Zoological Studies **47**(3): 258-267 (2008)

Zoological Studies

Spatial and Seasonal Variations in Chaetognath Assemblages in Two Subtropical Marine Inlets with Different Hydrographical Characteristics

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(Accepted October 17, 2007)

Pan Tse, Sami Souissi, Jiang-Shiou Hwang, Qing-Chao Chen, and Chong Kim Wong (2008) Spatial and seasonal variations in chaetognath assemblages in two subtropical marine inlets with different hydrographical characteristics. *Zoological Studies* **47**(3): 258-267. The seasonal and spatial occurrences of Chaetognatha were studied in 2 subtropical marine inlets with different hydrographical characteristics. Tolo Harbour and Mirs Bay are marine bays in the northeastern corner of Hong Kong. Tolo Harbour is a semi-enclosed bay with poor water circulation. It opens into Mirs Bay which is fully exposed to water currents from the South China Sea. Chaetognath species were grouped by hierarchical classification of samples using the Bray-Curtis similarity coefficient and a clustering strategy with flexible links. Indicator species for each group were used to characterize species assemblages. Indigenous species, including *Flaccisagitta enflata*, *Aidanosagitta neglecta*, *A. delicata*, *A. nagae*, *A. crassa*, *A. johorensis*, and *A. regularis*, occurred in the entire study area, but their densities were higher in Tolo Harbour. Non-indigenous species, including *A. bedfordii*, *Krohnitta pacifica*, *Pterosagitta draco*, *Decipisagitta decipiens*, *Ferosagitta ferox*, *Fer. robusta*, *Fer. tokiokai*, *Mesosagitta minima*, *Sagitta bipunctata*, *Serratosagitta pacifica*, *Zonosagitta bedoti*, *Z. bruuni*, and *Z. pulchra* were carried into Mirs Bay by ocean currents from the South China Sea and were rarely found in Tolo Harbour.
http://zoolstud.sinica.edu.tw/Journals/47.3/258.pdf

Key words: Chaetognaths, Spatial-seasonal distribution, Subtropical marine inlet, Indicator species.

Hong Kong is located on the northern edge of the South China Sea and is connected to the East China Sea via the Taiwan Strait (Fig. 1). The climate of Hong Kong is subtropical. The seas around Hong Kong are strongly influenced by ocean currents driven by 2 monsoon winds. In winter, the northeastern monsoon drives cold water masses from the East China Sea into the northern part of the South China Sea via the Taiwan Strait. Water temperatures remain moderate, ranging 15-22°C, as the Kuroshio Current carries warm waters from the Pacific Ocean into the South China Sea via the Luzon Strait (Hu et al. 2000). During the southwestern monsoon period in summer, the Kuroshio intrusion is restricted by northeasterly flowing ocean currents (Hu et al. 2000). The influence of ocean currents on plankton communities in the coastal seas of southern China is shown by the seasonal occurrence of *Calanus sinicus* Brodsky, 1962 which is carried from its population centers in the Yellow Sea and East China Sea into the South China Sea during winter (Hwang and Wong 2005).

Mirs Bay and Tolo Harbour are large inlets on the east coast of Hong Kong (Fig. 1). Flanked by China on the north and east and by Hong Kong on the west, Mirs Bay is exposed to ocean currents from the South China Sea from the south. Tolo

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Harbour, an almost land-locked and poorly flushed bay, opens into Mirs Bay via a narrow channel. The average water depth decreases from ~20 m in Mirs Bay to < 10 m in the inner part of Tolo Harbour. Both Mirs Bay and Tolo Harbour are marine in character, with little variation in salinity except after heavy rains. Tolo Harbour has a long history of eutrophication. Water samples collected between 2003 and 2005 showed average chlorophyll *a* concentrations of 5.75 μg/L in Tolo Harbor and 1.34 μg/L in Mirs Bay (Liu and Wong, 2006). High algal biomass and poor mixing lead to frequent development of hypoxia in the bottom of Tolo Harbour, particularly in summer when the water column is thermally stratified (Morton 1989). The mesozooplankton community of Tolo Harbour is dominated by smaller-sized copepods mainly of the genera *Oithona* and *Paracalanus* (Wong et al. 1993). Information on mesozooplankton in Mirs Bay is sparse.

Chaetognaths occur in almost all marine habitats including estuaries, open oceans, tidal pools, polar waters, marine caves, coastal lagoons, and the deep sea (Bone et al. 1991). In the world's oceans, chaetognaths constitute 5%-15% of the zooplankton biomass and are one of the main predators of copepods (Pearre 1980, Longhurst 1985). The distribution of chaetognath species has been used as an indicator of water masses (Bieri 1959, Alvariño 1965, Pierrot-Bults and Nair 1991). In the subtropical coastal waters of Hong Kong, chaetognaths often form an important component of the mesozooplankton (Chen 1982). A 2-yr study of chaetognaths in Tolo Harbour and Mirs Bay was carried out between July 2003 and July 2005 (Tse et al. 2007). In total, 20 species were recorded, including 6 species from the genus *Aidanosagitta*, 4 species from the genus *Zonosagitta*, 3 species from the genus *Ferosagitta*, and 1 species each from the genera *Serratosagitta*, *Decipisagitta*, *Flaccisagitta*, *Krohnitta*, *Mesosagitta*, *Pterosagitta*, and *Sagitta*. Tolo Harbour contains a higher density but a lower species diversity of chaetognaths than Mirs Bay. The three most abundant species, *Fla*. *enflata* (Grassi, 1881), *A*. *neglecta* (Aida, 1897), and *A*. *delicata* (Tokioka 1939), comprised almost 90% of all the chaetognaths collected in the study. All other species were uncommon and collectively made up only about 10% of the chaetognath communities.

