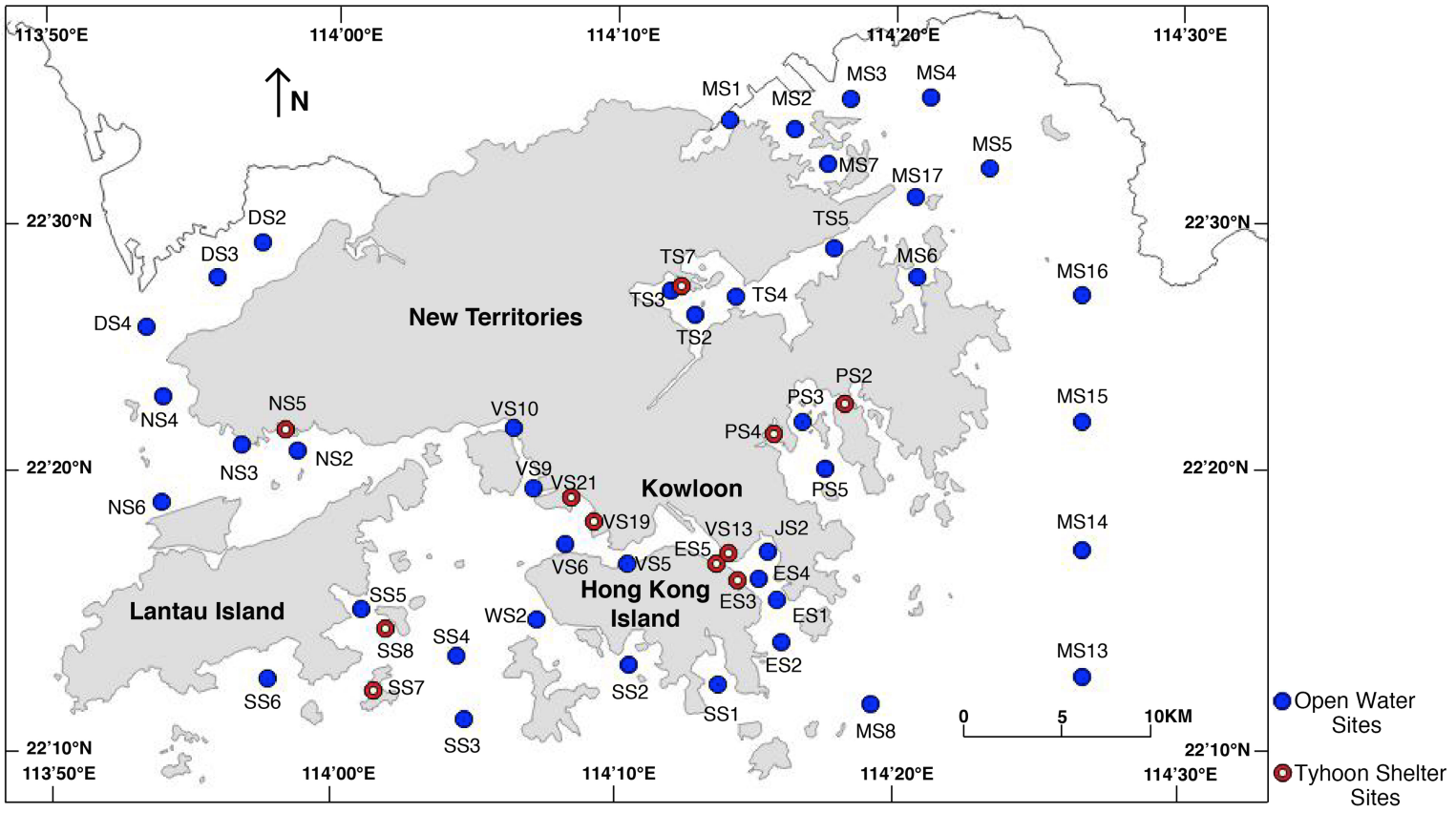
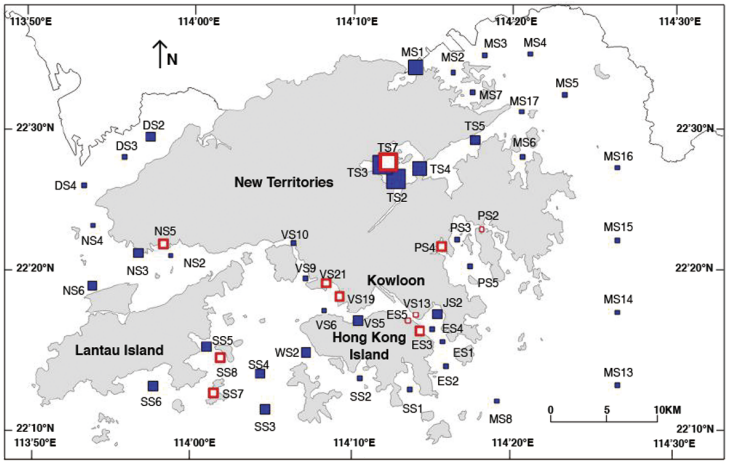
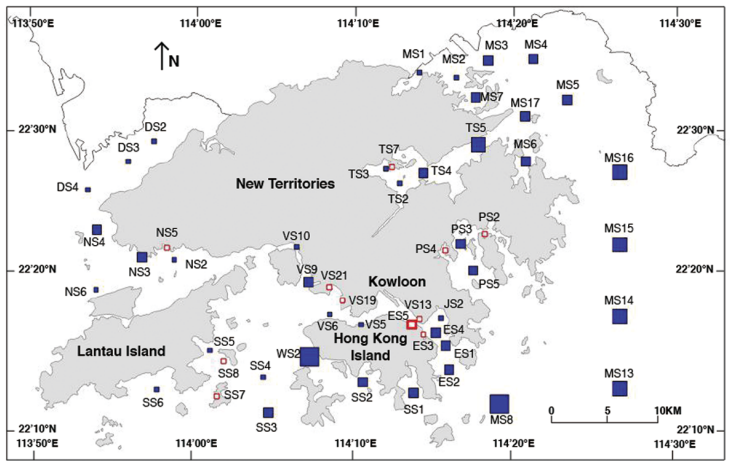

113°50'E
114°00'E
114°10'E
114°20'E
114°30'E
N
22°30'N
22°20'N
22°10'N
MS1
MS2
MS3
MS4
MS5
MS7
MS17
MS6
MS16
MS15
MS14
MS13
MS8
TS5
TS7
TS3
TS4
TS2
DS2
DS3
DS4
New Territories
PS2
PS3
PS4
PS5
NS5
NS4
NS3
NS2
NS6
VS10
VS9
VS21
VS19
VS6
VS5
VS13
JS2
ES5
ES4
ES3
ES1
ES2
Kowloon
Hong Kong Island
Lantau Island
SS5
SS8
SS4
SS6
SS7
SS3
WS2
SS2
SS1
0
5
10KM
Open Water Sites
Tyhoon Shelter Sites