Information on the seasonal and spatial distribution of chaetognaths is crucial for understanding the dynamics of marine plankton. In this study, the Bray-Curtis similarity coefficient and a clustering strategy (Souissi et al. 2001, Dur et al. 2007) were used to examine data on the spatial and seasonal patterns of chaetognath species assemblages in Tolo Harbour and Mirs Bay. The 2 marine inlets were chosen to represent 2 coastal environments with distinctly different hydrographical and ecological characteristics. Indicator species, based on the value of the indicator index proposed by Dufrêne and Legendre (1997), were used to identify the spatial and seasonal patterns of specific groups. The results of this study will provide information on habitat requirements for chaetognath species in the subtropical coastal seas of southern China.

MATERIALS AND METHODS

Zooplankton sampling

Zooplankton samples were collected monthly from July 2003 to July 2005 at 6 sampling stations in eastern Hong Kong (Fig. 1). S1 (22°26'725"N, 114°14'566"E) and S2 (22°28'539"N, 114°18' 034"E) were located inside Tolo Harbour. S3 (22° 29'468"N, 114°21'588"E) was in the inner part of Mirs Bay, near the mouth of Tolo Harbour. S4 (22° 26'670"N, 114°26'920"E), S5 (22°17'560"N, 114°26' 920"E), and S6 (22°13'000"N, 114°26'920"E) were located in Mirs Bay. Average water depths at S1, S2, S3, S4, S5, and S6 were 13, 20, 21, 22, 26, and 30 m, respectively. Zooplankton samples were collected at each station by making 2 vertical hauls from 2 m above the bottom to the surface with a conical plankton net (with a mouth diameter of 50 cm and a mesh size of 125 μm). All samples were preserved in 5% formaldehyde until processing. Immediately after zooplankton sampling, the surface temperature and salinity at each station were measured using a Hydrolab water quality monitoring system (Hydrolab Corporation, USA). In the laboratory, chaetognaths were sorted and identified to species level according to Zhang and Chen (1983) and Bieri (1991). Only adults which contained developing or mature reproductive organs were identified to species level. Juveniles with no visible reproductive organs could not be identified to species and were not included in our analysis. At least 25% of each sample was analyzed.

Statistical analysis

For statistical treatment, a matrix was constructed using species as variables and samples (stations and dates) as objects. A double square-root transformation of the original data of species abundances was applied before computing a similarity coefficient between samples. Then, a hierarchical classification of samples was performed using the Bray-Curtis similarity coefficient and clustering strategy of flexible links (Souissi et al. 2001, Dur et al. 2007). The advantage of using dendrograms is that different "resolutions" can be obtained from the dataset depending on the choice of cutoff levels (i.e., the 1st cutoff level produces 2 groups and each group is further separated into 2 clusters to give 4 groups, and so on). For the present analysis, 3 cutoff levels respectively giving 2, 4, and 8 clusters were retained and analyzed. In order to characterize species assemblages for each individual group and across all cutoff levels, indicator species were calculated from an indicator value index (IndVal) proposed by Dufrêne and Legendre (1997). This index is obtained by multiplying 2 independent pieces of information: specificity (measure of affiliation) and fidelity (measure of occurrence) of a species for a group. Species with a high IndVal characterize a group. For the present study, only species having an indicator value greater than the arbitrary threshold level of 25% were retained in the assemblage. Different steps of the cluster analysis and the graphical representation were programmed using Matlab Software (vers. 7.0.1; The MathWorks, Inc., USA).

RESULTS

Hydrography

Both surface temperature and salinity showed a distinct seasonality (Fig. 2). Four seasons including spring (Mar.-May), summer (June-Aug.), autumn (Sept.-Nov.), and winter (Dec.-Feb.) could be identified. The mean temperatures were 21.8°C in spring, 29.4°C in summer, 27.3°C in autumn, and 18.1°C in winter. The mean salinity levels were 33.2‰ in spring, 30.0‰ in summer, 31.0‰ in autumn, and 34.3‰ in winter. Salinity was lowest during the rainy season in summer.

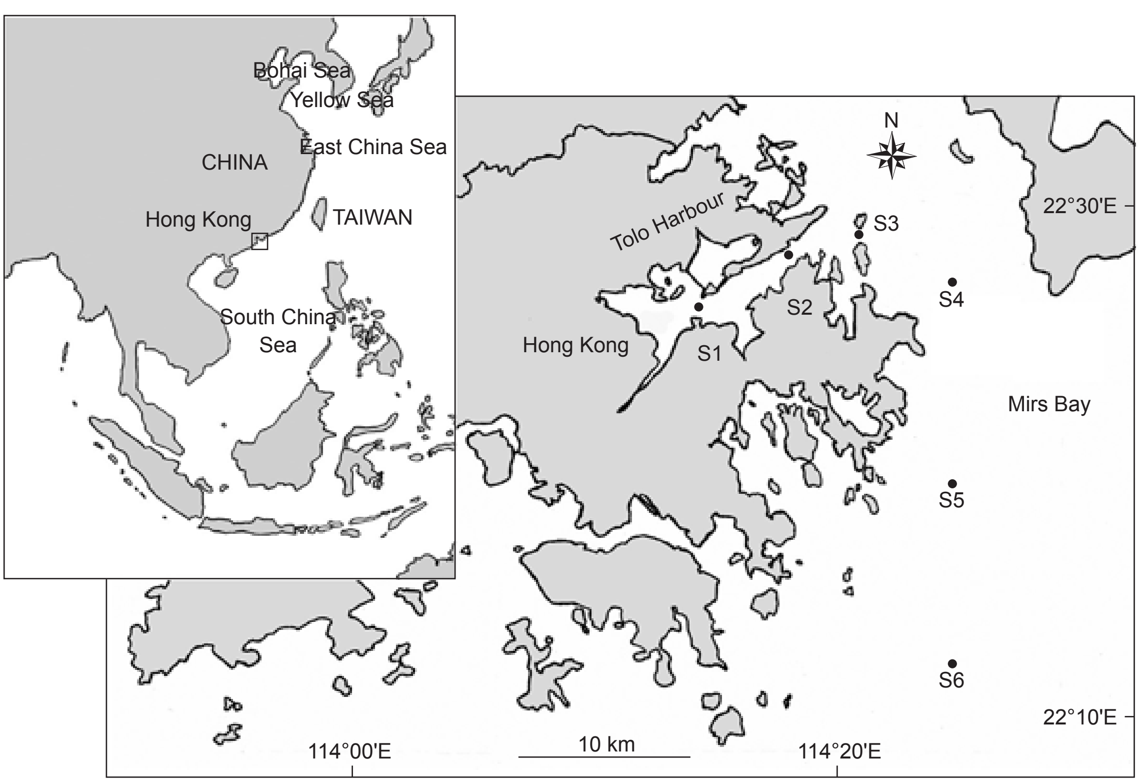

Fig. 1. Map of Hong Kong showing the locations of sampling stations in Tolo Harbour (S1, S2, and S3) and Mirs Bay (S4, S5, and S6).

Hierarchical classification and chaetognath assemblages

Chaetognath assemblages in the coastal water of eastern Hong Kong were identified using 3 cutoff levels of the dendrogram (Fig. 3). The 1st cutoff level generated 2 groups (I and II). The 2nd cutoff level further split each of the 1st cutoff level groups into 2 clusters, producing 4 groups (Ia, Ib, IIa, and IIb). The 3rd cutoff level produced 8 groups (Iai, Iaii, Ibi, Ibii, IIai, IIaii, IIbi, and IIbii) by splitting each of the 2nd cutoff level groups into 2 clusters.

Groups, identified from the dendrogram (Fig. 3), were further examined for spatial and seasonal patterns (Fig. 4). Group I consists mainly of samples collected from Mirs Bay in spring and winter, while group II is largely made up of samples taken from Tolo Harbour in summer and early autumn. Group Ia is mainly represented by samples taken in spring and winter from the inner part of Mirs Bay. In contrast, group Ib is primarily made up of samples collected year round from the outer part of Mirs Bay. Group IIa consists mainly of samples collected in summer and early autumn from Tolo Harbour. In comparison, group IIb contains only samples taken from Tolo Harbour at different times of the year. Group Iai consists mainly of samples collected in spring and winter. Group Iaii includes samples collected at different times of the year. Group Ibi includes many samples collected in spring and early summer from both Tolo Harbour and the outer part of Mirs Bay. In contrast, group Ibii includes only samples taken from Mirs Bay. Group IIai is mainly represented by samples taken from Tolo Harbour; Group IIaii, on the other hand, is dominated by samples taken from the inner part of Mirs Bay. Group IIai consists mainly of samples collected in summer and autumn, while group IIaii includes samples collected at different times of the year. Groups IIbi and IIbii are made up mainly of samples collected in Tolo Harbour and the inner part of Mirs Bay. Group IIbi includes only samples collected in summer and autumn, while group IIbii includes samples taken year round.

Indicator species

Indicator species of the different groups are listed in table 1. The 1st cutoff level did not provide sufficient resolution to identify indicator species specific to groups I or II. For example, *Flaccisagitta enflata* is an indicator species for both groups I and II. Sufficient resolution was obtained in groups Ia and Ib, which were generated by the 2nd cutoff level. However, in groups IIa and IIb, *Fla*. *enflata* and *A*. *delicata*, were indicator species of both groups. Therefore, a 3rd cutoff level was required to produce groups IIai, IIaii, IIbi, and IIbii, which contained specific indicator species.

DISCUSSION

Chaetognaths are predominantly holoplanktonic invertebrates and are well known as useful indicators of water movements (Bieri

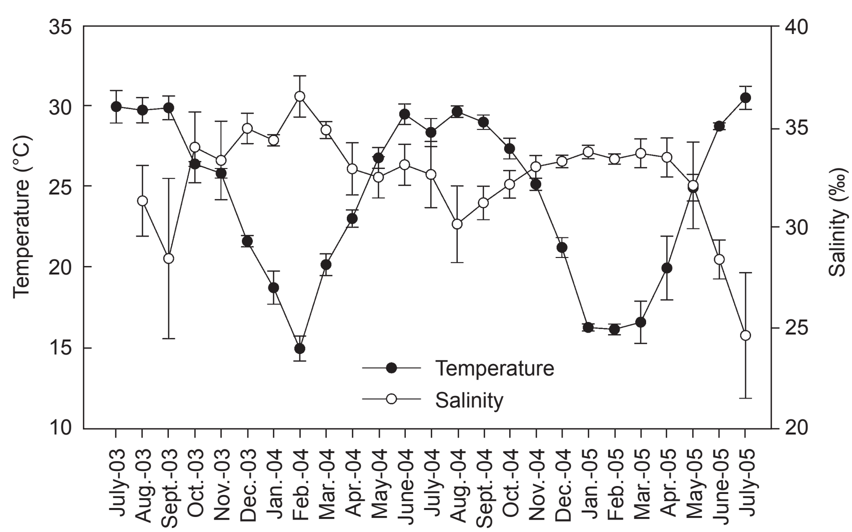

Fig. 2. Monthly variations in surface (at 0.5 m deep) water temperature and salinity in Tolo Harbour and Mirs Bay. Each point represents the mean (± SD) of 6 sampling stations (S1, S2, S3, S4, S5, and S6).

1959, Alvariño 1965, Pierrot-Bults and Nair 1991). Different species of chaetognaths have different distribution patterns. Two major patterns, belt-shaped and non-belt-shaped, have been used to describe the geographical distributions of chaetognath species (Pierrot-Bults and Nair 1991). Species with belt-shaped patterns are distributed circum-globally and can be further divided into 4 groups: wide ranges (± 70°N to ± 65°S), warm-water I (± 40°N to ± 40°S), warm-water II (± 30°N to ± 30°S), and cold water (> 40°N and > 40°S). Species with non-belt-shaped patterns are associated with specific water masses and may include oceanic and neritic groups.