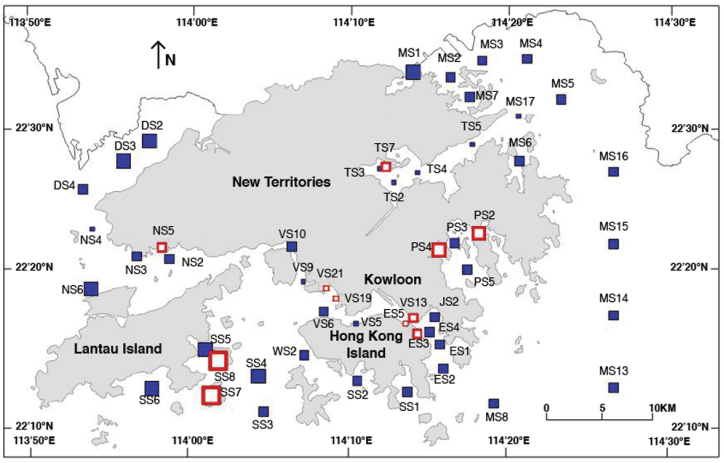
Fig. 1



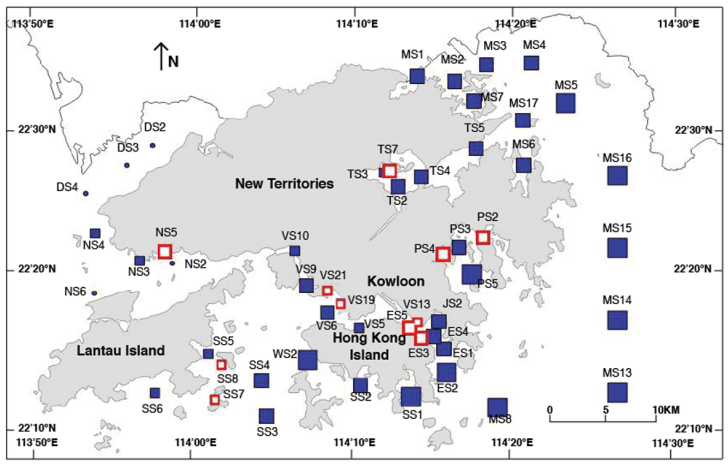
Chlorophyll-a (Chl) ▪1.0–4.0 ■4.1–8.0 ■8.1–12.0 ■>12.0μg/L



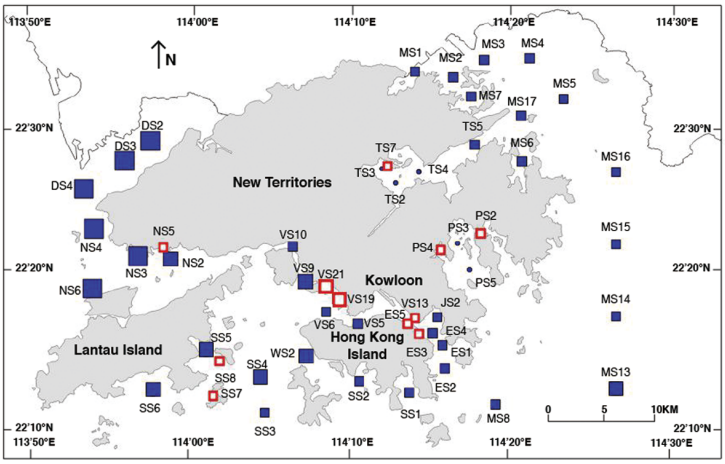
Water Depth(D) ▪1–10 ■11–20 ■21–30 ■>30m



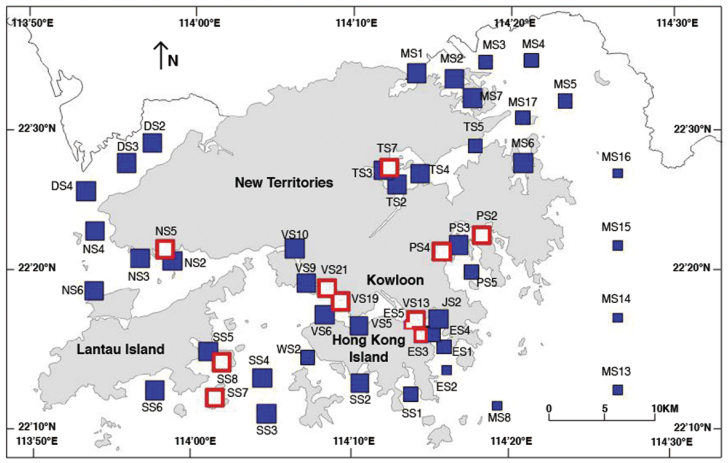
Dissolved Oxygen (DO) ▪2.95–4.00 ■4.01–5.00 ■5.01–6.00 ■>6.00mg/L



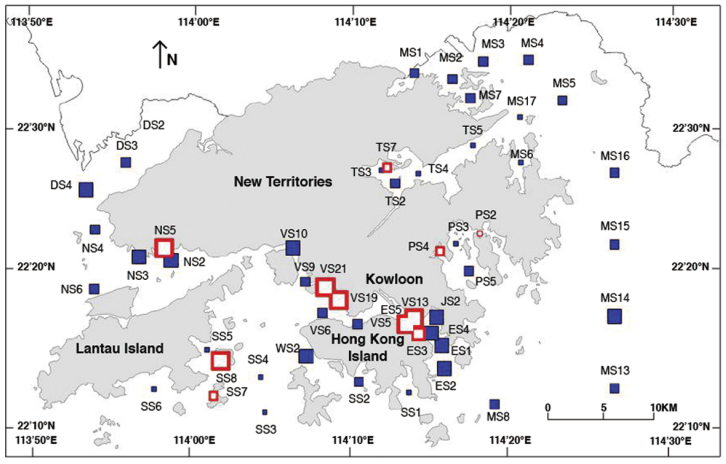
Salinity (Sal) ▪<30 ■30–31.5 ■31.6–33 ■>33psu



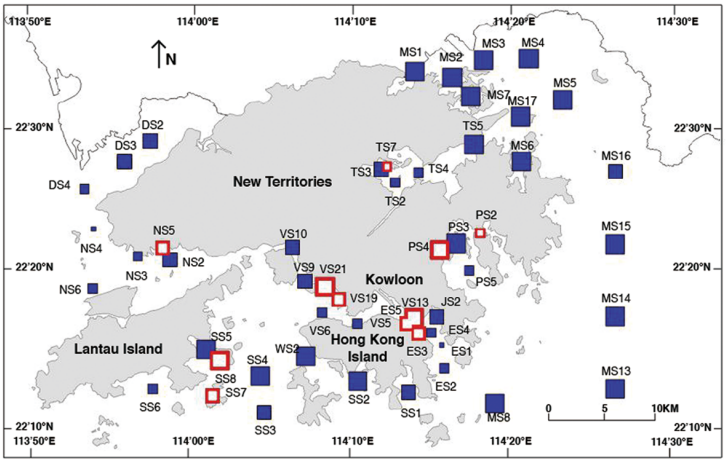
Turbidity (Tur) ▪0–5 ■5.1–10 ■10.1–15 ■>15NTU



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

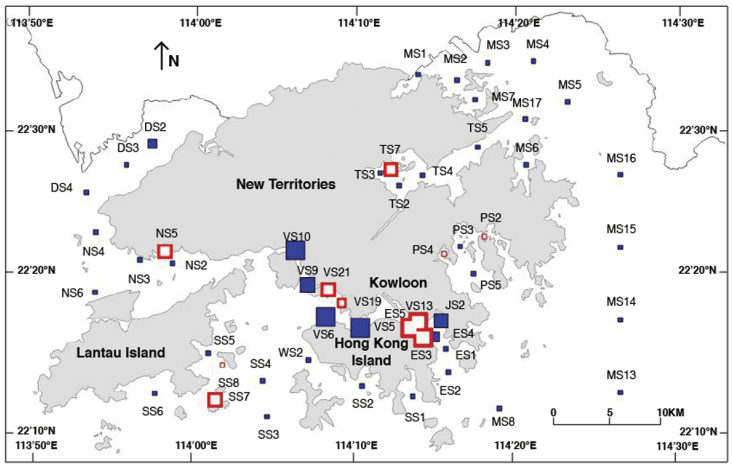


Winter Temperature (WT) ▪19.0–19.5 ■19.51–20.0 ■20.01–20.5 ■>20.5

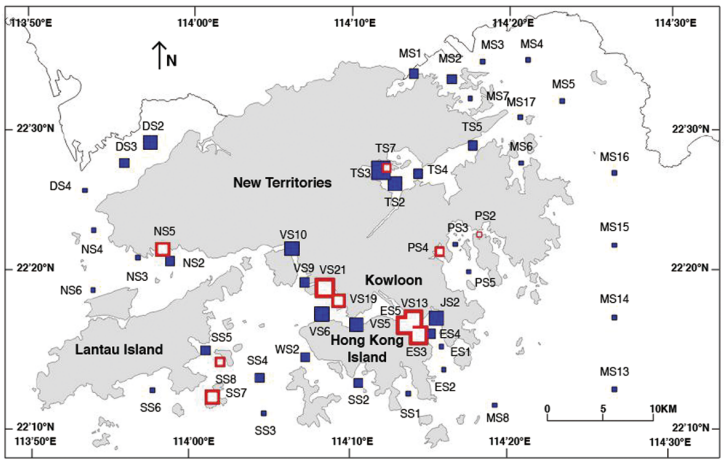


Mud Content (MD) ▪40–55 ■55.1–70 ■70.1–85 ■>85%w/w(<63μm)