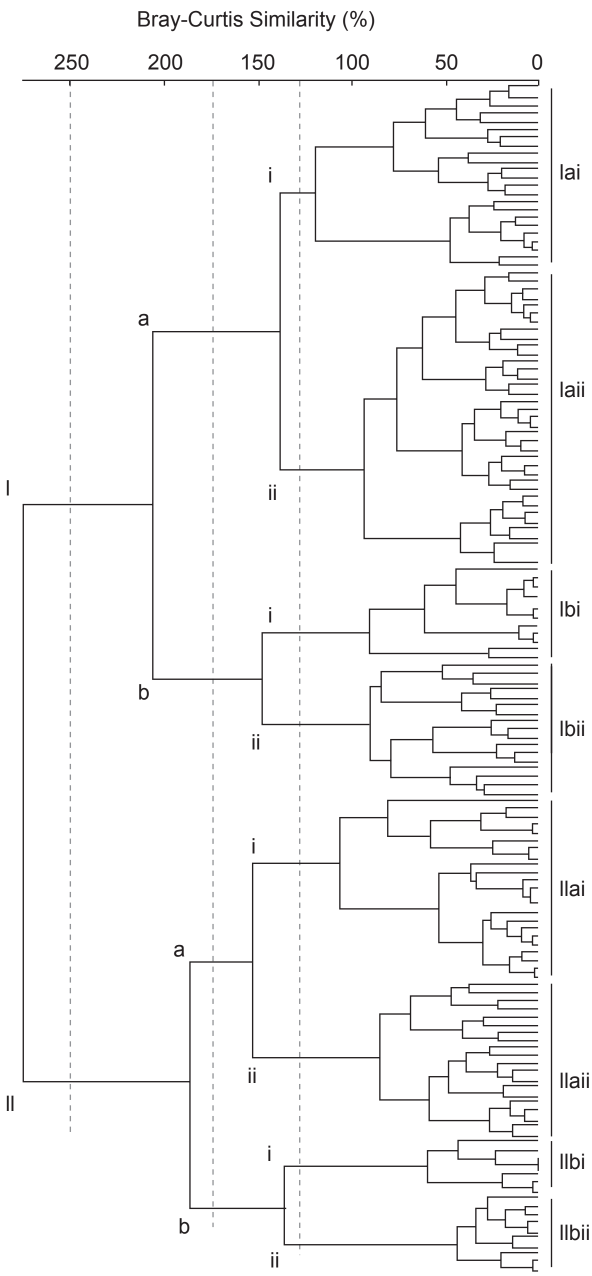

Fig. 3. Dendrogram from the cluster analysis performed on a Bray-Curtis similarity matrix using the strategy of flexible links. Twenty species of chaetognaths were recorded from monthly samples collected at 6 stations from July 2003 to July 2005. Assemblage groups were identified at various levels of resolution. The 1st level generated groups I and II; the 2nd level generated groups Ia, Ib, IIa, and IIb; and the 3rd level generated groups Iai, Iaii, Ibi, Ibii, IIai, IIaii, IIbi, and IIbii.

The 20 species of chaetognaths recorded in the subtropical coastal waters of Hong Kong (Tse et al. 2007) can be classified into both belt-shaped and non-belt-shaped patterns using information on species ranges provided by Pierrot-Bults and Nair (1991). The belt-shaped warm-water I group includes *P. draco* (Krohn, 1853), *D. decipiens* (Fowler, 1905), *Fla. enflata*, *M. minima* (Grassi, 1881), *Sag. bipunctata* Quoy and Gaimard, 1828, and *Ser. pacifica* (Tokioka, 1940). *Krohnitta pacifica* (Aida, 1897) is considered a belt-shaped warm-water II species, but its presence in the Yellow Sea (Du et al. 2003) and Sea of Japan (Johnson and Terazaki 2003, Nagai et al. 2006) suggests that it may also be classified as a warm-water I species. The non-belt-shaped neritic Indo-Pacific group includes *A. bedfordii* (Doncaster 1903), *A. crassa* (Tokioka, 1938), *A. delicata*, *A. johorensis* (Pathansali and Tokioka, 1963), *A. neglecta*, *Z. bedoti* (Beraneck, 1895), and *Z. pulchra* (Doncaster, 1902). The non-belt-shaped oceanic Indo-Pacific group includes *A. neglecta* (Aida, 1897), *Fer. ferox* (Doncaster, 1903), and *Fer. robusta* (Doncaster, 1903). *Ferosagitta tokiokai* (Alvariño, 1967), *Z. bruuni* (Beraneck, 1895), and *Z. nagae* are known to exist in the neritic regions of the South China Sea (Alvariño 1967, Zhang and Chen 1983). However, *Fer. tokiokai* and *Z. nagae* (Alvariño 1967) are also known to occur in the East China Sea and South China Sea, while *Z. nagae* has been reported from the Bohai Sea, Yellow Sea, East China Sea, and South China Sea (Du et al. 2003). Little is known about the distributions of *Fer. tokiokai*, *Z. bruuni*, and *Z. nagae* in other oceans, so it is possible that these species occur only in the Pacific Ocean.

Chaetognath species identified in this study were separated into 2 main groups by the clustering analysis. Group I consists of species which occur mainly in Mirs Bay throughout the entire year. These species tend to be most common in winter and spring and are likely to be non-indigenous species, which are carried into the seas around Hong Kong by ocean currents. Group

II consists of species which live mainly inside Tolo Harbour and are most common in spring and summer. Groups I and II could be further divided into subgroups which provided higher resolution for characterizing the spatial and seasonal occurrences of specific species assemblages.

Zonosagitta nagae, the only indicator species of group Ia, was most common in the inner parts of Mirs Bay. *Zonosagitta nagae* is widely distributed along the Chinese coast (Alvariño 1967, Zhang

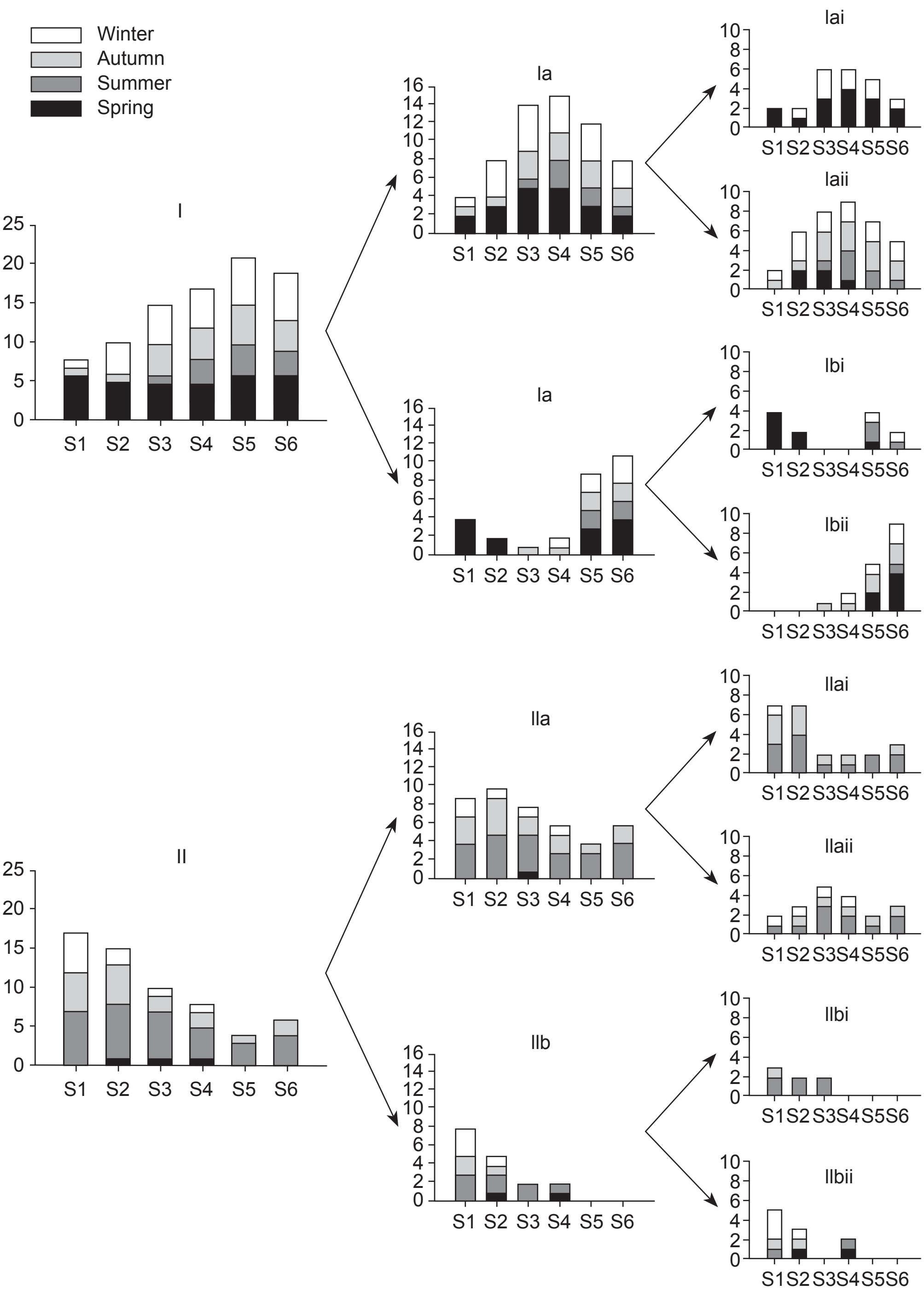

Fig. 4. Spatial and seasonal variations in the number of samples for chaetognath assemblage groups identified at various levels of resolution in the dendrogram. The 1st level generated groups I and II; the 2nd level generated groups Ia, Ib, IIa, and IIb; and the 3rd level generated groups Iai, Iaii, Ibi, Ibii, IIai, IIaii, IIbi, and IIbii. S1, S2, and S3 are located in Tolo Harbour, while S4, S5, and S6 are located in Mirs Bay. The study period from July 2003 to July 2005 was separated into spring, summer, autumn, and winter.

and Chen 1983, Du et al. 2003). The geographical distribution pattern of *Z. nagae* suggests that it can live in habitats used by warm-water I species (± 40°N to ± 40°S). *Zonosagitta nagae* is a dominant species in Suruga Bay, central Japan (Itoh et al. 2006). Along the Chinese coast, *Z. nagae* is a dominant species only in the East China Sea (Du et al. 2003). The prevalence of this species in both Tolo Harbour and Mirs Bay throughout the entire year suggests that it is probably a year-round indigenous species.

Aidanosagitta bedfordii and *K. pacifica* were indicator species of group Ib. Both species occur year-round but are most common in the outer reaches of Mirs Bay. *Aidanosagitta bedfordii* is a neritic Indo-Pacific species (Pierrot-Bults and Nair 1991), which also occurs in the East China Sea and South China Sea (Du et al. 2003). *Krohnitta pacifica* has a circum-global distribution between 30°N and 30°S (Pierrot-Bults and Nair 1991). Its range along the Chinese coast extends from the South China Sea in the south to the Yellow Sea in the north (Du et al. 2003). The prevalence of *A. bedfordii* and *K. pacifica* in Mirs Bay suggests that they are dispersed in near-shore areas by ocean currents and might not be well adapted to the shallow and poorly flushed waters of the semi-enclosed Tolo Harbour.

Aidanosagitta neglecta, the only indicator species of group IIai, was more common in Tolo Harbour than in Mirs Bay. Seasonally, the occurrence of this species was restricted to summer and autumn. *Aidanosagitta neglecta* is a neritic Indo-Pacific species (Pierrot-Bults and Nair 1991). From the Yellow Sea and the Sea of Japan in the north, the range of this species extends to the East China Sea and South China Sea (Du et al. 2003, Johnson and Terazaki 2003). *Aidanosagitta neglecta* is the 2nd most abundant chaetognath species in the coastal waters of eastern Hong Kong (Tse et al. 2007). The spatial and seasonal distribution patterns of this species suggest that it is an indigenous species capable of reaching high densities in the eutrophic, and occasionally hypoxic, shallow waters of Tolo Harbour in summer and autumn.