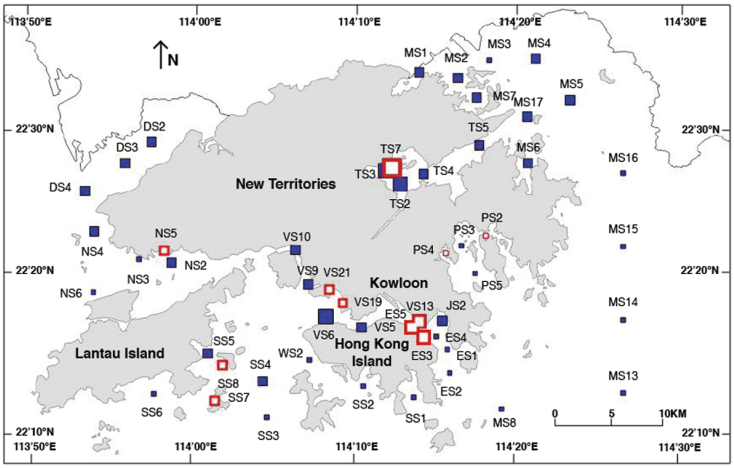
Fig. 2



Copper (Cu) ▪0–50 ■51–100 ■101–150 ■>150mg/kg

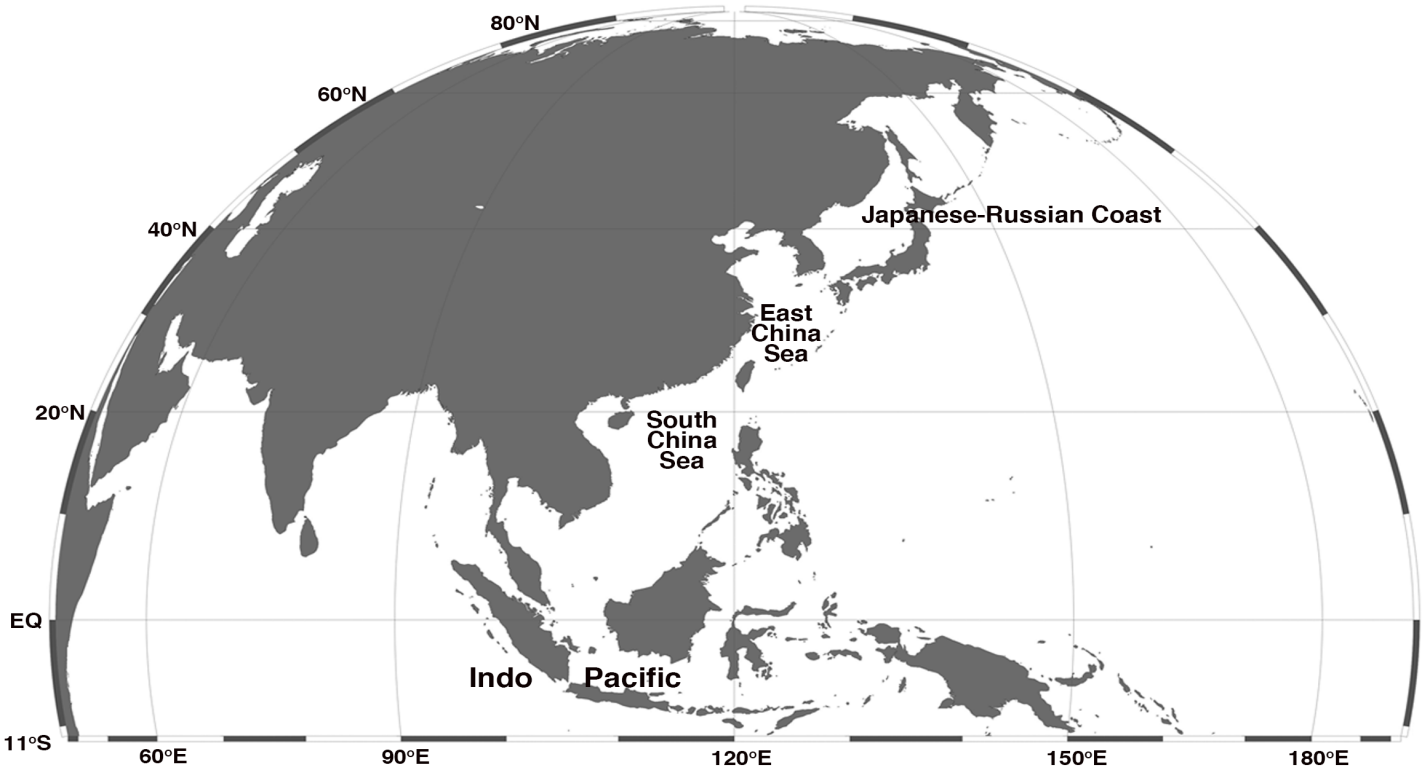


Zinc (Zn) ▪0–100 ■101–150 ■151–200 ■>200mg/kg



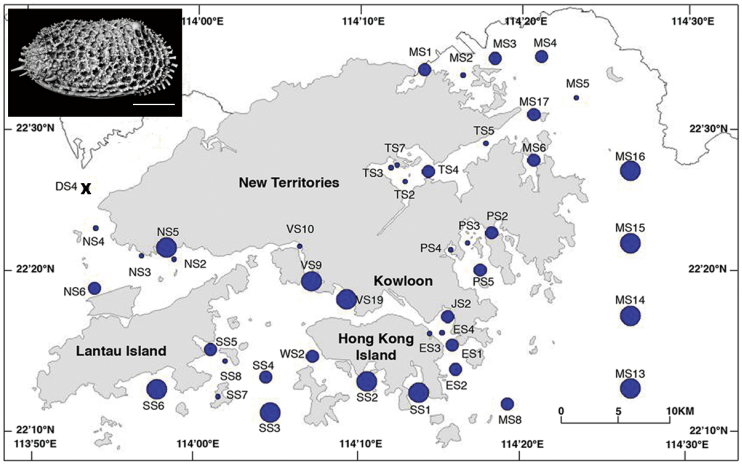
Lead (Pb) ▪0–40 ■41–80 ■81–120 ■>120mg/kg

Fig. 3

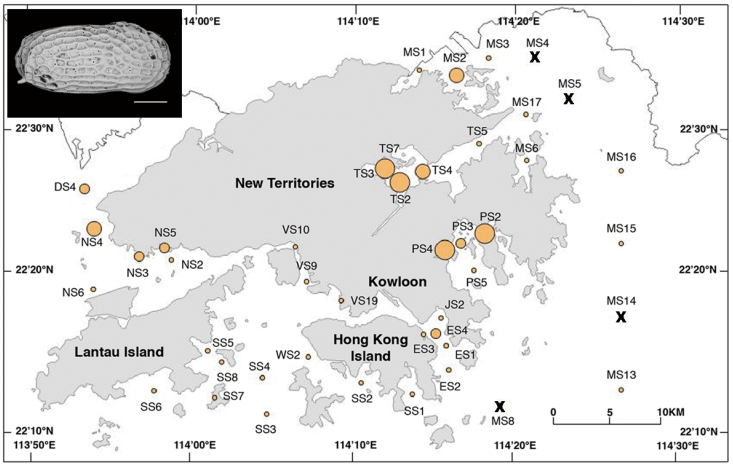


Species	Indo Pacific	South China Sea	East China Sea	Japanese-Russian Coast
Pistocythereis bradyi	(a)			
Bicornucythere bisanensis s.l.		(b)		
Nipponocythere bicarinata				
Spinileberis quadriaculeata				
Phlytocythere japonica				
Loxoconcha epeterseni				
Sinocytheridea impressa	(c)			
Neomonoceratina delicata				
Keijella kloempritensis				
Neosinocythere elongata				
Stigmatocythere roesmani				
Hemicytheridea reticulata				
Loxoconcha malayensis	(d)			
Alocopocythere goujoni				
Hemikrithe orientalis				
Propontocypris spp.	(e)			
Neonesidea spp.				
Xestoleberis spp.				

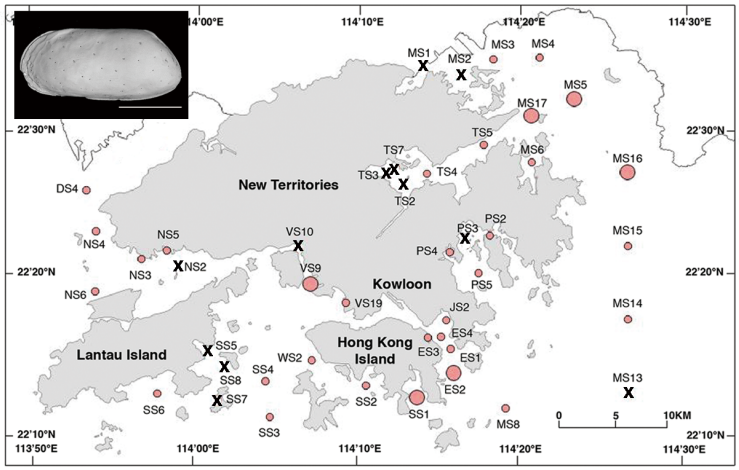
Fig. 4



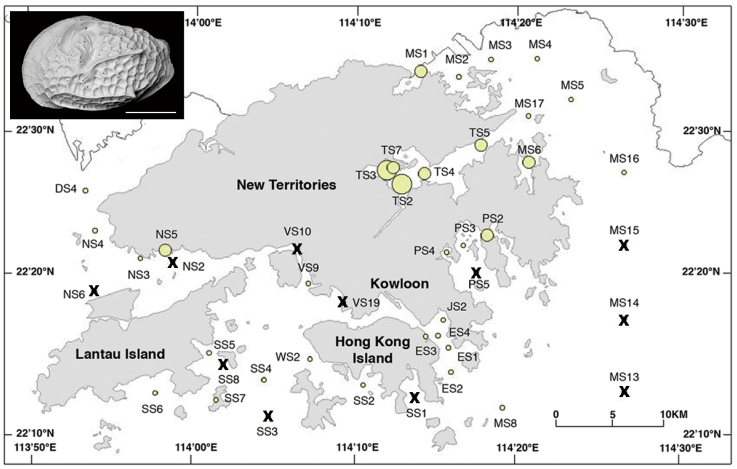
Pistocythereis bradyi 0< • ≤5% 5< ● ≤10% 10< ● ≤15% x absent



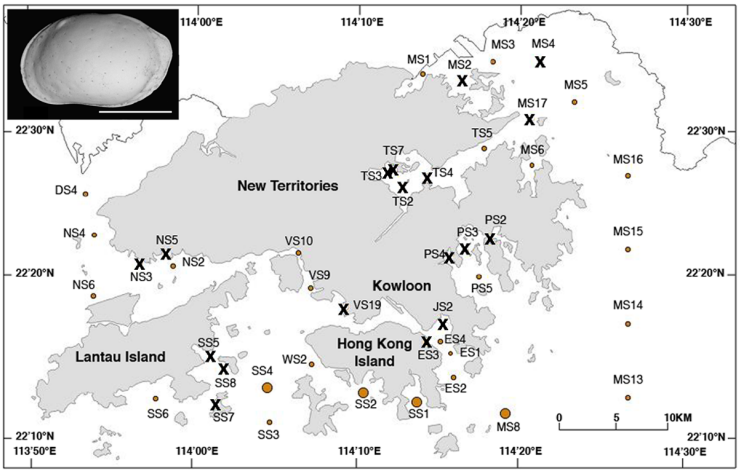
Bicornucythere bisanensis s.l. 0< ○ ≤5% 5< ○ ≤10% 10< ○ ≤15% 15< ○ ≤20% x absent