Aidanosagitta crassa, *A. johorensis*, and *A. regularis* were the indicator species of group IIaii. These species have a year-round occurrence in both Tolo Harbour and Mirs Bay. *Aidanosagitta crassa* and *A. johorensis* are considered to be neritic Indo-Pacific species, while *A. regularis* is regarded as an oceanic Indo-Pacific species (Pierrot-Bults and Nair 1991). However, the presence of *A. regularis* in the coastal waters of Hong Kong suggests that this species is not restricted to oceanic conditions. *Aidanosagitta crassa* is well adapted to cold-water environments (Du et al. 2003). It occurs in Tokioba Bay, Japan (Nagasawa 1985) and is the dominant chaetognath species in the Bohai Sea and Yellow Sea (Du et al. 2003). *Aidanosagitta regularis* is found in the Yellow Sea, East China Sea, South China Sea, and seas around Japan (Du et al. 2003, Johnson and Terazaki 2003). In contrast, *A. johorensis* is restricted to warmer waters of the East China Sea and South China Sea (Du et al. 2003). *Aidanosagitta crassa*, *A. johorensis*,

Table 1. Indicator species for assemblages generated by the cluster analysis. For each species, the indicator value and the number of samples (*n*) from which it was determined are presented

Group	*n*	Indicator species (Indicator value, %)
I	90	*Aidanosagitta bedfordii* (25.4), *Flaccisagitta enflata* (36.3), *Zonosagitta nagae* (55.7)
II	60	*Aidanosagitta crassa* (25), *Aidanosagitta delicata* (74.1), *Aidanosagitta neglecta* (55.7), *Aidanosagitta regularis* (29.5), *Flaccisagitta enflata* (54.8)
Ia	61	*Zonosagitta nagae* (60.8)
Ib	29	*Aidanosagitta bedfordii* (29.6), *Krohnitta pacifica* (26.3)
IIa	43	*Aidanosagitta crassa* (28.9), *Aidanosagitta delicata* (33.6), *Aidanosagitta neglecta* (70.2), *Aidanosagitta regularis* (40.2), *Flaccisagitta enflata* (25.8)
IIb	17	*Aidanosagitta delicata* (47.4), *Flaccisagitta enflata* (25)
IIai	23	*Aidanosagitta neglecta* (72.7)
IIaii	20	*Aidanosagitta crassa* (58.3), *Aidanosagitta johorensis* (38.5), *Aidanosagitta regularis* (79.8)
IIbi	7	*Aidanosagitta delicata* (46)
IIbii	10	*Flaccisagitta enflata* (34.7)

and *A*. *regularis* are able to live in a wide range of temperatures. Indeed, all 3 species can be found in the coastal waters of eastern Hong Kong throughout the year.

Aidanosagitta delicata was the indicator species of group IIbi. It occurred only in Tolo Harbour in summer and autumn. *Aidanosagitta delicata* is a neritic Indo-Pacific species (Pierrot-Bults and Nair 1991), which is found in both the East China Sea and South China Sea (Du et al. 2003). Tokioka (1979) considered *A*. *delicata* to be a neritic species which usually occurs in bays, inlets, and lagoons. Other studies (Chen 1982, Tse et al. 2007) revealed that *A*. *delicata* is one of the most abundant chaetognath species in the coastal waters of Hong Kong. In the coastal waters of eastern Hong Kong, *A*. *delicata* appears to be an indigenous species which is found only in the eutrophic waters of Tolo Harbour during summer and autumn.

Flaccisagitta enflata was the indicator species of group IIbii, as well as groups I and II. It occurred throughout the year in both Tolo Harbour and Mirs Bay. *Flaccisagitta enflata* has a circum-global distribution between 40°N and 40°S (Pierrot-Bults and Nair 1991). Along the Chinese coast, this species occurs in the Bohai Sea and Yellow Sea, and is considered to be the dominant chaetognath species in the East China Sea and South China Sea (Du et al. 2003). *Flaccisagitta enflata* is usually the dominant species in regions where it occurs (Duró et al. 1994, Terazaki 1996, Øresland 2000, Batistić 2003). It is the most abundant species in Hong Kong waters (Chen 1982, Tse et al. 2007). Although group IIbii was only represented by samples collected in Tolo Harbour, it must be noted that *Fla*. *enflata* is abundant in the entire study area.

Other chaetognath species including *P*. *draco*, *D*. *decipiens*, *Fer*. *ferox*, *Fer*. *robusta*, *Fer*. *tokiokai*, *M*. *minima*, *Sag*. *bipunctata*, *Ser*. *pacifica*, *Z*. *bedoti*, *Z*. *bruuni*, and *Z*. *pulchra* were not considered to be indicator species. In the subtropical coastal waters of Hong Kong, these species occur infrequently and in low densities (Tse et al. 2007). *Pterosagitta draco*, *D*. *decipiens*, *M*. *minima*, *Sag*. *bipunctata*, and *Ser*. *pacifica* are circum-globally distributed between 40°N and 40°S (Pierrot-Bults and Nair 1991). All 5 species occur in the Sea of Japan (Johnson and Terazaki 2003). *Pterosagitta draco* has been reported from the Central Equatorial Pacific (Terazaki 1996), Mediterranean Sea (Duró and Saiz 2000), and Caribbean Sea (Hernández et al. 2005). *Decipisagitta decipiens* is found in the North Atlantic (Cheney 1985), Mediterranean Sea (Duró and Saiz 2000, Kehayias 2003), Adriatic Sea (Batistić et al. 2003), and Caribbean Sea (Hernández et al. 2005). *Mesosagitta minima* is found in the Adriatic Sea (Batistić et al. 2003), Aegean Sea (Kehayias et al. 2005), Mejillones Bay of northern Chile (Giesecke and González 2004), and the Mediterranean Sea (Duró and Saiz 2000, Kehayias 2003). *Serratosagitta pacifica* is found in Mejillones Bay of northern Chile (Giesecke González 2004). *Ferosagitta ferox*, *Fer*. *robusta*, *Z*. *bedoti*, and *Z*. *pulchra* are common in Indo-Pacific regions (Pierrot-Bults and Nair 1991). *Ferosagitta tokiokai* and *Z*. *bruuni* are found in the South China Sea (Alvariño 1967). All these species are common in the coastal seas of China (Du et al. 2003). *Pterosagitta draco*, *M*. *minima*, and *Ser*. *pacifica* are considered to be dominant in the South China Sea (Du et al. 2003). The scarcity of these species in Tolo Harbour (Tse et al. 2007) suggests that they are carried into the coastal waters of Hong Kong by ocean currents from the South China Sea.