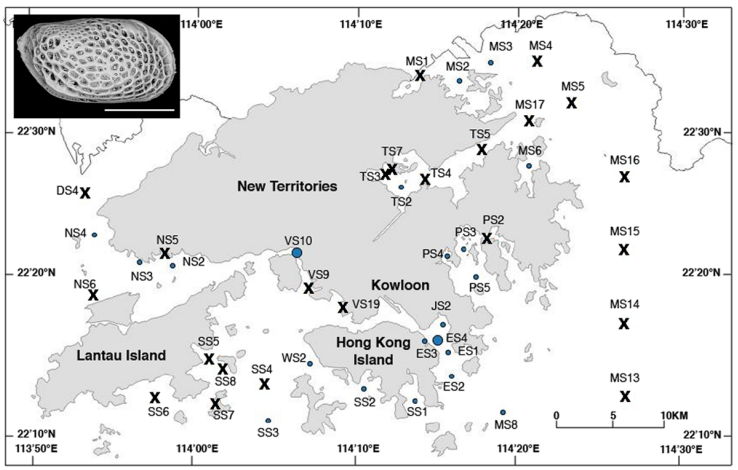
Nipponocythere bicarinata 0< ○ ≤5% 5< ○ ≤10% x absent



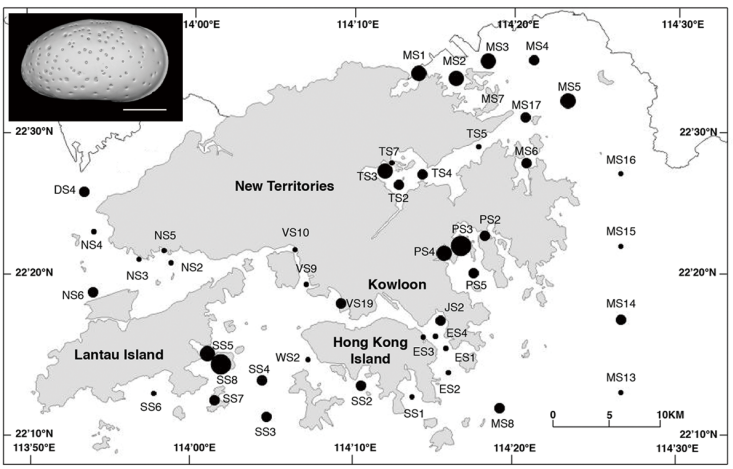
Spinileberis quadriaculeata 0< ○ ≤5% 5< ○ ≤10% 10%≤ ○ x absent



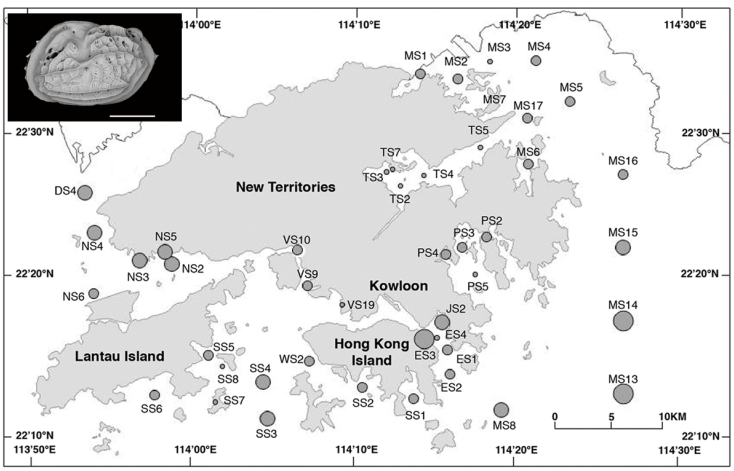
Phlyctocythere japonica 0< • ≤3.5% 3.5< ● ≤7% x absent



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

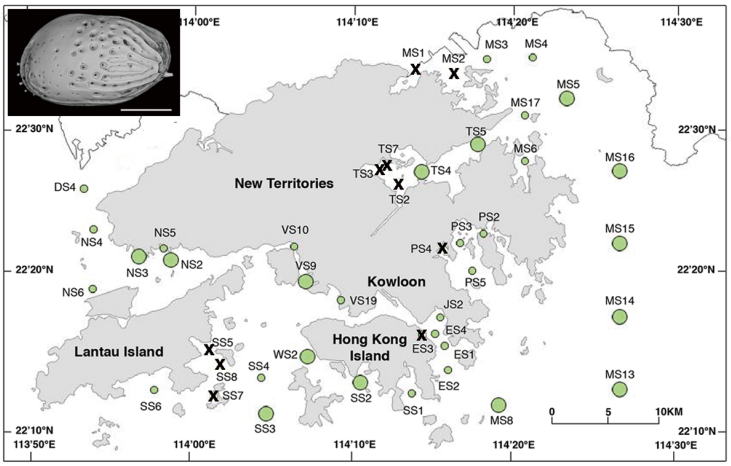


Sinocytheridea impressa 0< • ≤20% 20< ● ≤40% 40< ● ≤60% 60< ● ≤80%

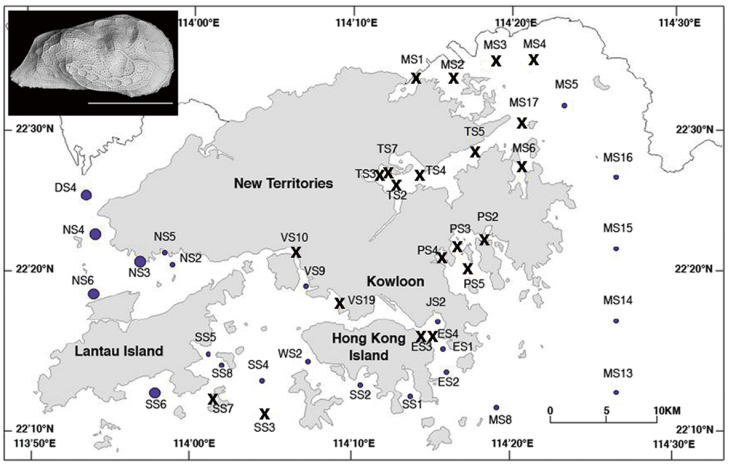


Neomonoceratina delicata 0< ○ ≤10% 10< ○ ≤20% 20< ○ ≤30% 30%<

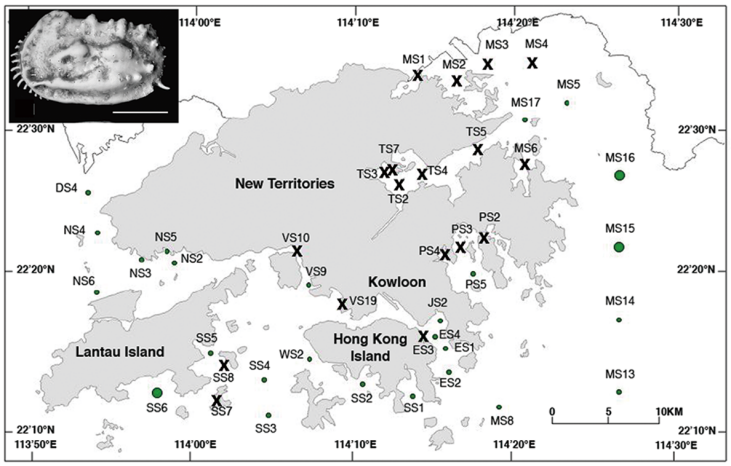
Fig. 5



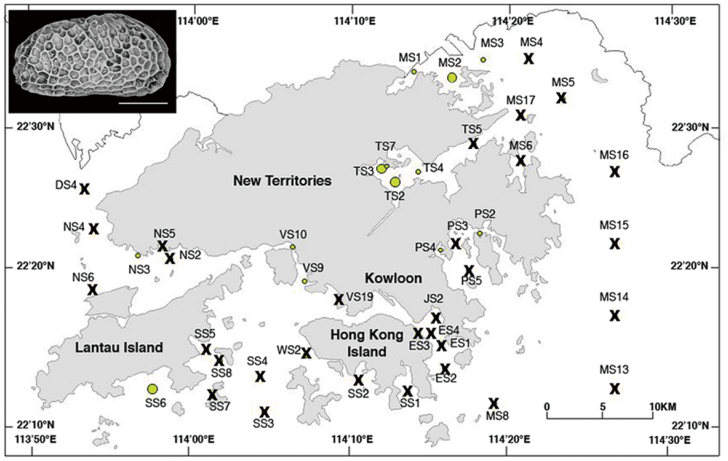
Keijella kloempritensis 0< ≤5% 5< ≤10% x absent



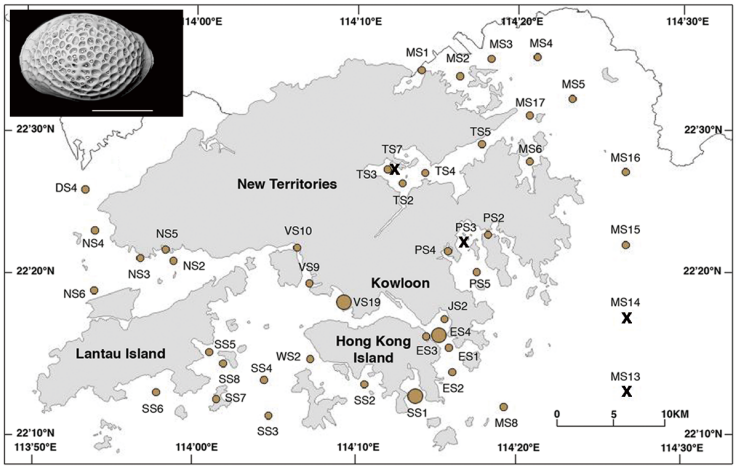
Neosinocythere elongata 0< • ≤5% 5< ≤10% x absent



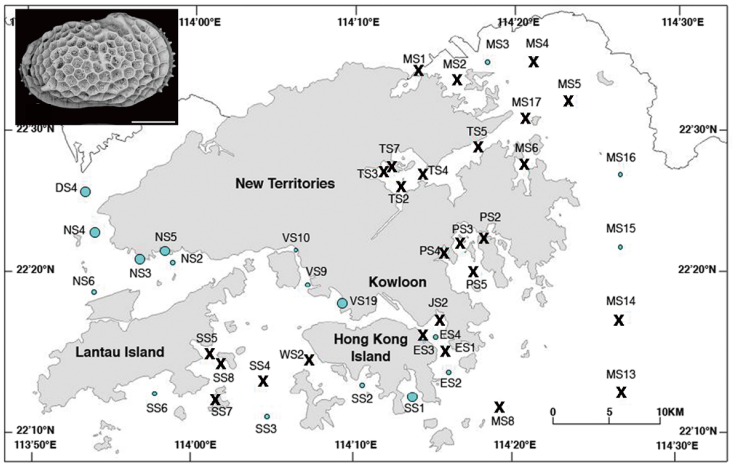
Stigmatocythere roesmani 0< • ≤4% 4< ≤8% x absent



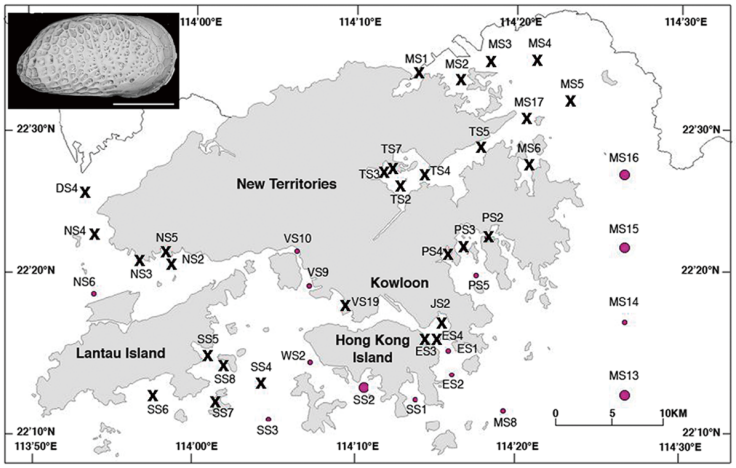
Hemicytheridea reticulata 0< • ≤2% 2< ≤4% x absent



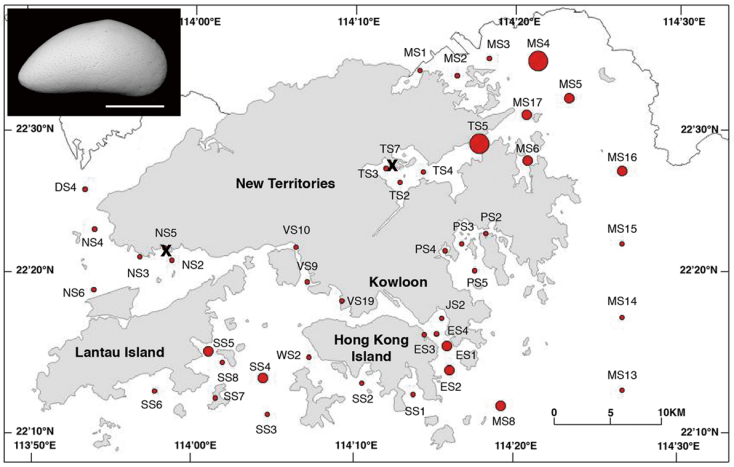
Loxoconcha malayensis 0< ≤5% 5< ≤10% x absent