Although detailed studies of the geographical distributions of chaetognaths exist for only a few species, many species are considered to be circum-globally distributed with wide climatological ranges. The distributions of chaetognaths are, however, known to be influenced by factors such as water circulation, temperature, food abundance, and inter-/intraspecific competition (Pierrot-Bults and Nair 1991). Tolo Harbour is impacted by continuous algal blooms during spring and summer (Environmental Protection Department 2004). Prominent vertical variations in dissolved oxygen, with very low levels in the bottom layer, are a common feature of Tolo Harbour during the summer when thermal stratification of the water column prevents effective vertical mixing (Morton 1989). Species which can tolerate low oxygen concentrations do not have to avoid the hypoxic bottom layer (Besiktepe and Unsal 2000). Less-tolerant species, on the other hand, must stay in the oxygenated surface layer and thus may be more exposed to visual predators. Tolo Harbour is an important feeding ground for the larvae and juveniles of several species of commercially important fish species (Nip et al. 2003). Chaetognath species which cannot tolerate low oxygen concentrations probably cannot establish viable populations in Tolo Harbour during the summer. Copepods are the most important prey for chaetognaths (Pearre 1980, Longhurst 1985).

Copepod densities are about 1.5 fold higher in Tolo Harbour than in Mirs Bay (C.K. Wong unpubl. data). High food densities within Tolo Harbour, therefore, may allow some species to establish dense populations. The semi-enclosed topography of Tolo Harbour makes it less likely for dense populations to be dispersed by water currents. Thus, various physical and biological factors interact with one another and have complex influences on the distributions of chaetognaths.

The chaetognath species in Tolo Harbour and Mirs Bay can be categorized into those that are indigenous to the area and those that are non-indigenous. Indigenous species includes *Fla*. *enflata*, *A*. *neglecta*, *A*. *delicata*, *A*. *nagae*, *A*. *crassa*, *A*. *johorensis*, and *A*. *regularis*. This group can be further divided into 3 subgroups. The 1st subgroup includes *Fla*. *enflata*, *A*. *crassa*, *A*. *johorensis*, and *A*. *regularis*. These species are common in both Tolo Harbour and Mirs Bay. The 2nd subgroup consists of *A*. *neglata* and *A*. *delicata*, which are most common in the eutrophic waters at the inner part of Tolo Harbour. The third subgroup is represented by *A*. *nagae* which is most commonly found in the inner part of Mirs Bay. Non-indigenous species include *A*. *bedfordii*, *K*. *pacifica*, *P*. *draco*, *D*. *decipiens*, *Fer*. *ferox*, *Fer*. *robusta*, *Fer*. *tokiokai*, *M*. *minima*, *Sag*. *bipunctata*, *Ser*. *pacifica*, *Z*. *bedoti*, *Z*. *bruuni*, and *Z*. *pulchra*. These species are rare in Tolo Harbour. Indeed, *D*. *decipiens*, *Z*. *bedoti*, *M*. *minima*, *P*. *draco*, *Fer*. *robusta*, *Ser*. *pacifica*, and *Z*. *pulchra* are found only in the outer reaches of Mirs Bay.

In conclusion, the community structure of chaetognaths is influenced by water circulation, food abundance, and eutrophication. Indigenous species may occur in the entire study area. Dense populations, however, are found mainly in Tolo Harbour and the inner part of Mirs Bay. Non-indigenous species exhibit sporadic occurrences in the open waters of Mirs Bay. These species are probably carried into the coastal waters of Hong Kong by ocean currents from the South China Sea.

Acknowledgments: We are grateful to A. Hui, A. Lie and K.C. Cheung for the technical support and Y.H. Yung for shipboard assistance.

REFERENCES

Alvariño A. 1965. Chaetognaths. Oceanogr. Mar. Biol. Ann. Rev. **3:** 115-194.

Alvariño A. 1967. The Chaetognatha of the NAGA Expedition (1959-1961) in the South China Sea and the Gulf of Thailand, Part 1: Systematics. NAGA Rep. **4:** 1-197.

Batistić M. 2003. Abundance, biomass, C- and N-content of *Flaccisagitta enflata* and *Mesosagitta minima* (Chaetognatha). Mar. Ecol. **24:** 1-13.

Batistić M, J Mikuš, J Njire. 2003. Chaetognaths in the South Adriatic: vertical distribution and feeding. J. Mar. Biol. **83:** 130-1306.

Besiktepe S, M Unsal. 2000. Population structure, vertical distribution and diel migration of *Sagitta setosa* (Chaetognatha) in the south-western part of the Black Sea. J. Plankton Res. **22:** 669-683.

Bieri R. 1959. The distribution of the planktonic Chaetognatha in the Pacific and their relationship to the water masses. Limnol. Oceanogr. **4:** 1-28.

Bieri R. 1991. Six new genera in the Chaetognath family Sagittidae. Gulf Res. Rep. **8:** 221-226.

Bone Q, H Kapp, AC Pierrot-Bults. 1991. Introduction and relationships of the group. *In* Q. Bone, H. Kapp, AC Pierrot-Bults, eds. The biology of chaetognaths. Oxford, UK: Oxford Univ. Press, pp. 1-4.

Chen QC. 1982. The marine zooplankton of Hong Kong. *In* BS Morton, CK Tseng, eds. Proceedings of the First International Marine Biological Workshop: The Marine Flora and Fauna of Hong Kong and Southern China. Hong Kong: Hong Kong Univ. Press, pp. 789-799.