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

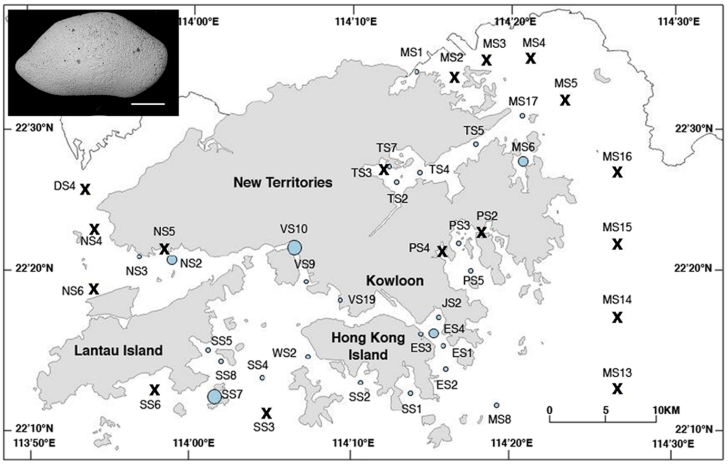


Hemikrithe orientalis 0< • ≤3% 3< ≤6% x absent

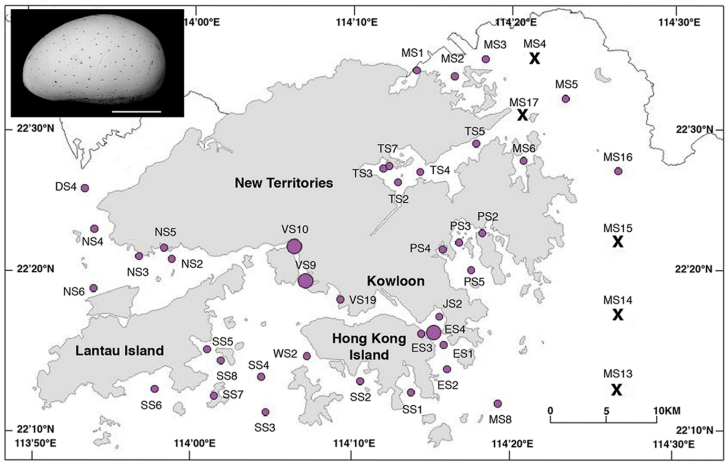


Propontocypris spp. 0< •≤10% 10< ≤20% 20%< ≤60% x absent

Fig. 6



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



Xestoleberis spp. 0< ● ≤5% 5< ● ≤15% x absent

Fig. 7

Table 1.

Parameter (Abbreviation)	Unit	Sampling Depth / Material	Season
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
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
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
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
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
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
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

Model	Chl	D	DO	MD	Sal	Tur	WT	Pb	Zn	R	R^2	AICc	AW
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
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
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
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
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
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
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

Table 3.

Term	RI	Coeffiencient	Lower CI	Upper CI	Term	RI	Coeffiencient	Lower CI	Upper CI
Pistocythereis bradyi					***Loxoconcha epeterseni***				
R	1.00	-0.06	-0.15	0.04	R	1.00	0.00	-0.02	0.03
Sal	**1.00**	**2.71**	**1.53**	**3.88**	**D**	**0.94**	**0.03**	**0.00**	**0.05**
D	**1.00**	**-0.12**	**-0.19**	**-0.06**	**Tur**	**0.76**	**-0.03**	**-0.06**	**0.00**
Pb	**0.97**	**-0.21**	**-0.32**	**-0.10**	Sal	0.53	-0.30	-0.62	0.02
Tur	0.12	0.04	-0.07	0.15	MD	0.38	-0.04	-0.08	0.01
Zn	0.11	-0.05	-0.23	0.13	Chl	0.30	0.02	-0.01	0.04
DO	0.10	0.06	-0.18	0.31	DO	0.26	0.04	-0.02	0.10
WT	0.10	0.33	-0.98	1.64	Pb	0.17	0.01	-0.02	0.05
Chl	0.09	0.02	-0.08	0.11	WT	0.13	-0.13	-0.48	0.22
MD	0.08	-0.01	-0.20	0.18	Zn	0.12	0.01	-0.03	0.04
***Bicornucythere bisanensis* s.l.**					***Sinocytheridea impressa***				
R	1.00	0.01	-0.11	0.12	R	1.00	0.36	-0.09	0.81
MD	0.63	-0.26	-0.52	0.00	**Sal**	**0.99**	**-9.26**	**-14.61**	**-3.91**
D	**0.62**	**-0.08**	**-0.16**	**0.00**	**DO**	**0.91**	**-1.42**	**-2.48**	**-0.37**
Pb	0.38	0.14	-0.05	0.33	**MD**	**0.75**	**0.82**	**0.07**	**1.57**
DO	0.20	0.17	-0.15	0.48	**Chl**	**0.74**	**0.82**	**0.03**	**0.70**
Chl	0.19	0.06	-0.07	0.19	WT	0.20	**0.82**	-2.34	8.89
Tur	0.19	0.07	-0.08	0.22	Zn	0.13	**0.82**	-0.68	0.51
Zn	0.16	-0.01	-0.28	0.25	Tur	0.11	**0.82**	-0.61	0.30
Sal	0.12	-0.02	-1.86	1.82	D	0.11	**0.82**	-0.29	0.41
WT	0.10	0.06	-1.80	1.92	Pb	0.10	**0.82**	-0.62	0.46
Nipponocythere bicarinata					***Neomonoceratina delicata***				
R	1.00	0.02	-0.04	0.09	R	1.00	-0.15	-0.42	0.12
Chl	**0.92**	**-0.08**	**-0.14**	**-0.02**	**Zn**	**0.94**	**0.41**	**0.11**	**0.70**
DO	0.50	-0.14	-0.30	0.02	**Sal**	**0.93**	**4.06**	**1.00**	**7.13**
D	0.30	-0.03	-0.08	0.02	**Tur**	**0.84**	**0.33**	**0.06**	**0.59**
WT	0.25	-0.03	-0.08	0.02	DO	0.33	0.45	-0.17	1.06
Sal	0.24	0.51	-0.35	1.36	Pb	0.17	-0.18	-0.67	0.30
Tur	0.19	-0.04	-0.11	0.04	MD	0.14	0.25	-0.33	0.84
Zn	0.18	-0.04	-0.12	0.04	D	0.11	-0.01	-0.22	0.20
Pb	0.13	-0.03	-0.11	0.06	WT	0.11	-0.86	-4.32	2.60
MD	0.10	0.00	-0.13	0.13	Chl	0.09	0.00	-0.24	0.23
Spinileberis quadriaculeata					***Keijella kloempritensis***				
R		-0.01	-0.10	0.07	R	1.00	-0.02	-0.09	0.04
Tur	**0.66**	**-0.09**	**-0.17**	**0.00**	**D**	**0.86**	**0.06**	**0.02**	**0.11**
Chl	**0.54**	**0.06**	**0.00**	**0.13**	Pb	0.58	-0.08	-0.17	0.01
D	0.45	-0.05	-0.10	0.01	Sal	0.35	0.68	-0.21	1.58
WT	0.32	-0.76	-1.82	0.31	MD	0.25	0.08	-0.05	0.21
DO	0.19	0.10	-0.10	0.30	Tur	0.24	0.05	-0.03	0.14
MD	0.17	-0.07	-0.23	0.09	Chl	0.22	-0.04	-0.11	0.03
Pb	0.17	-0.05	-0.16	0.07	Zn	0.17	0.02	-0.11	0.14
Zn	0.14	0.03	-0.09	0.15	WT	0.14	0.33	-0.55	1.22
Sal	0.13	0.11	-1.03	1.26	DO	0.11	0.03	-0.14	0.19
Phlyctocythere japonica					***Neosinocythere elongata***				
R	1.00	-0.01	-0.05	0.03	R	1.00	-0.03	-0.07	0.00
D	**0.80**	**0.03**	**0.01**	**0.06**	**Tur**	**1.00**	**0.08**	**0.04**	**0.13**
Sal	0.42	0.46	-0.10	1.02	MD	0.33	-0.05	-0.13	0.02
Pb	0.21	-0.03	-0.08	0.03	Chl	0.30	-0.02	-0.05	0.01
Zn	0.20	-0.02	-0.07	0.03	WT	0.26	-0.33	-0.85	0.18
WT	0.15	0.22	-0.38	0.81	Zn	0.21	-0.02	-0.06	0.02
DO	0.14	0.03	-0.08	0.15	Pb	0.19	-0.02	-0.07	0.02
Tur	0.12	0.00	-0.05	0.05	D	0.12	0.00	-0.03	0.03
Chl	0.12	0.00	-0.04	0.05	DO	0.12	-0.02	-0.11	0.07
MD	0.11	0.00	-0.09	0.08	Sal	0.10	0.04	-0.40	0.49