Cheney J. 1985. Spatial and temporal abundance patterns of oceanic chaetognaths in the western North Atlantic I. Hydrographic and seasonal abundance patterns. Deep Sea Res. **32:** 1041-1059.

Du FY, CH Li, XP Jia. 2003. The situation and development trend of the study on Chaetognatha in China. J. Shanghai Fish. Univ. **12:** 65-71.

Dufrêne M, P Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol. Monogr. **67:** 345-366.

Dur G, JS Hwang, S Souissi, LC Tseng, CH Wu, SH Hsiao, QC Chen. 2007. An overview of the influence of hydrodynamics on the spatial and temporal patterns of calanoid copepod communities around Taiwan. J. Plankton Res. **29:** 97-116.

Duró A, JM Gili, P Andreu. 1994. Influence of the pycnocline on the vertical migration of chaetognaths in the northern Benguela. J. Plankton Res. **16:** 1149-1165.

Duró A, E Saiz. 2000. Distribution and trophic ecology of chaetognaths in the western Mediterranean in relation to an inshore-offshore gradient. J. Plankton Res. **22:** 339-361.

Environmental Protection Department. 2004. Marine water quality in Hong Kong 2004. Hong Kong: Hong Kong Government Press, pp. 1-13.

Giesecke R, HE González. 2004. Feeding of *Sagitta enflata* and vertical distribution of chaetognaths in relation to low oxygen concentrations. J. Plankton Res. **26:** 475-486.

Hernández RM, E Suárez-Morales, R Gasca. 2005. Seasonal distribution of Chaetognath in Mexican Bay during a year cycle. J. Coast. Res. **21:** 186-192.

Hu J, H Kawamura, H Hong, Y Qi. 2000. A review on the currents in the South China Sea: seasonal circulation, South China Sea Warm Current and Kuroshio intrusion. J. Oceanogr. **56:** 607-624.

Hwang JS, CK Wong. 2005. The China Coastal Current as a driving force for transporting *Calanus sinicus* (Copepoda: Calanoida) from its population centers to waters off Taiwan and Hong Kong during the winter northeast monsoon period. J. Plankton Res. **27:** 205-210.

Itoh H, Y Ono, T Kubota. 2006. Vertical distribution of large-size chaetognaths in Suruga Bay, central Japan. J. School Mar. Sci. Technol. **4:** 1-13.

Johnson TB, M Terazaki. 2003. Species composition and depth distribution of chaetognaths in a Kuroshio warm-core ring and Oyashio water. J. Plankton Res. **25:** 1279-1289.

Kehayias G. 2003. Quantitative aspects of feeding of chaetognaths in the eastern Mediterranean pelagic waters. J. Mar. Biol. Assoc. UK **83:** 559-569.

Kehayias G, E Michaloudi, E Koutrakis. 2005. Feeding and predation impact of chaetognaths in the north Aegean Sea (Strymonikos and Ierissos Gulfs). J. Mar. Biol. Assoc. UK **85:** 1525-1532.

Liu XJ, CK Wong. 2006. Seasonal and spatial dynamics of *Noctiluca scintillans* in a semi-enclosed bay in the northeastern part of Hong Kong. Bot. Mar. **49:** 145-150.

Longhurst AR. 1985. The structure and evolution of plankton communities. Prog. Oceanogr. **15:** 1-35.

Morton B. 1989. Pollution of the coastal waters of Hong Kong. Mar. Pollut. Bull. **20:** 310-318.

Nagai N, K Tadokoro, K Kuroda, T Sugimoto. 2006. Occurrence characteristics of chaetognath species along the PM transect in Japan Sea during 1972-2002. J. Oceanogr. **62:** 597-606.

Nagasawa S. 1985. The digestive efficiency of the chaetognath *Sagitta crassa* Tokioka, with observations on the feeding process. J. Exp. Mar. Biol. Ecol. **87:** 271-282.

Nip THM, WY Ho, CK Wong. 2003. Feeding ecology of larval and juvenile black seabream (*Acanthopagrus schlegeli*) and Japanese seaperch (*Lateolabrax japonicus*) in Tolo Harbour, Hong Kong. Environ. Biol. Fish. **66:** 197-209.

Øresland V. 2000. Diel feeding of the chaetognath *Sagitta enflata* in the Zanzibar Channel, western Indian Ocean. Mar. Ecol. Prog. Ser. **193:** 117-123.

Pearre S Jr. 1980. Feeding by Chaetognatha: the relation of prey size to predator size in several species. Mar. Ecol.-Prog. Ser. **3:** 125-134.

Pierrot-Bults AC, R Nair. 1991. Distribution patterns in Chaetognatha. *In* Q Bone, H Kapp, AC Pierrot-Bults, eds. The biology of chaetognaths. Oxford, UK: Oxford Univ. Press, pp. 86-116.

Souissi S, F Ibanez, RB Hamadou, J Boucher, AC Cathelineau, F Blanchard, JC Poulard. 2001. A new multivariate mapping method for studying species assemblages and their habitats: example using bottom trawl surveys in the Bay of Biscay (France). Sarsia **86:** 527-542.

Terazaki M. 1996. Vertical distribution of pelagic chaetognaths and feeding of *Sagitta enflata* in the Central Equatorial Pacific. J. Plankton Res. **18:** 673-682.

Tokioka T. 1979. Neritic and oceanic plankton. *In* S van der Spoel, AC Pierrot-Bults, eds. Zoogeography and diversity of plankton. New York: Halsted Press, pp. 126-143.

Tse P, SY Hui, CK Wong. 2007. Species composition and seasonal abundance of Chaetognatha in the subtropical coastal waters of Hong Kong. Estuar. Coast. Shelf Sci. **73:** 290-298.

Wong CK, ALC Chan, QC Chen. 1993. Planktonic copepods of Tolo Harbour, Hong Kong. Crustaceana **64:** 76-84.

Zhang G, QC Chen. 1983. Studies on chaetognaths in the central and northern parts of the South China Sea. Contrib. Mar. Biol. Res. South China Sea **1:** 17-63.