Term	RI	Coeffiencient	Lower CI	Upper CI
Stigmatocythere roesmani				
R	1.00	-0.01	-0.07	0.05
Sal	0.61	0.62	-0.04	1.27
Pb	**0.61**	**-0.06**	**-0.12**	**0.00**
Tur	0.37	0.04	-0.01	0.10
Zn	0.31	-0.05	-0.11	0.02
DO	0.31	0.09	-0.04	0.22
MD	0.23	-0.06	-0.16	0.04
Chl	0.19	-0.02	-0.07	0.02
WT	0.19	0.35	-0.33	1.02
D	0.14	-0.01	-0.05	0.04
Hemicytheridea reticulata				
R	1.00	0.01	-0.02	0.03
Pb	**0.67**	**-0.04**	**-0.07**	**0.00**
D	**0.66**	**-0.02**	**-0.04**	**0.00**
Chl	0.49	0.03	0.00	0.05
WT	0.24	-0.24	-0.64	0.16
MD	0.23	-0.03	-0.09	0.02
Zn	0.17	-0.01	-0.06	0.05
DO	0.13	0.02	-0.05	0.10
Tur	0.13	-0.01	-0.05	0.03
Sal	0.11	-0.05	-0.43	0.34
Loxoconcha malayensis				
R	1.00	0.02	-0.02	0.06
DO	**0.87**	**-0.14**	**-0.25**	**-0.03**
MD	**0.85**	**-0.11**	**-0.20**	**-0.02**
D	0.48	-0.03	-0.06	0.00
Chl	0.40	0.03	-0.01	0.08
Pb	0.29	-0.04	-0.10	0.02
WT	0.26	0.41	-0.21	1.03
Zn	0.20	-0.03	-0.10	0.04
Sal	0.15	-0.26	-0.91	0.39
Tur	0.11	-0.01	-0.07	0.05
Alocopocythere goujoni				
R	1.00	-0.03	-0.05	-0.02
Sal	**0.78**	**0.22**	**0.03**	**0.41**
D	0.46	-0.01	-0.02	0.00
DO	0.43	-0.03	-0.07	0.01
Pb	0.31	-0.01	-0.03	0.01
Zn	0.29	-0.01	-0.03	0.01
WT	0.24	0.13	-0.08	0.33
Tur	0.18	0.01	-0.01	0.03
MD	0.14	-0.01	-0.04	0.02
Chl	0.11	0.00	-0.01	0.01

Term	RI	Coeffiencient	Lower CI	Upper CI
Hemikrithe orientalis				
R	1.00	0.00	-0.04	0.03
D	**0.77**	**0.03**	**0.00**	**0.05**
WT	0.46	0.43	-0.07	0.93
DO	0.44	0.08	-0.02	0.17
Sal	0.30	0.37	-0.17	0.90
Pb	0.22	-0.03	-0.08	0.02
Tur	0.17	0.02	-0.03	0.07
Chl	0.14	-0.01	-0.05	0.03
Zn	0.11	0.00	-0.05	0.05
MD	0.10	-0.01	-0.08	0.07
***Propontocypris* spp.**				
R	1.00	0.05	-0.19	0.30
Chl	**0.80**	**-0.26**	**-0.47**	**-0.04**
MD	0.58	0.50	-0.03	1.03
WT	0.29	-2.60	-6.48	1.28
Pb	0.19	-0.18	-0.55	0.20
Sal	0.17	-1.48	-4.88	1.92
DO	0.15	-0.27	-0.99	0.45
Zn	0.14	-0.03	-0.48	0.41
D	0.13	0.04	-0.17	0.26
Tur	0.10	0.01	-0.29	0.32
***Neonesidea* spp.**				
R	1.00	0.02	-0.09	0.13
DO	**0.72**	**0.30**	**0.02**	**0.57**
Zn	0.58	0.15	-0.01	0.31
MD	0.46	-0.23	-0.49	0.03
Chl	0.42	-0.09	-0.21	0.02
WT	0.32	-1.13	-2.69	0.42
Tur	0.24	-0.09	-0.22	0.05
D	0.23	0.05	-0.04	0.15
Pb	0.17	0.05	-0.13	0.24
Sal	0.15	-0.60	-2.20	1.01
***Xestoleberis* spp.**				
R	1.00	-0.01	-0.06	0.05
Tur	**0.77**	**-0.07**	**-0.12**	**-0.01**
MD	**0.66**	**-0.10**	**-0.19**	**0.00**
DO	**0.63**	**0.13**	**0.00**	**0.26**
D	0.42	0.03	-0.01	0.07
Pb	0.33	0.04	-0.02	0.11
Sal	0.27	0.46	-0.24	1.15
WT	0.19	-0.37	-1.06	0.31
Zn	0.14	0.00	-0.09	0.08
Chl	0.10	0.00	-0.05	0.05

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